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AQABA-AMMAN WATER DESALINATION & CONVEYANCE PROJECT

PSADC NEW SITE GEOTECHNICAL REPORT

USAID Jordan AAWDCP Procurement Support Contract

Prepared by CDM International Inc. for United States Agency for International Development under
Global Architect – Engineer Services II IDIQ
USAID Contract No. AID-OAA-I-15-00047

The Hashemite Kingdom of Jordan
Ministry of Water and Irrigation

August 2023

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Aqaba-Amman Water Desalination & Conveyance Project (AAWDCP)

PSADC New Site Geotechnical Report

Prepared by	CDM Smith	Date	August 2023
Reviewed by	CDM Smith	Date	August 2023
Approved by	Jose Maria Guzman	Date	August 2023

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1. EXECUTIVE SUMMARY

This report presents the findings of the Geotechnical Investigation works carried out by the contractors Engineering Axis for Studies (AXIS) on the new site of the PSADC.

The investigation works aim to obtain geotechnical information of the surface and subsurface conditions at the PSADC new site along with the physical, chemical, and mechanical properties of the encountered materials in order to provide sufficient information required for the design of the structures, pipeline, pipeline appurtenant structures foundations and other facilities in the detailed design stage.

The information contained herein is part of the AAWDCP Request for Proposal (RfP) documentation and shall replace the information provided for PSADC in the Volume 3A "Soil Investigation Report – Annex 2" issued to Bidders on March 16th, 2022.

Similar to the previous geotechnical information provided, the results obtained from this investigation program are for information only and it shall be considered as a reference. Therefore, the Bidders are responsible for use of the data and obtain own interpretations of the geotechnical information provided.

The PSADC new site is approximately 4 km to the southeast of its original location as shown in Figure 1 below.

2. PSADC New Site

Three (3) boreholes (BH-01 through BH-03) were drilled at the project site between the 17th and 18th of July 2023 in addition to one test pit drilled on 19th of July 2023. The boreholes and test pit details are presented in Table 1.

Table 1: Boreholes and Test Pits Details

BH-No.	Easting	Northing	Elevation (m)	Depth (m)
BH-01	406955	516384	747	20
BH-02	407044	516333	746	20
BH-03	407129	516323	746	20
TP-01	407054	516420	748	3

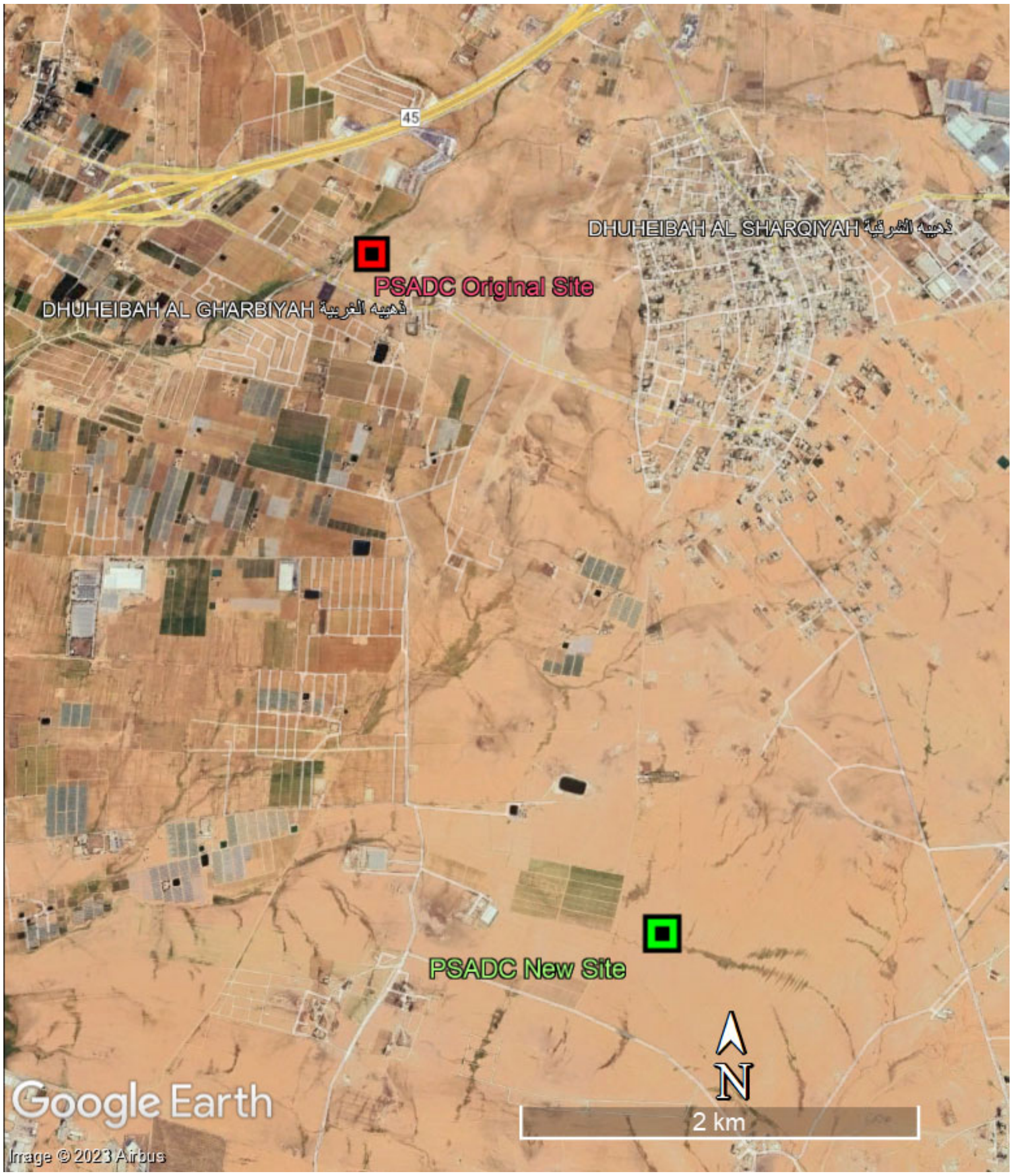

Figure 1: PSADC Original and New Sites

Appendix 1 to this report includes the factual findings of the geotechnical investigation works, while Appendix 2 includes the preliminary design recommendations for the new PSADC site.

APPENDIX 1: FACTUAL INFORMATION REPORT FOR PSADC NEW SITE

المحـــور الهنـدســـي للـدراســـات
Engineering Axis for Studies

FACTUAL REPORT OF SITE INVESTIGATION

FOR

AMMAN DEVELOPMENT CORRIDOR PUMP STATION (PSADC)
AMMAN -JORDAN

AAWDCP GEOTECHNICAL INVESTIGATION WORKS

Submitted to

CDM SMITH

AMMAN-JORDAN

REPORT NO.: SS23013 **Aug. - 2023**

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Messrs.: CDM Smith **Aug. 01, 2023**
Amman - Jordan **SS23013**

Subject: Factual Report of Site Investigation
For Amman Development Corridor Pump Station
(PSADC)
Amman –Jordan

Project: AAWDCP Geotechnical Investigation Works

Dear Sirs,

Engineering Axis for Studies **(AXIS)** has the pleasure to submit herewith this factual report of site investigation. This investigation was carried out in accordance with our approved proposal no. PR230345, the signed Agreement No. 277399.3029.006.CS Mod#1, and your notice to proceed.

This report includes the program of work that has been implemented, data collection, and findings of the field and laboratory testing.

We would like to express our sincere thanks to you for your confidence, looking forward for future cooperation. For further information, discussion or clarification, please do not hesitate to contact our office.

Engineering Axis for Studies

ABDULLA SHIHAB
M. Sc., B.Sc. in Civil Eng.
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General Manager

مكتب المحور الهندسي للدراسات
Engineering Axis for Studies

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1. INTRODUCTION

The Aqaba Amman Water Desalination and Conveyance Project (AAWDCP) will provide 300 million cubic meters per year (300 MCM/year) of potable water to Amman, Aqaba, and other points along the pipeline route from a new desalination plant located near Aqaba, taking water from the Red Sea.

The conveyance system includes around 450 kilometer of pipeline, booster pump stations and regulating tanks to convey freshwater all the way to ABU ALANDA and AL MUNTAZAH reservoirs in Amman.

1.1. General

This report presents findings of the site investigation study for the proposed Amman Development Corridor Pump Station (PSADC)/ Amman –Jordan. This project is composed of a proposed pumpstation located ~4.5km to the south of Amman Development Corridor.

1.2. Purposes of the Study

The general purpose of this study was to provide the Client with a factual report with the following information pertinent to the study site/s;

- General characterization of surface and subsurface geological/geotechnical conditions.
- Geological maps covering the project site as available from the NRA.
- Seismic zoning of the study site.
- Groundwater Conditions.
- Findings of laboratory & field works.
- Boreholes logs.

1.3. Study Methodology

In respect to the scope of work, the following methodology was adopted to fulfill the study purposes:

- Carrying out the desk study to identify site general published geological/geotechnical features. Seismic maps and geological maps pertinent to the area were acquired from the appropriate authorities. Available relevant information from AXIS previous studies for the area and vicinity was reviewed and used to serve the study purposes.
- Based on the desk study, a reconnaissance visit was conducted to the Project site by AXIS senior staff including geotechnical and geological engineers. Findings from the reconnaissance visit were used to guide the fieldworks in order to fulfill the study purposes.
- During the study time-span, several inspection visits were conducted by AXIS engineering staff. The inspection visits aimed to identify the general geology and geological features of the site, examination of the exposed lithology and stratigraphy of the site formations. The locations of boreholes were inspected, and any usable information regarding the site characteristics was documented.
- Drilling of a total of three (3) boreholes within the study site to a depth of 20m each. Boring aimed at stratigraphy exploration, in-situ testing and obtaining samples from the encountered strata for testing and evaluation.
- Excavation of one test pit to a depth of 3m to obtaining samples from the encountered strata for testing and evaluation.

- Laboratory testing of representative samples for evaluation of the physical, mechanical and chemical properties of the surface and subsurface materials.
- Submittal of the Factual Geotechnical report including all work items.

2. GENERAL SITE CHARACTERISTICS

2.1. General

The study site is located within Amman governorates. The study site is located ~4.5km to the south of Amman Development Corridor. Based on the provided limited information, the proposed project is composed of water collection tanks, pumping station, service buildings, administration building, and paved areas and streets. Figure 1 shows the proposed pump station site, the locations of the drilled boreholes, and the location of the excavated test pit.

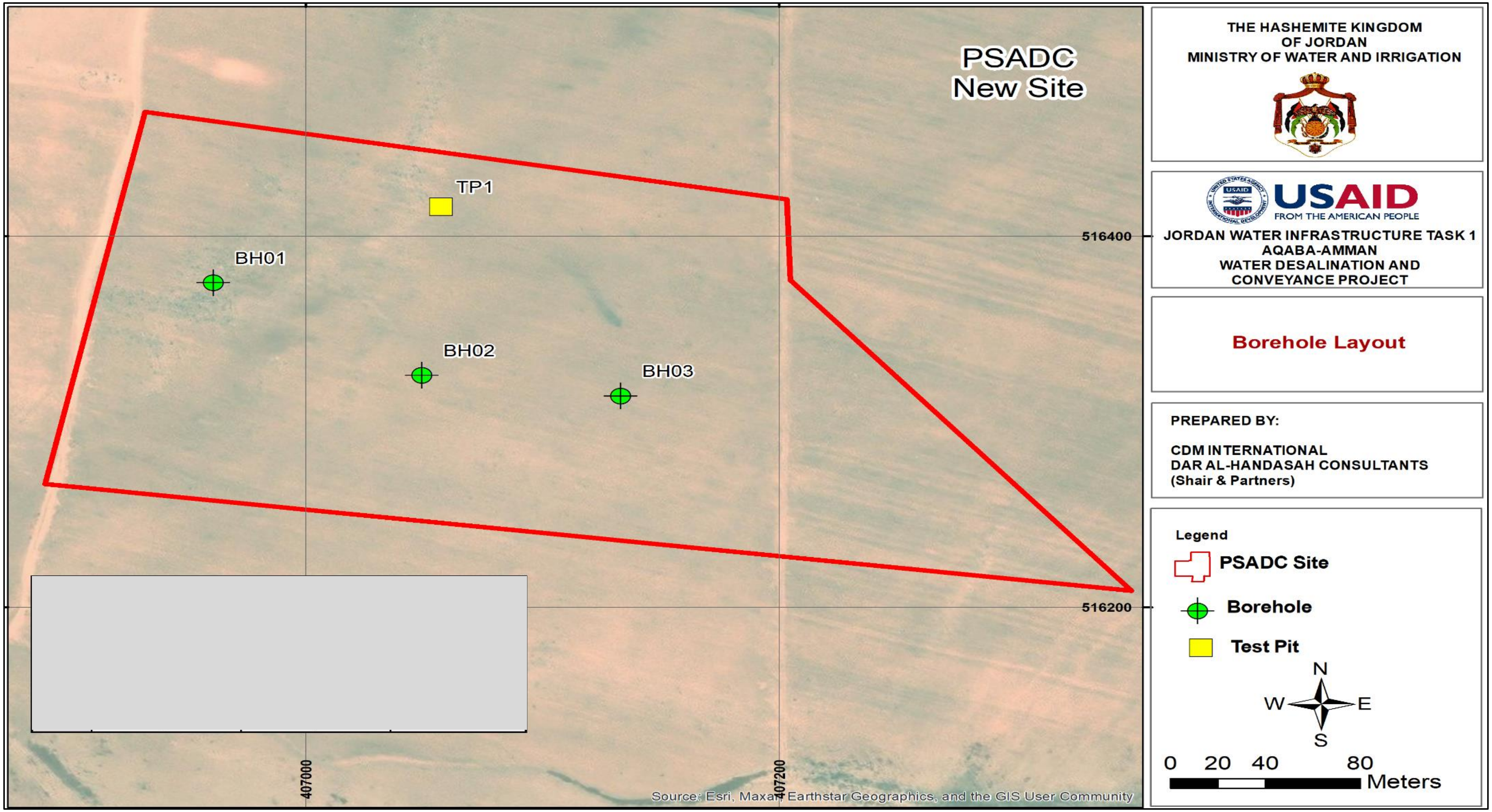


Figure 1: The proposed Pump Station Site, the Locations of the Drilled Boreholes, and the Location of the Excavated Test Pit.

2.2. General Geology for the Project Area

Based on the information obtained during site reconnaissance, and considering the data as reported in the available geological maps produced by Natural Resources Authority (NRA) that are related to the study site; The study site belongs to Pleistocene Sediments (**PI**); this formation is composed of fine materials (sand and silt) and coarse-grained clasts such as granules, pebbles, cobbles and boulders of different lithologies. However, in the study site Pleistocene Sediments were found to be composed mostly of silt and clay.

According to the (NRA) geological maps, any special geological features such as faults, folds, landslides were not recognized close to the site. Extracts from the geological maps related to the site area are shown in Appendix B.

3. SEISMICITY

In respect to Jordanian Seismic Code; the study site lies within **Zone (2A)** with a Seismic Zone Factor (Z) of 0.15.

The Jordan seismicity and earthquake zoning map (including the approximate study site location) is shown in Appendix B.

4. FIELD AND LABORATORY WORKS

4.1. Borehole Drilling and Test Pit excavation

According to the adopted methodology; three boreholes were drilled on July 17 & 18, 2023. In addition, one test pit was excavated on July 19, 2023. Test pit number, Boreholes numbers, depths, and coordinates are tabulated in Table 1 below. It is to be mentioned that, boring quantity (number of boreholes boring depths) and boring locations were predetermined by the Client. The drilling work was executed with "HALCO rotary rig, mounted on a Mercedes LB" and "MOBIL Drilling rig mounted on a Mercedes LB" both using the air and water flush drilling method.

No.	Borehole Depth, m	Coordinates		~ Elevation, m
		East	North	
BH01	20	406955	516384	747
BH02	20	407044	516333	746
BH03	20	407129	516323	746
TP01	3	407054	516420	748

4.2. Sampling

Disturbed and undisturbed samples were obtained from the different levels of the boring strata as conditions permit, considering the level of interest of the strata for the purpose of the study. Disturbed samples were collected from the cuttings of the penetrated strata and from the SPT spoon, where possible; whereas, undisturbed samples were collected using a double tube core barrel of ~76mm inner diameter.

The collected samples were inspected, labeled in a proper sequence, then contained in tight plastic bags and taken to AXIS laboratories for further inspection and testing. All drilling and sampling activities were supervised by AXIS specialist geotechnical staff.

4.3. Standard Penetration Test (SPT)

Standard Penetration Test (SPT) was performed at various depths of the drilled boreholes, where found appropriate. Cone attachment was utilized sometimes instead of the standard SPT split spoon, as found more appropriate. The utilized cone attachment is a solid 60 degree cone to replace shoe on the standard split spoon (see Bowles, 1997). SPT results obtained by cone attachment are differentiated from the split spoon results by (SPT/C) in the boring logs. Mentioning that cone penetration can be relatively easier than that of split spoon, no further correction is used for SPT/C readings in assessment of SPT results; taking in account the nature of the strata penetrated by the cone attachment, owing to be to the conservative side.

The test was performed in accordance with:

- ASTM D 1586-11, "Penetration Test and Split Barrel Sampling of Soils".

The SPT number of blows versus depth is presented on the logs of borings, Appendix A. The SPT is defined in the legend of borings logs, Appendix A. General Interpretation of the SPT results are also given in the legend.

4.4. Visual Examination

Visual examination was carried out on the obtained samples during boring according to the procedures outlined in:

1. ASTM D 2488-17; "Description and Identification of Soils (Visual-Manual Procedure)".
2. BS 5930-1999; "Code of Practice for Site Investigation".

4.5. Laboratory Work

As part of the adopted methodology; laboratory testing program was performed on representative samples for the evaluation of the physical and chemical properties of the subsurface materials. The following tests were carried out on samples taken from boreholes, selectively as appropriate:

1. ASTM D2216 – 19 (✰); "Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass".
2. ASTM D4318-17 (✰); "Liquid Limit, Plastic Limit, and Plasticity Index of Soils".
3. AASHTO T 88-20 (✰); "Particle-Size Analysis of Soils".
4. ASTM D7012-14 (✰); "Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures".
5. ASTM D 5731 – 08; "Determination of the Point Load Strength Index of Rock and Application to Rock Strength Classifications".
6. BS EN 1744-1:2009+A1:2012 (✰); "Method for Determination of Sulphate Content".
7. BS 1377-3: 2018; "Method for Determination of Chloride Content" (Water soluble).
8. ASTM D4972 – 13; "pH of Soils".
9. ASTM D2487-17 (✰); "Classification of Soils for Engineering Purposes (Unified Soil Classification System).

(✰) Test/s within AXIS Accreditation Scope by ISO/IEC 17025:2017 (Certificate No.: JAS Test-039).

5. STUDY FINDINGS

5.1. Site Formation Stratigraphy

The conducted investigation revealed that the surface and subsurface ground materials within the study area consist of the following distinct soil strata:

- **Topsoil materials** composed of brown clayey soil with occasional stone fragments and few rootlets. These materials were found from the existing ground surface level and extended to depths ranging between 0.75m and 1m.
- Light to dark reddish brown, very stiff to hard, dry **Lean Clay with Sand** to **Fat Clay** with occasional stone fragments of limestone and Chert and with carbonate dust. These materials were found below the topsoil materials and extended to depths ranging between 7m and 10m.
- **Stratified Rock Formation** composed of varied color, slightly to highly fractured, moderately weak to moderately strong, thinly to thickly bedded, Chert, limestone, dolomitic limestone, marly limestone, marlstone, marl and few clayey marl. These materials were found from depths ranging between 7m and 10m and extended to the end of the three drilled borehole.

Table 2 summarizes the encountered strata and depths at the boreholes' locations. Further details and information regarding the encountered materials and strata thicknesses, along with the obtained SPT values, are presented in the logs of borings, Appendix A.

Table 2: Summary of Stratifications at the Boreholes' Locations

BH No.	Depth, m	Layer
BH01	0.0 - 0.75	Topsoil
	0.75 - 9.8	Lean Clay with Sand to Fat Clay
	9.8 - 20.0	Stratified Rock Formation
BH02	0.0 - 1.0	Topsoil
	1.0 - 7.0	Lean Clay with Sand to Fat Clay
	7.0 - 20.0	Stratified Rock Formation
BH03	0.0 - 1.0	Topsoil
	1.0 - 10.0	Lean Clay with Sand to Fat Clay
	10.0 - 20.0	Stratified Rock Formation

The strata continuity was interpolated by imaginary lines connecting the encountered thicknesses of the similar ground strata in the drilled boreholes, as presented in the Generalized Subsurface Profile AA' in Figure 2. However, these lines are made for illustration purposes and may not represent the actual field conditions.

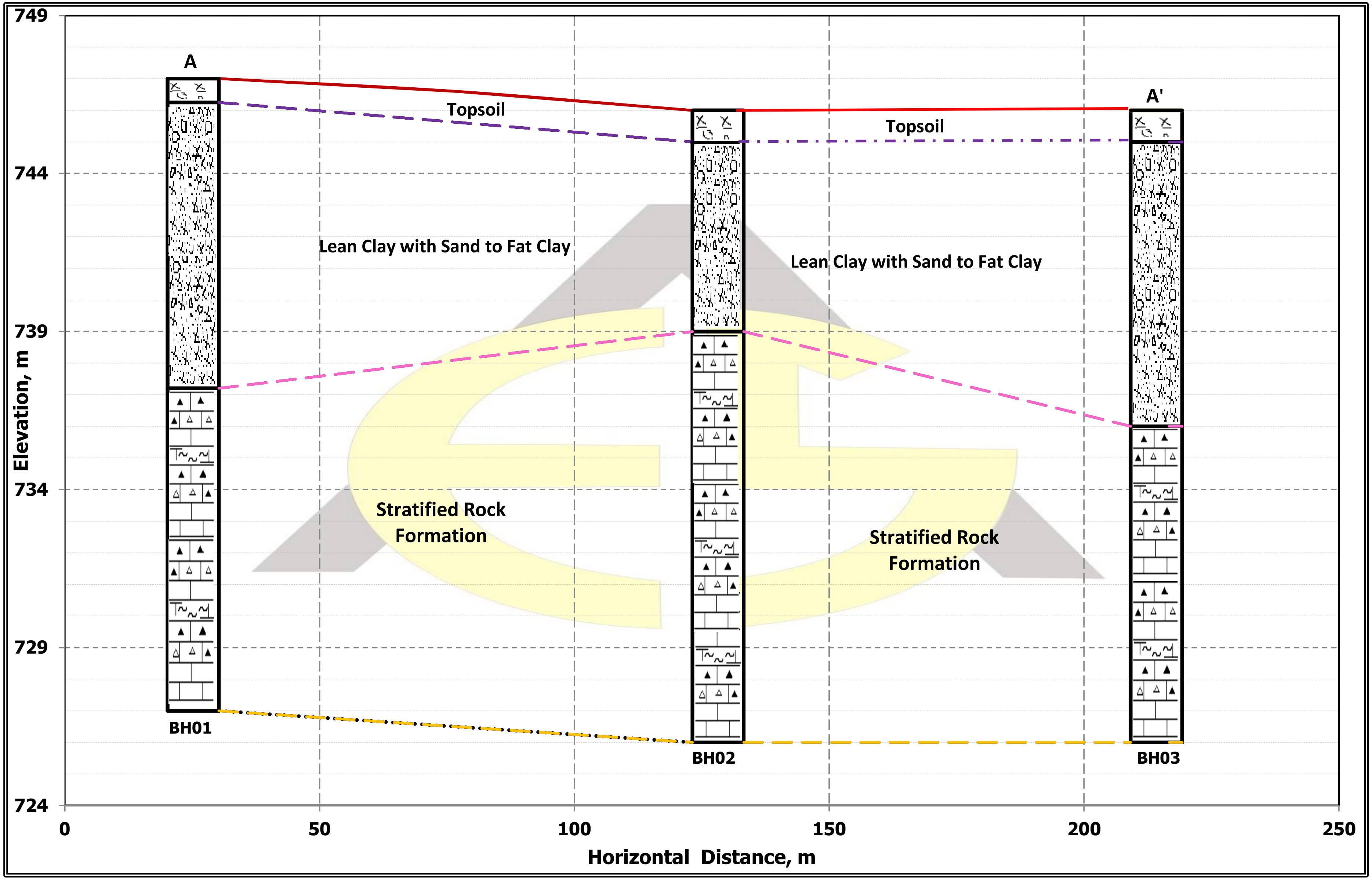


Figure No. 2: Generalized Subsurface Profile (AA')

5.2. Laboratory Tests Results for Boreholes Samples

The obtained tests results for the tested samples from the drilled boreholes are tabulated in Tables 3, 4, and 5.

Table 3: Laboratory Tests Results

BH No.	Depth, m	Unified Soil Classification/Layer Description	M.C, %	Insitu Bulk Density, g/cm^3	Dry Bulk Density, g/cm^3	Atterberg Limits			Grain Size Distribution				qu, kg/cm^2
						LL	PL	PI	Gravel+, %	Sand, %	Silt, %	Clay, %	
BH01	0.0-0.75	Topsoil	10.1										
	0.75-2.0	CL (Lean clay with sand)	9.6			47	22	25	1.1	16.9	47.1	34.9	
	2.0-3.0	CH (Fat clay with sand)	11.7			60	27	33	0.2	16.7	45.7	37.4	
	3.0-4.0		12.5										
	4.0-5.5		12.5										
	5.5-7.0	CH (Fat clay)	10.0			62	25	37	0.0	6.8	48.6	44.6	
	7.0-8.5		10.1										
	8.5-10.0		5.4										
	10.0-11.5	Stratified Rock Formation	4.0	2.41	2.32								115
	11.5-13.0		3.5	2.45	2.37								134
	13.0-14.5		5.9										
	14.5-16.0		3.6										
	16.0-17.5		4.8										
	17.5-19.0		5.9										
	19.0-20.0		4.6										
BH02	0.0-1.0	Topsoil	7.2										
	1.0-2.5	CH (Fat clay)	8.6			51	25	26	0.3	13.0	51.2	35.5	
	2.5-4.0	CH (Fat clay)	10.7			73	29	44	0.0	9.4	46.7	43.9	
	4.0-5.5		11.4										
	5.5-7.0	CH (Sandy fat clay)	8.3			55	22	33	2.1	32.9	36.0	29.0	
	7.0-8.5	Stratified Rock Formation	3.9										
	8.5-10.0		4.7										
	10.0-11.5		3.9	2.42	2.33								103
	11.5-13.0		0.4	2.41	2.40								--
	13.0-14.5		5.2	2.38	2.26								86
	14.5-16.0		3.7										
	16.0-17.5		2.6										
	17.5-19.0		3.3										
	19.0-20.0		3.1										
BH03	0.0-1.0	Topsoil	5.4										
	1.0-2.5	CH (Fat clay)	9.1			56	26	30	0.4	13.4	48.5	37.7	

M.C: Moisture Content, qu: Unconfined Compressive Strength, PL: Plastic Limit, LL: Liquid Limit, PI: Plasticity Index

Table 3: Laboratory Tests Results (Cont.)

BH No.	Depth, m	Unified Soil Classification/Layer Description	M.C, %	Insitu Bulk Density, g/cm^3	Dry Bulk Density, g/cm^3	Atterberg Limits			Grain Size Distribution				qu, kg/cm^2
						LL	PL	PI	Gravel+, %	Sand, %	Silt, %	Clay, %	
BH03	2.5-4.0	CH (Fat clay)	11.1			71	28	43	0.5	13.8	38.6	47.1	
	4.0-5.5		11.3										
	5.5-7.0	CH (Fat clay)	11.2			71	28	43	0.2	11.2	41.4	47.2	
	7.0-8.5		11.3										
	8.5-10.0		9.5										
	10.0-11.5	Stratified Rock Formation	8.7	--	--								--
	11.5-13.0		5.9										
	13.0-14.5		3.0	2.44	2.37								94
	14.5-16.0		2.9										
	16.0-17.5		3.0										
	17.5-19.0		3.0										
	19.0-20.0		2.1										

M.C: Moisture Content, qu: Unconfined Compressive Strength, PL: Plastic Limit, LL: Liquid Limit, PI: Plasticity Index

Table 4: Laboratory Tests Results for Boreholes Samples

Sample Identification	Borehole No.	BH01					Borehole Materials (Boring Cuttings)	
	Depth, m	(0.75-2.0)	(2.0-3.0)	(5.5-7.0)	(10.0-11.5)	(11.5-13.0)		
Test Name		Test Result					Test Standard	
- Hydrometer	Gravel + (%)	1.1	0.2	0.0	--	--	AASHTO T 88-22	☆
	Sand (%)	16.9	16.7	6.8	--	--		
	Silt (%)	47.1	45.7	48.6	--	--		
	Clay (%)	34.9	37.4	44.6	--	--		
- Atterberg Limits (Wet Preparation)	Liquid Limit	47	60	62	--	--	ASTM D4318 - 17	☆
	Plastic Limit	22	27	25	--	--		
	Plasticity Index	25	33	37	--	--		
- Unified Soil Classification		CL (Lean clay with sand)	CH (Fat clay with sand)	CH (Fat clay)	--	--	ASTM D2487 – 17	☆
- AASHTO Classification		A-7-6	A-7-6	A-7-6	--	--	AASHTO M 145-91 (2021)	☆
- Water Soluble Sulphate Content (SO_3), %		0.002	0.03	0.03	0.03	0.001	BS 1377-3: 2018 (2:1 Water:Soil Ratio)	--
- Water Soluble Chloride Content (Cl), %		0.006	0.019	0.021	0.013	0.007		
-pH Value	in distilled water	9.0	8.3	8.5	8.7	8.7	ASTM D4972 - 13 (Method A)	--
	in $CaCl_2$ solution	8.6	8.2	8.3	8.5	8.3		

☆ Test/s within AXIS Accreditation Scope by ISO/IEC 17025:2017 (Certificate No.: JAS Test-039).

Table 4: Laboratory Tests Results for Boreholes Samples (Cont.)

Sample Identification	Borehole No.	BH02					Borehole Materials (Boring Cuttings)	
	Depth, m	(1.0-2.5)	(2.5-4.0)	(5.5-7.0)	(10.0-11.5)	(13.0-14.5)		
Test Name		Test Result					Test Standard	
- Hydrometer	Gravel + (%)	0.3	0.0	2.1	--	--	AASHTO T 88-22	☆
	Sand (%)	13.0	9.4	32.9	--	--		
	Silt (%)	51.2	46.7	36.0	--	--		
	Clay (%)	35.5	43.9	29.0	--	--		
- Atterberg Limits (Wet Preparation)	Liquid Limit	51	73	55	--	--	ASTM D4318 - 17	☆
	Plastic Limit	25	29	22	--	--		
	Plasticity Index	26	44	33	--	--		
- Unified Soil Classification		CH (Fat clay)	CH (Fat clay)	CH (Sandy fat clay)	--	--	ASTM D2487 – 17	☆
- AASHTO Classification		A-7-6	A-7-6	A-7-6	--	--	AASHTO M 145-91 (2021)	☆
- Water Soluble Sulphate Content (SO_3), %		0.07	0.04	0.02	0.002	0.001	BS 1377-3: 2018 (2:1 Water:Soil Ratio)	--
- Water Soluble Chloride Content (Cl), %		0.021	0.020	0.019	0.014	0.004		
-pH Value	in distilled water	8.1	8.4	8.7	8.7	8.7	ASTM D4972 - 13 (Method A)	--
	in $CaCl_2$ solution	8.0	8.2	8.6	8.4	8.4		

☆ Test/s within AXIS Accreditation Scope by ISO/IEC 17025:2017 (Certificate No.: JAS Test-039).

Table 4: Laboratory Tests Results for Boreholes Samples (Cont.)

Sample Identification	Borehole No.	BH03					Borehole Materials (Boring Cuttings)	
	Depth, m	(1.0-2.5)	(2.5-4.0)	(5.5-7.0)	(10.0-11.5)	(13.0-14.5)		
Test Name		Test Result					Test Standard	
- Hydrometer	Gravel + (%)	0.4	0.5	0.2	--	--	AASHTO T 88-22	☆
	Sand (%)	13.4	13.8	11.2	--	--		
	Silt (%)	48.5	38.6	41.4	--	--		
	Clay (%)	37.7	47.1	47.2	--	--		
- Atterberg Limits (Wet Preparation)	Liquid Limit	56	71	71	--	--	ASTM D4318 - 17	☆
	Plastic Limit	26	28	28	--	--		
	Plasticity Index	30	43	43	--	--		
- Unified Soil Classification		CH (Fat clay)	CH (Fat clay)	CH (Fat clay)	--	--	ASTM D2487 – 17	☆
- AASHTO Classification		A-7-6	A-7-6	A-7-6	--	--	AASHTO M 145-91 (2021)	☆
- Water Soluble Sulphate Content (SO_3), %		0.04	0.05	0.03	0.001	0.001	BS 1377-3: 2018 (2:1 Water:Soil Ratio)	--
- Water Soluble Chloride Content (Cl), %		0.014	0.021	0.021	0.013	0.006		
-pH Value	in distilled water	8.2	8.5	8.3	8.5	8.7	ASTM D4972 - 13 (Method A)	--
	in $CaCl_2$ solution	8.1	8.4	8.1	8.3	8.3		

☆ Test/s within AXIS Accreditation Scope by ISO/IEC 17025:2017 (Certificate No.: JAS Test-039).

Table 5: Laboratory Tests Results of Point Load Test

Sample Identification			Insitu Bulk Density, g/cm3	Point Load Strength Index (Is), kg/cm^2
BH	Depth, m	Specimen No. (Description)		
BH01	10.0-11.5	S 1 (Limestone)	2.43	4.4
		S 2 (Limestone)	2.41	3.8
	11.5-13.0	S 3 (Limestone)	2.44	5.1
BH02	10.0-11.5	S 4 (Limestone)	2.41	4.1
	13.0-14.5	S 5 (Marly Limestone)	2.31	2.8
		S 6 (Marly Limestone)	2.28	2.4
BH02	10.0-11.5	S 7 (Limestone)	2.39	3.1
	13.0-14.5	S 8 (Limestone)	2.44	4.1

5.3. Laboratory Tests Results for the Test Pit Samples

The obtained tests results for the tested samples from the excavated Test Pit are tabulated in Table 6.

Sample Identification	Test Pit No.	T.P 1			Test Pits	
	Depth, m	0.2 - 1.0	1.0 - 2.0	2.0 - 3.2		
Test Name		Test Result			Test Standard	JAS
- Sieve Analysis: -		% Passing by Weight			AASHTO T 88-22	☆
- Sieve Number:	1/2"	100	100	100		
	No. 4	100	99	97		
	No. 10	99	97	94		
	No. 40	98	92	88		
	No. 200	94	87	83		
- Hydrometer	Gravel + (%)	0.2	1.0	2.2		
	Sand (%)	5.7	13.4	17.0		
	Silt (%)	71.0	53.5	60.3		
	Clay (%)	23.1	32.1	20.5		
- Atterberg Limits (Dry Preparation)	Liquid Limit	36	43	40	AASHTO T 89-22 (Method A), AASHTO T 90-22	☆
	Plastic Limit	22	24	21		
	Plasticity Index	14	19	19		
- AASHTO Classification		A-6	A-7-6	A-6	AASHTO M 145-91 (2021)	☆
- Unified Soil Classification		CL (Lean clay)	CL (Lean clay)	CL (Lean clay with sand)	ASTM D2487 – 17	☆
- Moisture Density Relationship *(Replacement according to 97-edition)*		Figure 1	Figure 3	Figure 5	AASHTO T 180-22	☆
- Optimum Moisture Content, %		16.8	17.0	17.4		
- Max. Dry Density, gm/cm^3		1.805	1.824	1.816		
- California Bearing Ratio		Figure 2	Figure 4	Figure 6	AASHTO T 193-22	☆
- CBR		6.3	5.8	6.4		
- Water Soluble Sulphate Content (SO3), %		0.02	--	--	BS 1377-3: 2018 (2:1 Water:Soil Ratio)	--
- Water Soluble Chloride Content (Cl), %		0.001	--	--		
-pH Value	in distilled water	8.6	--	--	ASTM D4972 - 13 (Method A)	--
	in CaCl2 solution	8.1	--	--		

☆ **Test/s within AXIS Accreditation Scope by ISO/IEC 17025:2017 (Certificate No.: JAS Test-039).**

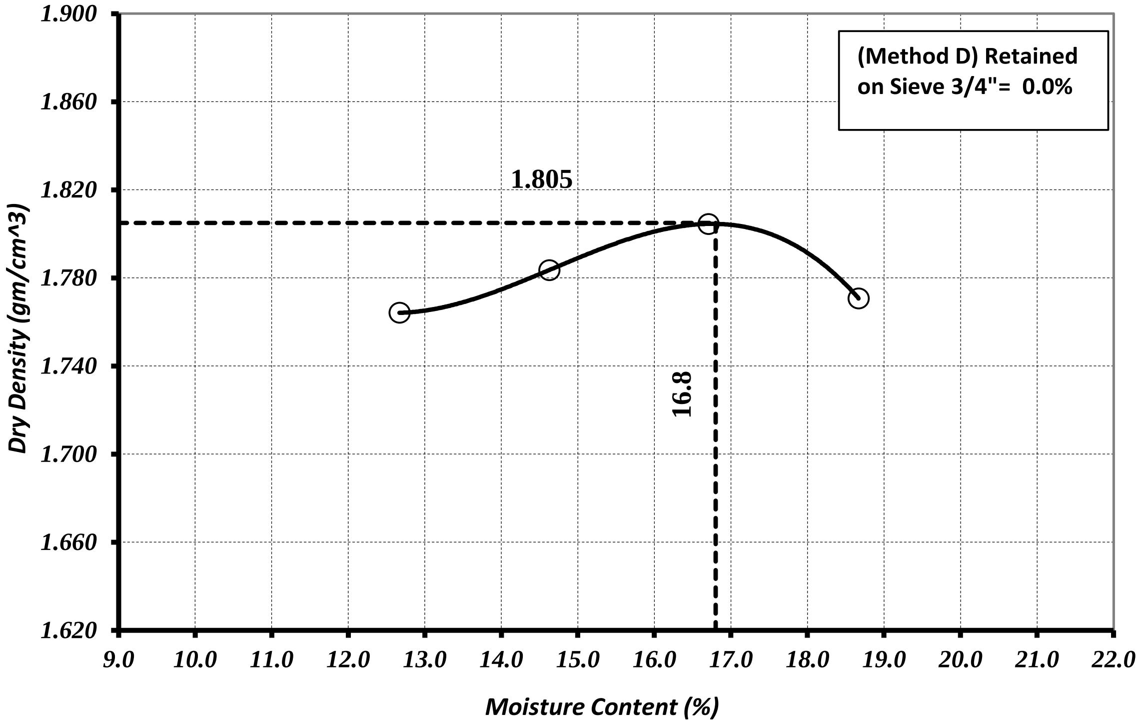
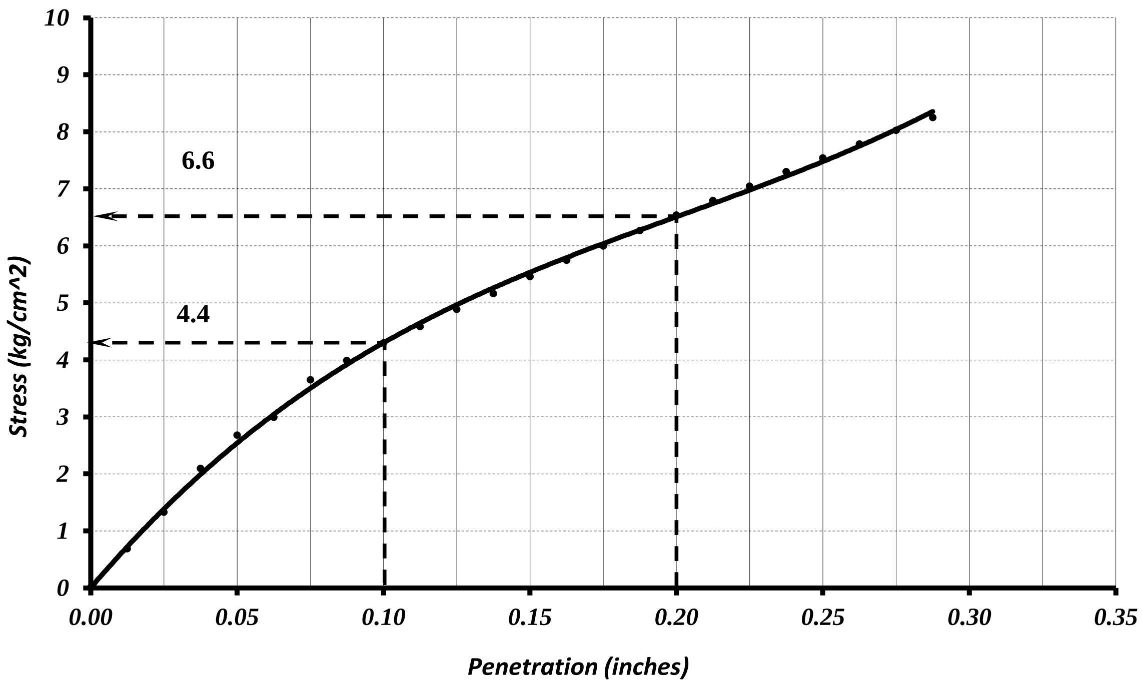


Figure 1: Moisture-Density Relationship



CBR @ 0.1" = 100*(4.4 / 70)= 6.3	CBR @ 0.2" = 100*(6.6 / 105)= 6.3

CBR= 6.3

Figure 2: California Bearing Ratio

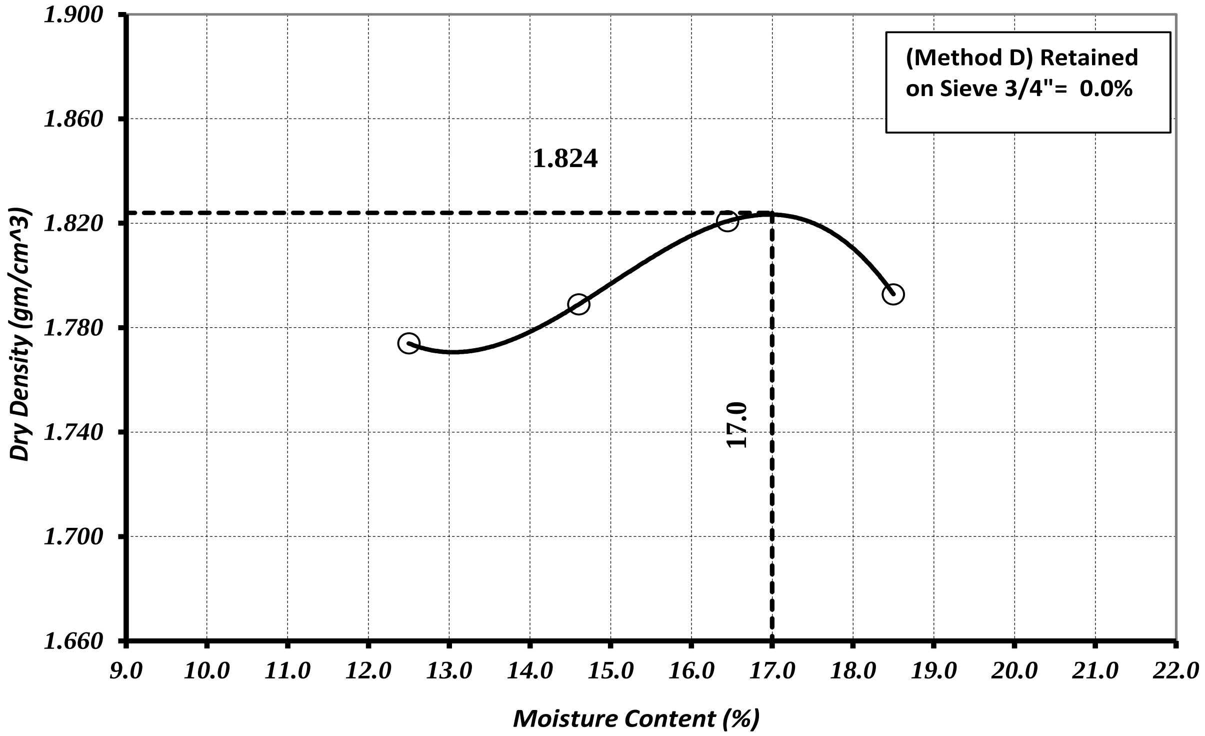
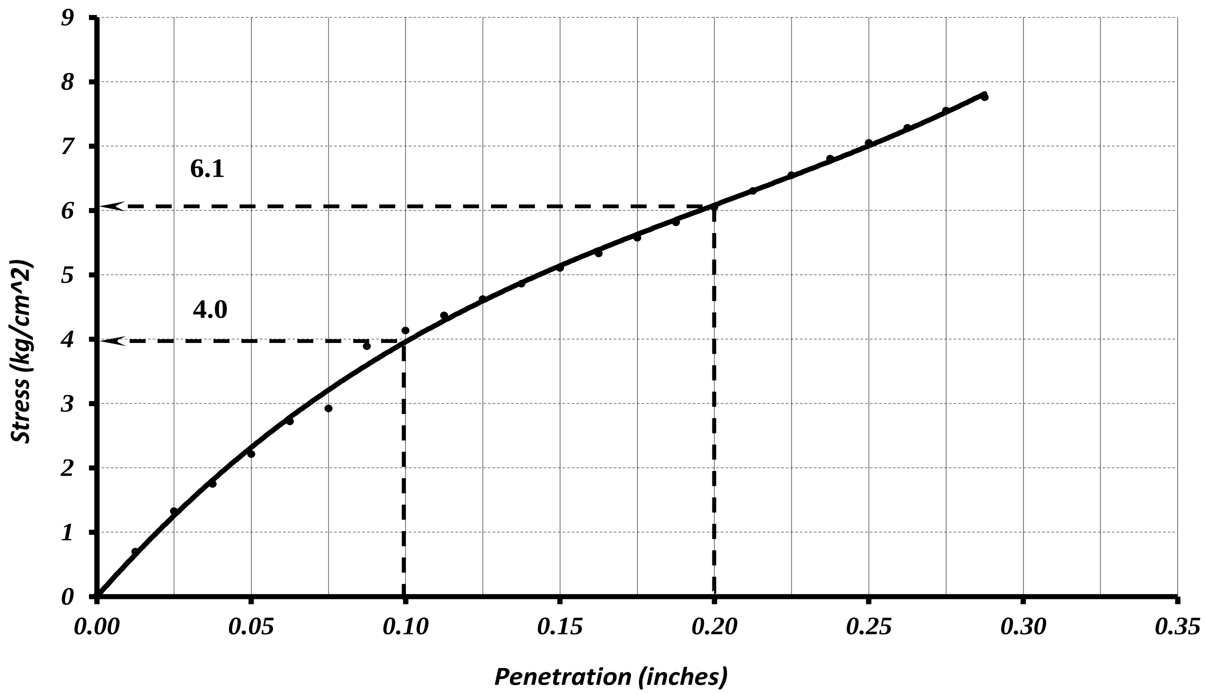


Figure 3: Moisture-Density Relationship



CBR @ 0.1" = 100*(4 / 70)= 5.7	CBR @ 0.2" = 100*(6.1 / 105)= 5.8

CBR= 5.8

Figure 4: California Bearing Ratio

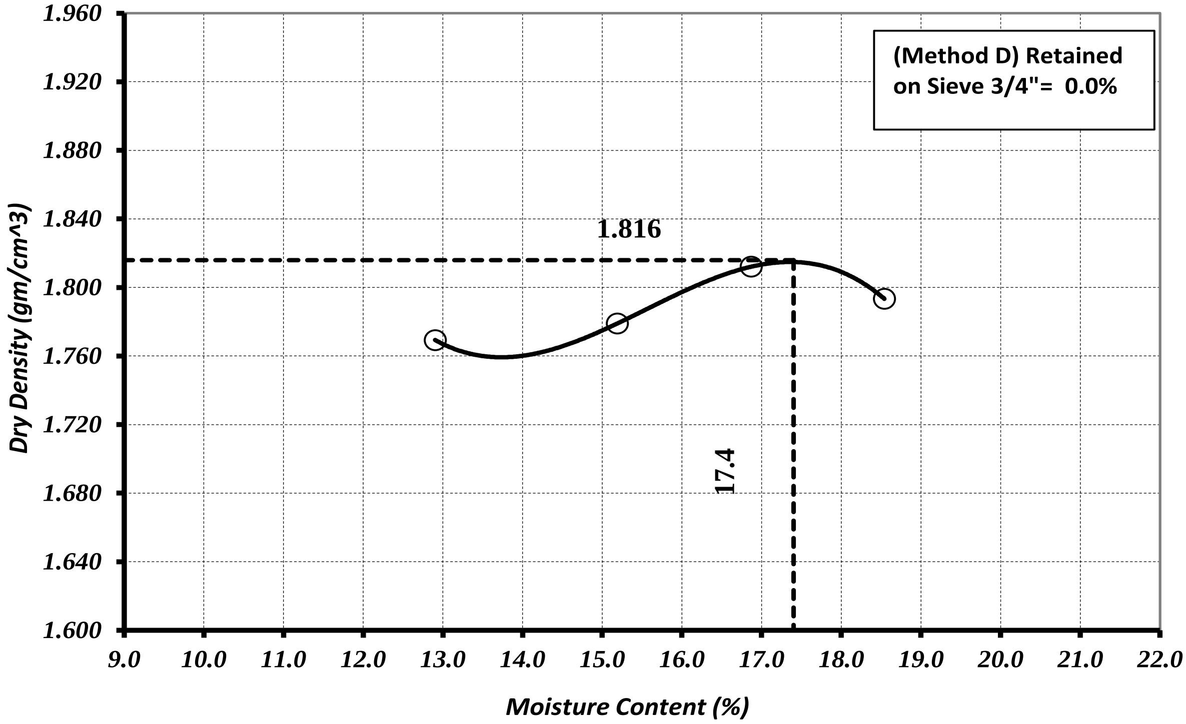
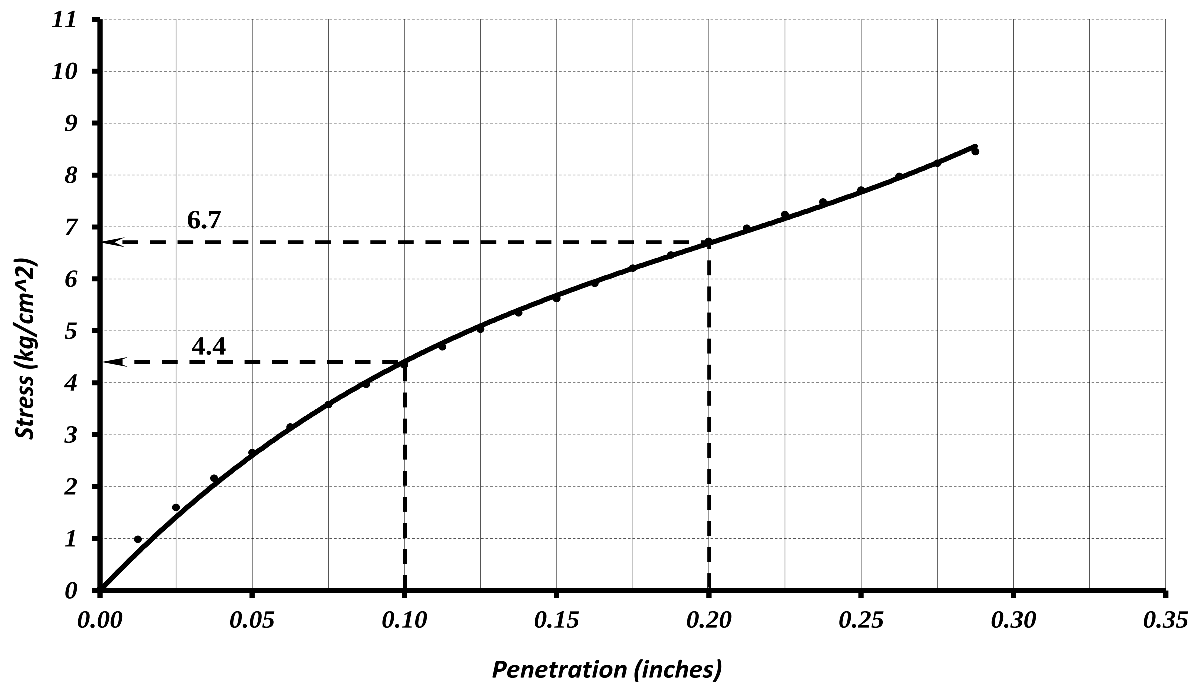


Figure 5: Moisture-Density Relationship



CBR @ 0.1" = 100*(4.4 / 70)= 6.3	CBR @ 0.2" = 100*(6.7 / 105)= 6.4

CBR= 6.4

Figure 6: California Bearing Ratio

5.4. Ground Water and Cavities

Neither free ground water nor cavities were encountered in any of the borings to the drilled depths during or at the completion of the field works. In general, the surface/subsurface hydrology is outside the scope of this study.

6. Important Remarks

- All given information are based on boring records, examination of samples, and laboratory testing. However, any unforeseen conditions that have not been revealed by the boreholes are beyond our responsibility.
- The boring logs and related information presented in this report depict approximate subsurface conditions only at the specific boring locations noted and at the time of drilling. Conditions at other locations may differ from those occurring at the boring locations. Also, the fluctuation of weather conditions may result in advert change in the formation characteristics.
- It is to be emphasized that the Client is solely responsible, and our office does not bear any responsibility in case of inappropriate interpretation/implementation of the information given in this report.

APPENDIX A *(Boring Logs)*

Terms and Symbols Used on Boring Logs

Symbols for Common Soil & Rock Types

CLAY **SILT** **SAND** **GRAVEL** **COBBLES & BOULDERS** **FILL**

LIMESTONE **CHERT** **CHALK** **MARL** **SANDSTONE** **BASALT**

Sampler Type	HAMMER	CORE BARREL	DRIVEN CYLENDER	DRIVEN BARREL	DRIVEN SPLIT SPOON/CONE (SPT-SPT/C)	AUGER
Sample Disturbance	Disturbed	Relatively Undisturbed	Relatively Undisturbed	Relatively Undisturbed	Disturbed	Disturbed

S.P.T. (Blows/30cm) : The number of blows, in the Standard Penetration Test, required to drive a 50mm diameter split tube sampler a distance of 300mm using 63.5kg weight falling 760mm.

S.P.T/C. (Blows/30cm) : The number of blows, in the Standard Penetration Test, required to drive a solid 60 degree cone a distance of 300mm using 63.5kg weight falling 760mm.

Ref. (**Refusal**) : The number of blows >50 blows for 15cm penetration.

Fine Grained Soils

S.P.T N_{70} (Blows/30cm)	Estimated Consistency	Field Identification	Unconfined Compressive Strength (kg/cm^2)
0-2	Very Soft	Extruded between fingers when squeezed.	<0.25
3-5	Soft	Molded by light finger pressure.	0.25-0.5
6-9	Firm	Molded by strong finger pressure.	0.5-1.0
10-16	Stiff	Readily indented by thumb but penetrated only with great effort.	1.0-2.0
17-30	Very Stiff	Readily indented by thumbnail.	2.0-4.0
>30	Hard	Indented with difficulty by thumbnail.	>4.0

Coarse Grained Soils

S.P.T N_{70} (Blows/30cm)	Density	Field Identification	Relative Density (%)
0-4	Very Loose	Easily indented with finger , thumb, or fist.	0-20
5-10	Loose	Less easily indented with fist but easily shoveled.	20-40
11-30	Medium Dense	Shoveled with difficulty.	40-60
31-50	Dense	Requires pick to loosen for shoveling by hand.	60-80
>50	Very Dense	Requires blasting or heavy equipment to loosen.	80-100

<u>Recovery</u>: The percentage of length of core recovered in each run to the total length of the core run.

<u>R.Q.D.</u>: Rock Quality Designation is the sum of lengths of all intact core pieces that are 10cm or longer, measured along the center line of the core, expressed as percentage of the total length of the core run.

Rock Quality

Rock Quality Designation, RQD (%)	Rock Quality Description
0 - 25	Very Poor
25 - 50	Poor
50 - 70	Fair
70 - 90	Good
90 - 100	Excellent

Rock Strength

Description	Unconfined Compressive Strength (kg/cm^2)
Very Weak	< 12.5
Weak	12.5 - 50
Moderately Weak	50 - 125
Moderately Strong	125 - 500
Strong	500 - 1000
Very Strong	> 1000

BORING LOG

Project: Amman Development Corridor Pump Station (PSADC) Project		**Boring No.:**	**BH01 (Page 1 of 2)**
Location (Coordinates):	406955 516384	**Depth, m:**	20
Drilling Date:	17/7/2023	**Elevation, m:**	747
Driller:	**EAS-MJ**	**Boring Method:**	Rotary Air Flush
Report No.:	**SS23013**	**Ground Water:**	Not encountered

Depth, m	Sampler Type	Sampling Method	Graphic Log	GEOLOGICAL DESCRIPTION	SPT Records: Field Records 0-15 cm	15-30 cm	30-45 cm	N, Blows	N'70	Recovery, %	R Q D, %
		FT		**Topsoil** materials **...**							
746		FT		Light to dark reddish brown, very stiff to hard, dry **Lean Clay with Sand to Fat Clay** with occasional stone fragments of limestone and Chert and with carbonate dust.							
745		SPT			Ref.	--	--	**Ref.**	**Ref.**		
744		FT									
		SPT			Ref.	--	--	**Ref.**	**Ref.**		
743		FT									
742		SPT/C			23	22	24	**46**	**36**		
741		FT									
		SPT			Ref.	--	--	**Ref.**	**Ref.**		
740		FT									
739		SPT/C			17	18	22	**40**	**27**		
738		FT									
		SPT/C			20	20	21	**41**	**25**		
737		FT									
736		Core		**Stratified Rock Formation** composed of varied color, slightly to highly fractured, moderately weak to moderately strong, thinly to thickly bedded, Chert, limestone, dolomitic limestone, marly limestone, marlstone, marl and few clayey marl						**68**	**25**
735 / 734		Core								**64**	**22**
733 / 732		P									

	AXIS	***See LEGEND for Other Abbreviations***

BORING LOG

Project: Amman Development Corridor Pump Station (PSADC) Project			Boring No.: BH01 (Page 2 of 2)
Location (Coordinates):	406955	516384	Depth, m: 20
Drilling Date:	17/7/2023		Elevation, m: 747
Driller: EAS-MJ			Boring Method: Rotary Air Flush
Report No.: SS23013			Ground Water: Not encountered

Depth, m	Sampler Type	Sampling Method	Graphic Log	GEOLOGICAL DESCRIPTION	SPT Records: Field Records 0-15 cm	15-30 cm	30-45 cm	N, Blows	N'70	Recovery, %	R Q D, %
731 730 729 728 727		P		**Stratified Rock Formation** composed of varied color, slightly to highly fractured, moderately weak to moderately strong, thinly to thickly bedded, Chert, limestone, dolomitic limestone, marly limestone, marlstone, marl and few clayey marl ** From (16-20)m-depth; considerable increases of Chert.*							
726 725 724 723 722 721 720 719 718 717				**End of Boring**							

	AXIS	*See LEGEND for Other Abbreviations*

BORING LOG

Project: Amman Development Corridor Pump Station (PSADC) Project		**Boring No.:**	**BH02 (Page 1 of 2)**
Location (Coordinates): 407044	516333	**Depth, m:**	20
Drilling Date: 17&18/7/2023		**Elevation, m:**	746
Driller: EAS-MJ		**Boring Method:**	Rotary Air Flush
Report No.: SS23013		**Ground Water:**	Not encountered

Depth, m	Sampler Type	Sampling Method	Graphic Log	GEOLOGICAL DESCRIPTION	SPT Records – Field Records 0-15 cm	15-30 cm	30-45 cm	N, Blows	N'_{70}	Recovery, %	R Q D, %
745		FT		**Topsoil** materials **...**							
744		FT		Light to dark reddish brown, very stiff to hard, dry **Lean Clay with Sand to Fat Clay** with occasional stone fragments of limestone and Chert and with carbonate dust.							
		SPT			Ref.	--	--	**Ref.**	**Ref.**		
743		FT									
		SPT			Ref.	--	--	**Ref.**	**Ref.**		
742		FT									
741		SPT/C			23	20	21	**41**	**32**		
740		FT									
		SPT/C			18	18	19	**37**	**25**		
739		FT									
738–736		P		**Stratified Rock Formation** composed of varied color, slightly to highly fractured, moderately weak to moderately strong, thinly to thickly bedded, Chert, limestone, dolomitic limestone, marly limestone, marlstone, marl and few clayey marl							
735		Core								**71**	**29**
734–733		Core								**0**	**0**
732		Core		** From (8-10)m-depth; with beds of brown clay*						**73**	**24**
731		P									

AXIS

See LEGEND for Other Abbreviations

BORING LOG

Project: Amman Development Corridor Pump Station (PSADC) Project	**Boring No.:** BH02 (Page 2 of 2)
Location (Coordinates): 407044 516333	**Depth, m:** 20
Drilling Date: 17&18/7/2023	**Elevation, m:** 746
Driller: EAS-MJ	**Boring Method:** Rotary Air Flush
Report No.: SS23013	**Ground Water:** Not encountered

Depth, m	Sampler Type	Sampling Method	Graphic Log	GEOLOGICAL DESCRIPTION	SPT Records: Field Records 0-15 cm	15-30 cm	30-45 cm	N, Blows	N'_{70}	Recovery, %	R Q D, %
730 729 728 727 726		P		**Stratified Rock Formation** composed of varied color, slightly to highly fractured, moderately weak to moderately strong, thinly to thickly bedded, Chert, limestone, dolomitic limestone, marly limestone, marlstone, marl and few clayey marl ** From (15-20)m-depth; considerable increases of Chert.*							
725 724 723 722 721 720 719 718 717 716				**End of Boring**							

	AXIS	*See LEGEND for Other Abbreviations*

BORING LOG

Project: Amman Development Corridor Pump Station (PSADC) Project			Boring No.: BH03 (Page 1 of 2)
Location (Coordinates):	407129	516323	Depth, m: 20
Drilling Date:	18/7/2023		Elevation, m: 746
Driller: EAS-MJ			Boring Method: Rotary Air Flush
Report No.: SS23013			Ground Water: Not encountered

Depth, m	Sampler Type	Sampling Method	Graphic Log	GEOLOGICAL DESCRIPTION	SPT Records – Field Records 0-15 cm	15-30 cm	30-45 cm	N, Blows	N'_{70}	Recovery, %	R Q D, %
745		FT		**Topsoil** materials **...**							
744		FT									
		SPT			Ref.	--	--	**Ref.**	**Ref.**		
743		FT									
		SPT			34	38	37	**75**	**63**		
742		FT									
741		SPT		Light to dark reddish brown, very stiff to hard, dry **Lean Clay with Sand to Fat Clay** with occasional stone fragments of limestone and Chert and with carbonate dust.	Ref.	--	--	**Ref.**	**Ref.**		
740		FT									
		SPT/C			16	18	20	**38**	**25**		
739		FT									
738		SPT/C			22	24	25	**49**	**33**		
737		FT									
		SPT/C			23	23	21	**44**	**27**		
736		FT									
735		Core		**Stratified Rock Formation** composed of varied color, slightly to highly fractured, moderately weak to moderately strong, thinly to thickly bedded, Chert, limestone, dolomitic limestone, marly limestone, marlstone, marl and few clayey marl						**62**	**0**
734		P									
733											
732		Core		* From (11.5-13)m-depth; with beds of brown clay						**68**	**21**
731		P									

AXIS

See LEGEND for Other Abbreviations

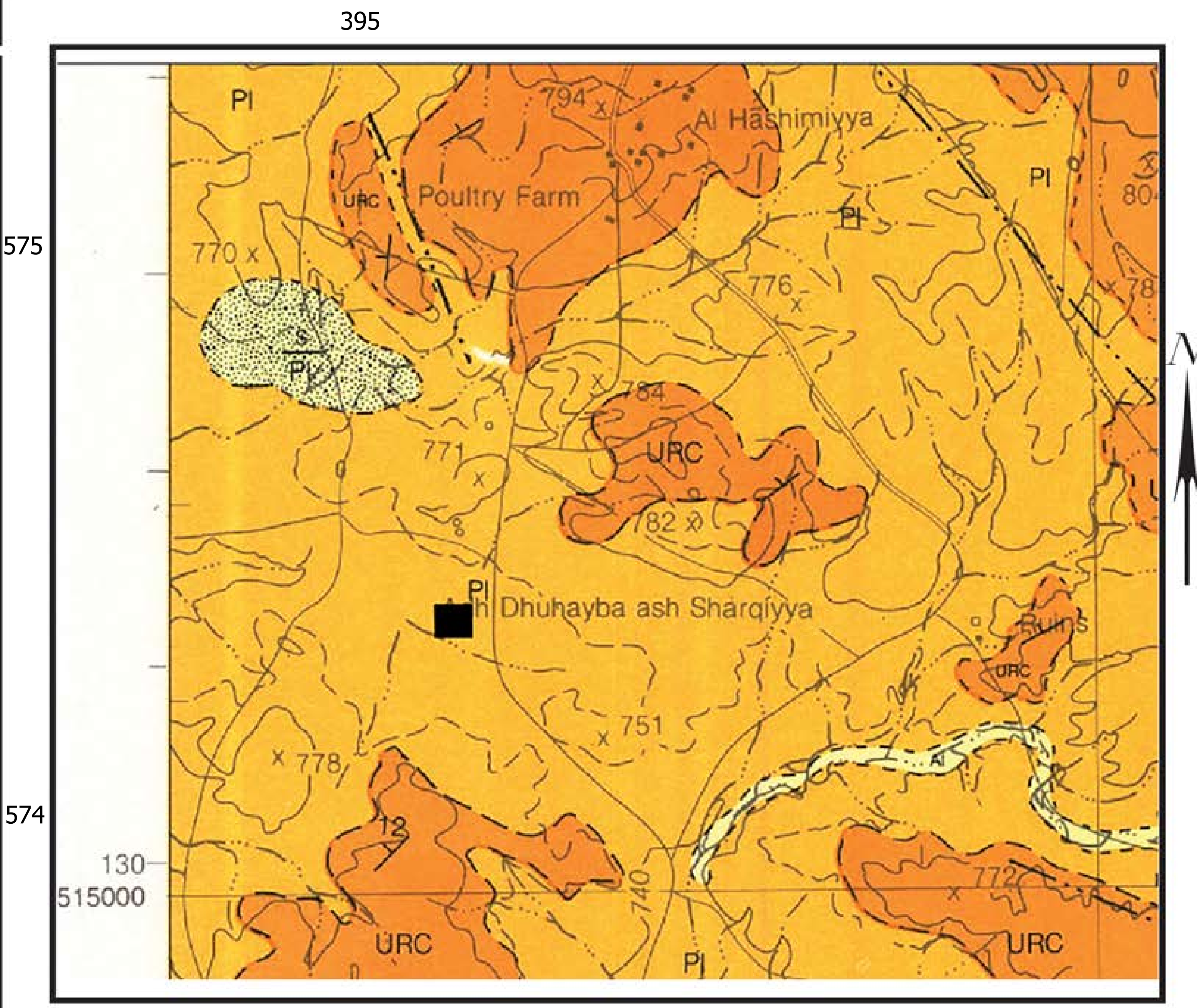
BORING LOG

Project: Amman Development Corridor Pump Station (PSADC) Project	**Boring No.:** BH03 (Page 2 of 2)
Location (Coordinates): 407129 516323	**Depth, m:** 20
Drilling Date: 18/7/2023	**Elevation, m:** 746
Driller: EAS-MJ	**Boring Method:** Rotary Air Flush
Report No.: SS23013	**Ground Water:** Not encountered

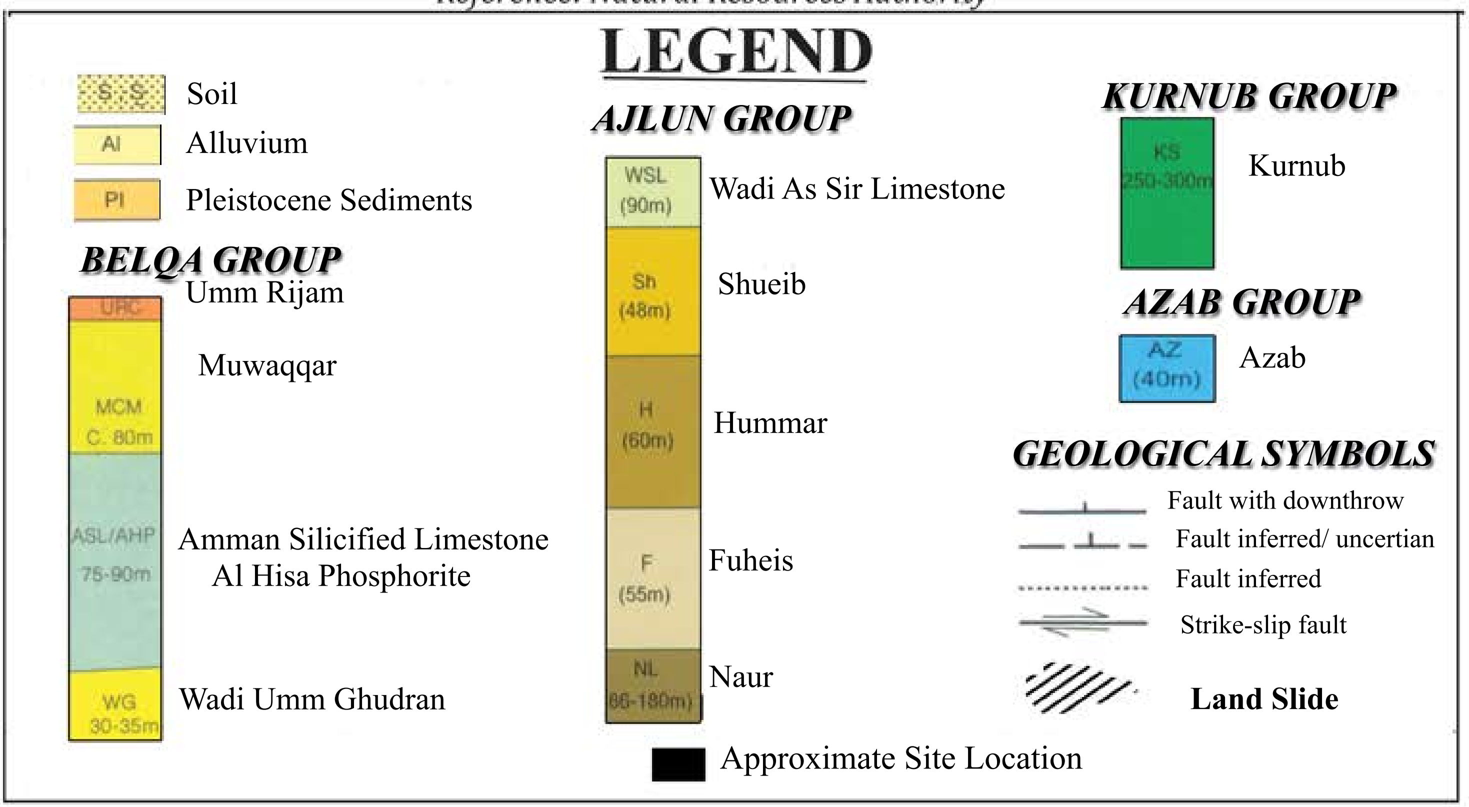
Depth, m	Sampler Type	Sampling Method	Graphic Log	GEOLOGICAL DESCRIPTION	SPT Records: Field Records 0-15 cm	15-30 cm	30-45 cm	N, Blows	N'$_{70}$	Recovery, %	R Q D, %
730 729 728 727 726		P		**Stratified Rock Formation** composed of varied color, slightly to highly fractured, moderately weak to moderately strong, thinly to thickly bedded, Chert, limestone, dolomitic limestone, marly limestone, marlstone, marl and few clayey marl ** From (15-20)m-depth; increases of Chert.*							
725 724 723 722 721 720 719 718 717 716				**End of Boring**							

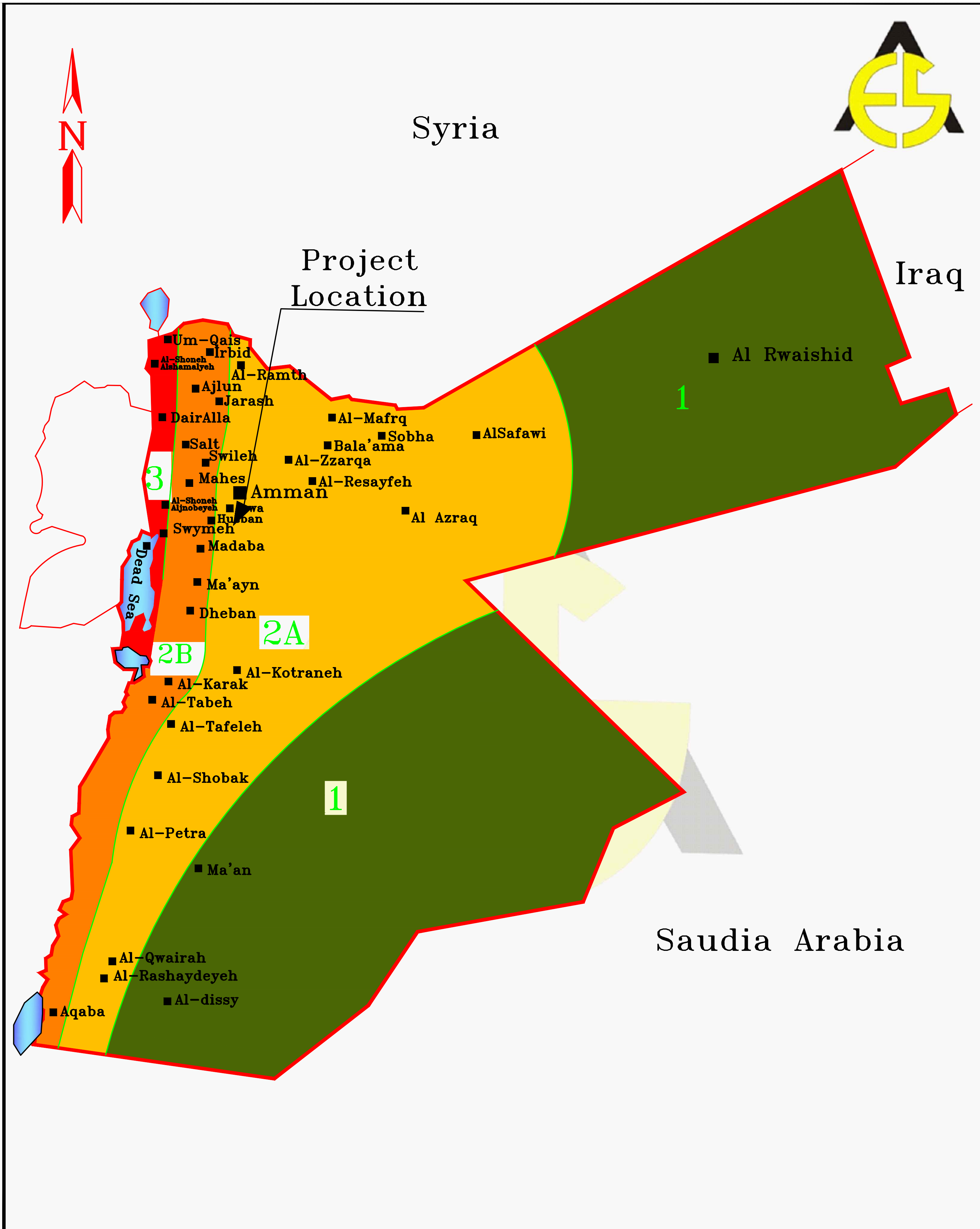
	AXIS	*See LEGEND for Other Abbreviations*

APPENDIX B *(Geological and Seismicity Maps)*



Reference: Natural Resources Authority





Jordan Seismicity and Zoning Map

APPENDIX 2: NEW PSADC PRELIMINARY DESIGN RECOMMENDATIONS

Messrs.: CDM Smith **Aug. 08, 2023**
Amman - Jordan **SS23013/L1**

Subject: Supplementary Report of Preliminary Design Recommendations For the Proposed Amman Development Corridor Pump Station (PSADC) Amman –Jordan Project: AAWDCP Geotechnical Investigation Works

Dear Sirs,

Following our Factual Report No. SS23013 dated Aug. 01, 2023, and upon your request for preliminary design recommendations for the proposed Amman Development Corridor Pump Station (PSADC), Engineering Axis for Studies **(AXIS)** has the pleasure to submit herewith this supplementary report of the requested preliminary design recommendations. It's to be recognized that the drilled boreholes quantity (as determined by the Client) is considered minimal, in respect to the Project facilities, and it doesn't satisfy the minimum requirements of the local cods as well. Therefore, the given recommendations in this report should be considered as preliminary generalized recommendations, which may assist in preliminary designs not in final designs.

We would like to express our sincere thanks to you for your confidence, looking forward for future cooperation. For further information, discussion or clarification, please do not hesitate to contact our office.

Engineering Axis for Studies

ABDULLA SHIHAB
M. Sc., B.Sc. in Civil Eng.
(Chartered & Consultant Engineer)
General Manager

مكتب المحور الهندسي للدراسات
Engineering Axis for Studies

1. INTERPRETATION AND ANALYSIS OF FINDINGS

1.1. For the Lean Clay with Sand to Fat Clay Formation

1.1.1. Interpretation of SPT Results

The SPT results, as obtained from fieldwork for the Lean Clay with Sand to Fat Clay layer, are tabulated in Table 1. The obtained number of blows per 30-cm (N Field) was corrected to obtain the corrected SPT Number (N Corrected). The composite correction factor was obtained for each (N Field) value, utilizing equations at the table footnote.

Table 1: SPT Results and Analysis of Results for the Lean Clay with Sand to Fat Clay Formation

BH ID.	Depth, m	N_{Field}	GWT, m	N'_{70}
BH01	1.5	Ref.	N.E	Ref.
	3.0	Ref.	N.E	Ref.
	4.5	46	N.E	36
	6.0	Ref.	N.E	Ref.
	7.5	40	N.E	27
	9.0	41	N.E	25
BH02	1.5	Ref.	N.E	Ref.
	3.0	Ref.	N.E	Ref.
	4.5	41	N.E	32
	6.0	37	N.E	25

BH ID.	Depth, m	N_{Field}	GWT, m	N'_{70}
BH03	1.5	Ref.	N.E	Ref.
	3.0	75	N.E	63
	4.5	Ref.	N.E	Ref.
	6.0	38	N.E	25
	7.5	49	N.E	33
	9.0	44	N.E	27

	Uncorr. SPT (N_{Field})	Corr. SPT (N'_{70})
Number of Obtained SPT Values (Excluding Refusal Results)=	9	9
Lowest Obtained Value =	37	25
Highest Obtained Value =	75	63
Average Value =	45.7	32.7
Standard Deviation of the Obtained Values=	11.6	11.9
Statistically Deduced Value (Avg. - 0.5*σ)=	**40**	**27**

Remark: $N'_{70} = (95.76/\rho'_o)^{0.5} * N * \eta 1 * \eta 2 * \eta 3 * \eta 4$

where;

ρ'_o; Effect Effective overburden pressure, kPa.

$\eta 1$; Energy Ratio (Ero)/70 (80/70); (1.14)

$\eta 2$; Rod length correction

$\eta 3$; Sampler correction (0.85)

$\eta 4$; Borehole diameter correction (1.0)

The SPT revealed relatively high values. Based on AXIS previous studies in similar site materials and taking in consideration the limited number of tests (excluding refusal results), scattering and inherent variation in such materials; a design value (N'_{70}) of 27 was considered for the Lean Clay with Sand to Fat Clay Layer.

1.1.2. Assessment of Geotechnical Parameters

Taking in account the inherent discrepancies and unreliability of utilizing SPT results for assessment of cohesive native grounds, several widely used relationships were exercised to assess bearing capacity of the Lean Clay with Sand to Fat Clay Layer based on the concluded SPT design value of 27. However, the obtained bearing capacity values were unreliably high. Therefore, another approach was utilized for assessment of bearing capacity for this layer by using shear parameters. Nevertheless, assessment of deformation modulus for the Lean Clay with Sand to Fat Clay Layer was based on the concluded SPT design value, considering the equation shown in Table B1 of Appendix A.

Assessment of shear parameters for the Lean Clay with Sand to Fat Clay Layer was based on the classification tests results (e.g. moisture content, Atterberg Limits, and Particle Size Analysis), monitoring of drilling progress, AXIS previous experience with such materials mentioning that such Lean Clay with Sand to Fat Clay Layer is common in Jordan, all along with the obtained SPT values. Accordingly, the adopted geotechnical parameters for the Lean Clay with Sand to Fat Clay materials in the subsequent analyses of this report are presented in Table 2.

Table 2: Adopted Geotechnical Parameters for the Lean Clay with Sand to Fat Clay

Property	Lean Clay with Sand to Fat Clay
Unit weight (γ), kN/m^3	17.50
Stress-state	effective
Angle of internal friction (φ_{ef})	15°
Cohesion of soil (c_{ef}), kPa	40
Angle of friction structure-soil (δ)	10°
Soil	Cohesive
Poisson's ratio (ν)	0.35
Saturated unit weight (γ_{sat}), kN/m^3	19.50

1.1.3. Evaluation Potential for Expansiveness of Foundations Formation

The encountered Recent Fill and Lean Clay with Sand to Fat Clay materials were evaluated for potential for expansiveness; In addition to Casagrande Plasticity Chart to classify plasticity of soils, potential for expansiveness used 'Van der Merwe, 1964 (modified by Williams and Donaldson, 1980)' method, as being adopted in the relevant Jordanian Code. Clay Contents (by Hydrometer Method) and Atterberg limits, carried out on samples from the Lean Clay with Sand to Fat Clay, were used for assessment of potential for expansiveness.

Classification by Casagrande Plasticity Chart and potential for expansiveness for the Lean Clay with Sand to Fat Clay are plotted in Figures 1 and 2, respectively. It can be seen that the Lean Clay with Sand to Fat Clay materials are classified as Clay of medium to very high Plasticity (**CI-CV**), of high to very high Potential for Expansiveness, with prevalent Very High Potential for Expansiveness.

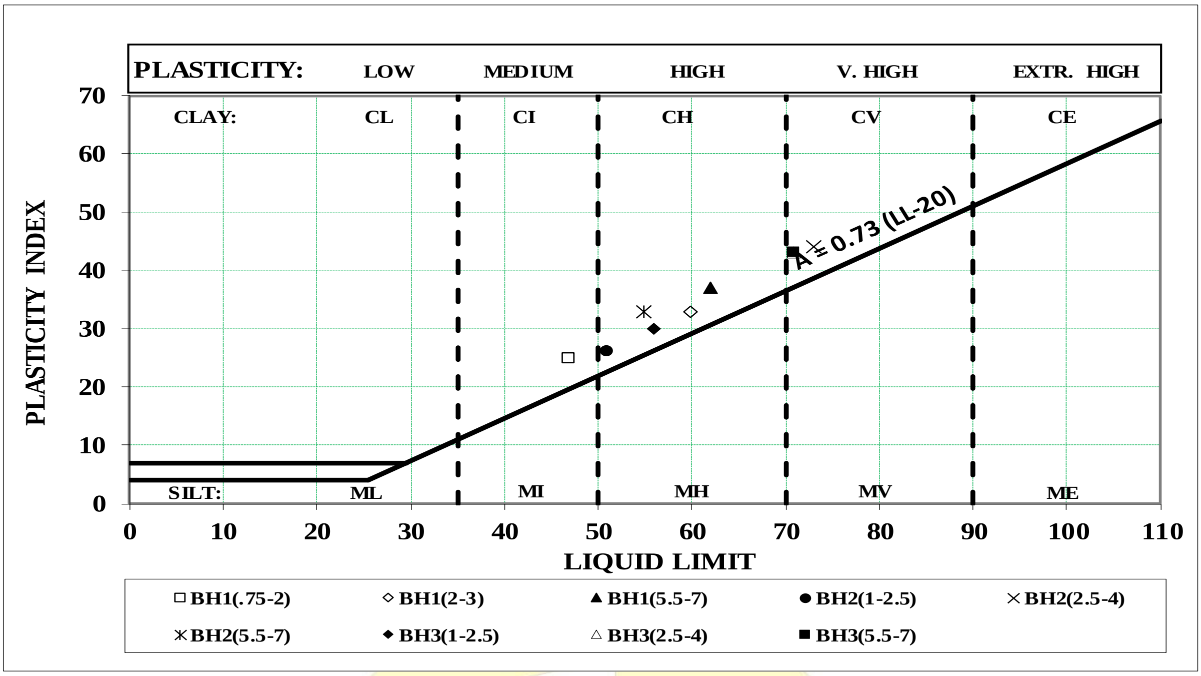


FIGURE NO. 1: CASAGRANDE Plasticity Chart

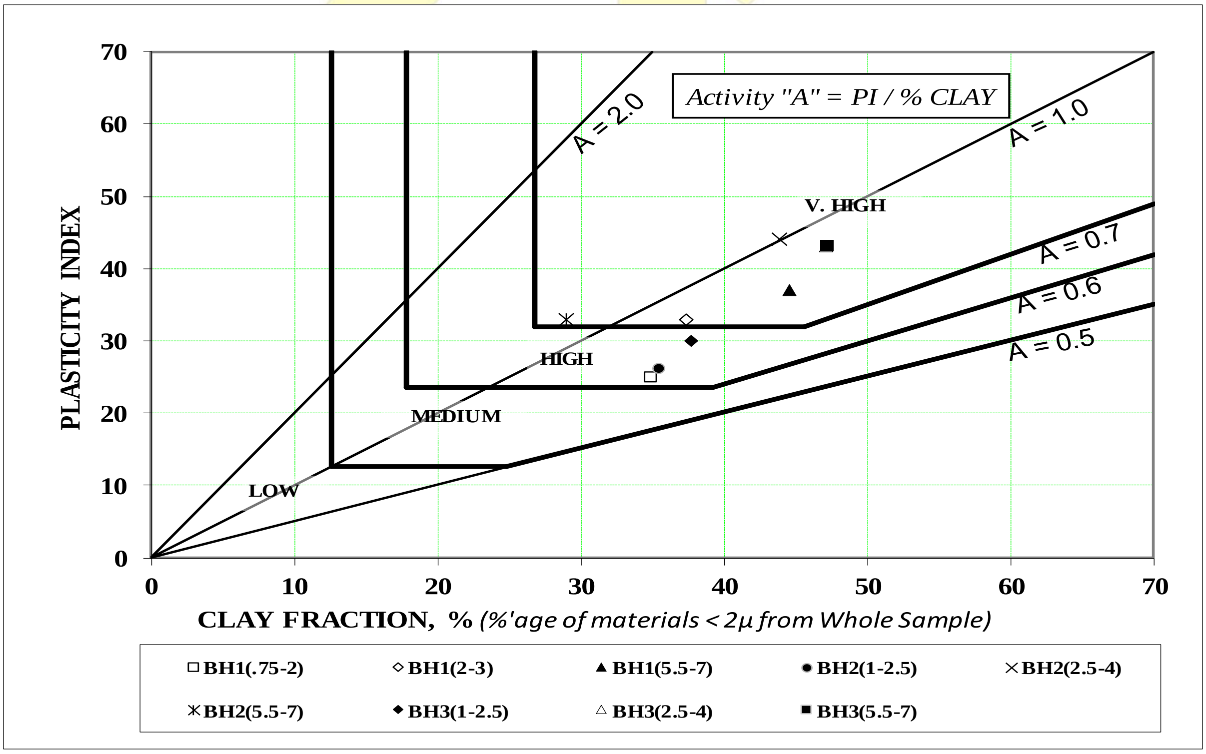


FIGURE No. 2: Potential for Expansiveness

1.2. For the Stratified Rock Formation

1.2.1. Adoption of Laboratory Tests Results

A judgmental statistical procedure was followed for adoption of the materials characteristics, as obtained from lab testing, with the tendency of being at the conservative side. Table 3 presents the adopted values from lab tests for the Stratified Rock Formation.

Table 3: Adopted Values from Laboratory Tests Results for the Site Formation/s

Formation	In-situ Bulk Density, gm/cm^3	Point Load Strength Index (Is), Mpa	Unconfined Compressive Strength, MPa	Axial Strain, % (-)	Young's Modulus, MPa
Stratified Rock	2.40	0.4	9.5	0.44	2,159

1.2.2. Adoption of Geotechnical Parameters

The geological description given under Subsurface Stratigraphy, inspected lithologies and laboratory tests results were utilized to evaluate the site rock mass characteristics. Rock Mass Rating (RMR) was carried out based on the procedure outlined in ASTM D 5878 - 08; "Standard Guides for Using Rock-Mass Classification Systems for Engineering Purposes". The following six parameters are used by this procedure to assess the RMR;

1. Unconfined Compressive Strength (qu) & Point Load Strength Index (Is)
2. Rock Quality Designation (RQD)
3. Spacing of discontinuities
4. Condition of discontinuities
5. Ground water conditions
6. Orientation of discontinuities

Assessment of the said six parameters was performed utilizing the geological description of core samples, laboratory tests results, published literature on the formations encountered and engineering assessment of rock physical properties. The adopted characteristics and the revealed ranges of RMR with the adopted RMR for the Stratified Rock Formations are presented in Table 4.

Table 4: General Characteristics of the Site Formation/s

Formation	Unconfined Compressive Strength of Intact Cores, KPa	In-situ Unit Weight, KN/m^3	RMR			Class No.	Description
			Lowest	Highest	Adopted		
Stratified Rock	9,500	24	25	42	34	IV	Poor rock

Shear parameters of site rock mass formations (φ; friction angle and C; cohesion), to be used in bearing capacity assessment, were obtained from the ASTM standard, utilizing the adopted RMR values and interpolation. The revealed friction angle was adopted, whereas, cohesion was reduced by 50%, as recommended by U.S. Army Corps of Engineers (Rock Foundations, EM 1110-1-2908 30 Nov 94).

Rock mass deformation moduli (E_{rm}) for the site formation were assessed in the light of several published methods (7 methods), utilizing the concluded characteristics of the rock formation. The adopted (E_{rm}) was finally guided by Judgmental statistical procedure of the revealed values, as shown in Table B2 of Appendix A.

In addition to parameters presented in Table 4, the remaining rock mass parameters for assessment of bearing capacity and settlement are presented in Table 5.

Table 5: Rock Mass Parameters

Formation	Revealed Parameters from ASTM		Adopted Parameters		μ	Rock Mass Deformation Modulus, E_{rm}, MPa
	Rock Mass ϕ, Degrees	Rock Mass C, kPa	Rock Mass ϕ', Degrees	Rock Mass C', kPa		
Stratified Rock	22	168	22	84	0.32	380

2. PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

2.1. Candidate Foundation Formation/s and Foundation Depths

The candidate formation for foundations of the proposed project facilities is the "Light to dark reddish brown, very stiff to hard, dry **Lean Clay with Sand** to **Fat Clay** with occasional stone fragments of limestone and Chert and with carbonate dust" Layer. Therefore, the topsoil materials should be totally removed under foundations and the buildings foundations should be erected on the **Lean Clay with Sand** to **Fat Clay** Formation. Cyclopean concrete (i.e. plain concrete with approximately 40-60% stones) can be used for leveling up to reach the planned foundation level, as conditions necessitate.

The recommended foundation grounds would be suitable to support the project loads by any shallow foundation system such as raft foundation (for the tank) and strip (continuous) footings, individual footings with tie rigid beams, or a combination thereof (for buildings). However, strip (continuous) footings for foundations on Lean Clay with Sand to Fat Clay materials can be more satisfactory than individual (isolated) footing systems.

In general, several considerations for selection of the level at which foundations are to be erected should be taken in account. Such considerations include, but may not be limited to, design requirements (structural, architectural, etc.), suitable ground type, foundation penetration and foundation depth. From geotechnical viewpoint, foundation depth is measured from the bottom of foundation to the adjacent finished level of ground surrounding the structure (i.e. foundation ground cover). Foundation depth shall be sufficient to provide protection for the foundation soil against environmental factors. Therefore, the foundation depth shall not be less than **3.0m** for foundations to be erected on the **Lean Clay with Sand** to **Fat Clay .**

2.2. Allowable Bearing Capacity

2.2.1. For the Proposed Buildings Foundations

Assessment of allowable bearing capacity for the candidate formation/s was based on two well recognized philosophies for general shear failure; namely 'Terzaghi, 1943 & Bowles, 1997' and 'Meyerhof, 1963'. A Safety Factor (SF) of (3) was adopted for general shear failure. Evaluation of shear parameters to be used in bearing capacity assessment is indicated in Table 2 of Section 1.1.2.

Table 6 summarizes the concluded allowable bearing capacities of buildings foundations on the Lean Clay with Sand to Fat Clay materials. The calculation sheets are presented in Table B3 of Appendix A.

Table 6: Concluded Allowable Bearing Capacities of Buildings Foundations

Mode of Failure	Philosophy	Safety Factor	Allowable Bearing Capacity, kPa	
			Gross	Net
General Shear Failure	Terzaghi, 1943 & Bowles, 1997	3	260	210
	Meyerhof, 1963	3	250	200
Lowest Value			**250**	**200**
Adopted Value			**230**	**180**

Based on these calculations and AXIS experience with similar foundation grounds; a net allowable bearing capacity value of **180kPa** (≈1.8kg/cm^2) is recommended for the buildings foundations to be erected on the **Lean Clay with Sand** to **Fat Clay** materials.

2.2.2. For the Proposed Tank Raft Foundation

Assessment of allowable bearing capacity for the candidate formation/s was based on two well recognized philosophies for general shear failure; namely 'Terzaghi, 1943 & Bowles, 1997' and 'Meyerhof, 1963'. A Safety Factor (SF) of (6) was adopted for general shear failure. Evaluation of shear parameters to be used in bearing capacity assessment is indicated in Table 2 of Section 1.1.2.

Table 7 summarizes the concluded allowable bearing capacities of the Tank foundation on the Lean Clay with Sand to Fat Clay materials. The calculation sheets are presented in Table B4 of Appendix A.

Table 7: Concluded Allowable Bearing Capacities of Tank Foundation

Mode of Failure	Philosophy	Safety Factor	Allowable Bearing Capacity, kPa	
			Gross	Net
General Shear Failure	Terzaghi, 1943 & Bowles, 1997	6	290	220
	Meyerhof, 1963	6	250	180
Lowest Value			**250**	**180**
Adopted Value			**130**	**--**

Mentioning that the relevant bearing capacity for tanks is the gross bearing capacity, and based on these calculations and AXIS experience with similar foundation grounds and in order to control settlement; a gross allowable bearing capacity value of **130kPa** (≈1.3kg/cm^2) is recommended for the tanks foundations to be erected on the **Lean Clay with Sand** to **Fat Clay** materials.

2.3. Anticipated Settlements

According to the revealed characteristics of the site formation/s, short-term (immediate or elastic) settlement is the candidate type of settlement to prevail rather than long-term settlement. Long-term settlement (primary and secondary consolidation settlement) is usually used to describe settlement other than immediate or elastic settlement. Formations candidate for consolidation settlement are mainly saturated or *semi-saturated* "clays and silts" and "mudstone and shale", usually located below water table (Bowles; 1997, Das; 1999). Nevertheless, the revealed Immediate Settlements were increased by ~ 30% to account for creep and secondary compression after 3 years (U.S. Army Corps of Engineers, EM 1110-1-1904, 30 Sep. 1990).

2.3.1. For the Proposed Buildings Foundations

Based on general geology of the site, as provided by the NRA geological maps and the revealed subsurface formations by drilling, it is assumed that the contact foundation materials (**Lean Clay with Sand** to **Fat Clay** materials) are extending down to a depth of 7m followed by the stratified Rock Formation which is extended down to the whole effective depth under the foundations. Three widely-used philosophies were incorporated in assessment of the anticipated settlements of foundations, and the highest settlement among these three was adopted. Table 8 summarizes the anticipated settlements of foundations on the Lean Clay with Sand to Fat Clay materials. The calculation sheets are presented in Table B5 of Appendix A. The tabulated settlement values, representing the upper bound values, are for the recommended maximum allowable static stresses. However, for lower stresses settlements will be less than tabulated.

Table 8: Concluded Immediate Settlement of the Buildings Foundations

No.	Author/Method	Foundations Settlement, mm		
		Flexible		Rigid
		Center	Corner	
1	Bowles, 1997	3.7	1.2	3.5
2	U.S. Corps, EM 1110-1-2908 30 Nov 94	14.0	6.6	11.6
3	Bieniawski (Boussinesq, Newmark and Fadum)	12.2	7.3	8.5
Upper Bound Settlement		14	7	12
Settlement after 3 years from creep and secondary compression, ρ_t [~ 1.3 * ρ_i] (U.S. Army Corps of Engineers, EM 1110-1-1904, 30 Sep. 1990), mm		**18**	**9**	**16**
Differential Settlement; Upper Bound (~ 0.75 * ΔH), mm		**12**		
Coefficient of Subgrade Reaction (k_s)				
Method 1: $k_s = E_s / (B * (1-\mu^2))$, MN/m^3		38		
Method 2: $k_s = q_a * SF / \Delta H$, MN/m^3		33		
Recommended Coefficient of Subgrade Reaction (k_s), MN/m^3		**36**		

2.3.2. For the Proposed Tank Raft Foundation

Based on general geology of the site, as provided by the NRA geological maps and the revealed subsurface formations by drilling, it is assumed that the contact foundation materials (**Lean Clay with Sand** to **Fat Clay** materials) are extending down to a depth of 6m followed by the stratified Rock Formation which is extended down to the whole effective depth under the foundations. Three widely-used philosophies were incorporated in assessment of the anticipated settlements of foundations, and the highest settlement among these three was adopted. Table 9 summarizes the anticipated settlements of foundations on the Lean Clay with Sand to Fat Clay materials. The calculation sheets are presented in Table B6 of Appendix A. The tabulated settlement values, representing the upper bound values, are for the recommended maximum allowable static stresses. However, for lower stresses settlements will be less than tabulated.

Table 9: Concluded Immediate Settlement of the Tank Foundation

No.	Author/Method	Foundations Settlement, mm		
		Flexible		Rigid
		Center	Corner	
1	Bowles, 1997	25.3	10.7	23.6
2	U.S. Corps, EM 1110-1-2908 30 Nov 94	30.7	14.7	24.2
3	Bieniawski (Boussinesq, Newmark and Fadum)	53.0	31.8	37.1
Upper Bound Settlement		53	32	37
Settlement after 3 years from creep and secondary compression, ρ_t [~ 1.3 * ρ_i] (U.S. Army Corps of Engineers, EM 1110-1-1904, 30 Sep. 1990), mm		**69**	**42**	**48**
Differential Settlement; Upper Bound (~ 0.4* ΔH), mm		**25**		
Angular Distortion for Mat Foundation		**1/ 2400**		
Coefficient of Subgrade Reaction (k_s)				
Method 1: $k_s = E_s / (B * (1-\mu^2))$, MN/m³		7		
Method 2: $k_s = q_a * SF / \Delta H$, MN/m³		12		
Recommended Coefficient of Subgrade Reaction (k_s), MN/m³		**9**		

3. IMPORTANT REMARKS

- All preliminary conclusions and recommendations are based on boring records, examination of samples, and laboratory testing. However, any unforeseen conditions that have not been revealed by the boreholes are beyond our responsibility.
- It is to be emphasized that the Client is solely responsible, and our office does not bear any responsibility in case of inappropriate implementation of the preliminary recommendations given in this report.

APPENDIX A *(Methods of Calculations)*

Table B1: Assessment of Deformation Moduli for Lean Clay with Sand to Fat Clay Layer

Layer	N_{70}	N_{55}	N_{60}
Lean Clay with Sand to Fat Clay	27	21	23

No.	Author/Method	Equation for $E_{m, kPa}$	Formation	E_m, MPa
1	Trofimenkov, 1974 (Das, 2007)	E/p_a = (350 to 500) * log(N_{60})	Lean Clay with Sand to Fat Clay	51

Table B2: Assessment of Deformation Moduli for Site Stratified Rock Formation

Formation	q_{ui}, MPa	E_{si}, MPa	RQD	RMR *(GSI = RMR - 5)*
Stratified Rock	9.5	2,159	20	34
--				
--				

No.	Author/Method	Equation for E_{rm}	Formation	E_{rm}, MPa
1	1. Bieniawski, 1978 (Serafim and Periera, 1983)	$10^{((GSI-10)/40)}$	Stratified Rock	2,990
			--	--
			--	--
2	Hoek, Carranza-Torres, Corkum (2002)	$(q_{ui}/100)^{0.5}*10^{((GSI-10)/40)}$	Stratified Rock	920
			--	--
			--	--
3	Hoek and Diederichs (2006)	$E_{si}*(0.02+1/(1+e^{((60-GSI)/11))}))$	Stratified Rock	160
			--	--
			--	--
4	Hoek and Diederichs (2006)	$100,000*(1/(1+e^{((75-GSI)/11))}))$	Stratified Rock	1,500
			--	--
			--	--
5	M. Ghamgosar (2010)	$0.0912*e^{(0.0866*GSI)}$	Stratified Rock	1,120
			--	--
			--	--
6	Gokceoglu (2003)	$0.145*e^{(0.0645*GSI)}$	Stratified Rock	940
			--	--
			--	--
7	Carter and Kulhay (1988)	$0.15*E_{si}$ *(for RQD ~ 20 - 50)*	Stratified Rock	320
			--	--
			--	--

Formation	Average	Standard Deviation	Avgerage - 0.5* Standard Dev.	Lowest Value	Adopted E_m, MPa
Stratified Rock	1,136	938	667	160	**380**
--	--	--	--	--	**--**
--	--	--	--	--	**--**

Table B3: Bearing Capacity of Buildings Foundations

Foundation Shape			φ', deg.	c', kPa (*)	ρ', kN/m³	B, m	L, m	D_f, m
Strip		Square	15	40	18.0	1.5	10	3.0

1- Terzaghi, 1943 & Bowles, 1997 (General Shear Failure) $q_{ult} = cN_cs_c + q'N_q + 0.5\Upsilon BN_\gamma s_\gamma r_\gamma$

r_γ	$K_{p\gamma}$	a	N_q	N_c	N_γ
1.00	18.60	1.82	4.45	12.86	2.54

Foundation Shape	Strip	Round	Square
s_c	1.0	--	1.3
s_γ	1.0	--	0.8
q_{ult} , kPa =	790	--	940
Safety Factor	3	3	3
Allowable Gross Bearing Capacity, kPa	260	--	310
Allowable Net Bearing Capacity, kPa	210	--	260

2- Meyerhof, 1963 (General Shear Failure) $q_{ult} = cN_cs_cd_c + q'N_qs_qd_q + 0.5\Upsilon B'N_\gamma s_\gamma d_\gamma$

K_p	d_c	d_q, d_γ	N_q	N_c	N_γ
1.70	1.08	1.04	3.94	10.98	1.13

Foundation Shape	Strip	Round	Square
s_c	1.05	--	1.34
s_q, s_γ	1.03	--	1.17
q_{ult} , kPa =	740	--	910
Safety Factor	3	3	3
Allowable Gross Bearing Capacity, kPa	250	--	300
Allowable Net Bearing Capacity, kPa	200	--	250

Table B4: Bearing Capacity of Tank Foundation

Foundation Shape			φ', deg.	c', kPa (*)	ρ', kN/m^3	B, m	L, m	D_f, m
Raft			15	40	18.0	62	124	4.0

1- Terzaghi, 1943 & Bowles, 1997 (General Shear Failure) $q_{ult} = cN_cs_c + q'N_q + 0.5\gamma BN_\gamma s_\gamma r_\gamma$

r_γ	$K_{p\gamma}$	a	N_q	N_c	N_γ
0.63	18.60	1.82	4.45	12.86	2.54

Foundation Shape	Raft	Round	Square
s_c	1.0	--	--
s_γ	1.0	--	--
q_{ult}, kPa =	1720	--	--
Safety Factor	6	6	6
Allowable Gross Bearing Capacity, kPa	290	--	--
Allowable Net Bearing Capacity, kPa	220	--	--

2- Meyerhof, 1963 (General Shear Failure) $q_{ult} = cN_cs_cd_c + q'N_qs_qd_q + 0.5\gamma B'N_\gamma s_\gamma d_\gamma$

K_p	d_c	d_q, d_γ	N_q	N_c	N_γ
1.70	1.01	1.00	3.94	10.98	1.13

Foundation Shape	Raft	Round	Square
s_c	1.17	--	--
s_q, s_γ	1.08	--	--
q_{ult}, kPa =	1510	--	--
Safety Factor	6	6	6
Allowable Gross Bearing Capacity, kPa	250	--	--
Allowable Net Bearing Capacity, kPa	180	--	--

Table B5: Immediate Settlement of Buildings Foundations

Foundation Shape			q_o, kPa	B, m	L, m	D_f, m
Strip	round	Square	180	1.5	10	3.00

1- BOWLES 1997 $\Delta H = q_o B'[(1-\mu^2)/E] m I_s I_F$

Strata	Description	Depth Range, m		E_m, MPa	μ	H, m	E_{mwt}, MPa	E_{mav}, MPa
Layer 1	with Sand to Fat Clay	0	10	50	0.35	4.5	50.0	50.0
Layer 2	Stratified Rock	10	NA	380	0.32		0.0	
Layer 3	--	NA	NA	400	--		0.0	

Foundation Shape	Strip		Round		Square	
Foundation Point	Center	Corner	Center	Corner	Center	Corner
M	6.7	6.7	1.0	1.0	1.0	1.0
N	6.0	3.0	6.8	3.4	6.0	3.0
D/B	2.00	2.00	2.26	2.26	2.00	2.00
L/B	6.67	6.67	1.00	1.00	1.00	1.00
I_1	0.606	0.379	0.468	0.383	0.457	0.363
I_2	0.117	0.140	0.023	0.043	0.026	0.048
I_s	0.66	0.44	0.48	0.40	0.47	0.39
I_F	0.58	0.58	0.69	0.69	0.69	0.69
ΔH; Settlement (Flexible Foundation), mm	3.7	1.2	3.2	1.3	3.1	1.3
ΔH; Settlement (Rigid Foundation), mm	3.5		3.0		2.9	

2- U.S. Army Corps of Engineers, EM 1110-1-2908 30 Nov 94 $\Delta H = 1.12 q_o B[(1-\mu^2)(L/B)^{0.5}/E_m$

Strata	Description	Depth Range, m		E_m, MPa	μ	H, m	E_{mwt}, MPa	E_{mav}, MPa
Layer 1	with Sand to Fat Clay	0	10	50	0.35	4.5	50.0	50.0
Layer 2	Stratified Rock	10	NA	380	0.32		0.0	
Layer 3	--	NA	NA	400	--		0.0	

Foundation Shape	Strip		Round		Square	
Foundation Point	Center	Corner	Center	Corner	Center	Corner
L/B	6.67	6.67	1.00	1.00	1.00	1.00
Reduction Factor for Point	1.00	0.47	1.00	0.57	1.00	0.50
Reduction Factor for Rigid	0.83		0.70		0.76	
ΔH; Settlement (Flexible Foundation), mm	14.0	6.6	5.4	3.1	5.4	2.7
ΔH; Settlement (Rigid Foundation), mm	11.6		3.8		4.1	

Table B5: Immediate Settlement of Buildings Foundations (Continued)

2- Bieniawski ***(Similar to Boussinesq, Newmark, and Fadum); DAS 2011*** **$\Delta H = \Sigma(\Delta q . \Delta h / E_m)$**

Strata	Description	Depth Range, m		E_m, MPa
Layer 1	with Sand to Fat Clay	0	10	50
Layer 2	Stratified Rock	10	NA	380
Layer 3	--	NA	NA	400

Depth, m	%age of Stress	Incr. sett., mm	Depth, m	%age of Stress	Incr. sett., mm
0.0	100.0%	--	3.6	24.5%	0.26
0.3	97.7%	1.07	3.9	22.4%	0.25
0.6	88.1%	1.00	4.2	20.6%	0.23
0.9	75.5%	0.88	4.5	18.9%	0.21
1.2	64.1%	0.75	4.8	17.5%	0.20
1.5	54.8%	0.64	5.1	16.2%	0.18
1.8	47.5%	0.55	5.4	15.0%	0.17
2.1	41.6%	0.48	5.7	14.0%	0.16
2.4	36.9%	0.42	6.0	13.0%	0.15
2.7	32.9%	0.38	6.3	12.2%	0.14
3.0	29.7%	0.34	6.6	11.4%	0.13
3.3	26.9%	0.31	6.9	10.7%	0.12

Foundation Shape	Strip	
Foundation Point	Center	Corner
Reduction factor for embedment	0.90	
Reduction Factor for Point	1.00	0.60
Reduction Factor for Rigid	0.70	
ΔH; (Flexible Foundation), mm	12.2	7.3
ΔH; (Rigid Foundation), mm	8.5	

Table B6: Immediate Settlement of Foundations

Foundation Shape			q_o, kPa	B, m	L, m	D_f, m
Strip	round	Square	130	62	124	4.00

1- BOWLES 1997

$$\Delta H = q_o B'[(1-\mu^2)/E] m I_s I_F$$

Strata	Description	Depth Range, m		E_m, MPa	μ	H, m	E_{mwt}, MPa	E_{mav}, MPa
Layer 1	with Sand to Fat Clay	0	10	50	0.35	306.0	1.0	373.5
Layer 2	Stratified Rock	10	NA	380	0.32		372.5	
Layer 3	--	NA	NA	--	--		0.0	

Foundation Shape	Strip		Round		Square	
Foundation Point	Center	Corner	Center	Corner	Center	Corner
M	2.0	2.0	1.0	1.0	1.0	1.0
N	9.9	4.9	11.1	5.6	9.9	4.9
D/B	0.06	0.06	0.07	0.07	0.06	0.06
L/B	2.00	2.00	1.00	1.00	1.00	1.00
I_1	0.639	0.524	0.504	0.449	0.497	0.435
I_2	0.031	0.059	0.014	0.028	0.016	0.031
I_s	0.65	0.55	0.51	0.46	0.50	0.45
I_F	1.00	1.00	1.00	1.00	1.00	1.00
ΔH; Settlement (Flexible Foundation), mm	25.3	10.7	19.8	8.9	19.5	8.7
ΔH; Settlement (Rigid Foundation), mm	23.6		18.4		18.2	

2- U.S. Army Corps of Engineers, EM 1110-1-2908 30 Nov 94

$$\Delta H = 1.12 q_o B[(1-\mu^2)(L/B)^{0.5}/E_m$$

Strata	Description	Depth Range, m		E_m, MPa	μ	H, m	E_{mwt}, MPa	E_{mav}, MPa
Layer 1	with Sand to Fat Clay	0	10	50	0.35	306.0	1.0	373.5
Layer 2	Stratified Rock	10	NA	380	0.32		372.5	
Layer 3	--	NA	NA	--	--		0.0	

Foundation Shape	Strip		Round		Square	
Foundation Point	Center	Corner	Center	Corner	Center	Corner
L/B	2.00	2.00	1.00	1.00	1.00	1.00
Reduction Factor for Point	1.00	0.48	1.00	0.57	1.00	0.50
Reduction Factor for Rigid	0.79		0.70		0.76	
ΔH; Settlement (Flexible Foundation), mm	30.7	14.7	21.7	12.4	21.7	10.8
ΔH; Settlement (Rigid Foundation), mm	24.2		15.2		16.5	

Table B6: Immediate Settlement of Foundations (Continued)

2- Bieniawski *(Similar to Boussinesq, Newmark, and Fadum); DAS 2011* $\Delta H = \Sigma(\Delta q . \Delta h / E_m)$

Strata	Description	Depth Range, m		E_m, MPa
Layer 1	with Sand to Fat Clay	0	10	50
Layer 2	Stratified Rock	10	NA	380
Layer 3	--	NA	NA	--

Depth, m	%age of Stress	Incr. sett., mm	Depth, m	%age of Stress	Incr. sett., mm	Foundation Shape	Strip	
0.0	100.0%	--	142.4	15.2%	0.64			
6.0	99.7%	15.58	154.8	13.1%	0.60	Foundation Point	Center	Corner
18.4	93.4%	4.09	167.2	11.5%	0.52	Reduction factor for embedment	0.90	
30.8	80.2%	3.68	179.6	10.1%	0.46			
43.2	66.0%	3.10	192.0	9.0%	--	Reduction Factor for Point	1.00	0.60
55.6	53.5%	2.54	204.4	8.0%	--			
68.0	43.5%	2.06	216.8	7.2%	--	Reduction Factor for Rigid	0.70	
80.4	35.6%	1.68	229.2	6.5%	--			
92.8	29.4%	1.38	241.6	5.9%	--	ΔH; (Flexible Foundation), mm	53.0	31.8
105.2	24.5%	1.14	254.0	5.4%	--			
117.6	20.7%	0.96	266.4	4.9%	--	ΔH; (Rigid Foundation), mm	37.1	
130.0	17.6%	0.81	278.8	4.5%	--			