# GEOTECHNICAL SITE INVESTIGATION REPORT

# KUNNAR LPG PLANT & OIL FIELD, KPDTAY SITE, TANDO JAM, SINDH

**DEPARTMENT OF CIVIL ENGINEERING**
**NED UNIVERSITY OF ENGINEERING AND TECHNOLOGY, KARACHI-75270**

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No. NED/CIVIL/SML/220108 Date: 08/01/2022

| *Report* | *Revised Geotechnical Site Investigation Report* |
|---|---|

| | |
|---|---|
| **M/s.** | Oil and Gas Development Company Limited (OGDCL) |
| **Project Name** | |
| **Project details** | |
| **Project Location** | Kunnar LPG Plant & Oil Field, KPDTAY Site, Tando Jam, Sindh. |
| **Type of Testing** | Geotechnical Site Investigation Report |
| **Date of Field Testing** | 06-12-2021 to 20-12-2021 |
| **Standard Test Method** | ASTM D 1452 – 07a Standard Practice for Soil Investigation and Sampling<br>D2487 - 17e1 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)<br>D 1194 – 94 Standard Test Method for Bearing Capacity of Soil. |
| **Note** | 1) The geotechnical investigation report is based on the field and laboratory testing<br>2) The tests were conducted based on the undisturbed and disturbed samples delivered to our laboratory.<br>3) The results along with graphs are enclosed.<br>4) Any additional information pertaining to the geotechnical site investigation and within the scope of work shall be shared if and when required.<br>5) Revised report is issued after updating and incorporating comments from the client. |

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# Project Summary

Department of Civil Engineering NED University of Engineering and Technology was contacted by Petrochemical Engineering Consultants (PEC) and entrusted to conduct the Geotechnical Site Investigation at Kunnar LPG Plant & Oil Field, KPDTAY Site, Tando Jam, Sindh for OGDCL. The investigations were carried out based on the field and laboratory testing. Fieldwork consisting of three (03) boreholes drilled up to a depth of 15.0 m followed by laboratory investigations.

Based on the field and laboratory investigations it is revealed that the geological site conditions consisted of sandy silty soil from depth up to 0.0 m to 15.0 m. The groundwater table encountered at a depth of 2.0 m from NGL. The seismic conditions of the site are given in the table below:

Table: Seismic parameters

| Seismic zone | Seismic Zone factor | Soil Profile Type | Seismic Coefficients $C_\alpha$ | Seismic Coefficients $C_v$ |
|---|---|---|---|---|
| 2A | 0.15 | $S_E$ | 0.30 | 0.50 |

Peak ground acceleration is 0.08 to 0.16g.

The index properties, physical and chemical properties of the soil for various layers are given in Annexure-A and Annexure-B of the report. The bearing capacity and modulus of subgrade reaction of the soil for various layers are given in Annexure-C.

The bearing capacity for isolated (spread) footing is around 1.08 tsf at depth of 2.0 m based on the normal scenario exhumed from the site investigations, the bearing capacity for raft foundations is around 1.2 tsf with breadth and length of 8.0 m by 8.0 m at 25.0 mm settlement. However, based on the worst-case scenario of the site, the bearing capacity for raft foundations is around 1.0 tsf.

Table: Load carrying capacity

| Foundation type | Isolated footing | Raft Foundation |
|---|---|---|
| Bearing capacity | 1.08 tsf | 1.2 tsf |
| Worst case Scenario | 0.9 tsf | 1.2 tsf |
| Conservative approach based upon BS 8004-1986 | 0.85 tsf | 0.85 tsf |

For the machine foundations design, the involvement of a design engineer is essential. The design engineer can consult the geotechnical engineer for further queries if any related to the geotechnical site conditions. Nevertheless, the bearing capacity value of 1.08 tsf is recommended to be satisfactory for primary and secondary foundations.

The thermal and electrical conductivity/resistivity of the clayey and sandy silty soil layers are given in the following table.

Table: Conductivity/Resistivity characteristics of soil

| BH No. | Electrical conductivity (*m*S/m) | Thermal conductivity (W/m.K) |
|---|---|---|
| BH-No.1 to BH-No.3 | 0.3 to 3.5 | 2.3 to 4.1 |

The chemical characteristics of the soil samples collected from each borehole are given in the following table.

Table: Chemical properties of soil

| BH No. | pH | Sulphate content (%) | Chloride content (%) |
|---|---|---|---|
| BH-No.1 to BH-No.3 | 6.2 | 0.5 to 0.8 | 0.05 to 0.1 |

- 1 ppm= 1mg/liter = 0.0001%

The pH value is normal; however, the salt content is slightly high which makes the groundwater unsuitable for drinking as well using it in the concrete. The conclusions and recommendations are given in Chapter No. 5 of the report.

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# Disclaimer

This report presents the results of a geotechnical investigation performed at the request of the client. This report may not contain sufficient information for other uses or the purposes of other parties.

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Department of Civil Engineering NED University of Engineering and Technology was contacted by Petrochemical Engineering Consultants (PEC) and entrusted to conduct the Geotechnical Site Investigation of Kunnar LPG Plant & Oil Field, KPDTAY Site, Tando Jam, Sindh. The investigations were carried out based on field and laboratory testing. Fieldwork consisting of three (03) boreholes drilled up to a depth of 15.0 m. The samples were brought in core boxes for laboratory investigations. All the tests were conducted as per ASTM standards or otherwise wherever, required. The laboratory testing consisted of soil gradation (sieve/hydrometer analysis), consistency limits, the density of soil samples (from undisturbed/remoulded samples and correlations, etc.), strength parameters (through the direct shear test), the elastic parameters were determined through testing and correlations with the type of soil and relative density, etc. The results for the borehole are summarized corresponding to the depth of samples from which the samples were exhumed.

## 1.2 Scope of work

The objective of this investigation was to assess the nature and engineering properties of the encountered subsurface materials and to provide geotechnical design recommendations for the proposed site. The scope of the present geotechnical site investigation report comprises of the geotechnical site investigation of the site based on field and laboratory testing and geotechnical recommendations for the proposed structures to be constructed.

## 1.3 Site description

The proposed site is fairly level, and the site consists of clayey soil. The project details and site pictures are presented in Figure 1.2 and Figure 1.3.

Table 1.1 Site Description

| | |
|---|---|
| Owner | Gas Development Company Limited (OGDCL) |
| Site Area | 4.069 Acres |
| Project Location | Kunnar LPG Plant & Oil Field, KPDTAY Site, Tando Jam, Sindh. |

## 1.4 Site investigation details

The site investigation details are summarized in Table 1.2.

Table 1.2 Site investigation details

| | |
|---|---|
| Type of boring | Rotary drilling method |
| Type of barrel | Double core barrel sampler |
| Boring Machine | Straight Rotary |
| Number of boreholes | Three (03) |
| Depth of boring | 15.0 m. |
| Date of field investigations | 06-12-2021 to 10-12-2021 |

## 1.5 Plot variation with road

The plot-level variation with road may be mentioned.

## 1.6 Borehole locations

The site locations are shown in Figure 1.2. The pictures of the site during the investigation are shown in Figure 1.3 and Figure 1.3. To depict the subsoil conditions effectively the locations were selected in a diagonal pattern.


Figure 1.1 Google earth site location

Figure 1.2 Site pictures during drilling

Figure 1.3 Site pictures during drilling

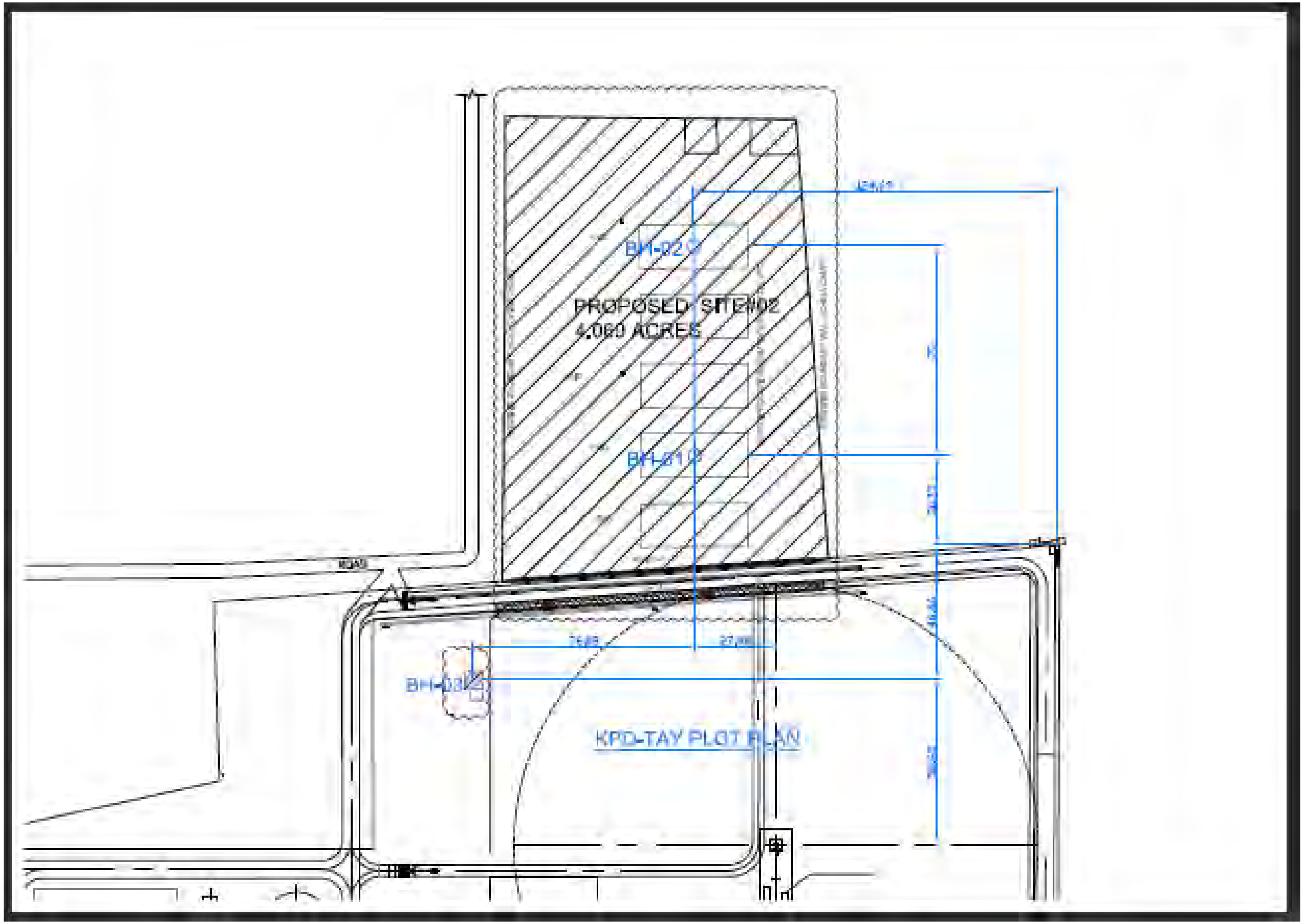


Figure 1.4 Borehole locations


Figure 1.5  Sample collected from the site

# CHAPTER 2

# LITERATURE

## 2.1 Geotechnical investigation

Geotechnical investigation is of prime importance before constructing any structure on the ground as the load of the structure is eventually transferred to the soil beneath and soil must withstand this load during the life of the structure. In the field of construction geotechnical engineering is one of the main pillars. Geotechnical engineering covers soil investigation, geotechnical designs, and the study of soil behaviour under different conditions.

## 2.2 Multi-storey buildings

A multi-storey building must be resting on a safer foundation resting on stable ground. The purpose of a foundation is to transfer structural loads reliably from a building into the ground. The most important role of the foundation is to prevent building failure. The foundation must receive the multiple loads acting on the building and transfer these loads into the underlying earth in such a way that the building remains standing and stable.

Foundations must limit *settlement*. All foundations settle to some extent as the surrounding earth compresses and adjusts to the loads imposed by the building above. Over the life of the building, the settlement must not exceed amounts that would cause structural distress, nonstructural damage, or interfere with building functions. Foundations on bedrock settle a negligible amount. Foundations in other types of soil may settle more but are normally designed to limit settling to amounts measured in millimetres or fractions of an inch.

## 2.3 Spread foundations

Spread foundations are usually comprised of isolated footings, combined footing, spread footing and raft foundations to offer support to the lightweight or one to two-storey buildings. The shallow foundations usually draw their load-carrying capacity through soil-foundation interaction based on the soil behaviour and foundation dimensions. Therefore, the type of soil, its relative density and strength parameters have a significant contribution to the design of shallow foundations.

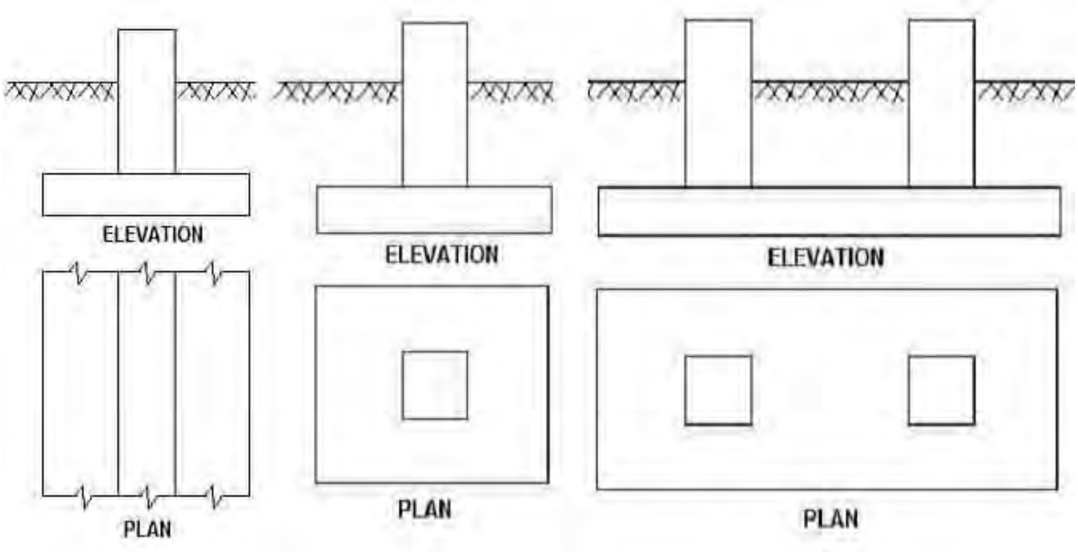


Figure 2.1 Spread foundations

## 2.4 Raft foundation

A mat foundation is a large concrete slab used to interface one column, or more than one column in several lines, with the base soil. It may encompass the entire foundation area or only a portion. A mat foundation may be used where the base soil has a low bearing capacity and/or the column loads are so large that more than 50% of the area is covered by conventional spread footings.

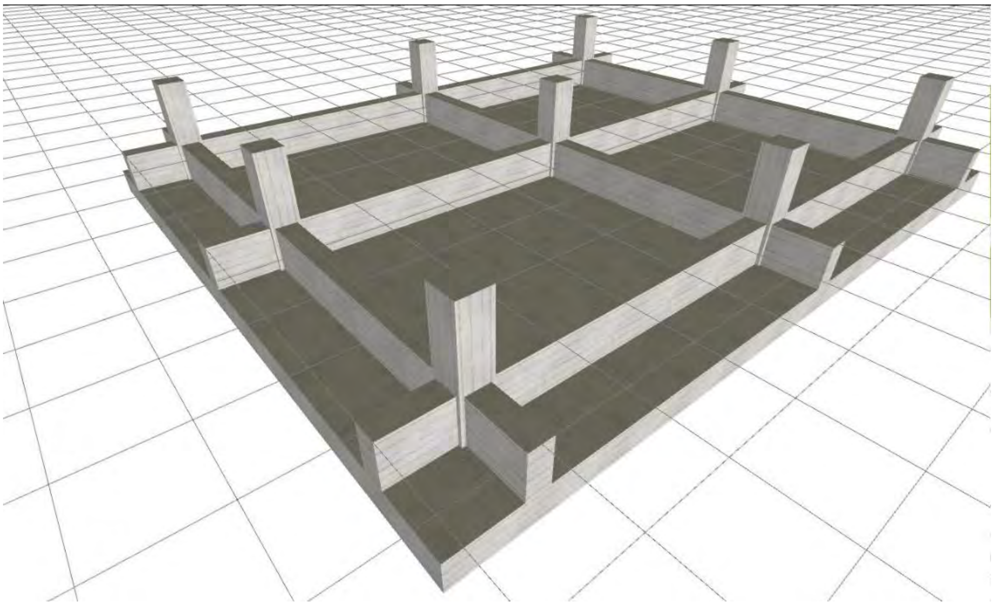

Figure 2.2 Typical raft foundations

## 2.5 Machine foundation

Machine foundations are special types of foundations required for machines, machine tools and heavy equipment which have a wide range of speeds, loads and operating conditions.

These foundations are designed considering the shocks and vibrations (dynamic forces) resulting from the operation of machines.

Figure 2.3 Typical machine foundation

## 2.6 Pile and Pier Foundations

A pile foundation is a relatively long and slender member that is forced or driven into the soil, or it may be poured in place. If a pile is driven until it rests on a hard, impenetrable layer of soil or rock, the load of the structure is transmitted primarily axially through the pile to the impenetrable layer. This type of pile is called an end-bearing pile. With end-bearing piles, care must be exercised to ensure that the hard, impenetrable layer is adequate to support the load. If a pile cannot be driven to a hard stratum of soil or rock (e.g., if such a stratum is located too far below the ground surface), the load of the structure must be borne primarily by skin friction or adhesion between the surface of the pile and adjacent soil. Such a pile is known as a friction pile.

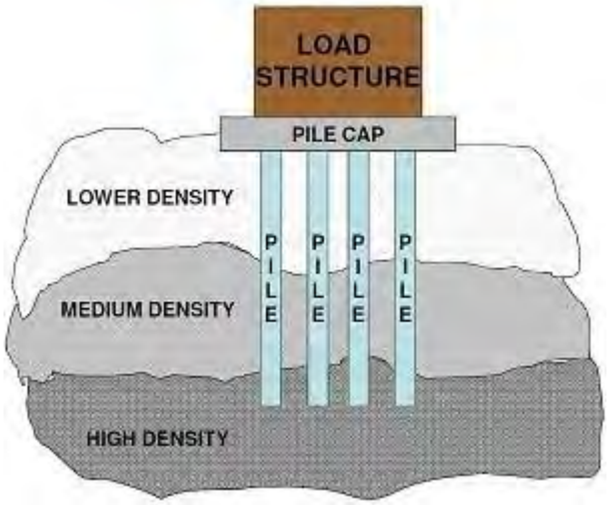


Figure 2.4 Typical pile foundation type

Figure 2.5 Typical foundation type for substations

## 2.7 Gas field constructions

With limited foundation requirements, energy-efficient insulation packages, and options for temporary and semi-permanent construction, the possibilities for oil and gas buildings with Sprung structures are endless. Popular energy industry uses include natural gas storage facilities, gas compressor station construction, on-site warehousing, gymnasiums, lunch tents, and other oilfield buildings. Sprung offers a virtually maintenance-free product made of durable materials like aluminum, and a high-performance architectural membrane that ensures your oil and gas structures are built to last.

Figure 2.6 Gas field constructions

## 2.8 Compressor foundation

A typical compressor machine is shown in Figure 2.7. The compressors are usually attached with a rigid steel frame base. Compressors are critical to many processes, and the foundations that support compressors need to be designed, assessed and repaired properly to minimize vibration and increase compressor reliability. Typical foundation components for a compressor are shown in Figure 2.8.

Although machine bearings, misalignment or other mechanical issues can cause vibration, most vibration problems stem from the foundation.

For compressors, a reinforced concrete foundation typically consists of grout, concrete, anchor bolts, jack bolts and soil (see Figure 2.8.). The compressor frame is typically bolted to a baseplate or soleplate attached to the grout and concrete foundation. Jack bolts, chocks or shims might be used at the anchor bolt locations to assist with alignment.

API 686 and ACI 351 provide good guidelines for foundation design (and repair) using modern standards and best practices. API uses the phrase “system” often to reinforce the importance of a unified foundation where all parts work together to minimize vibration.

Figure 2.7 Typical API compressor

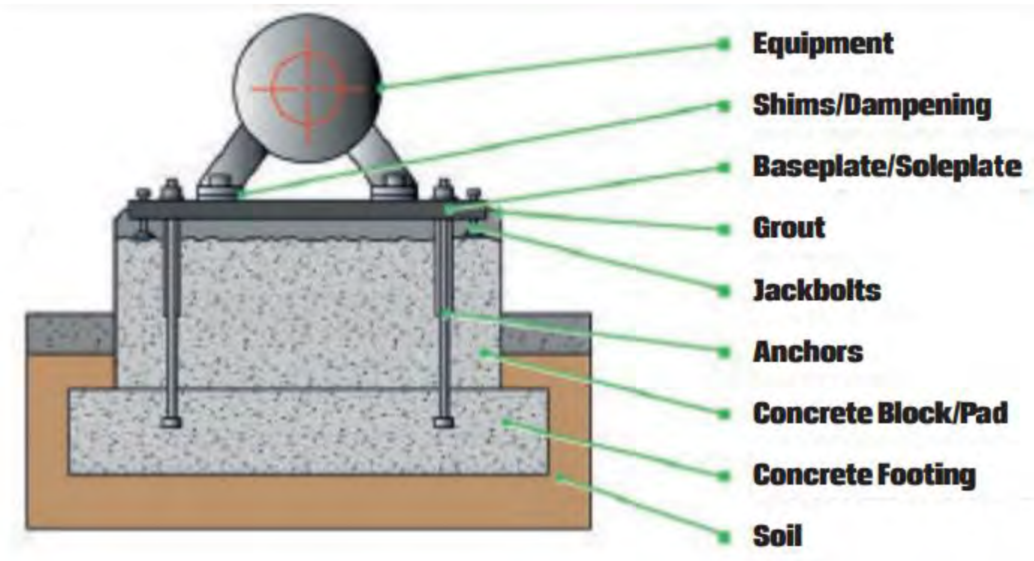


Figure 2.8 Reinforced concrete foundation for compressors

## 2.9 Pile capacity

In addition to the strength of the pile/pier itself, pile/pier capacity is limited by the soil's supporting strength. The load carried by a pile is ultimately borne by either or both of two ways. The load is transmitted to the soil surrounding the pile by friction or adhesion between the soil and the sides of the pile, and the load is transmitted directly to the soil just below the pile's tip. This can be expressed in equation form as follows:

$$Q_{ultimate} = Q_{friction} + Q_{tip}$$

where $Q_{ultimate}$ = ultimate (at failure) bearing capacity of a single pile.

$Q_{friction}$ = bearing capacity furnished by friction or adhesion between the soil and the sides of the pile.

$Q_{tip}$ = bearing capacity furnished by the soil just below the pile's tip.

The term $Q_{friction}$ as mentioned above can be evaluated by multiplying the unit skin friction or adhesion between the soil and the sides of the pile (f ) by the pile's surface (skin) area ($A_{surface}$). The term $Q_{tip}$ can be evaluated by multiplying the ultimate bearing capacity of the soil at the tip of the pile (q) by the area of the tip (Atip). Hence, the above can be expressed as follows:

$$Q_{ultimate} = f * A_{surface} + q * A_{tip}$$

## 2.10 Bearing capacity estimation

Terzaghi and Peck (1948) recommended that N values should be determined between the foundation level and a depth of approximately B below the foundation. They proposed a correlation between allowable bearing capacity and the corrected N-values in the form of a chart as shown in Figure 2.9. The breadth of footing and the corrected N-values are used as entry data and the allowable bearing capacity ($q_{TP}$) is read off the left vertical axis.

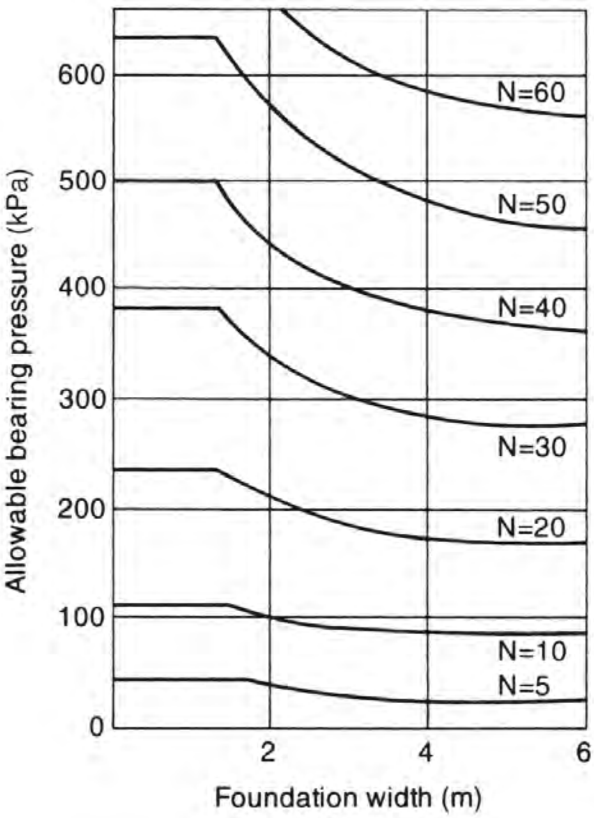


Figure 2.9Allowable bearing pressure from the standard penetration test (after Terzaghi and Peck, 1948).

As per Teng (1962) the safe bearing capacity can be obtained from the results of the SPT test.

1. From shear failure criteria, the net safe bearing capacity is given by:

$$q_{ns} = 0.02N^2BR_{W1} + 0.06(100 + B^2)\ D_fR_{W2} \qquad (1)$$

2. From settlement criteria of 25 mm, the safe bearing pressure is,

$$q_{na} = 1.75(N\text{-}3)\ R_{W1} \qquad (2)$$

Where B = smaller dimension of the foundation

$D_f$ = Depth of foundation

N = corrected SPT Value

$R_{W1}$, $R_{W2}$ = water table correction factors

Where $q_{ns}$ and $q_{na}$ are in ton/m$^2$

As per Terzaghi the ultimate bearing capacity of a rectangular foundation can be obtained by using the following equation.

$$q_u = cN_c\left(1+0.3\times\frac{B}{L}\right)+\gamma D_f N_q+\frac{1}{2}\gamma BN_\gamma\left(1-0.2\times\frac{B}{L}\right) \qquad (3)$$

### 2.10.1 Bearing capacity of soil for raft foundation

The bearing capacity of the raft foundation can be estimated by using the following formula.

$$q_{\text{ult}} = cN_c s_c i_c d_c + \gamma D N_q s_q i_q d_q + \frac{1}{2}\lambda B N_\gamma s_\gamma i_\gamma d_\gamma \quad (4)$$

When the bearing capacity is based on penetration tests (e.g., SPT, CPT) in sands and sandy gravel.

$$q_a = \frac{N_{55}}{0.08}\left(\frac{\Delta H_a}{25.0}\right)K_d \qquad \text{(kPa)} \quad (5)$$

where $K_d = 1 + 0.33D/B \leq 1.33$

$\Delta H_a$ = allowable settlement such as 25, 40, 50, 60 mm, etc.

### 2.10.2 The typical range of bearing capacity

The typical range of bearing capacity for cohesive and cohesionless soils is given in Table 2.1.

Table 2.1 Typical bearing capacity range and soil type for cohesionless soil (BS 8004-1986).

| Category | Types of rocks and soils | Presumed allowable bearing value | | Remarks |
|---|---|---|---|---|
| | | kN/m$^2$ [a] | kgf/cm$^2$ [a] tontf/ft$^2$ | |
| Non-cohesive soils | Dense gravel, or dense sand and gravel | > 600 | > 6 | Width of foundation not less than 1 m. Groundwater level assumed to be a depth not less than below the base of the foundation. For effect of relative density and groundwater level, |
| | Medium dense gravel, or medium dense sand and gravel | < 200 to 600 | < 2 to 6 | |
| | Loose gravel, or loose sand and gravel | < 200 | < 2 | |
| | Compact sand | > 300 | > 3 | |
| | Medium dense sand | 100 to 300 | 1 to 3 | |
| | Loose sand | < 100 Value depending on degree of looseness | < 1 | |

Table 2.2 Bearing capacity range and soil type for cohesive soil (BS 8004-1986).

NOTE These values are for preliminary design purposes only, and may need alteration upwards or downwards. No addition has been made for the depth of embedment of the foundation (see **2.1.2.3.2** and **2.1.2.3.3**).

| Category | Types of rocks and soils | Presumed allowable bearing value | | Remarks |
|---|---|---|---|---|
| | | kN/m$^2$ [a] | kgf/cm$^2$ [a] tontf/ft$^2$ | |
| Cohesive soils | Very stiff boulder clays and hard clays | 300 to 600 | 3 to 6 | Group 3 is susceptible to long-term consolidation settlement |
| | Stiff clays | 150 to 300 | 1.5 to 3 | |
| | Firm clays | 75 to 150 | 0.75 to 1.5 | |
| | Soft clays and silts | <75 | <0.75 | |
| | Very soft clays and silts | Not applicable | | |
| Peat and organic soils | | Not applicable | | |
| Made ground or fill | | Not applicable | | |

[a] 107.25 kN/m$^2$ = 1.094 kgf/cm$^2$ = 1 tonf/ft$^2$.

## 2.11 Selection of a suitable type of foundation

The selection of the suitable type of foundation depends on many factors. Some of those important factors are followings:

1. Load on structure
2. Bearing capacity of soil
3. Soil type encountered at the site
4. The water table at the site
5. Economical design
6. The conservativeness of the proposed structure (Suraa Sadoon 2014).
7. The soil type and foundation selection criteria are briefly illustrated in Table 2.3.

Table 2.3 Soil Type and Foundation (Suraa Sadoon 2014)

| Type of Soil | Type of Foundation |
|---|---|
| Clayey Soil | Raft/Mat Foundation |
| Peat Soil | Pile Foundation |
| Silt Soil | Not suitable for Shallow Foundation |
| Rock | Shallow Foundation |
| Sand and Gravel | Shallow (Isolate/Strip) Foundation |
| Loamy Soil | Isolated Foundation |

## 2.12 Ground Improvement

Ground Improvement is the application of various geotechnical techniques that are used to re-engineer existing soils to improve their engineering characteristics. Ground Improvement techniques may include Soil Stabilization, Vibro Stone Columns, Jet Grouting, Deep Soil Mixing, Dynamic Compaction etc. Ground Improvement can be used to engineer complex sites, simplify follow on construction and minimize development costs.

### 2.12.1 Soling

Soling is the process of hand packing rubble stones one adjacent to another, to provide a stable base to the foundation and footing, before concreting work as shown in Figure 2.10. Rubble or boulder soling is done to enhance the bearing capacity of the soil, where hard strata are not available. Usually, the thickness of the rubble soling varies from 150mm (6 inches) to 250 mm. (10 inches).

Figure 2.10 Stone soling work

### 2.12.2 Sand-gravel cushion

Sand-gravel cushion influences the bearing capacity and settlement and offers the highest value of ultimate bearing capacity and the lowest value of settlement. Thickness of sand-gravel cushion shall not be less than 100mm.

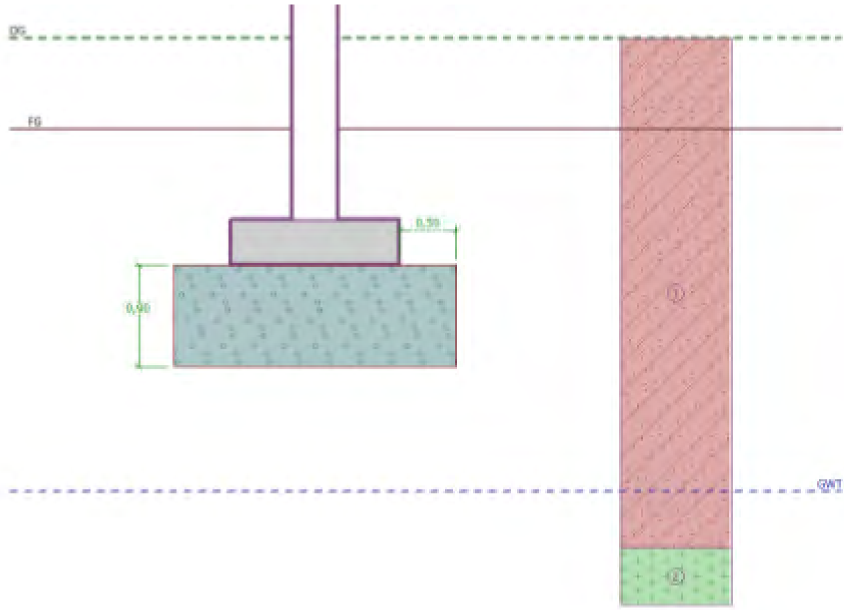


Figure 2.11 Sand-gravel cushion

# CHAPTER 3

# METHODOLOGY

## 3.1 Drilling

Three (03) test borings were drilled with the Rotary drilling method. A double-core barrel sampler was used for sample collection as shown in Figure 3.1.

Figure 3.1 Straight rotary drilling machine

## 3.2 Sampling

### 3.2.1 Soil Sampling

Double tube core barrel samplers and thin wall samplers were used for the collection of the specimens. Samples were obtained using a 2.5-inch inner diameter California Modified sampler (ASTM D3550) and during Standard Penetration Testing (SPT, ASTM D1586). The samplers were driven with a 140-pound hammer falling 30 inches. The blows required to drive the samplers every 6 inches (or less) of an 18-inch derive were recorded and are noted on the boring logs.

Figure 3.2 Double tube core barrel sampler and thin wall sampler

### 3.2.2 Water Sampling

The soil on the site consisted of moist soil and mixed with oil.

## 3.3 Testing

All the required tests comprising index properties, physical properties, mechanical properties, and chemical properties were performed as per ASTM standards. The results are summarized in the Annexures.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Soil profile

The soil profile up to a depth of 15.0 m for the Kunnar LPG Plant & Oil Field, KPDTAY Site, Tando Jam, Sindh is shown in Table 4.1, Table 4.2, and Table 4.3. The soil on the site mainly consists of clayey and sandy silty soil.

Table 4.1 Borelog No. 1

| **Borehole ID: BH. No.1** | | | | | | | | **Soil type** | **layer depth (m)** |
|---|---|---|---|---|---|---|---|---|---|
| S. No. | Depth (m) | Soil Composition (%) | | | Atterberg Limits (%) | | | Stratum description | |
| | | Gravel | Sand | Fine Content (Silt+ Clay) | L.L | P.L | P.I | | |
| 1 | 0.0-1.50 | 0.00 | 82.18 | 17.82 | -- | -- | N.P | Light greyish silty sand | 4.5 |
| 2 | 1.50-3.0 | 0.00 | 79.85 | 20.15 | -- | -- | N.P | | |
| 3 | 3.0-4.50 | 0.00 | 85.70 | 14.30 | -- | -- | N.P | | |
| 4 | 4.50-6.0 | 0.00 | 43.46 | 56.54 | -- | -- | N.P | Dark greyish sandy silt | 10.5 |
| 5 | 6.0-7.50 | 0.00 | 47.73 | 52.27 | -- | -- | N.P | | |
| 6 | 7.50-10.0 | 0.00 | 45.70 | 54.30 | -- | -- | N.P | | |
| 7 | 10.0-11.10 | 0.00 | 41.09 | 58.91 | -- | -- | N.P | | |
| 8 | 10.60-11.10 | 0.00 | 46.6 | 53.40 | -- | -- | N.P | | |
| 9 | 11.10-12.10 | 0.00 | 44.94 | 55.06 | -- | -- | N.P | | |
| 10 | 12.10-12.60 | 0.00 | 40.99 | 59.01 | -- | -- | N.P | | |
| 11 | 12.60-13.70 | 0.00 | 38.68 | 61.32 | -- | -- | N.P | | |
| 12 | 13.70-14.10 | 0.00 | 39.53 | 60.47 | -- | -- | N.P | | |
| 13 | 14.10-15.0 | 0.00 | 35.91 | 64.09 | -- | -- | N.P | | |

Table 4.2 Borelog No. 2

| **Borehole ID: BH. No.2** | | | | | | | | | **Soil type** | **layer depth (m)** |
|---|---|---|---|---|---|---|---|---|---|---|
| S. No. | Depth (m) | Soil Composition (%) | | | Atterberg Limits (%) | | | Stratum description | | |
| | | Gravel | Sand | Fine Content (Silt+ Clay) | L.L | P.L | P.I | | | |
| 1 | 0.0-1.50 | 0.00 | 51.26 | 48.74 | -- | -- | N.P | Light greyish silty sand | | 4.5 |
| 2 | 1.50-3.0 | 0.00 | 64.34 | 35.66 | -- | -- | N.P | | | |
| 3 | 3.0-4.50 | 0.00 | 58.84 | 41.16 | -- | -- | N.P | | | |
| 4 | 4.50-6.0 | 0.00 | 21.18 | 78.82 | -- | -- | N.P | Dark greyish sandy silt | | 10.5 |
| 5 | 6.0-7.50 | 0.00 | 22.79 | 77.21 | -- | -- | N.P | | | |
| 6 | 7.50-10.0 | 0.00 | 39.44 | 60.56 | -- | -- | N.P | | | |
| 7 | 10.0-11.10 | 0.00 | 36.24 | 63.76 | -- | -- | N.P | | | |
| 8 | 10.60-11.10 | 0.00 | 29.19 | 70.81 | -- | -- | N.P | | | |
| 9 | 11.10-12.10 | 0.00 | 27.61 | 72.39 | -- | -- | N.P | | | |
| 10 | 12.10-12.60 | 0.00 | 25.87 | 74.13 | -- | -- | N.P | | | |
| 11 | 12.60-13.70 | 0.00 | 22.21 | 77.79 | -- | -- | N.P | | | |
| 12 | 13.70-14.10 | 0.00 | 20.79 | 79.21 | -- | -- | N.P | | | |
| 13 | 14.10-15.0 | 0.00 | 21.10 | 78.90 | -- | -- | N.P | | | |

Table 4.3 Borelog No. 3

| Borehole ID: BH. No.3 | | | | | | | | | Soil type | layer depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| S. No. | Depth (m) | Soil Composition (%) | | | Atterberg Limits (%) | | | | Stratum description | |
| | | Gravel | Sand | Fine Content (Silt+ Clay) | L.L | P.L | P.I | | | |
| 1 | 0.0-1.50 | 0.00 | 2.15 | 97.85 | 33.0 | 29.66 | 3.34 | | Light brownish sandy silt | 3.0 |
| 2 | 1.50-3.0 | 0.00 | 41.81 | 58.19 | -- | -- | N.P | | | |
| 3 | 3.0-4.50 | 0.00 | 43.97 | 56.03 | -- | -- | N.P | | Dark greyish sandy silt | 12.0 |
| 4 | 4.50-6.0 | 0.00 | 40.06 | 59.94 | -- | -- | N.P | | | |
| 5 | 6.0-7.50 | 0.00 | 45.62 | 54.38 | -- | -- | N.P | | | |
| 6 | 7.50-10.0 | 0.00 | 45.07 | 54.93 | -- | -- | N.P | | | |
| 7 | 10.0-11.10 | 0.00 | 42.59 | 57.41 | -- | -- | N.P | | | |
| 8 | 10.60-11.10 | 0.00 | 41.09 | 58.91 | -- | -- | N.P | | | |
| 9 | 11.10-12.10 | 0.00 | 40.97 | 59.03 | -- | -- | N.P | | | |
| 10 | 12.10-12.60 | 0.00 | 44.97 | 55.03 | -- | -- | N.P | | | |
| 11 | 12.60-13.70 | 0.00 | 48.78 | 51.22 | -- | -- | N.P | | | |
| 12 | 13.70-14.10 | 0.00 | 45.89 | 54.11 | -- | -- | N.P | | | |
| 13 | 14.10-15.0 | 0.00 | 40.93 | 59.07 | -- | -- | N.P | | | |

## 4.2 Groundwater table

Groundwater was encountered at depth of 2.0 m (6.0 ft approximately) at the time of drilling and even after 24 hours, there were wet conditions at the boring site.

## 4.3 Settlement Criteria

The allowable limit of settlement for the foundation is considered as 25 mm for isolated footings and 50 mm for raft foundations. The estimation of the bearing capacity was made based on these allowable limits of settlement.

## 4.4 Bearing capacity analysis

The bearing capacity analysis was based on the field test results of SPT and laboratory investigations results based on shear parameters. The analysis was made for spread foundation, raft foundation and pile foundations.

### 4.4.1 Based on SPT

The SPT resistance value (N-value) variation along the depth is shown in Figure 4.1. From the figure, N-value is low at 5.0 m, but it gradually increases from 5.0 to 15.0 m depth. The bearing capacity based on N-values is shown in Figure 4.2. The range of the bearing capacity at a depth of 2.0 m is ***0.90 tsf*** to ***1.3 tsf***. The variation of bearing capacity along the depth up to 15.0 m is given in Table 4.5.

Table 4.4 SPT blow counts for various boreholes

| S. No. | Depth (m) | BH-01 N-values | BH-02 N-values | BH-03 N-values |
|---|---|---|---|---|
| 1 | 2.0 | 9.0 | 10.0 | 13.0 |
| 2 | 3.5 | 13.0 | 13.0 | 14.0 |
| 3 | 5.0 | 16.0 | 14.0 | 17.0 |
| 4 | 6.5 | 17.0 | 21.0 | 22.0 |
| 5 | 8.0 | 23.0 | 24.0 | 26.0 |
| 6 | 9.6 | 31.0 | 37.0 | 33.0 |
| 7 | 11.1 | 32.0 | 37.0 | 34.0 |
| 8 | 12.6 | 34.0 | 41.0 | 37.0 |
| 9 | 14.1 | 36.0 | 40.0 | 36.0 |

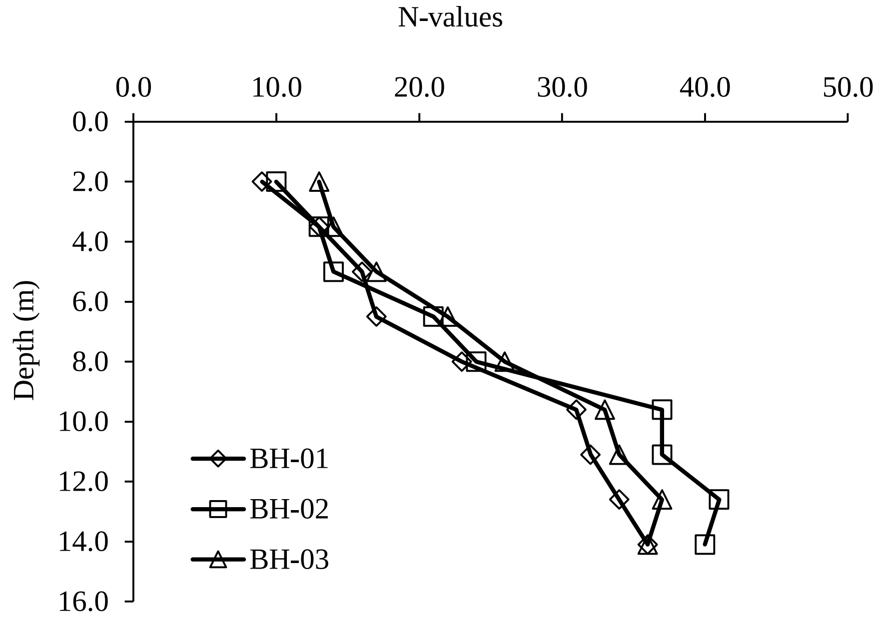


Figure 4.1 Variation of N-values along with the depth

Table 4.5 Bearing capacity values for various boreholes on the basic of SPT Blows

| S. No. | Depth (m) | BH-01 | BH-02 | BH-03 |
|---|---|---|---|---|
| | | Bearing Capacity (tsf) | Bearing Capacity (tsf) | Bearing Capacity (tsf) |
| 1 | 2.0 | 0.90 | 1.00 | 1.30 |
| 2 | 3.5 | 1.30 | 1.30 | 1.40 |
| 3 | 5.0 | 1.60 | 1.40 | 1.70 |
| 4 | 6.5 | 1.70 | 2.10 | 2.20 |
| 5 | 8.0 | 2.30 | 2.40 | 2.60 |
| 6 | 9.6 | 3.10 | 3.70 | 3.30 |
| 7 | 11.1 | 3.20 | 3.70 | 3.40 |
| 8 | 12.6 | 3.40 | 4.10 | 3.70 |
| 9 | 14.1 | 3.60 | 4.00 | 3.60 |

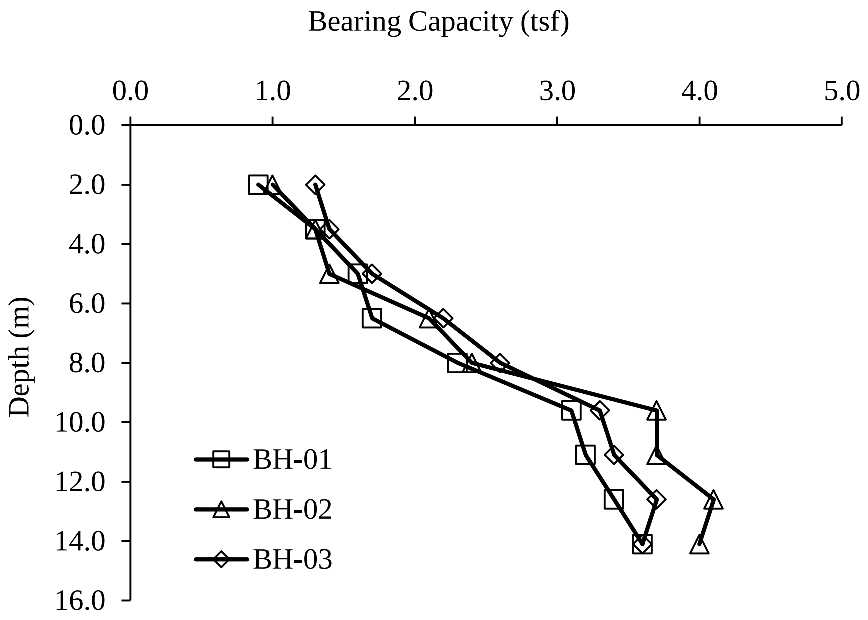


Figure 4.2 Variation of bearing capacity along with the depth

### 4.4.2 Based on shear parameters for spread footing

The bearing capacity based on the soil density, cohesion and angle of internal friction etc. was estimated using various methods such as Terzaghi, Terzaghi and Peck, Hensen, Vesic and Bowles formulae. The bearing capacity values for various boreholes are given in Table 4.6 and graphically represented in Figure 4.3 which is around **1.08 tsf** to **1.28 tsf.** The variation of bearing capacity concerning depth and width of the foundation is given in Table 4.7 and Table 4.8 also graphically represented in Figure 4.4 and Figure 4.5.

Table 4.6 Bearing capacity around a depth of 2.0 m

| Location | Allowable Bearing Capacity (tsf) |
|---|---|
| BH-1 | 1.17 |
| BH-2 | 1.28 |
| BH-3 | 1.08 |

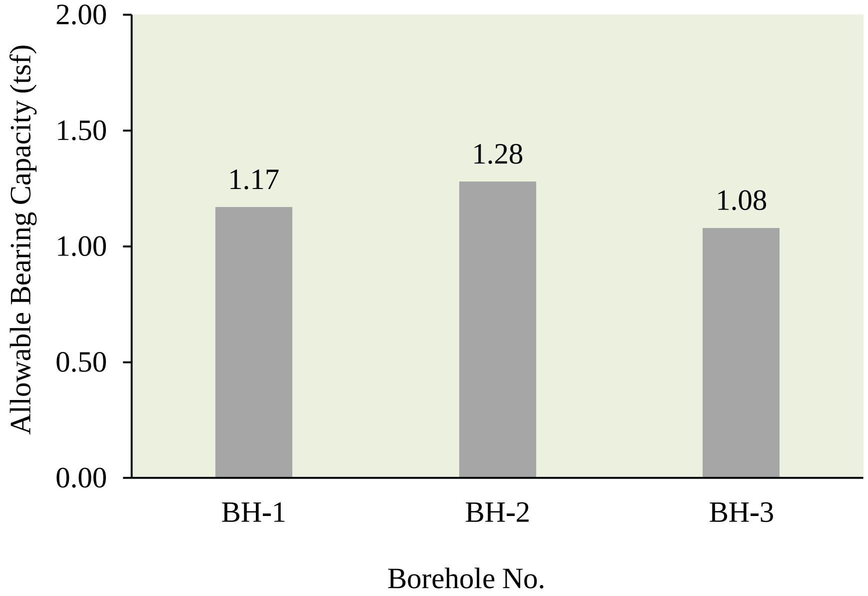


Figure 4.3 Bearing capacity for various boreholes around a depth of 2.0 m

Table 4.7 Bearing Capacity values as a function of width at the depth of 2.0 m

| Width of footing (m) | Allowable Bearing Capacity (tsf) (BH-01) | Allowable Bearing Capacity (tsf) (BH-02) | Allowable Bearing Capacity (tsf) (BH-03) |
|---|---|---|---|
| 0.50 | 1.07 | 1.17 | 1.00 |
| 0.75 | 1.12 | 1.23 | 1.04 |
| 1.00 | 1.17 | 1.28 | 1.08 |
| 1.25 | 1.22 | 1.34 | 1.12 |
| 1.50 | 1.27 | 1.39 | 1.16 |
| 1.75 | 1.31 | 1.44 | 1.20 |
| 2.00 | 1.36 | 1.48 | 1.23 |

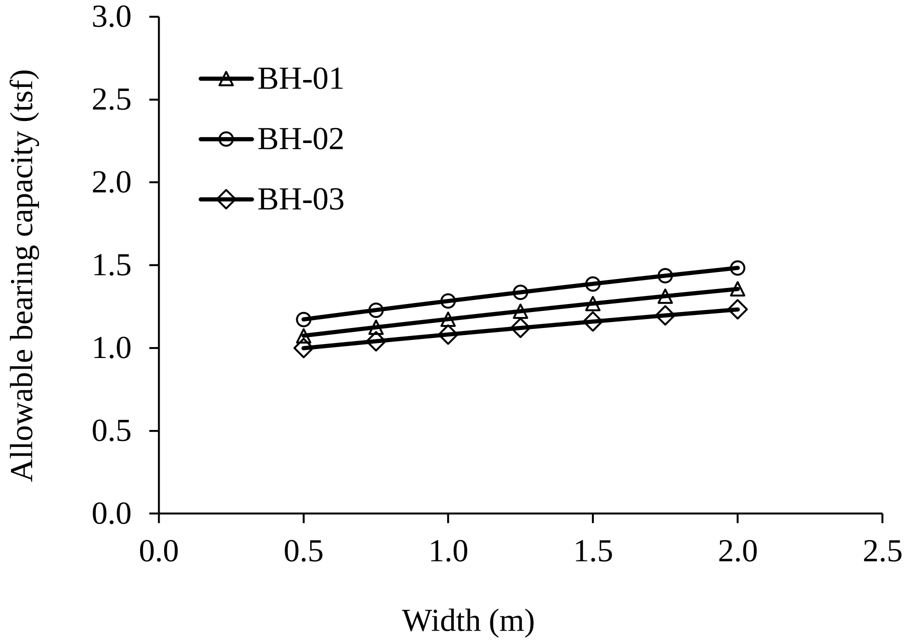


Figure 4.4 Bearing Capacity Curves as a function of breadth at the depth of 2.0 m

Table 4.8 Bearing Capacity values as a function of depth for the breadth of 1.0 m

| Depth of Footing (m) | Allowable Bearing Capacity (tsf) (BH-01) | Allowable Bearing Capacity (tsf) (BH-02) | Allowable Bearing Capacity (tsf) (BH-03) |
|---|---|---|---|
| 0.50 | 0.84 | 0.92 | 0.73 |
| 1.00 | 0.95 | 1.04 | 0.85 |
| 1.50 | 1.06 | 1.16 | 0.96 |
| 2.00 | 1.17 | 1.28 | 1.08 |
| 2.50 | 1.28 | 1.40 | 1.20 |
| 3.00 | 1.39 | 1.53 | 1.32 |
| 3.50 | 1.50 | 1.65 | 1.43 |

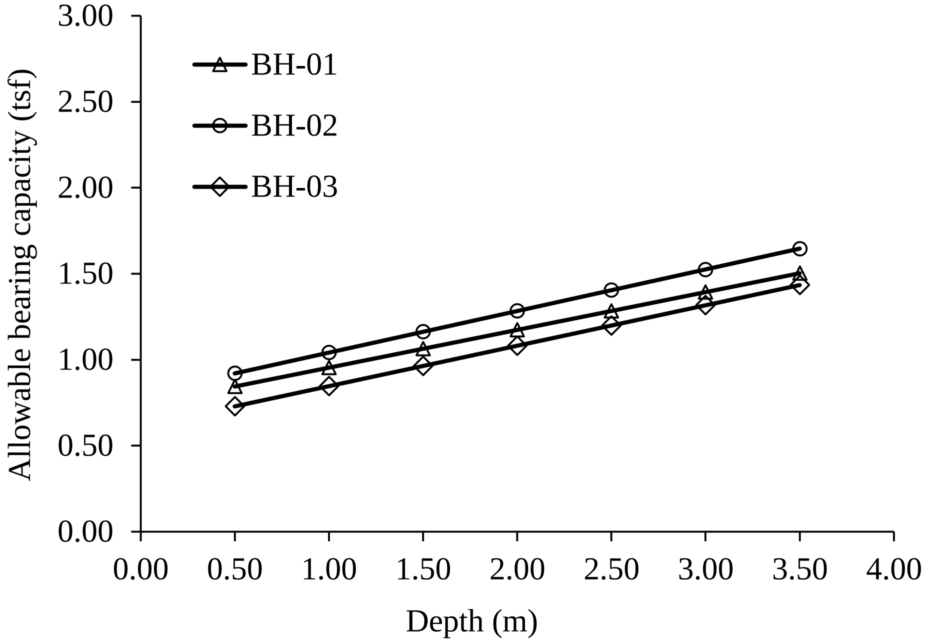


Figure 4.5 Bearing Capacity Curves as a function of depth for the breadth of 1.0 m

### 4.4.3 Bearing capacity of soil for raft foundations based on SPT

The bearing capacity analysis for a raft foundation at a depth of 2.0 m and at a variable length and width is made based on the allowable limit of the settlement of 25 mm and 50 mm. The bearing capacity results are summarized in Table 4.9 to Table 4.14. The allowable bearing capacity of a raft foundation as a function of foundation depth is shown in Figure 2.6.

Table 4.9 Allowable bearing capacity of raft foundation for limiting settlement of 25 mm (BH-1)

| SPT run | $N_{55}$ | Settlement ΔH (mm) | Depth D (m) | Breadth B (m) | Length L (m) | Depth factor $K_d$ | Allowable bearing capacity $q_a$ (kPa) | Allowable bearing capacity $q_a$ (tsf) |
|---|---|---|---|---|---|---|---|---|
| SPT-01 | 9.0 | 25.0 | 2.0 | 2.0 | 8.0 | 1.3 | 149.6 | 1.5 |
| SPT-01 | 9.0 | 25.0 | 2.0 | 4.0 | 8.0 | 1.2 | 131.1 | 1.3 |
| SPT-01 | 9.0 | 25.0 | 2.0 | 6.0 | 8.0 | 1.1 | 124.9 | 1.2 |
| SPT-01 | 9.0 | 25.0 | 2.0 | 8.0 | 8.0 | 1.1 | 121.8 | 1.2 |

Table 4.10 Allowable bearing capacity of raft foundation for limiting settlement of 25 mm (BH-2)

| SPT run | $N_{55}$ | Settlement $\Delta H$ (mm) | Depth D (m) | Breadth B (m) | Length L (m) | Depth factor $K_d$ | Allowable bearing capacity $q_a$ (kPa) | Allowable bearing capacity $q_a$ (tsf) |
|---|---|---|---|---|---|---|---|---|
| SPT-01 | 10.0 | 25.0 | 2.0 | 2.0 | 8.0 | 1.3 | 166.3 | 1.7 |
| SPT-01 | 10.0 | 25.0 | 2.0 | 4.0 | 8.0 | 1.2 | 145.6 | 1.5 |
| SPT-01 | 10.0 | 25.0 | 2.0 | 6.0 | 8.0 | 1.1 | 138.8 | 1.4 |
| SPT-01 | 10.0 | 25.0 | 2.0 | 8.0 | 8.0 | 1.1 | 135.3 | 1.4 |

Table 4.11 Allowable bearing capacity of raft foundation for limiting settlement of 25 mm (BH-3)

| SPT run | $N_{55}$ | Settlement $\Delta H$ (mm) | Depth D (m) | Breadth B (m) | Length L (m) | Depth factor $K_d$ | Allowable bearing capacity $q_a$ (kPa) | Allowable bearing capacity $q_a$ (tsf) |
|---|---|---|---|---|---|---|---|---|
| SPT-01 | 13.0 | 25.0 | 2.0 | 2.0 | 8.0 | 1.3 | 216.1 | 2.2 |
| SPT-01 | 13.0 | 25.0 | 2.0 | 4.0 | 8.0 | 1.2 | 189.3 | 1.9 |
| SPT-01 | 13.0 | 25.0 | 2.0 | 6.0 | 8.0 | 1.1 | 180.4 | 1.8 |
| SPT-01 | 13.0 | 25.0 | 2.0 | 8.0 | 8.0 | 1.1 | 175.9 | 1.8 |

Table 4.12 Allowable bearing capacity of raft foundation for limiting settlement of 50 mm (BH-1)

| SPT run | $N_{55}$ | Settlement $\Delta H$ (mm) | Depth D (m) | Breadth B (m) | Length L (m) | Depth factor $K_d$ | Allowable bearing capacity $q_a$ (kPa) | Allowable bearing capacity $q_a$ (tsf) |
|---|---|---|---|---|---|---|---|---|
| SPT-01 | 9.0 | 50.0 | 2.0 | 2.0 | 8.0 | 1.3 | 299.3 | 3.0 |
| SPT-01 | 9.0 | 50.0 | 2.0 | 4.0 | 8.0 | 1.2 | 262.1 | 2.6 |
| SPT-01 | 9.0 | 50.0 | 2.0 | 6.0 | 8.0 | 1.1 | 249.8 | 2.5 |
| SPT-01 | 9.0 | 50.0 | 2.0 | 8.0 | 8.0 | 1.1 | 243.6 | 2.4 |

Table 4.13 Allowable bearing capacity of raft foundation for limiting settlement of 50 mm (BH-2)

| SPT run | $N_{55}$ | Settlement $\Delta H$ (mm) | Depth D (m) | Breadth B (m) | Length L (m) | Depth factor $K_d$ | Allowable bearing capacity $q_a$ (kPa) | Allowable bearing capacity $q_a$ (tsf) |
|---|---|---|---|---|---|---|---|---|
| SPT-01 | 10.0 | 50.0 | 2.0 | 2.0 | 8.0 | 1.3 | 332.5 | 3.3 |
| SPT-01 | 10.0 | 50.0 | 2.0 | 4.0 | 8.0 | 1.2 | 291.3 | 2.9 |
| SPT-01 | 10.0 | 50.0 | 2.0 | 6.0 | 8.0 | 1.1 | 277.5 | 2.8 |
| SPT-01 | 10.0 | 50.0 | 2.0 | 8.0 | 8.0 | 1.1 | 270.6 | 2.7 |

Table 4.14 Allowable bearing capacity of raft foundation for limiting settlement of 50 mm (BH-3)

| SPT run | $N_{55}$ | Settlement $\Delta H$ (mm) | Depth D (m) | Breadth B (m) | Length L (m) | Depth factor $K_d$ | Allowable bearing capacity $q_a$ (kPa) | Allowable bearing capacity $q_a$ (tsf) |
|---|---|---|---|---|---|---|---|---|
| SPT-01 | 13.0 | 50.0 | 2.0 | 2.0 | 8.0 | 1.3 | 432.3 | 4.3 |
| SPT-01 | 13.0 | 50.0 | 2.0 | 4.0 | 8.0 | 1.2 | 378.6 | 3.8 |
| SPT-01 | 13.0 | 50.0 | 2.0 | 6.0 | 8.0 | 1.1 | 360.8 | 3.6 |
| SPT-01 | 13.0 | 50.0 | 2.0 | 8.0 | 8.0 | 1.1 | 351.8 | 3.5 |

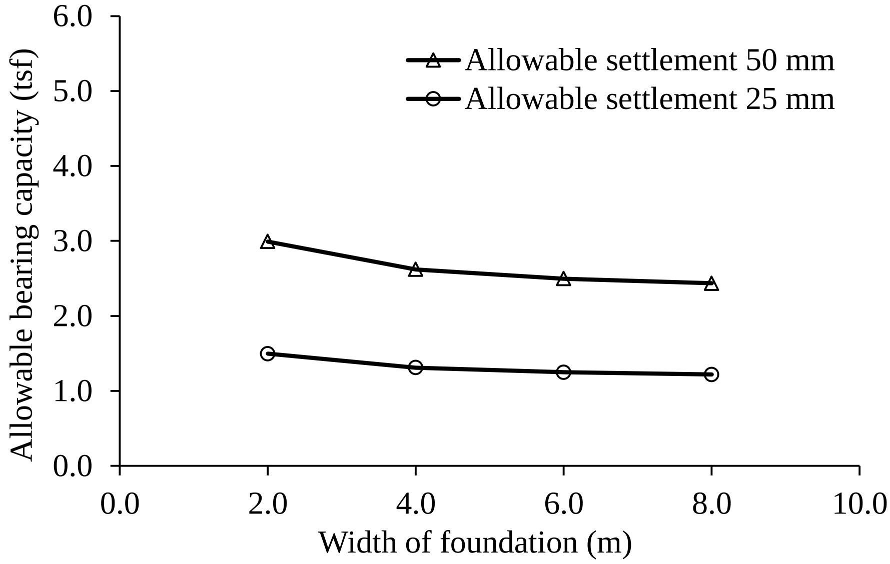


Figure 4.6 Allowable bearing capacity for a raft foundation of BH-1 as a function of foundation width for 25 mm and 50 mm settlement limit.

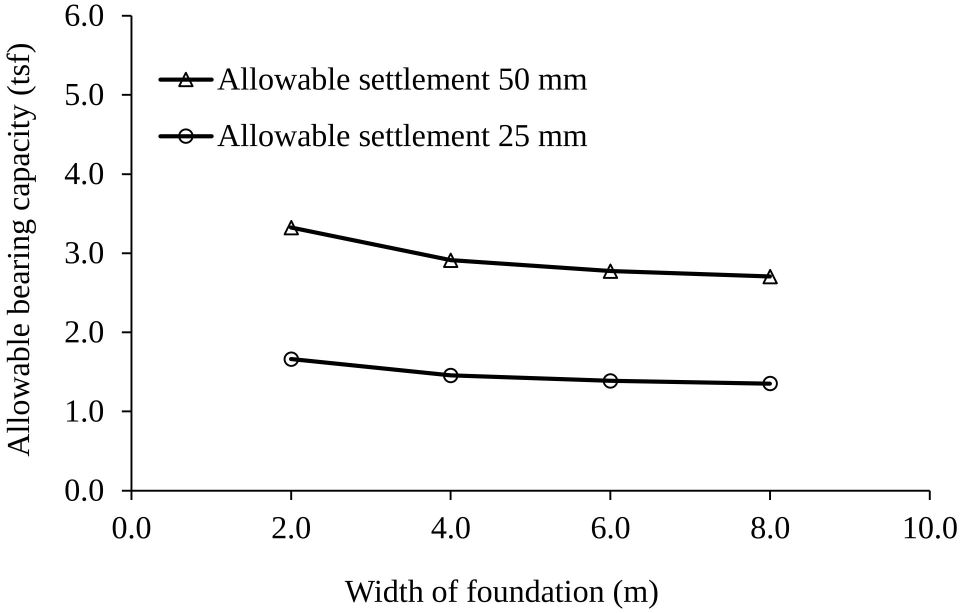


Figure 4.7 Allowable bearing capacity for a raft foundation of BH-2 as a function of foundation width for 25 mm and 50 mm settlement limit

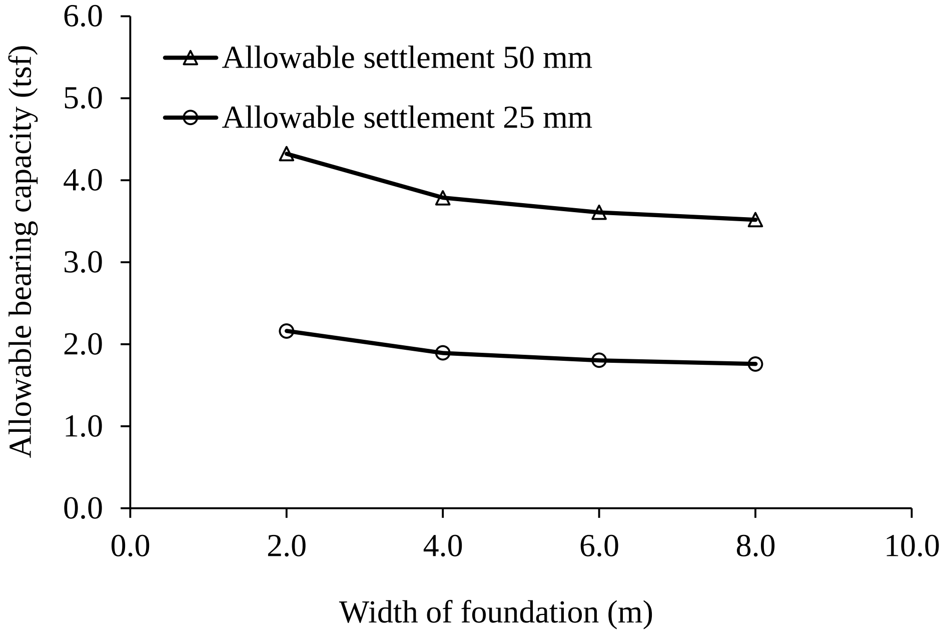


Figure 4.8 Allowable bearing capacity for a raft foundation of BH-3 as a function of foundation width for 25 mm and 50 mm settlement limit

## 4.5 Seismic profile of Hyderabad region.

The proposed project is in the low seismic zone, where a moderate level of seismic activity is believed to exist, but large magnitude earthquakes are very rare. The seismic factors as per the building code of Pakistan are given in Table 4.15. Tectonic Plates/Seismic Zoning Map of Pakistan can be seen in Figure 4.9. The peak ground acceleration for different cities of Pakistan is given in Table 4.16. The PGA of 0.08g to 0.16g is proposed for this area and nearby.

Table 4.15 Seismic factors as per the Building Code of Pakistan

| Seismic zone | Seismic Zone factor | Soil Profile Type | Seismic Coefficients Cα | Seismic Coefficients $C_V$ |
|---|---|---|---|---|
| 2A | 0.15 | $S_E$ | 0.30 | 0.50 |

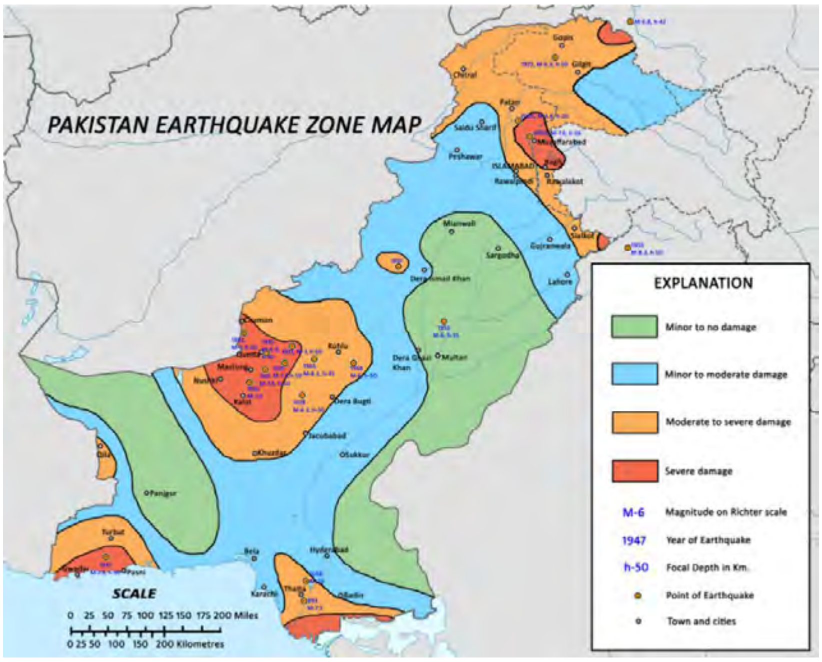


Figure 4.9 Pakistan Earthquake Zone Map

Table 4.16 Expected Peak Ground Acceleration (PGA) in [m/s$^2$] for the different cities against annual exceedance probabilities and return periods.

| Annual exceedance probability | Return period (years) | Expected PGA (m/s$^2$) for the cities of | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Islamabad | Peshawar | Quetta | Karachi | Gwadar | Muzaffarabad | Gilgit | Lahore | Multan | Khuzdar |
| 0.02 | 50 | 1.50 | 1.35 | 1.91 | 0.54 | 0.53 | 2.04 | 2.93 | 0.97 | 0.71 | 1.34 |
| 0.01 | 100 | 2.25 | 2.40 | 2.90 | 0.95 | 0.88 | 3.23 | 4.42 | 1.69 | 1.22 | 2.26 |
| 0.005 | 200 | 3.33 | 3.19 | 3.59 | 1.28 | 1.15 | 4.02 | 5.28 | 2.24 | 1.61 | 2.96 |
| 0.002 | 500 | 3.65 | 3.49 | 3.85 | 1.42 | 1.25 | 4.31 | 5.55 | 2.46 | 1.78 | 3.24 |
| 0.001 | 1000 | 3.71 | 3.55 | 3.90 | 1.45 | 1.28 | 4.36 | 5.60 | 2.51 | 1.81 | 3.30 |

## 4.6 Chemical properties of soil and water

The chemical properties of soil as shown in Table 4.17 were determined through pH, chloride, and sulphate content values. The samples were exhumed from the depth of 1.0 to 15.0 m. The chemical properties of water samples collected from BH No. 1 to BH No.3 were analyzed for chemical characteristics the chemical properties are given in Table 4.18.

Table 4.17 Chemical Properties of soil

| BH No. | pH | Sulphate content (%) | Chloride content (%) |
|---|---|---|---|
| BH-No.1 to BH-No.3 | 6.2 | 0.5 to 0.8 | 0.05 to 0.1 |

- 1 ppm= 1mg/liter = 0.0001%

## 4.7 Thermal and electrical conductivity/Resistivity of soil

The thermal and electrical conductivity/resistivity tests were conducted on the selected samples of silty sand exhumed from BH No.1 to BH No.3. The conductivity/resistivity characteristics of the soils are given in Table 4.18. Variation in the conductivity characteristics of the soil samples was noticed as a function of sample density and moisture contents present in the samples.

Table 4.18 Thermal properties of soil

| BH No. | Electrical conductivity (*m*S/m) | Thermal conductivity (W/m.K) |
|---|---|---|
| BH-No.1 to BH-No.3 | 0.3 to 3.5 | 2.3 to 4.1 |

## 4.8 Discussion

As from the field testing results, the N-value (SPT resistance value) is showing low SPT values from 0.0 to 5.0 m. The site mainly consists of sandy silt with low plasticity. By progressing the boring depth continuous has been displayed by very low SPT values. Which intern suggests that the site consists of loose soil.

Soil can hardly offer a safe allowable bearing capacity of 1.08 tsf to 1.28 tsf at varying depths which is evident from the field investigations (such as SPT) and laboratory investigations (such as shear strength parameters). The foundations resting on loose soils usually fail due to punching failure as shown in Figure 4.10. In the present site conditions, there is much likelihood on the site. The material state may be considered loose soil.

As discussed in the Terzaghi bearing capacity equation that the bearing capacity of soil not only depends upon the soil parameters it equally depends on the size, depth, and type of foundation. Therefore, the higher value of bearing capacity can be achieved by increasing the depth and size of the foundation as shown in Figure 4.11.

Table 4.19 Correlation between SPT resistance value-N and shear parameters

**Correlation between N and $\phi$**

| *N* | *Denseness* | $\phi$ |
|---|---|---|
| 0—4 | Very Loose | 25°—32° |
| 4—10 | Loose | 27°—35° |
| 10—30 | Medium | 30°—40° |
| 30—50 | Dense | 35°—45° |
| > 50 | Very Dense | > 45° |

**Correlation between N and $q_u$**

| *N* | *Consistency* | $q_u$ ($kN/m^2$) |
|---|---|---|
| 0—2 | Very Soft | < 25 |
| 2—4 | Soft | 25—50 |
| 4—8 | Medium | 50—100 |
| 8—15 | Stiff | 100—200 |
| 15—30 | Very Stiff | 200—400 |
| > 30 | Hard | > 400 |

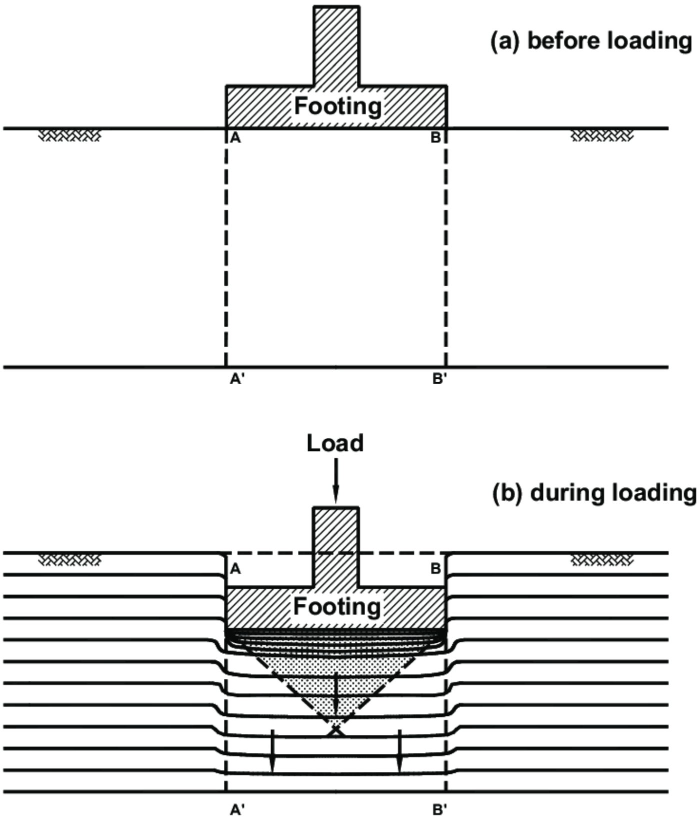


Figure 4.10 Punching shear failure of foundation resting on soft soil

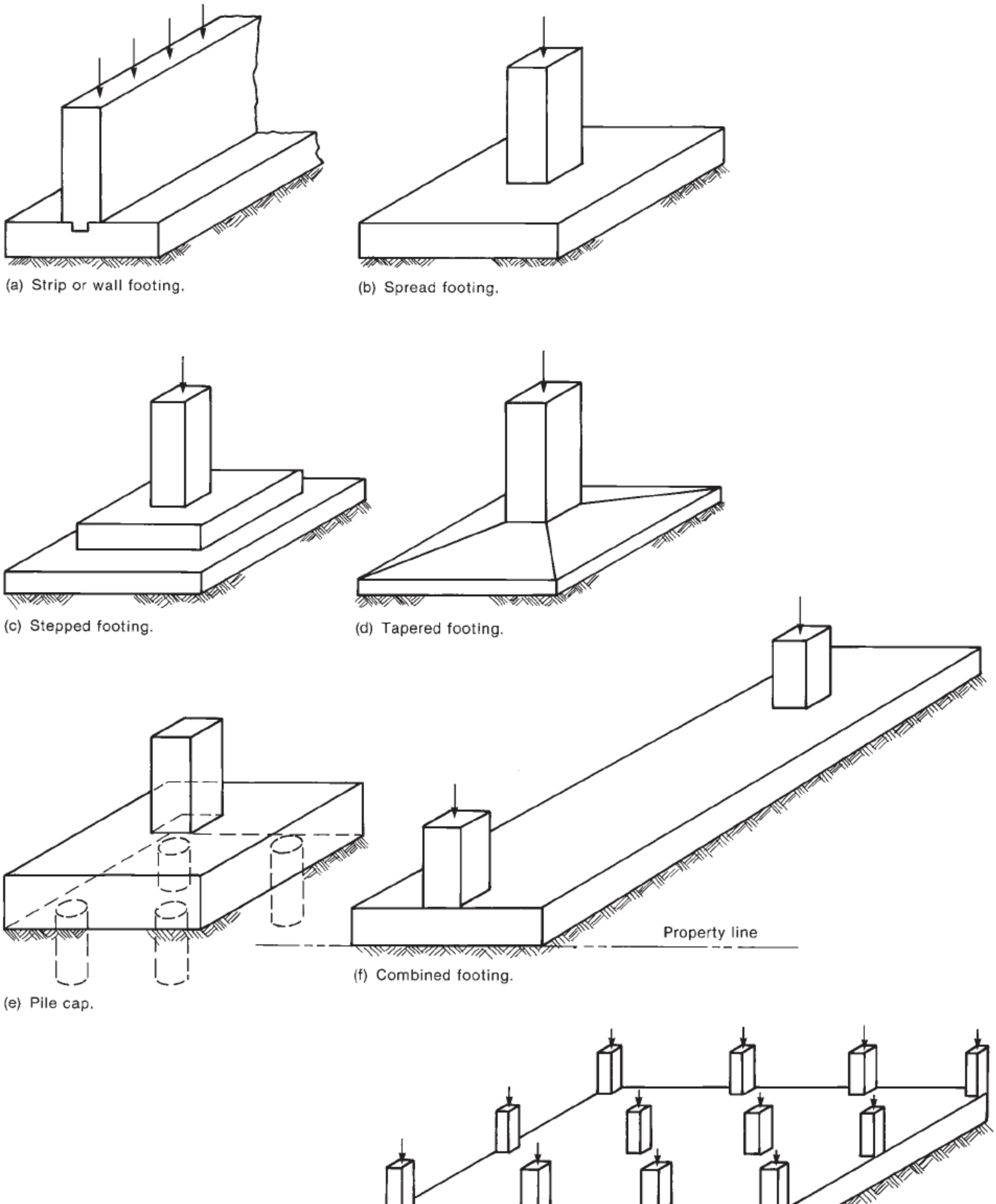


Figure 4.11 Extended footing sizes to avoid punching failure on loose soil

### 4.8.1 Worst case scenario

As the soil profile on the site of Kunnar Gas Field consisted of a loose soil up to the depth of 15.0 m in general; therefore, considering the worst-case scenario and limiting the depth of foundations for isolated (spread) and raft foundations to a depth of 2.0 m, on which the bearing capacity values are estimated. The SPT blow counts indicates a loose soil layer with relatively low bearing capacity.

#### 4.8.1.1 Bearing capacity for raft foundations

The bearing capacity for raft foundations was estimated considering the worst-case scenario where the lowest SPT N-value was noted as 09. The depth of the raft foundation is considered 2.0 m depth as per the client requirement. The bearing capacity of the raft foundation is estimated to be around ***1.2 tsf to 3.0 tsf with varying breath*** for the limiting settlement of 25 mm and 50 mm respectively as shown in Table 4.20 and Table 4.21. The variation of the bearing capacity as a function of raft foundation dimensions are shown in Figure 4.12.

Table 4.20 Allowable bearing capacity of raft foundation for the limiting settlement of 25 mm

| SPT run | $N_{55}$ | $\Delta H$ (mm) | D (m) | B (m) | L (m) | $K_d$ | $q_a$ (kPa) | $q_a$ (tsf) |
|---|---|---|---|---|---|---|---|---|
| SPT-01 | 9.0 | 25.0 | 2.0 | 2.0 | 8.0 | 1.3 | 149.6 | 1.5 |
| SPT-01 | 9.0 | 25.0 | 2.0 | 4.0 | 8.0 | 1.2 | 131.1 | 1.3 |
| SPT-01 | 9.0 | 25.0 | 2.0 | 6.0 | 8.0 | 1.1 | 124.9 | 1.2 |
| SPT-01 | 9.0 | 25.0 | 2.0 | 8.0 | 8.0 | 1.1 | 121.8 | 1.2 |

Table 4.21 Allowable bearing capacity of raft foundation for the limiting settlement of 50 mm

| SPT run | $N_{55}$ | $\Delta H$ (mm) | D (m) | B (m) | L (m) | $K_d$ | $q_a$ (kPa) | $q_a$ (tsf) |
|---|---|---|---|---|---|---|---|---|
| SPT-01 | 9.0 | 50.0 | 2.0 | 2.0 | 8.0 | 1.3 | 299.3 | 3.0 |
| SPT-01 | 9.0 | 50.0 | 2.0 | 4.0 | 8.0 | 1.2 | 262.1 | 2.6 |
| SPT-01 | 9.0 | 50.0 | 2.0 | 6.0 | 8.0 | 1.1 | 249.8 | 2.5 |
| SPT-01 | 9.0 | 50.0 | 2.0 | 8.0 | 8.0 | 1.1 | 243.6 | 2.4 |

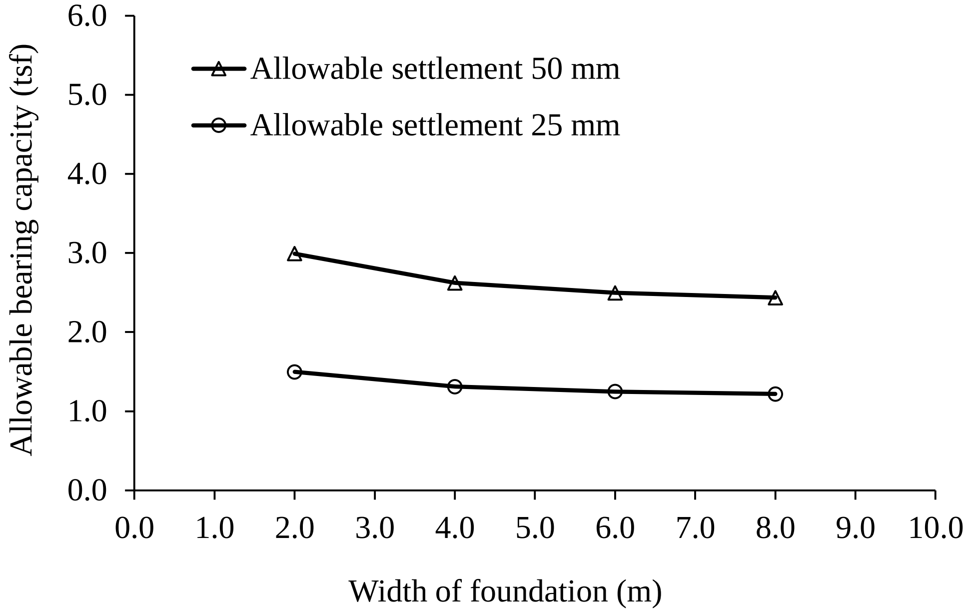


Figure 4.12 Allowable bearing capacity of raft foundation resting at the depth of 2.0 m

#### 4.8.1.2 Bearing capacity for isolated (spread) footing

The bearing capacity for isolated foundations was estimated considering the worst-case scenario where the lowest SPT N-value was noted as 9. The depth of the isolated foundation is considered 2.0 m depth. Considering Terzaghi, Meyerhof, Bowles methods. The bearing capacity analysis results are summarized; the bearing capacity of the isolated foundation is estimated to be around ***0.9 tsf***.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations for the Kunnar Gas field are given as follow:

## 5.1 Conclusions

1) **Site conditions**: - Flat land with the elevated groundwater table. The soil and water samples contain relatively high salinity levels.
2) **Soil type**: - From the results, it may be concluded that the soil on the site consisted of silty sand to low plastic silt up to the depth of 15.0 m. The site soil is contaminated with oil.
3) **Soil profile**: - The field and laboratory investigation results reveal that the entire soil layer from 0.0 to 15.0 m on the site is mainly medium dense to a loose state sandy silty soil with low plasticity. Oil contamination were noticed throughout the profile.
4) **Water table**: - Groundwater table is located 2.0 m below natural ground level (NGL) which would affect the bearing capacity of the foundations.
5) **Water quality:** - The samples collected were oily in nature and contaminated with oil.
6) **Hard strata:** Up to the depth of boring the soil may be considered as loose to medium dense. No hard strata were identified within the depth of exploration.
7) **Contamination:** During the laboratory examination oil contamination were noticed in the soil samples.
8) **Bearing capacity**: - The bearing capacity of the soil may be kept *low to medium* from ground level to a depth of 15.0 m.
9) **Seismic factor**: - As the region lies in a seismically low to the moderate active zone, therefore, a seismic factor may not be a major threat.
10) **Primary Foundation:** The main foundation will be the compressor foundation, Compressor foundation is a dynamic foundation for the compressor which lies in the category of vibratory API machine of around 1200 to 1800 rpm, with the required bearing capacity of around 60 to 80 $kN/m^2$. The present investigations reveal that the bearing capacity of the soil is around 115.84 $kN/m^2$ (1.08 tsf approx.:)
11) **Secondary Foundations:** Another secondary foundation is of a required bearing capacity of 70 $kN/m^2$.
    a) Raft or block foundation for static machines.

b) Isolated foundation for steel columns.

## 5.2 Recommendations

1) **Bearing Capacity**

a) The recommended bearing capacity of the soil for the site for spread footing is **1.08 tsf.** at a depth of 2.0 m approximately.

b) For Raft foundations of the typical size of 8.0 m by 8.0 m for 25 mm allowable settlement is **1.2 tsf** at a depth of 2.0 m.

c) For Raft foundations of the typical size of 8.0 m by 8.0 m for 50 mm allowable settlement is **2.4 tsf** at a depth of 2.0 m.

d) Considering the worst-case scenario as predicted during geotechnical site investigations, the bearing capacity of the raft foundation may be around ***1.2 tsf*** for a foundation of typical size 8.0 m by 8.0 m with limiting settlement of 25 mm.

e) Applying conservative approach based upon BS 8004-1986 the bearing capacity may be taken as **0.85 tsf** for isolated and raft foundations.

f) **Foundation depth: -** The depth of spread foundations and raft foundations may be kept within **2.0 m**.

g) **Foundation type:** - The type of foundation may be decided based on the structural load to be transferred. Spread footing can work for the nominal loading conditions. However, for multi-storey buildings, heavy machinery foundations and storage tanks, raft and pile foundations would be the alternative options. However, for pile foundation, the depth of hard strata was not reached within the depth of exploration.

h) **Foundation size:** - The foundation dimensions and depth may be decided based on the superimposed load and the corresponding bearing capacity of the soil.

i) **Seismic effect: -** The peak ground acceleration (PGA) may be taken as 0.08g to 0.16g.

j) **Suitability of groundwater**: - The groundwater is not suitable for concrete mixing or curing purposes due to its high salinity content.

k) **Design requirements**: - The bearing capacity value of **1.08 tsf** is recommended to be satisfactory for primary and secondary foundations.

l) **Ground elevation**: - The ground level survey may be conducted. In case the construction site level is lower than the surrounding area a road level, the site filling with a suitable type of soil with adequate compaction will be required. This would help to avoid inundation and ease the surface drainage in rainy seasons.

m) **Soling stone/Sand-gravel cushion: -** The very purpose of soling is to rest the upper crust of road or floor to withstand the elastic deformation on account of load to come. Usually, the thickness of the rubble soling varies from 150mm (6 inches) to 250 mm. (10 inches). Thickness of sand-gravel cushion shall not be less than 100mm.

n) **Site contamination**: -Contaminated site characterization may be required if needed.

## 5.3 Challenges

1) The soil on the site consists of loose silty sand to low plastic silt. Excessive immediate or elastic settlement is likely due to loose state soil conditions.
2) Adequate site compaction prior to the construction can help to avoid the excessive immediate settlements that may occur during construction period.
3) The salinity level in the soil and water samples is relatively high may be given consideration.
4) To avoid the inflow of water (rain, seepage and sewage) elevation of the ground level with good quality fill material is important.
5) Oil contamination in the soil samples may pose problems, which may be given due consideration.

Moreover, the following points may be considered while planning to design and install a compressor foundation.

1. For the site conditions where the entire soil layer is loose; the bearing capacity will be low and settlement will be high; therefore, special arrangement would be essential as shown in Figure 5.1.

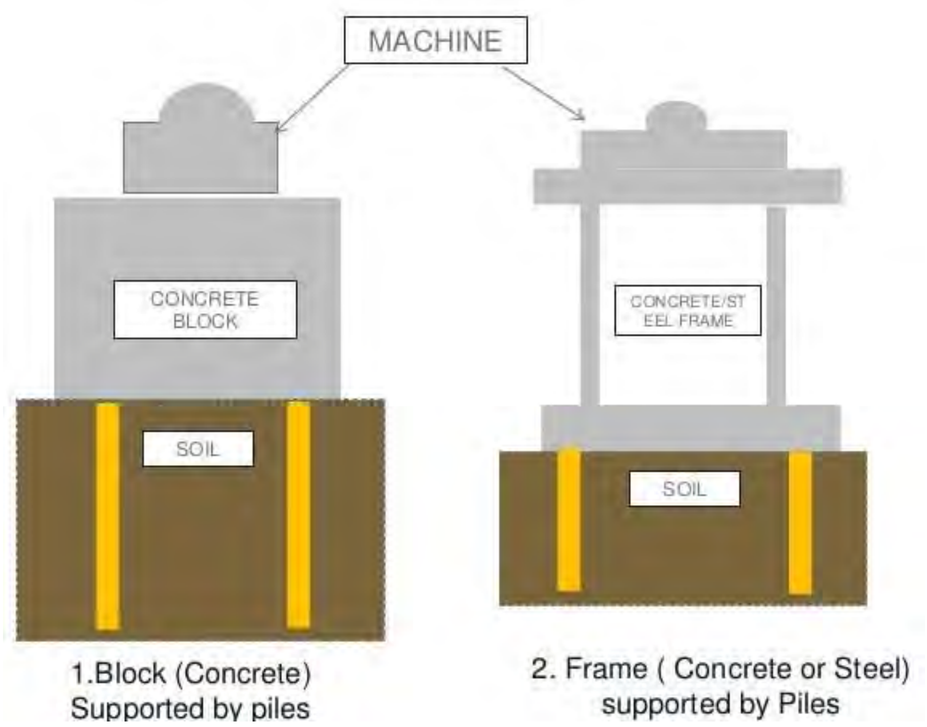


Figure 5.1 Mechanisms of load transfer and interaction.

2. The improvement of the loose soil can be done by adequate compaction with the help of suitable type of vibratory roller compactors.
3. The modification/improvement in the soil properties would make it safer, nevertheless even considering the worst-case scenario the bearing capacity of the soil may not go below 1.08 tsf in the present case.
4. It is suggested to simulate the compressor foundation with the given field conditions as depicted during geotechnical site investigations. The software-based simulation would predict the chances of failures easily and would ultimately provide a safer design.
5. The scope of a geotechnical engineer is to provide with soil profile that a design engineer converts to a safer design of a suitable type of foundation. The involvement of a design engineer would help to clear the entire scenario at this stage in a proper way.

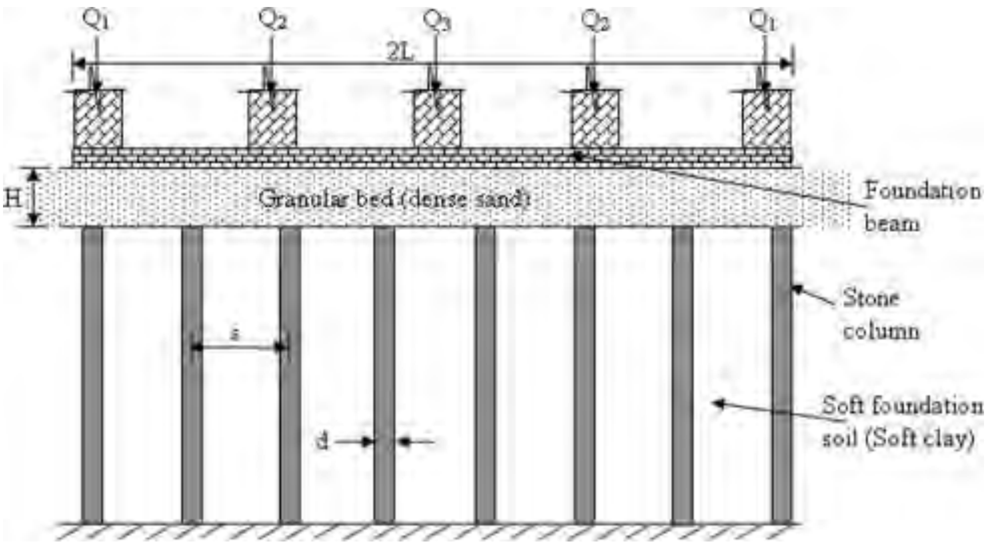


Figure 5.2 Installation of sand or stone columns

## 5.4 Queries

As the site consists of loose soil and variation in groundwater table is likely due to the agricultural lands with frequent irrigation water cycles; therefore, a conservative approach may be adopted.

**Reply**

The bearing capacity was calculated based on the field and laboratory test results. If the construction site is compacted adequately as recommended; the proposed bearing capacity of **1.2 tsf** for raft foundations would be safer. However, if the conservative approach is to be applied without any assurance if the construction site would be compacted adequately; the bearing capacity may be decided based upon BS 8004-1986 (as given in Table 5.1 and Table 5.2) which is around **0.85 tsf**.

Table 5.1 Bearing capacity range and soil type for cohesive soil (BS 8004-1986).

NOTE These values are for preliminary design purposes only, and may need alteration upwards or downwards. No addition has been made for the depth of embedment of the foundation (see **2.1.2.3.2** and **2.1.2.3.3**).

| Category | Types of rocks and soils | Presumed allowable bearing value | | Remarks |
|---|---|---|---|---|
| | | $kN/m^{2\,a}$ | $kgf/cm^{2\,a}$ $tontf/ft^2$ | |
| Cohesive soils | Very stiff boulder clays and hard clays | 300 to 600 | 3 to 6 | Group 3 is susceptible to long-term consolidation settlement |
| | Stiff clays | 150 to 300 | 1.5 to 3 | |
| | Firm clays | 75 to 150 | 0.75 to 1.5 | |
| | Soft clays and silts | <75 | <0.75 | |
| | Very soft clays and silts | Not applicable | | |
| Peat and organic soils | | Not applicable | | |
| Made ground or fill | | Not applicable | | |

[a] $107.25\ kN/m^2 = 1.094\ kgf/cm^2 = 1\ tonf/ft^2$.

Table 5.2 Typical bearing capacity range and soil type for cohesionless soil (BS 8004-1986).

| Category | Types of rocks and soils | Presumed allowable bearing value | | Remarks |
|---|---|---|---|---|
| | | kN/m$^{2\,a}$ | kgf/cm$^{2\,a}$ tontf/ft$^2$ | |
| Non-cohesive soils | Dense gravel, or dense sand and gravel | > 600 | > 6 | Width of foundation not less than 1 m. Groundwater level assumed to be a depth not less than below the base of the foundation. For effect of relative density and groundwater level, |
| | Medium dense gravel, or medium dense sand and gravel | < 200 to 600 | < 2 to 6 | |
| | Loose gravel, or loose sand and gravel | < 200 | < 2 | |
| | Compact sand | > 300 | > 3 | |
| | Medium dense sand | 100 to 300 | 1 to 3 | |
| | Loose sand | < 100 Value depending on degree of looseness | < 1 | |

# Annexure -A

Index properties of soil samples

Table 5.3 Index Properties of BH No.1

| ***Borehole ID: BH 01*** | | | | ***Gradation parameters*** | | | | ***Consistency limits*** | | | ***Soil Classification*** | ***Field description*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***S. No.*** | **Depth (m)** | **Run** | **Sample No.** | **Cu** | **Cc** | **$D_{mean}$ (mm)** | **Fine content (%)** | **LL (%)** | **PL (%)** | **PI (%)** | **USCS** | |
| 1 | 0.0-1.50 | -- | 01 | 3.02 | 1.50 | 0.11 | 17.82 | -- | -- | N.P | SM | Light greyish silty sand |
| 2 | 1.50-2.0 | SPT-01 | 02 | 3.11 | 1.57 | 0.10 | 15.66 | -- | -- | N.P | SM | |
| 3 | 2.0-3.0 | -- | 03 | 3.08 | 1.60 | 0.11 | 19.25 | -- | -- | N.P | SM | |
| 4 | 3.0-3.50 | SPT-02 | 04 | 3.14 | 1.55 | 0.13 | 18.91 | -- | -- | N.P | SM | |
| 5 | 3.50-4.50 | -- | 05 | 3.04 | 1.51 | 0.12 | 14.35 | -- | -- | N.P | SM | |
| 6 | 4.50-5.0 | SPT-03 | 06 | 3.07 | 1.62 | 0.14 | 14.03 | -- | -- | N.P | SM | |
| 7 | 5.0-6.0 | -- | 07 | 7.12 | 1.15 | 0.06 | 56.45 | -- | -- | N.P | ML | Dark greyish sandy silt |
| 8 | 6.0-6.50 | SPT-04 | 08 | 7.11 | 1.13 | 0.07 | 53.05 | -- | -- | N.P | ML | |
| 9 | 6.50-7.50 | -- | 09 | 7.10 | 1.12 | 0.08 | 52.27 | -- | -- | N.P | ML | |
| 10 | 7.50-8.0 | SPT-05 | 10 | 7.15 | 1.14 | 0.05 | 59.11 | -- | -- | N.P | ML | |
| 11 | 8.0-10.0 | -- | 11 | 8.34 | 1.13 | 0.07 | 54.30 | -- | -- | N.P | ML | |
| 12 | 9.10-9.60 | SPT-06 | 12 | 8.30 | 1.13 | 0.08 | 58.92 | -- | -- | N.P | ML | |
| 13 | 10.0-11.10 | -- | 13 | 8.16 | 1.12 | 0.08 | 58.91 | -- | -- | N.P | ML | |
| 14 | 10.60-11.10 | SPT-07 | 14 | 8.24 | 1.14 | 0.05 | 53.40 | -- | -- | N.P | ML | |
| 15 | 11.10-12.10 | -- | 15 | 8.20 | 1.13 | 0.07 | 55.06 | -- | -- | N.P | ML | |
| 16 | 12.10-12.60 | SPT-08 | 16 | 8.14 | 1.13 | 0.08 | 59.01 | -- | -- | N.P | ML | |
| 17 | 12.60-13.70 | -- | 17 | 8.10 | 1.12 | 0.08 | 61.32 | -- | -- | N.P | ML | |
| 18 | 13.70-14.10 | SPT-09 | 18 | 8.17 | 1.14 | 0.05 | 60.47 | -- | -- | N.P | ML | |
| 19 | 14.10-15.0 | -- | 19 | 8.15 | 1.12 | 0.07 | 64.09 | -- | -- | N.P | ML | |

Table 5.4 Index Properties of BH No.2

| ***Borehole ID: BH 02*** | | | | ***Gradation parameters*** | | | | ***Consistency limits*** | | | ***Soil Classification*** | ***Field description*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***S. No.*** | **Depth (m)** | **Run** | **Sample No.** | **Cu** | **Cc** | **$D_{mean}$ (mm)** | **Fine content (%)** | **LL (%)** | **PL (%)** | **PI (%)** | **USCS** | |
| 1 | 0.0-1.50 | -- | 01 | 8.81 | 0.94 | 0.08 | 48.74 | -- | -- | N.P | SM | Light greyish silty sand |
| 2 | 1.50-2.0 | SPT-01 | 02 | 8.77 | 0.95 | 0.07 | 41.30 | -- | -- | N.P | SM | |
| 3 | 2.0-3.0 | -- | 03 | 8.75 | 0.94 | 0.08 | 35.66 | -- | -- | N.P | SM | |
| 4 | 3.0-3.50 | SPT-02 | 04 | 8.64 | 0.94 | 0.08 | 37.89 | -- | -- | N.P | SM | |
| 5 | 3.50-4.50 | -- | 05 | 8.62 | 0.94 | 0.08 | 41.16 | -- | -- | N.P | SM | |
| 6 | 4.50-5.0 | SPT-03 | 06 | 5.52 | 1.43 | 0.04 | 70.91 | -- | -- | N.P | ML | Dark greyish sandy silt |
| 7 | 5.0-6.0 | -- | 07 | 5.59 | 1.44 | 0.05 | 78.82 | -- | -- | N.P | ML | |
| 8 | 6.0-6.50 | SPT-04 | 08 | 6.82 | 1.20 | 0.06 | 76.54 | -- | -- | N.P | ML | |
| 9 | 6.50-7.50 | -- | 09 | 6.81 | 1.22 | 0.07 | 77.21 | -- | -- | N.P | ML | |
| 10 | 7.50-8.0 | SPT-05 | 10 | 6.83 | 1.34 | 0.07 | 73.41 | -- | -- | N.P | ML | |
| 11 | 8.0-10.0 | -- | 11 | 5.62 | 1.44 | 0.06 | 60.56 | -- | -- | N.P | ML | |
| 12 | 9.10-9.60 | SPT-06 | 12 | 5.60 | 1.45 | 0.06 | 63.41 | -- | -- | N.P | ML | |
| 13 | 10.0-11.10 | -- | 13 | 6.80 | 1.22 | 0.07 | 63.76 | -- | -- | N.P | ML | |
| 14 | 10.60-11.10 | SPT-07 | 14 | 6.73 | 1.34 | 0.05 | 70.81 | -- | -- | N.P | ML | |
| 15 | 11.10-12.10 | -- | 15 | 5.52 | 1.44 | 0.06 | 72.39 | -- | -- | N.P | ML | |
| 16 | 12.10-12.60 | SPT-08 | 16 | 5.61 | 1.45 | 0.06 | 74.13 | -- | -- | N.P | ML | |
| 17 | 12.60-13.70 | -- | 17 | 6.86 | 1.22 | 0.07 | 77.79 | -- | -- | N.P | ML | |
| 18 | 13.70-14.10 | SPT-09 | 18 | 6.82 | 1.34 | 0.07 | 79.21 | -- | -- | N.P | ML | |
| 19 | 14.10-15.0 | -- | 19 | 5.64 | 1.44 | 0.06 | 78.90 | -- | -- | N.P | ML | |

Table 5.5 Index properties of BH No.3

| ***Borehole ID: BH 03*** | | | | ***Gradation parameters*** | | | | ***Consistency limits*** | | | ***Soil Classification*** | ***Field description*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***S. No.*** | **Depth (m)** | **Run** | **Sample No.** | **Cu** | **Cc** | **$D_{mean}$ (mm)** | **Fine content (%)** | **LL (%)** | **PL (%)** | **PI (%)** | **USCS** | |
| 1 | 0.0-1.50 | -- | 01 | 5.41 | 1.41 | 0.03 | 97.85 | 33.0 | 29.66 | 3.34 | ML | Light brownish sandy silt |
| 2 | 1.50-2.0 | SPT-01 | 02 | 5.53 | 1.43 | 0.03 | 65.42 | -- | -- | N.P | ML | |
| 3 | 2.0-3.0 | -- | 03 | 5.71 | 1.42 | 0.03 | 58.19 | -- | -- | N.P | ML | Dark greyish sandy silt |
| 4 | 3.0-3.50 | SPT-02 | 04 | 5.80 | 1.41 | 0.04 | 60.12 | -- | -- | N.P | ML | |
| 5 | 3.50-4.50 | -- | 05 | 5.81 | 1.40 | 0.04 | 56.03 | -- | -- | N.P | ML | |
| 6 | 4.50-5.0 | SPT-03 | 06 | 5.84 | 1.41 | 0.03 | 64.31 | -- | -- | N.P | ML | |
| 7 | 5.0-6.0 | -- | 07 | 5.73 | 1.43 | 0.04 | 59.94 | -- | -- | N.P | ML | |
| 8 | 6.0-6.50 | SPT-04 | 08 | 5.70 | 1.44 | 0.04 | 57.80 | -- | -- | N.P | ML | |
| 9 | 6.50-7.50 | -- | 09 | 5.71 | 1.45 | 0.04 | 54.38 | -- | -- | N.P | ML | |
| 10 | 7.50-8.0 | SPT-05 | 10 | 5.66 | 1.42 | 0.04 | 59.10 | -- | -- | N.P | ML | |
| 11 | 8.0-10.0 | -- | 11 | 5.84 | 1.40 | 0.04 | 54.87 | -- | -- | N.P | ML | |
| 12 | 9.10-9.60 | SPT-06 | 12 | 5.85 | 1.43 | 0.04 | 53.60 | -- | -- | N.P | ML | |
| 13 | 10.0-11.10 | -- | 13 | 5.70 | 1.45 | 0.04 | 57.41 | -- | -- | N.P | ML | |
| 14 | 10.60-11.10 | SPT-07 | 14 | 5.65 | 1.42 | 0.04 | 58.91 | -- | -- | N.P | ML | |
| 15 | 11.10-12.10 | -- | 15 | 5.87 | 1.40 | 0.04 | 59.03 | -- | -- | N.P | ML | |
| 16 | 12.10-12.60 | SPT-08 | 16 | 5.85 | 1.43 | 0.04 | 55.03 | -- | -- | N.P | ML | |
| 17 | 12.60-13.70 | -- | 17 | 5.76 | 1.45 | 0.04 | 51.22 | -- | -- | N.P | ML | |
| 18 | 13.70-14.10 | SPT-09 | 18 | 5.69 | 1.42 | 0.04 | 54.11 | -- | -- | N.P | ML | |
| 19 | 14.10-15.0 | -- | 19 | 5.84 | 1.40 | 0.04 | 59.07 | -- | -- | N.P | ML | |

# Annexure -B

Physical and Mechanical properties of soil samples

Table 5.6 Mechanical properties of BH No.1

| Borehole ID's BH-01 | | | | | Soil type | Soil Density | | | | | Strength parameters | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. No. | Depth (m) | Run | SPT Blows | | USCS Symbol | Saturated Unit weight $\gamma_{sat}$ (kN/m$^3$) | Dry Unit weight $\gamma_d$ (kN/m$^3$) | Bulk Unit weight $\gamma_b$ KN/m$^3$ | Moisture content $w$, (%) | Specific Gravity, Gs | Cohesion, c (kN/m$^2$) | Friction angle $\phi$ (degree) |
| 1 | 0.0-1.50 | -- | -- | -- | SM | 18.04 | 13.10 | 15.47 | 18.06 | 2.66 | 19.56 | 29.05 |
| 2 | 1.50-2.0 | SPT-01 | 4 | 5 | SM | 18.14 | 13.18 | 15.14 | 14.90 | 2.67 | 19.90 | 29.43 |
| 3 | 2.0-3.0 | -- | -- | -- | SM | 18.19 | 13.23 | 15.57 | 17.69 | 2.65 | 19.78 | 29.76 |
| 4 | 3.0-3.50 | SPT-02 | 6 | 7 | SM | 18.22 | 13.40 | 16.52 | 23.31 | 2.67 | 19.54 | 29.80 |
| 5 | 3.50-4.50 | -- | -- | -- | SM | 18.34 | 13.34 | 15.18 | 13.80 | 2.66 | 19.34 | 29.94 |
| 6 | 4.50-5.0 | SPT-03 | 7 | 9 | SM | 18.67 | 13.76 | 16.96 | 23.28 | 2.67 | 19.40 | 15.67 |
| 7 | 5.0-6.0 | -- | -- | -- | ML | 18.93 | 14.06 | 17.11 | 21.68 | 2.68 | 7.89 | 14.93 |
| 8 | 6.0-6.50 | SPT-04 | 9 | 8 | ML | 19.12 | 14.09 | 16.87 | 19.75 | 2.67 | 8.45 | 15.40 |
| 9 | 6.50-7.50 | -- | -- | -- | ML | 19.14 | 14.12 | 17.23 | 22.03 | 2.69 | 9.14 | 14.55 |
| 10 | 7.50-8.0 | SPT-05 | 11 | 12 | ML | 19.38 | 14.17 | 16.98 | 19.85 | 2.66 | 9.25 | 16.33 |
| 11 | 8.0-10.0 | -- | -- | -- | ML | 19.30 | 14.22 | 17.04 | 19.84 | 2.67 | 10.50 | 14.95 |
| 12 | 9.10-9.60 | SPT-06 | 14 | 18 | ML | 19.41 | 14.40 | 17.24 | 19.72 | 2.68 | 10.43 | 14.10 |
| 13 | 10.0-11.10 | -- | -- | -- | ML | 19.32 | 14.10 | 16.82 | 19.31 | 2.68 | 10.40 | 14.34 |
| 14 | 10.60-11.10 | SPT-07 | 13 | 19 | ML | 19.51 | 14.47 | 17.28 | 19.39 | 2.68 | 10.34 | 14.38 |
| 15 | 11.10-12.10 | -- | -- | -- | ML | 19.65 | 14.50 | 17.27 | 19.13 | 2.68 | 10.37 | 14.35 |
| 16 | 12.10-12.60 | SPT-08 | 16 | 18 | ML | 19.11 | 14.76 | 17.59 | 19.17 | 2.68 | 10.45 | 14.39 |
| 17 | 12.60-13.70 | -- | -- | -- | ML | 19.22 | 14.73 | 17.70 | 20.18 | 2.68 | 10.48 | 14.41 |
| 18 | 13.70-14.10 | SPT-09 | 16 | 20 | ML | 19.61 | 14.61 | 17.66 | 20.91 | 2.68 | 10.60 | 14.56 |
| 19 | 14.10-15.0 | -- | -- | -- | ML | 19.59 | 14.31 | 17.36 | 21.34 | 2.68 | 10.10 | 14.67 |

Table 5.7 Mechanical properties of BH No.2

| **Borehole ID's BH-02** | | | | | **Soil type** | **Soil Density** | | | | | **Strength parameters** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **S. No.** | **Depth (m)** | **Run** | **SPT Blows** | | **USCS Symbol** | **Saturated Unit weight $\gamma_{sat}$ (kN/m$^3$)** | **Dry Unit weight $\gamma_d$ (kN/m$^3$)** | **Bulk Unit weight $\gamma_b$ KN/m$^3$** | **Moisture content *w*, (%)** | **Specific Gravity, Gs** | **Cohesion, c (kN/m$^2$)** | **Friction angle $\phi$ (degree)** |
| 1 | 0.0-1.50 | -- | -- | -- | SM | 18.45 | 13.04 | 16.18 | 24.05 | 2.65 | 19.40 | 28.50 |
| 2 | 1.50-2.0 | SPT-01 | 4 | 6 | SM | 18.10 | 13.10 | 15.80 | 20.64 | 2.66 | 19.52 | 29.00 |
| 3 | 2.0-3.0 | -- | -- | -- | SM | 18.22 | 13.20 | 16.17 | 22.47 | 2.67 | 19.70 | 29.12 |
| 4 | 3.0-3.50 | SPT-02 | 6 | 7 | SM | 18.29 | 13.32 | 16.10 | 20.86 | 2.66 | 19.55 | 29.32 |
| 5 | 3.50-4.50 | -- | -- | -- | SM | 18.38 | 13.39 | 16.13 | 20.45 | 2.65 | 19.37 | 29.06 |
| 6 | 4.50-5.0 | SPT-03 | 7 | 7 | ML | 18.75 | 13.70 | 16.55 | 20.77 | 2.66 | 19.60 | 14.06 |
| 7 | 5.0-6.0 | -- | -- | -- | ML | 18.90 | 14.00 | 16.80 | 20.00 | 2.67 | 9.45 | 16.78 |
| 8 | 6.0-6.50 | SPT-04 | 10 | 11 | ML | 19.09 | 14.04 | 16.87 | 20.15 | 2.66 | 9.32 | 16.93 |
| 9 | 6.50-7.50 | -- | -- | -- | ML | 19.11 | 14.10 | 17.29 | 22.60 | 2.68 | 9.89 | 16.54 |
| 10 | 7.50-8.0 | SPT-05 | 11 | 13 | ML | 19.32 | 14.43 | 17.53 | 21.51 | 2.67 | 9.85 | 16.33 |
| 11 | 8.0-10.0 | -- | -- | -- | ML | 19.07 | 14.66 | 17.50 | 19.35 | 2.68 | 10.12 | 16.95 |
| 12 | 9.10-9.60 | SPT-06 | 19 | 18 | ML | 19.11 | 14.87 | 17.24 | 15.97 | 2.68 | 10.45 | 16.08 |
| 13 | 10.0-11.10 | -- | -- | -- | ML | 19.05 | 14.80 | 17.11 | 15.60 | 2.68 | 10.09 | 16.11 |
| 14 | 10.60-11.10 | SPT-07 | 17 | 20 | ML | 19.14 | 14.71 | 17.00 | 15.56 | 2.66 | 10.11 | 16.78 |
| 15 | 11.10-12.10 | -- | -- | -- | ML | 19.18 | 14.75 | 17.07 | 15.71 | 2.66 | 10.43 | 16.80 |
| 16 | 12.10-12.60 | SPT-08 | 19 | 22 | ML | 19.20 | 14.77 | 17.08 | 15.63 | 2.66 | 10.54 | 16.72 |
| 17 | 12.60-13.70 | -- | -- | -- | ML | 19.42 | 14.86 | 17.20 | 15.72 | 2.66 | 10.89 | 16.77 |
| 18 | 13.70-14.10 | SPT-09 | 18 | 22 | ML | 19.34 | 14.80 | 17.13 | 15.76 | 2.66 | 10.76 | 16.34 |
| 19 | 14.10-15.0 | -- | -- | -- | ML | 19.56 | 14.70 | 17.00 | 15.63 | 2.66 | 10.41 | 16.23 |

Table 5.8 Mechanical properties of BH No.3

| Borehole ID's BH-03 | | | | | Soil type | Soil Density | | | | | Strength parameters | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. No. | Depth (m) | Run | SPT Blows | | USCS Symbol | Saturated Unit weight $\gamma_{sat}$ (kN/m$^3$) | Dry Unit weight $\gamma_d$ (kN/m$^3$) | Bulk Unit weight $\gamma_b$ KN/m$^3$ | Moisture content *w*, (%) | Specific Gravity, Gs | Cohesion, c (kN/m$^2$) | Friction angle $\phi$ (degree) |
| 1 | 0.0-1.50 | -- | -- | -- | ML | 18.11 | 14.07 | 18.44 | 31.03 | 2.66 | 9.12 | 15.60 |
| 2 | 1.50-2.0 | SPT-01 | 6 | 7 | ML | 18.43 | 14.60 | 17.23 | 18.02 | 2.67 | 9.34 | 15.60 |
| 3 | 2.0-3.0 | -- | -- | -- | ML | 18.40 | 14.59 | 18.21 | 24.80 | 2.66 | 9.21 | 15.87 |
| 4 | 3.0-3.50 | SPT-02 | 6 | 8 | ML | 18.50 | 14.65 | 16.80 | 14.69 | 2.65 | 9.11 | 15.80 |
| 5 | 3.50-4.50 | -- | -- | -- | ML | 18.54 | 14.54 | 17.51 | 20.45 | 2.66 | 9.19 | 15.76 |
| 6 | 4.50-5.0 | SPT-03 | 8 | 9 | ML | 18.67 | 14.65 | 16.35 | 11.62 | 2.67 | 9.16 | 15.45 |
| 7 | 5.0-6.0 | -- | -- | -- | ML | 18.56 | 14.60 | 17.49 | 19.78 | 2.67 | 9.56 | 15.40 |
| 8 | 6.0-6.50 | SPT-04 | 10 | 12 | ML | 18.50 | 14.40 | 16.21 | 12.54 | 2.67 | 9.87 | 15.68 |
| 9 | 6.50-7.50 | -- | -- | -- | ML | 18.34 | 14.12 | 16.96 | 20.13 | 2.66 | 9.94 | 14.45 |
| 10 | 7.50-8.0 | SPT-05 | 12 | 14 | ML | 18.53 | 14.47 | 17.35 | 19.92 | 2.67 | 9.56 | 15.65 |
| 11 | 8.0-10.0 | -- | -- | -- | ML | 18.65 | 14.70 | 17.93 | 21.98 | 2.67 | 9.34 | 11.56 |
| 12 | 9.10-9.60 | SPT-06 | 14 | 19 | ML | 18.70 | 14.43 | 17.24 | 19.49 | 2.67 | 9.80 | 14.50 |
| 13 | 10.0-11.10 | -- | -- | -- | ML | 18.10 | 14.71 | 17.42 | 18.40 | 2.67 | 9.75 | 13.42 |
| 14 | 10.60-11.10 | SPT-07 | 15 | 19 | ML | 18.60 | 14.75 | 17.76 | 20.44 | 2.68 | 9.71 | 15.80 |
| 15 | 11.10-12.10 | -- | -- | -- | ML | 18.78 | 14.77 | 17.99 | 21.80 | 2.68 | 9.74 | 15.85 |
| 16 | 12.10-12.60 | SPT-08 | 17 | 20 | ML | 18.71 | 14.81 | 17.63 | 19.07 | 2.68 | 9.65 | 14.67 |
| 17 | 12.60-13.70 | -- | -- | -- | ML | 18.76 | 14.65 | 17.30 | 18.11 | 2.68 | 9.67 | 16.70 |
| 18 | 13.70-14.10 | SPT-09 | 16 | 20 | ML | 18.82 | 14.67 | 17.19 | 17.19 | 2.67 | 9.69 | 14.55 |
| 19 | 14.10-15.0 | -- | -- | -- | ML | 18.86 | 14.76 | 17.60 | 19.22 | 2.67 | 9.71 | 15.69 |

# Annexure-C

## Bearing capacity analysis of Boreholes

Table 5.9 Statistical Analysis of BH No.1

| BH-No.1 | Soil Density | | | | | Strength parameters | |
|---|---|---|---|---|---|---|---|
| | **Saturated Unit weight $\gamma_{sat}$ (kN/m$^3$)** | **Dry Unit weight $\gamma_d$ (kN/m$^3$)** | **Bulk Unit weight $\gamma_b$ (kN/m$^3$)** | **Moisture content *w*, (%)** | **Specific Gravity, Gs** | **Cohesion, c (kN/m$^2$)** | **Friction angle $\phi$ (degree)** |
| Minimum | 18.04 | 13.10 | 15.14 | 13.80 | 2.65 | 7.89 | 14.10 |
| Maximum | 19.65 | 14.76 | 17.70 | 23.31 | 2.69 | 19.90 | 29.94 |
| Mean | 19.10 | 14.13 | 16.79 | 19.65 | 2.67 | 12.94 | 18.68 |
| ST-DEV | 0.55 | 0.54 | 0.83 | 2.42 | 0.01 | 4.70 | 6.72 |

Table 5.10 Bearing capacity analysis of BH No.1

| BH-No.1 | Foundation dimensions | | | Allowable settlement | Soil parameters | | | SPT | | Terzaghi Bearing capacity | | Coefficient of subgrade reaction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Length, L (m)** | **Breadth, B (m)** | **Depth, $D_f$ (m)** | **$\delta$ (mm)** | **Cohesion, c (kPa)** | **Friction angle, $\phi$** | **Unit weight, $\gamma$ (kN/m$^3$)** | **N-value** | **N`-value** | **$q_{all}$** | | **Ks** |
| | | | | | | | | | | kPa | tsf | MN/m$^3$ |
| Isolated | 1.00 | 1.00 | 2.00 | 25.0 | 12.9 | 18.7 | 13.1 | 9.0 | 10.3 | 112.4 | 1.17 | 4.50 |

Table 5.11 Statistical Analysis of BH No.2

| **BH-No.02** | **Soil Density** | | | | | **Strength parameters** | |
|---|---|---|---|---|---|---|---|
| | **Saturated Unit weight $\gamma_{sat}$ (kN/m$^3$)** | **Dry Unit weight $\gamma_d$ (kN/m$^3$)** | **Bulk Unit weight $\gamma_b$ (kN/m$^3$)** | **Moisture content *w*, (%)** | **Specific Gravity, Gs** | **Cohesion, c (kN/m$^2$)** | **Friction angle $\phi$ (degree)** |
| Minimum | 18.10 | 13.04 | 15.80 | 15.56 | 2.65 | 9.32 | 14.06 |
| Maximum | 19.56 | 14.87 | 17.53 | 24.05 | 2.68 | 19.70 | 29.32 |
| Mean | 19.01 | 14.30 | 16.83 | 18.86 | 2.66 | 13.13 | 19.71 |
| ST-DEV | 0.44 | 0.68 | 0.52 | 2.96 | 0.01 | 4.48 | 5.74 |

Table 5.12 Bearing capacity analysis of BH No.2

| **BH-No.2** | **Foundation dimensions** | | | **Allowable settlement** | **Soil parameters** | | | **SPT** | | **Terzaghi Bearing capacity** | | **Coefficient of subgrade reaction** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Length, L (m)** | **Breadth, B (m)** | **Depth, $D_f$ (m)** | **$\delta$ (mm)** | **Cohesion, c (kPa)** | **Friction angle, $\phi$** | **Unit weight, $\gamma$ (kN/m$^3$)** | **N-value** | **N`-value** | **$q_{all}$** | | **Ks** |
| | | | | | | | | | | kPa | tsf | MN/m$^3$ |
| Isolated | 1.00 | 1.00 | 2.00 | 25.0 | 13.1 | 19.7 | 13.0 | 6.0 | 6.8 | 122.9 | 1.28 | 4.90 |

Table 5.13 Statistical Analysis of BH No.3

| **BH-No.03** | **Soil Density** | | | | | **Strength parameters** | |
|---|---|---|---|---|---|---|---|
| | **Saturated Unit weight $\gamma_{sat}$ (kN/m$^3$)** | **Dry Unit weight $\gamma_d$ (kN/m$^3$)** | **Bulk Unit weight $\gamma_b$ (kN/m$^3$)** | **Moisture content *w*, (%)** | **Specific Gravity, Gs** | **Cohesion, c (kN/m$^2$)** | **Friction angle $\phi$ (degree)** |
| Minimum | 18.10 | 14.07 | 16.21 | 11.62 | 2.65 | 9.11 | 11.56 |
| Maximum | 18.86 | 14.81 | 18.44 | 31.03 | 2.68 | 9.94 | 16.70 |
| Mean | 18.59 | 14.60 | 17.40 | 19.40 | 2.67 | 9.53 | 15.16 |
| ST-DEV | 0.21 | 0.20 | 0.57 | 4.21 | 0.01 | 0.27 | 1.14 |

Table 5.14 Bearing capacity analysis of BH No.3

| **BH-No.3** | **Foundation dimensions** | | | **Allowable settlement** | **Soil parameters** | | | **SPT** | | **Terzaghi Bearing capacity** | | **Coefficient of subgrade reaction** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Length, L (m)** | **Breadth, B (m)** | **Depth, $D_f$ (m)** | **$\delta$ (mm)** | **Cohesion, c (kPa)** | **Friction angle, $\phi$** | **Unit weight, $\gamma$ (kN/m$^3$)** | **N-value** | **N\`-value** | **$q_{all}$** | | **Ks** |
| | | | | | | | | | | kPa | tsf | MN/m$^3$ |
| Isolated | 1.00 | 1.00 | 2.00 | 25.0 | 9.5 | 15.2 | 14.1 | 13.0 | 14.7 | 103.6 | 1.08 | 4.10 |

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