Appendix 1.0-K SRK, Geotechnical Foundation Assessment for Mine Infrastructure, Tenas Project

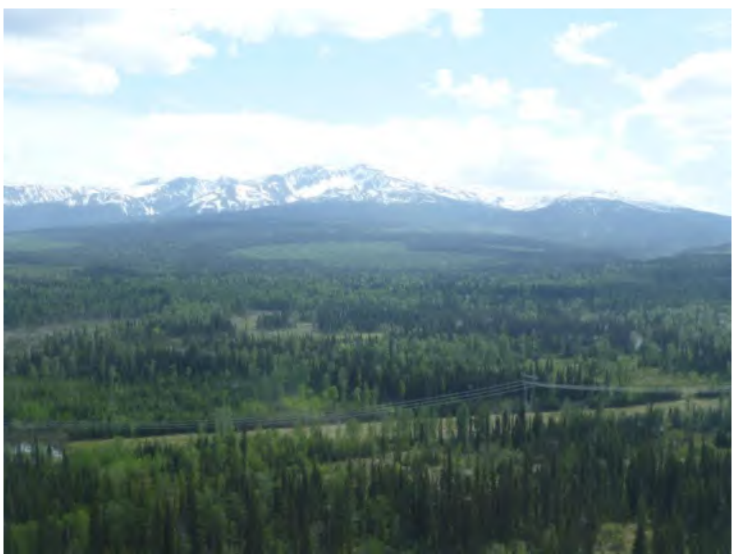
TELKWA COAL
LIMITED

TELKWA COAL LIMITED

Geotechnical Foundation Assessment for Mine Infrastructure, Tenas Project

Prepared for

Telkwa Coal Ltd.



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2CT025.008
February 2021

Geotechnical Foundation Assessment for Mine Infrastructure, Tenas Project

February 2021

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File Name: Telkwa_Tenas_Foundation Assessment_Report_2CT025.008_20210201.docx

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Table of Contents

1 Introduction 7
1.1 Project Development 7
2 Available Information 9
3 Field Investigation 9
3.1 Test Pit Investigations 9
3.2 Sonic Drilling Investigations 12
3.3 Laboratory testing 13
4 Site Conditions 13
4.1 Physiography 13
4.2 Bedrock 13
4.3 Surficial Soils 14
4.4 Site Subsurface Conditions 15
4.4.1 Mine Infrastructure 15
4.4.2 Explosives Depot 19
4.5 Other Laboratory Testing 20
4.6 Shallow Groundwater Conditions 21
4.7 Seismicity 21
5 Foundation Assessment 22
5.1 Soil Design Parameters 22
5.2 Shallow Foundations 22
5.3 Allowable Bearing Capacity and Estimated Settlement 23
5.4 Raft/Slab Foundations 27
5.5 Deep Foundations Considerations 29
5.5.1 Driven Piles 30
5.6 Machine Foundation Guidelines 30
5.7 Seismicity 32
5.8 Frost and Adfreeze Conditions 32
6 Earthworks 32
6.1 Temporary Excavations 32
6.2 Permanent Cut and Fill Slopes 33
6.3 Engineered Backfill and Fill Materials Compaction 33
6.4 Lateral Earth Pressures 34
6.5 Winter Earthwork Construction 35
6.6 Drainage 35
6.7 Field Inspections 36

7 Haul Road Cut Stability Review 36

8 Stockpile Stability Review 37

8.1 Stockpile Rating 37

8.2 Stability Analyses 38

8.3 Management Practices and Monitoring 41

9 Recommendations 42

10 References 44

List of Figures

Figure 1-1: Tenas Project Location Plan.. 7

Figure 1-2: Proposed Mine Infrastructure Layout 8

Figure 1-3: Example Explosives Deport Area 8

Figure 3-1: Location Plan showing Sonic Drillholes and Test Pit Investigations 11

Figure 3-2: Test Pit and Drillhole Locations at the Plant Infrastructure Area... 12

Figure 4-1: Modelled depth to bedrock below the MI footprint.. 14

Figure 4-2: Generalized shallow subsurface section through the sonic drillholes and test pits located at the proposed Mine Infrastructure area... 16

Figure 4-3: Materials encountered in 19-49TP (left) and 19-55TP (right).. 17

Figure 4-4: Summary of Particle Size Distribution Results 18

Figure 4-5: Summary of Atterberg Limits Testing 18

Figure 4-6: Summary of SPT Results for Mine Infrastructure Area Drillholes 19

Figure 4-7: Materials encountered in 19-52TP (left) and 19-54TP (right).. 20

Figure 5-1: Allowable Bearing Capacity and Settlement Estimates for Lean Clay with Gravel unit. 25

Figure 5-2: Allowable Bearing Capacity and Settlement Estimates for Lean Clay unit. 26

Figure 7-1: Location of proposed haul road cut and stability section location 36

Figure 7-2: Stability analyses results for Section A-A' through the proposed haul road 37

Figure 8-1: Topsoil Stockpile Stability Analyses Results 39

Figure 8-2: Processed Coal Stockpile Stability Analyses Results 40

Figure 8-3: Processed Rock (Coal Rejects) Stockpile Stability Analyses Results 40

Figure 8-4: ROM Coal Stockpile Stability Analyses Results... 41

List of Tables

Table 2-1: Provided Background Information ... 9
Table 3-1: Test Pit Locations and Sampling Summary ... 10
Table 3-2: Sonic Drillhole Locations and Testing Summary ... 12
Table 4-1: Atterberg Limits and PSD Results for the MI Footprint ... 17
Table 4-2: Atterberg Limits and Particle Size Distribution Test Results Summary ... 20
Table 4-3: Summary of Compaction Laboratory Testing ... 21
Table 5-1: Estimated slope design parameters ... 22
Table 5-2: Vertical Moduli of Subgrade Reaction for Slab-on-Grade Foundations ... 27
Table 5-3: Advantages and Disadvantages of Pile Foundation Types (based on CGS, 2006) ... 29
Table 5-4: Summary of Dynamic Loads for Machine Foundations (CGS, 2006) ... 31
Table 7-1: Geotechnical Strength Parameters for Haul Road Cut ... 37
Table 8-1: Geotechnical Strength Parameters for Stockpiles ... 38

Appendices

Appendix A: Test Pit and Sonic Drillhole Soil Logs
Appendix B: Laboratory Testing Results
Appendix C: Bearing Capacity and Settlement Estimate Calculations

Abbreviations

TCL	Telkwa Coal Ltd
SRK	SRK Consulting (Canada) Inc
MI	Mine Infrastructure
ED	Explosives Depot
CPP	Coal Product Processing
SPT	Standard Penetration Tests
PSD	Particle Size Distribution
ULS	Ultimate Limit Slate
NBCC	National Building Code of Canada
WSRHC	Waste Dump and Stockpile Stability Rating and Hazard Classification
FOS	Factor of Safety
PGA	Peak Ground Acceleration
Sa	Spectral Acceleration
SPMDD	Standard Proctor Maximum Dry Density
CGS	Canadian Geotechnical Society

1 Introduction

This report presents a geotechnical assessment of the mine infrastructure foundations at the Telkwa Coal Ltd. (TCL) Tenas Project, located in central British Columbia. TCL retained SRK Consulting (Canada) Inc. (SRK) to conduct geotechnical field investigations and an assessment of the site foundation conditions within the proposed Mine Infrastructure (MI) and Explosives Depot (ED) footprints.

1.1 Project Development

The MI footprint is located on relatively flat topography approximately 1 km northeast of the Tenas Pit (Figure 1-1). The MI pad is to include the following critical elements; administration building, coal product processing (CPP) building, tailing thickener, crushed coal conveyor, raw coal conveyor, stockpiles, fueling depot and other ancillary structures (i.e. fire hydrants, transformers, sewage treatment plant). The proposed MI layout is shown in Figure 1-2.

The ED is located approximately 2 km northwest of the pit (Figure 1-1). The ED includes a explosives storage and handling facility, maintenance garage and office buildings. An example ED layout is shown in Figure 1-3.

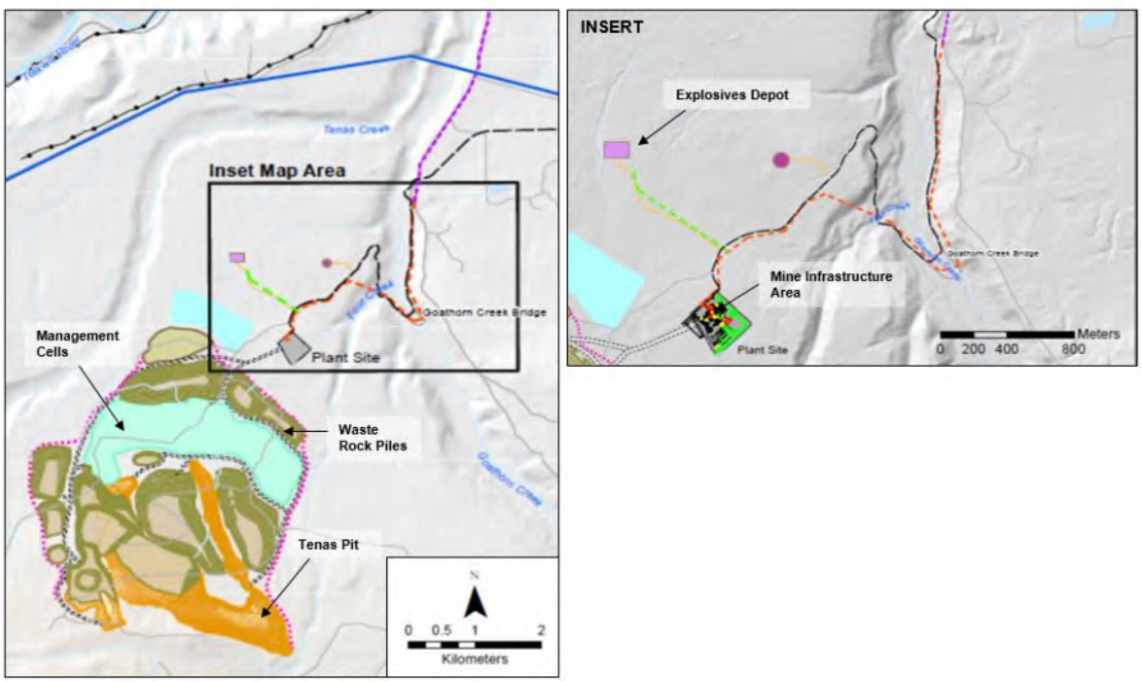


Figure 1-1: Tenas Project Location Plan

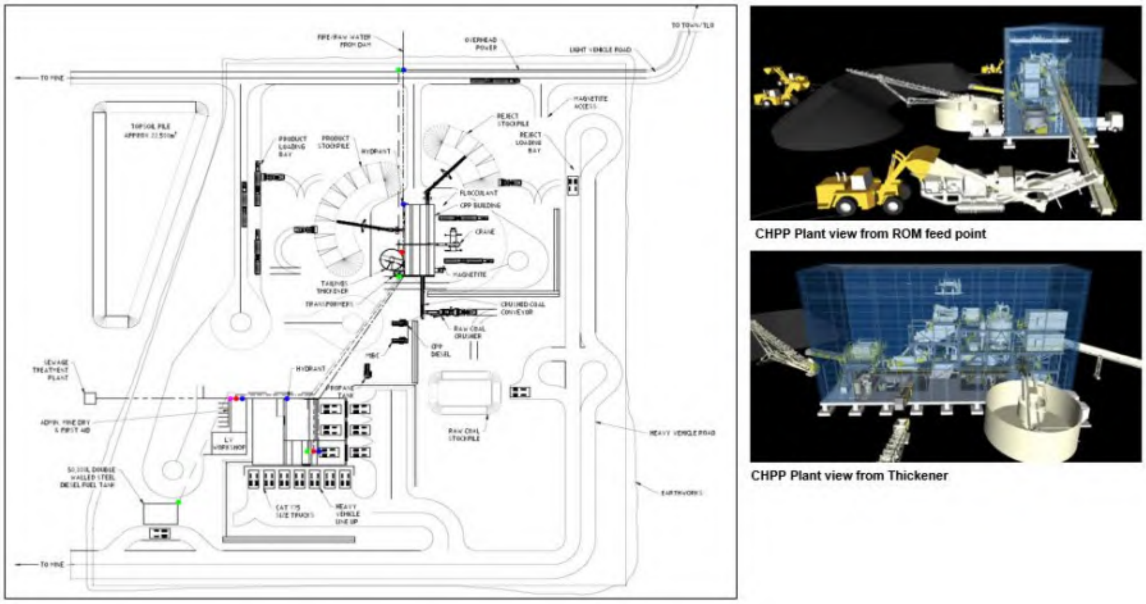


Figure 1-2: Proposed Mine Infrastructure Layout

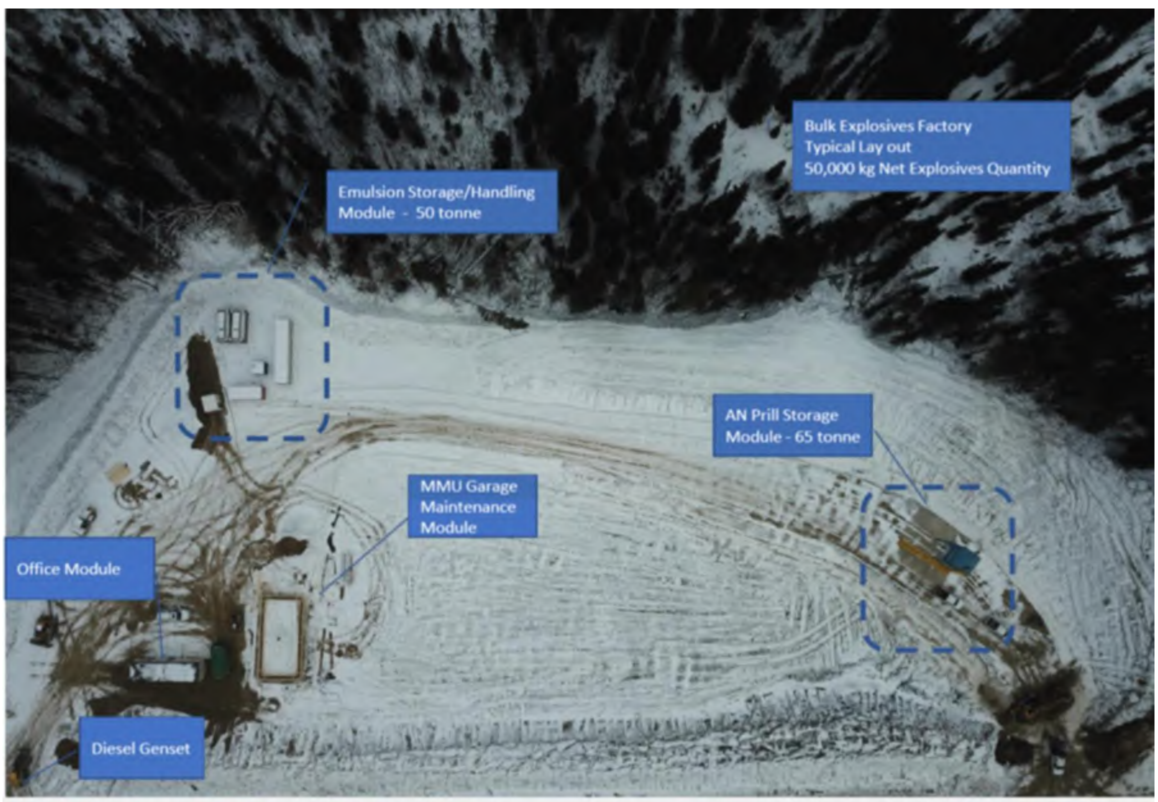


Figure 1-3: Example Explosives Deport Area

2 Available Information

TCL provided SRK with a number of drawings as background information for the geotechnical assessment of the MI area. The information was generally preliminary and/or pre-feasibility in nature. Table 2-1 provides the details for the provided background information.

Table 2-1: Provided Background Information

Item	Document Title
TCL Proposed Mine Infrastructure and Explosives Depot Layouts	A570-D1-01-0001_01.pdf
Seko Construction – Preliminary Warehouse and Truck Shop Details	Schedule 4 – Concept Drawings
Seko Construction – Preliminary Warehouse and Truck Shop Details	Schedule 5 - Pre-engineered Building Drawings
Seko Construction - Preliminary CHPP Building Structure and Foundation Details	Schedule 6 - Foundation Concept Drawings.pdf
TCL – Typical explosives depot layout	Explosives Yard.jpeg
TCL – Foundation Design Criteria	3.6.3.6 Foundation Design Criteria 0.doc

3 Field Investigation

As part of the 2018 and 2019 SRK supervised field investigations, a total of 26 sonic drillholes and 31 test pits were conducted around project site to characterize the foundation materials. The investigations were carried out during winter. The locations of the sonic and test pits are shown in Table 3-1. The results of the field investigations are summarised two separate data reports (SRK, 2018 and SRK, 2019) and pertinent findings summarised throughout this report. In addition to the SRK field investigations, historical Piteau Associates (Piteau, 1997) have been carried out.

Prior to the drilling and test pitting, the subsurface conditions from the other field investigation locations were reviewed. The results indicated relative consistency in the shallow foundation conditions across the project site.

Specific to the MI and ED footprints, eight test pits and three sonic drillholes were completed as shown in Figure 3-1. The locations of the sonic drilling were selected to investigate the subsurface conditions directly below the tailing thickener and CPP infrastructure. The test pits were located to investigate general shallow subsurface conditions across both footprints.

Eleven standpipe piezometers were installed within the 2018/2019 sonic drillholes to monitor shallow groundwater conditions in combination with the established deep groundwater monitoring network.

3.1 Test Pit Investigations

A total of eight test pits were using a John Deere LC 270 tracked excavator within in the MI and ED footprints (Figure 1-2 and Figure 1-3). The logged materials, test pit photographs and test results are presented in downhole plots in Appendix A. A summary of the test pit field investigation details is shown in Table 3-1 and the results compiled in Appendix A.

Table 3-1: Test Pit Locations and Sampling Summary

Location ID	Eating (m)	Northing (m)	Elevation (m)	Depth (m)	Water Inflow	Location
19-48TP	619054	6053559	801	4.3	Not Observed	Mine Infrastructure
19-49TP	619087	6053535	801	4.3	Not Observed	Mine Infrastructure
19-50TP	619149	6053478	801	4.2	Not Observed	Mine Infrastructure
19-51TP	619100	6053391	803	4.1	Not Observed	Mine Infrastructure
19-52TP	618485	6054492	781	3.3	Not Observed	Explosives Depot
19-53TP	618516	6054468	782	3.1	Not Observed	Explosives Depot
19-54TP	619042	6053477	802	4.2	Not Observed	Mine Infrastructure
19-55TP	619054	6053453	827	4.1	Observed	Mine Infrastructure

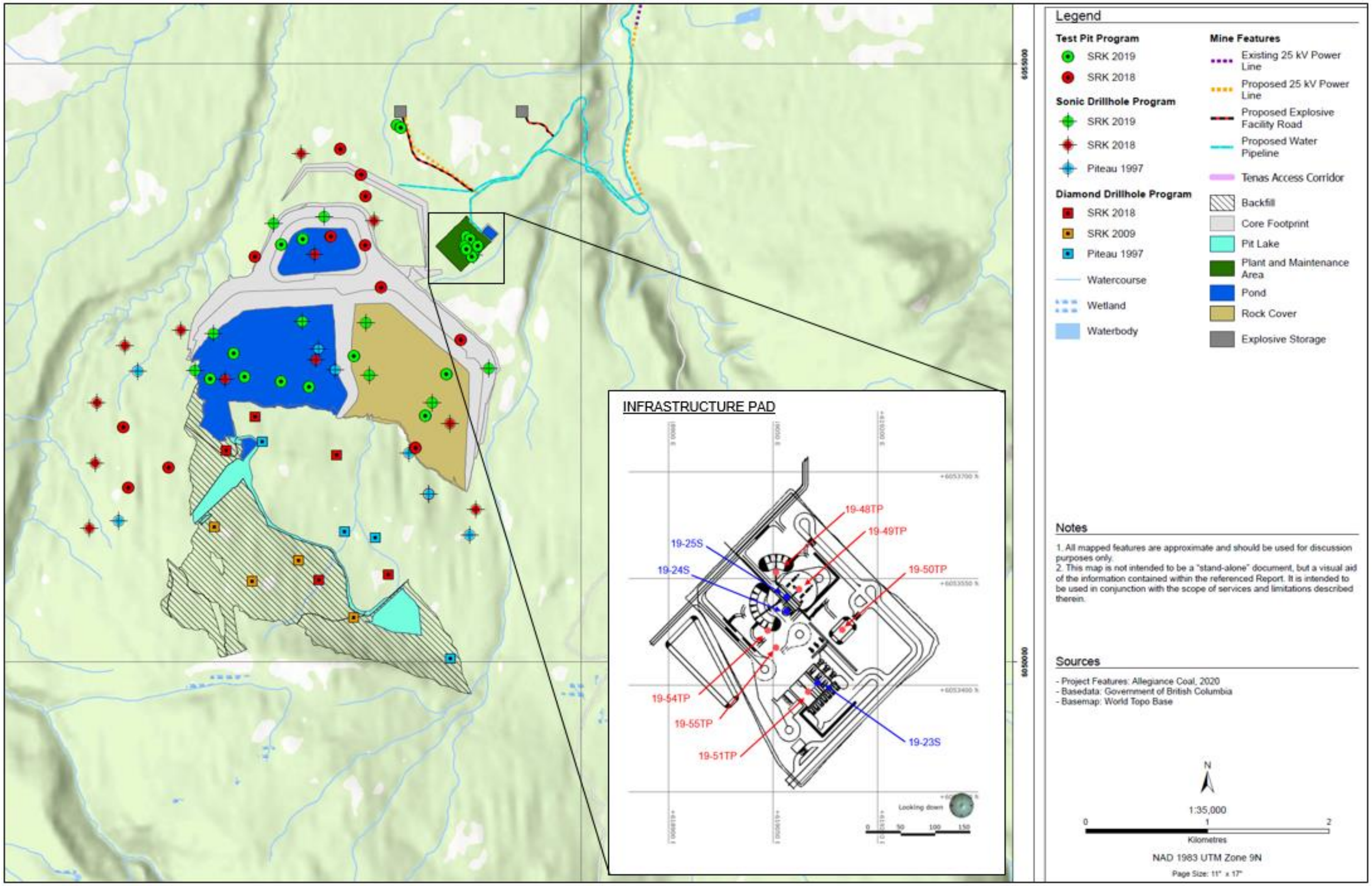


Figure 3-1: Location Plan showing Sonic Drillholes and Test Pit Investigations

3.2 Sonic Drilling Investigations

Three sonic drillholes were completed in the MI footprint as shown in Figure 3-2. The drilling investigation details are summarized in Table 3-2. The logged materials and test results are presented in downhole plots in Appendix A. Representative soil samples were sent to the Golder Associates Burnaby Laboratory for soil classification testing. Standard Penetration Tests (SPT) were conducted at regular intervals during drilling to investigate relative compactness/density and to collect split spoon samples.

Table 3-2: Sonic Drillhole Locations and Testing Summary

Location ID	Eating (m)	Northing (m)	Elevation (m)	Termination Depth (m)	Number of SPT Tests	Water Inflow
19-23S	619117	6053405	798	11.3	4	Not Encountered
19-24S	619070	6053505	797	20.4	7	Not Encountered
19-25S	619072	6053523	798	10.7	3	Not Encountered

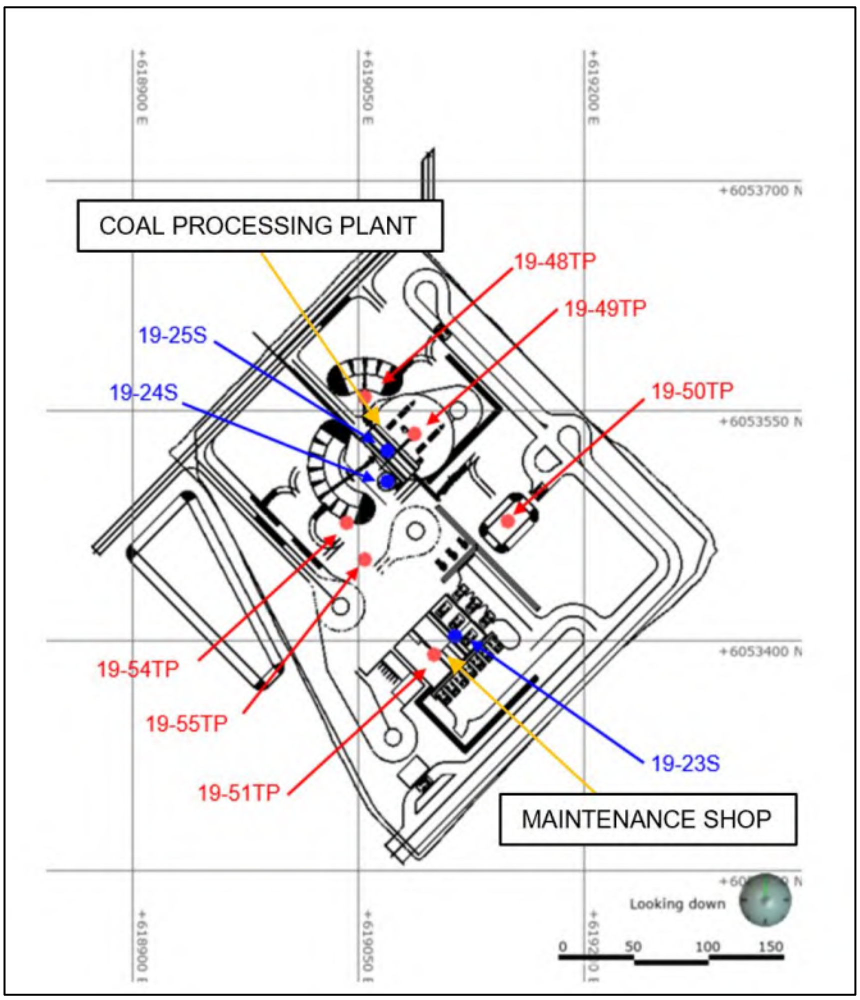


Figure 3-2: Test Pit and Drillhole Locations at the Plant Infrastructure Area

3.3 Laboratory testing

Samples were delivered to the Golder Associates Laboratory in Burnaby, British Columbia for testing. Testing was completed on representative overburden samples collected during test pitting and sonic drilling. Laboratory testing included Atterberg Limits and Particle Size Distribution (PSD). Individual laboratory tests certificates are compiled in Appendix B.

4 Site Conditions

4.1 Physiography

The Tenas site is located within the foothills of British Columbia, between the Bulkley Mountain Range to the north and west, and the low-lying gently sloping relief of the Nechako Plateau. Bedrock is typically covered by Quaternary soils, except for rocky outcrops along deeply eroded sections in adjacent river and stream valleys. Elevation across the site ranges generally from 600 to 900 m, with maximum elevations along the east side of the property (Levson et al, 1997).

4.2 Bedrock

The coal that is to be mined from the Tenas Pit is located within the sedimentary sequences of the early Cretaceous-aged Skeena Group. The Skeena Group consists of mudstones, siltstones, sandstones and conglomerates with inter-bedded, bituminous coal seams. The Skeena Group does not underlie the MI or ED footprints. The Hazelton Volcanic Group rocks are in contact with the Skeena Group. The upper contact of the volcanic group bedrock lies between 100 m and 140 m below the proposed MI and ED footprints as indicated by depth to bedrock heat map Figure 4-1 derived using the TCL Geological Model.

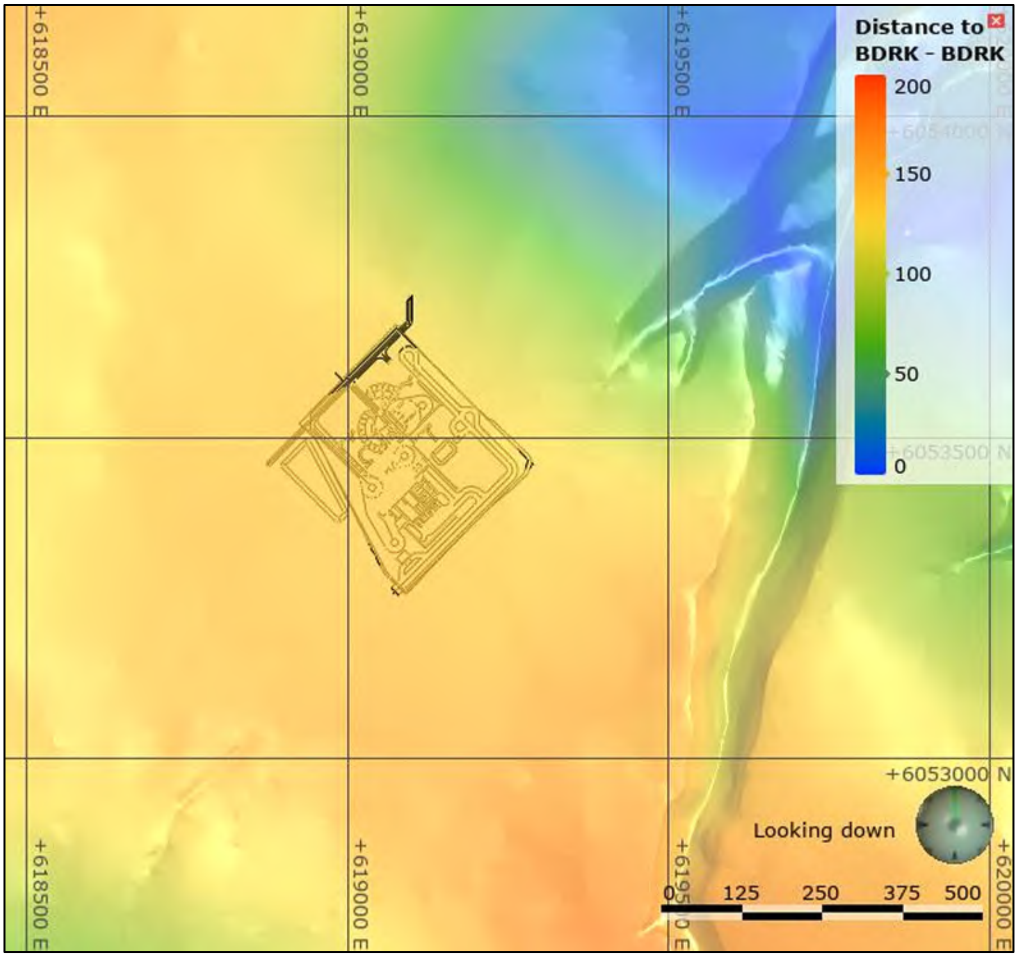


Figure 4-1: Modelled depth to bedrock below the MI footprint

4.3 Surficial Soils

The overburden soils range in thickness from approximately 4 m to over 100 m, as indicated by the current 3D Geology Model developed by Telkwa (TCL, 2019). The regional surficial soils have been studied by Levson et al. Two soil units are characterized regionally, and include:

- A widespread, massive unit, interpreted as a till, is located at or near the ground surface. The till is described as a diamicton, with particle sizes ranging from clay to boulders within a fine grained or sandy matrix. No thickness information was provided by Levson et al.
- In some areas, the till is underlain by both glaciofluvial stratified sands and gravels, and horizontally bedded sand, silt and clay sequences interpreted to be advanced-phase glacio-lacustrine sediments.

Most of the surficial soils that were intercepted during the 2018/2019 investigations were comprised of till, including the MI and ED areas. In general, the till was a sandy lean clay (CL). The clay typically contains silt and fine sand with some gravel, is commonly stiff to hard in consistency with low to medium plasticity, and well graded. Cobbles and boulders were encountered, and these generally comprised less than 5% of the materials recovered in the sonic drillholes. The colour ranges from medium-brown to very-dark-brown or dark-grey. Sand, silt and gravel lenses were commonly encountered within the till at depth. These materials are generally comparable to the massive diamicton till unit described by Levson et al. These materials are also consistent the MI and ED test pit and sonic drilling results.

4.4 Site Subsurface Conditions

4.4.1 Mine Infrastructure

Three sonic drillholes and six test pits where carried out across the MI area. The sonic drillholes were completed to investigate the foundation conditions beneath the more settlement-sensitive load bearing infrastructure (i.e. tailings thickener). The test pits provided spatial coverage across the infrastructure pad. The subsurface conditions encountered at the plant site is summarised below:

- **Test Pits 19-48TP, 19-49TP, 19-50TP, 19-51TP, 19-55TP and 19-56TP:**
    - Black, saturated, mostly organic soil was encountered within the first 0.3 m of 19-55TP only. The organic soil was not observed in the other test pits.
    - Silty sand and clayey sandy gravels from surface to between about 0.8 to 1.2 m depth (Figure 4-3); overlying.
    - Lean clay with gravel to termination depths of about 4 m. The lean clay with gravel is stiff to very stiff in consistency (Figure 4-3).
    - The test pits did not slough, and medium to high excavator resistance persisted to test pit refusal depth.
    - Water inflow was observed in 19-55TP toward the base of the test pit. Water inflow was not observed in the other test pits.
- **Drillhole 19-23S:** encountered clayey sand or lean clay with gravel from ground surface to about 6 m. Thereafter a lean clay with some gravel was encountered to drillhole termination depth (11.7 m).
- **Drillhole 19-24S and 19-25S:** encountered clayey sands to surface to about 1 m and similar to the test pits. Thereafter lean clays with gravel were encountered to about 5 m, underlain by lean clay, very stiff to hard in consistency was encountered from 5 m to 14 m, underlain by a sandy lean clay, hard in consistency.

As discussed in Section 4.2, bedrock was not encountered in the test pits or drillholes.

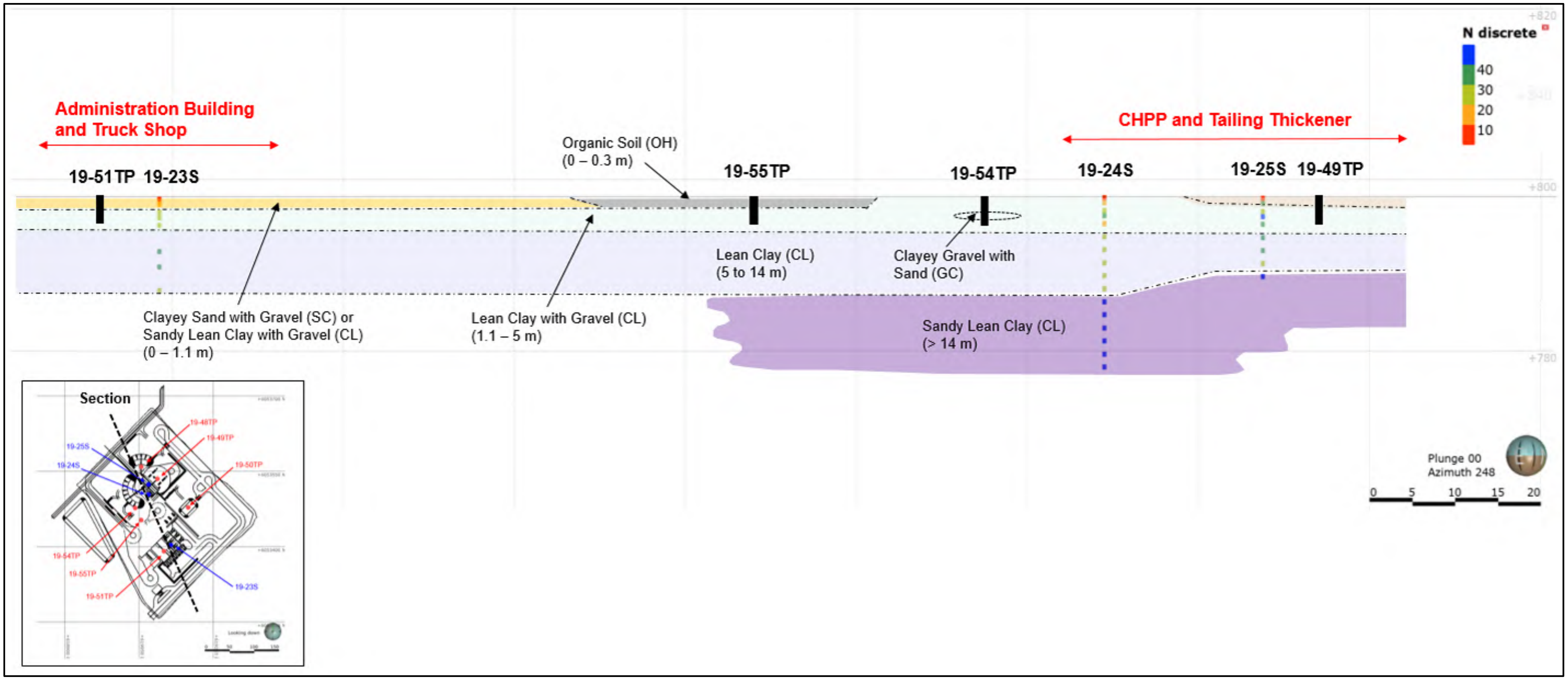


Figure 4-2: Generalized shallow subsurface section through the sonic drillholes and test pits located at the proposed Mine Infrastructure area

Figure 4-3: Materials encountered in 19-49TP (left) and 19-55TP (right)

Nine Atterberg Limits tests and eight PSD tests were completed on representative samples from the test pits and drillholes completed in this area. The test results are summarised in , Figure 4-4 and Figure 4-5. The laboratory testing results indicate that the subsurface conditions are generally similar to the fine grained till materials described by Levson et al and observed elsewhere at Tenas. The PSD results indicate a well graded soil (Figure 4-4 and Table 4-1).The Atterberg limits results indicate CL or CI classification (Figure 4-5**Error! Reference source not found.**). The liquidity index below 1.0 indicated by the laboratory testing indicates rigid soil behaviour.

The one highly plastic sample form the black organic clay (0 to 0.3 m, 19-55TP) plotted off the graph (Figure 4-5) . This represents surface materials that were locally ponding.

Table 4-1: Atterberg Limits and PSD Results for the MI Footprint

Location ID	Sample Depth (m)	Grain Size Distribution (%)				Natura Water Content (%)	Atterberg Limits (%)	
		Gravel	Sand	Silt	Clay		Liquid Limit	Plastic Limit
19-23S	1.1 – 1.5	18	31	33	18	12.5	32	15
19-24S	7.0 – 7.6	20	28	32	20	12.5	32	14
19-24S	16.2 – 16.8	7	39	34	20	11.3	31	14
19-25S	8.2 – 8.8	13	35	31	21	11.7	33	15
19-48TP	0.5 – 0.7	29	39	22	10	-	-	-
19-49TP	0.0 – 0.2	12	30	34	4	12.6	-	-
19-49TP	2.9 – 3.1	12	30	31	26	11.8	37	16
19-50TP	3.5 – 3.7	-	-	-		11.4	37	15
19-51TP	2.3 – 2.5	-	-	-		10.3	36	15
19-55TP	0.0 – 0.2	-	-	-		157.3	>100	>50
19-55TP	1.1 – 1.3	31	29	24	16	15.6	37	18

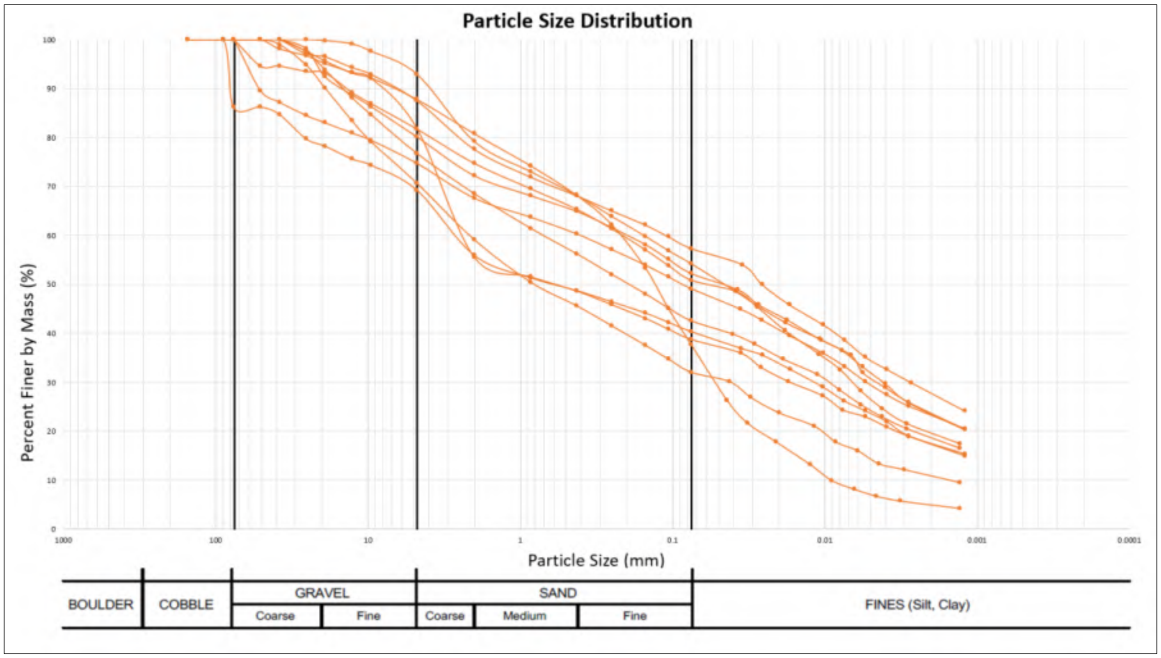


Figure 4-4: Summary of Particle Size Distribution Results

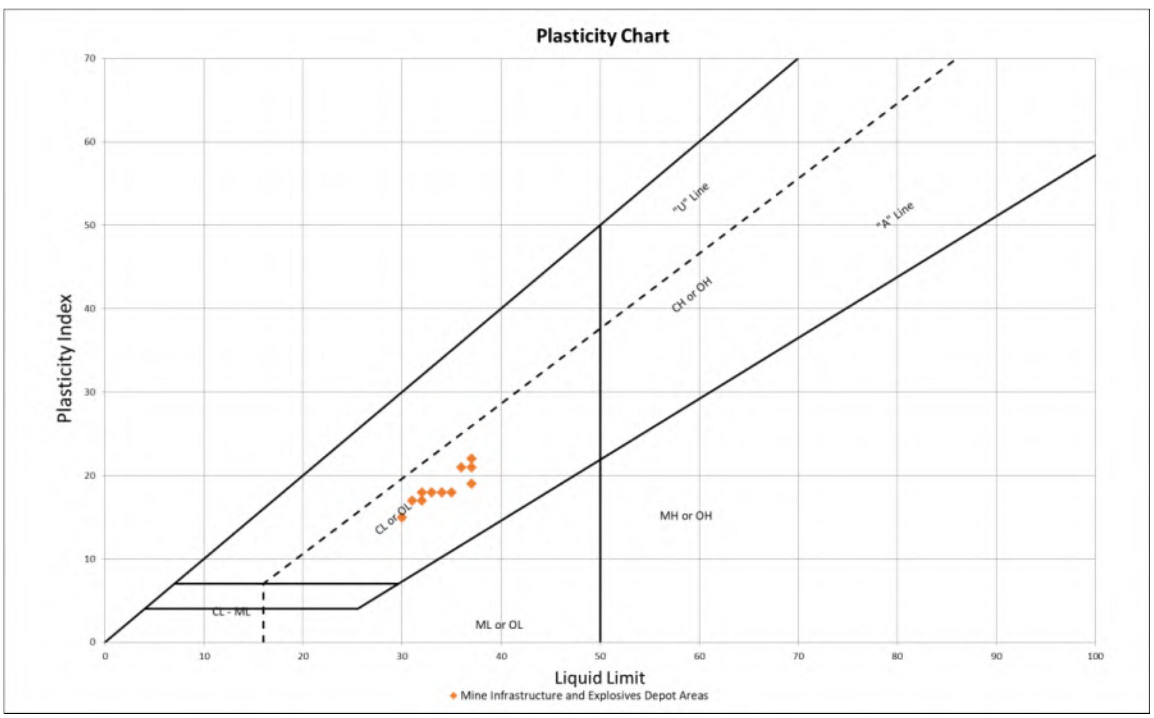


Figure 4-5: Summary of Atterberg Limits Testing

A summary of the SPT results from the three sonic drillholes within the MI area is presented in Figure 4-6. The field testing indicates that the N counts were typically above 30 blows within 3 m to 11 m depth, and refusal (i.e. 50 blows) achieved from 14 m onwards in drillhole 19-24S.

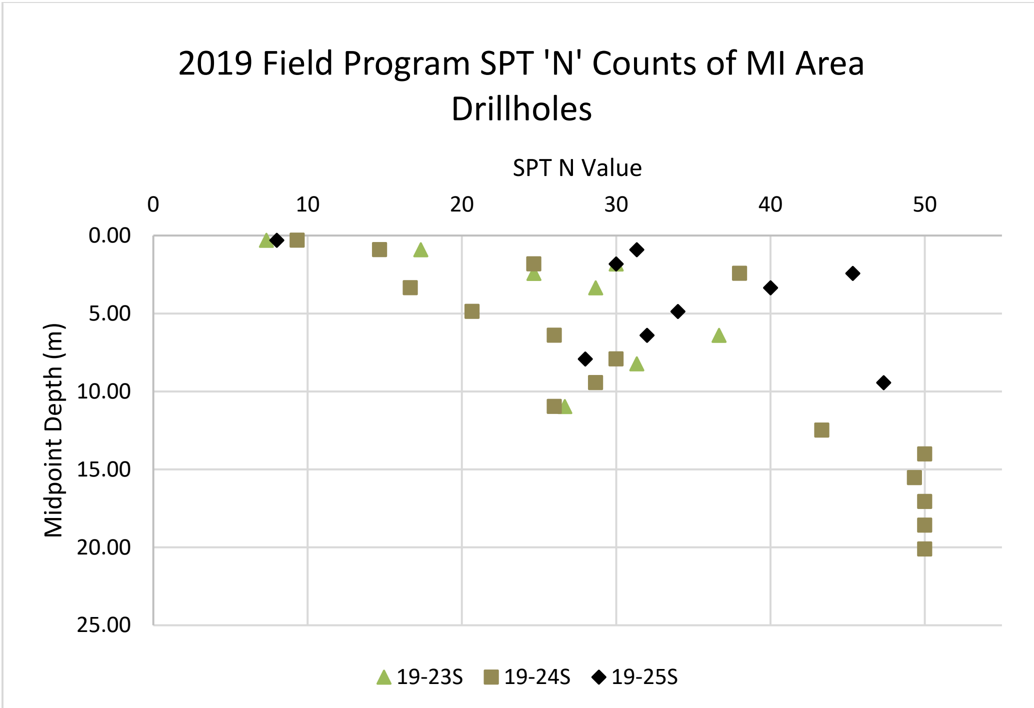


Figure 4-6: Summary of SPT Results for Mine Infrastructure Area Drillholes

4.4.2 Explosives Depot

Three test pits were located for general characterization purposes across the ED. The appearance of the test pit materials is shown in Figure 4-7. The subsurface conditions encountered are summarised below:

- **19-52TP and 19-53TP:** encountered gravely lean clay with medium plasticity from surface to test pit termination depths (Figure 4-7). Roots were present within the first 0.5 m. Test pit did not slough, and high excavator resistance persisted from surface until refusal at 3.3 m depth.

- **19-53TP:** encountered sandy lean clay with gravel and medium plasticity from surface to 0.3 m. Medium plasticity clayey sand with gravel continued from 0.3 m to termination depth (Figure 4-7 At 1.5 m, cobbles/boulders up to 30 cm were present. Test pit did not slough, and high excavator resistance persisted from surface until refusal at 3.1 m depth.

The subsurface soils observed at the ED test pits are similar to those encountered within the MI test pits and sonic drillholes. As discussed in Section 4.2, bedrock was not encountered in the test pits or drillholes.

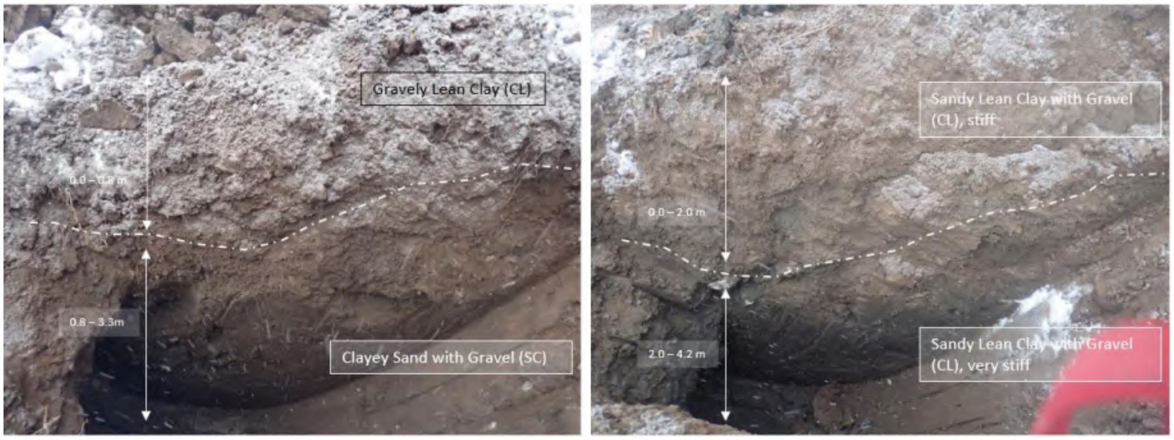


Figure 4-7: Materials encountered in 19-52TP (left) and 19-54TP (right)

Three Atterberg Limits tests and three PSD tests were completed samples collected from the test pits. The test results are shown in Table 4-2.

Table 4-2: Atterberg Limits and Particle Size Distribution Test Results Summary

Location ID	Sample Depth (m)	Grain Size Distribution (%)				Natural Water Content (%)	Atterberg Limits (%)	
		Gravel	Sand	Silt	Clay		Liquid Limit	Plastic Limit
19-52TP	1.1 – 1.3	23	34	24	18	12.6	30	15
19-53TP	0.5 – 0.7	18	43	23	16	10.3	34	16
19-53TP	1.7 – 1.9	25	26	28	21	14.1	35	17

4.5 Other Laboratory Testing

Compaction testing was carried out on three other combined samples from sonic drillholes located on the mine site outside of the MI or ED areas. The compaction results are presented in Table 4-3 and should be considered for general compaction conditions.

Table 4-3: Summary of Compaction Laboratory Testing

Location	Sample ID	Sample Mid-Point Depth	As-Received Water Content (%)	Corrected Optimum Water Content (%)	Corrected Max Dry Density	Corrected Max Unit Weight
		(m)			(kg/m³)	(kN/m³)
T18-05S	BLK-01 & BLK-02	5.7 & 10.5	16.4	10.5	2108	20.66
T18-07S	BLK-02 & BLK-03	14.7 & 21.7	10.6	9.9	2128	20.86
T18-07TP	BLK-01 & BLK-02	1.0 & 2.0	11.9	9.7	2054	20.13

4.6 Shallow Groundwater Conditions

Water inflow was observed in one test pit, 19-55TP. The water inflow is considered to represent a perched water table above the finer gained till and is sporadically encountered in the test pits carried out across the Tenas project site. Where observed, the perched water table is located about 0.3 m to 1.5 m below existing ground surface.

Groundwater levels recorded in nearby standpipe monitoring wells are indicate that groundwater is expected to be located below about 30 m depth below existing ground surface.

4.7 Seismicity

The 2015 National Building Code of Canada (NBCC) seismic design procedures are based on ground motion parameters (peak ground acceleration (PGA) and spectral acceleration (Sa)). Sa values have a 2% probability of exceedance in 50 years; i.e., the 2,475-year return period earthquake event. The PGA for a two percent probability of exceedance is 0.049 g (NRC, 2019).

5 Foundation Assessment

The following subsections summarize the foundation assessment and recommendations for the proposed infrastructure within the MI and ED footprints. The assessment is based on the site conditions presented in the prior sections and the conceptual infrastructure design information provided by TCL.

Shallow foundation type at Tenas will be suitable for structures that have light to moderate loading and/or are not sensitivity to significantly settlement. Typically, shallow foundations are also suitable for sites where bedrock is shallow or where competent foundation soils are located close to ground surface.

Deep foundations types may be considered where structures have a heavy load and/or are sensitivity to settlement. As the depth bedrock is significantly great at Tenas, the settlement sensitive structures, such as the Fine Processed Rock Thickener and Cranes, should consider deep foundation options.

5.1 Soil Design Parameters

Although triaxial or direct shear testing was not conducted on samples taken from the MI and ED investigations, shear strength testing was carried out for the waste dump and dam foundations at Tenas during 2018 and 2019 laboratory testing programs (SRK, 2018 and SRK, 2019). Based on the soil classification testing and the previous testing, typical soil shear strength parameters are provided in Table 5-1.

Table 5-1: Estimated slope design parameters

Soil Type	Consistency/ Compactness	Approximate Depth	Unit Weight (kN/m^3)	Friction Angle (°)[2]	Cohesion (kPa)	Youngs Modulus, E (MPa)[2]	Poisson's Ratio (v)[2]
Clean Clay with Gravel (CL)	Stiff	1.1 - 5 m	18	28	0	75	0.3
Lean Clay (CL)	Very Stiff to Hard	5 – 14 m	19	30	0	100	0.3
Sandy Lean Clay (CL)	Hard	14 – 20 m	19	32	0	125	0.3
Engineered fill[1]	Dense to very dense	n/a	22	38	0	150	0.25

Note: [1] – assumed compacted, well graded, [2] – estimated from published literature

5.2 Shallow Foundations

Shallow foundations, such as spread footings, could be suitable for light to moderate loads and non-settlement sensitive structures. Structures such as the CHPP and Admin Buildings may be placed on shallow foundations with footings placed directly onto stiff to very stiff undisturbed till soils or on compacted engineered fill placed on the native (undisturbed) soils. All concrete should be designed to Canadian Standards.

5.3 Allowable Bearing Capacity and Estimated Settlement

The ultimate resistance of the foundation materials at Tenas was evaluated using the estimated material parameters in Figure 5-1. The groundwater depth was assumed to be below about 30 m and deeper than the foundation pads. The ultimate bearing capacities were calculated for different footing geometries using the following equations:

$q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma$, for square footings (1)

$q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma$, for continuous footings (2)

$q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma$, for circular footings (3)

where:

- q_{ult}: ultimate bearing capacity
- $\sigma'_D = \gamma D$: effective vertical stress at the depth of footing D below the ground surface
- B: width or diameter of footing
- $\gamma' = \gamma - \gamma_w$: submerged unit weight
- N_c, N_q and N_γ are the bearings capacity coefficients

For $c' = 0$ (see Table 5-1) the N_c-terms in equations (1) and (3) are zero, therefore the N_c-coefficients are not required. The values of $N_q$and N_γ were determined using to the following equations (Gudehus 1981)

$N_q = \frac{1-\sin\varphi}{1+\sin\varphi}\exp(\pi\tan\varphi)$ (4)

and

$N_\gamma \approx \exp[5.71(\tan\varphi)^{1.15}] - 1$ (5)

Using equations (4) and (5), N_q and N_γ values were calculated for the natural soil types included in Table 5-1. The allowable bearing capacity q_a was estimated by applying a global factor of safety of 3, and neglecting the weight of overburden material above the foundation footings.

Figure 5-1 and Figure 5-2present the allowable bearing capacities for square, rectangular and circular foundations for the shallower Lean Clay with Gravel (1 to 5 m) and the Lean Clay (5 to 14 m) units. The bearing capacities were calculated as a function of the foundation width, diameter and depth. The details of the calculations for the presented are compiled in Attachment C, including the Sandy Lean Clay unit which is located below about 14 m and too deep for the shallow foundations.

To determine the allowable bearing pressure, the total elastic settlement due to the effect of q_a was estimated the materials at the center point of bottom surface of the foundation footings. It was assumed that sub-surface granular material will experience elastic deformations. The elastic settlement values s were calculated by using the following equation:

$$s = C_s q_a B \left(\frac{1-\mu^2}{E}\right) \qquad (6)$$

Where μ is the Poisson ratio, E is the elastic modulus and C_s is a factor which depends on the geometry and stiffness of the foundation footings. Figure 5-1 and Figure 5-2 show the calculated elastic settlements for square, rectangular and circular foundation footings with respect to q_a for rigid and flexible foundations. The elastic settlements were calculated for different L/B (length/width) ratios.

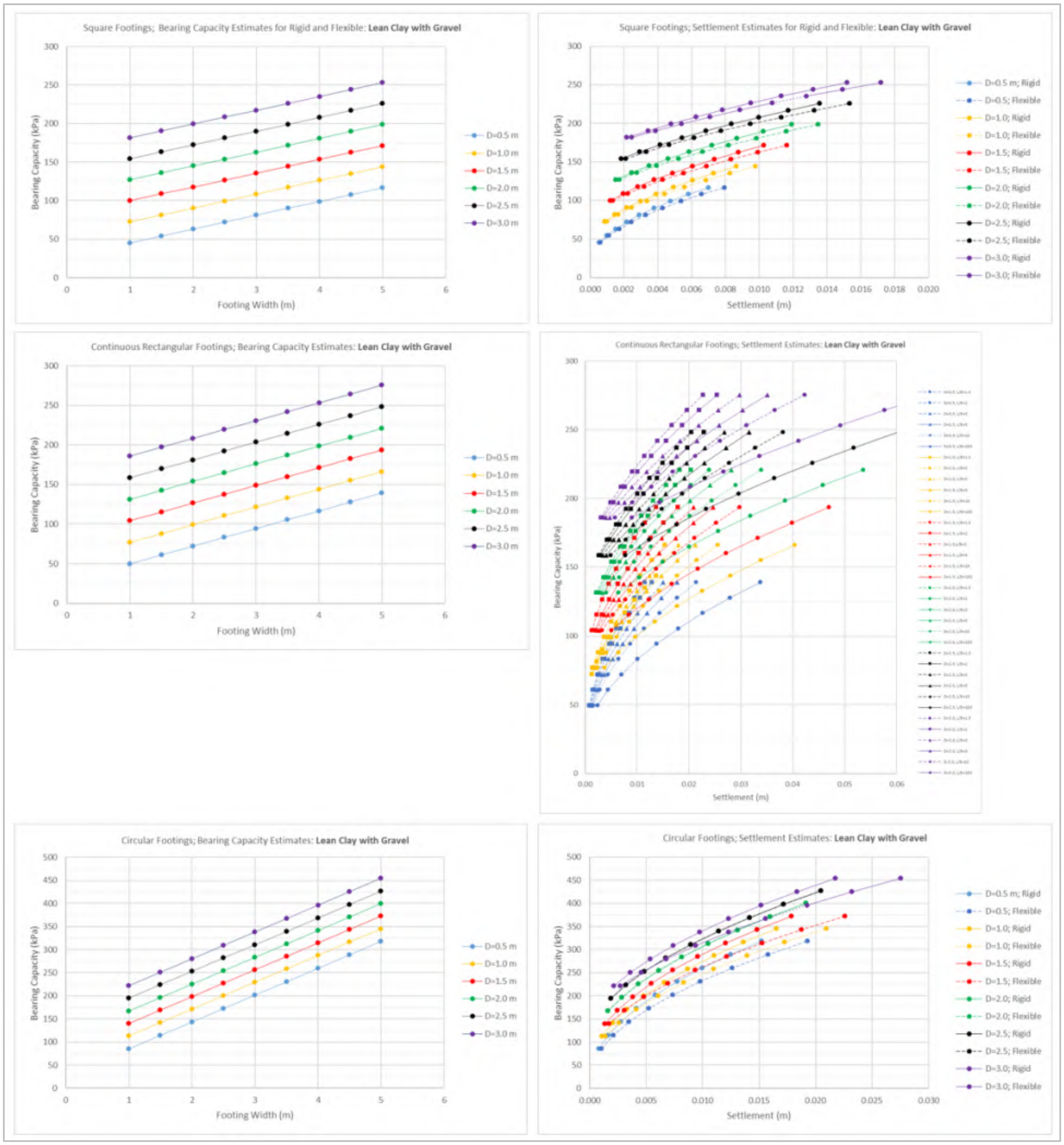


Figure 5-1: Allowable Bearing Capacity and Settlement Estimates for Lean Clay with Gravel unit (approximately 1 to 5 m).

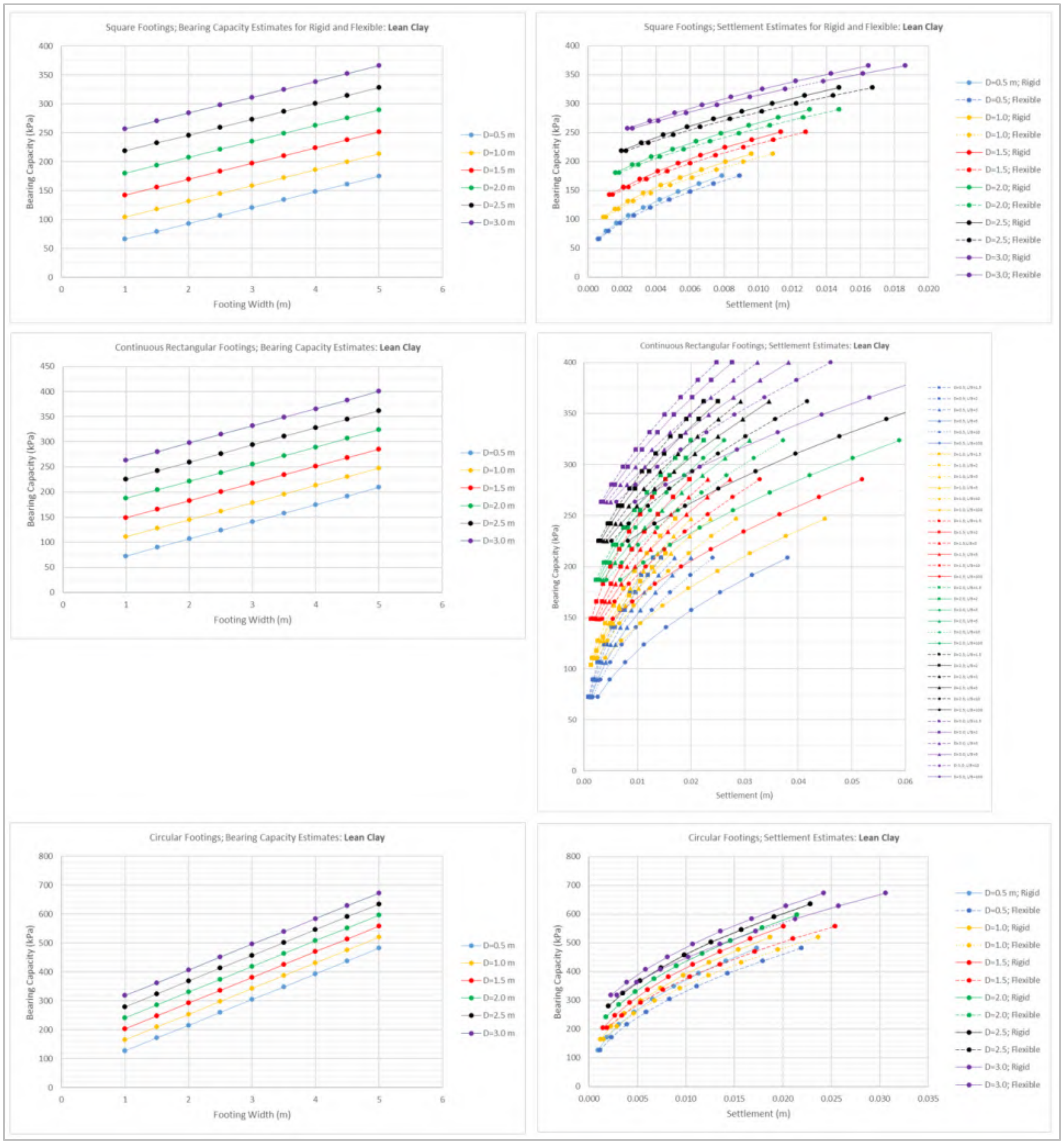


Figure 5-2: Allowable Bearing Capacity and Settlement Estimates for Lean Clay unit (approximately 5 to 14 m).

Based on the information provided by TCL, the following bearing capacities are required for the structural infrastructure designs at Telkwa:

- CHPP raft pad – 200 kPa;
- Tailing Thickener Footings (utilizing a ring-beam foundation) – 150 kPa; and
- MI facilities raft pad – 250 kPa.

With consideration to the above bearing capacities, the Figure 5-1 and Figure 5-2 plots for the shallow soil units should be referred to for the structural design work considering the proposed footing geometries, widths and depths. Full calculations are provided in Appendix C for bearing capacity and settlement estimates. The serviceability limit state bearing capacity should be determined at detailed design based on the allowable total settlement less than 20 mm and a differential settlement less than 10 mm, as defined by TCL for the structures within the MI footprint. The above information indicates that bearing capacities of at least 150 kPa is required with foundation preparation to the stiff and very stiff silty clays.

Foundation excavations and bearing surfaces should be protected from rain, snow and freezing temperatures, excessing drying and ingress of shallow perched water during and before the footing construction. Soils beneath the foundations should be protected from seasonal frost during and after construction by providing either soil cover or insultation.

5.4 Raft/Slab Foundations

TCL indicate that raft foundations are being considered for the CHPP and other buildings. The foundations are considered suitable, providing that relatively uniform, very stiff till soils are excavated across the structure footprint. In some cases, additional footings are necessary either around the perimeter or the centre of the slab. Typle values of subgrade reaction values based on for shallow soil units below the MI based on guidance in the Canadian Foundation Engineering Manuel (CGS, 2006) are provided in Table 5-2.

Table 5-2: Vertical Moduli of Subgrade Reaction for Slab-on-Grade Foundations

Soil Type	Consistency/ Compactness	Approximate Depth	Vertical Modulus of Subgrade Reaction, K_{v1} (MPa/m)
Clean Clay with Gravel (CL)	Stiff	1.1 - 5 m	25
Lean Clay (CL)	Very Stiff to Hard	5 – 14 m	100
Sandy Lean Clay (CL)	Hard	14 – 20 m	150
Engineered fill[1]	Dense to Very Dense	n/a	200

Note: moduli of subgrade parameters assumes at least 95% SPMDD

Moisture Management

As the foundation is in contact with the underlying soil, moisture management must be considered. Proper water management techniques are important to avoid accumulations of water under or around the foundation. Some of there techniques are:

- Divert rainwater away from the foundation of the building using gutters and downspouts;
- Grade the surrounding ground away from the building foundation;
- Polyethylene vapour barrier placed directly under the concrete slab; and
- A well-draining break layer consisting of clean granular fill (no fines) should be installed below the vapour barrier to avoid capillary action.

Insulation

In locations that experience freezing temperatures, it is important to protect foundations from the effects of frost and freezing ground. Insulating the foundation and walls also helps to prevent heat loss in the winter and heat gain in the summer (see Section 5.8).

Excavation and Ground Preparation

To avoid or reduce the potential for frost heave and settlement, proper preparation of the underlying ground is important. Differential movements within the slab and relative movements between the slab and adjacent walls or foundations should be anticipated.

All topsoil, organics and soft materials should be removed. Based on the field investigation data, materials to depths of approximately 1.1 m should be removed for shallow footings. The exposed surface should then be proof-rolled. If pockets of soft or loose soil are encountered, they should be over-excavated and replaced with general engineered fill and compacted to at least 98% of the SPMDD unless otherwise specified.

General engineered fill should be placed directly under the slab to restore the final grade. To limit potential stress concentrations, the levelling course should not contain very coarse material. The levelling course may comprise 200 mm thick compacted layer of 25 mm minus crush and should be compacted to 98% of SPMDD and moisture content is within ±3% of optimum.

If the slab is expected to support vibrating equipment, traffic is expected to be high or loading is expected to be high, a geotechnical engineer should evaluate the recommendations for slab-on-grade floors. To account for the affects of any differential settlement, equipment placed on the slab should be designed to allow for re-levelling and plumbing or electrical conduits should permit some flexibility as well. The risk of post construction damage should be weighed against any additional costs associated with alternative slab support systems.

5.5 Deep Foundations Considerations

Based on the infrastructure design information provided by TCL, deep foundations are not proposed at Tenas. The following subsections provides general information should these be considered in the future. Deep foundations are typically required for settlement sensitive or heavy loaded structures. The selection of the pile types will depend on foundation loads, an assessment of construction and performance risk and cost estimates. Some advantages and disadvantages of pile type examples are presented in Table 5-3.

Table 5-3: Advantages and Disadvantages of Pile Foundation Types (based on CGS, 2006)

Pile Type	Advantages	Disadvantages
Driven – Open Steel Piles	• Generally higher load capacity. • When driven to practical refusal in bedrock, not highly susceptible to down-drag or settlement. • Less susceptible to significant damage during driving and more resistant to over-stressing due to drag loads. • Capacity can be evaluated at time of installation using PDA. • Minimal drilling (possible pre-drilling) and sleeves not required. No spoil.	• Cobbles and boulders can result in abrupt pile refusal and/or pile tip damage before reaching minimum embedment depth. • Where shallow bedrock is encountered, this can result in too shallow refusal and an ineffective pile to resist lateral and uplift loads.
Driven Steel Piles – H-Pile	• Generally higher load capacity • Lower risk of damage than open steel pipe when given through dense sands/gravels • Less susceptible to significant damage during driving. • Pile capacity can be evaluated during installation	• Cobbles and boulders can result in abrupt pile refusal and/or pile tip damage before reaching minimum embedment depth. • Where shallow bedrock is encountered, this can result in too shallow refusal and an ineffective pile to resist lateral and uplift loads. • More susceptible to bending and may not be suitable when small tolerances of lateral displacement of pile during driving are required.
Driven Pre-cast Pre-stressed Concrete Piles	• When driven to practical refusal in bedrock, not highly susceptible to down-drag or settlement. • Capacity can be evaluated at time of installation using PDA. • Minimal drilling (possible pre-drilling) and sleeves not required. No spoil.	• Generally lower pile load capacity (single pile). • Shallow bedrock (generally 6 mbgs) can result in too shallow refusal and an ineffective pile to resist lateral and uplift loads. • More susceptible than steel to damage during installation. • Cobbles and boulders can result in abrupt pile refusal and/or pile tip damage before reaching minimum embedment depth. • Very hard to splice.
Drilled Shafts (rock socket cast-in-place concrete piles)	• Allows visual observation of soil/rock conditions. • Can be sized to provide significant lateral load capacity (in vertical configuration).	• Deep piles may require casing to prevent sloughing. • Installed capacity cannot readily be confirmed at time of installation. • Expensive and installation is slow.

5.5.1 Driven Piles

Driven Piles are unlikely to be driven into rock due to the significant depths below the MI footprint (i.e. greater than 100 m). Therefore, the pile capacity should be confirmed on the basis of driving observations, equipment experience and the location conditions (including winter construction). Dynamic testing should be carried out to aid in the evaluation of the pile axial resistances that are achieved.

Construction Considerations

The following constructions aspects require consideration:

- The rig, hammer and approaches should be incorporated into the design process ahead of construction.
- Winter construction needs consideration due to increased pile resistance through frozen layers.
- Should significant resistance be met, the driving should immediately stop. The piling records should be inspected by a geotechnical engineer and the requirement for piled foundations evaluated.
- Following completion of each pile, a survey should be completed for the top and sides. The survey should be checked frequently as the adjacent piles are driven to evaluate any deflection and uplift forces.
- Driving shows can require the ability to advance the piles and reduce damage to the ends.
- Full time inspection from a qualified geotechnical engineer experienced in the local terrain is needed. Records of the construction and piling activities (i.e. number of blows per 0.3 m, anvil weight, hammer type) are needed to validate the design requirements.

5.6 Machine Foundation Guidelines

Pending the determination of the actual operating characteristics and a detailed dynamic analysis, guidelines for the design of machine foundations subject to dynamic forces have been outlined by the Canadian Foundation Engineering Manual (CGS, 2006). There are various types of loads that should be considered when designing machine foundations as summarised in Table 5-4.

Table 5-4: Summary of Dynamic Loads for Machine Foundations (CGS, 2006)

Type of Load		Summary
Dynamic	Periodic	Rotating and reciprocating machines produce centrifugal periodic forces (i.e., Tailing Thickener)
	Transient	Non-periodic time varying load (i.e., Vehicle traffic)
	Random	Some machines such as mills, pumps and crushers produce fluctuating forces that are random in nature (i.e., Raw Coal Crusher)

If there are machines that are sensitive to vibration (i.e., traffic, blasting activities) it may be necessary to further equip the foundations for protection. Ground vibration monitoring equipment may also be installed, if necessary. There are various types of foundations that can be used for machines: block, wall, mat and frame. These foundations can be designed as shallow foundations and rest directly on the soil or they can be placed on piles.

- Generally, the base of the block should be above water level. The top of the block should be 0.3 m above the elevation of the finished floor.
- The mass of the block should be two to three times the mass of the supported centrifugal machine, and three to five times the mass of the supported reciprocating machine if shallow foundations are used. If piles are used, the mass of the block should be one and one half to two times the mass of the supported centrifugal machine, and two and one half to four times the mass of the support reciprocating machine.
- The width of the block should be one to one and one half times the vertical distance from the base to the machine centreline to increase damping in the rocking machine.
- The length of the block is estimated from the mass requirements and estimated thickness and width of the foundation. The length should be increased by 0.3 m for maintenance purposes.
- The length and the width of the block are adjusted so that the centre of gravity of the machine plus equipment lies within 5% of the block dimension in each direction, from the block centre of gravity.
- It is desirable to increase the embedded depth of the block to increase the damping and provide lateral restraint as well.
- If resonance is predicted from the dynamic analysis, mass of the block should be changed to change its natural frequency.

The following guidelines may be used for the trial configuration of the pile group.

- The number and size of the piles should be such that the average static load per pile is less than or equal to half the pile design load.
- The piles should be arranged so that the centroid of the pile group coincides with the centre of gravity of the combined structure and machine.

- If battered piles are used, the batter should be away from the pile cap and should be symmetrical.
- Piles should be properly anchored to the pile cap for adequate rigidity.

5.7 Seismicity

Based on the results of the 2018 and 2019 field investigations, it is appropriate to generally classify the existing ground conditions at the site as a Class C Site in accordance with the 2015 NBCC (Table 4.1.8.4.A) indicating that the Telkwa Coal project site is located in a relatively stable seismic area. Liquefaction of the native soils is unlikely due to their high fines content and the relatively low seismicity in the area.

5.8 Frost and Adfreeze Conditions

Frost heave should be considered in the design and construction of the foundations at Tenas. This is due to the silts, silty/clayey sands and gravels materials that were encountered during the field investigations, and the perched water within the upper 0.5 m to 1.5 m that can be observed at Tenas. Furthermore, the Freezing Index in Smithers, roughly 18 km north of the site, is 823 degree-days (ºC) which equates to a theoretical frost penetration depth of approximately 1.52 m, assuming no snow cover or organics close to surface.

Soils beneath the shallow foundations should be protected from seasonal frost during and after construction by providing either soil cover or insultation. For perimeter footings, depth of soil cover should be a minimum 1.75 m with heating during winter construction. Compacted general granular engineered fill should be placed above the insulation. The surface should be capped with a 300 mm thick compacted clay layer and should have a minimum grade of 1% to reduce infiltration and ponding of water.

Average adfreeze bond stresses on shallow foundations in fine-grained soils, typically range from 65 to 100 kPa for wood/concrete or steel, respectively (CFEM, 2006). Site specific values need to be determined during final design. For this reason, unheated and un-insulated shallow foundations should be founded below the frost zone.

6 Earthworks

6.1 Temporary Excavations

The composition and consistency of the soils encountered within the MI and ED footprints will allow for tracked hydraulic excavator to excavated to the depth of the shallow footings. The John Deere LC 270 tracked excavator used to complete the test pits encountered challenges advancing below about 3 m depth. This was due to the very stiff tills intercepted and possible limitations with the bucket reach. The test pits were narrower that which may limit the ease of excavation depths in some areas.

All excavations should be in accordance with provisions within Work Safe BC's *Occupational Health & Safety: Construction, Excavation and Demolition*. The excavation walls should be sloped or adequately shored. The appropriate side slopes will depend on the soil type, drainage method, groundwater infiltration control and the time the trench is left open. Localized instability (seepage/sloughing/flowing soil) in excavation walls may occur where the perched water is encountered. In these cases, side slopes should need to be made flatter, under the direction and supervision of a qualified geotechnical engineer.

In general, a slope of 1.5 horizontal to 1 vertical (1.5H:1V) is the steepest recommended for dry temporary excavation in the upper 1.5 m. Slope of 1H:1V is recommended for the stiff to very stiff Lean Clays up to 5 m. A geotechnical engineer should be consulted for excavations greater than 5 m or if significant sloughing from water inflow occurs. In this case, temporary excavation should be made shallower.

The stability of cut slopes will deteriorate with time. Excavation slopes should be monitored during construction by qualified geotechnical personnel to check for any signs of changing conditions which may reduce stability. The excavated material should be stockpiled away from the crest of the slope at a minimum distance equal to the depth of the excavation.

6.2 Permanent Cut and Fill Slopes

Permanent slopes excavated in dry materials at the MI and ED pads should be between 3H:1V to 4H:1V or flatter depending on location specific soil and water inflows. Compacted engineered fill may be steeper to 2.5H:1V. Where continuous water inflow occurs, permanent slopes will need to be flatted than 4H:1V as reviewed by a geotechnical engineer.

All permanent slopes will be required erosion protection to prevent scour and erosion from the slope face. Erosion protection can include organic cover, seeding and/or covered with erosion mats.

6.3 Engineered Backfill and Fill Materials Compaction

General engineered fill should consist of non to low plastic, clean, free of organics materials, however, site-won fill can be suitable for reuse as engineered fill with proper conditioning, removal or organics and oversized materials. Site-won fill will require a review by a geotechnical engineer.

Engineered fill consisting of clay soils should be moisture conditioned to between optimum and 2% above optimum moisture content (ASTM D698) and compacted to a minimum of 98% of SPMDD. Engineered fill consisting of silty/sandy soils should be moisture conditioned to within +2%,and compacted to a minimum of 98% of SPMDD.

Backfill placed under structural elements of buildings such as foundations, columns, mats/rafts, etc., should be comprised of clean, well-graded, inorganic granular soils (sand and gravel). Such fill should be placed in compacted lifts no thicker than 150 mm and compacted to at least 100% of SPMDD at a water content at or slightly above the Standard optimum water content.

Backfill materials should not be placed in a frozen state or placed on frozen subgrade. All lumps within the material should be broken up during placement. Cobbles and boulders should be removed. Particle size within the backfill material should not exceed half the lift thickness.

Soils that cannot achieve proper compaction specifications or that are otherwise unsuitable for reuse may be used in non-structural and landscaped areas.

6.4 Lateral Earth Pressures

Buried structures should be designed to resist any lateral earth pressures present in resting conditions. The stability of structures against overturning and sliding should be checked by a qualified structural engineer. Coefficients of lateral earth pressure have been estimated for subsurface materials using the following equation:

$$P = Ko\ (\gamma_b H + q)$$

Where:

- P = Lateral earth pressure at rest (kPa)
- Ko = Coefficient of earth pressure at rest
- γ_b = Unit weight of backfill soil
- H = Depth below final grade (m)
- q = Any surface pressure at ground level (kPa)

Should there be water pressures at Tenas, design of buried structures will need to be account for hydrostatic pressures. Hydrostatic pressures on the structures can be calculated using the following:

$$P_w = \gamma_w H_w(max)$$

Where:

- P_w = Hydrostatic pressure (kPa)
- γ_w = Unit weight of water
- $H_w(max)$ = maximum height of water above structure base

Estimates from the calculation assume a vertical retaining structure with free draining material placed behind the wall in horizontal lifts. Backfill around buried walls should not be placed until the concrete has reached a minimum two-thirds of their 28-day strength and the floor framing and intake chamber floor slab are in place. Inspection of the granular backfill should be carried out to identify any settlement prior to placement of final lifts.

Heavy compaction should be reduced within 1.5 m of the structure walls to reduce any induced lateral forces during compaction. Only hand operated compaction should be used within 0.6 m of the structure walls. Where deflections are apparent, the compaction effort should be reduced. During compaction, continuous inspection is important for observation of any movement or deflection of the structure.

6.5 Winter Earthwork Construction

Earthworks should be avoided in winter if possible, however, in certain circumstances where winter earthwork is unavailable cold weather procedures should be strictly followed using contractors experience with winter construction.

Fill should be hauled, placed and compacted in an unfrozen state. Compaction of backfill materials to the required standards can be achieved where air temperatures are above -5°C, and more compaction effort is needed if temperatures are below 0°C. Compaction is increasingly difficult as temperatures drop and should be avoided at temperatures below -10°C. Pockets of seasonally frozen ground present at the time construction should be over-excavated and replaced with engineered fill as well. The exposed subgrade should be protected from weather and should not be allowed to freeze during or after constuction.

Cold weather compaction also requires attention to fill quality (i.e. water content), placement and compaction practices. As it is difficult to adjust the water content of fill material in temperatures below freezing, it is important to note that material which is suitable in the summer may not be during the winter. If the required density cannot be achieved, the choice is to either suspend fill placement until conditions allow, implementing heating and re-compaction procedures on material that does not meet requirements or, the use of a dry, cohesionless, non-frost-susceptible material for backfill.

The time for placement and compaction of the soil before it freezes depends on many factors including, but not limited to, soil type, lift thickness, time for loading, unloading and hauling, air temperature, and wind speed. Common fill placement and compaction should be possible provided the borrow soil is placed and compacted quickly (within half an hour). The lifts should not be allowed to freeze prior to placement of the next lift. At the end of each day, a loose layer of soil should be placed over the development and borrow areas to provide insulation. The following day, prior to compaction, the cover layer should be removed and wasted or stockpiled separately. After completion of the fill placement and compaction, it is acceptable to allow the soil to freeze provided the frost can thaw prior to continued development the following spring.

6.6 Drainage

Generally, all areas (parking, roads, loading zones) should be well drained towards lower elevations and towards collector ditches. The ground surrounding buildings should slope away from the buildings at a slope of 2%. Temporary drainage works are likely needed to dewater excavations where shallow water inflows are observed, particularly if construction activities are completed during the freshet.

6.7 Field Inspections

During the construction works, field inspections by qualified engineers are recommended for excavation for shallow foundations and temporary slopes, installation of deep foundations, placement and compaction and drainage aspects.

7 Haul Road Cut Stability Review

Stability analyses were carried out using the limit-equilibrium program Slide2 (Rocscience, 2020) to evaluate a proposed haul road cut which is up to approximately 20 m in height. The location of the proposed cut is shown in Figure 7-1. The analyses were carried out for the east side walls which represent the most adverse aspect due to west-dipping sedimentary rock bedding structures which will be exposed along the cut.

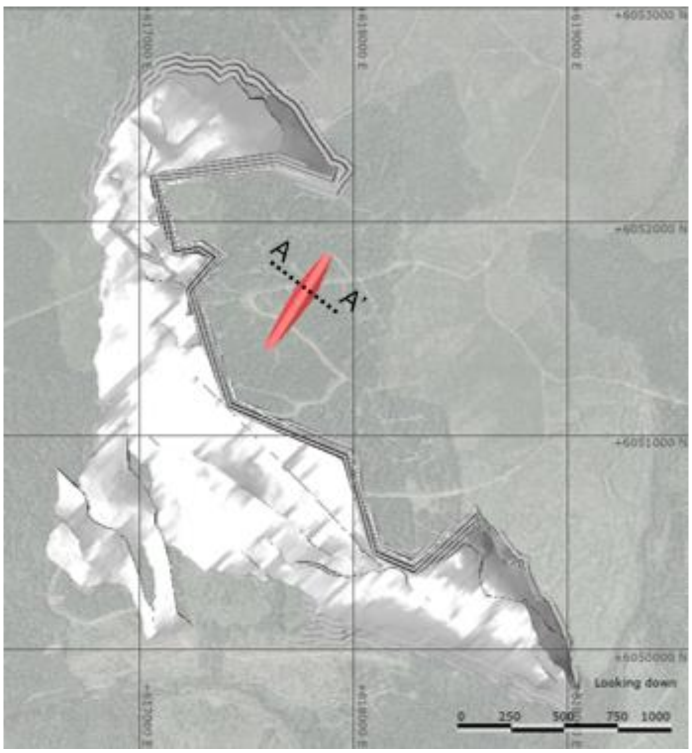


Figure 7-1: Location of proposed haul road cut and stability section location

Geotechnical strength parameters are presented in Table 7-1 and are based on the characterization work carried out as part SRK's Rock and Overburden Pile Slope and Pit Slope Studies (SRK, 2019b and 2019c).The results of the stability analyses indicate a Factor of Safety (FOS) of 1.4 and 1.5 for an overall non-circular and circular failure, respectively. The result for the non-circular failure mechanism is shown in Figure 7-2, and represents failure through the overburden and sliding along bedding.

Table 7-1: Geotechnical Strength Parameters for Haul Road Cut

Unit	Unit Weight (kN/m2)	Mohr-Coulomb		Hoek-Brown Strength			
		Friction Angle (°)	Cohesion (kPa)	UCS (MPa)	GSI	mi	D
Overburden Foundation (Stiff to Very Stiff Till)	18	30	2	-	-	-	-
Bedrock	26	-	-	35	46	7	0.85
Bedding	26	23	0	-	-	-	-

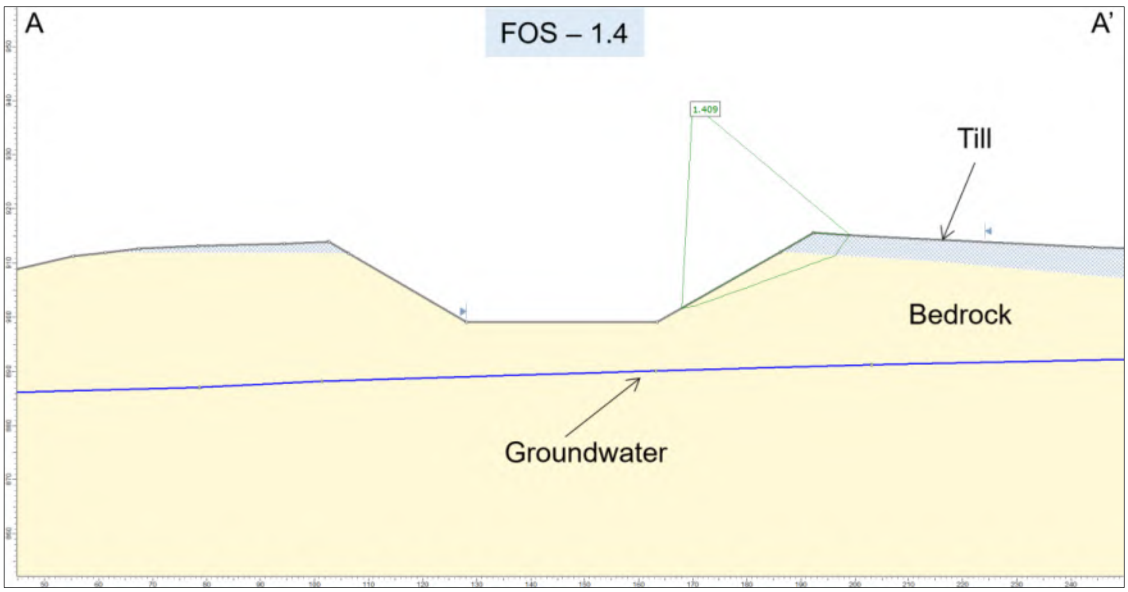


Figure 7-2: Stability analyses results for Section A-A' through the proposed haul road

8 Stockpile Stability Review

Four stockpiles are to be located within or close to the MI footprint. The stockpiles include Topsoil, ROM coal, Processed Rock and Processed Coal. The stockpiles are to be constructed to relatively small heights.

8.1 Stockpile Rating

A semi-qualitative Waste Dump and Stockpile Stability Rating and Hazard Classification (WSRHC) using guidance provided by Hawley and Cunning (2017) was completed. A low rating is assigned to each stockpile primarily due to the relatively small heights and volumes proposed by TCL.

8.2 Stability Analyses

Stability analyses were carried out using the limit-equilibrium program Slide2 (Rocscience, 2020). The analyses were performed to evaluate a range of FOS values for the following stockpile configurations:

- Topsoil - 4H:1V slope gradient (14 degrees slope angle);
- ROM Coal - 2H:1V slope gradient (26 degrees);
- Processed Rock - 2H:1V slope gradient; and
- Processed Coal - 3H:1V slope gradient (14 degrees).

The analyses considered slope heights of 6 m, 10 m, 15 m and 20 m. The maximum height of the topsoil stockpile is recommended to be 6 m, however, can be increased to 12 m where benched with a berm width of at least 25 m separating the slope faces. It is understood that the conveyor spreading equipment will limit the heights of the Processed Road and Processed Coal stockpiles to a maximum 16 m high.

The analyses were based on possible failure mechanism that could be consequential to people, equipment and infrastructure directly downslope of the stockpile. A range of material saturation conditions within the stockpiles, represented as an Ru, were analyzed to consider possible longer-term infiltration. For this review, an Ru of 0 is considered dry and an Ru of 0.3 considered partially saturated. It is likely that the coarse rock (i.e. ROM Coal, Processed Rock and Processed Coal stockpiles) will be drained in the short- and long-term and an Ru of 0 is most representative. Partial saturation of the Topsoil Stockpile may occur through continual infiltration and these structures requires perimeter surface water control and slope profiling to increase run-off away from the critical sloping areas.

The selected geotechnical strength parameters are summarised Table 8-1. The results are summarised in Figure 8-1 to Figure 8-4. For short-term stockpiles, with lower consequence of failure, a design stability with a FOS greater than 1.1 is considered acceptable. For any long-term stockpile, a FOS greater than 1.3 is considered appropriate for a consequential event.

Table 8-1: Geotechnical Strength Parameters for Stockpiles

Material	Unit Weight (kN/m^2)	Friction Angle (°)	Cohesion (kPa)
Overburden Foundation (Stiff to Very Stiff Till)	18	30	2
Topsoil Stockpile	15	15	0
Processed Coal Stockpile	17	30	0
Processed Rock (“Coal Rejects” Stockpile	19	35	0
ROM Coal Stockpile	17	32	0

The results indicate that the Topsoil stockpile slopes are most sensitive to saturation due to the expected finer grained material composition and presence of organics. For a Topsoil stockpiles designed at a 3:1 profile, groundwater conditions representing at Ru less than approximately 0.3 should be used as a target to validate acceptable design stability conditions (Figure 8-1). Where a Topsoil stockpile is considered to exhibit a higher slope risk, water level or pore pressure monitoring should be installed to support validation of the saturation conditions.

As discussed, the other stockpiles are expected to be drained the results of an Ru of 0 representative of the design conditions in most cases. The results indicates that a FOS greater than 1.3 was achieved for the Processed Coal, Processed Rock and ROM Coal Stockpile under an Ru of 0.

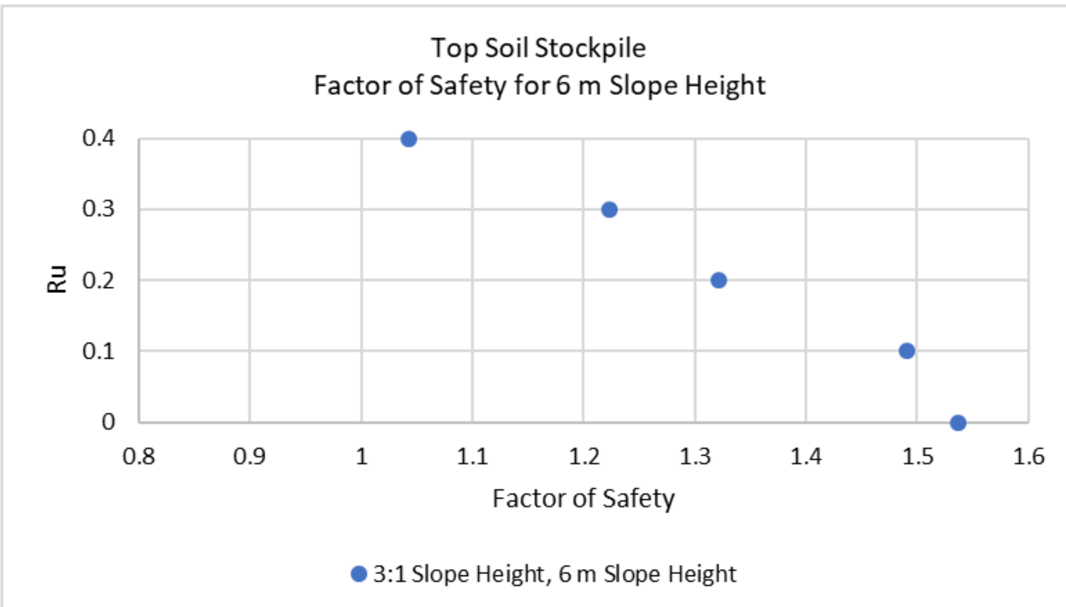


Figure 8-1: Topsoil Stockpile Stability Analyses Results

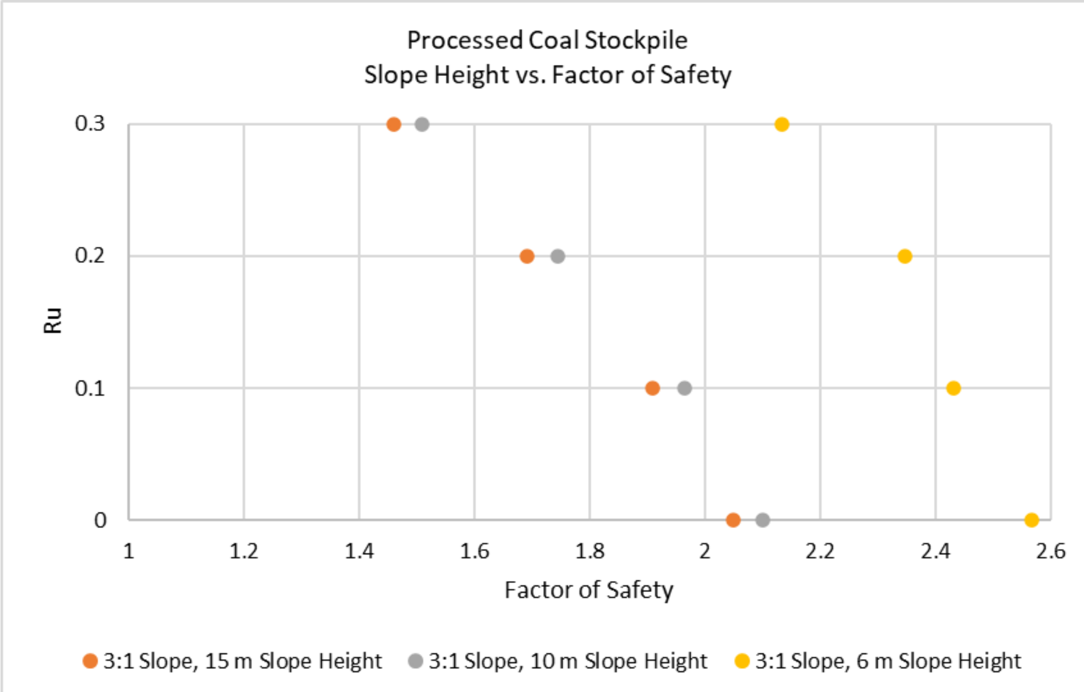


Figure 8-2: Processed Coal Stockpile Stability Analyses Results

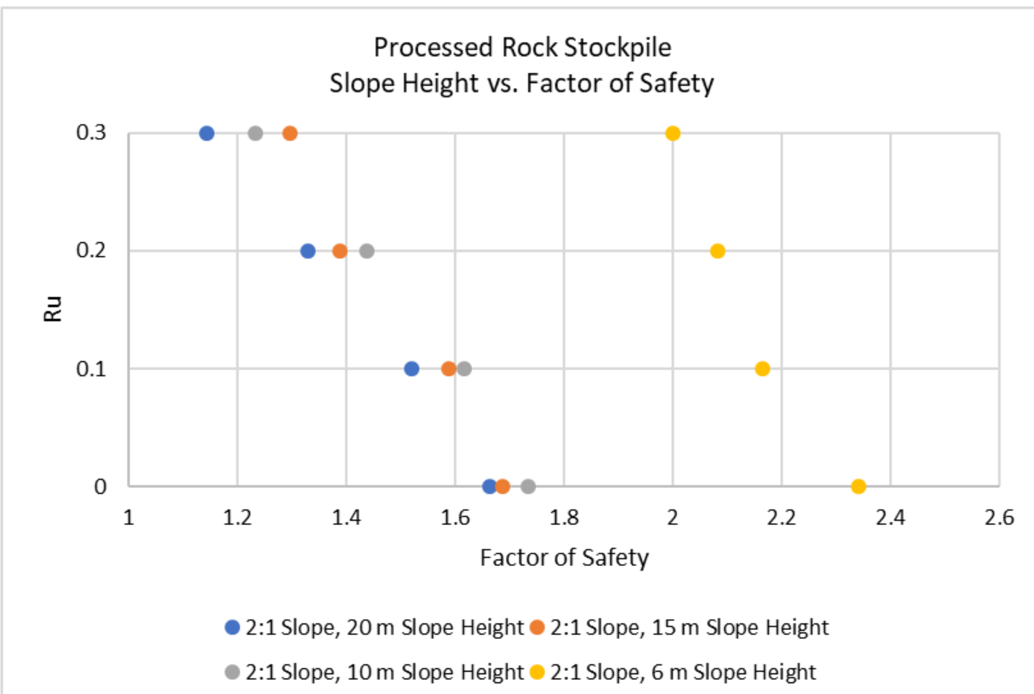


Figure 8-3: Processed Rock (Coal Rejects) Stockpile Stability Analyses Results

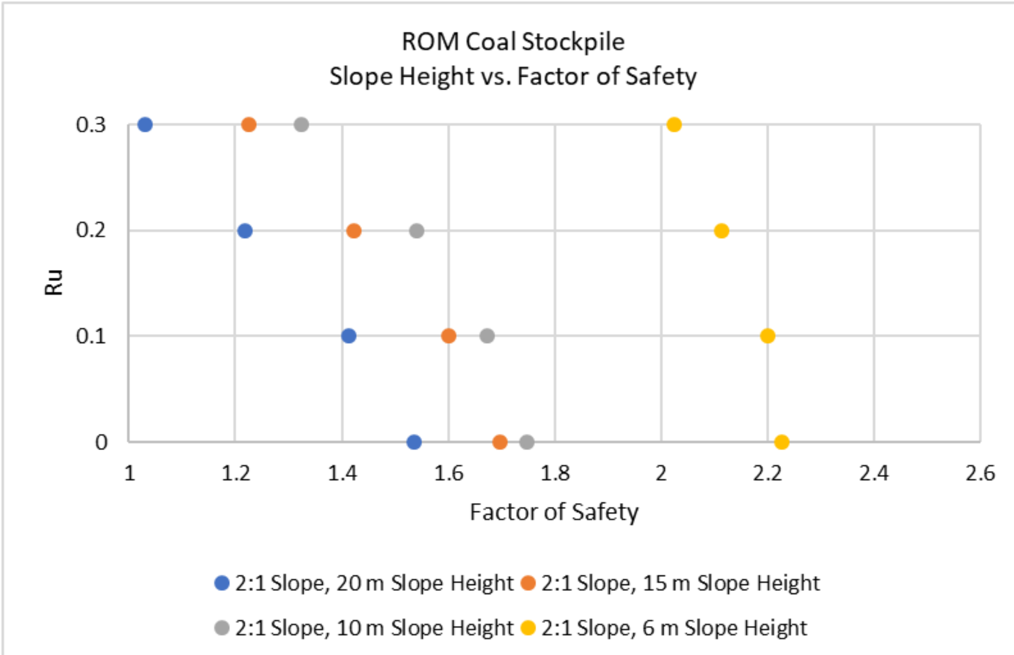


Figure 8-4: ROM Coal Stockpile Stability Analyses Results

8.3 Management Practices and Monitoring

Foundation preparation for the stockpiles should include the clearing to topsoil and soft materials, and the establishment of surface water management within the MI footprint. It is understood that the Processed Rock and Processed Coal stockpiles will be located near the MI area and these should be suitably sloped to achieve acceptable stability conditions, and reduce the risk of a run-out event should this occur. The heights of the slopes will be restricted to approximately 16 m by the height of the conveyer boom. Rock fill berms should be located between the stockpiles and nearby infrastructure and access roads to reduce the potential of damage from a shallow slope failure event, if this was to occur.

Topsoil stockpiles should be located a sufficient distance from infrastructure with appropriate rock fill berms to contain any slope surface failures and surface water management. For any Topsoil stockpiles located close to infrastructure or critical access roads, a base layer of rockfill or coarse coal rejects with a finer outer layer should below the stockpile to promote underdrainage and reduce the potential for saturation. Erosion of the stockpiles will be achieved through the surface water control and limiting the immediate slope heights to a maximum of 6 m.

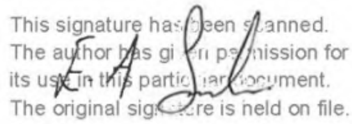
Inspections of the stockpiles should be carried out to review the performance of the stockpile slopes. Consideration should be given for groundwater monitoring installations within any medium to longer-term stockpile structures to evaluate the Ru inputs used in the analyses and identify any saturation or perched water.

9 Recommendations

As the civil/structural infrastructure engineering design work advances, the geotechnical data should be continuously evaluated. Should the required loads from the proposed infrastructure exceed the geotechnical capacity of the shallower foundation materials at the MI or ED sites, adjustments to the structural design and/or future investigation with specialized laboratory testing may be required to validate the detailed design work.

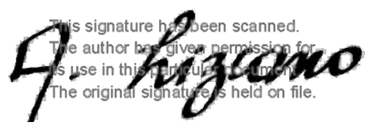
Following completion of detailed infrastructure design or changes in layouts, a geotechnical review should be carried out to evaluate the suitability of the proposed foundations. New field investigations should be carried out where the sensitivity structures differ to the proposed locations detailed in this report.

This report, Tenas Foundation Assessment Report, was prepared by



Ed Saunders, PEng (BC),
Principal Consultant (Mining Rock Mechanics)

and reviewed by



Arcesio Lizcano, PhD
Principal Consultant (Geotechnical)

All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

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The opinions expressed in this report have been based on the information available to SRK at the time of preparation. SRK has exercised all due care in reviewing information supplied by others for use on this project. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information, except to the extent that SRK was hired to verify the data.

10 References

British Columbia Mine Waste Rock Pile Research17T Committee (BCMWRPRC). 1991. Investigation and Design Manuel, Interim Guidelines, May 1991.

Canadian Geotechnical Society, 2006. Canadian Foundation Engineering Manual, 4th Edition

G. Gudehus 1981, Bodenmechanik. Published by Ferdinand Enke Verlag, Stuttgart.

Hawley, M. and Cunning, J. 2017. Guidelines for Mine Waste Dump and Stockpile Design. CRC Press/ Balkema.

Levson et al, 1997. Quaternary Geology and Ice-Flow Studies in the Smithers and Hazelton Map Areas (93L and M): Implications for Exploration: British Columbia Geological Survey Branch. Geological Fieldwork 1997. Paper 1998-1.

National Building of Canada (NBCC). 2015. Site Classification for Seismic Response. (Table 4.1.8.4A)

National Resources Canada (NRC). 2019. 2015 National Building Code Seismic Hazard Calculation for site: 54.6163 N, 127.152 W: National Resources Canada. Accessed May 15, 2018.

Piteau, 1997. Engineering Geology and Geotechnical Assessment for the Tenas Pit and Waste Dumps: Piteau Associates Engineering Ltd.

Rocscience, 2020. Software Program Slide2.

SRK Consulting (Canada) Inc., 2018. Tenas Project – Factual Data Report for 2018 Geotechnical Investigation: SRK Consulting (Canada) Inc.

SRK Consulting (Canada) Inc. 2019a. Tenas Project – Factual Data Report for 2019 Geotechnical Investigation: SRK Consulting (Canada) Inc.

SRK Consulting (Canada) Inc. 2019b. Tenas Project, Feasibility Study – Pit Slope Stability and Design Technical Report, May 2019.

SRK Consulting (Canada) Inc. 2019c. Tenas Project, Feasibility Study – Pile Stability and Design Technical Report, March 2019

Appendix A: Test Pit and Sonic Drillhole Logs

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TELKWA COAL LIMITED

PROJECT: Tenas Coal Project

CLIENT: Telkwa Coal Ltd.

DRILLHOLE ID: 19-48TP
LOCATION: Tenas Exploration Site
PROJECT NO: 2CT025.006
TYPE: Test Pit
CONTRACTOR: Telkwa Coal Ltd. Excavator
LOGGED BY: EC, SRK

DRILLING DATE: 30-Jan-19 **TO:** 30-Jan-19
COORDINATES: 619054 m E 6053559 m N
DATUM: UTM NAD83, Zone 9 North
GROUND EL (masl): 800.7
TOTAL DEPTH (m): 4.3
WATER LEVEL EL (masl): N/A

Soil Log and USCS Classification | **Lab Testing**

Primary Soil Type: Organic Silt/Clay, Silt, Gravel, Clay, Sand, Bedrock

PSD: Sand, Gravel, Fines
Atterberg Limits: Moisture Content, Liquid Limit, Plastic Limit

Percentage: 0%, 20%, 40%, 60%, 80%, 100%

Pocket Penetrometer (kg/cm^2): 1.0, 2.0, 3.0, 4.0

Depth (m)	USCS	Soil Description	Test Pit Notes	Sample ID	PSD
0.0–0.8	SM	Silty Sand with Gravel (SM) - Mostly sand, some silt, little gravel, red brown, dry to moist, stiff, massive structure, non-plastic, low toughness, noncohesive, med. - coarse sand, fine - coarse gravel, coubles/boulders up to 8cm, well graded, subangular, with roots.	Medium Excavator Resistance. Minor Sloughing.	29669	29% Gravel, 39% Sand, 32% Fines
0.8–1.7	CL	Gravely Lean Clay (CL) - Mostly clay, little gravel, few sand, dark grey, moist, hard, massive structure, medium plasticity, high toughness, cohesive, coarse sand, fine - coarse gravel, coubles/boulders up to 10cm, well graded, subangular.			
1.7–2.2	CL	Becomes: mostly clay, few gravel, red brown, low plasticity.		29670	
2.2–4.3	CL	Becomes: mostly clay, little gravel, very dark brown, medium plasticity.	High Excavator Resistance. No Sloughing. Test pit dry.	29671	
4.3			EOH = 4.3m. Refusal		

srk consulting

TELKWA COAL LIMITED

PROJECT: Tenas Coal Project

CLIENT: Telkwa Coal Ltd.

DRILLHOLE ID: 19-49TP
LOCATION: Tenas Exploration Site
PROJECT NO: 2CT025.006
TYPE: Test Pit
CONTRACTOR: Telkwa Coal Ltd. Excavator
LOGGED BY: EC, SRK

DRILLING DATE: 30-Jan-19 **TO:** 30-Jan-19
COORDINATES: 619087 m E 6053535 m N
DATUM: UTM NAD83, Zone 9 North
GROUND EL (masl): 801.0
TOTAL DEPTH (m): 4.3
WATER LEVEL EL (masl): N/A

Soil Log and USCS Classification | **Lab Testing**

Primary Soil Type: Organic Silt/Clay, Silt, Gravel, Clay, Sand, Bedrock

Pocket Penetrometer (kg/cm²): 1.0, 2.0, 3.0, 4.0

PSD: Sand, Gravel, Fines. **Atterberg Limits:** Moisture Content, Liquid Limit, Plastic Limit. Percentage: 0%, 20%, 40%, 60%, 80%, 100%

Depth (m)	USCS	Soil Description	Test Pit Notes	Sample ID	PSD / Atterberg Limits
0.0–0.5	SM	Silty Sand (SM) - Mostly sand, some silt, few gravel, red brown, dry, medium dense, massive structure, non-plastic, low toughness, noncohesive, fine - coarse sand, fine - med. gravel, well graded, subangular, with roots.	Medium Excavator Resistance. Some sloughing.	29672	Gravel 12%, Sand 50%, Fines 38%
0.5–1.2	SC	Clayey Sand with Gravel (SC) - Mostly sand, some clay, little gravel, brown, moist, very stiff, massive structure, low plasticity, low toughness, cohesive, fine - coarse sand, fine - coarse gravel, coubles/boulders up to 15cm, well graded, subangular.		29673	
1.2–4.3	CL	Sandy Lean Clay (CL) - Mostly clay, some sand, few gravel, dark grey, moist, hard, massive structure, medium plasticity, high toughness, cohesive, coarse gravel, coubles/boulders up to 30cm, well graded, subangular.	High Excavator Resistance. No Sloughing. Test pit dry.	29674	Gravel 12%, Sand 30%, Fines 57%; PL=16%, LL=37%
			EOH = 4.3m. Refusal		

srk consulting

TELKWA COAL LIMITED

PROJECT: Tenas Coal Project
CLIENT: Telkwa Coal Ltd.

DRILLHOLE ID: 19-50TP
LOCATION: Tenas Exploration Site
PROJECT NO: 2CT025.006
TYPE: Test Pit
CONTRACTOR: Telkwa Coal Ltd. Excavator
LOGGED BY: EC, SRK

DRILLING DATE: 30-Jan-19 **TO:** 30-Jan-19
COORDINATES: 619149 m E 6053478 m N
DATUM: UTM NAD83, Zone 9 North
GROUND EL (masl): 801.4
TOTAL DEPTH (m): 4.2
WATER LEVEL EL (masl): N/A

Soil Log and USCS Classification | **Lab Testing**

Primary Soil Type: Organic Silt/Clay, Silt, Gravel, Clay, Sand, Bedrock

PSD: Sand, Gravel, Fines | **Atterberg Limits:** Moisture Content, Liquid Limit, Plastic Limit

Depth (m)	USCS	Soil Description	Test Pit Notes	Pocket Penetrometer (kg/cm²)	Sample ID	PSD / Atterberg Limits (Percentage)
0.0	SM	Silty Sand (SM) - Mostly sand, some silt, red brown, dry, medium dense, massive structure, non-plastic, no toughness, noncohesive, fine - med. sand, poorly graded.	Medium Excavator Resistance. Some sloughing.		29675	
0.5	SM	Silty Sand with Gravel (SM) - Mostly sand, little silt, few gravel, brown, dry, medium dense, massive structure, non-plastic, no toughness, noncohesive, fine sand, coarse gravel, coubles/boulders up to 8cm, gap graded, subangular.			35046	
1.1	CL	Lean Clay with Gravel (CL) - Mostly clay, little gravel, dark grey, moist, very stiff, massive structure, medium plasticity, high toughness, cohesive, coarse gravel, coubles/boulders up to 30cm, well graded, subangular.	High Excavator Resistance. No Sloughing. Test pit dry.			
3.5					35047	PL=15%, LL=37%
4.2			EOH = 4.2m. Refusal			

srk consulting

TELKWA COAL LIMITED

PROJECT: Tenas Coal Project
CLIENT: Telkwa Coal Ltd.

DRILLHOLE ID: 19-51TP
LOCATION: Tenas Exploration Site
PROJECT NO: 2CT025.006
TYPE: Test Pit
CONTRACTOR: Telkwa Coal Ltd. Excavator
LOGGED BY: EC, SRK

DRILLING DATE: 30-Jan-19 **TO:** 30-Jan-19
COORDINATES: 619100 m E 6053391 m N
DATUM: UTM NAD83, Zone 9 North
GROUND EL (masl): 803.2
TOTAL DEPTH (m): 4.1
WATER LEVEL EL (masl): N/A

Soil Log and USCS Classification | **Lab Testing**

Primary Soil Type: Organic Silt/Clay, Silt, Gravel, Clay, Sand, Bedrock

Pocket Penetrometer (kg/cm²): 1.0, 2.0, 3.0, 4.0

PSD: Sand, Gravel, Fines
Atterberg Limits: Moisture Content, Liquid Limit, Plastic Limit
Percentage: 0%, 20%, 40%, 60%, 80%, 100%

Depth (m)	USCS	Soil Description	Test Pit Notes	Sample ID
0.0–1.0	SC	Clayey Sand with Gravel (SC) - Mostly sand, little clay, few gravel, brown, saturated, loose, massive structure, low plasticity, low toughness, cohesive, fine - med. sand, coarse gravel, coubles/boulders up to 8cm, gap graded, subangular.	Medium Excavator Resistance. Minor Sloughing.	
1.0–4.1	CL	Lean Clay with Gravel (CL) - Mostly clay, little gravel, dark grey, moist, very stiff, massive structure, medium plasticity, high toughness, cohesive, coarse gravel, coubles/boulders up to 30cm, well graded, subangular.	High Excavator Resistance. No Sloughing. Very high water inflow from nearby ponded surface water. Test pit located in a local topographic low.	35048 (~1.2 m), 35049 (~2.4 m), 35050 (~3.6 m)
4.0			EOH = 4.1m. Refusal	

PL=15%
LL=36%

srk consulting

TELKWA COAL LIMITED

PROJECT: Tenas Coal Project

CLIENT: Telkwa Coal Ltd.

DRILLHOLE ID: 19-52TP
LOCATION: Tenas Exploration Site
PROJECT NO: 2CT025.006
TYPE: Test Pit
CONTRACTOR: Telkwa Coal Ltd. Excavator
LOGGED BY: EC, SRK

DRILLING DATE: 31-Jan-19 **TO:** 31-Jan-19
COORDINATES: 618485 m E 6054492 m N
DATUM: UTM NAD83, Zone 9 North
GROUND EL (masl): 781.1
TOTAL DEPTH (m): 3.3
WATER LEVEL EL (masl): N/A

Soil Log and USCS Classification

Primary Soil Type

Organic Silt/Clay, Silt, Gravel, Clay, Sand, Bedrock

Lab Testing

PSD: Sand, Gravel, Fines

Atterberg Limits: Moisture Content, Liquid Limit, Plastic Limit

Percentage: 0%, 20%, 40%, 60%, 80%, 100%

Pocket Penetrometer (kg/cm^2): 1.0, 2.0, 3.0, 4.0

Depth (m)	USCS	Soil Description	Test Pit Notes	Sample ID	Lab Testing
0.0–0.8	CL	Gravely Lean Clay (CL) - Mostly clay, little gravel, few sand, red, dry to moist, stiff, massive structure, medium plasticity, medium toughness, cohesive, med. - coarse sand, fine - coarse gravel, coubles/boulders up to 10cm, well graded, subangular, with roots. Becomes: no roots.	High Excavator Resistance throughout. No Sloughing. Test pit dry.		
0.8–3.3	SC	Clayey Sand with Gravel (SC) - Mostly sand, some clay, little gravel, red, dry to moist, stiff, massive structure, medium plasticity, medium toughness, cohesive, med. - coarse sand, fine - coarse gravel, coubles/boulders up to 30cm, well graded, subangular, no roots.		29690	Gravel 23%, Sand 34%, Fines 42%; PL=15%, LL=30%
				29691	
3.3			EOH = 3.3m. Refusal		

DRILLHOLE ID: 19-53TP
LOCATION: Tenas Exploration Site
PROJECT NO: 2CT025.006
TYPE: Test Pit
CONTRACTOR: Telkwa Coal Ltd. Excavator
LOGGED BY: EC, SRK

DRILLING DATE: 31-Jan-19 **TO:** 31-Jan-19
COORDINATES: 618516 m E 6054468 m N
DATUM: UTM NAD83, Zone 9 North
GROUND EL (masl): 781.9
TOTAL DEPTH (m): 3.1
WATER LEVEL EL (masl): N/A

PROJECT: Tenas Coal Project
CLIENT: Telkwa Coal Ltd.

Soil Log and USCS Classification

Primary Soil Type: Organic Silt/Clay, Silt, Gravel, Clay, Sand, Bedrock

Lab Testing

PSD: Sand, Gravel, Fines
Atterberg Limits: Moisture Content, Liquid Limit, Plastic Limit

Depth (m)	USCS	Soil Description	Test Pit Notes	Pocket Penetrometer (kg/cm²)	Sample ID	PSD / Atterberg Limits (Percentage)
0.0–0.3	CL	Sandy Lean Clay with Gravel (CL) - Mostly clay, little sand, little gravel, red, dry to moist, stiff, massive structure, medium plasticity, medium toughness, cohesive, med. - coarse sand, fine - coarse gravel, coubles/boulders up to 5cm, well graded, subangular, with roots.	High Excavator Resistance throughout. No Sloughing. Test pit dry.			
~0.6	SC	Clayey Sand with Gravel (SC) - Mostly sand, some clay, little gravel, red, dry to moist, stiff, massive structure, medium plasticity, medium toughness, cohesive, med. - coarse sand, fine - coarse gravel, coubles/boulders up to 5cm, well graded, subangular, no roots.			29692	Gravel 18%, Sand 43%, Fines 39%; PL=16%, LL=34%
~1.8	SC				29693	Gravel 25%, Sand 26%, Fines 49%; PL=17%, LL=35%
1.5–3.1	SC	Becomes: coubles/boulders up to 30cm.	EOH = 3.1m. Refusal			

DRILLHOLE ID: 19-54TP
LOCATION: Tenas Exploration Site
PROJECT NO: 2CT025.006
TYPE: Test Pit
CONTRACTOR: Telkwa Coal Ltd. Excavator
LOGGED BY: EC, SRK

DRILLING DATE: 31-Jan-19 **TO:** 31-Jan-19
COORDINATES: 619042 m E 6053477 m N
DATUM: UTM NAD83, Zone 9 North
GROUND EL (masl): 801.6
TOTAL DEPTH (m): 4.2
WATER LEVEL EL (masl): N/A

PROJECT: Tenas Coal Project
CLIENT: Telkwa Coal Ltd.

Soil Log and USCS Classification | **Lab Testing**

Primary Soil Type: Organic Silt/Clay, Silt, Gravel, Clay, Sand, Bedrock

PSD: Sand, Gravel, Fines — **Atterberg Limits:** Moisture Content, Liquid Limit, Plastic Limit — Percentage (0%, 20%, 40%, 60%, 80%, 100%)

Pocket Penetrometer (kg/cm^2): 1.0, 2.0, 3.0, 4.0

Depth (m)	USCS	Soil Description	Test Pit Notes	Sample ID
0.0–0.3	CL	Sandy Lean Clay with Gravel (CL) - Mostly clay, little sand, few gravel, brown, moist, stiff, massive structure, medium plasticity, medium toughness, cohesive, coarse sand, fine - coarse gravel, coubles/boulders up to 10cm, well graded, subangular, with roots.		
0.3–2.0	CL	Becomes: no roots.	Medium Excavator Resistance. Minor Sloughing.	29694
2.0–4.2	CL	Lean Clay with Gravel (CL) - Mostly clay, few gravel, dark grey, moist, very stiff, massive structure, medium plasticity, medium toughness, cohesive, coarse gravel, coubles/boulders up to 30cm, well graded, subangular.	High Excavator Resistance. No Sloughing. Test pit dry.	29695
4.2			EOH = 4.2m. Refusal	

srk consulting

TELKWA COAL LIMITED

PROJECT:	Tenas Coal Project	**DRILLHOLE ID:**	19-55TP
CLIENT:	Telkwa Coal Ltd.	**LOCATION:**	Tenas Exploration Site
		PROJECT NO:	2CT025.006
		TYPE:	Test Pit
		CONTRACTOR:	Telkwa Coal Ltd. Excavator
		LOGGED BY:	EC, SRK

DRILLING DATE:	31-Jan-19 **TO:** 31-Jan-19
COORDINATES:	619054 m E 6053453 m N
DATUM:	UTM NAD83, Zone 9 North
GROUND EL (masl):	801.8
TOTAL DEPTH (m):	4.1
WATER LEVEL EL (masl):	N/A

Soil Log and USCS Classification | **Lab Testing**

Primary Soil Type: Organic Silt/Clay, Silt, Gravel, Clay, Sand, Bedrock

PSD: Sand, Gravel, Fines — **Atterberg Limits:** Moisture Content, Liquid Limit, Plastic Limit

Depth (m)	USCS	Soil Description	Test Pit Notes	Pocket Penetrometer (kg/cm²)	Sample ID	PSD / Atterberg Limits (Percentage)
0.0 – 0.3	OL/OH	Organic Soil (OL/OH) - Mostly organic, black, saturated, soft, massive structure, low plasticity, no toughness, cohesive, with roots.	Low Resistance. Some Sloughing.		29696	
0.3 – 1.0	CL	Sandy Lean Clay with Gravel (CL) - Mostly clay, little sand, few gravel, brown, moist, stiff, massive structure, medium plasticity, medium toughness, cohesive, coarse sand, fine - coarse gravel, coubles/boulders up to 10cm, well graded, subangular.	Medium Excavator Resistance. No Sloughing. Very high water inflow from nearby ponded surface water. Test pit located in a local topographic low.			PL=18% LL=37%
1.0 – 2.2	GC	Clayey Gravel with Sand (GC) - Mostly gravel, some clay, little sand, dark brown, moist, very stiff, massive structure, medium plasticity, medium toughness, cohesive, coarse sand, fine - coarse gravel, coubles/boulders up to 10cm, well graded, subangular.		●	29697	Gravel 31%, Sand 29%, Fines 40%
2.2 – 4.1	CL	Lean Clay with Gravel (CL) - Mostly clay, few gravel, dark grey, moist, very stiff, massive structure, medium plasticity, medium toughness, cohesive, coarse sand, fine - coarse gravel, coubles/boulders up to 10cm, well graded, subangular.	EOH = 4.1m. Refusal	●		

DRILLHOLE ID:	19-23S	**DRILLING DATE:**	30-Jan-19 **TO:** 31-Jan-19
LOCATION:	Tenas Exploration Site	**COORDINATES:**	619116.7 m E 6053404.9 m N
PROJECT NO:	2CT025.006	**DATUM:**	UTM NAD83, Zone 9 North
DRILL TYPE:	Sonic Drillhole	**GROUND EL (masl):**	797.5
CORE DIA:	8"	**AZIMUTH:**	0° **DIP:** -90°
CONTRACTOR:	Boart Longyear	**TOTAL LENGTH (m):**	11.3
LOGGED BY:	EC, SRK	**WATER LEVEL EL (masl):**	N/A

PROJECT: Tenas Coal Project

CLIENT: Telkwa Coal Ltd.

Soil Log and USCS Classification

Primary Soil Type

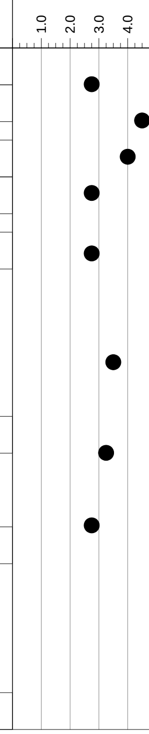
Organic Silt/Clay, Silt, Gravel, Clay, Sand, Bedrock

Depth (m)	USCS	Soil Description	Blows per 15 cm	SPT N Value	Sample ID
0.0	CL	Sandy Lean Clay with Gravel (CL) - Mostly clay, little sand, little gravel, brown, wet, medium stiff, massive structure, medium plasticity, medium toughness, cohesive, coarse sand, fine - coarse gravel, coubles/boulders up to 3cm, well graded, subangular, with roots and other organic debris.	4, 3, 4, 4	7	
1.0	CL	Becomes: no roots or organic debris.	4, 6, 6, 14	17	29676
	CL	Becomes: stiff.			
2.0	CL	Becomes: mostly clay, some sand, little gravel, dark brown, very stiff.	17, 12, 15, 18	30	
	CL	Lean Clay with Gravel (CL) - Mostly clay, little gravel, dark grey, moist, very stiff, massive structure, medium plasticity, medium toughness, cohesive, fine - coarse gravel, coubles/boulders up to 5cm, well graded, subangular.	8, 11, 12, 14	25	
3.0–6.0	CL	Becomes: mostly clay, little gravel, trace sand, dark brown.	5, 13, 13, 17	29	29677
6.0–10.0	CL	Becomes: hard.	8, 15, 17, 23	37	29678
			8, 9, 16, 22	31	29679
11.0	CL	Becomes: very stiff.	7, 10, 12, 18	27	

Consistency

Standard Penetration Test (SPT)

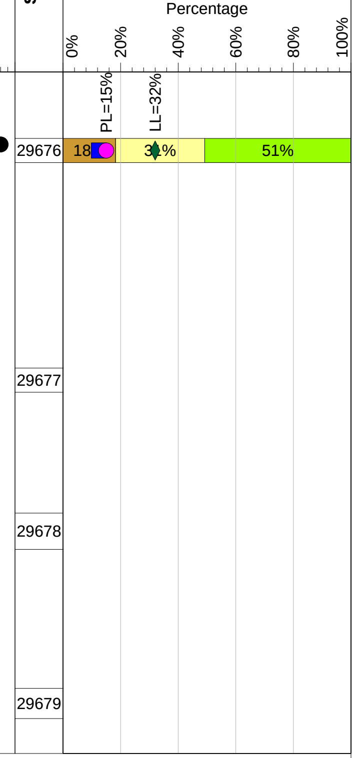
Pocket Penetrometer (kg/cm²)



Lab Testing

PSD: Sand, Gravel, Fines

Atterberg Limits: Moisture Content, Liquid Limit, Plastic Limit



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TELKWA COAL LIMITED

PROJECT: Tenas Coal Project
CLIENT: Telkwa Coal Ltd.

DRILLHOLE ID: 19-24S
LOCATION: Tenas Exploration Site
PROJECT NO: 2CT025.006
DRILL TYPE: Sonic Drillhole
CORE DIA: 8"
CONTRACTOR: Boart Longyear
LOGGED BY: EC, SRK

DRILLING DATE: 01-Feb-19 **TO:** 01-Feb-19
COORDINATES: 619072.1 m E 6053522.7 m N
DATUM: UTM NAD83, Zone 9 North
GROUND EL (masl): 797.5
AZIMUTH: 0° **DIP:** -90°
TOTAL LENGTH (m): 20.4
WATER LEVEL EL (masl): N/A

Soil Log and USCS Classification

Primary Soil Type

Organic Silt/Clay · Silt · Gravel · Clay · Sand · Bedrock

Depth (m): 0.0 – 20.0

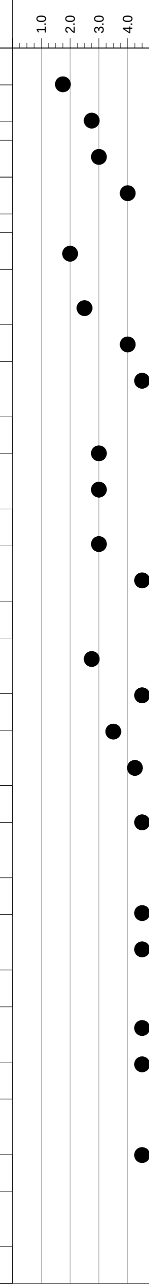
USCS	Soil Description
CL	Gravely Lean Clay (CL) - Mostly clay, little gravel, few sand, brown, stiff, low plasticity, low toughness, cohesive, fine - coarse sand, fine - coarse gravel, coubles/boulders up to 3cm, well graded, subangular.
CL	Lean Clay with Gravel (CL) - Mostly clay, few gravel, trace sand, dark brown, medium plasticity, medium toughness, cohesive, fine - coarse gravel, coubles/boulders up to 8cm, well graded, subangular.
CL	Becomes: very stiff.
CL	Becomes: mostly clay, few gravel.
CL	Lean Clay (CL) - Mostly clay, few gravel, dark brown, very stiff, medium plasticity, medium toughness, cohesive, fine - coarse gravel, coubles/boulders up to 8cm, well graded, subangular.
CL	Becomes: mostly clay, little sand, little gravel.
CL	Becomes: hard.
CL	Sandy Lean Clay (CL) - Mostly clay, some sand, few gravel, very dark brown, dry to moist, hard, massive structure, medium plasticity, high toughness, cohesive, coarse gravel, coubles/boulders up to 5cm, well graded, subangular.
CL	Becomes: coubles/boulders up to 10cm.

Consistency

Standard Penetration Test (SPT)

Blows per 15 cm	SPT N Value
3, 6, 3, 5	9
3, 6, 7, 9	15
7, 9, 12, 16	25
20, 17, 18, 22	38
1, 3, 9, 13	17
6, 6, 11, 14	21
4, 10, 13, 16	26
6, 10, 15, 20	30
4, 12, 15, 16	29
6, 9, 11, 19	26
6, 12, 23, 30	43
18, 27, 30, 37	50
7, 14, 24, 36	49
50/4", -, -, -	50
10, 50/1", -, -	50
24, 25, 33, 43	50

Pocket Penetrometer (kg/cm²)



Lab Testing

PSD: Sand, Gravel, Fines
Atterberg Limits: Moisture Content, Liquid Limit, Plastic Limit

Percentage: 0% 20% 40% 60% 80% 100%

Sample ID	Gravel	Sand	Fines	Atterberg Limits
29680				
29681				
29682	20	28%	52%	PL=14%, LL=32%
29683				
29684				
29685	7.1%	39%	54%	PL=14%, LL=31%
29686				

srk consulting

TELKWA COAL LIMITED

PROJECT: Tenas Coal Project
CLIENT: Telkwa Coal Ltd.

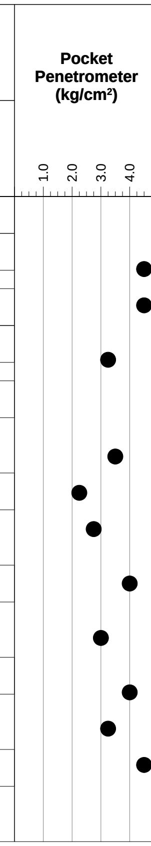
DRILLHOLE ID: 19-25S
LOCATION: Tenas Exploration Site
PROJECT NO: 2CT025.006
DRILL TYPE: Sonic Drillhole
CORE DIA: 8"
CONTRACTOR: Boart Longyear
LOGGED BY: EC, SRK

DRILLING DATE: 31-Jan-19 **TO:** 01-Feb-19
COORDINATES: 619069.7 m E 6053505.3 m N
DATUM: UTM NAD83, Zone 9 North
GROUND EL (masl): 797.4
AZIMUTH: 0° **DIP:** -90°
TOTAL LENGTH (m): 10.7
WATER LEVEL EL (masl): N/A

Primary Soil Type: Organic Silt/Clay, Silt, Gravel, Clay, Sand, Bedrock

Lab Testing: PSD: Sand, Gravel, Fines. Atterberg Limits: Moisture Content, Liquid Limit, Plastic Limit.

Depth (m)	USCS	Soil Description	Blows per 15 cm	SPT N Value	Sample ID	Lab Testing
0.0–0.8	SC	Clayey Sand (SC) - Mostly sand, some clay, trace gravel, brown, moist, medium stiff, massive structure, medium plasticity, low toughness, cohesive, fine sand, coarse gravel, gap graded, subangular.	10, 5, 4, 3	8		
0.8–1.8	CL	Sandy Lean Clay with Gravel (CL) - Mostly clay, little sand, few gravel, dark brown, dry to moist, hard, massive structure, low plasticity, medium toughness, cohesive, fine sand, coarse gravel, coubles/boulders up to 5cm, gap graded, subangular.	7, 8, 13, 26	31		
1.8–3.2	CL	Becomes: mostly clay, few gravel, medium plasticity.	9, 14, 15, 16 / 15, 24, 20, 24	30 / 45	29687	
3.2–4.0	SC	Clayey Sand with Gravel (SC) - Mostly sand, little clay, little gravel, dark brown, moist, hard, massive structure, medium plasticity, low toughness, cohesive, fine - coarse sand, fine - coarse gravel, coubles/boulders up to 3cm, well graded, subangular.	6, 16, 18, 26	40		
4.0–6.0	CL	Lean Clay (CL) - Mostly clay, few gravel, red brown, moist, hard, massive structure, medium plasticity, medium toughness, cohesive, fine - coarse gravel, coubles/boulders up to 3cm, well graded, subangular.	7, 12, 18, 21	34	29688	
6.0–7.5	CL	Becomes: mostly clay, some sand, few gravel, coubles/boulders up to 8cm.	9, 10, 14, 24	32		
7.5–9.0	CL	Becomes: very stiff.	6, 10, 15, 17	28	29689	13 / 35% / 52%; PL=15%; LL=33%
9.0–10.7	CL	Becomes: hard.	6, 13, 39, 19	47		



Appendix B: Laboratory Testing Results

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

GOLDER

ASTM D 4318

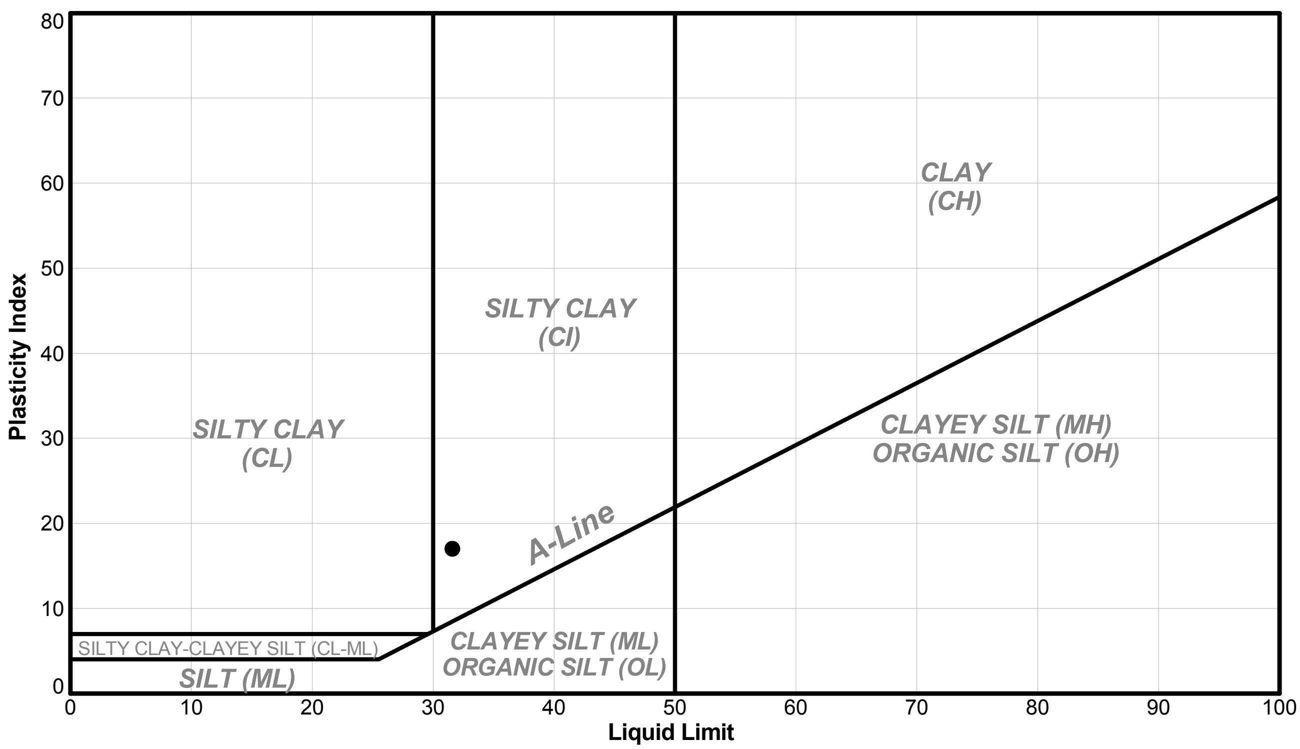
Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

ID: 19-23S
Sample No.: 29676
Depth Interval (m): 1.10 to 1.50
Lab Schedule No.:

Other Remarks: N/A

Test Method: A-Multi Point | **Preparation Method:** Air Dried

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-23S	29676	1.10	1.50	65	32	15	17.0	12.5	-0.1

NP - NON-PLASTIC RESULT   ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

BJ	5/1/2019	LP	5/3/2019
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID: Output Form:_LAB ATTERBERG CASAGRANDE (SINGLE) 2018 SJohn 22/5/19

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LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

GOLDER

ASTM D 4318

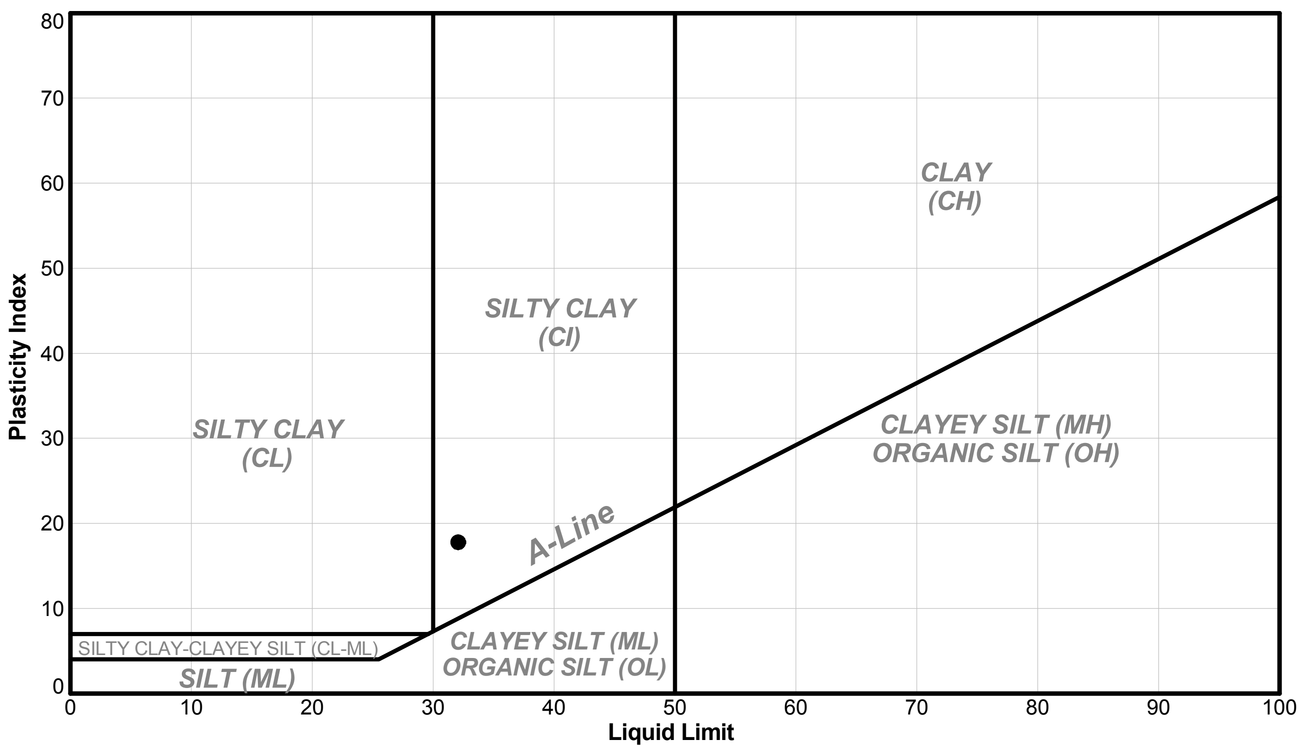
Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

ID: 19-24S
Sample No.: 29682
Depth Interval (m): 7.00 to 7.60
Lab Schedule No.:

Other Remarks: N/A

Test Method: A-Multi Point | **Preparation Method:** Air Dried

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-24S	29682	7.00	7.60	65	32	14	18.0	12.5	-0.1

NP - NON-PLASTIC RESULT ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

BJ	5/1/2019	LP	5/3/2019
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID: Output Form:_LAB ATTERBERG CASAGRANDE (SINGLE) 2018 SJohn 22/5/19

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LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

ASTM D 4318

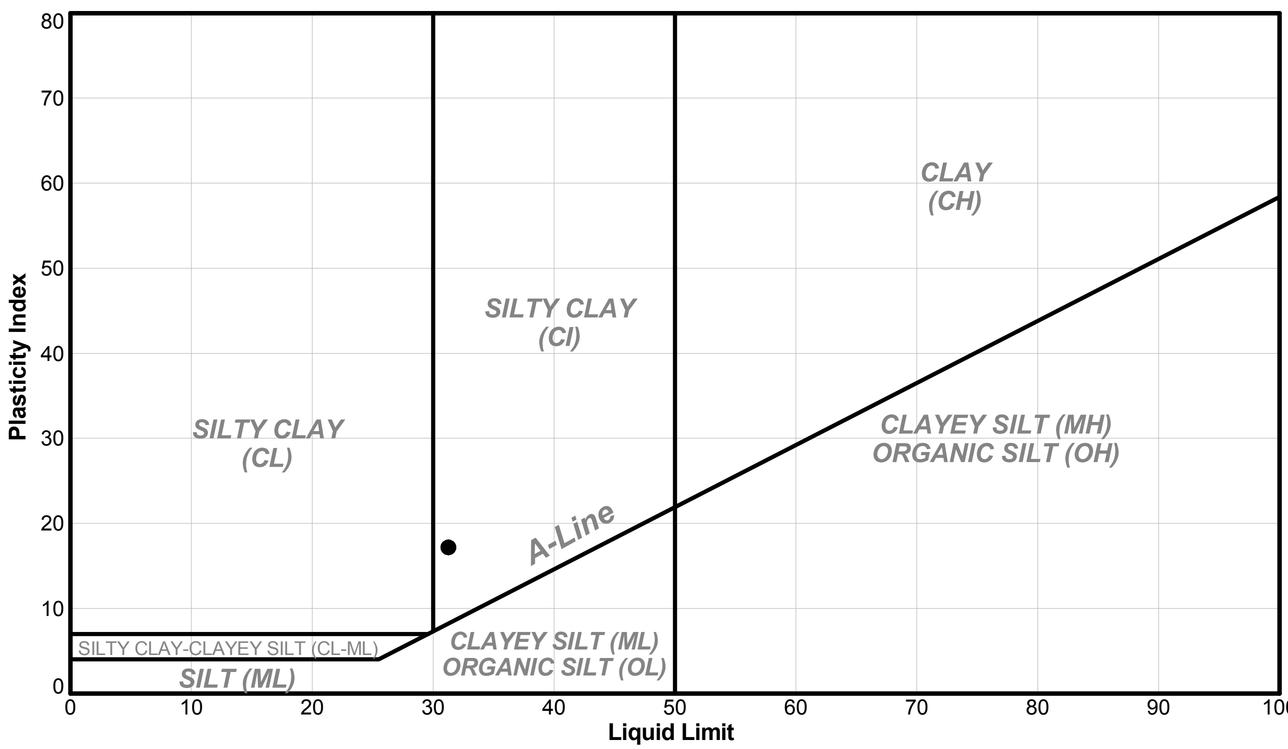
Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

ID: 19-24S
Sample No.: 29685
Depth Interval (m): 16.20 to 16.80
Lab Schedule No.:

Other Remarks: N/A

Test Method: A-Multi Point | **Preparation Method:** Air Dried

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-24S	29685	16.20	16.80	68	31	14	17.0	11.3	-0.2

NP - NON-PLASTIC RESULT ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

BJ	5/1/2019	LP	5/3/2019
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID: Output Form:_LAB ATTERBERG CASAGRANDE (SINGLE) 2018 SJohn 22/5/19

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LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

GOLDER

ASTM D 4318

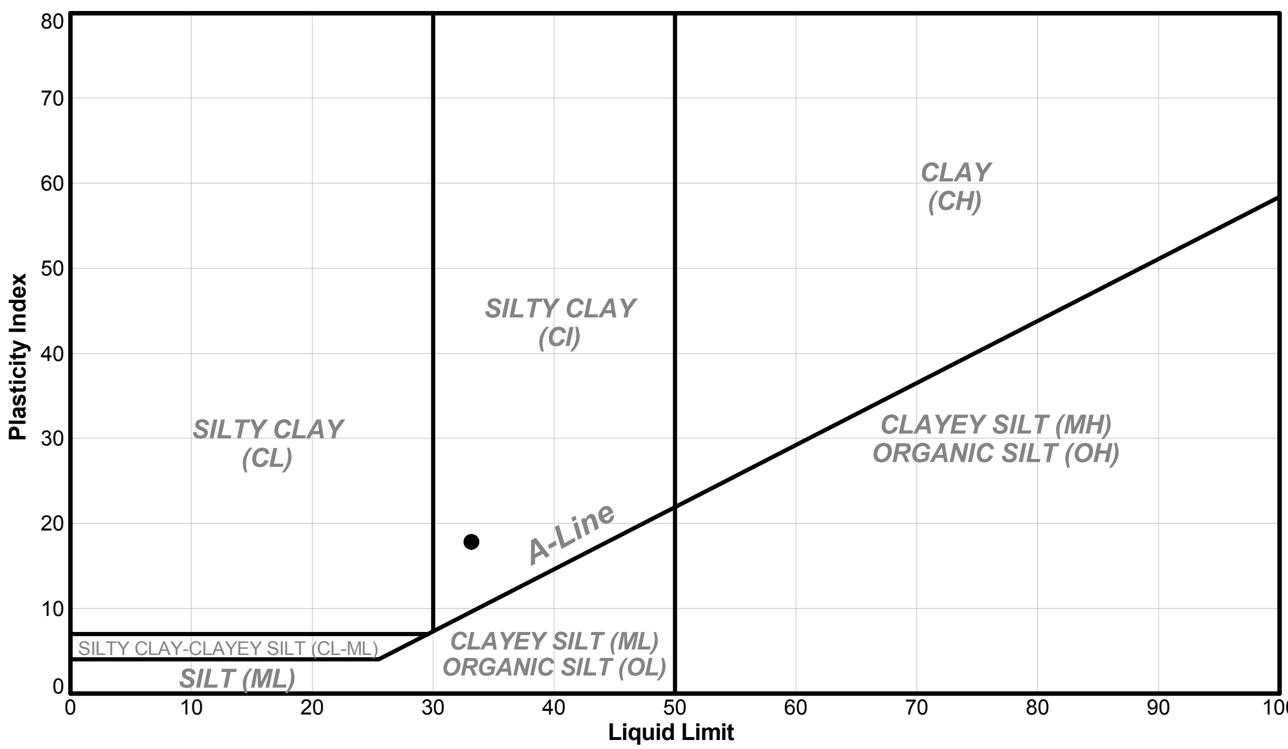
Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

ID: 19-25S
Sample No.: 29689
Depth Interval (m): 8.20 to 8.80
Lab Schedule No.:

Other Remarks: N/A

Test Method: A-Multi Point | **Preparation Method:** Air Dried

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-25S	29689	8.20	8.80	65	33	15	18.0	11.7	-0.2

NP - NON-PLASTIC RESULT ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

BJ	5/2/2019	LP	5/3/2019
Tech	Date	Checked	Date

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LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

GOLDER

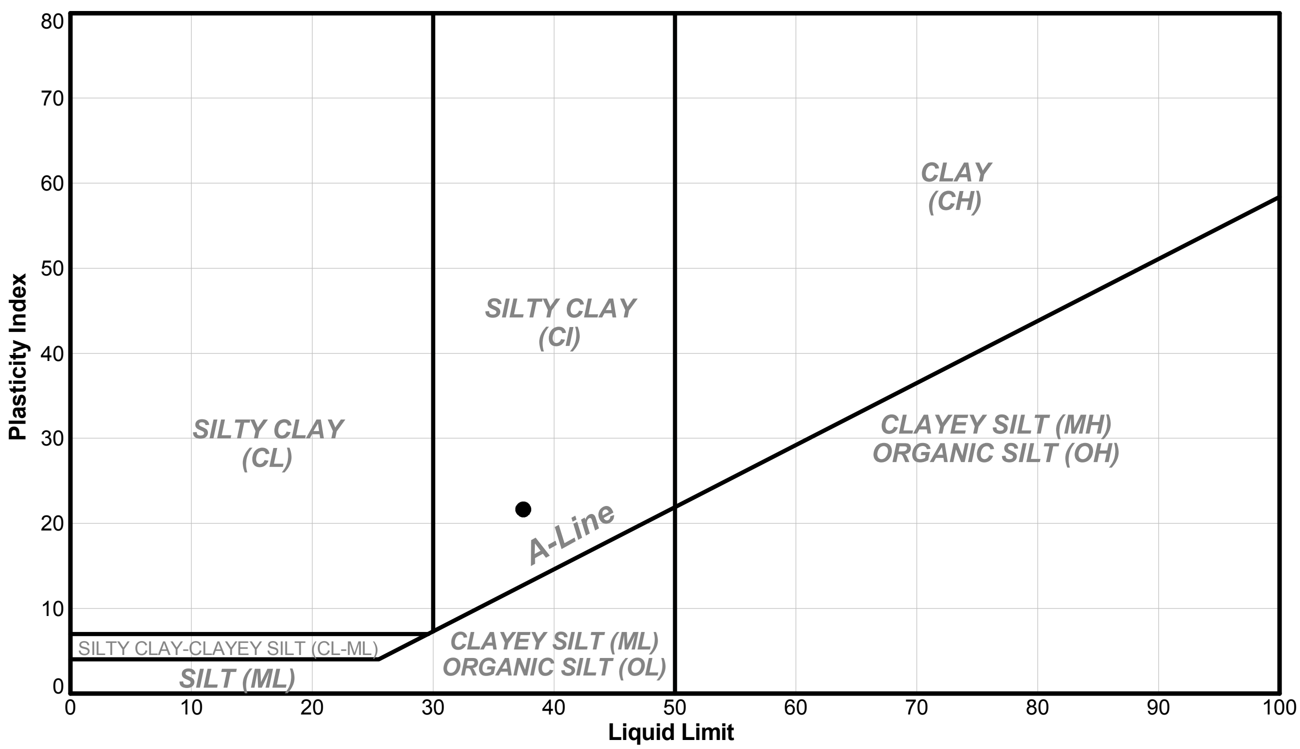
ASTM D 4318

Client: Telkwa Coal Ltd. **ID: 19-49TP**
Project: Explore 0112 **Sample No.: 29674**
Location: **Depth Interval (m):** 2.90 to 3.10
Project No.: 18109666 **Phase:** 2000 **Lab Schedule No.:**

Other Remarks: **N/A**

Test Method: A-Multi Point | **Preparation Method: Air Dried**

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-49TP	29674	2.90	3.10	68	37	16	21.0	12.6	-0.2

NP - NON-PLASTIC RESULT ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

BJ	5/1/2019	LP	5/3/2019
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID: Output Form:_LAB ATTERBERG CASAGRANDE (SINGLE) 2018 SJohn 22/5/19

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LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

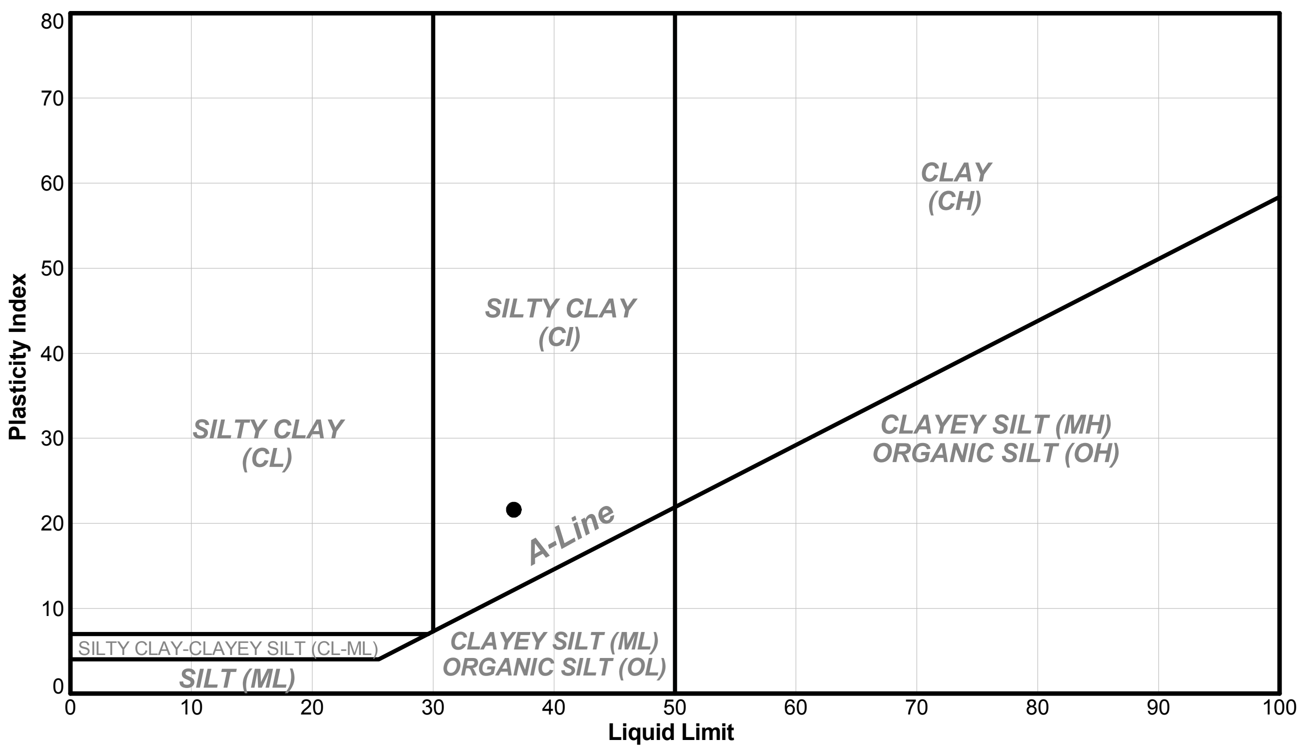
ASTM D 4318

Client:	Telkwa Coal Ltd.	**ID:**	**19-50TP**
Project:	Explore 0112	**Sample No.:**	**35047**
Location:		**Depth Interval (m):**	3.50 to 3.70
Project No.:	18109666 **Phase:** 2000	**Lab Schedule No.:**	

Other Remarks: **N/A**

Test Method: A-Multi Point | **Preparation Method: Air Dried**

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-50TP	35047	3.50	3.70	ND	37	15	22.0	11.4	-0.2

NP - NON-PLASTIC RESULT ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

BJ	**5/1/2019**	**LP**	**5/3/2019**
Tech	Date	Checked	Date

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LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

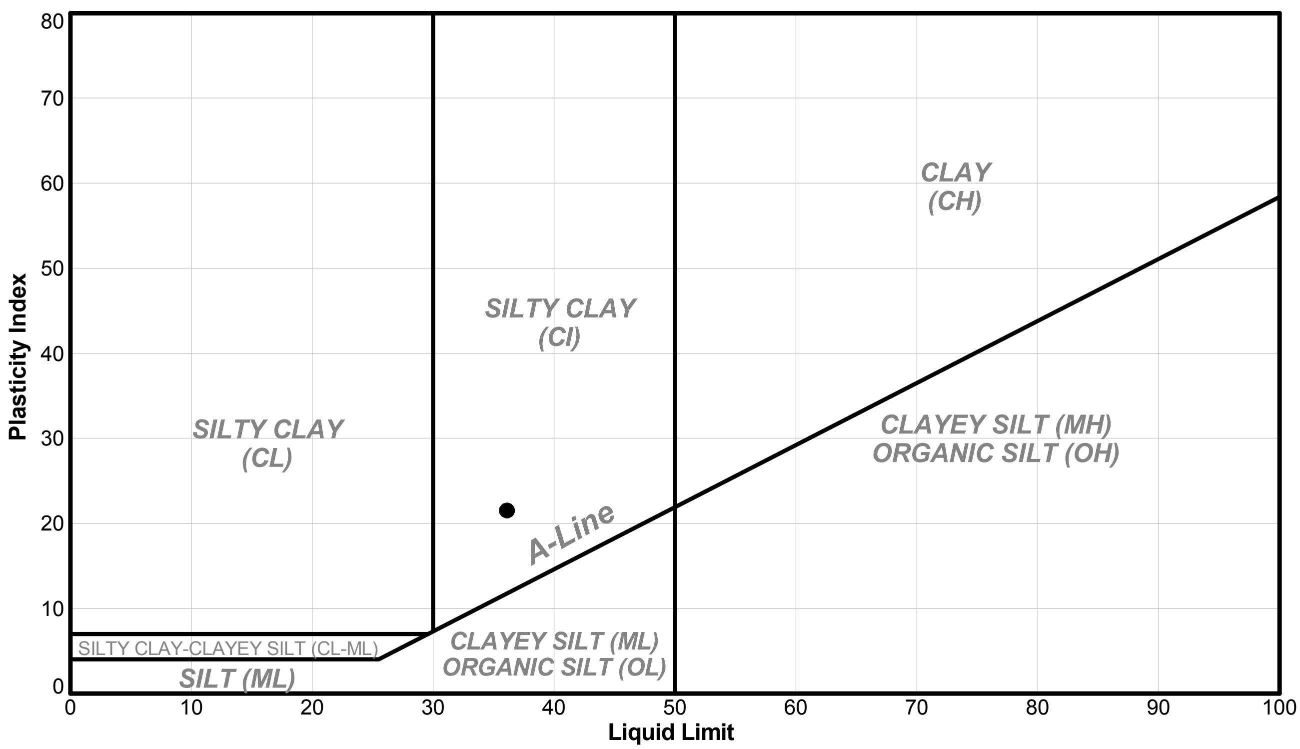
ASTM D 4318

Client:	Telkwa Coal Ltd.	**ID:**	**19-51TP**
Project:	Explore 0112	**Sample No.:**	**35049**
Location:		**Depth Interval (m):**	2.30 to 2.50
Project No.:	18109666 **Phase:** 2000	**Lab Schedule No.:**	

Other Remarks: **N/A**

Test Method: A-Multi Point	**Preparation Method: Air Dried**

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-51TP	35049	2.30	2.50	ND	36	15	21.0	10.3	-0.2

NP - NON-PLASTIC RESULT   ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

BJ	**5/1/2019**	**LP**	**5/3/2019**
Tech	Date	Checked	Date

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

GOLDER

ASTM D 4318

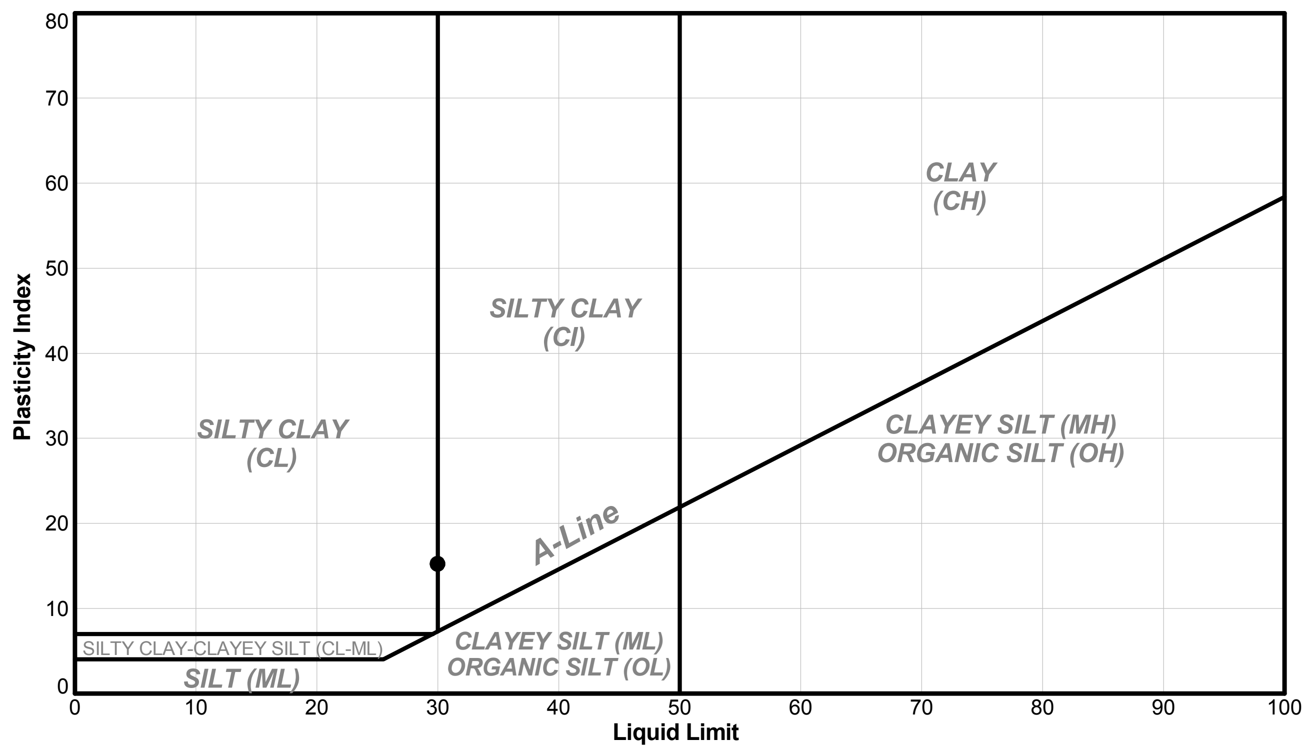
Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

ID: 19-52TP
Sample No.: 29690
Depth Interval (m): 1.10 to 1.30
Lab Schedule No.:

Other Remarks: **N/A**

Test Method: A-Multi Point | **Preparation Method: Air Dried**

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-52TP	29690	1.10	1.30	56	30	15	15.0	12.6	-0.2

NP - NON-PLASTIC RESULT ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

BJ	5/1/2019	LP	5/3/2019
Tech	Date	Checked	Date

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LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

ASTM D 4318

GOLDER

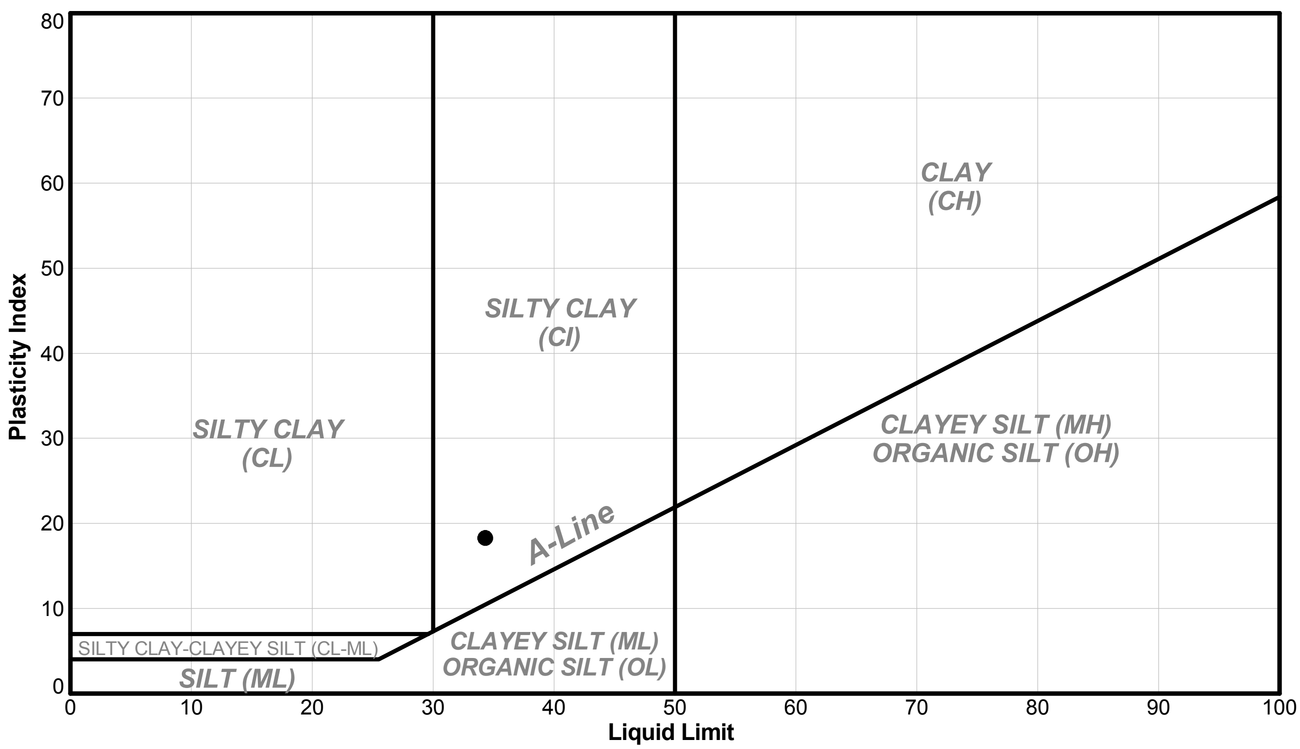
Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

ID: 19-53TP
Sample No.: 29692
Depth Interval (m): 0.50 to 0.70
Lab Schedule No.:

Other Remarks: N/A

Test Method: A-Multi Point | **Preparation Method:** Air Dried

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-53TP	29692	0.50	0.70	49	34	16	18.0	10.1	-0.3

NP - NON-PLASTIC RESULT ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

BJ	**5/2/2019**	**LP**	**5/3/2019**
Tech	Date	Checked	Date

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GOLDER

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

ASTM D 4318

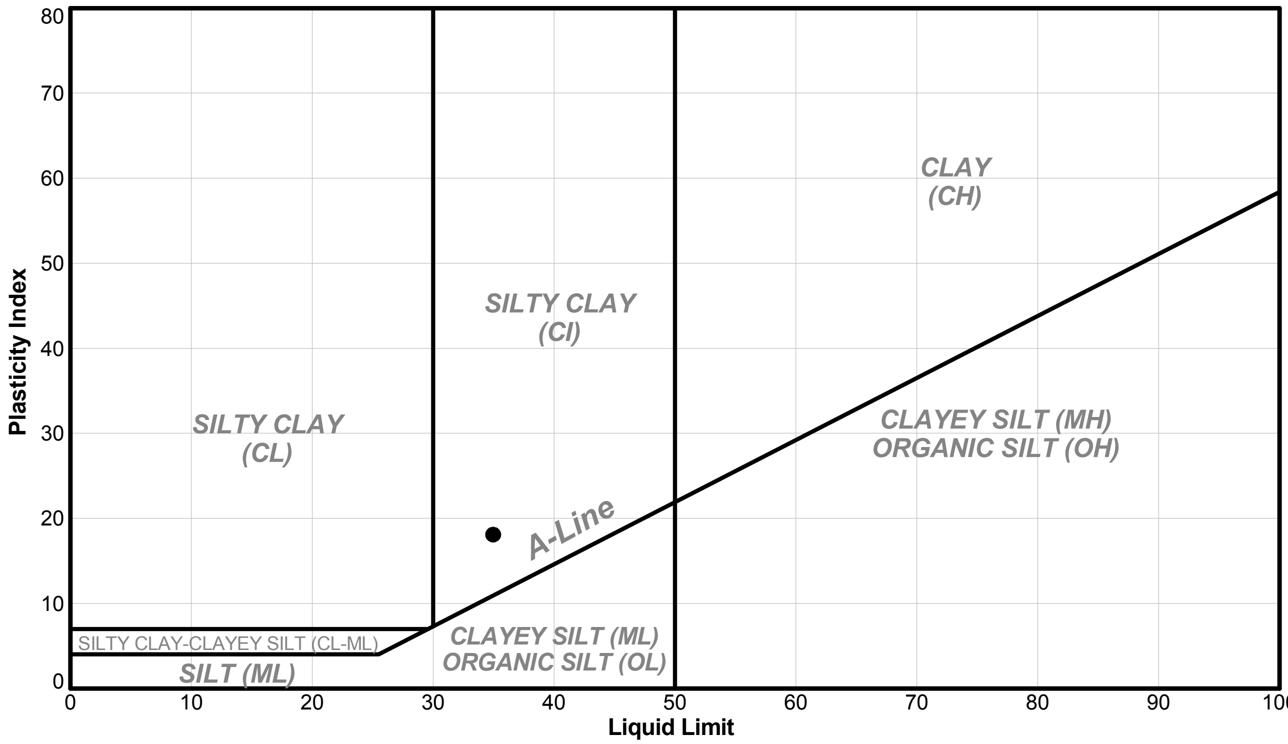
Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

ID: 19-53TP
Sample No.: 29693
Depth Interval (m): 1.70 to 1.90
Lab Schedule No.:

Other Remarks: N/A

Test Method: A-Multi Point | **Preparation Method:** Air Dried

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-53TP	29693	1.70	1.90	60	35	17	18.0	14.1	-0.2

NP - NON-PLASTIC RESULT ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

FF	5/2/2019	LP	5/3/2019
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID: Output Form:_LAB ATTERBERG CASAGRANDE (SINGLE) 2018 SJohn 22/5/19

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LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

ASTM D 4318

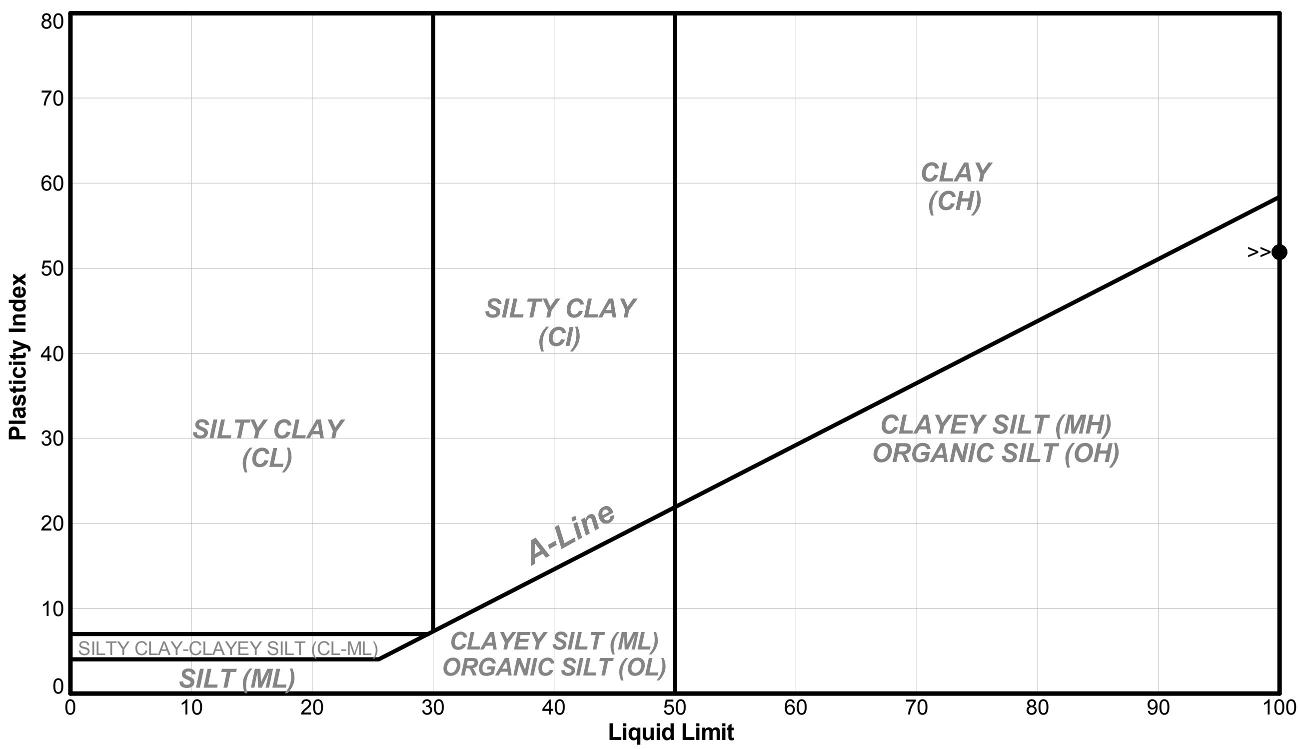
Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

ID: 19-55TP
Sample No.: 29696
Depth Interval (m): 0.00 to 0.20
Lab Schedule No.:

Other Remarks: N/A

Test Method: A-Multi Point | **Preparation Method:** Wet

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-55TP	29696	0.00	0.20	ND	180	128	52.0	157.3	0.6

NP - NON-PLASTIC RESULT ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

RG	4/30/2019	LP	5/1/2019
Tech	Date	Checked	Date

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LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

ASTM D 4318

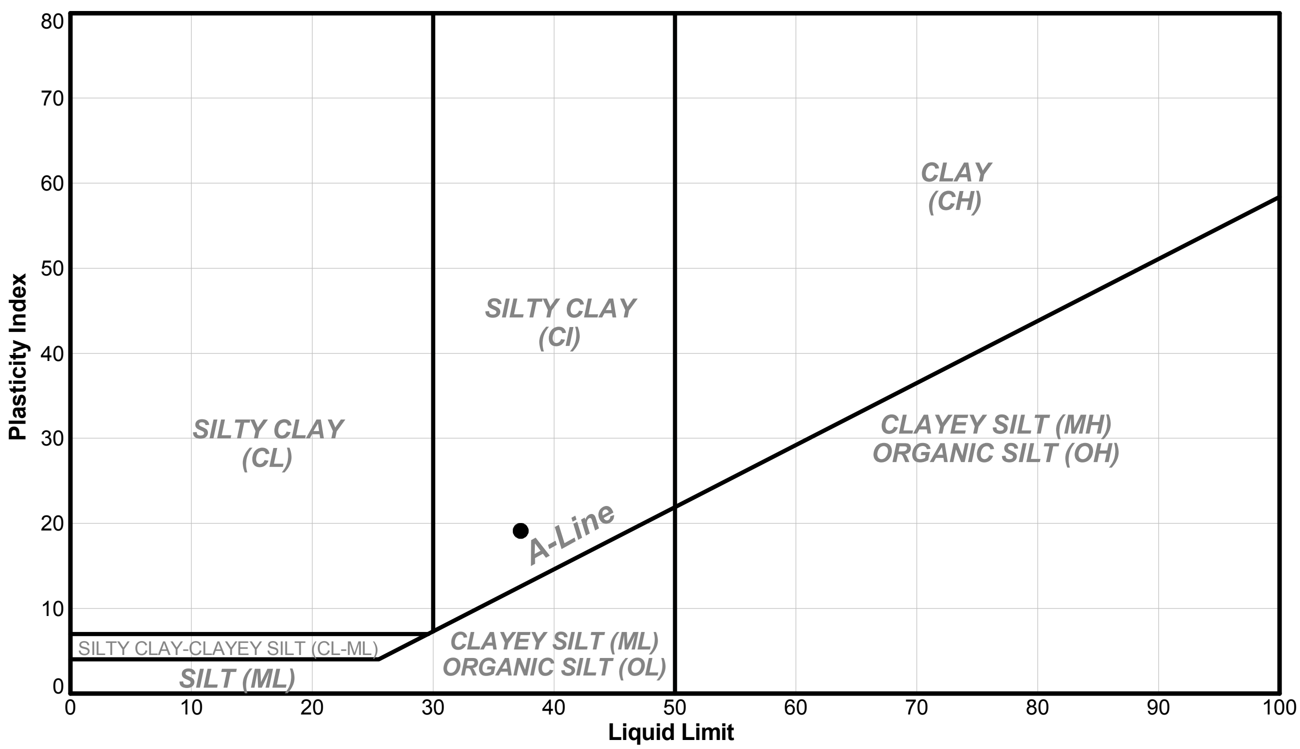
Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

ID: 19-55TP
Sample No.: 29697
Depth Interval (m): 1.10 to 1.30
Lab Schedule No.:

Other Remarks: N/A

Test Method: A-Multi Point | **Preparation Method:** Air Dried

PLASTICITY CHART



Sym.	Sample Location	Sample / Specimen Number	Depth (m)	Bottom (m)	Percent Passing #40 Sieve (%)	Liquid Limit	Plastic Limit	Plasticity Index	Natural Water Content (%)	Liquidity Index
●	19-55TP	29697	1.10	1.30	49	37	18	19.0	15.6	-0.1

NP - NON-PLASTIC RESULT ND - NOT DETERMINED

Note: The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

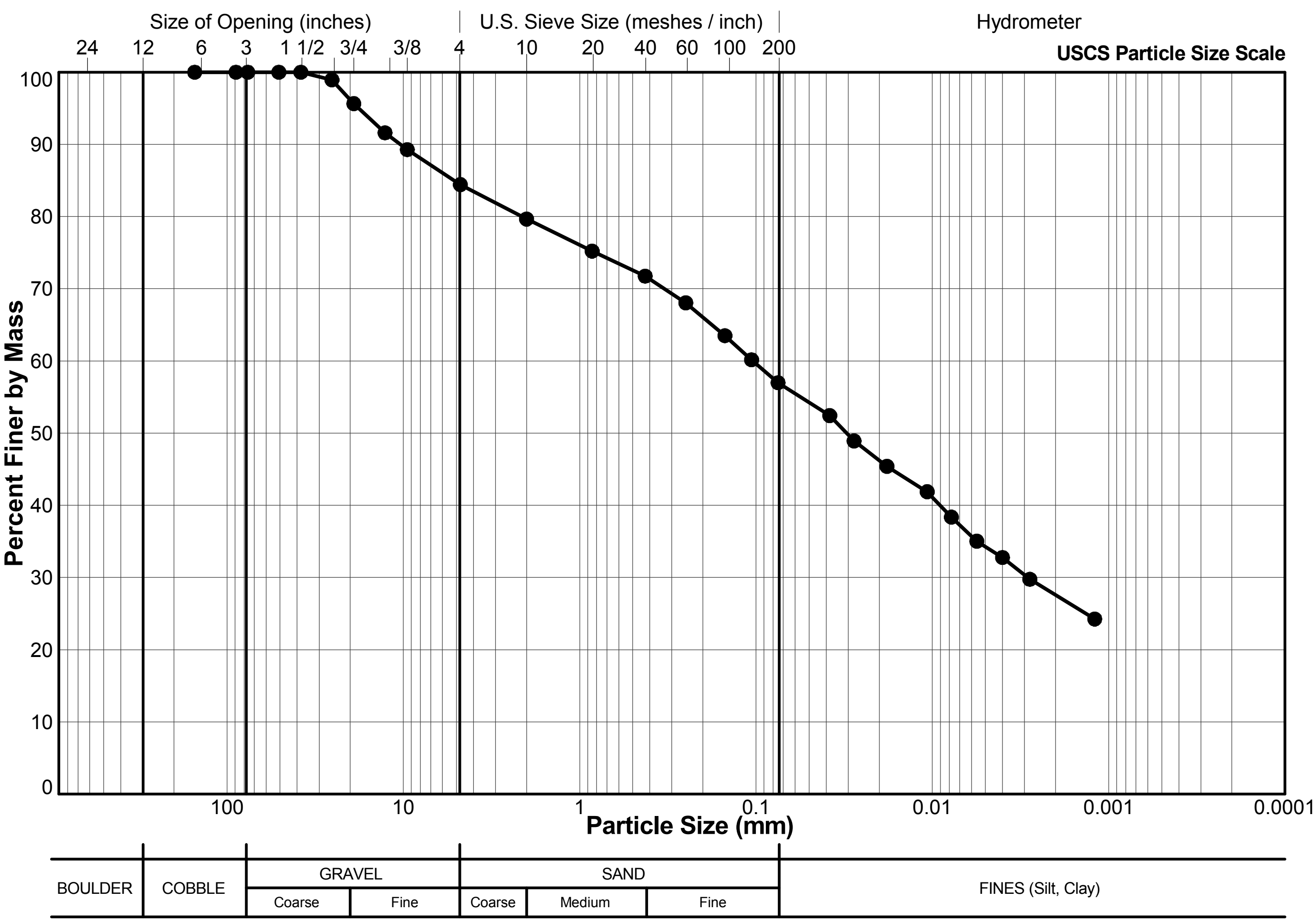
BJ	**5/2/2019**	**LP**	**5/3/2019**
Tech	Date	Checked	Date

SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-22S
Sample No.: 29661
Depth Interval (m): 3.00 to 3.70
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		100.0
1"	25.4		98.9
3/4"	19.1		95.6
1/2"	12.7		91.6
3/8"	9.5		89.3
#4 US MESH	4.75		84.4
#10 US MESH	2		79.7
#20 US MESH	0.85		75.2
#40 US MESH	0.425		71.7
#60 US MESH	0.25		68.1
#100 US MESH	0.15		63.5
#140 US MESH	0.106		60.2
#200 US MESH	0.075		57.0
		0.0382	52.4
		0.0278	48.9
		0.0181	45.4
		0.0107	41.9
		0.0078	38.4
		0.0056	35.0
		0.0040	32.8
		0.0028	29.8
		0.0012	24.2

DC	**3/13/2019**	**LP**	**3/27/2019**
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2191 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 2/4/19

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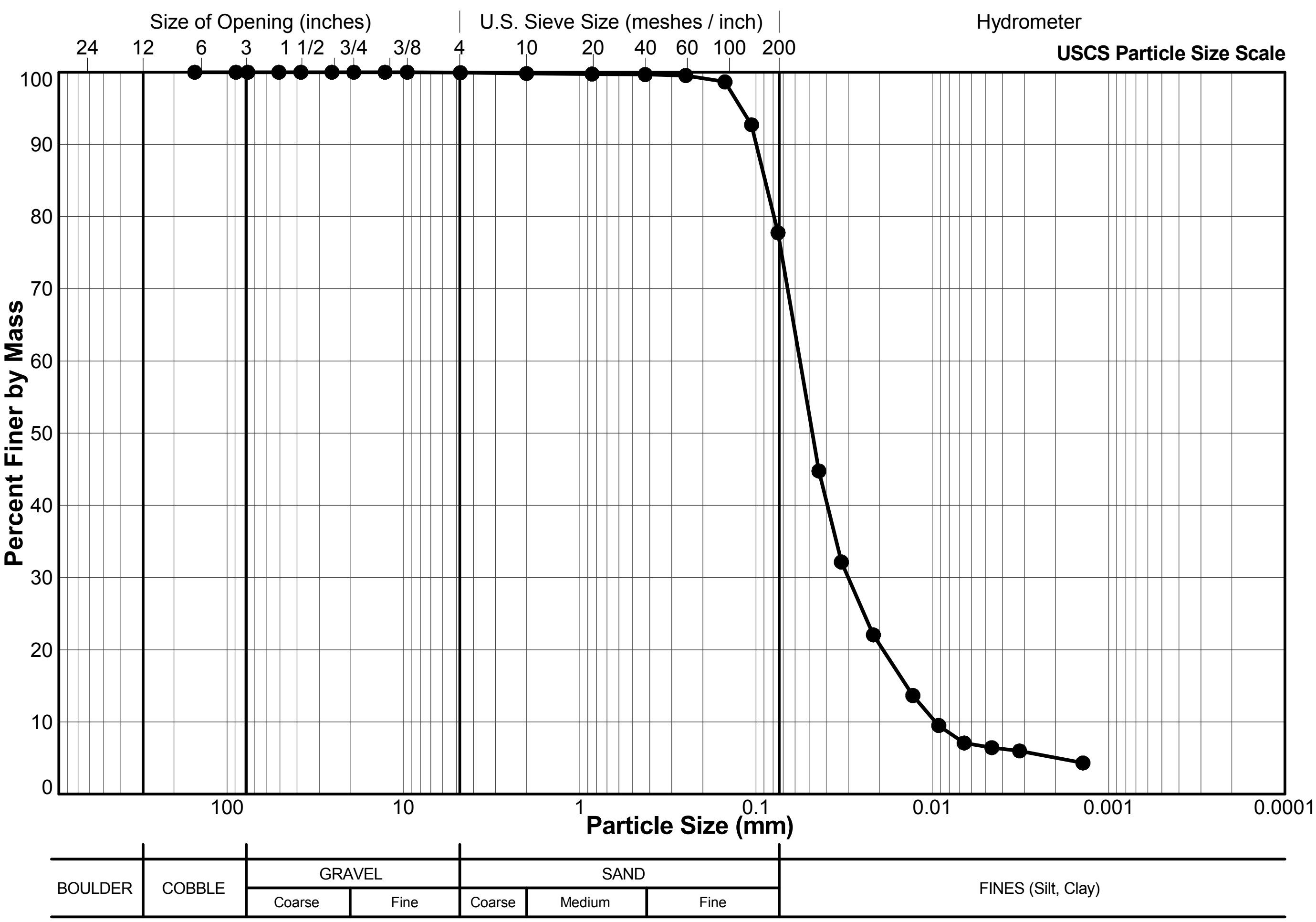
SUMMARY OF PARTICLE SIZE DISTRIBUTION

GOLDER

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-22S
Sample No.: 29663
Depth Interval (m): 10.70 to 11.30
Lab Schedule No.:



Legend

Sieve Size (USS)	Sieve Size (mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		100.0
1"	25.4		100.0
3/4"	19.1		100.0
1/2"	12.7		100.0
3/8"	9.5		100.0
#4 US MESH	4.75		99.9
#10 US MESH	2		99.8
#20 US MESH	0.85		99.7
#40 US MESH	0.425		99.7
#60 US MESH	0.25		99.5
#100 US MESH	0.15		98.7
#140 US MESH	0.106		92.7
#200 US MESH	0.075		77.8
		0.0440	44.7
		0.0328	32.1
		0.0216	22.1
		0.0129	13.7
		0.0092	9.5
		0.0066	7.1
		0.0046	6.4
		0.0032	6.0
		0.0014	4.3

DC	**3/13/2019**	**LP**	**3/27/2019**
Tech	Date	Checked	Date

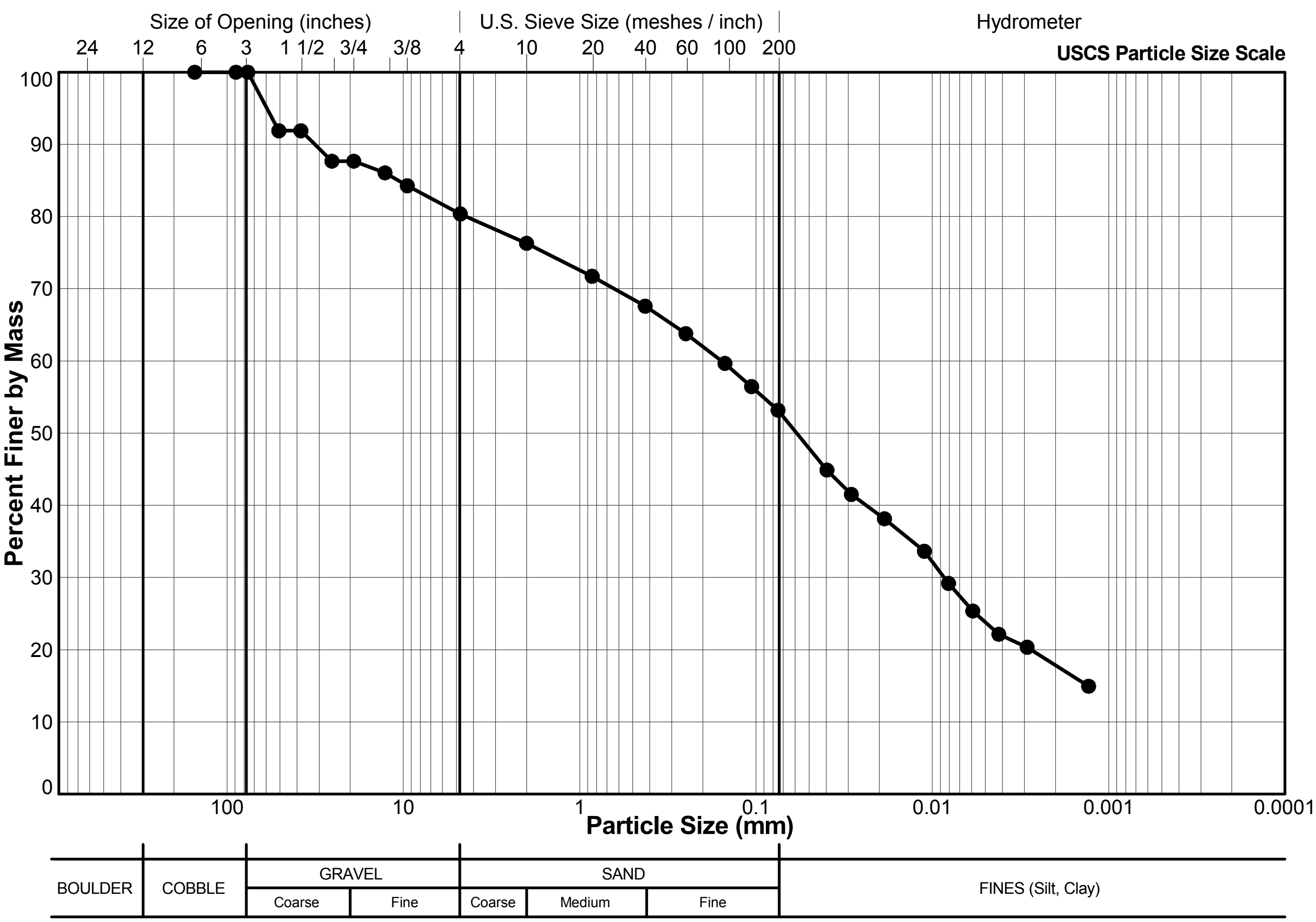
National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2191 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 2/4/19

SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-22S
Sample No.: 29665
Depth Interval (m): 16.20 to 16.80
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		91.9
1 1/2"	38.1		91.9
1"	25.4		87.7
3/4"	19.1		87.7
1/2"	12.7		86.1
3/8"	9.5		84.3
#4 US MESH	4.75		80.4
#10 US MESH	2		76.3
#20 US MESH	0.85		71.7
#40 US MESH	0.425		67.6
#60 US MESH	0.25		63.8
#100 US MESH	0.15		59.7
#140 US MESH	0.106		56.4
#200 US MESH	0.075		53.2
		0.0396	44.9
		0.0288	41.5
		0.0187	38.1
		0.0111	33.6
		0.0081	29.2
		0.0059	25.4
		0.0042	22.1
		0.0029	20.3
		0.0013	14.9

DC	**3/13/2019**	**LP**	**3/27/2019**
Tech	Date	Checked	Date

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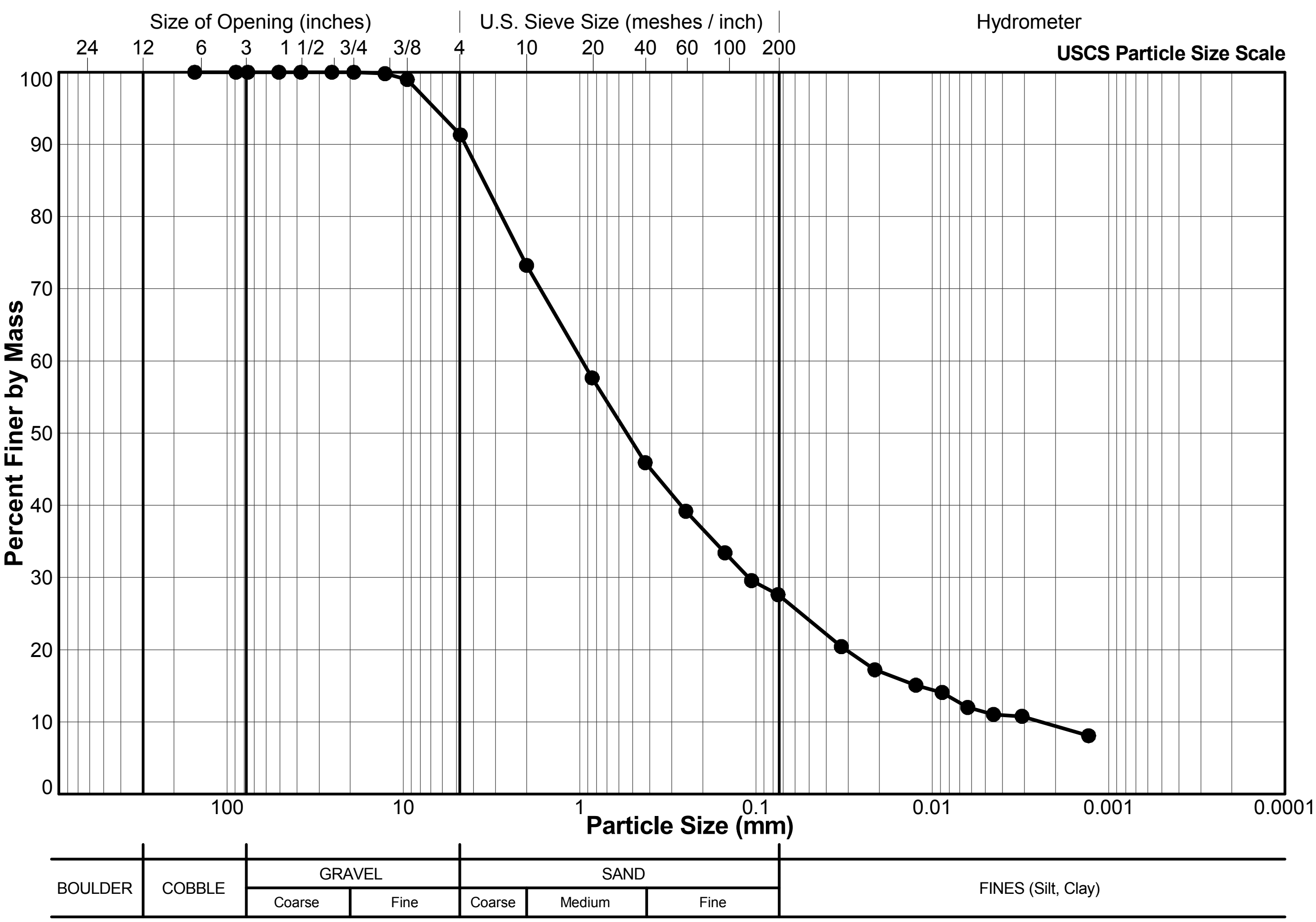
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-22S
Sample No.: 29666
Depth Interval (m): 18.90 to 19.50
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		100.0
1"	25.4		100.0
3/4"	19.1		100.0
1/2"	12.7		99.8
3/8"	9.5		99.0
#4 US MESH	4.75		91.3
#10 US MESH	2		73.2
#20 US MESH	0.85		57.7
#40 US MESH	0.425		45.9
#60 US MESH	0.25		39.2
#100 US MESH	0.15		33.4
#140 US MESH	0.106		29.6
#200 US MESH	0.075		27.6
		0.0328	20.4
		0.0212	17.2
		0.0124	15.1
		0.0088	14.1
		0.0063	12.0
		0.0045	11.0
		0.0031	10.8
		0.0013	8.1

DC	3/13/2019	LP	3/27/2019
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2191 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 2/4/19

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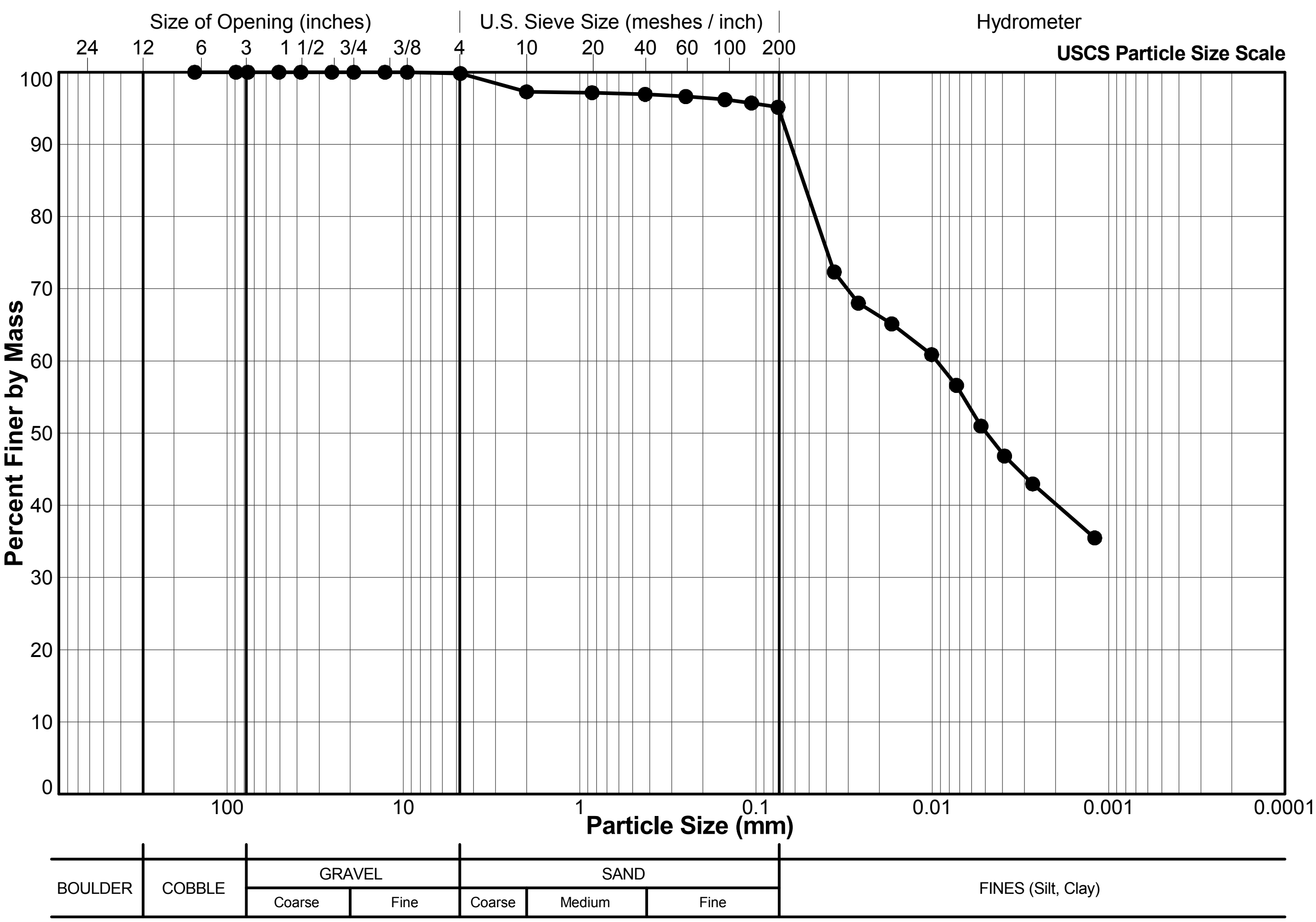
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-22S
Sample No.: 29668
Depth Interval (m): 26.20 to 26.80
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		100.0
1"	25.4		100.0
3/4"	19.1		100.0
1/2"	12.7		100.0
3/8"	9.5		100.0
#4 US MESH	4.75		99.8
#10 US MESH	2		97.3
#20 US MESH	0.85		97.2
#40 US MESH	0.425		96.9
#60 US MESH	0.25		96.6
#100 US MESH	0.15		96.2
#140 US MESH	0.106		95.7
#200 US MESH	0.075		95.1
		0.0360	72.3
		0.0263	68.0
		0.0170	65.1
		0.0101	60.9
		0.0073	56.6
		0.0053	51.0
		0.0039	46.8
		0.0027	43.0
		0.0012	35.5

DC	3/13/2019	LP	3/27/2019
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2191 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 2/4/19

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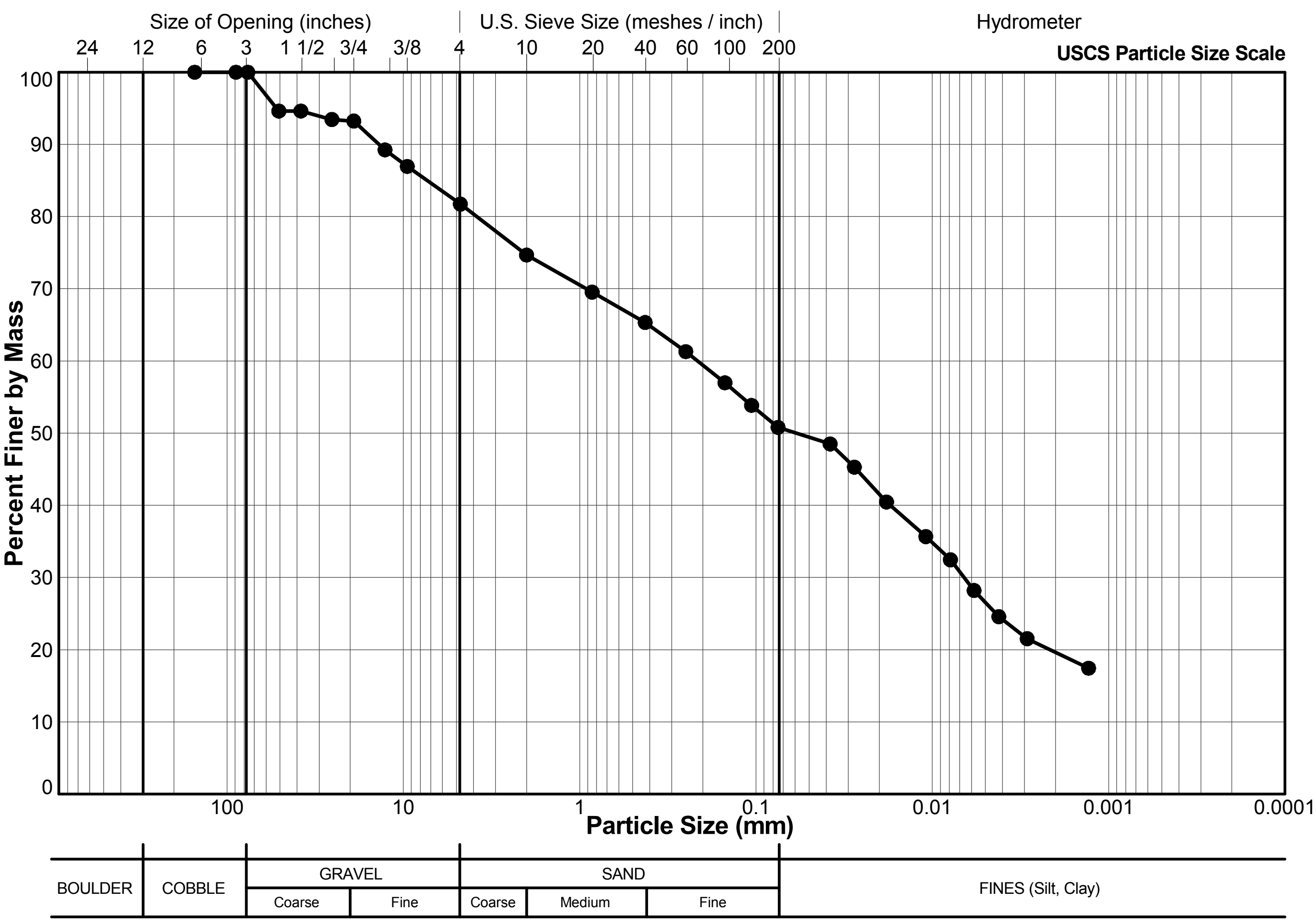
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-23S
Sample No.: 29676
Depth Interval (m): 1.10 to 1.50
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		94.6
1 1/2"	38.1		94.6
1"	25.4		93.5
3/4"	19.1		93.2
1/2"	12.7		89.2
3/8"	9.5		86.9
#4 US MESH	4.75		81.7
#10 US MESH	2		74.7
#20 US MESH	0.85		69.5
#40 US MESH	0.425		65.3
#60 US MESH	0.25		61.3
#100 US MESH	0.15		57.0
#140 US MESH	0.106		53.8
#200 US MESH	0.075		50.8
		0.0380	48.5
		0.0277	45.3
		0.0182	40.5
		0.0109	35.7
		0.0079	32.5
		0.0058	28.2
		0.0042	24.6
		0.0029	21.5
		0.0013	17.4

DC/PE	**4/30/2019**	**LP**	**5/1/2019**
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2191 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 22/5/19

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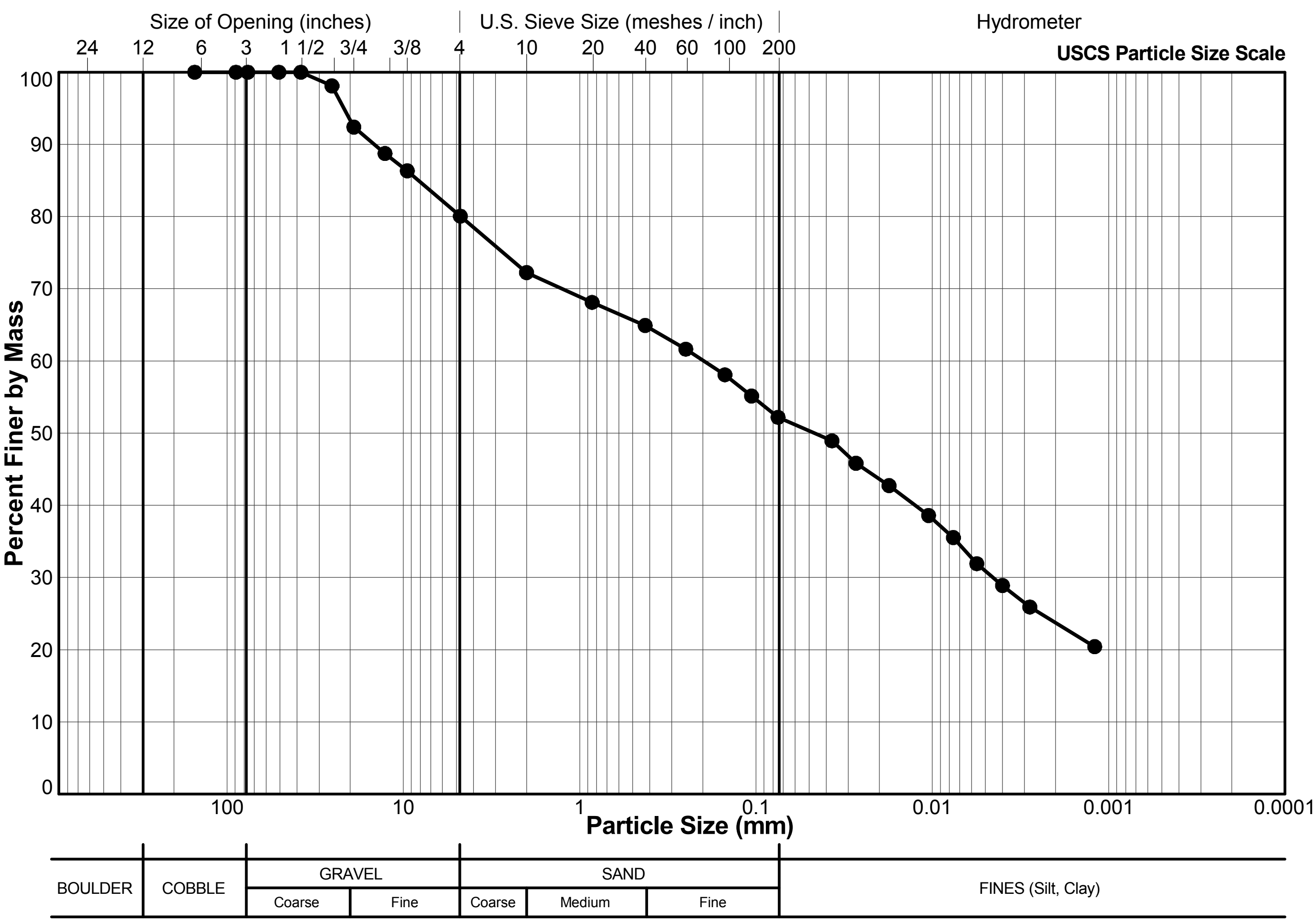
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-24S
Sample No.: 29682
Depth Interval (m): 7.00 to 7.60
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		100.0
1"	25.4		98.1
3/4"	19.1		92.4
1/2"	12.7		88.7
3/8"	9.5		86.3
#4 US MESH	4.75		80.1
#10 US MESH	2		72.2
#20 US MESH	0.85		68.1
#40 US MESH	0.425		64.9
#60 US MESH	0.25		61.6
#100 US MESH	0.15		58.1
#140 US MESH	0.106		55.1
#200 US MESH	0.075		52.2
		0.0371	48.9
		0.0271	45.8
		0.0176	42.7
		0.0105	38.6
		0.0076	35.5
		0.0056	31.9
		0.0040	28.9
		0.0028	25.9
		0.0012	20.4

DC/PE	4/30/2019	LP	5/1/2019
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2191 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 22/5/19

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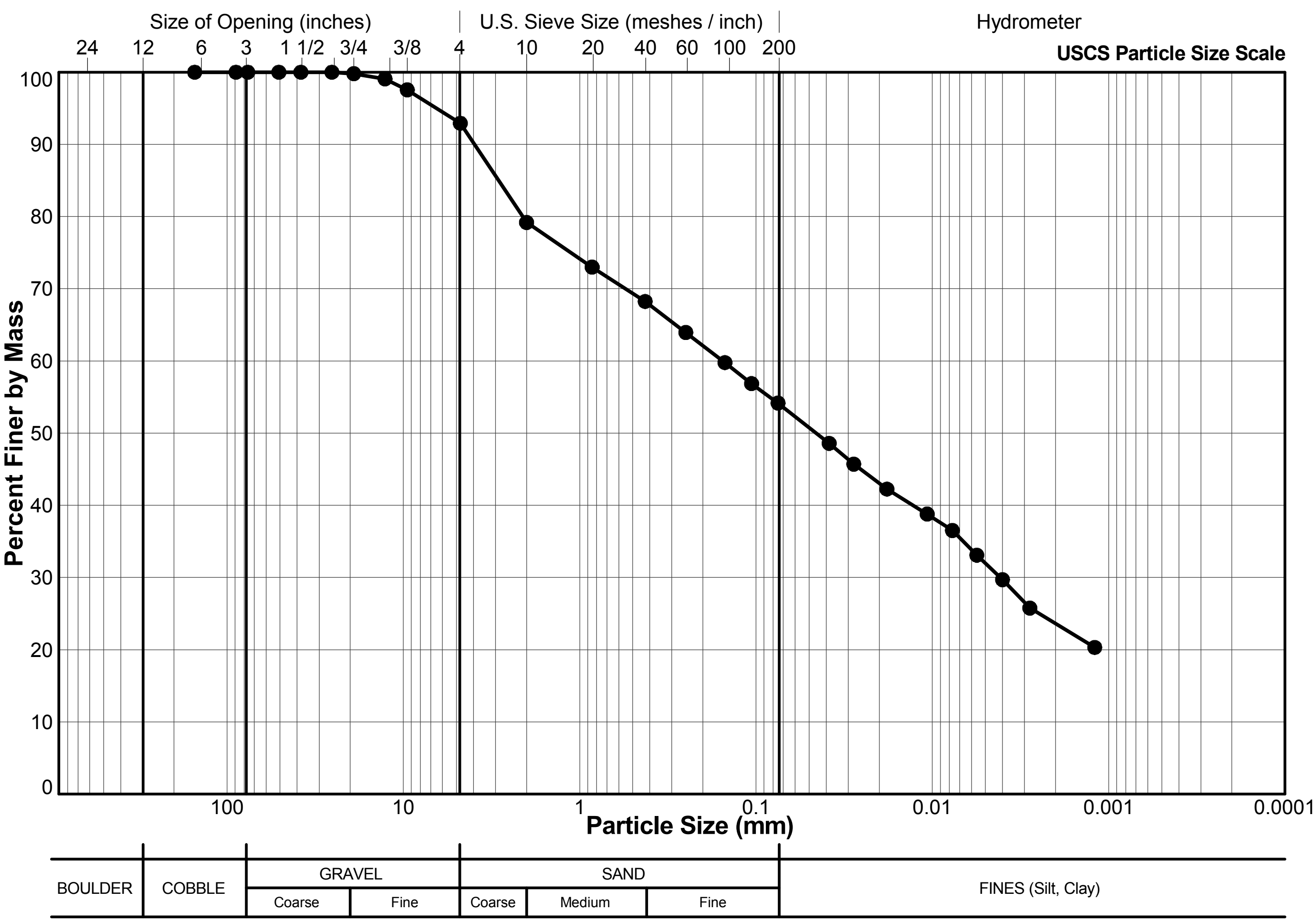
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-24S
Sample No.: 29685
Depth Interval (m): 16.20 to 16.80
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		100.0
1"	25.4		100.0
3/4"	19.1		99.8
1/2"	12.7		99.1
3/8"	9.5		97.6
#4 US MESH	4.75		92.9
#10 US MESH	2		79.2
#20 US MESH	0.85		73.0
#40 US MESH	0.425		68.2
#60 US MESH	0.25		63.9
#100 US MESH	0.15		59.8
#140 US MESH	0.106		56.9
#200 US MESH	0.075		54.2
		0.0385	48.6
		0.0279	45.7
		0.0181	42.2
		0.0107	38.8
		0.0077	36.5
		0.0056	33.1
		0.0040	29.7
		0.0028	25.8
		0.0012	20.3

DC/PE	**4/30/2019**	**LP**	**5/1/2019**
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2191 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 22/5/19

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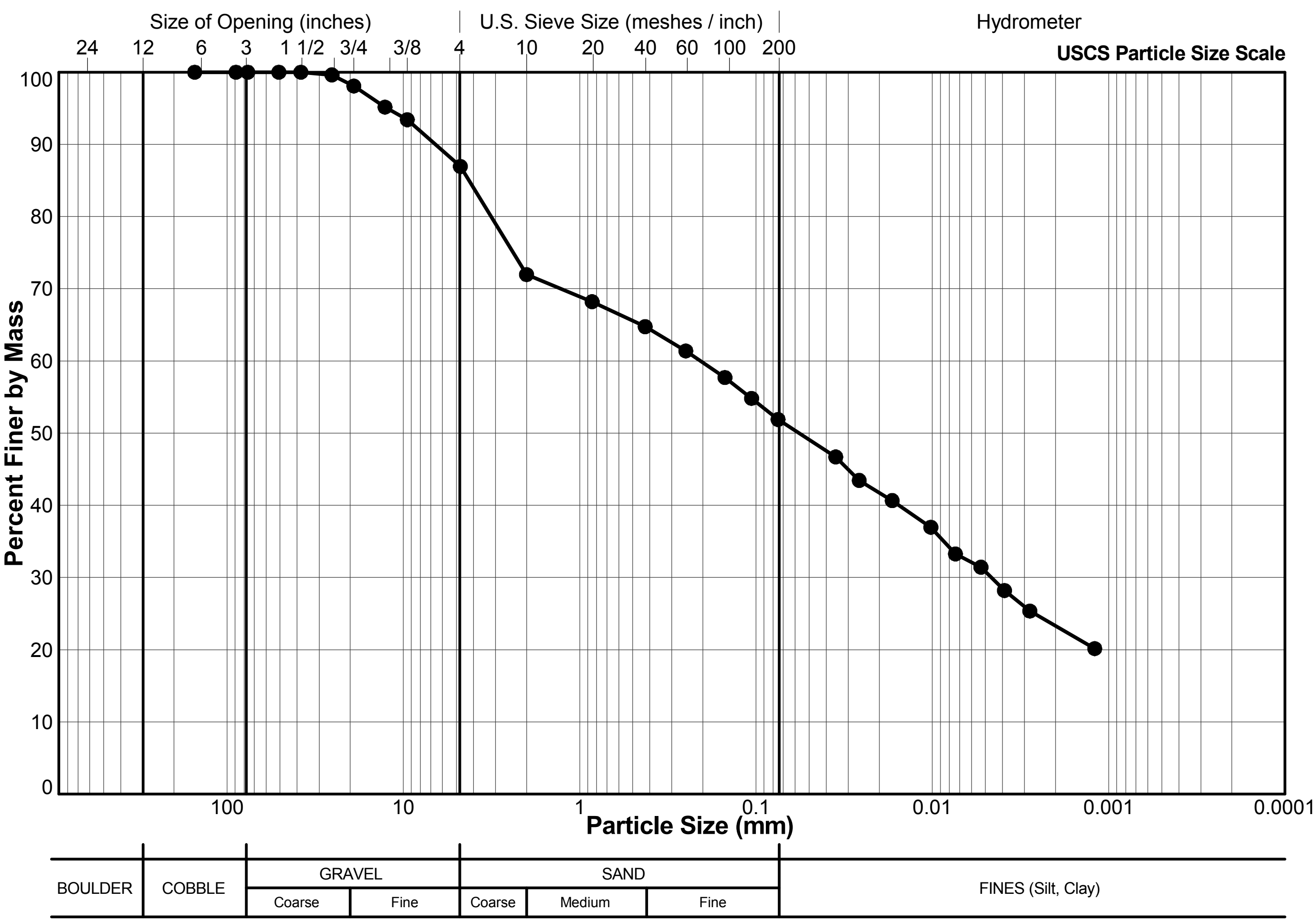
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-25S
Sample No.: 29689
Depth Interval (m): 8.20 to 8.80
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		100.0
1"	25.4		99.6
3/4"	19.1		98.1
1/2"	12.7		95.2
3/8"	9.5		93.4
#4 US MESH	4.75		86.9
#10 US MESH	2		72.0
#20 US MESH	0.85		68.2
#40 US MESH	0.425		64.8
#60 US MESH	0.25		61.4
#100 US MESH	0.15		57.7
#140 US MESH	0.106		54.8
#200 US MESH	0.075		51.9
		0.0353	46.7
		0.0260	43.4
		0.0169	40.7
		0.0102	37.0
		0.0074	33.3
		0.0053	31.4
		0.0039	28.2
		0.0028	25.4
		0.0012	20.2

DC/PE	5/2/2019	LP	5/6/2019
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2191 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 22/5/19

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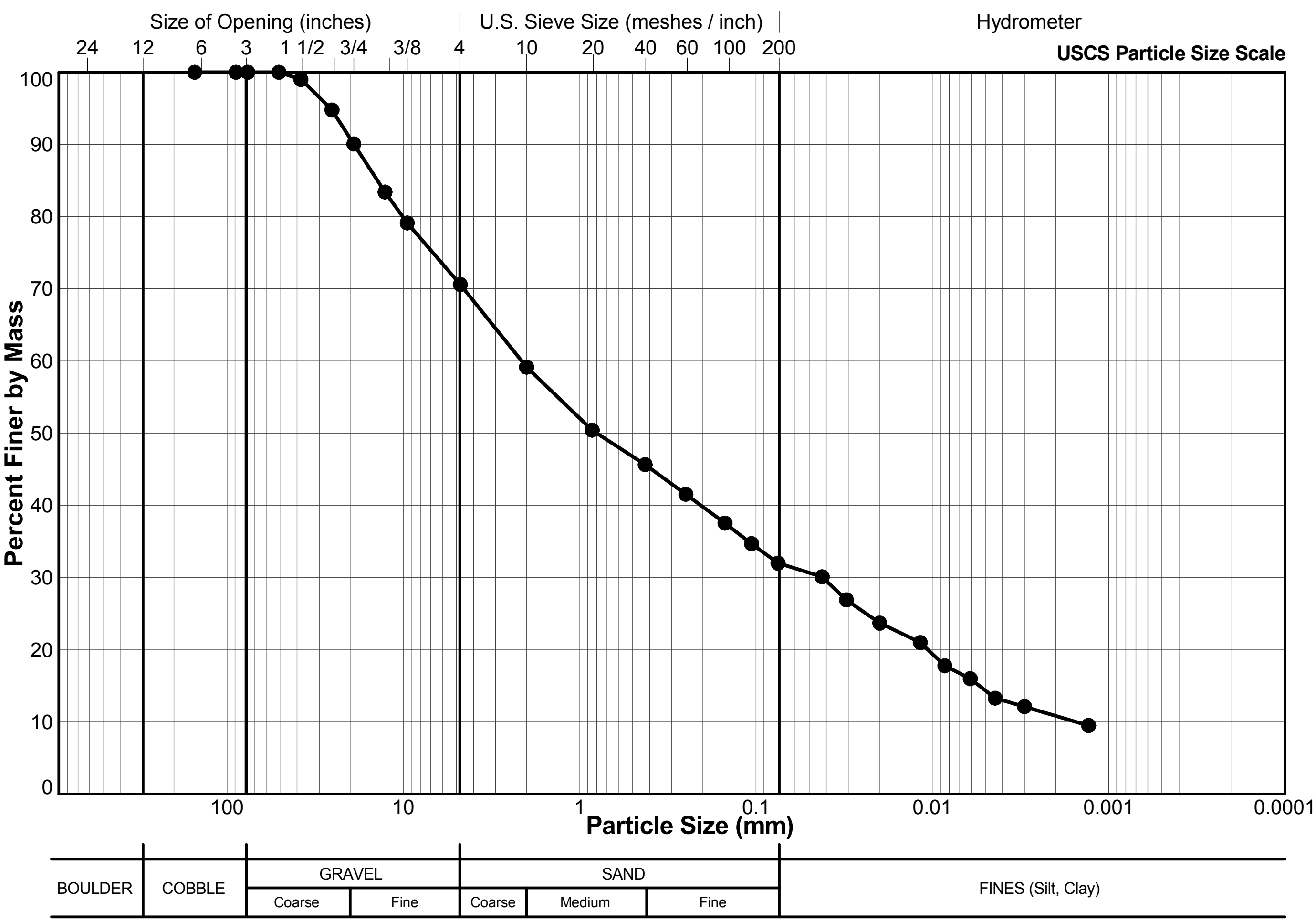
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-48TP
Sample No.: 29669
Depth Interval (m): 0.50 to 0.70
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		99.0
1"	25.4		94.8
3/4"	19.1		90.1
1/2"	12.7		83.4
3/8"	9.5		79.1
#4 US MESH	4.75		70.6
#10 US MESH	2		59.1
#20 US MESH	0.85		50.4
#40 US MESH	0.425		45.6
#60 US MESH	0.25		41.5
#100 US MESH	0.15		37.5
#140 US MESH	0.106		34.7
#200 US MESH	0.075		32.0
		0.0422	30.1
		0.0307	26.9
		0.0199	23.7
		0.0117	21.0
		0.0085	17.8
		0.0061	16.0
		0.0044	13.3
		0.0030	12.1
		0.0013	9.5

DC/PE	4/30/2019	LP	5/1/2019
Tech	Date	Checked	Date

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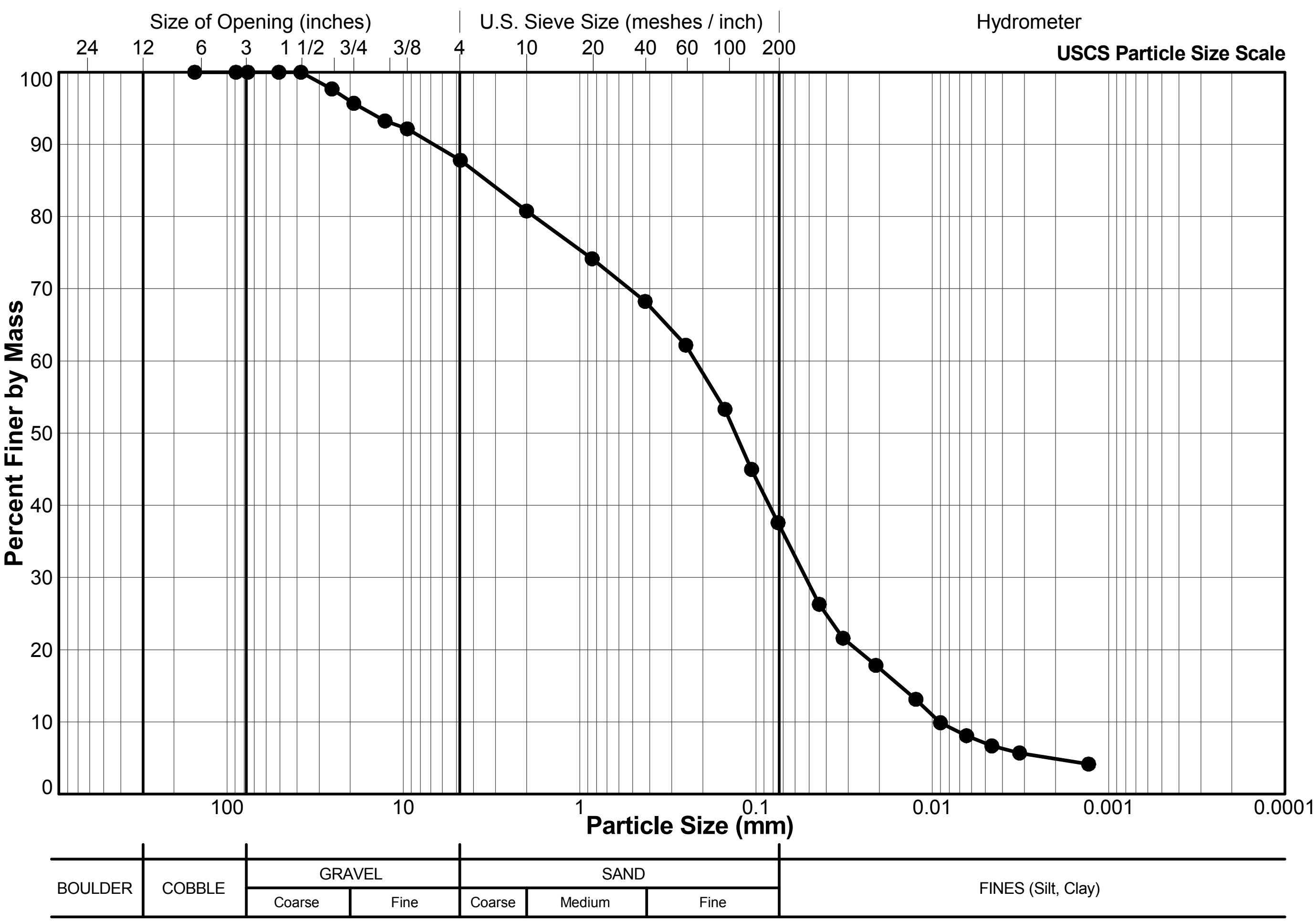
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-49TP
Sample No.: 29672
Depth Interval (m): 0.00 to 0.20
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		100.0
1"	25.4		97.7
3/4"	19.1		95.7
1/2"	12.7		93.2
3/8"	9.5		92.2
#4 US MESH	4.75		87.8
#10 US MESH	2		80.8
#20 US MESH	0.85		74.2
#40 US MESH	0.425		68.2
#60 US MESH	0.25		62.2
#100 US MESH	0.15		53.3
#140 US MESH	0.106		45.0
#200 US MESH	0.075		37.6
		0.0438	26.3
		0.0321	21.6
		0.0209	17.8
		0.0124	13.1
		0.0090	9.9
		0.0064	8.1
		0.0046	6.7
		0.0032	5.7
		0.0013	4.2

DC/PE	**5/2/2019**	**LP**	**5/6/2019**
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2191 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 22/5/19

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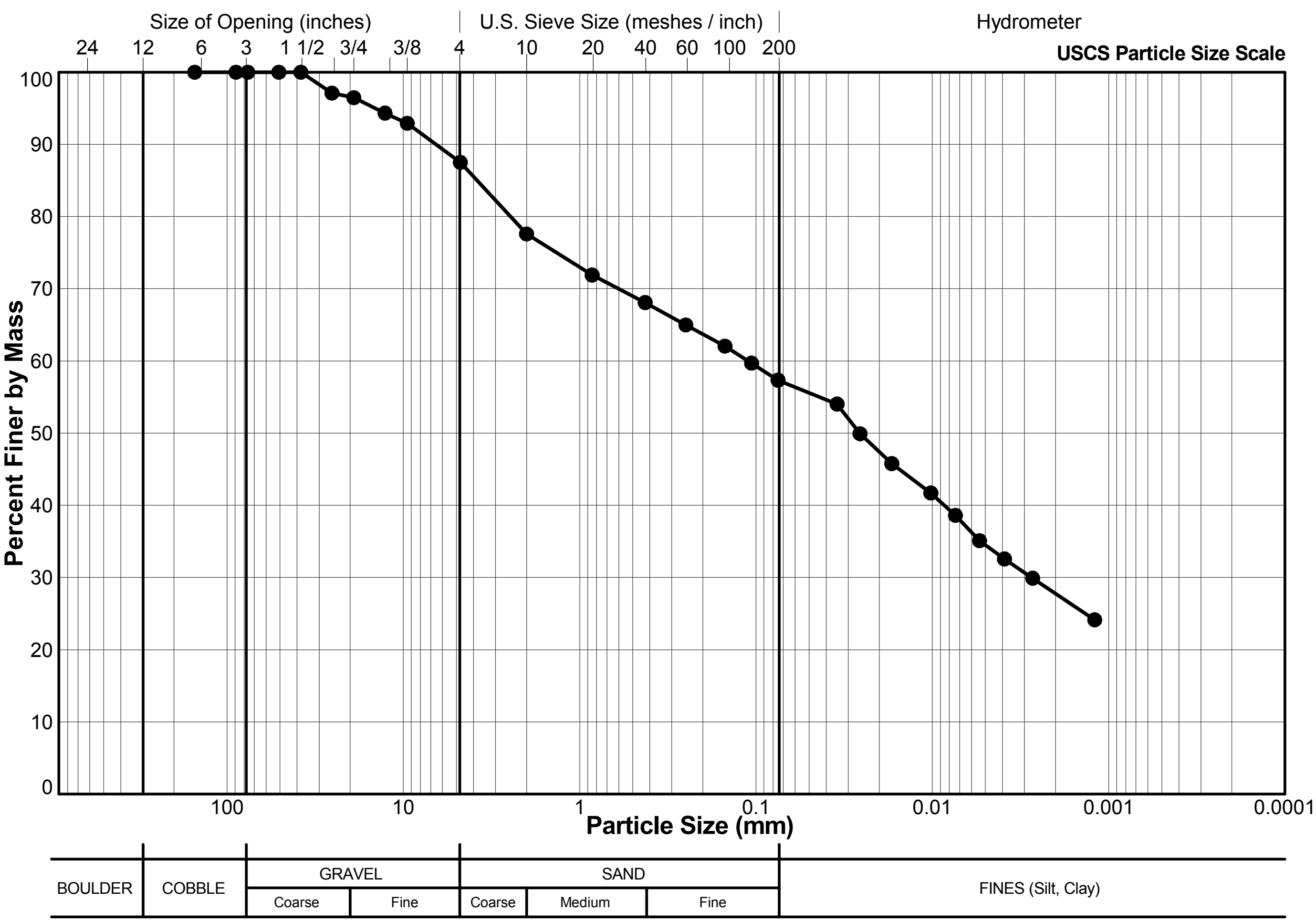
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-49TP
Sample No.: 29674
Depth Interval (m): 2.90 to 3.10
Lab Schedule No.:



Legend

Sieve Size (USS)	Sieve Size (mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		100.0
1"	25.4		97.1
3/4"	19.1		96.5
1/2"	12.7		94.3
3/8"	9.5		92.9
#4 US MESH	4.75		87.5
#10 US MESH	2		77.6
#20 US MESH	0.85		71.9
#40 US MESH	0.425		68.1
#60 US MESH	0.25		65.0
#100 US MESH	0.15		62.1
#140 US MESH	0.106		59.7
#200 US MESH	0.075		57.3
		0.0347	54.0
		0.0257	49.9
		0.0170	45.8
		0.0102	41.7
		0.0074	38.6
		0.0054	35.1
		0.0039	32.6
		0.0027	29.9
		0.0012	24.1

DC/BJ	4/30/2019	LP	5/1/2019
Tech	Date	Checked	Date

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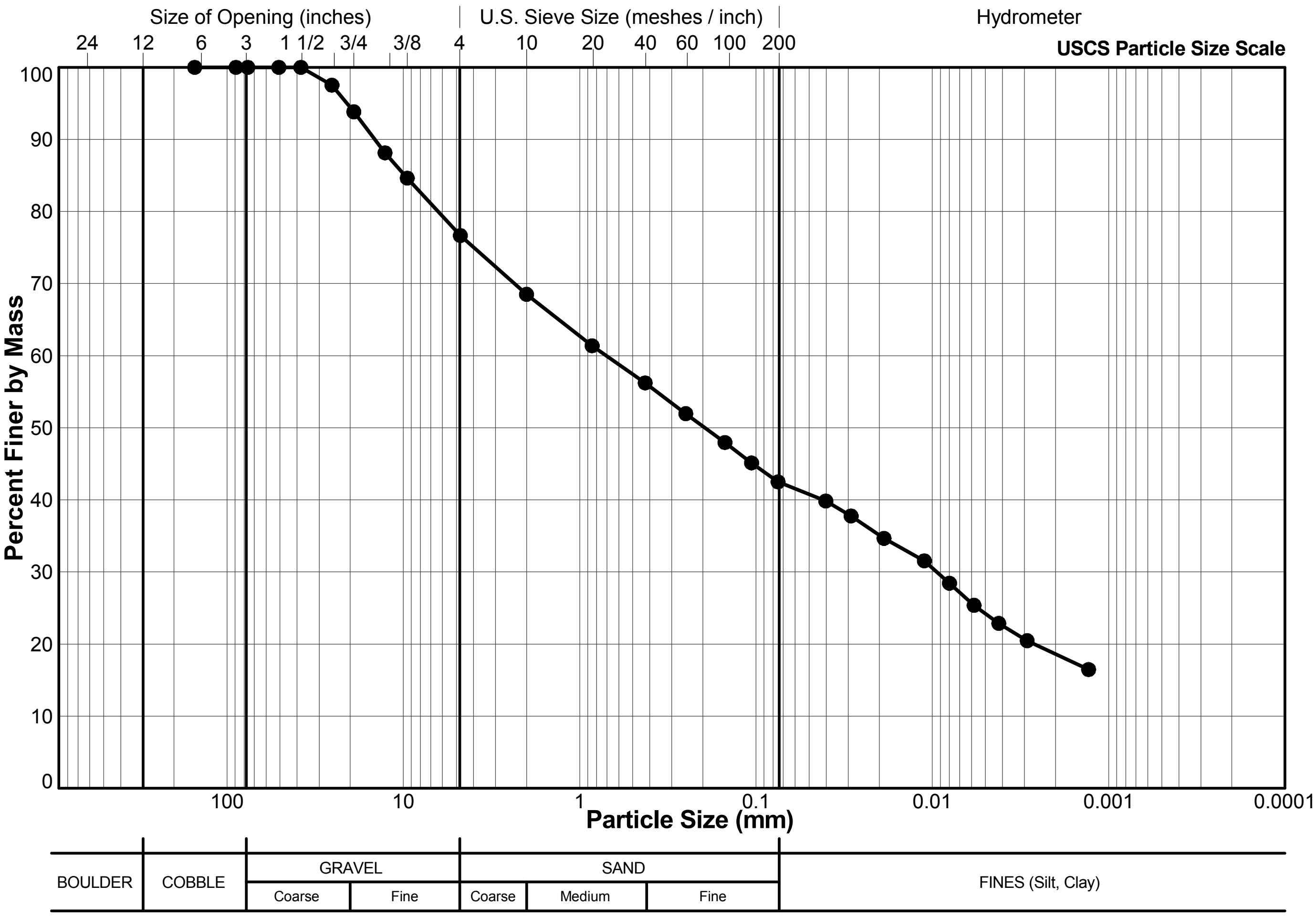
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-52TP
Sample No.: 29690
Depth Interval (m): 1.10 to 1.30
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		100.0
1"	25.4		97.5
3/4"	19.1		93.8
1/2"	12.7		88.1
3/8"	9.5		84.6
#4 US MESH	4.75		76.7
#10 US MESH	2		68.5
#20 US MESH	0.85		61.4
#40 US MESH	0.425		56.2
#60 US MESH	0.25		52.0
#100 US MESH	0.15		48.0
#140 US MESH	0.106		45.1
#200 US MESH	0.075		42.5
		0.0402	39.8
		0.0289	37.8
		0.0188	34.7
		0.0111	31.5
		0.0080	28.4
		0.0058	25.4
		0.0042	22.9
		0.0029	20.5
		0.0013	16.5

DC/PE	**4/30/2019**	**LP**	**5/1/2019**
Tech	Date	Checked	Date

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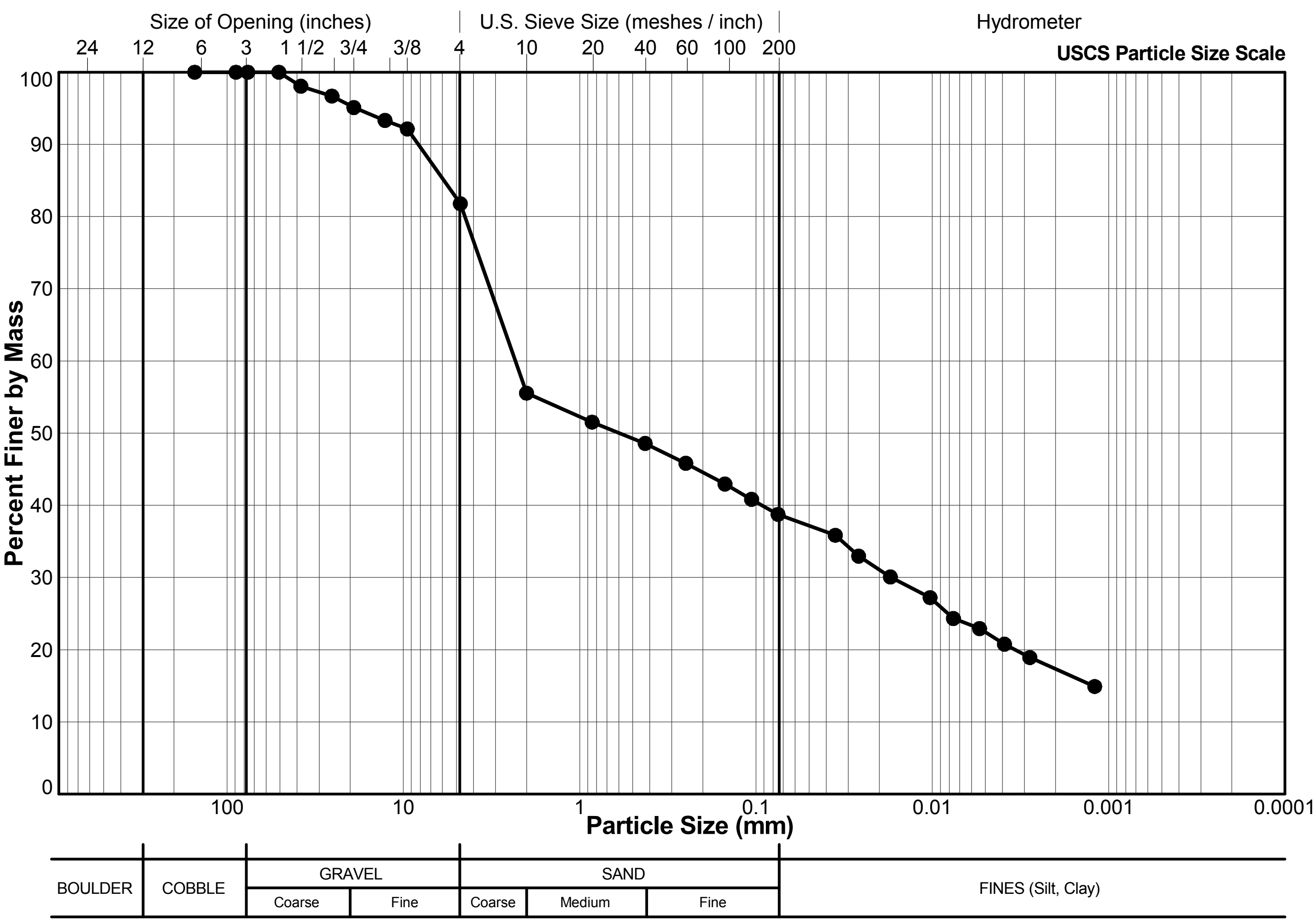
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-53TP
Sample No.: 29692
Depth Interval (m): 0.50 to 0.70
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		98.1
1"	25.4		96.7
3/4"	19.1		95.1
1/2"	12.7		93.3
3/8"	9.5		92.1
#4 US MESH	4.75		81.8
#10 US MESH	2		55.5
#20 US MESH	0.85		51.5
#40 US MESH	0.425		48.6
#60 US MESH	0.25		45.8
#100 US MESH	0.15		43.0
#140 US MESH	0.106		40.8
#200 US MESH	0.075		38.7
		0.0355	35.9
		0.0262	33.0
		0.0173	30.1
		0.0103	27.2
		0.0076	24.3
		0.0054	22.9
		0.0039	20.8
		0.0028	18.9
		0.0012	14.9

DC/PE	5/2/2019	LP	5/6/2019
Tech	Date	Checked	Date

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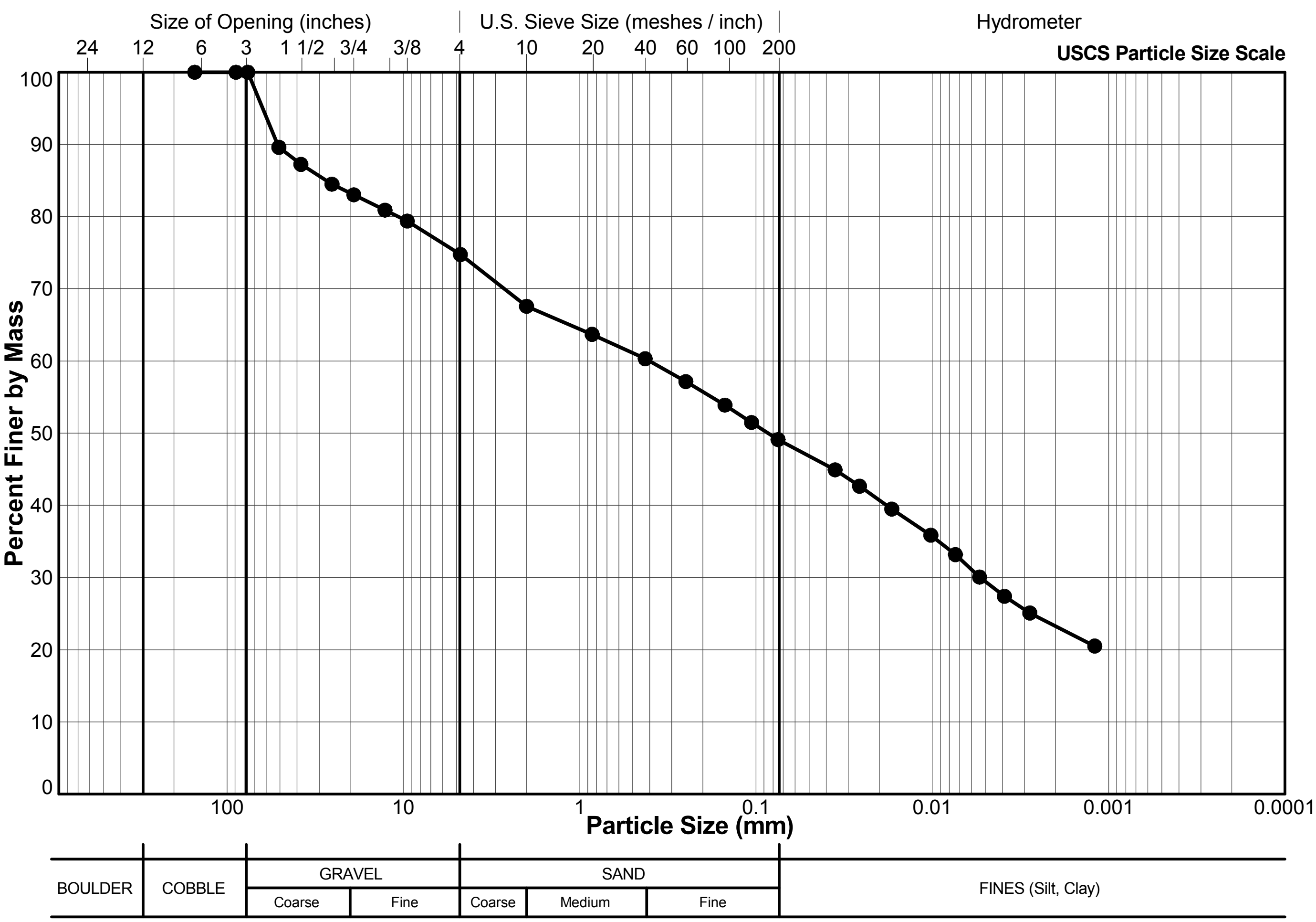
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-53TP
Sample No.: 29693
Depth Interval (m): 1.70 to 1.90
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		89.6
1 1/2"	38.1		87.2
1"	25.4		84.5
3/4"	19.1		83.0
1/2"	12.7		80.9
3/8"	9.5		79.4
#4 US MESH	4.75		74.7
#10 US MESH	2		67.6
#20 US MESH	0.85		63.7
#40 US MESH	0.425		60.3
#60 US MESH	0.25		57.1
#100 US MESH	0.15		53.9
#140 US MESH	0.106		51.5
#200 US MESH	0.075		49.1
		0.0356	44.9
		0.0259	42.7
		0.0170	39.5
		0.0102	35.9
		0.0074	33.2
		0.0054	30.1
		0.0039	27.4
		0.0028	25.1
		0.0012	20.5

DC/PE	5/2/2019	LP	5/6/2019
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2191 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 22/5/19

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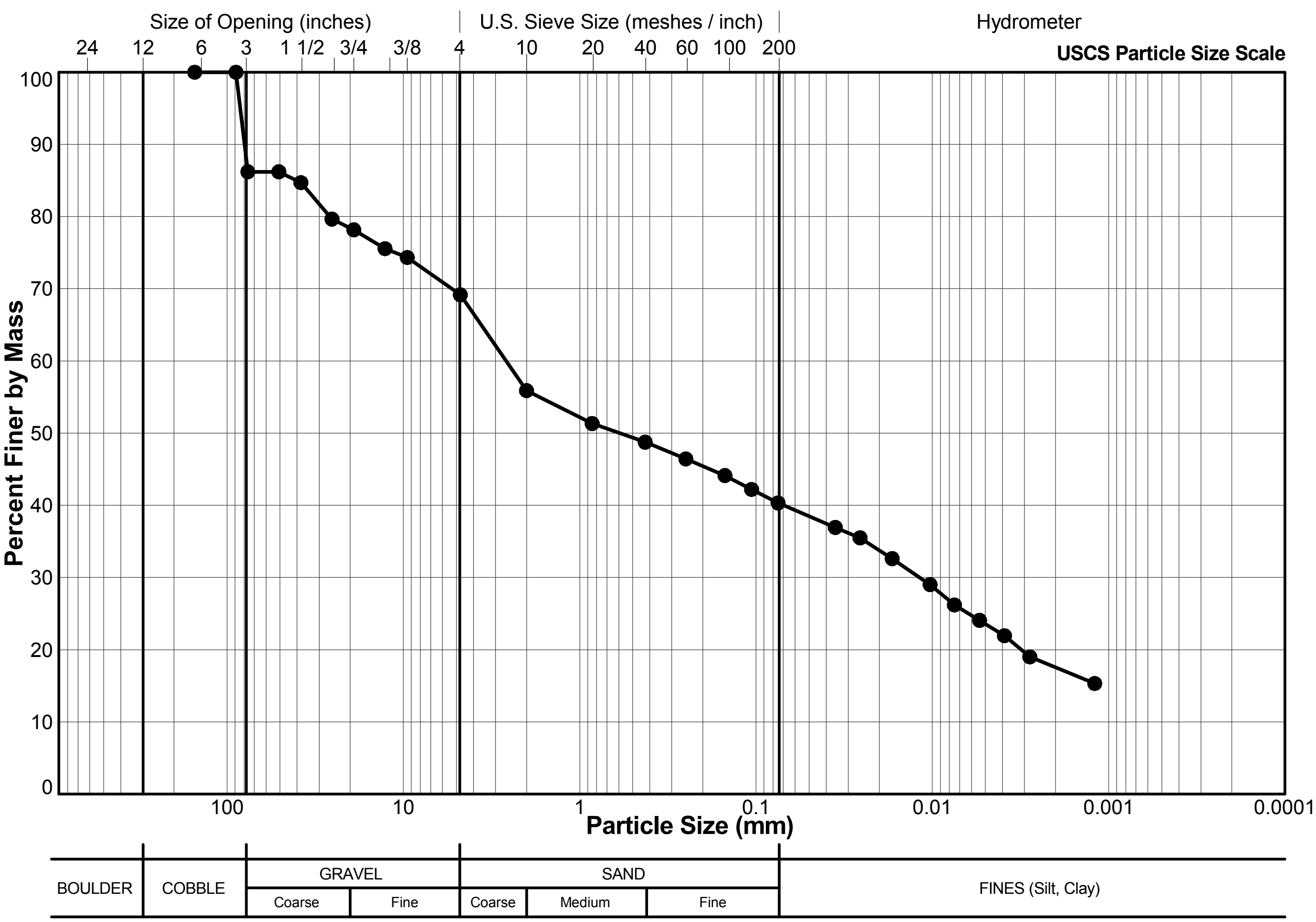
SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Telkwa Coal Ltd.
Project: Explore 0112
Location:
Project No.: 18109666 **Phase:** 2000

Sample Location: 19-55TP
Sample No.: 29697
Depth Interval (m): 1.10 to 1.30
Lab Schedule No.:



Legend

Sieve Size (USS)	(mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		86.2
2"	50.8		86.2
1 1/2"	38.1		84.7
1"	25.4		79.7
3/4"	19.1		78.2
1/2"	12.7		75.6
3/8"	9.5		74.3
#4 US MESH	4.75		69.2
#10 US MESH	2		55.9
#20 US MESH	0.85		51.3
#40 US MESH	0.425		48.7
#60 US MESH	0.25		46.4
#100 US MESH	0.15		44.1
#140 US MESH	0.106		42.2
#200 US MESH	0.075		40.3
		0.0355	36.9
		0.0257	35.5
		0.0169	32.6
		0.0103	29.0
		0.0075	26.2
		0.0054	24.1
		0.0039	21.9
		0.0028	19.0
		0.0012	15.3

DC/PE	**5/2/2019**	**LP**	**5/6/2019**
Tech	Date	Checked	Date

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Compaction Characteristics of Soil Using Standard Effort (12,000 ft-lbf/ft³ (600 kN-m/m³))

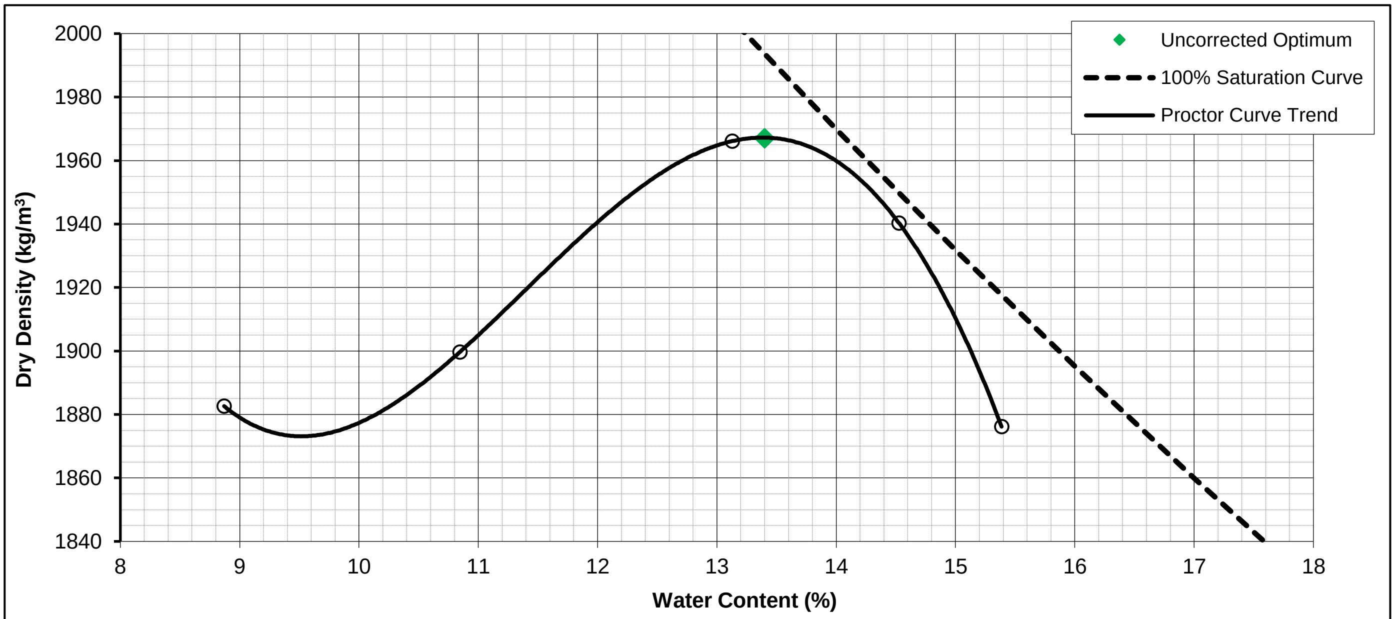
ASTM D698

Project No.:	1784620-2000	**Sample No.:**	BLK-01 & BLK-02
Project:	Telkwa Coal Limited	**Sample Depth (m):**	5.70 - 10.50
Location:	Prince Rupert, BC	**Sample Source:**	T18-05S
Client:	SRK Consulting Ltd.	**Sampled By:**	Client
Lab ID No:	43	**Date sampled:**	Not Given

Effort Type:	Standard	**Preparation Method:**	Moist
Test Method:	A	**As Received w (%):**	16.4
Mold Volume (cm^3):	942	**Visual Description:**	
Type of Rammer:	Manual	**Remarks:**	

ASTM D 4718 - Correction for Oversize Particles			
Oversized Fraction		*Test Fraction*	
Oversized Fraction (%):	24.2	**Max Nominal Size of Test Fraction (mm):**	4.75
G_{SC} (assumed):	2.72	**G_{SF} (assumed):**	2.72
Water Content, w (%):	1.5	**Water Content, w (%):**	13.4

Compaction Results					
Trial No.:	1	2	3	4	5
Dry Density (kg/m^3)	1883	1900	1966	1876	1940
Water Content (%):	8.9	10.8	13.1	15.4	14.5



Final Results			
Uncorrected Optimum w (%):	13.4	**Corrected Optimum w (%):**	**10.5**
Uncorrected Max Dry Density (kg/m^3)	1967	**Corrected Max Dry Density (kg/m^3)**	**2108**
Uncorrected Max Unit Weight (kN/m^3)	19.29	**Corrected Max Unit Weight (kN/m^3)**	**20.66**

The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

RG	April 25, 2018	LH	May 1, 2018
TESTED BY	DATE	CHECKED BY	DATE

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Compaction Characteristics of Soil Using Standard Effort (12,000 ft-lbf/ft³ (600 kN-m/m³))

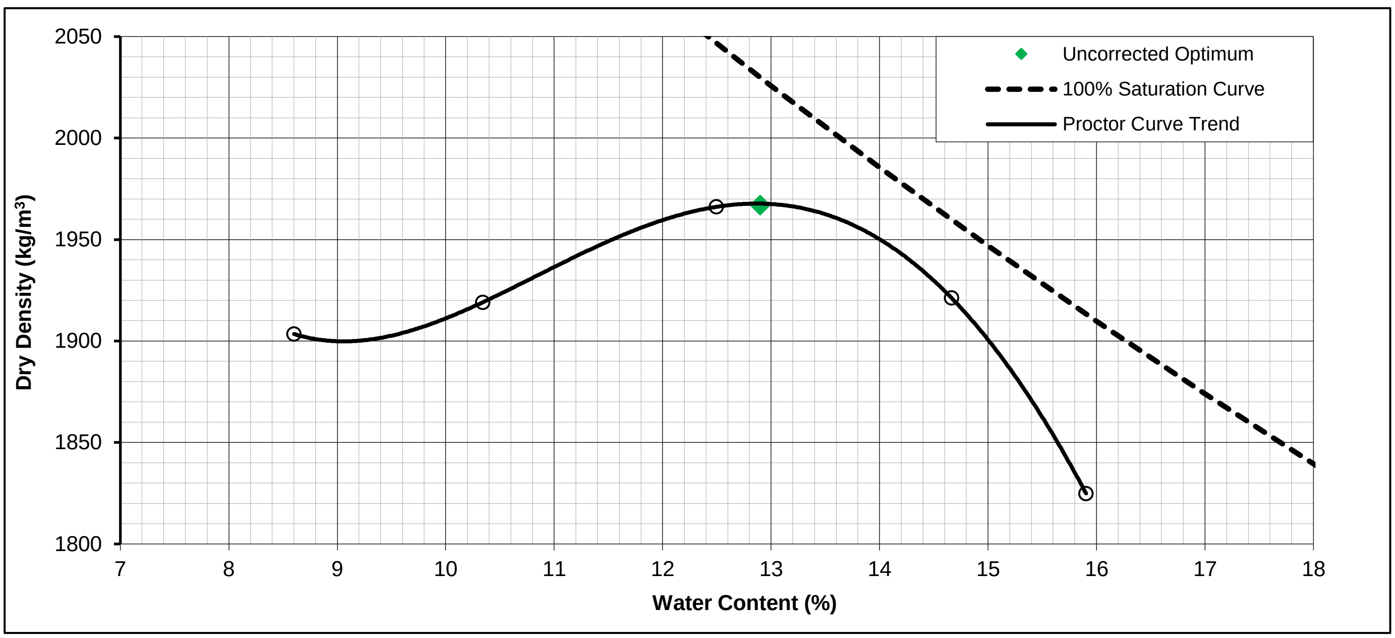
ASTM D698

Project No.:	1786980/2000	**Sample No.:**	Blk 02 & Blk 03
Project:	Telkwa Coal Limited	**Sample Depth (m):**	14.70 - 21.70
Location:	Prince Rupert, BC	**Sample Source:**	T18-07S
Client:	SRK Consulting (Canada) Inc.	**Sampled By:**	Client
Lab ID No:	43	**Date sampled:**	Not provided

Effort Type:	Standard	**Preparation Method:**	Moist
Test Method:	A	**As Received w (%):**	#DIV/0!
Mold Volume (cm^3):	940	**Visual Description:**	
Type of Rammer:	Manual	**Remarks:**	

ASTM D 4718 - Correction for Oversize Particles			
Oversized Fraction		*Test Fraction*	
Oversized Fraction (%):	26.6	**Max Nominal Size of Test Fraction (mm):**	4.75
G_{SC} (calculated):	2.75	**G_{SF} (calculated):**	2.75
Water Content, w (%):	1.5	**Water Content, w (%):**	12.9

Compaction Results					
Trial No.:	1	2	3	4	5
Dry Density (kg/m^3)	1903	1919	1966	1921	1825
Water Content (%):	8.6	10.3	12.5	14.7	15.9



Final Results			
Uncorrected Optimum w (%):	12.9	**Corrected Optimum w (%):**	**9.9**
Uncorrected Max Dry Density (kg/m^3)	1967	**Corrected Max Dry Density (kg/m^3)**	**2128**
Uncorrected Max Unit Weight (kN/m^3)	19.29	**Corrected Max Unit Weight (kN/m^3)**	**20.86**

The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

RG	April 27, 2018	LH	May 3, 2018
TESTED BY	DATE	CHECKED BY	DATE

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Compaction Characteristics of Soil Using Standard Effort (12,000 ft-lbf/ft³ (600 kN-m/m³))

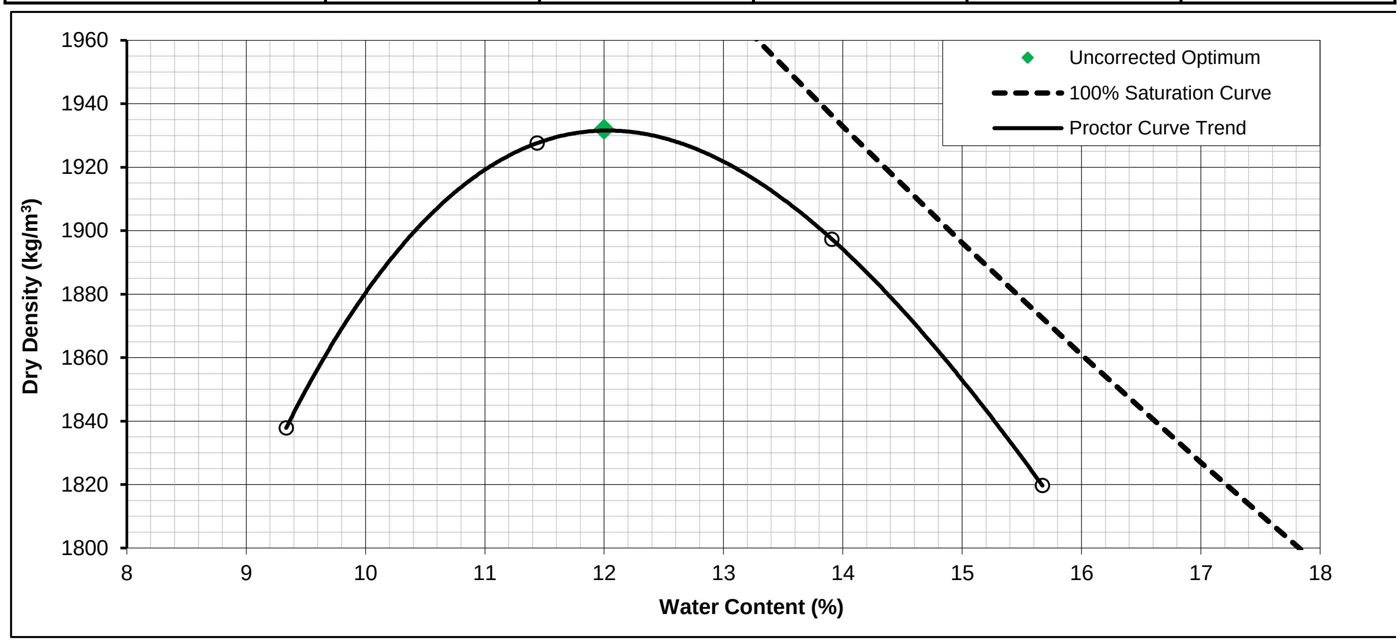
ASTM D698

Project No.:	1784620-2000	**Sample No.:**	BLK-01 & BLK-02
Project:	Telkwa Coal Limited	**Sample Depth (m):**	1.0 - 2.0
Location:	Prince Rupert, BC	**Sample Source:**	T18-07TP
Client:	SRK Consulting (Canada) Inc.	**Sampled By:**	Client
Lab ID No:	43	**Date sampled:**	Not Given

Effort Type:	Standard	**Preparation Method:**	Dry
Test Method:	A	**As Received w (%):**	11.9
Mold Volume (cm^3):	942	**Visual Description:**	
Type of Rammer:	Manual	**Remarks:**	

ASTM D 4718 - Correction for Oversize Particles			
Oversized Fraction		*Test Fraction*	
Oversized Fraction (%):	21.9	**Max Nominal Size of Test Fraction (mm):**	4.75
G_{SC} (assumed):	2.65	**G_{SF} (assumed):**	2.65
Water Content, w (%):	1.5	**Water Content, w (%):**	12.0

Compaction Results					
Trial No.:	1	2	3	4	
Dry Density (kg/m^3)	1838	1928	1897	1820	
Water Content (%):	9.3	11.4	13.9	15.7	



Final Results			
Uncorrected Optimum w (%):	12.0	**Corrected Optimum w (%):**	**9.7**
Uncorrected Max Dry Density (kg/m^3)	1932	**Corrected Max Dry Density (kg/m^3)**	**2054**
Uncorrected Max Unit Weight (kN/m^3)	18.95	**Corrected Max Unit Weight (kN/m^3)**	**20.13**

The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

KS	April 30, 2018	LH	May 1, 2018
TESTED BY	DATE	CHECKED BY	DATE

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Compaction Characteristics of Soil Using Standard Effort (12,000 ft-lbf/ft³ (600 kN-m/m³))

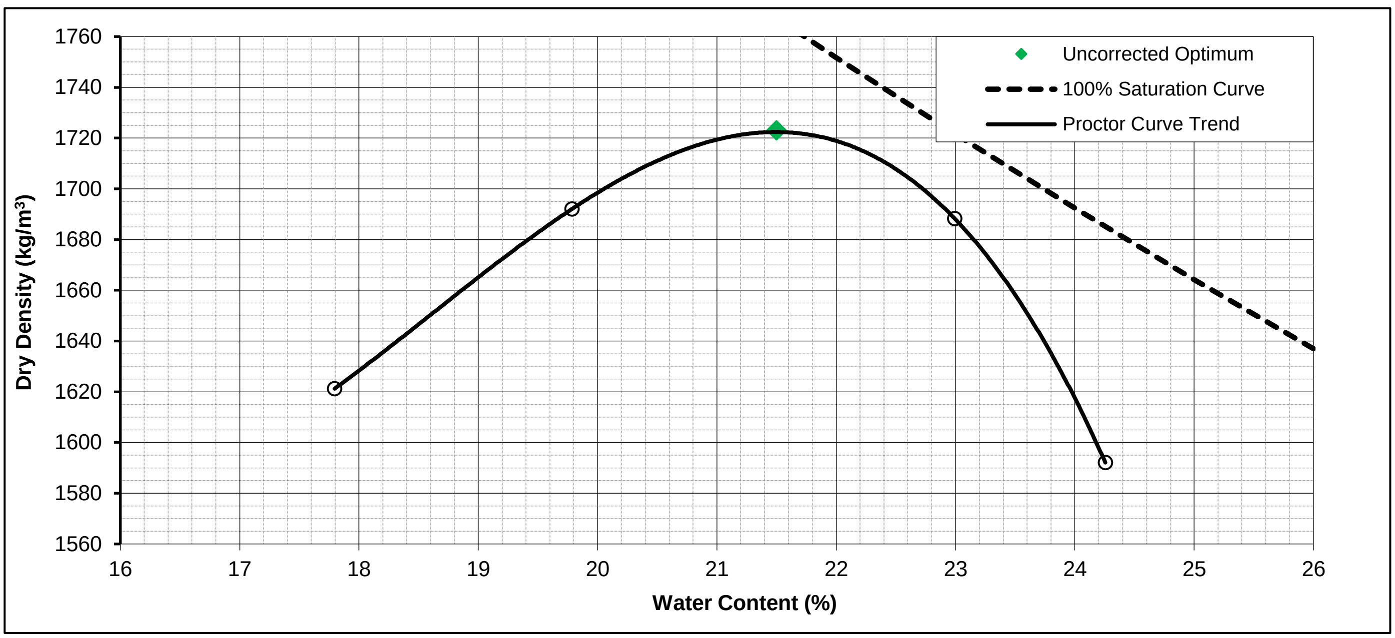
ASTM D698

Project No.:	1786980/2000	**Sample No.:**	Blk 01 & Blk 02
Project:	Telkwa Coal Limited	**Sample Depth (m):**	12.40 - 14.60
Location:	Prince Rupert, BC	**Sample Source:**	T18-13S
Client:	SRK Consulting (Canada) Inc.	**Sampled By:**	Client
Lab ID No:	43	**Date sampled:**	Not Given

Effort Type:	Standard	**Preparation Method:**	Moist
Test Method:	A	**As Received w (%):**	#DIV/0!
Mold Volume (cm^3):	940	**Visual Description:**	
Type of Rammer:	Manual	**Remarks:**	

ASTM D 4718 - Correction for Oversize Particles			
Oversized Fraction		*Test Fraction*	
Oversized Fraction (%):	2.5	**Max Nominal Size of Test Fraction (mm):**	4.75
G_{SC} (calculated):	2.60	**G_{SF} (calculated):**	2.85
Water Content, w (%):	1.5	**Water Content, w (%):**	21.5

Compaction Results					
Trial No.:	1	2	3	4	
Dry Density (kg/m^3)	1621	1692	1688	1592	
Water Content (%):	17.8	19.8	23.0	24.3	



Final Results			
Uncorrected Optimum w (%):	21.5	**Corrected Optimum w (%):**	**Not Required**
Uncorrected Max Dry Density (kg/m^3)	1723	**Corrected Max Dry Density (kg/m^3)**	**Not Required**
Uncorrected Max Unit Weight (kN/m^3)	16.90	**Corrected Max Unit Weight (kN/m^3)**	**Not Required**

The test data given herein pertain to the sample provided only. This report constitutes a testing service only.

DT	April 27, 2018	LH	May 3, 2018
TESTED BY	DATE	CHECKED BY	DATE

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Appendix C: Bearing Capacity and Settlement Estimate Calculations

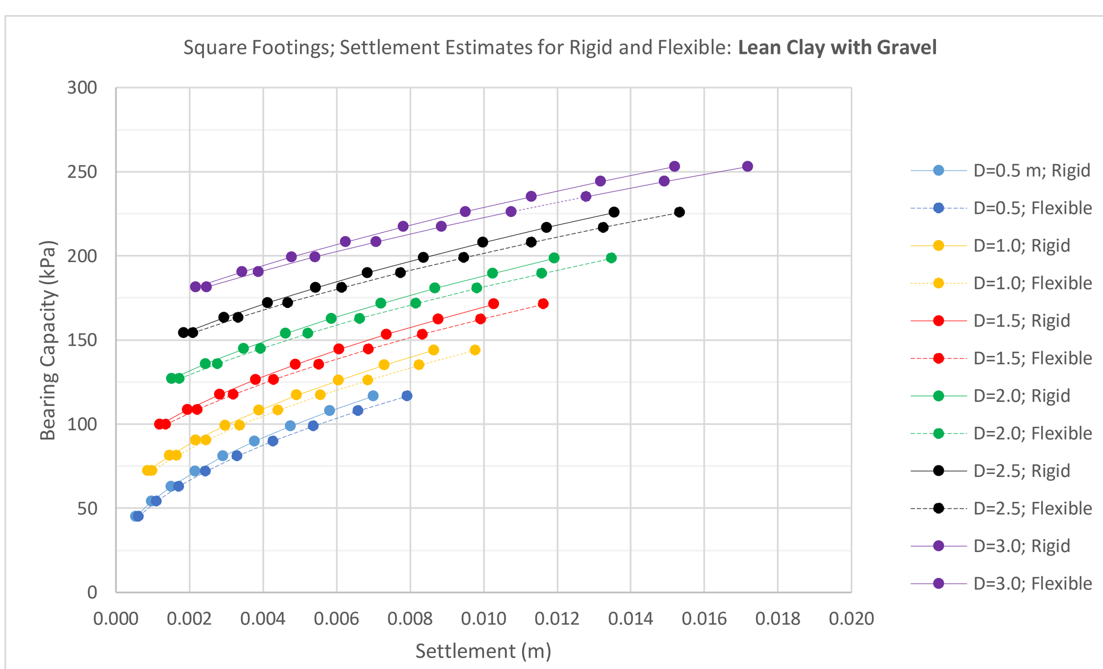
Rigid Square Footings

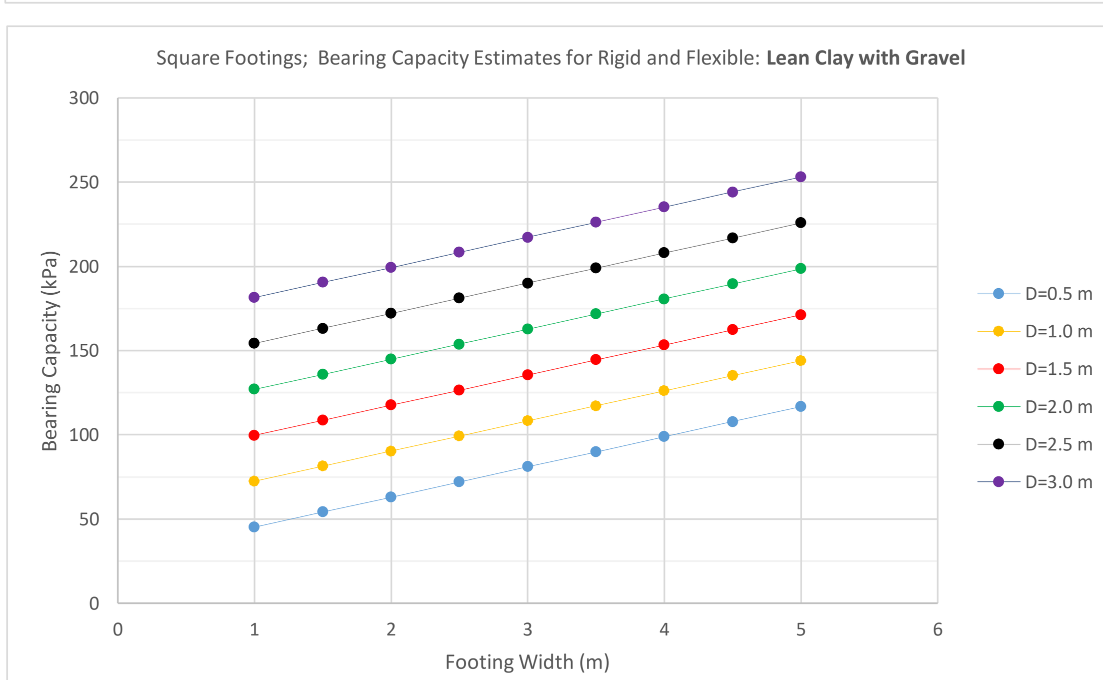
Soil Unit	**Lean Clay with Gravel**	
Layer Thickness	5	
Topsoil Layer Thickness	0.3	
Dry Weigh, kN/m3	19.0	
Saturated Unit Weight, kN/m3	19.0	= dry as water table is greater than 30 m
Friction Angle, Φ (°)	28	
Cohesion c'	0	
water table depth	>30 m	
E (kPa)	75000	
Poisson Ratio	0.3	
Nc	31.6	
Nq	17.8	
Nγ	14.6	

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	4.6	9.2	13.8	18.4	23.0	27.6

B/L	1.5	2	3	5	10	100
Cs	0.99	0.99	0.99	0.99	0.99	0.99

		0.5	1	1.5	2	2.5	3
	Footing Width (m)	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**
Square Footings (B<4L)	1	45	72	100	127	154	181
	1.5	54	81	109	136	163	190
	2	63	90	118	145	172	199
	2.5	72	99	127	154	181	208
	3	81	108	135	163	190	217
	3.5	90	117	144	172	199	226
	4	99	126	153	181	208	235
	4.5	108	135	162	190	217	244
	5	117	144	171	199	226	253





Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
0.5	1.0	45	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	54	0.001	0.001	0.001	0.001	0.001	0.001
	2.0	63	0.002	0.002	0.002	0.002	0.002	0.002
	2.5	72	0.002	0.002	0.002	0.002	0.002	0.002
	3.0	81	0.003	0.003	0.003	0.003	0.003	0.003
	3.5	90	0.004	0.004	0.004	0.004	0.004	0.004
	4.0	99	0.005	0.005	0.005	0.005	0.005	0.005
	4.5	108	0.006	0.006	0.006	0.006	0.006	0.006
	5.0	117	0.007	0.007	0.007	0.007	0.007	0.007

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1	1.0	72	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	81	0.001	0.001	0.001	0.001	0.001	0.001
	2.0	90	0.002	0.002	0.002	0.002	0.002	0.002
	2.5	99	0.003	0.003	0.003	0.003	0.003	0.003
	3.0	108	0.004	0.004	0.004	0.004	0.004	0.004
	3.5	117	0.005	0.005	0.005	0.005	0.005	0.005
	4.0	126	0.006	0.006	0.006	0.006	0.006	0.006
	4.5	135	0.007	0.007	0.007	0.007	0.007	0.007
	5.0	144	0.009	0.009	0.009	0.009	0.009	0.009

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1.5	1.0	100	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	109	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	118	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	127	0.004	0.004	0.004	0.004	0.004	0.004
	3.0	135	0.005	0.005	0.005	0.005	0.005	0.005
	3.5	144	0.006	0.006	0.006	0.006	0.006	0.006
	4.0	153	0.007	0.007	0.007	0.007	0.007	0.007
	4.5	162	0.009	0.009	0.009	0.009	0.009	0.009
	5.0	171	0.010	0.010	0.010	0.010	0.010	0.010

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2	1.0	127	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	136	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	145	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	154	0.005	0.005	0.005	0.005	0.005	0.005
	3.0	163	0.006	0.006	0.006	0.006	0.006	0.006
	3.5	172	0.007	0.007	0.007	0.007	0.007	0.007
	4.0	181	0.009	0.009	0.009	0.009	0.009	0.009
	4.5	190	0.010	0.010	0.010	0.010	0.010	0.010
	5.0	199	0.012	0.012	0.012	0.012	0.012	0.012

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2.5	1.0	154	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	163	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	172	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	181	0.005	0.005	0.005	0.005	0.005	0.005
	3.0	190	0.007	0.007	0.007	0.007	0.007	0.007
	3.5	199	0.008	0.008	0.008	0.008	0.008	0.008
	4.0	208	0.010	0.010	0.010	0.010	0.010	0.010
	4.5	217	0.012	0.012	0.012	0.012	0.012	0.012
	5.0	226	0.014	0.014	0.014	0.014	0.014	0.014

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
3	1.0	181	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	190	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	199	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	208	0.006	0.006	0.006	0.006	0.006	0.006
	3.0	217	0.008	0.008	0.008	0.008	0.008	0.008
	3.5	226	0.010	0.010	0.010	0.010	0.010	0.010
	4.0	235	0.011	0.011	0.011	0.011	0.011	0.011
	4.5	244	0.013	0.013	0.013	0.013	0.013	0.013
	5.0	253	0.015	0.015	0.015	0.015	0.015	0.015

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

φ' (deg)	N_c	N_q	N_γ	φ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

For square footings:

$$q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma \qquad (17.5)$$

For continuous footings:

$$q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma \qquad (17.6)$$

For circular footings:

$$q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma \qquad (17.7)$$

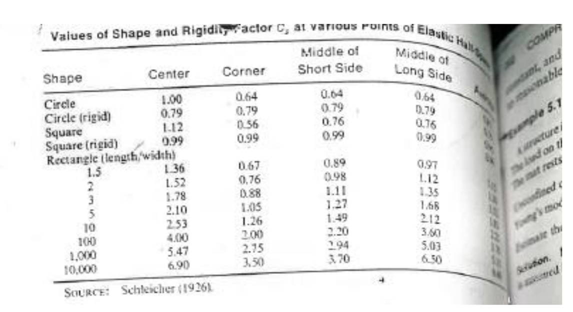
where:
q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface ($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_i(x, y) = C_s qB\left(\frac{1-\mu^2}{E}\right) \qquad (5\text{–}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated



Flexible Square Footings

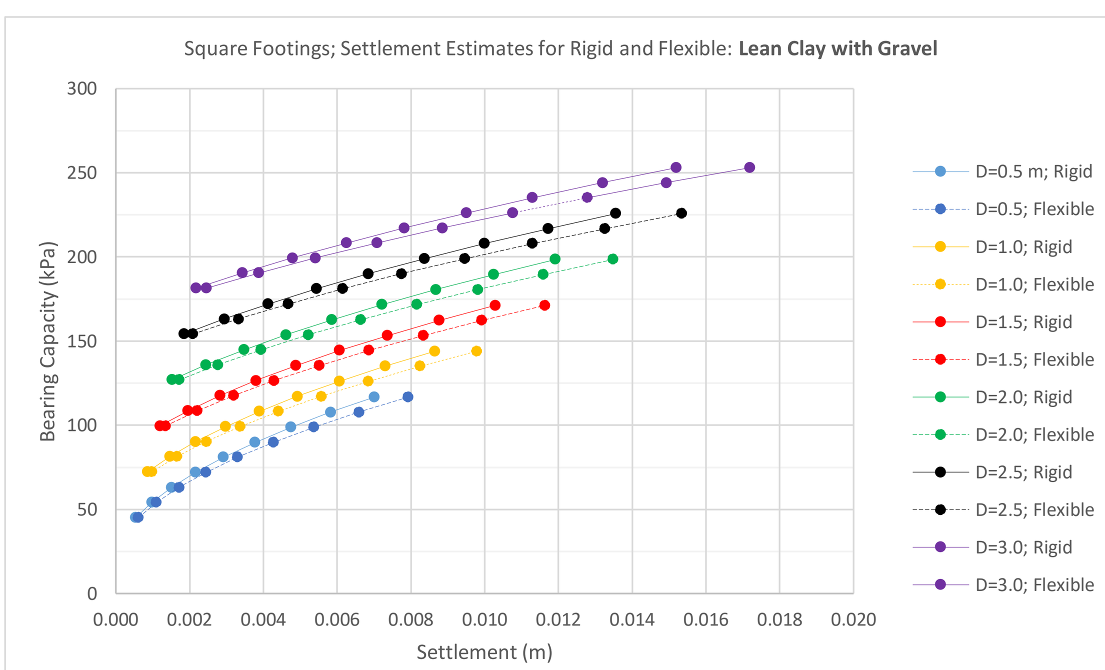
Soil Unit	**Lean Clay with Gravel**
Layer Thickness	5
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	19.0
Saturated Unit Weight, kN/m4	19.0
Friction Angle, Φ (°)	28
Cohesion c'	0
water table depth	>30 m
E (kPa)	75000
Poisson Ratio	0.3

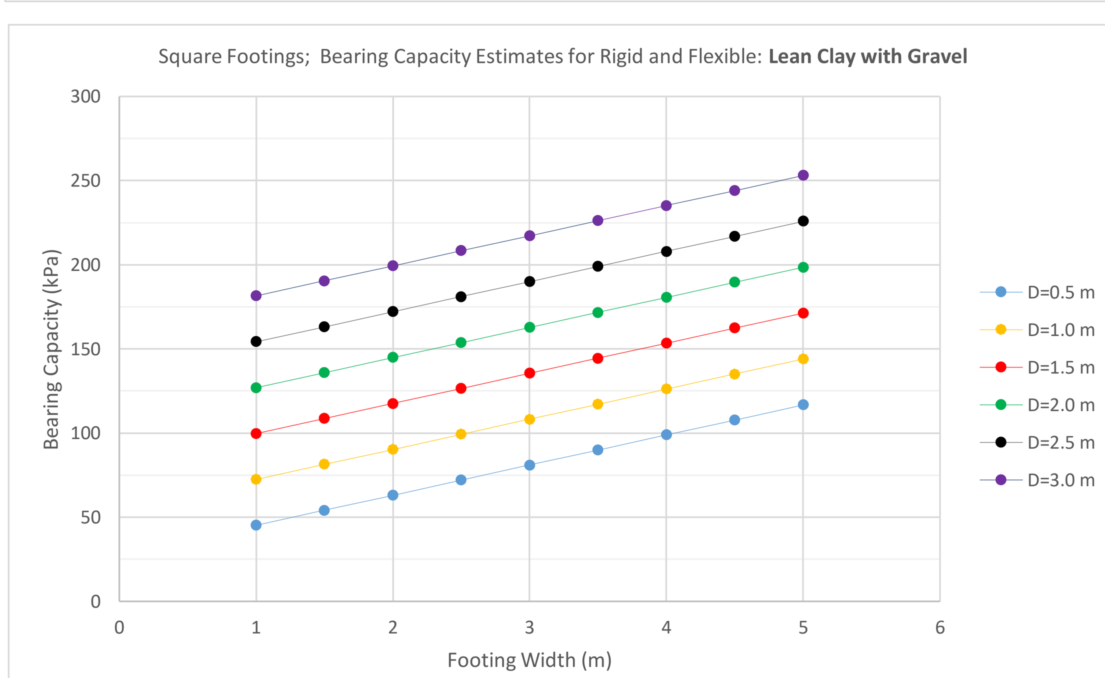
Nc	31.6
Nq	17.8
Nγ	14.6

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	4.6	9.2	13.8	18.4	23.0	27.6

B/L	1.5	2	3	5	10	100
Cs	1.12	1.12	1.12	1.12	1.12	1.12

	Footing Width (m)	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**
Square Footings (B<4L)	1	45	72	100	127	154	181
	1.5	54	81	109	136	163	190
	2	63	90	118	145	172	199
	2.5	72	99	127	154	181	208
	3	81	108	135	163	190	217
	3.5	90	117	144	172	199	226
	4	99	126	153	181	208	235
	4.5	108	135	162	190	217	244
	5	117	144	171	199	226	253





Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
0.5	1.0	45	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	54	0.001	0.001	0.001	0.001	0.001	0.001
	2.0	63	0.002	0.002	0.002	0.002	0.002	0.002
	2.5	72	0.002	0.002	0.002	0.002	0.002	0.002
	3.0	81	0.003	0.003	0.003	0.003	0.003	0.003
	3.5	90	0.004	0.004	0.004	0.004	0.004	0.004
	4.0	99	0.005	0.005	0.005	0.005	0.005	0.005
	4.5	108	0.007	0.007	0.007	0.007	0.007	0.007
	5.0	117	0.008	0.008	0.008	0.008	0.008	0.008

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1	1.0	72	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	81	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	90	0.002	0.002	0.002	0.002	0.002	0.002
	2.5	99	0.003	0.003	0.003	0.003	0.003	0.003
	3.0	108	0.004	0.004	0.004	0.004	0.004	0.004
	3.5	117	0.006	0.006	0.006	0.006	0.006	0.006
	4.0	126	0.007	0.007	0.007	0.007	0.007	0.007
	4.5	135	0.008	0.008	0.008	0.008	0.008	0.008
	5.0	144	0.010	0.010	0.010	0.010	0.010	0.010

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1.5	1.0	100	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	109	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	118	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	127	0.004	0.004	0.004	0.004	0.004	0.004
	3.0	135	0.006	0.006	0.006	0.006	0.006	0.006
	3.5	144	0.007	0.007	0.007	0.007	0.007	0.007
	4.0	153	0.008	0.008	0.008	0.008	0.008	0.008
	4.5	162	0.010	0.010	0.010	0.010	0.010	0.010
	5.0	171	0.012	0.012	0.012	0.012	0.012	0.012

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2	1.0	127	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	136	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	145	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	154	0.005	0.005	0.005	0.005	0.005	0.005
	3.0	163	0.007	0.007	0.007	0.007	0.007	0.007
	3.5	172	0.008	0.008	0.008	0.008	0.008	0.008
	4.0	181	0.010	0.010	0.010	0.010	0.010	0.010
	4.5	190	0.012	0.012	0.012	0.012	0.012	0.012
	5.0	199	0.013	0.013	0.013	0.013	0.013	0.013

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2.5	1.0	154	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	163	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	172	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	181	0.006	0.006	0.006	0.006	0.006	0.006
	3.0	190	0.008	0.008	0.008	0.008	0.008	0.008
	3.5	199	0.009	0.009	0.009	0.009	0.009	0.009
	4.0	208	0.011	0.011	0.011	0.011	0.011	0.011
	4.5	217	0.013	0.013	0.013	0.013	0.013	0.013
	5.0	226	0.015	0.015	0.015	0.015	0.015	0.015

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
3	1.0	181	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	190	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	199	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	208	0.007	0.007	0.007	0.007	0.007	0.007
	3.0	217	0.009	0.009	0.009	0.009	0.009	0.009
	3.5	226	0.011	0.011	0.011	0.011	0.011	0.011
	4.0	235	0.013	0.013	0.013	0.013	0.013	0.013
	4.5	244	0.015	0.015	0.015	0.015	0.015	0.015
	5.0	253	0.017	0.017	0.017	0.017	0.017	0.017

For square footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma} \qquad (17.5)$$

For continuous footings:

$$\boxed{q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma} \qquad (17.6)$$

For circular footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma} \qquad (17.7)$$

where:

q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface ($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_d(x, y) = C_s q B \left(\frac{1-\mu^2}{E}\right) \qquad (5\text{-}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

Continous Footings

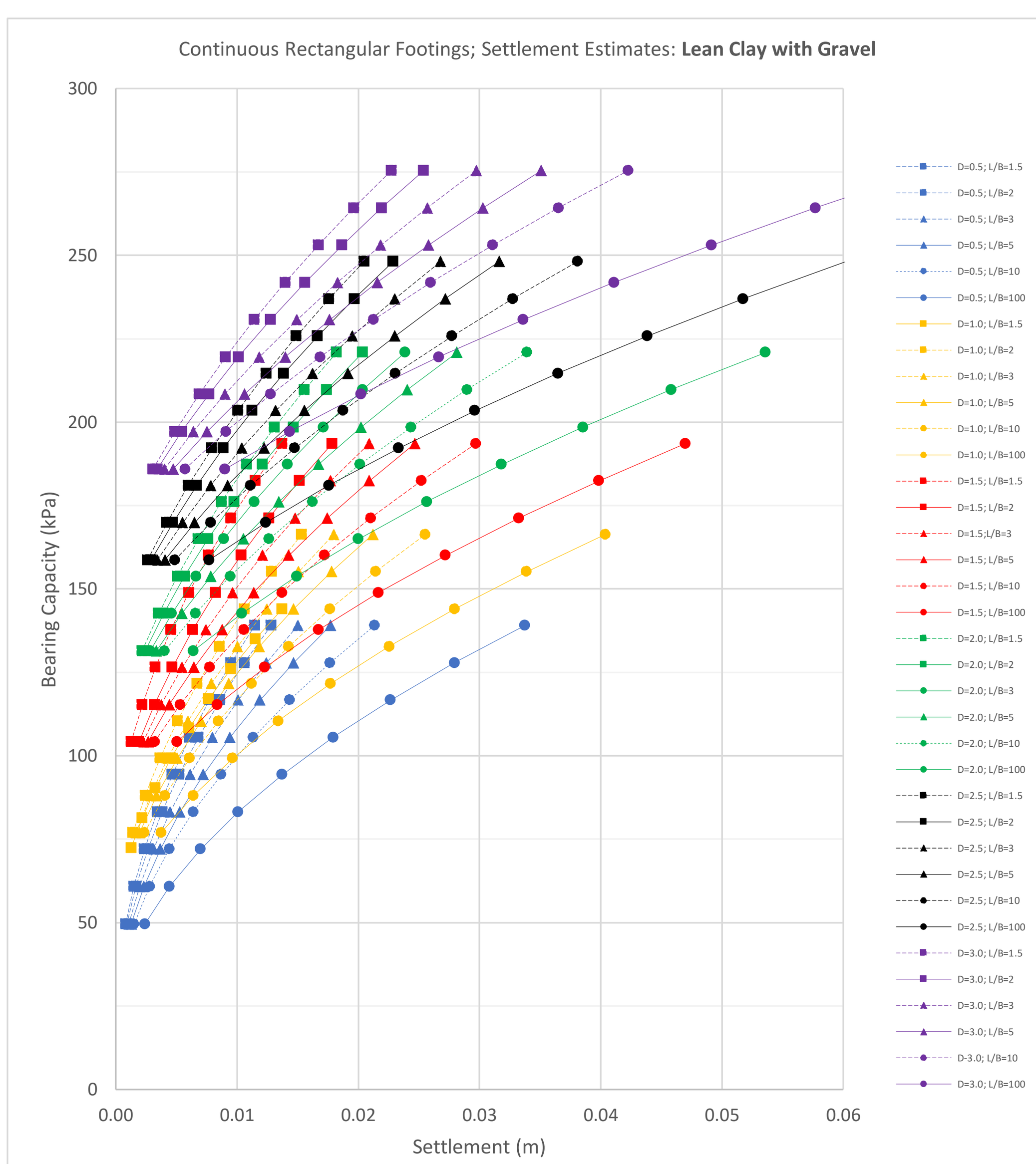
Soil Unit	**Lean Clay with Gravel**
Layer Thickness	5
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	19.0
Saturated Unit Weight, kN/m4	19.0
Friction Angle, Φ (°)	28
Cohesion c'	0
water table depth	>30 m
E (kPa)	75000
Poisson Ratio	0.3

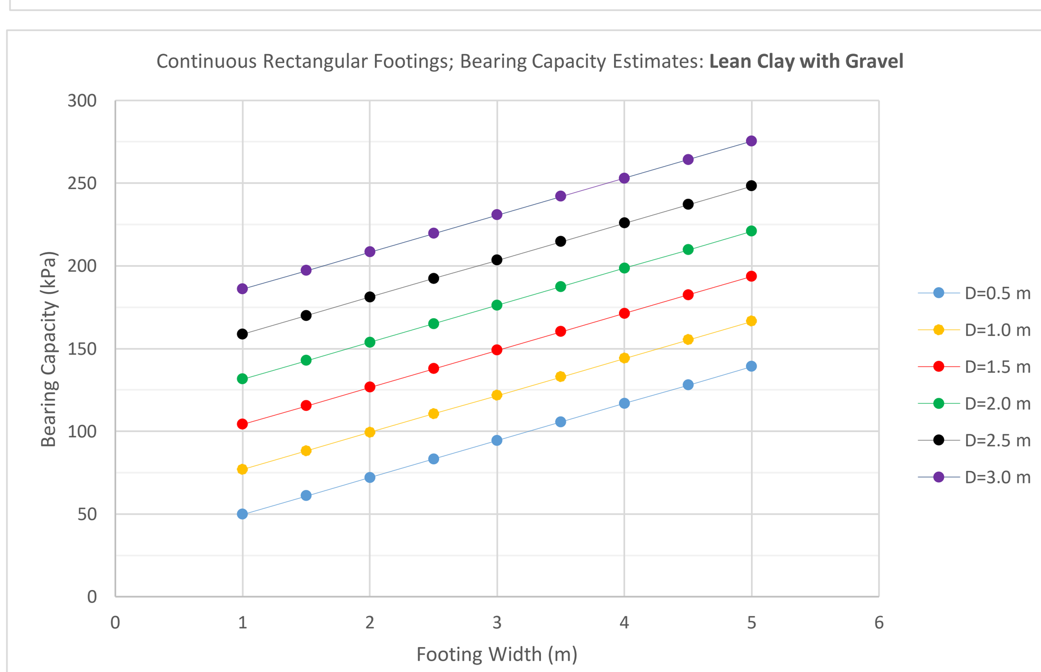
Nc	31.6
Nq	17.8
Nγ	14.6

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	4.6	9.2	13.8	18.4	23.0	27.6

B/L	1.5	2	3	5	10	100
Cs	1.36	1.52	1.78	2.1	2.53	4

	Footing Width (m)	q (kPa)	q (kPa)	q (kPa)	q (kPa)	q (kPa)	q (kPa)
Square Footings (B<4L)	1	50	77	104	131	159	186
	1.5	61	88	115	143	170	197
	2	72	99	127	154	181	208
	2.5	83	110	138	165	192	219
	3	94	122	149	176	203	231
	3.5	106	133	160	187	215	242
	4	117	144	171	199	226	253
	4.5	128	155	182	210	237	264
	5	139	166	194	221	248	275





Depth (m)	B	q	L/B=1.5	L/B=2	L/B=3	L/B=5	L/B=10	L/B=100
0.5	1.0	50	0.001	0.001	0.001	0.001	0.002	0.002
	1.5	61	0.002	0.002	0.002	0.002	0.003	0.004
	2.0	72	0.002	0.003	0.003	0.004	0.004	0.007
	2.5	83	0.003	0.004	0.004	0.005	0.006	0.010
	3.0	94	0.005	0.005	0.006	0.007	0.009	0.014
	3.5	106	0.006	0.007	0.008	0.009	0.011	0.018
	4.0	117	0.008	0.009	0.010	0.012	0.014	0.023
	4.5	128	0.009	0.011	0.012	0.015	0.018	0.028
	5.0	139	0.011	0.013	0.015	0.018	0.021	0.034

Depth (m)	B	q	L/B=1.5	L/B=2	L/B=3	L/B=5	L/B=10	L/B=100
1	1.0	77	0.001	0.001	0.002	0.002	0.002	0.004
	1.5	88	0.002	0.002	0.003	0.003	0.004	0.006
	2.0	99	0.003	0.004	0.004	0.005	0.006	0.010
	2.5	110	0.005	0.005	0.006	0.007	0.008	0.013
	3.0	122	0.006	0.007	0.008	0.009	0.011	0.018
	3.5	133	0.008	0.009	0.010	0.012	0.014	0.023
	4.0	144	0.010	0.011	0.012	0.015	0.018	0.028
	4.5	155	0.012	0.013	0.015	0.018	0.021	0.034
	5.0	166	0.014	0.015	0.018	0.021	0.026	0.040

Depth (m)	B	q	L/B=1.5	L/B=2	L/B=3	L/B=5	L/B=10	L/B=100
1.5	1.0	104	0.002	0.002	0.002	0.003	0.003	0.005
	1.5	115	0.003	0.003	0.004	0.004	0.005	0.008
	2.0	127	0.004	0.005	0.005	0.006	0.008	0.012
	2.5	138	0.006	0.006	0.007	0.009	0.011	0.017
	3.0	149	0.007	0.008	0.010	0.011	0.014	0.022
	3.5	160	0.009	0.010	0.012	0.014	0.017	0.027
	4.0	171	0.011	0.013	0.015	0.017	0.021	0.033
	4.5	182	0.014	0.015	0.018	0.021	0.025	0.040
	5.0	194	0.016	0.018	0.021	0.025	0.030	0.047

Depth (m)	B	q	L/B=1.5	L/B=2	L/B=3	L/B=5	L/B=10	L/B=100
2	1.0	131	0.002	0.002	0.003	0.003	0.004	0.006
	1.5	143	0.004	0.004	0.005	0.005	0.007	0.010
	2.0	154	0.005	0.006	0.007	0.008	0.009	0.015
	2.5	165	0.007	0.008	0.009	0.011	0.013	0.020
	3.0	176	0.009	0.010	0.011	0.013	0.016	0.026
	3.5	187	0.011	0.012	0.014	0.017	0.020	0.032
	4.0	199	0.013	0.015	0.017	0.020	0.024	0.039
	4.5	210	0.016	0.017	0.020	0.024	0.029	0.046
	5.0	221	0.018	0.020	0.024	0.028	0.034	0.054

Depth (m)	B	q	L/B=1.5	L/B=2	L/B=3	L/B=5	L/B=10	L/B=100
2.5	1.0	159	0.003	0.003	0.003	0.004	0.005	0.008
	1.5	170	0.004	0.005	0.006	0.006	0.008	0.012
	2.0	181	0.006	0.007	0.008	0.009	0.011	0.018
	2.5	192	0.008	0.009	0.010	0.012	0.015	0.023
	3.0	203	0.010	0.011	0.013	0.016	0.019	0.030
	3.5	215	0.012	0.014	0.016	0.019	0.023	0.036
	4.0	226	0.015	0.017	0.020	0.023	0.028	0.044
	4.5	237	0.018	0.020	0.023	0.027	0.033	0.052
	5.0	248	0.020	0.023	0.027	0.032	0.038	0.060

Depth (m)	B	q	L/B=1.5	L/B=2	L/B=3	L/B=5	L/B=10	L/B=100
3	1.0	186	0.003	0.003	0.004	0.005	0.006	0.009
	1.5	197	0.005	0.005	0.006	0.008	0.009	0.014
	2.0	208	0.007	0.008	0.009	0.011	0.013	0.020
	2.5	219	0.009	0.010	0.012	0.014	0.017	0.027
	3.0	231	0.011	0.013	0.015	0.018	0.021	0.034
	3.5	242	0.014	0.016	0.018	0.022	0.026	0.041
	4.0	253	0.017	0.019	0.022	0.026	0.031	0.049
	4.5	264	0.020	0.022	0.026	0.030	0.036	0.058
	5.0	275	0.023	0.025	0.030	0.035	0.042	0.067

For square footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma} \quad (17.5)$$

For continuous footings:

$$\boxed{q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma} \quad (17.6)$$

For circular footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma} \quad (17.7)$$

where:
q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface
($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_s(x, y) = C_s q B \left(\frac{1-\mu^2}{E}\right) \quad (5\text{-}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

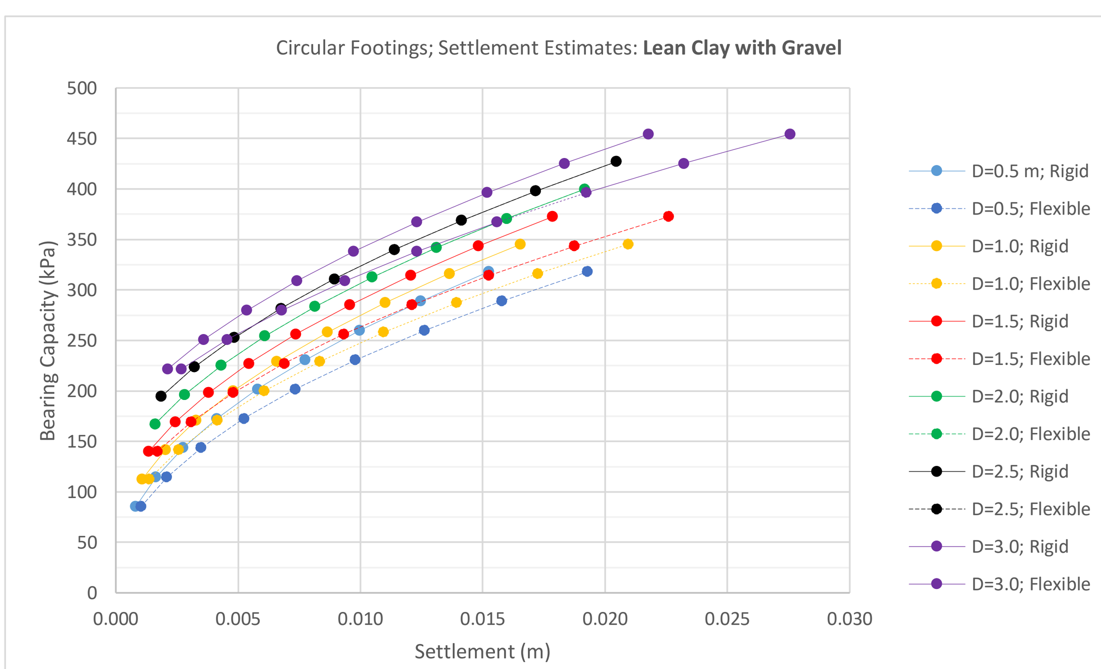
Rigid Circular Footings

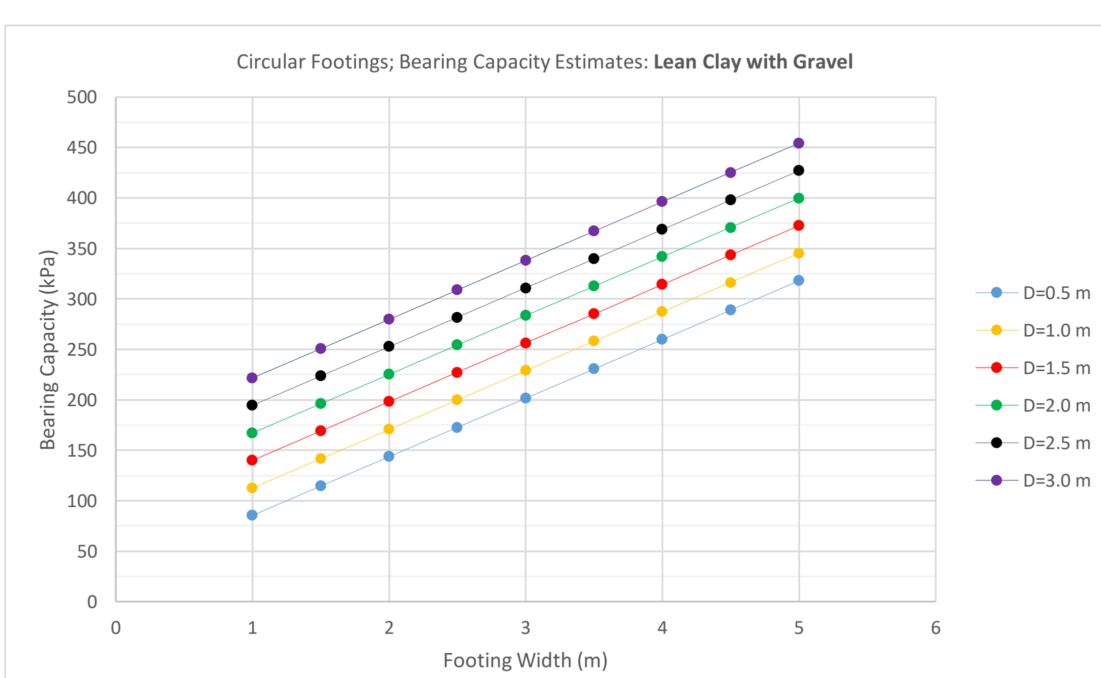
Soil Unit	**Lean Clay with Gravel**
Layer Thickness	5
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	19.0
Saturated Unit Weight, kN/m4	19.0
Friction Angle, Φ (°)	28
Cohesion c'	0
water table depth	>30 m
E (kPa)	75000
Poisson Ratio	0.3

Nc	31.6
Nq	17.8
Nγ	14.6

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	4.6	9.2	13.8	18.4	23.0	27.6

	Footing Width (m)	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**
Square Footings (B<4L)	1	85	113	140	167	194	222
	1.5	114	142	169	196	224	251
	2	144	171	198	225	253	280
	2.5	173	200	227	254	282	309
	3	202	229	256	283	311	338
	3.5	231	258	285	313	340	367
	4	260	287	314	342	369	396
	4.5	289	316	343	371	398	425
	5	318	345	373	400	427	454





B/L	1.5	2	3	5	10	100
Cs	0.79	0.79	0.79	0.79	0.79	0.79

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
	1.0	85	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	114	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	144	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	173	0.004	0.004	0.004	0.004	0.004	0.004
0.5	3.0	202	0.006	0.006	0.006	0.006	0.006	0.006
	3.5	231	0.008	0.008	0.008	0.008	0.008	0.008
	4.0	260	0.010	0.010	0.010	0.010	0.010	0.010
	4.5	289	0.012	0.012	0.012	0.012	0.012	0.012
	5.0	318	0.015	0.015	0.015	0.015	0.015	0.015

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
	1.0	113	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	142	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	171	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	200	0.005	0.005	0.005	0.005	0.005	0.005
1	3.0	229	0.007	0.007	0.007	0.007	0.007	0.007
	3.5	258	0.009	0.009	0.009	0.009	0.009	0.009
	4.0	287	0.011	0.011	0.011	0.011	0.011	0.011
	4.5	316	0.014	0.014	0.014	0.014	0.014	0.014
	5.0	345	0.017	0.017	0.017	0.017	0.017	0.017

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
	1.0	140	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	169	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	198	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	227	0.005	0.005	0.005	0.005	0.005	0.005
1.5	3.0	256	0.007	0.007	0.007	0.007	0.007	0.007
	3.5	285	0.010	0.010	0.010	0.010	0.010	0.010
	4.0	314	0.012	0.012	0.012	0.012	0.012	0.012
	4.5	343	0.015	0.015	0.015	0.015	0.015	0.015
	5.0	373	0.018	0.018	0.018	0.018	0.018	0.018

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
	1.0	167	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	196	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	225	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	254	0.006	0.006	0.006	0.006	0.006	0.006
2	3.0	283	0.008	0.008	0.008	0.008	0.008	0.008
	3.5	313	0.010	0.010	0.010	0.010	0.010	0.010
	4.0	342	0.013	0.013	0.013	0.013	0.013	0.013
	4.5	371	0.016	0.016	0.016	0.016	0.016	0.016
	5.0	400	0.019	0.019	0.019	0.019	0.019	0.019

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
	1.0	194	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	224	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	253	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	282	0.007	0.007	0.007	0.007	0.007	0.007
2.5	3.0	311	0.009	0.009	0.009	0.009	0.009	0.009
	3.5	340	0.011	0.011	0.011	0.011	0.011	0.011
	4.0	369	0.014	0.014	0.014	0.014	0.014	0.014
	4.5	398	0.017	0.017	0.017	0.017	0.017	0.017
	5.0	427	0.020	0.020	0.020	0.020	0.020	0.020

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
	1.0	222	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	251	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	280	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	309	0.007	0.007	0.007	0.007	0.007	0.007
3	3.0	338	0.010	0.010	0.010	0.010	0.010	0.010
	3.5	367	0.012	0.012	0.012	0.012	0.012	0.012
	4.0	396	0.015	0.015	0.015	0.015	0.015	0.015
	4.5	425	0.018	0.018	0.018	0.018	0.018	0.018
	5.0	454	0.022	0.022	0.022	0.022	0.022	0.022

For square footings:

$$q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma \tag{17.5}$$

For continuous footings:

$$q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma \tag{17.6}$$

For circular footings:

$$q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma \tag{17.7}$$

where:
q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface ($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_i(x, y) = C_s B\left(\frac{1-\mu^2}{E}\right) \tag{5-2}$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

Flexible Circular Footings

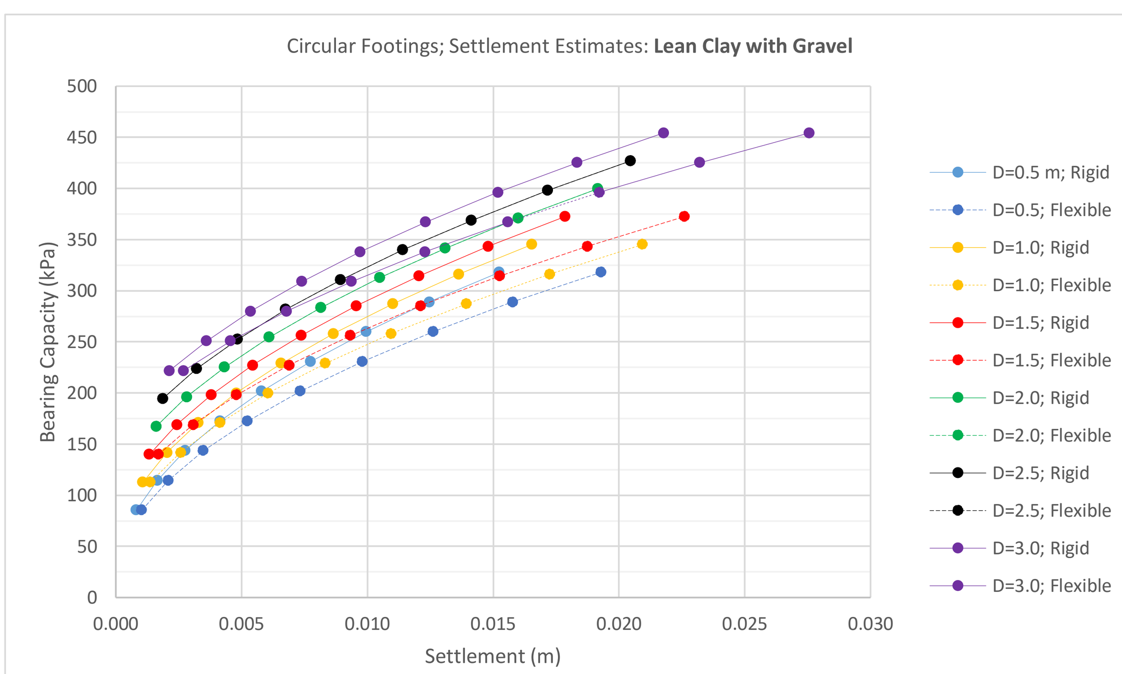
Soil Unit	**Lean Clay with Gravel**
Layer Thickness	5
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	19.0
Saturated Unit Weight, kN/m4	19.0
Friction Angle, Φ (°)	28
Cohesion c'	0
water table depth	>30 m
E (kPa)	75000
Poisson Ratio	0.3

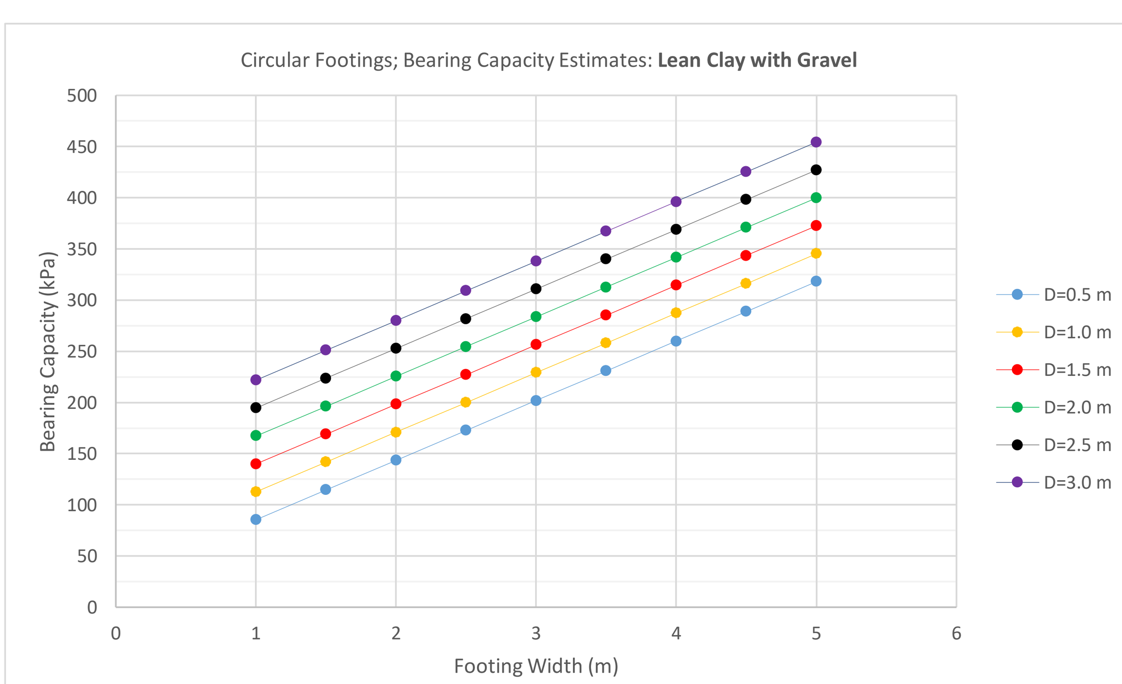
Nc	31.6	
Nq	17.8	terzaghi
Nγ	14.6	

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	4.6	9.2	13.8	18.4	23.0	27.6

B/L	1.5	2	3	5	10	100
Cs	1	1	1	1	1	1

	Footing Width (m)	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**
Square Footings (B<4L)	1	85	113	140	167	194	222
	1.5	114	142	169	196	224	251
	2	144	171	198	225	253	280
	2.5	173	200	227	254	282	309
	3	202	229	256	283	311	338
	3.5	231	258	285	313	340	367
	4	260	287	314	342	369	396
	4.5	289	316	343	371	398	425
	5	318	345	373	400	427	454





Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
0.5	1.0	85	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	114	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	144	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	173	0.005	0.005	0.005	0.005	0.005	0.005
	3.0	202	0.007	0.007	0.007	0.007	0.007	0.007
	3.5	231	0.010	0.010	0.010	0.010	0.010	0.010
	4.0	260	0.013	0.013	0.013	0.013	0.013	0.013
	4.5	289	0.016	0.016	0.016	0.016	0.016	0.016
	5.0	318	0.019	0.019	0.019	0.019	0.019	0.019

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1	1.0	113	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	142	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	171	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	200	0.006	0.006	0.006	0.006	0.006	0.006
	3.0	229	0.008	0.008	0.008	0.008	0.008	0.008
	3.5	258	0.011	0.011	0.011	0.011	0.011	0.011
	4.0	287	0.014	0.014	0.014	0.014	0.014	0.014
	4.5	316	0.017	0.017	0.017	0.017	0.017	0.017
	5.0	345	0.021	0.021	0.021	0.021	0.021	0.021

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1.5	1.0	140	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	169	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	198	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	227	0.007	0.007	0.007	0.007	0.007	0.007
	3.0	256	0.009	0.009	0.009	0.009	0.009	0.009
	3.5	285	0.012	0.012	0.012	0.012	0.012	0.012
	4.0	314	0.015	0.015	0.015	0.015	0.015	0.015
	4.5	343	0.019	0.019	0.019	0.019	0.019	0.019
	5.0	373	0.023	0.023	0.023	0.023	0.023	0.023

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2	1.0	167	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	196	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	225	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	254	0.008	0.008	0.008	0.008	0.008	0.008
	3.0	283	0.010	0.010	0.010	0.010	0.010	0.010
	3.5	313	0.013	0.013	0.013	0.013	0.013	0.013
	4.0	342	0.017	0.017	0.017	0.017	0.017	0.017
	4.5	371	0.020	0.020	0.020	0.020	0.020	0.020
	5.0	400	0.024	0.024	0.024	0.024	0.024	0.024

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2.5	1.0	194	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	224	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	253	0.006	0.006	0.006	0.006	0.006	0.006
	2.5	282	0.009	0.009	0.009	0.009	0.009	0.009
	3.0	311	0.011	0.011	0.011	0.011	0.011	0.011
	3.5	340	0.014	0.014	0.014	0.014	0.014	0.014
	4.0	369	0.018	0.018	0.018	0.018	0.018	0.018
	4.5	398	0.022	0.022	0.022	0.022	0.022	0.022
	5.0	427	0.026	0.026	0.026	0.026	0.026	0.026

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
3	1.0	222	0.003	0.003	0.003	0.003	0.003	0.003
	1.5	251	0.005	0.005	0.005	0.005	0.005	0.005
	2.0	280	0.007	0.007	0.007	0.007	0.007	0.007
	2.5	309	0.009	0.009	0.009	0.009	0.009	0.009
	3.0	338	0.012	0.012	0.012	0.012	0.012	0.012
	3.5	367	0.016	0.016	0.016	0.016	0.016	0.016
	4.0	396	0.019	0.019	0.019	0.019	0.019	0.019
	4.5	425	0.023	0.023	0.023	0.023	0.023	0.023
	5.0	454	0.028	0.028	0.028	0.028	0.028	0.028

For square footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma} \quad (17.5)$$

For continuous footings:

$$\boxed{q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma} \quad (17.6)$$

For circular footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma} \quad (17.7)$$

where:
q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface
($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_i(x, y) = C_s B\left(\frac{1-\mu^2}{E}\right) \quad (5\text{-}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

Rigid Square Footings

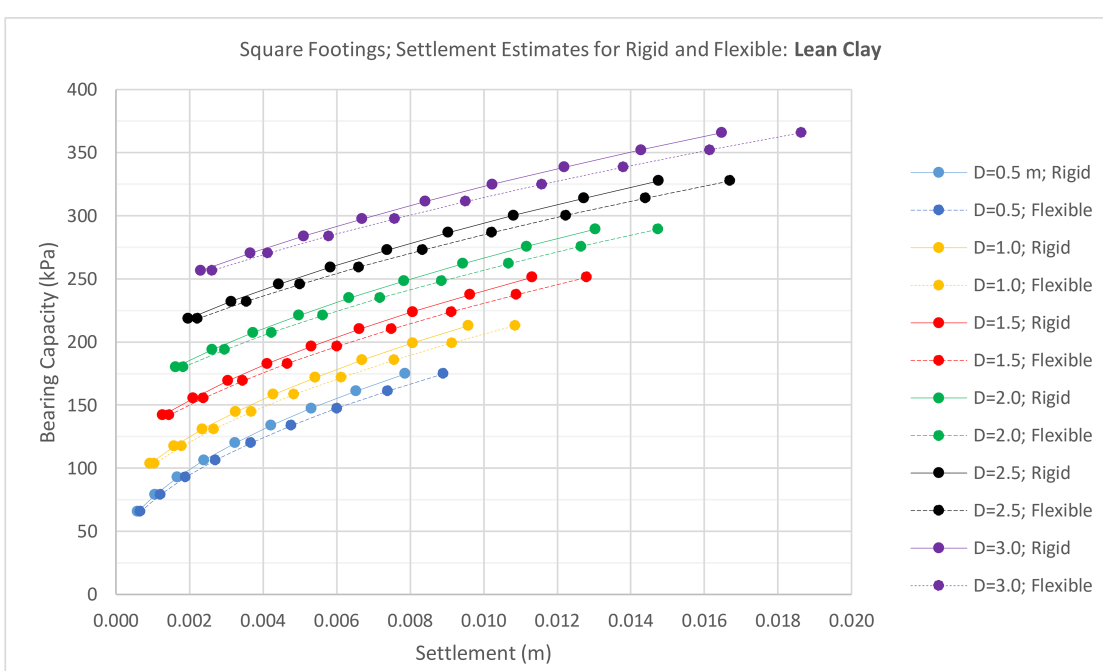
Soil Unit	**Lean Clay**	
Layer Thickness	10	
Topsoil Layer Thickness	0.3	
Dry Weigh, kN/m3	20.0	
Saturated Unit Weight, kN/m3	20.0	= dry as water table is greater than 30 m
Friction Angle, Φ (°)	30	
Cohesion c'	0	
water table depth	>30 m	
E (kPa)	100000	
Poisson Ratio	0.3	

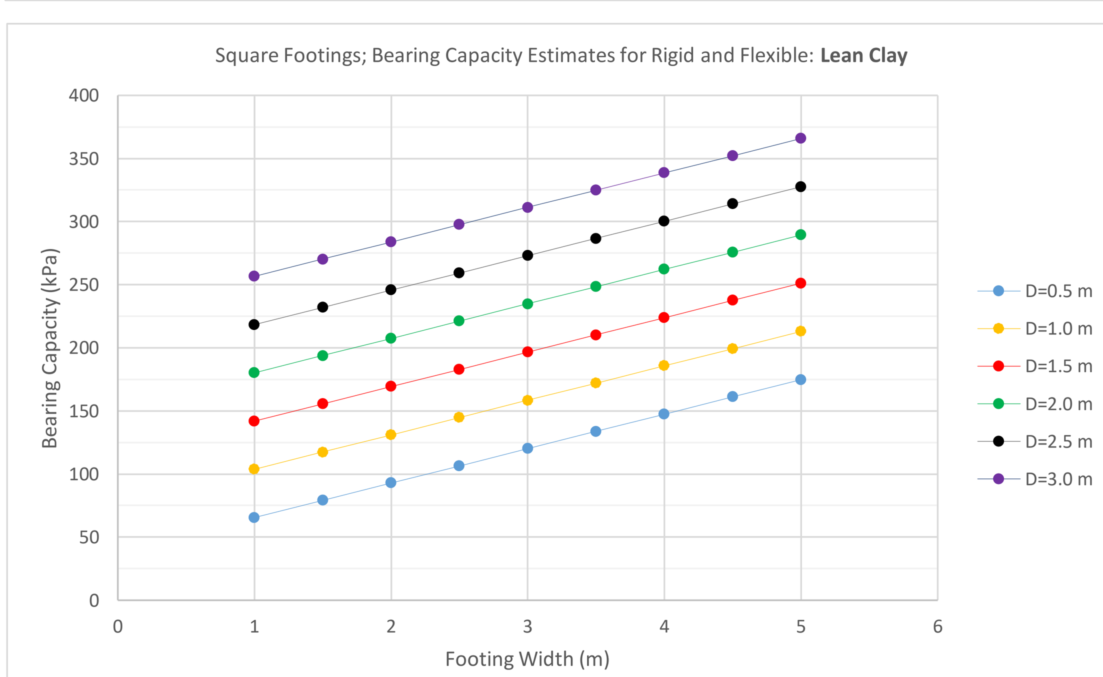
Nc	37.2
Nq	22.5
Nγ	20.1

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	5.1	10.2	15.3	20.4	25.5	30.6

B/L	1.5	2	3	5	10	100
Cs	0.99	0.99	0.99	0.99	0.99	0.99

		0.5	1	1.5	2	2.5	3
	Footing Width (m)	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**
Square Footings (B<4L)	1	66	104	142	180	218	257
	1.5	79	117	156	194	232	270
	2	93	131	169	207	246	284
	2.5	106	145	183	221	259	298
	3	120	158	197	235	273	311
	3.5	134	172	210	248	287	325
	4	147	186	224	262	300	339
	4.5	161	199	238	276	314	352
	5	175	213	251	289	328	366





Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
0.5	1.0	66	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	79	0.001	0.001	0.001	0.001	0.001	0.001
	2.0	93	0.002	0.002	0.002	0.002	0.002	0.002
	2.5	106	0.002	0.002	0.002	0.002	0.002	0.002
	3.0	120	0.003	0.003	0.003	0.003	0.003	0.003
	3.5	134	0.004	0.004	0.004	0.004	0.004	0.004
	4.0	147	0.005	0.005	0.005	0.005	0.005	0.005
	4.5	161	0.007	0.007	0.007	0.007	0.007	0.007
	5.0	175	0.008	0.008	0.008	0.008	0.008	0.008

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1	1.0	104	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	117	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	131	0.002	0.002	0.002	0.002	0.002	0.002
	2.5	145	0.003	0.003	0.003	0.003	0.003	0.003
	3.0	158	0.004	0.004	0.004	0.004	0.004	0.004
	3.5	172	0.005	0.005	0.005	0.005	0.005	0.005
	4.0	186	0.007	0.007	0.007	0.007	0.007	0.007
	4.5	199	0.008	0.008	0.008	0.008	0.008	0.008
	5.0	213	0.010	0.010	0.010	0.010	0.010	0.010

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1.5	1.0	142	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	156	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	169	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	183	0.004	0.004	0.004	0.004	0.004	0.004
	3.0	197	0.005	0.005	0.005	0.005	0.005	0.005
	3.5	210	0.007	0.007	0.007	0.007	0.007	0.007
	4.0	224	0.008	0.008	0.008	0.008	0.008	0.008
	4.5	238	0.010	0.010	0.010	0.010	0.010	0.010
	5.0	251	0.011	0.011	0.011	0.011	0.011	0.011

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2	1.0	180	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	194	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	207	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	221	0.005	0.005	0.005	0.005	0.005	0.005
	3.0	235	0.006	0.006	0.006	0.006	0.006	0.006
	3.5	248	0.008	0.008	0.008	0.008	0.008	0.008
	4.0	262	0.009	0.009	0.009	0.009	0.009	0.009
	4.5	276	0.011	0.011	0.011	0.011	0.011	0.011
	5.0	289	0.013	0.013	0.013	0.013	0.013	0.013

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2.5	1.0	218	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	232	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	246	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	259	0.006	0.006	0.006	0.006	0.006	0.006
	3.0	273	0.007	0.007	0.007	0.007	0.007	0.007
	3.5	287	0.009	0.009	0.009	0.009	0.009	0.009
	4.0	300	0.011	0.011	0.011	0.011	0.011	0.011
	4.5	314	0.013	0.013	0.013	0.013	0.013	0.013
	5.0	328	0.015	0.015	0.015	0.015	0.015	0.015

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
3	1.0	257	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	270	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	284	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	298	0.007	0.007	0.007	0.007	0.007	0.007
	3.0	311	0.008	0.008	0.008	0.008	0.008	0.008
	3.5	325	0.010	0.010	0.010	0.010	0.010	0.010
	4.0	339	0.012	0.012	0.012	0.012	0.012	0.012
	4.5	352	0.014	0.014	0.014	0.014	0.014	0.014
	5.0	366	0.016	0.016	0.016	0.016	0.016	0.016

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

For square footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma} \quad (17.5)$$

For continuous footings:

$$\boxed{q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma} \quad (17.6)$$

For circular footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma} \quad (17.7)$$

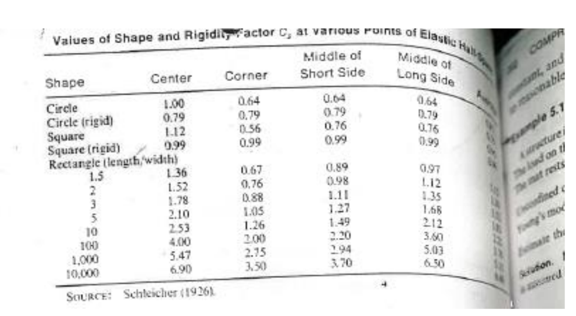
where:
q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface
($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_d(x, y) = C_s q B \left(\frac{1-\mu^2}{E}\right) \quad (5\text{–}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated


Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

Continous Footings

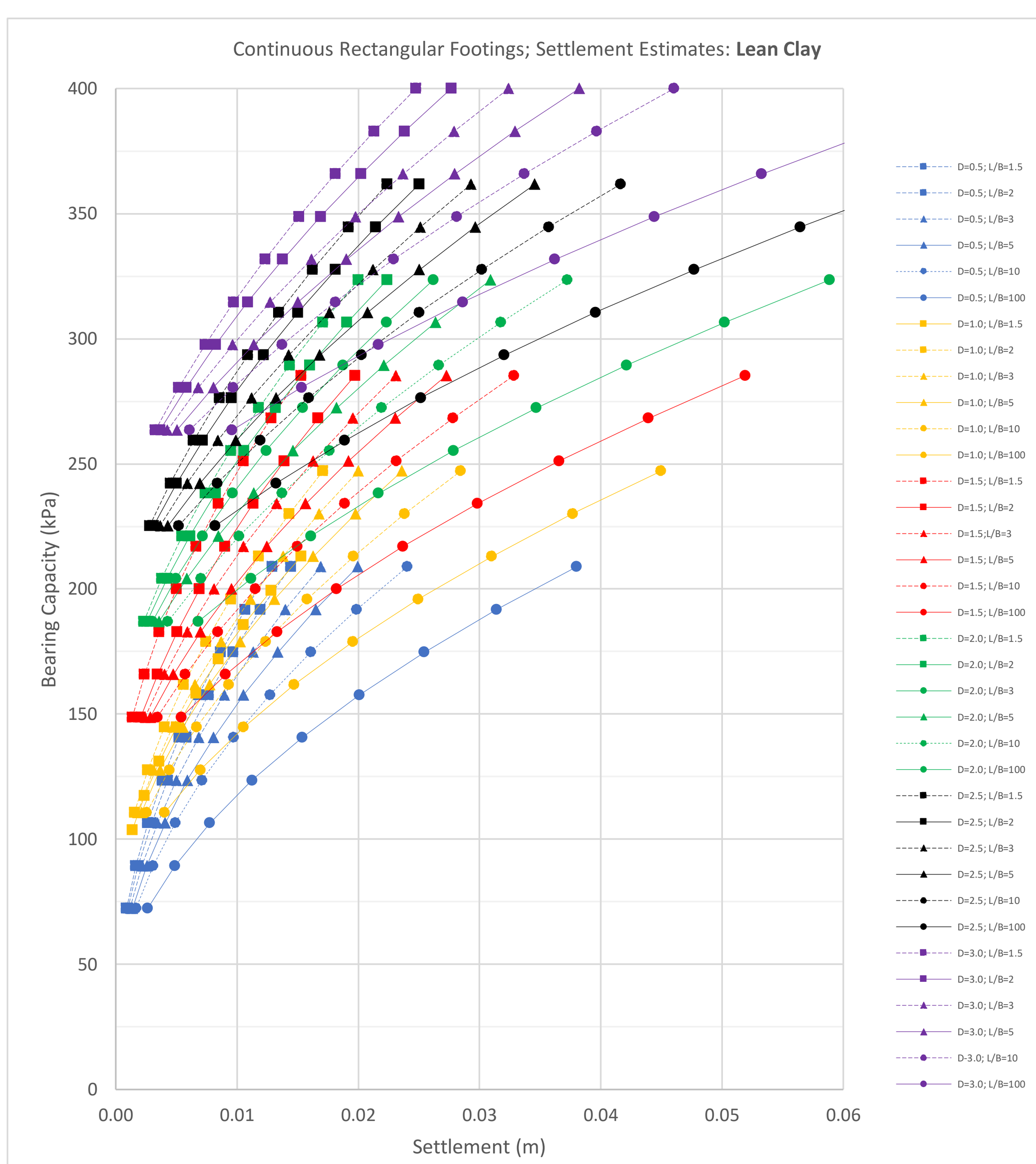
Soil Unit	**Lean Clay**
Layer Thickness	10
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	20.0
Saturated Unit Weight, kN/m4	20.0
Friction Angle, Φ (°)	30
Cohesion c'	0
water table depth	>30 m
E (kPa)	100000
Poisson Ratio	0.3

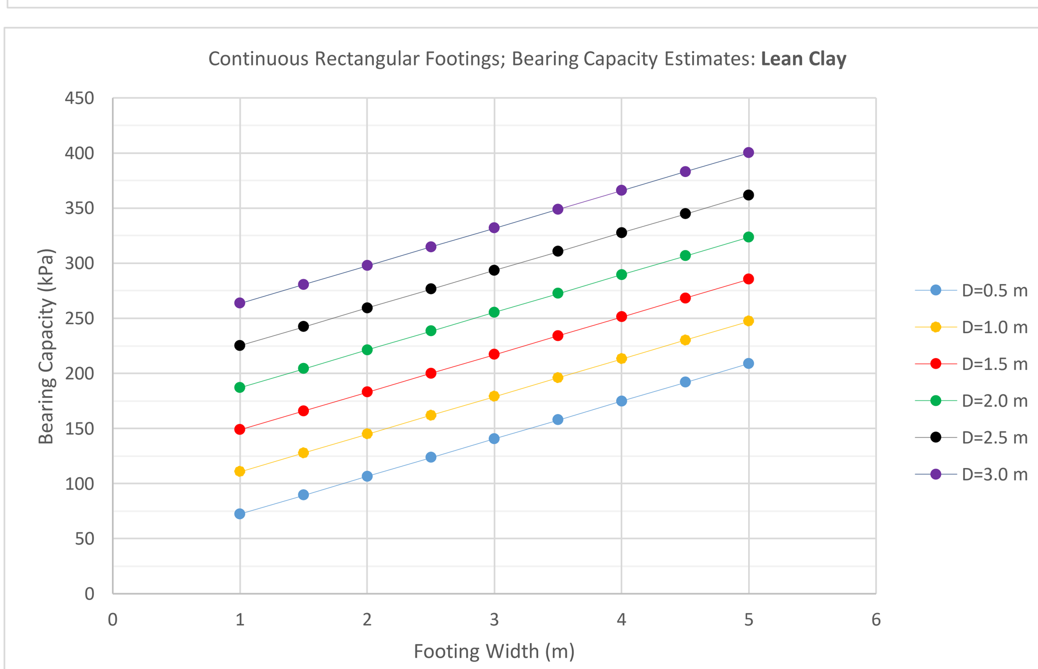
Nc	37.2
Nq	22.5
Nγ	20.1

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	5.1	10.2	15.3	20.4	25.5	30.6

B/L	1.5	2	3	5	10	100
Cs	1.36	1.52	1.78	2.1	2.53	4

	Footing Width (m)	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**
Square Footings (B<4L)	1	72	111	149	187	225	263
	1.5	89	128	166	204	242	280
	2	106	145	183	221	259	298
	2.5	124	162	200	238	276	315
	3	141	179	217	255	293	332
	3.5	158	196	234	272	311	349
	4	175	213	251	289	328	366
	4.5	192	230	268	306	345	383
	5	209	247	285	324	362	400





Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
0.5	1.0	72	0.001	0.001	0.001	0.001	0.002	0.003
	1.5	89	0.002	0.002	0.002	0.003	0.003	0.005
	2.0	106	0.003	0.003	0.003	0.004	0.005	0.008
	2.5	124	0.004	0.004	0.005	0.006	0.007	0.011
	3.0	141	0.005	0.006	0.007	0.008	0.010	0.015
	3.5	158	0.007	0.008	0.009	0.011	0.013	0.020
	4.0	175	0.009	0.010	0.011	0.013	0.016	0.025
	4.5	192	0.011	0.012	0.014	0.016	0.020	0.031
	5.0	209	0.013	0.014	0.017	0.020	0.024	0.038

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1	1.0	111	0.001	0.002	0.002	0.002	0.003	0.004
	1.5	128	0.002	0.003	0.003	0.004	0.004	0.007
	2.0	145	0.004	0.004	0.005	0.006	0.007	0.011
	2.5	162	0.005	0.006	0.007	0.008	0.009	0.015
	3.0	179	0.007	0.007	0.009	0.010	0.012	0.020
	3.5	196	0.008	0.009	0.011	0.013	0.016	0.025
	4.0	213	0.011	0.012	0.014	0.016	0.020	0.031
	4.5	230	0.013	0.014	0.017	0.020	0.024	0.038
	5.0	247	0.015	0.017	0.020	0.024	0.028	0.045

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1.5	1.0	149	0.002	0.002	0.002	0.003	0.003	0.005
	1.5	166	0.003	0.003	0.004	0.005	0.006	0.009
	2.0	183	0.005	0.005	0.006	0.007	0.008	0.013
	2.5	200	0.006	0.007	0.008	0.010	0.012	0.018
	3.0	217	0.008	0.009	0.011	0.012	0.015	0.024
	3.5	234	0.010	0.011	0.013	0.016	0.019	0.030
	4.0	251	0.012	0.014	0.016	0.019	0.023	0.037
	4.5	268	0.015	0.017	0.020	0.023	0.028	0.044
	5.0	285	0.018	0.020	0.023	0.027	0.033	0.052

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2	1.0	187	0.002	0.003	0.003	0.004	0.004	0.007
	1.5	204	0.004	0.004	0.005	0.006	0.007	0.011
	2.0	221	0.005	0.006	0.007	0.008	0.010	0.016
	2.5	238	0.007	0.008	0.010	0.011	0.014	0.022
	3.0	255	0.009	0.011	0.012	0.015	0.018	0.028
	3.5	272	0.012	0.013	0.015	0.018	0.022	0.035
	4.0	289	0.014	0.016	0.019	0.022	0.027	0.042
	4.5	306	0.017	0.019	0.022	0.026	0.032	0.050
	5.0	324	0.020	0.022	0.026	0.031	0.037	0.059

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2.5	1.0	225	0.003	0.003	0.004	0.004	0.005	0.008
	1.5	242	0.004	0.005	0.006	0.007	0.008	0.013
	2.0	259	0.006	0.007	0.008	0.010	0.012	0.019
	2.5	276	0.009	0.010	0.011	0.013	0.016	0.025
	3.0	293	0.011	0.012	0.014	0.017	0.020	0.032
	3.5	311	0.013	0.015	0.018	0.021	0.025	0.040
	4.0	328	0.016	0.018	0.021	0.025	0.030	0.048
	4.5	345	0.019	0.021	0.025	0.030	0.036	0.056
	5.0	362	0.022	0.025	0.029	0.035	0.042	0.066

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
3	1.0	263	0.003	0.004	0.004	0.005	0.006	0.010
	1.5	280	0.005	0.006	0.007	0.008	0.010	0.015
	2.0	298	0.007	0.008	0.010	0.011	0.014	0.022
	2.5	315	0.010	0.011	0.013	0.015	0.018	0.029
	3.0	332	0.012	0.014	0.016	0.019	0.023	0.036
	3.5	349	0.015	0.017	0.020	0.023	0.028	0.044
	4.0	366	0.018	0.020	0.024	0.028	0.034	0.053
	4.5	383	0.021	0.024	0.028	0.033	0.040	0.063
	5.0	400	0.025	0.028	0.032	0.038	0.046	0.073

For square footings:

$$q_{ult} = 1.3c'N_c + \sigma_D' N_q + 0.4\gamma' B N_\gamma \qquad (17.5)$$

For continuous footings:

$$q_{ult} = c'N_c + \sigma_D' N_q + 0.5\gamma' B N_\gamma \qquad (17.6)$$

For circular footings:

$$q_{ult} = 1.3c'N_c + \sigma_D' N_q + 0.3\gamma' B N_\gamma \qquad (17.7)$$

where:
q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface
($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_i(x, y) = C_s q B\left(\frac{1-\mu^2}{E}\right) \qquad (5\text{-}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

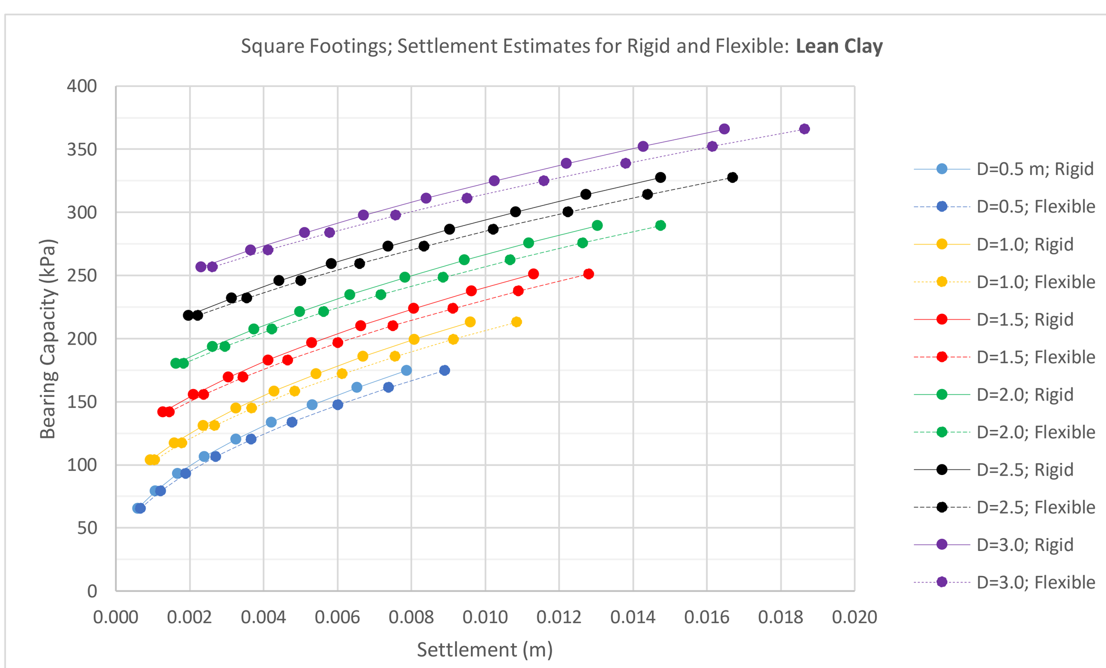
Flexible Square Footings

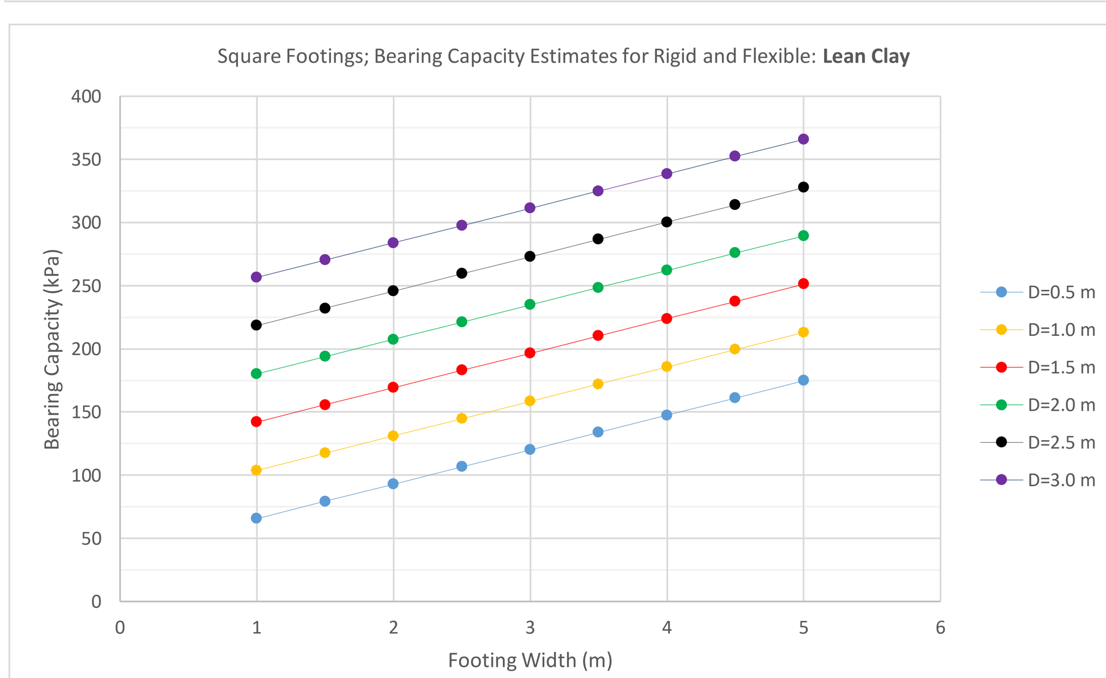
Soil Unit	**Lean Clay**
Layer Thickness	10
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	20.0
Saturated Unit Weight, kN/m4	20.0
Friction Angle, Φ (°)	30
Cohesion c'	0
water table depth	>30 m
E (kPa)	100000
Poisson Ratio	0.3

Nc	37.2
Nq	22.5
Nγ	20.1

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	5.1	10.2	15.3	20.4	25.5	30.6

	Footing Width (m)	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**
Square Footings (B<4L)	1	66	104	142	180	218	257
	1.5	79	117	156	194	232	270
	2	93	131	169	207	246	284
	2.5	106	145	183	221	259	298
	3	120	158	197	235	273	311
	3.5	134	172	210	248	287	325
	4	147	186	224	262	300	339
	4.5	161	199	238	276	314	352
	5	175	213	251	289	328	366





B/L	1.5	2	3	5	10	100
Cs	1.12	1.12	1.12	1.12	1.12	1.12

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
0.5	1.0	66	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	79	0.001	0.001	0.001	0.001	0.001	0.001
	2.0	93	0.002	0.002	0.002	0.002	0.002	0.002
	2.5	106	0.003	0.003	0.003	0.003	0.003	0.003
	3.0	120	0.004	0.004	0.004	0.004	0.004	0.004
	3.5	134	0.005	0.005	0.005	0.005	0.005	0.005
	4.0	147	0.006	0.006	0.006	0.006	0.006	0.006
	4.5	161	0.007	0.007	0.007	0.007	0.007	0.007
	5.0	175	0.009	0.009	0.009	0.009	0.009	0.009

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1	1.0	104	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	117	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	131	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	145	0.004	0.004	0.004	0.004	0.004	0.004
	3.0	158	0.005	0.005	0.005	0.005	0.005	0.005
	3.5	172	0.006	0.006	0.006	0.006	0.006	0.006
	4.0	186	0.008	0.008	0.008	0.008	0.008	0.008
	4.5	199	0.009	0.009	0.009	0.009	0.009	0.009
	5.0	213	0.011	0.011	0.011	0.011	0.011	0.011

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1.5	1.0	142	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	156	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	169	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	183	0.005	0.005	0.005	0.005	0.005	0.005
	3.0	197	0.006	0.006	0.006	0.006	0.006	0.006
	3.5	210	0.007	0.007	0.007	0.007	0.007	0.007
	4.0	224	0.009	0.009	0.009	0.009	0.009	0.009
	4.5	238	0.011	0.011	0.011	0.011	0.011	0.011
	5.0	251	0.013	0.013	0.013	0.013	0.013	0.013

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2	1.0	180	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	194	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	207	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	221	0.006	0.006	0.006	0.006	0.006	0.006
	3.0	235	0.007	0.007	0.007	0.007	0.007	0.007
	3.5	248	0.009	0.009	0.009	0.009	0.009	0.009
	4.0	262	0.011	0.011	0.011	0.011	0.011	0.011
	4.5	276	0.013	0.013	0.013	0.013	0.013	0.013
	5.0	289	0.015	0.015	0.015	0.015	0.015	0.015

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2.5	1.0	218	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	232	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	246	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	259	0.007	0.007	0.007	0.007	0.007	0.007
	3.0	273	0.008	0.008	0.008	0.008	0.008	0.008
	3.5	287	0.010	0.010	0.010	0.010	0.010	0.010
	4.0	300	0.012	0.012	0.012	0.012	0.012	0.012
	4.5	314	0.014	0.014	0.014	0.014	0.014	0.014
	5.0	328	0.017	0.017	0.017	0.017	0.017	0.017

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
3	1.0	257	0.003	0.003	0.003	0.003	0.003	0.003
	1.5	270	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	284	0.006	0.006	0.006	0.006	0.006	0.006
	2.5	298	0.008	0.008	0.008	0.008	0.008	0.008
	3.0	311	0.010	0.010	0.010	0.010	0.010	0.010
	3.5	325	0.012	0.012	0.012	0.012	0.012	0.012
	4.0	339	0.014	0.014	0.014	0.014	0.014	0.014
	4.5	352	0.016	0.016	0.016	0.016	0.016	0.016
	5.0	366	0.019	0.019	0.019	0.019	0.019	0.019

For square footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma} \qquad (17.5)$$

For continuous footings:

$$\boxed{q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma} \qquad (17.6)$$

For circular footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma} \qquad (17.7)$$

where:

q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface
($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

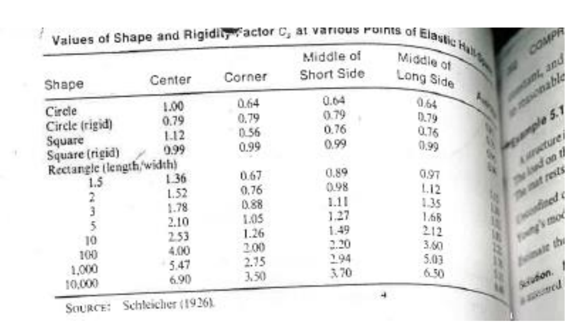
ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_i(x, y) = C_s B \left(\frac{1-\mu^2}{E}\right) \qquad (5\text{–}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated



Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

Rigid Circular Footings

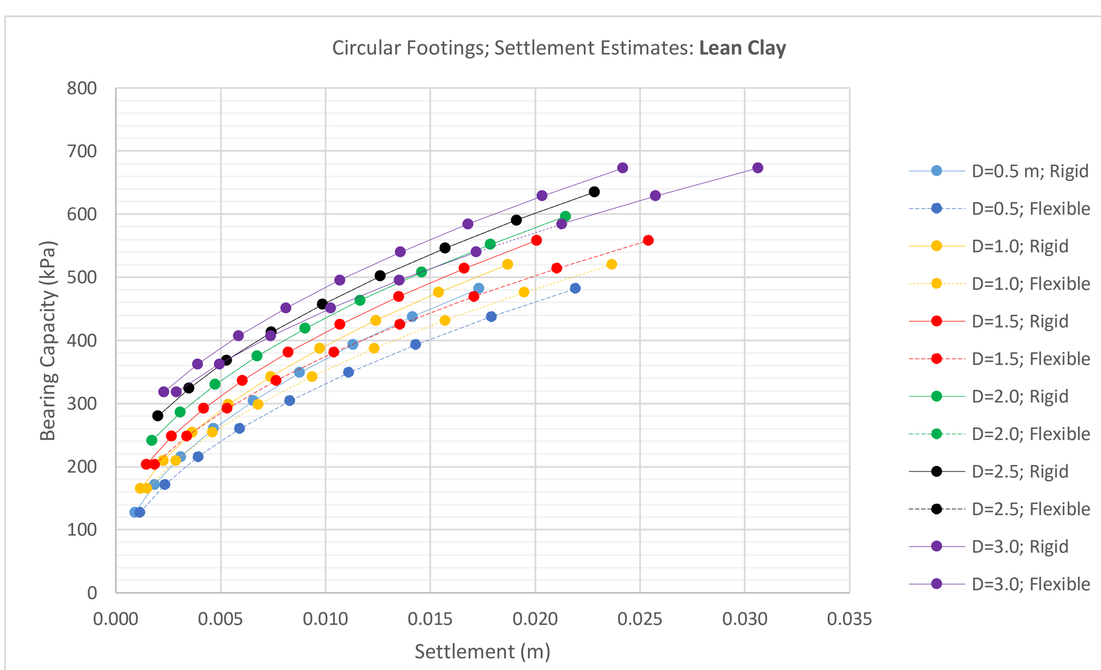
Soil Unit	**Lean Clay**
Layer Thickness	10
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	20.0
Saturated Unit Weight, kN/m4	20.0
Friction Angle, Φ (°)	30
Cohesion c'	0
water table depth	>30 m
E (kPa)	100000
Poisson Ratio	0.3

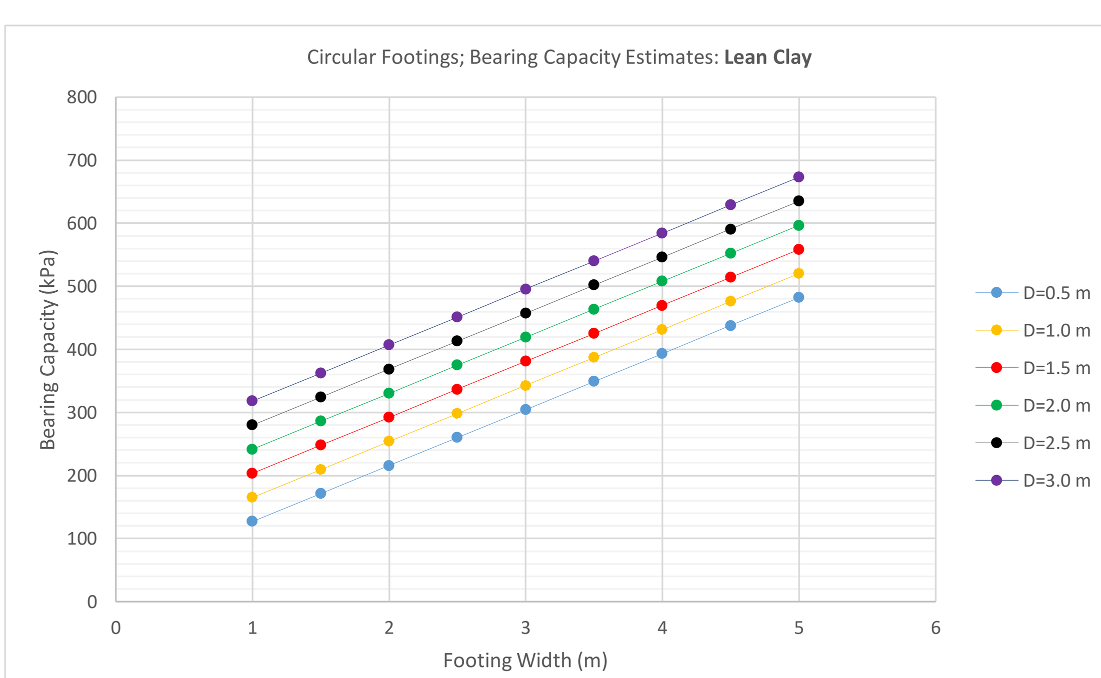
Nc	37.2
Nq	22.5
Nγ	20.1

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	5.1	10.2	15.3	20.4	25.5	30.6

B/L	1.5	2	3	5	10	100
Cs	0.79	0.79	0.79	0.79	0.79	0.79

	Footing Width (m)	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**
Square Footings (B<4L)	1	127	165	203	242	280	318
	1.5	171	210	248	286	324	362
	2	216	254	292	330	369	407
	2.5	260	298	337	375	413	451
	3	304	343	381	419	457	496
	3.5	349	387	425	463	502	540
	4	393	431	470	508	546	584
	4.5	438	476	514	552	590	629
	5	482	520	558	597	635	673





Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
0.5	1.0	127	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	171	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	216	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	260	0.005	0.005	0.005	0.005	0.005	0.005
	3.0	304	0.007	0.007	0.007	0.007	0.007	0.007
	3.5	349	0.009	0.009	0.009	0.009	0.009	0.009
	4.0	393	0.011	0.011	0.011	0.011	0.011	0.011
	4.5	438	0.014	0.014	0.014	0.014	0.014	0.014
	5.0	482	0.017	0.017	0.017	0.017	0.017	0.017

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1	1.0	165	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	210	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	254	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	298	0.005	0.005	0.005	0.005	0.005	0.005
	3.0	343	0.007	0.007	0.007	0.007	0.007	0.007
	3.5	387	0.010	0.010	0.010	0.010	0.010	0.010
	4.0	431	0.012	0.012	0.012	0.012	0.012	0.012
	4.5	476	0.015	0.015	0.015	0.015	0.015	0.015
	5.0	520	0.019	0.019	0.019	0.019	0.019	0.019

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1.5	1.0	203	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	248	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	292	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	337	0.006	0.006	0.006	0.006	0.006	0.006
	3.0	381	0.008	0.008	0.008	0.008	0.008	0.008
	3.5	425	0.011	0.011	0.011	0.011	0.011	0.011
	4.0	470	0.014	0.014	0.014	0.014	0.014	0.014
	4.5	514	0.017	0.017	0.017	0.017	0.017	0.017
	5.0	558	0.020	0.020	0.020	0.020	0.020	0.020

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2	1.0	242	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	286	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	330	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	375	0.007	0.007	0.007	0.007	0.007	0.007
	3.0	419	0.009	0.009	0.009	0.009	0.009	0.009
	3.5	463	0.012	0.012	0.012	0.012	0.012	0.012
	4.0	508	0.015	0.015	0.015	0.015	0.015	0.015
	4.5	552	0.018	0.018	0.018	0.018	0.018	0.018
	5.0	597	0.021	0.021	0.021	0.021	0.021	0.021

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2.5	1.0	280	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	324	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	369	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	413	0.007	0.007	0.007	0.007	0.007	0.007
	3.0	457	0.010	0.010	0.010	0.010	0.010	0.010
	3.5	502	0.013	0.013	0.013	0.013	0.013	0.013
	4.0	546	0.016	0.016	0.016	0.016	0.016	0.016
	4.5	590	0.019	0.019	0.019	0.019	0.019	0.019
	5.0	635	0.023	0.023	0.023	0.023	0.023	0.023

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
3	1.0	318	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	362	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	407	0.006	0.006	0.006	0.006	0.006	0.006
	2.5	451	0.008	0.008	0.008	0.008	0.008	0.008
	3.0	496	0.011	0.011	0.011	0.011	0.011	0.011
	3.5	540	0.014	0.014	0.014	0.014	0.014	0.014
	4.0	584	0.017	0.017	0.017	0.017	0.017	0.017
	4.5	629	0.020	0.020	0.020	0.020	0.020	0.020
	5.0	673	0.024	0.024	0.024	0.024	0.024	0.024

For square footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma} \qquad (17.5)$$

For continuous footings:

$$\boxed{q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma} \qquad (17.6)$$

For circular footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma} \qquad (17.7)$$

where:

q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface ($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surfdce of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_d(x, y) = C_s B\left(\frac{1-\mu^2}{E}\right) \qquad (5\text{-}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

Flexible Circular Footings

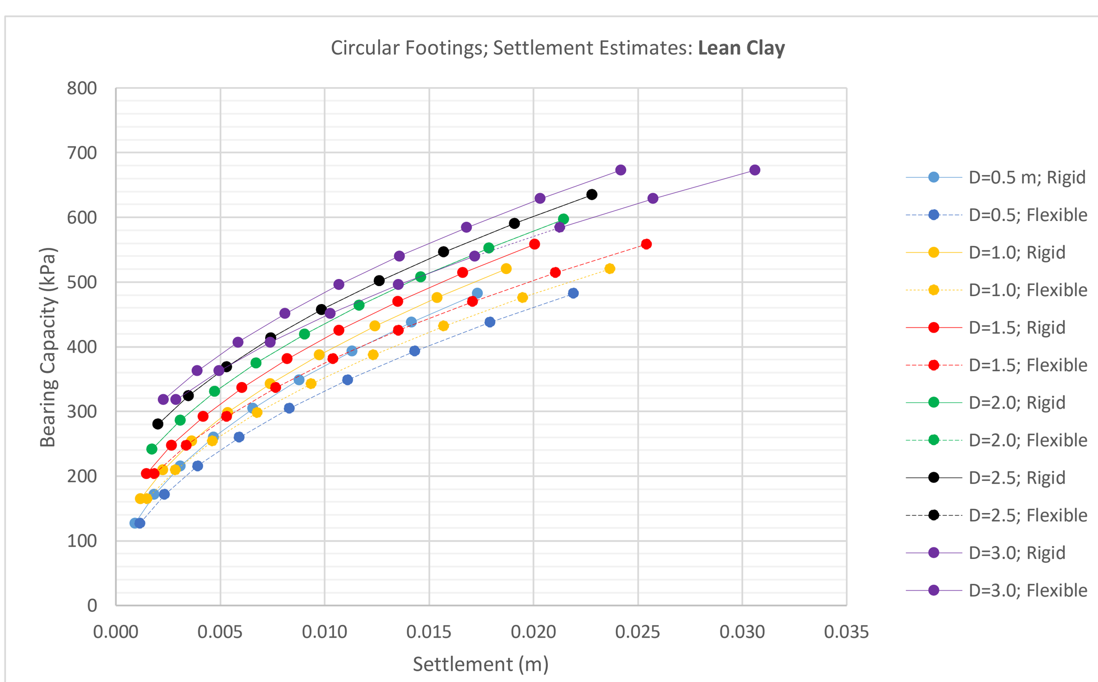
Soil Unit	**Lean Clay**
Layer Thickness	10
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	20.0
Saturated Unit Weight, kN/m4	20.0
Friction Angle, Φ (°)	30
Cohesion c'	0
water table depth	>30 m
E (kPa)	100000
Poisson Ratio	0.3

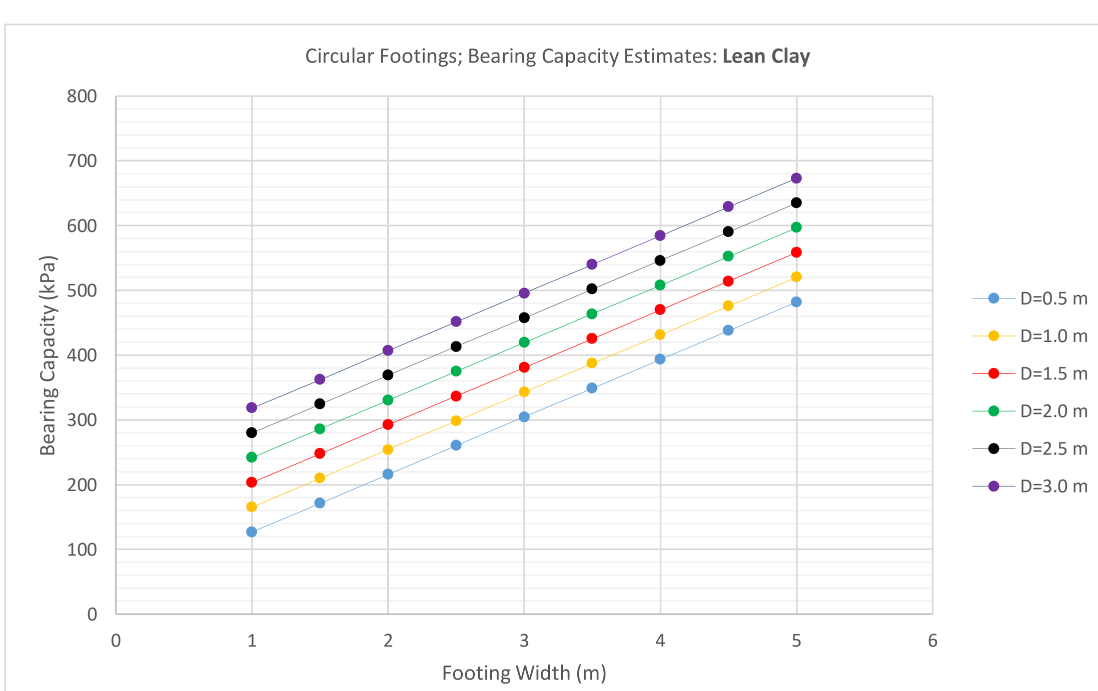
Nc	37.2	
Nq	22.5	terzaghi
Nγ	20.1	

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	5.1	10.2	15.3	20.4	25.5	30.6

B/L	1.5	2	3	5	10	100
Cs	1	1	1	1	1	1

	Footing Width (m)	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**
Square Footings (B<4L)	1	127	165	203	242	280	318
	1.5	171	210	248	286	324	362
	2	216	254	292	330	369	407
	2.5	260	298	337	375	413	451
	3	304	343	381	419	457	496
	3.5	349	387	425	463	502	540
	4	393	431	470	508	546	584
	4.5	438	476	514	552	590	629
	5	482	520	558	597	635	673





Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
0.5	1.0	127	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	171	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	216	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	260	0.006	0.006	0.006	0.006	0.006	0.006
	3.0	304	0.008	0.008	0.008	0.008	0.008	0.008
	3.5	349	0.011	0.011	0.011	0.011	0.011	0.011
	4.0	393	0.014	0.014	0.014	0.014	0.014	0.014
	4.5	438	0.018	0.018	0.018	0.018	0.018	0.018
	5.0	482	0.022	0.022	0.022	0.022	0.022	0.022

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1	1.0	165	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	210	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	254	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	298	0.007	0.007	0.007	0.007	0.007	0.007
	3.0	343	0.009	0.009	0.009	0.009	0.009	0.009
	3.5	387	0.012	0.012	0.012	0.012	0.012	0.012
	4.0	431	0.016	0.016	0.016	0.016	0.016	0.016
	4.5	476	0.019	0.019	0.019	0.019	0.019	0.019
	5.0	520	0.024	0.024	0.024	0.024	0.024	0.024

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
1.5	1.0	203	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	248	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	292	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	337	0.008	0.008	0.008	0.008	0.008	0.008
	3.0	381	0.010	0.010	0.010	0.010	0.010	0.010
	3.5	425	0.014	0.014	0.014	0.014	0.014	0.014
	4.0	470	0.017	0.017	0.017	0.017	0.017	0.017
	4.5	514	0.021	0.021	0.021	0.021	0.021	0.021
	5.0	558	0.025	0.025	0.025	0.025	0.025	0.025

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2	1.0	242	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	286	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	330	0.006	0.006	0.006	0.006	0.006	0.006
	2.5	375	0.009	0.009	0.009	0.009	0.009	0.009
	3.0	419	0.011	0.011	0.011	0.011	0.011	0.011
	3.5	463	0.015	0.015	0.015	0.015	0.015	0.015
	4.0	508	0.018	0.018	0.018	0.018	0.018	0.018
	4.5	552	0.023	0.023	0.023	0.023	0.023	0.023
	5.0	597	0.027	0.027	0.027	0.027	0.027	0.027

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
2.5	1.0	280	0.003	0.003	0.003	0.003	0.003	0.003
	1.5	324	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	369	0.007	0.007	0.007	0.007	0.007	0.007
	2.5	413	0.009	0.009	0.009	0.009	0.009	0.009
	3.0	457	0.012	0.012	0.012	0.012	0.012	0.012
	3.5	502	0.016	0.016	0.016	0.016	0.016	0.016
	4.0	546	0.020	0.020	0.020	0.020	0.020	0.020
	4.5	590	0.024	0.024	0.024	0.024	0.024	0.024
	5.0	635	0.029	0.029	0.029	0.029	0.029	0.029

Depth (m)	**B**	**q**	**L/B=1.5**	**L/B=2**	**L/B=3**	**L/B=5**	**L/B=10**	**L/B=100**
3	1.0	318	0.003	0.003	0.003	0.003	0.003	0.003
	1.5	362	0.005	0.005	0.005	0.005	0.005	0.005
	2.0	407	0.007	0.007	0.007	0.007	0.007	0.007
	2.5	451	0.010	0.010	0.010	0.010	0.010	0.010
	3.0	496	0.014	0.014	0.014	0.014	0.014	0.014
	3.5	540	0.017	0.017	0.017	0.017	0.017	0.017
	4.0	584	0.021	0.021	0.021	0.021	0.021	0.021
	4.5	629	0.026	0.026	0.026	0.026	0.026	0.026
	5.0	673	0.031	0.031	0.031	0.031	0.031	0.031

For square footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma} \quad (17.5)$$

For continuous footings:

$$\boxed{q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma} \quad (17.6)$$

For circular footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma} \quad (17.7)$$

where:
q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface ($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_d(x, y) = C_{xy} B \left(\frac{1 - \mu^2}{E}\right) \quad (5\text{-}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

Rigid Square Footings

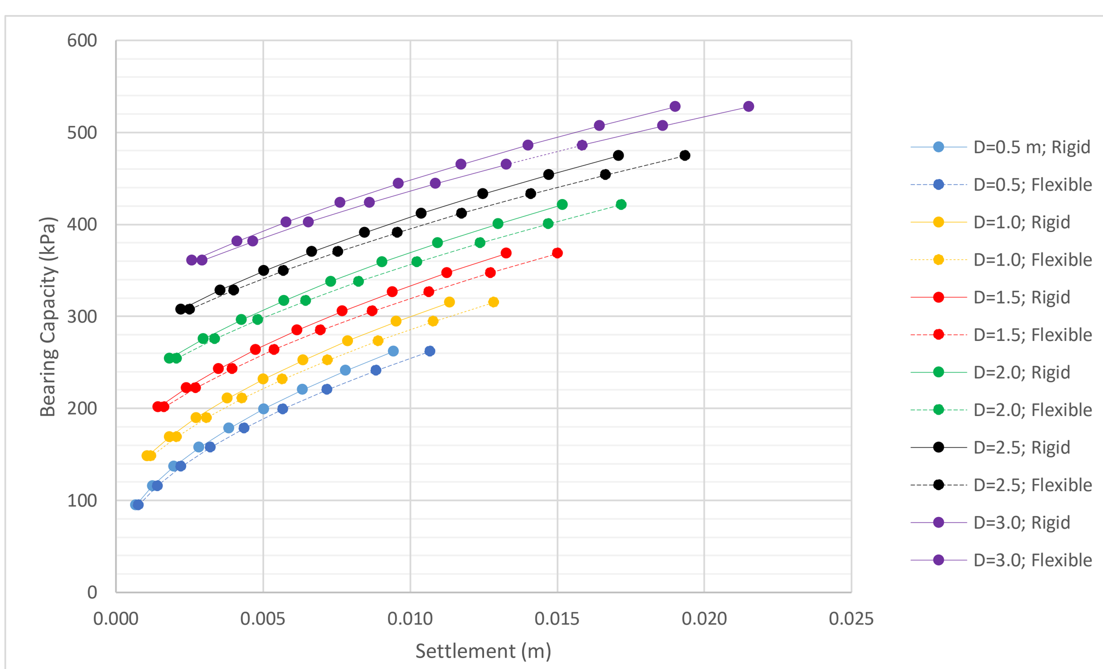
Soil Unit	Sandy Clay
Layer Thickness	20
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	21.0
Saturated Unit Weight, kN/m3	21.0 = dry as water table is greater than 30 m
Friction Angle, Φ (°)	32
Cohesion c'	0
water table depth	>30 m
E (kPa)	125000
Poisson Ratio	0.3

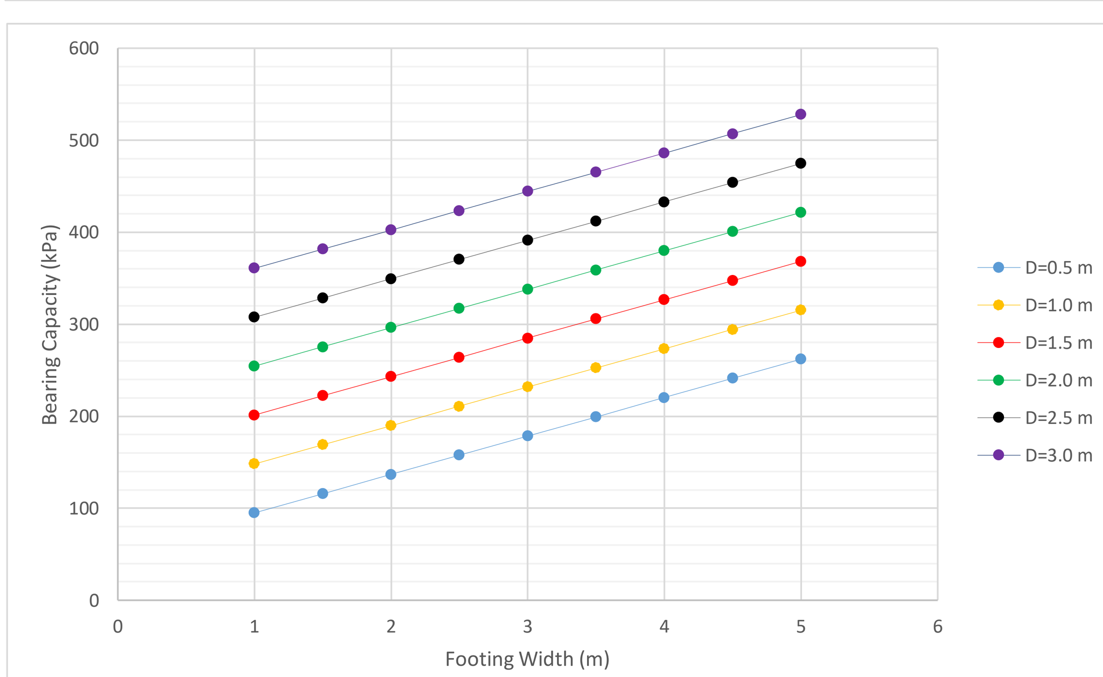
Nc	44
Nq	28.5
Nγ	28

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	5.6	11.2	16.8	22.4	28.0	33.6

B/L	1.5	2	3	5	10	100
Cs	0.99	0.99	0.99	0.99	0.99	0.99

		0.5	1	1.5	2	2.5	3
	Footing Width (m)	q (kPa)	q (kPa)	q (kPa)	q (kPa)	q (kPa)	q (kPa)
Square Footings (B<4L)	1	95	148	201	254	308	361
	1.5	116	169	222	275	328	382
	2	137	190	243	296	349	402
	2.5	158	211	264	317	370	423
	3	178	232	285	338	391	444
	3.5	199	253	306	359	412	465
	4	220	273	327	380	433	486
	4.5	241	294	347	401	454	507
	5	262	315	368	421	475	528





Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
0.5	1.0	95	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	116	0.001	0.001	0.001	0.001	0.001	0.001
	2.0	137	0.002	0.002	0.002	0.002	0.002	0.002
	2.5	158	0.003	0.003	0.003	0.003	0.003	0.003
	3.0	178	0.004	0.004	0.004	0.004	0.004	0.004
	3.5	199	0.005	0.005	0.005	0.005	0.005	0.005
	4.0	220	0.006	0.006	0.006	0.006	0.006	0.006
	4.5	241	0.008	0.008	0.008	0.008	0.008	0.008
	5.0	262	0.009	0.009	0.009	0.009	0.009	0.009

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
1	1.0	148	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	169	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	190	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	211	0.004	0.004	0.004	0.004	0.004	0.004
	3.0	232	0.005	0.005	0.005	0.005	0.005	0.005
	3.5	253	0.006	0.006	0.006	0.006	0.006	0.006
	4.0	273	0.008	0.008	0.008	0.008	0.008	0.008
	4.5	294	0.010	0.010	0.010	0.010	0.010	0.010
	5.0	315	0.011	0.011	0.011	0.011	0.011	0.011

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
1.5	1.0	201	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	222	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	243	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	264	0.005	0.005	0.005	0.005	0.005	0.005
	3.0	285	0.006	0.006	0.006	0.006	0.006	0.006
	3.5	306	0.008	0.008	0.008	0.008	0.008	0.008
	4.0	327	0.009	0.009	0.009	0.009	0.009	0.009
	4.5	347	0.011	0.011	0.011	0.011	0.011	0.011
	5.0	368	0.013	0.013	0.013	0.013	0.013	0.013

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
2	1.0	254	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	275	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	296	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	317	0.006	0.006	0.006	0.006	0.006	0.006
	3.0	338	0.007	0.007	0.007	0.007	0.007	0.007
	3.5	359	0.009	0.009	0.009	0.009	0.009	0.009
	4.0	380	0.011	0.011	0.011	0.011	0.011	0.011
	4.5	401	0.013	0.013	0.013	0.013	0.013	0.013
	5.0	421	0.015	0.015	0.015	0.015	0.015	0.015

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
2.5	1.0	308	0.0	0.0	0.0	0.0	0.0	0.0
	1.5	328	0.0	0.0	0.0	0.0	0.0	0.0
	2.0	349	0.0	0.0	0.0	0.0	0.0	0.0
	2.5	370	0.0	0.0	0.0	0.0	0.0	0.0
	3.0	391	0.0	0.0	0.0	0.0	0.0	0.0
	3.5	412	0.0	0.0	0.0	0.0	0.0	0.0
	4.0	433	0.0	0.0	0.0	0.0	0.0	0.0
	4.5	454	0.0	0.0	0.0	0.0	0.0	0.0
	5.0	475	0.0	0.0	0.0	0.0	0.0	0.0

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
3	1.0	361	0.003	0.003	0.003	0.003	0.003	0.003
	1.5	382	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	402	0.006	0.006	0.006	0.006	0.006	0.006
	2.5	423	0.008	0.008	0.008	0.008	0.008	0.008
	3.0	444	0.010	0.010	0.010	0.010	0.010	0.010
	3.5	465	0.012	0.012	0.012	0.012	0.012	0.012
	4.0	486	0.014	0.014	0.014	0.014	0.014	0.014
	4.5	507	0.016	0.016	0.016	0.016	0.016	0.016
	5.0	528	0.019	0.019	0.019	0.019	0.019	0.019

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

For square footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma} \quad (17.5)$$

For continuous footings:

$$\boxed{q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma} \quad (17.6)$$

For circular footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma} \quad (17.7)$$

where:

q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface ($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_d(x, y) = C_s q B \left(\frac{1 - \mu^2}{E}\right) \quad (5\text{–}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

Flexible Square Footings

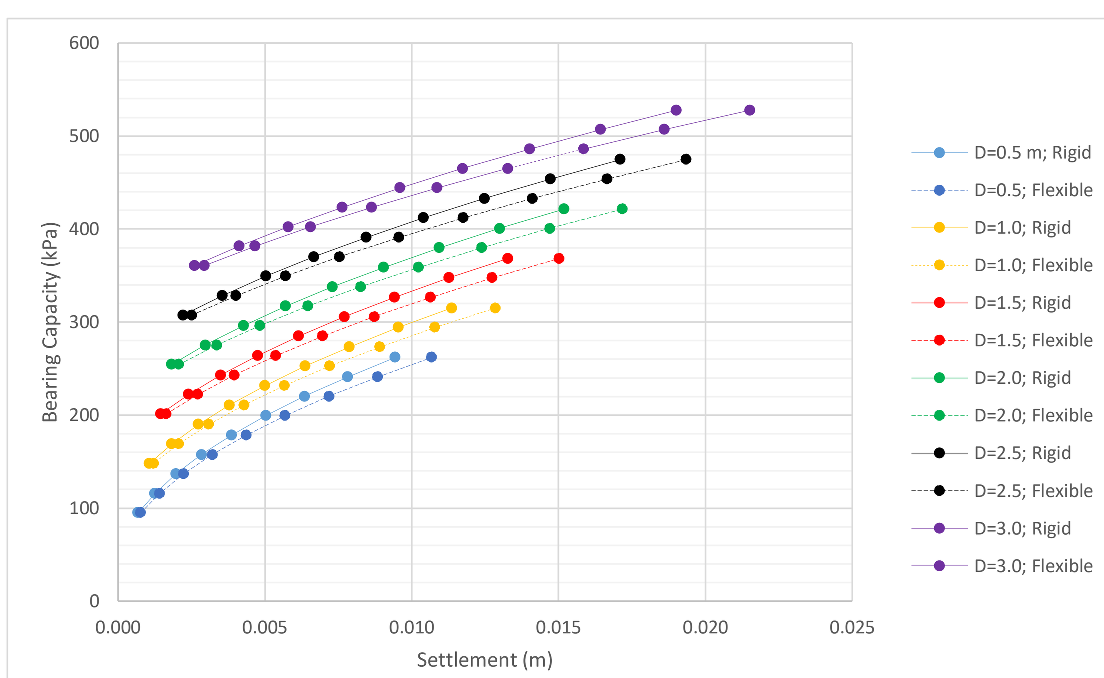
Soil Unit	Sandy Clay
Layer Thickness	20
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	21.0
Saturated Unit Weight, kN/m4	21.0
Friction Angle, Φ (°)	32
Cohesion c'	0
water table depth	>30 m
E (kPa)	125000
Poisson Ratio	0.3

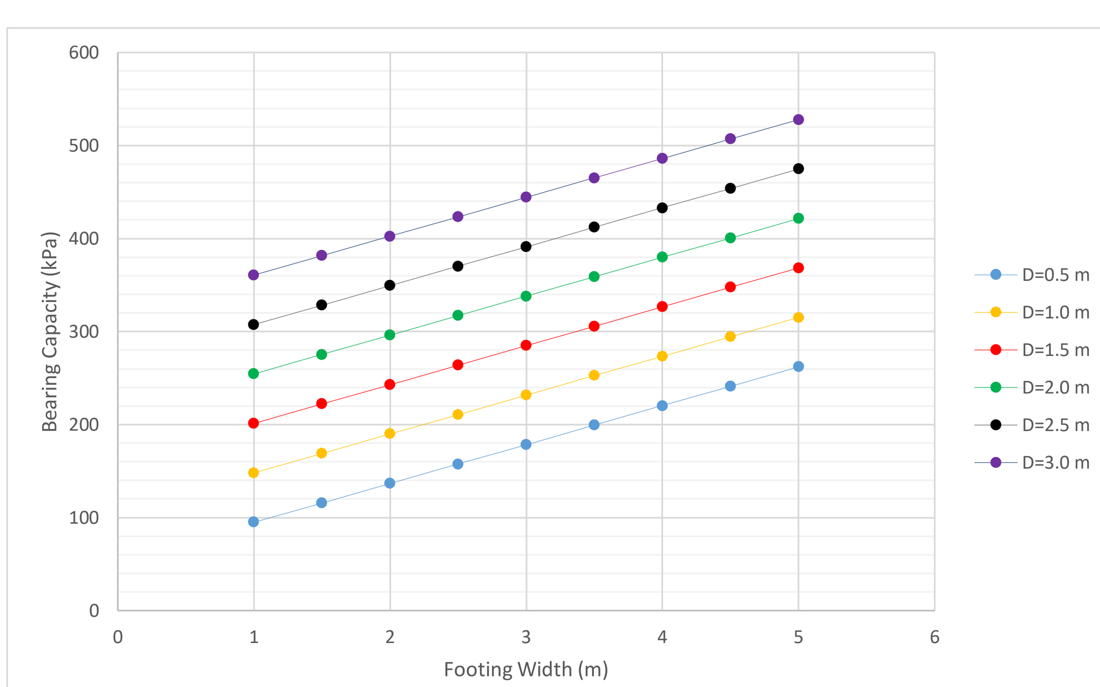
Nc	44
Nq	28.5
Nγ	28

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	5.6	11.2	16.8	22.4	28.0	33.6

B/L	1.5	2	3	5	10	100
Cs	1.12	1.12	1.12	1.12	1.12	1.12

	Footing Width (m)	q (kPa)	q (kPa)	q (kPa)	q (kPa)	q (kPa)	q (kPa)
Square Footings (B<4L)	1	95	148	201	254	308	361
	1.5	116	169	222	275	328	382
	2	137	190	243	296	349	402
	2.5	158	211	264	317	370	423
	3	178	232	285	338	391	444
	3.5	199	253	306	359	412	465
	4	220	273	327	380	433	486
	4.5	241	294	347	401	454	507
	5	262	315	368	421	475	528





Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
0.5	1.0	95	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	116	0.001	0.001	0.001	0.001	0.001	0.001
	2.0	137	0.002	0.002	0.002	0.002	0.002	0.002
	2.5	158	0.003	0.003	0.003	0.003	0.003	0.003
	3.0	178	0.004	0.004	0.004	0.004	0.004	0.004
	3.5	199	0.006	0.006	0.006	0.006	0.006	0.006
	4.0	220	0.007	0.007	0.007	0.007	0.007	0.007
	4.5	241	0.009	0.009	0.009	0.009	0.009	0.009
	5.0	262	0.011	0.011	0.011	0.011	0.011	0.011

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
1	1.0	148	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	169	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	190	0.003	0.003	0.003	0.003	0.003	0.003
	2.5	211	0.004	0.004	0.004	0.004	0.004	0.004
	3.0	232	0.006	0.006	0.006	0.006	0.006	0.006
	3.5	253	0.007	0.007	0.007	0.007	0.007	0.007
	4.0	273	0.009	0.009	0.009	0.009	0.009	0.009
	4.5	294	0.011	0.011	0.011	0.011	0.011	0.011
	5.0	315	0.013	0.013	0.013	0.013	0.013	0.013

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
1.5	1.0	201	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	222	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	243	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	264	0.005	0.005	0.005	0.005	0.005	0.005
	3.0	285	0.007	0.007	0.007	0.007	0.007	0.007
	3.5	306	0.009	0.009	0.009	0.009	0.009	0.009
	4.0	327	0.011	0.011	0.011	0.011	0.011	0.011
	4.5	347	0.013	0.013	0.013	0.013	0.013	0.013
	5.0	368	0.015	0.015	0.015	0.015	0.015	0.015

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
2	1.0	254	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	275	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	296	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	317	0.006	0.006	0.006	0.006	0.006	0.006
	3.0	338	0.008	0.008	0.008	0.008	0.008	0.008
	3.5	359	0.010	0.010	0.010	0.010	0.010	0.010
	4.0	380	0.012	0.012	0.012	0.012	0.012	0.012
	4.5	401	0.015	0.015	0.015	0.015	0.015	0.015
	5.0	421	0.017	0.017	0.017	0.017	0.017	0.017

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
2.5	1.0	308	0.003	0.003	0.003	0.003	0.003	0.003
	1.5	328	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	349	0.006	0.006	0.006	0.006	0.006	0.006
	2.5	370	0.008	0.008	0.008	0.008	0.008	0.008
	3.0	391	0.010	0.010	0.010	0.010	0.010	0.010
	3.5	412	0.012	0.012	0.012	0.012	0.012	0.012
	4.0	433	0.014	0.014	0.014	0.014	0.014	0.014
	4.5	454	0.017	0.017	0.017	0.017	0.017	0.017
	5.0	475	0.019	0.019	0.019	0.019	0.019	0.019

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
3	1.0	361	0.00	0.00	0.00	0.00	0.00	0.00
	1.5	382	0.00	0.00	0.00	0.00	0.00	0.00
	2.0	402	0.01	0.01	0.01	0.01	0.01	0.01
	2.5	423	0.01	0.01	0.01	0.01	0.01	0.01
	3.0	444	0.01	0.01	0.01	0.01	0.01	0.01
	3.5	465	0.01	0.01	0.01	0.01	0.01	0.01
	4.0	486	0.02	0.02	0.02	0.02	0.02	0.02
	4.5	507	0.02	0.02	0.02	0.02	0.02	0.02
	5.0	528	0.02	0.02	0.02	0.02	0.02	0.02

For square footings:

$$q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma \qquad (17.5)$$

For continuous footings:

$$q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma \qquad (17.6)$$

For circular footings:

$$q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma \qquad (17.7)$$

where:
q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface ($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surfdce of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_i(x, y) = C_s q B\left(\frac{1-\mu^2}{E}\right) \qquad (5\text{–}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

Continous Footings

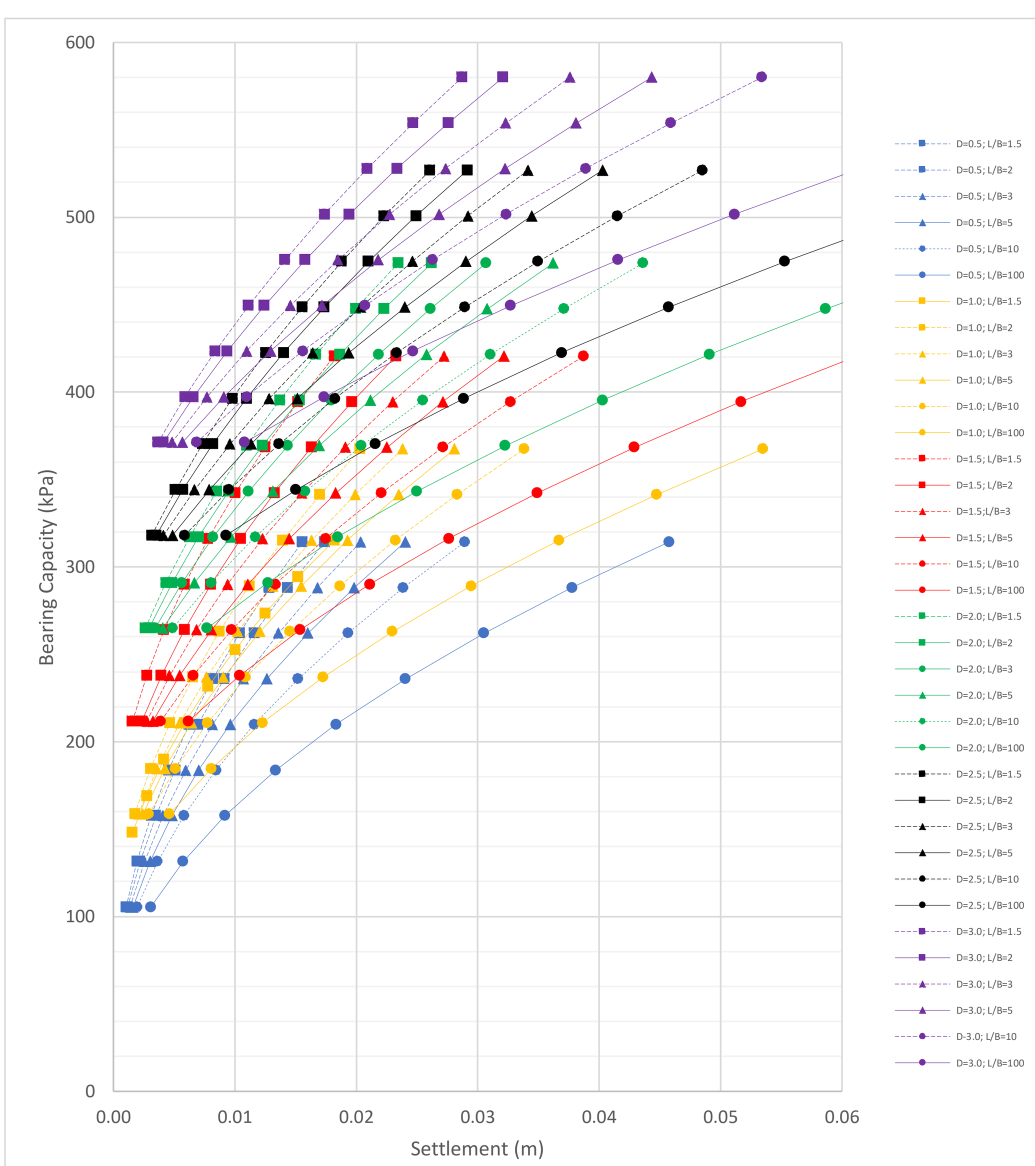
Soil Unit	Sandy Clay
Layer Thickness	20
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	21.0
Saturated Unit Weight, kN/m4	21.0
Friction Angle, Φ (°)	32
Cohesion c'	0
water table depth	>30 m
E (kPa)	125000
Poisson Ratio	0.3

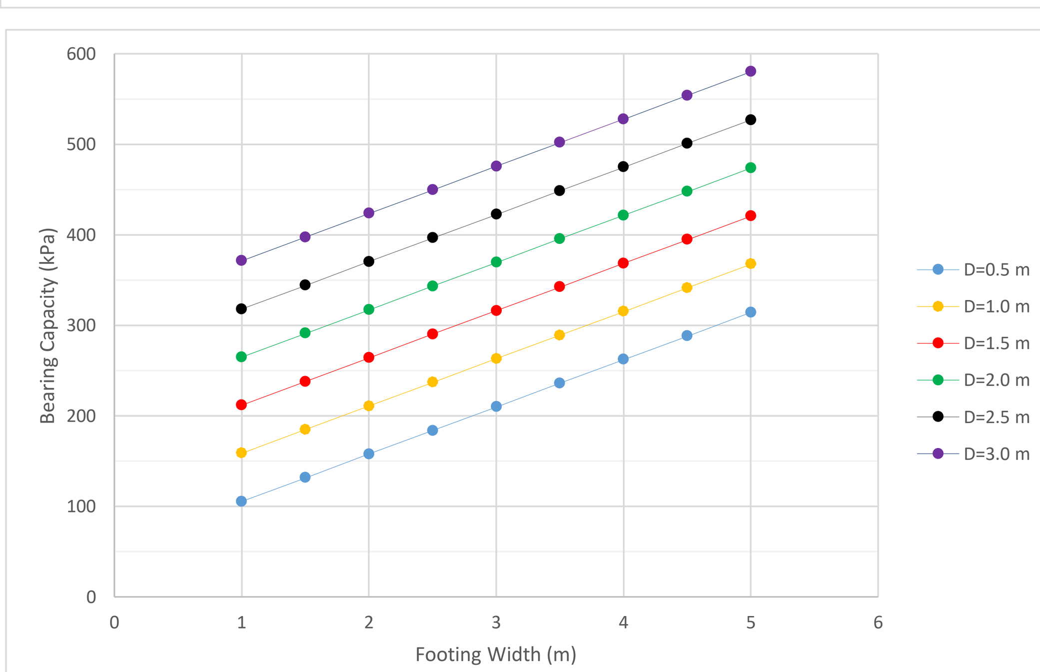
Nc	44
Nq	28.5
Nγ	28

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	5.6	11.2	16.8	22.4	28.0	33.6

B/L	1.5	2	3	5	10	100
Cs	1.36	1.52	1.78	2.1	2.53	4

	Footing Width (m)	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**	**q (kPa)**
Square Footings (B<4L)	1	105	159	212	265	318	371
	1.5	131	185	238	291	344	397
	2	158	211	264	317	370	423
	2.5	184	237	290	343	396	449
	3	210	263	316	369	422	476
	3.5	236	289	342	395	449	502
	4	262	315	368	421	475	528
	4.5	288	341	394	448	501	554
	5	314	367	421	474	527	580





Depth (m)	**B**	**q**	**B/L=1.5**	**B/L=2**	**B/L=3**	**B/L=5**	**B/L=10**	**B/L=100**
0.5	1.0	105	0.001	0.001	0.001	0.002	0.002	0.003
	1.5	131	0.002	0.002	0.003	0.003	0.004	0.006
	2.0	158	0.003	0.003	0.004	0.005	0.006	0.009
	2.5	184	0.005	0.005	0.006	0.007	0.008	0.013
	3.0	210	0.006	0.007	0.008	0.010	0.012	0.018
	3.5	236	0.008	0.009	0.011	0.013	0.015	0.024
	4.0	262	0.010	0.012	0.014	0.016	0.019	0.031
	4.5	288	0.013	0.014	0.017	0.020	0.024	0.038
	5.0	314	0.016	0.017	0.020	0.024	0.029	0.046

Depth (m)	**B**	**q**	**B/L=1.5**	**B/L=2**	**B/L=3**	**B/L=5**	**B/L=10**	**B/L=100**
1	1.0	159	0.002	0.002	0.002	0.002	0.003	0.005
	1.5	185	0.003	0.003	0.004	0.004	0.005	0.008
	2.0	211	0.004	0.005	0.005	0.006	0.008	0.012
	2.5	237	0.006	0.007	0.008	0.009	0.011	0.017
	3.0	263	0.008	0.009	0.010	0.012	0.015	0.023
	3.5	289	0.010	0.011	0.013	0.015	0.019	0.029
	4.0	315	0.012	0.014	0.016	0.019	0.023	0.037
	4.5	341	0.015	0.017	0.020	0.023	0.028	0.045
	5.0	367	0.018	0.020	0.024	0.028	0.034	0.053

Depth (m)	**B**	**q**	**B/L=1.5**	**B/L=2**	**B/L=3**	**B/L=5**	**B/L=10**	**B/L=100**
1.5	1.0	212	0.002	0.002	0.003	0.003	0.004	0.006
	1.5	238	0.004	0.004	0.005	0.005	0.007	0.010
	2.0	264	0.005	0.006	0.007	0.008	0.010	0.015
	2.5	290	0.007	0.008	0.009	0.011	0.013	0.021
	3.0	316	0.009	0.010	0.012	0.014	0.017	0.028
	3.5	342	0.012	0.013	0.016	0.018	0.022	0.035
	4.0	368	0.015	0.016	0.019	0.023	0.027	0.043
	4.5	394	0.018	0.020	0.023	0.027	0.033	0.052
	5.0	421	0.021	0.023	0.027	0.032	0.039	0.061

Depth (m)	**B**	**q**	**B/L=1.5**	**B/L=2**	**B/L=3**	**B/L=5**	**B/L=10**	**B/L=100**
2	1.0	265	0.003	0.003	0.003	0.004	0.005	0.008
	1.5	291	0.004	0.005	0.006	0.007	0.008	0.013
	2.0	317	0.006	0.007	0.008	0.010	0.012	0.018
	2.5	343	0.008	0.009	0.011	0.013	0.016	0.025
	3.0	369	0.011	0.012	0.014	0.017	0.020	0.032
	3.5	395	0.014	0.015	0.018	0.021	0.025	0.040
	4.0	421	0.017	0.019	0.022	0.026	0.031	0.049
	4.5	448	0.020	0.022	0.026	0.031	0.037	0.059
	5.0	474	0.023	0.026	0.031	0.036	0.044	0.069

Depth (m)	**B**	**q**	**B/L=1.5**	**B/L=2**	**B/L=3**	**B/L=5**	**B/L=10**	**B/L=100**
2.5	1.0	318	0.003	0.004	0.004	0.005	0.006	0.009
	1.5	344	0.005	0.006	0.007	0.008	0.010	0.015
	2.0	370	0.007	0.008	0.010	0.011	0.014	0.022
	2.5	396	0.010	0.011	0.013	0.015	0.018	0.029
	3.0	422	0.013	0.014	0.016	0.019	0.023	0.037
	3.5	449	0.016	0.017	0.020	0.024	0.029	0.046
	4.0	475	0.019	0.021	0.025	0.029	0.035	0.055
	4.5	501	0.022	0.025	0.029	0.034	0.042	0.066
	5.0	527	0.026	0.029	0.034	0.040	0.049	0.077

Depth (m)	**B**	**q**	**B/L=1.5**	**B/L=2**	**B/L=3**	**B/L=5**	**B/L=10**	**B/L=100**
3	1.0	371	0.004	0.004	0.005	0.006	0.007	0.011
	1.5	397	0.006	0.007	0.008	0.009	0.011	0.017
	2.0	423	0.008	0.009	0.011	0.013	0.016	0.025
	2.5	449	0.011	0.012	0.015	0.017	0.021	0.033
	3.0	476	0.014	0.016	0.018	0.022	0.026	0.042
	3.5	502	0.017	0.019	0.023	0.027	0.032	0.051
	4.0	528	0.021	0.023	0.027	0.032	0.039	0.061
	4.5	554	0.025	0.028	0.032	0.038	0.046	0.073
	5.0	580	0.029	0.032	0.038	0.044	0.053	0.084

For square footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma} \qquad (17.5)$$

For continuous footings:

$$\boxed{q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma} \qquad (17.6)$$

For circular footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma} \qquad (17.7)$$

where:
q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface
($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_i(x, y) = C_s qB\left(\frac{1-\mu^2}{E}\right) \qquad (5\text{-}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

Rigid Circular Footings

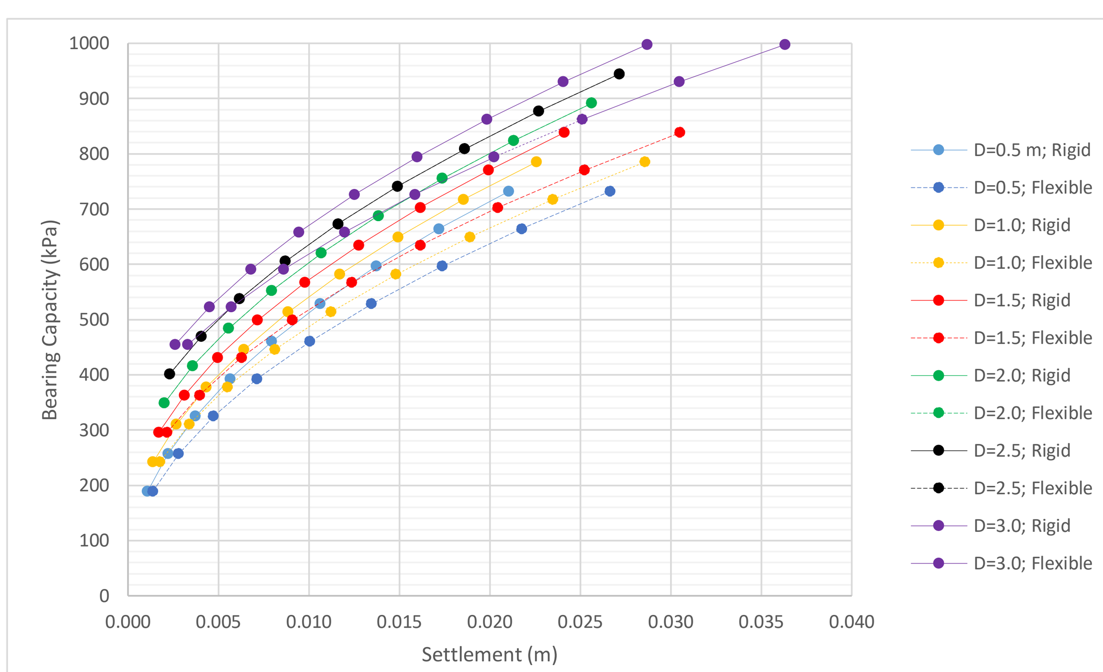
Soil Unit	Sandy Clay
Layer Thickness	20
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	21.0
Saturated Unit Weight, kN/m4	21.0
Friction Angle, Φ (°)	32
Cohesion c'	0
water table depth	>30 m
E (kPa)	125000
Poisson Ratio	0.3

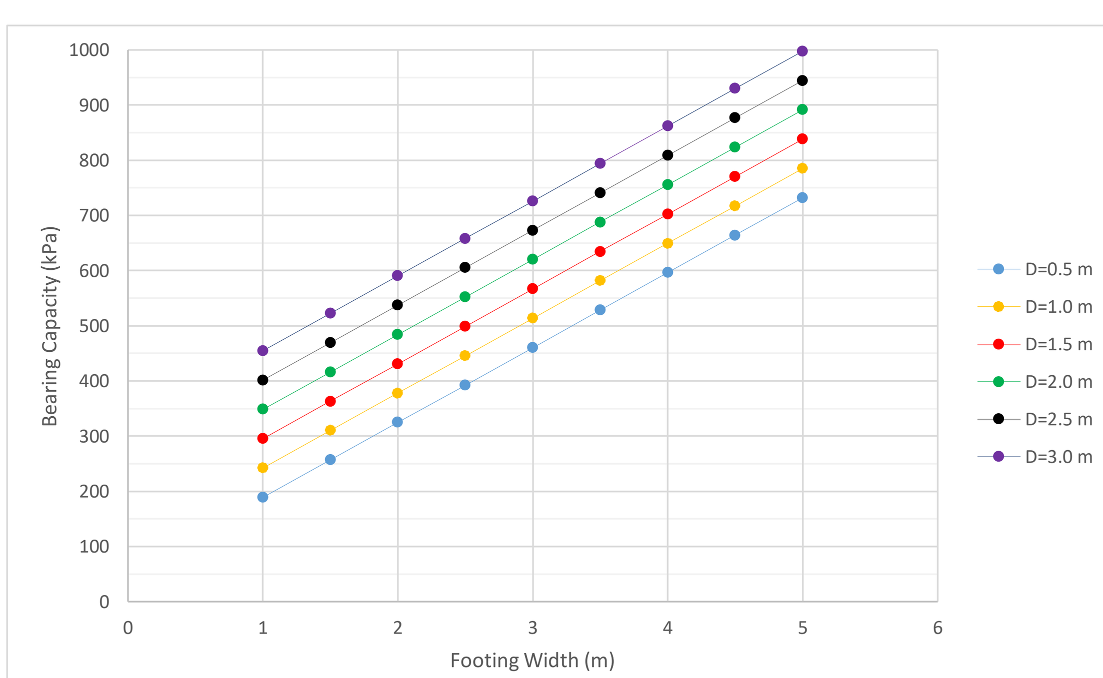
Nc	44
Nq	28.5
Nγ	28

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	5.6	11.2	16.8	22.4	28.0	33.6

B/L	1.5	2	3	5	10	100
Cs	0.79	0.79	0.79	0.79	0.79	0.79

	Footing Width (m)	q (kPa)	q (kPa)	q (kPa)	q (kPa)	q (kPa)	q (kPa)
Square Footings (B<4L)	1	189	242	295	348	402	455
	1.5	257	310	363	416	469	523
	2	325	378	431	484	537	590
	2.5	393	446	499	552	605	658
	3	460	514	567	620	673	726
	3.5	528	582	635	688	741	794
	4	596	649	703	756	809	862
	4.5	664	717	770	824	877	930
	5	732	785	838	891	945	998





Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
0.5	1.0	189	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	257	0.002	0.002	0.002	0.002	0.002	0.002
	2.0	325	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	393	0.006	0.006	0.006	0.006	0.006	0.006
	3.0	460	0.008	0.008	0.008	0.008	0.008	0.008
	3.5	528	0.011	0.011	0.011	0.011	0.011	0.011
	4.0	596	0.014	0.014	0.014	0.014	0.014	0.014
	4.5	664	0.017	0.017	0.017	0.017	0.017	0.017
	5.0	732	0.021	0.021	0.021	0.021	0.021	0.021

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
1	1.0	242	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	310	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	378	0.004	0.004	0.004	0.004	0.004	0.004
	2.5	446	0.006	0.006	0.006	0.006	0.006	0.006
	3.0	514	0.009	0.009	0.009	0.009	0.009	0.009
	3.5	582	0.012	0.012	0.012	0.012	0.012	0.012
	4.0	649	0.015	0.015	0.015	0.015	0.015	0.015
	4.5	717	0.019	0.019	0.019	0.019	0.019	0.019
	5.0	785	0.023	0.023	0.023	0.023	0.023	0.023

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
1.5	1.0	295	0.00	0.00	0.00	0.00	0.00	0.00
	1.5	363	0.00	0.00	0.00	0.00	0.00	0.00
	2.0	431	0.00	0.00	0.00	0.00	0.00	0.00
	2.5	499	0.01	0.01	0.01	0.01	0.01	0.01
	3.0	567	0.01	0.01	0.01	0.01	0.01	0.01
	3.5	635	0.01	0.01	0.01	0.01	0.01	0.01
	4.0	703	0.02	0.02	0.02	0.02	0.02	0.02
	4.5	770	0.02	0.02	0.02	0.02	0.02	0.02
	5.0	838	0.02	0.02	0.02	0.02	0.02	0.02

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
2	1.0	348	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	416	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	484	0.006	0.006	0.006	0.006	0.006	0.006
	2.5	552	0.008	0.008	0.008	0.008	0.008	0.008
	3.0	620	0.011	0.011	0.011	0.011	0.011	0.011
	3.5	688	0.014	0.014	0.014	0.014	0.014	0.014
	4.0	756	0.017	0.017	0.017	0.017	0.017	0.017
	4.5	824	0.021	0.021	0.021	0.021	0.021	0.021
	5.0	891	0.026	0.026	0.026	0.026	0.026	0.026

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
2.5	1.0	402	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	469	0.004	0.004	0.004	0.004	0.004	0.004
	2.0	537	0.006	0.006	0.006	0.006	0.006	0.006
	2.5	605	0.009	0.009	0.009	0.009	0.009	0.009
	3.0	673	0.012	0.012	0.012	0.012	0.012	0.012
	3.5	741	0.015	0.015	0.015	0.015	0.015	0.015
	4.0	809	0.019	0.019	0.019	0.019	0.019	0.019
	4.5	877	0.023	0.023	0.023	0.023	0.023	0.023
	5.0	945	0.027	0.027	0.027	0.027	0.027	0.027

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
3	1.0	455	0.003	0.003	0.003	0.003	0.003	0.003
	1.5	523	0.005	0.005	0.005	0.005	0.005	0.005
	2.0	590	0.007	0.007	0.007	0.007	0.007	0.007
	2.5	658	0.009	0.009	0.009	0.009	0.009	0.009
	3.0	726	0.013	0.013	0.013	0.013	0.013	0.013
	3.5	794	0.016	0.016	0.016	0.016	0.016	0.016
	4.0	862	0.020	0.020	0.020	0.020	0.020	0.020
	4.5	930	0.024	0.024	0.024	0.024	0.024	0.024
	5.0	998	0.029	0.029	0.029	0.029	0.029	0.029

For square footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma} \qquad (17.5)$$

For continuous footings:

$$\boxed{q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma} \qquad (17.6)$$

For circular footings:

$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma} \qquad (17.7)$$

where:

q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface ($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surfdce of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_d(x, y) = C_s B\left(\frac{1-\mu^2}{E}\right) \qquad (5\text{–}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).

Flexible Circular Footings

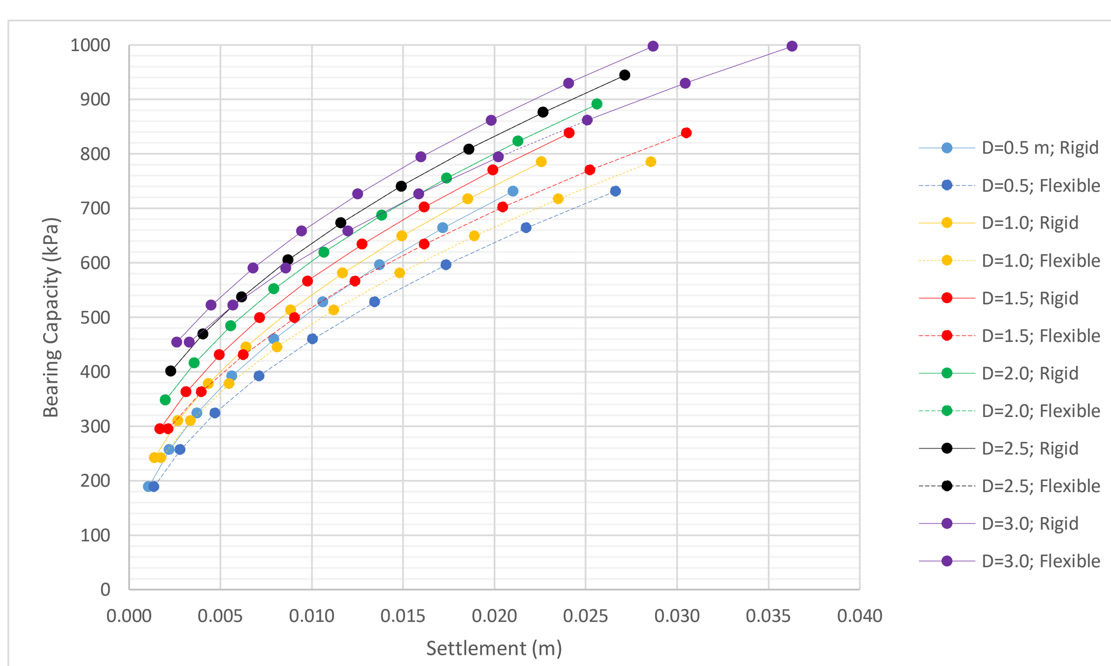
Soil Unit	**Sandy Clay**
Layer Thickness	20
Topsoil Layer Thickness	0.3
Dry Weigh, kN/m3	21.0
Saturated Unit Weight, kN/m4	21.0
Friction Angle, Φ (°)	32
Cohesion c'	0
water table depth	>30 m
E (kPa)	125000
Poisson Ratio	0.3

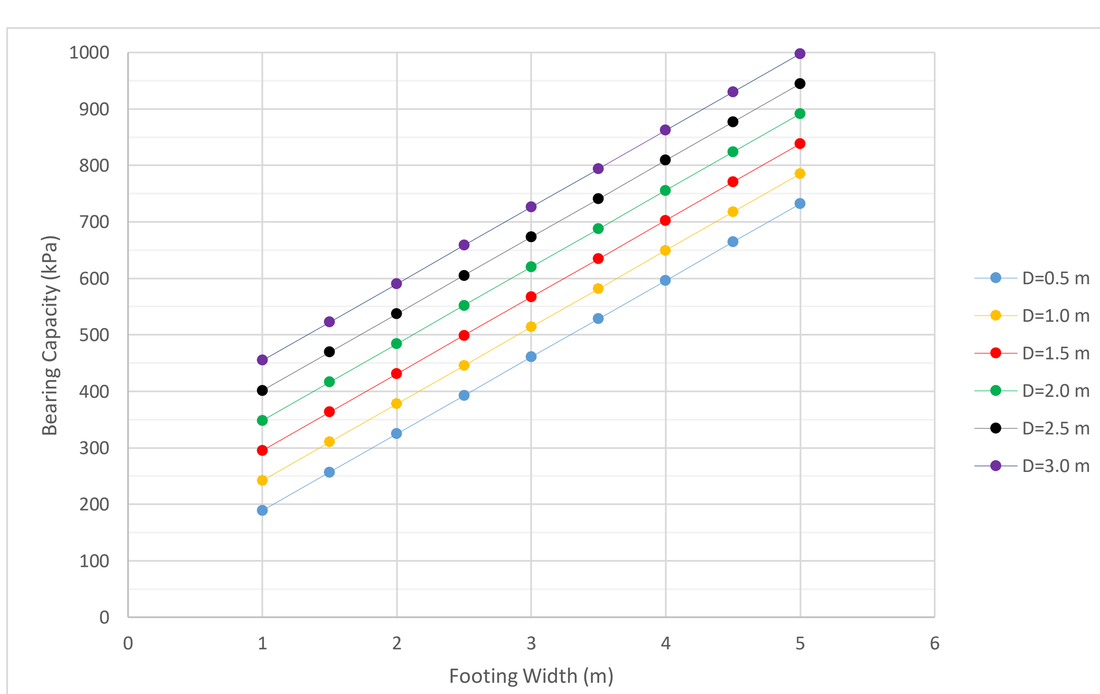
Nc	44
Nq	28.5
Nγ	28

Depth (m)	0.5	1	1.5	2	2.5	3
Effective Stress (kPa)	5.6	11.2	16.8	22.4	28.0	33.6

B/L	1.5	2	3	5	10	100
Cs	1	1	1	1	1	1

	Footing Width (m)	q (kPa)	q (kPa)	q (kPa)	q (kPa)	q (kPa)	q (kPa)
Square Footings (B<4L)	1	189	242	295	348	402	455
	1.5	257	310	363	416	469	523
	2	325	378	431	484	537	590
	2.5	393	446	499	552	605	658
	3	460	514	567	620	673	726
	3.5	528	582	635	688	741	794
	4	596	649	703	756	809	862
	4.5	664	717	770	824	877	930
	5	732	785	838	891	945	998





Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
0.5	1.0	189	0.001	0.001	0.001	0.001	0.001	0.001
	1.5	257	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	325	0.005	0.005	0.005	0.005	0.005	0.005
	2.5	393	0.007	0.007	0.007	0.007	0.007	0.007
	3.0	460	0.010	0.010	0.010	0.010	0.010	0.010
	3.5	528	0.013	0.013	0.013	0.013	0.013	0.013
	4.0	596	0.017	0.017	0.017	0.017	0.017	0.017
	4.5	664	0.022	0.022	0.022	0.022	0.022	0.022
	5.0	732	0.027	0.027	0.027	0.027	0.027	0.027

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
1	1.0	242	0.002	0.002	0.002	0.002	0.002	0.002
	1.5	310	0.003	0.003	0.003	0.003	0.003	0.003
	2.0	378	0.006	0.006	0.006	0.006	0.006	0.006
	2.5	446	0.008	0.008	0.008	0.008	0.008	0.008
	3.0	514	0.011	0.011	0.011	0.011	0.011	0.011
	3.5	582	0.015	0.015	0.015	0.015	0.015	0.015
	4.0	649	0.019	0.019	0.019	0.019	0.019	0.019
	4.5	717	0.023	0.023	0.023	0.023	0.023	0.023
	5.0	785	0.029	0.029	0.029	0.029	0.029	0.029

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
1.5	1.0	295	0.00	0.00	0.00	0.00	0.00	0.00
	1.5	363	0.00	0.00	0.00	0.00	0.00	0.00
	2.0	431	0.01	0.01	0.01	0.01	0.01	0.01
	2.5	499	0.01	0.01	0.01	0.01	0.01	0.01
	3.0	567	0.01	0.01	0.01	0.01	0.01	0.01
	3.5	635	0.02	0.02	0.02	0.02	0.02	0.02
	4.0	703	0.02	0.02	0.02	0.02	0.02	0.02
	4.5	770	0.03	0.03	0.03	0.03	0.03	0.03
	5.0	838	0.03	0.03	0.03	0.03	0.03	0.03

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
2	1.0	348	0.00	0.00	0.00	0.00	0.00	0.00
	1.5	416	0.00	0.00	0.00	0.00	0.00	0.00
	2.0	484	0.01	0.01	0.01	0.01	0.01	0.01
	2.5	552	0.01	0.01	0.01	0.01	0.01	0.01
	3.0	620	0.01	0.01	0.01	0.01	0.01	0.01
	3.5	688	0.02	0.02	0.02	0.02	0.02	0.02
	4.0	756	0.02	0.02	0.02	0.02	0.02	0.02
	4.5	824	0.03	0.03	0.03	0.03	0.03	0.03
	5.0	891	0.03	0.03	0.03	0.03	0.03	0.03

Depth (m)	B	q	B/L=1.5	B/L=2	B/L=3	B/L=5	B/L=10	B/L=100
2.5	1.0	402	0.00	0.00	0.00	0.00	0.00	0.00
	1.5	469	0.01	0.01	0.01	0.01	0.01	0.01
	2.0	537	0.01	0.01	0.01	0.01	0.01	0.01
	2.5	605	0.01	0.01	0.01	0.01	0.01	0.01
	3.0	673	0.01	0.01	0.01	0.01	0.01	0.01
	3.5	741	0.02	0.02	0.02	0.02	0.02	0.02
	4.0	809	0.02	0.02	0.02	0.02	0.02	0.02
	4.5	877	0.03	0.03	0.03	0.03	0.03	0.03
	5.0	945	0.03	0.03	0.03	0.03	0.03	0.03

Depth (m)	B	q	S	S	S	S	S	S
3	1.0	455	0.0	0.0	0.0	0.0	0.0	0.0
	1.5	523	0.0	0.0	0.0	0.0	0.0	0.0
	2.0	590	0.0	0.0	0.0	0.0	0.0	0.0
	2.5	658	0.0	0.0	0.0	0.0	0.0	0.0
	3.0	726	0.0	0.0	0.0	0.0	0.0	0.0
	3.5	794	0.0	0.0	0.0	0.0	0.0	0.0
	4.0	862	0.0	0.0	0.0	0.0	0.0	0.0
	4.5	930	0.0	0.0	0.0	0.0	0.0	0.0
	5.0	998	0.0	0.0	0.0	0.0	0.0	0.0

For square footings:

$$q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.4\gamma' B N_\gamma \qquad (17.5)$$

For continuous footings:

$$q_{ult} = c'N_c + \sigma'_D N_q + 0.5\gamma' B N_\gamma \qquad (17.6)$$

For circular footings:

$$q_{ult} = 1.3c'N_c + \sigma'_D N_q + 0.3\gamma' B N_\gamma \qquad (17.7)$$

where:
q_{ult} = ultimate bearing capacity
c' = effective soil cohesion
σ_D' = vertical effective stress at depth D below the ground surface
($\sigma_D' = \gamma D$ if depth to groundwater table is greater than D)
γ' = effective unit weight of the soil ($\gamma' = \gamma$ if the groundwater table is very deep; see discussion later in this section for shallow groundwater conditions)
D = depth of footing below ground surface
B = width (or diameter) of footing
N_c, N_q, N_γ = bearing capacity factors = $f(\phi')$ — see Table 17.1

TABLE 17.1 BEARING CAPACITY FACTORS FOR TERZAGHI'S EQUATIONS

ϕ' (deg)	N_c	N_q	N_γ	ϕ' (deg)	N_c	N_q	N_γ
0	5.7	1.0	0.0	20	17.7	7.4	4.4
1	6.0	1.1	0.1	21	18.9	8.3	5.1
2	6.3	1.2	0.1	22	20.3	9.2	5.9
3	6.6	1.3	0.2	23	21.7	10.2	6.8
4	7.0	1.5	0.3	24	23.4	11.4	7.9
5	7.3	1.6	0.4	25	25.1	12.7	9.2
6	7.7	1.8	0.5	26	27.1	14.2	10.7
7	8.2	2.0	0.6	27	29.2	15.9	12.5
8	8.6	2.2	0.7	28	31.6	17.8	14.6
9	9.1	2.4	0.9	29	34.2	20.0	17.1
10	9.6	2.7	1.0	30	37.2	22.5	20.1
11	10.2	3.0	1.2	31	40.4	25.3	23.7
12	10.8	3.3	1.4	32	44.0	28.5	28.0
13	11.4	3.6	1.6	33	48.1	32.2	33.3
14	12.1	4.0	1.9	34	52.6	36.5	39.6
15	12.9	4.4	2.2	35	57.8	41.4	47.3
16	13.7	4.9	2.5	36	63.5	47.2	56.7
17	14.6	5.5	2.9	37	70.1	53.8	68.1
18	15.5	6.0	3.3	38	77.5	61.5	82.3
19	16.6	6.7	3.8	39	86.0	70.6	99.8

Immediate Settlement of Surface of a Half-space

The vertical settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is (Schleicher, 1926)

$$\rho_A(x, y) = C_s q B\left(\frac{1-\mu^2}{E}\right) \qquad (5\text{–}2)$$

in which C_s is a geometric factor which accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated

Values of Shape and Rigidity Factor C_s at Various Points of Elastic Half-Space

Shape	Center	Corner	Middle of Short Side	Middle of Long Side
Circle	1.00	0.64	0.64	0.64
Circle (rigid)	0.79	0.79	0.79	0.79
Square	1.12	0.56	0.76	0.76
Square (rigid)	0.99	0.99	0.99	0.99
Rectangle (length/width)				
1.5	1.36	0.67	0.89	0.97
2	1.52	0.76	0.98	1.12
3	1.78	0.88	1.11	1.35
5	2.10	1.05	1.27	1.68
10	2.53	1.26	1.49	2.12
100	4.00	2.00	2.20	3.60
1,000	5.47	2.75	2.94	5.03
10,000	6.90	3.50	3.70	6.50

SOURCE: Schleicher (1926).