TRANSMITTAL LETTER

June 10, 2022

Jeff Tullis – VP Transmission Operations
Grand River Dam Authority
9933 E. 16th St.
Tulsa, OK 74128

RE: GRDA Kinzie Substation Stillwater – Report No. CEC-22-12 – CEC Project No. 220454.1

CEC Corporation appreciated the opportunity to provide geotechnical engineering services for the project located in Stillwater, Oklahoma. We have included the geotechnical report which includes the results of the field exploration and recommendations. If there are any additional questions, feel free to contact me at beth.ryon@connectcec.com or 918-323-5583. We enjoyed working with on this project and look forward to continuing to provide services for future projects utilizing our in-house services and trusted partners.

Sincerely,

Beth Ryon, P.E.
CEI Testing Department Manager

Enclosure: Geotechnical Report

CEC Corporation
4555 W. Memorial Rd
Oklahoma City, OK 73142
Phone: 405.753.4200 | Fax: 405.260.9524
www.connectcec.com

GEOTECHNICAL ENGINEERING REPORT
GRDA KINZIE SUBSTATION

N 3310 ROAD
STILLWATER, OKLAHOMA

PROJECT NO. CEC-22-12

PREPARED FOR:

CEC CORPORATION
OKLAHOMA CITY

DATE:

JUNE 10, 2022

HINDERLITER
GEOTECHNICAL ENGINEERING

June 10, 2022

CEC Corporation
4555 W Memorial Road
Oklahoma City, OK 73142

Attn: Ms. Beth Ryon, P.E.

Re: Geotechnical Engineering Report
GRDA Kinzie Substation
Stillwater, Oklahoma
HGE Project No. CEC-22-12

Dear Ms. Ryon:

The Geotechnical Engineering Report has been completed for the GRDA Kinzie Substation in Stillwater, Oklahoma. Our services and fee were detailed in email correspondence dated April 5, 2022. Acceptance of the scope and fee was provided by issuance of CEC Task Order No. 156.

The purpose of the attached report is to provide a summary of the field investigation methods used and provide recommendations for the design and construction of power pole foundations. Laboratory test results are provided in the appendices of this report.

Ms. Ryon, please do not hesitate to contact HGE at (405) 942-4090 should you have questions regarding this report.

Respectfully Submitted:
HINDERLITER GEOTECHNICAL ENGINEERING, LLC
Certificate of Authorization No. 5528, Expires 30-June-2023

LICENSED PROFESSIONAL ENGINEER
MARK
H.
HINDERLITER
6-10-2022
21327
OKLAHOMA

Mark H. Hinderliter, P.E.
Oklahoma No. 21327

P:\HGE\Reports\2022 Geo\June\CEC-22-12 Report

Copies: beth.ryon@connectcec.com (pdf report & invoice)

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

The subsurface exploration and laboratory soil testing are complete for the proposed Kinzie Substation improvements in Stillwater, Oklahoma. We understand a new pole or dead-end structure will be added. Tower loads were not transmitted to us at the time of this report. This report describes the subsurface conditions encountered in the boring and provides geotechnical recommendations for the design and construction of tower foundations.

Exploration of the subsurface materials at the project site consisted of advancing one soil test boring to a depth of 50 feet. The boring was located in the field by HGE personnel based on the information provided to us by the Client. The final location was determined based on site conditions and accessibility to the drill rig. Samples were returned to the laboratory for further examination and testing.

In general, the boring encountered surficial gravel underlain by lean clays, lean to fat clays and silty clays. AASHTO classifications of these soils were A-6. The laboratory resistivity of one bulk sample obtained from the top 10 feet of the boring was determined to be 1,600 ohm-cm at a pH of 7.3. Soil color was generally red or brown. The soils were stiff to a depth of approximately 17 feet where a soft clay zone was encountered. Below 23 feet the soils were very stiff, becoming hard below 33 feet. Rock refusal was encountered at a depth of 49-1/2 feet; the base of the boring. Subsurface geology appears best described as belonging to the Wellington-Admire Unit (Pwa).

The boring was monitored for the presence of groundwater while drilling or sampling and immediately after boring completion. Groundwater was encountered within the boring at a depth of approximately 19 feet while drilling and was measured at 17 feet 4 inches after boring completion. The boring was plugged per OWRB requirements immediately after boring completion.

Based on the subsurface conditions encountered within the borings and the laboratory test results obtained, the proposed tower can be supported on drilled pier foundations. Specific recommendations regarding foundation design are presented subsequently in this report.

2.0 PROJECT DESCRIPTION

The subsurface exploration and laboratory soil testing are complete for the proposed Kinzie Substation improvements in Stillwater, Oklahoma. We understand a new pole or dead-end structure will be added. Tower loads were not transmitted to us at the time of this report. This report describes the subsurface conditions encountered in the boring and provides geotechnical recommendations for the design and construction of tower foundations.

3.0 SITE EXPLORATION

3.1 Boring Layout & Elevations

Exploration of the subsurface materials at the project site consisted of advancing one soil test boring to a depth of 50 feet. The boring was located in the field by HGE personnel based on information provided to us by the Client. The final boring location was determined at a place accessible to the drill rig. Ground surface elevations at the boring locations were determined using common GIS software.

Boring layout and elevations should be considered approximate and not survey quality. Borings are often offset to locations accessible to the drill rig or to avoid conflicts with buried or overhead utilities. Significant offsets are noted on the boring logs.

3.2 Subsurface Investigation

A CME-45 truck-mounted rotary drill rig outfitted with 6-inch solid-stem augers was used to advance the borehole. Representative soil samples were obtained using the split-barrel sampling procedure generally as detailed in ASTM D 1586.

ASTM D 1586 is commonly referred to as the Standard Penetration Test (SPT). The split-barrel sampling process requires a two-piece sampling tube be used to obtain soil samples. A two-inch outside diameter split sampling tube is hammered into the bottom of the boring with a 140-pound weight falling 30 inches. The number of blows required to advance the sampling tube the last 12 inches, or less, of an 18-inch sampling interval is recorded as the SPT resistance value, N. The in-situ relative density of granular soils, consistency of cohesive soils, and the hardness of weathered bedrock can be estimated from the N value. The N values recorded for each test are displayed on the attached boring logs adjacent to their relative sampling depths.

An automatic drive hammer was used to advance the split-barrel sampler. A greater mechanical efficiency is achieved using an automatic drive hammer when compared to a conventional safety drive hammer operated with a cathead and rope. The effect of this higher efficiency on the N values has been considered in our interpretation and analysis of the subsurface information provided with this report.

The drill crew prepared field boring logs as part of the subsurface exploration operations. The samples were packaged in plastic bags to reduce moisture loss, labeled for identification and transported to our laboratory for further evaluation. Appendix A of this report contains the final boring logs that represent modifications based on the engineer's observations.

The borings were grouted after the drilling operations were completed. Groundwater level measurements are included in Section 5.3 of this report.

4.0 LABORATORY EVALUATION

As part of the geotechnical investigation, soil samples obtained from the borings were evaluated for in-situ moisture content. A geotechnical engineer selected representative samples for further laboratory analysis. These tests were chosen to help the engineer classify the soils and to provide their engineering properties. These laboratory tests include Liquid and Plastic Limits (commonly referred to as Atterberg Limits) and Washed Sieve Analysis. The engineer reviewed all soil descriptions and made modifications based on the materials plasticity, texture, and color along with the laboratory test results.

The laboratory test results and an estimated group symbol from the Unified Soil Classification System are provided next to their representative sample locations in the appropriate column of the boring logs. The following sections provide brief information about the tests performed.

4.1 In-Situ Moisture Content

The in-situ moisture content of soil samples was determined in the laboratory in general accordance with specification ASTM D 2216. The results of these tests have been provided in the appropriate column of the boring logs. The moisture content is expressed as a percentage and is the ratio of the weight of water in a given amount of soil to the weight of solid particles.

4.2 Liquid & Plastic Limits

The Liquid Limit (LL) and Plastic Limit (PL) of selected soil samples were determined in the laboratory in general accordance with ASTM D 4318. The results of these tests have been provided in the appropriate column of the boring logs. The Liquid Limit (LL) of a soil is the water content at which the soil passes from a liquid state to a plastic state. The Plastic Limit (PL) of a soil is the water content at which the soil passes from a plastic state to a semi-solid state. The Plasticity Index (PI) is the difference between the Liquid Limit and the Plastic Limit (PI = LL – PL). There is a correlation between these limits and experimental shrink / swell data.

4.3 Sieve Analysis Test

The amount of material passing the No. 4, No. 10, No. 40 and No. 200 U.S. Standard Sieves was determined in the laboratory in general accordance with ASTM D 1140. Determination of the material grading, combined with the LL, PL and PI provide the information needed to classify the soil according to the Unified Soil Classification System (USCS). The resultant percentage of material passing each sieve has been provided in the appropriate column of the boring logs.

5.0 FINDINGS & RECOMMENDATIONS

Based on the subsurface conditions encountered within the boring and the laboratory test results obtained, the proposed tower can be supported on drilled pier foundations. Specific recommendations regarding foundation design are presented subsequently in this report.

5.1 Existing Site Conditions

The proposed transmission line tower will be located inside the GRDA Kinzie Substation. Due to wet ground conditions the boring was located on the gravel entrance drive away from existing overhead power lines. Adjacent properties appeared to be a part of the Oklahoma State University agricultural program. There were also nearby residential properties.

5.2 Subsurface Conditions

In general, the boring encountered surficial gravel underlain by lean clays, lean to fat clays and silty clays. AASHTO classifications of these soils were A-6. The laboratory resistivity of one bulk sample obtained from the top 10 feet of the boring was determined to be 1,600 ohm-cm at a pH of 7.3. Soil color was generally red or brown. The soils were stiff to a depth of approximately 17 feet where a soft clay zone was encountered. Below 23 feet the soils were very stiff, becoming hard below 33 feet. Rock refusal was encountered at a depth of 49-1/2 feet; the base of the boring. Subsurface geology appears best described as belonging to the Wellington-Admire Unit (Pwa).

Based on published reports[1], the Wellington-Admire Unit consists of shale, sandstone, limestone and siltstone. Most of the unit is shale which, for the most part, is reddish colored and clayey to silty in texture. The total thickness of the unit is undetermined but is known to be several hundred feet. The shales generally form gently rolling hills.

In accordance with publication ASCE 7-10 Chapter 20, a Seismic Site Class of C can be used for foundation design. The site class is based on Standard Penetration Tests conducted to a depth of 50 feet and the reported depth of the geologic unit.

Graphic logs of the borings are included in Appendix A of this report. Every attempt is made to accurately reflect the depths of material change; however, stratification boundaries should be considered approximate. Specific recommendations concerning the design of foundations are presented in the following sections of this report.

5.3 Groundwater Conditions

The boring was monitored for the presence of groundwater while drilling or sampling and immediately after boring completion. Groundwater was encountered within the boring at a depth of approximately 19 feet while drilling and was measured at 17 feet 4 inches after boring completion. The boring was plugged per OWRB requirements immediately after boring completion.

To obtain more accurate groundwater level information, long-term observations in a well or piezometer that is sealed from the influence of surface water would be needed. Groundwater level fluctuations and / or perched water conditions may occur due to seasonal variations in the amount of rainfall and other factors such as drainage characteristics. The possibility of groundwater level fluctuations should be considered during the preparation of construction plans.

5.4 Drilled Pier Foundations

Tables located in Appendix C of this report provide parameters for design of drilled pier foundations. Drilled piers should extend at least 3 feet into the desired bearing strata to use the indicated values.

Excavation of the overburden soils can be accomplished using an earth auger. However, a rock bit will be required to penetrate the hard lean clays encountered below depths of 33 feet. Temporary casing is not expected to be required to prevent caving of the subgrade soils. Dewatering is expected

[1] Oklahoma Highway Department; Research and Development Division; 1967; Engineering Classification of Geologic Materials – Division Four

to be required for pier installation, and should be anticipated. The need for casing and dewatering will depend on the actual groundwater and soil conditions at the time of construction.

Any water deeper than 2 inches and loose or sloughed material should be removed from the bottom of the drilled piers prior to placing concrete. To facilitate pier construction, concrete should be on-site and ready for placement as pier excavations are completed. Concrete should be directed down the center of the pier excavation through use of a tremie or concrete pump. In no case should concrete be allowed to strike reinforcing steel, wire ties or excavation sides while being placed. Pier excavations should not be allowed to remain open for more than 4 hours without approval of the geotechnical engineer.

Straight shaft drilled piers bearing within suitable bedrock and constructed as recommended are expected to experience long-term settlements less than one half inch. Design parameters provided within the tables are raw values with no safety factors applied. Straight shaft drilled piers should be provided with sufficient reinforcing steel to resist tensile stresses.

6.0 CONCLUDING REMARKS

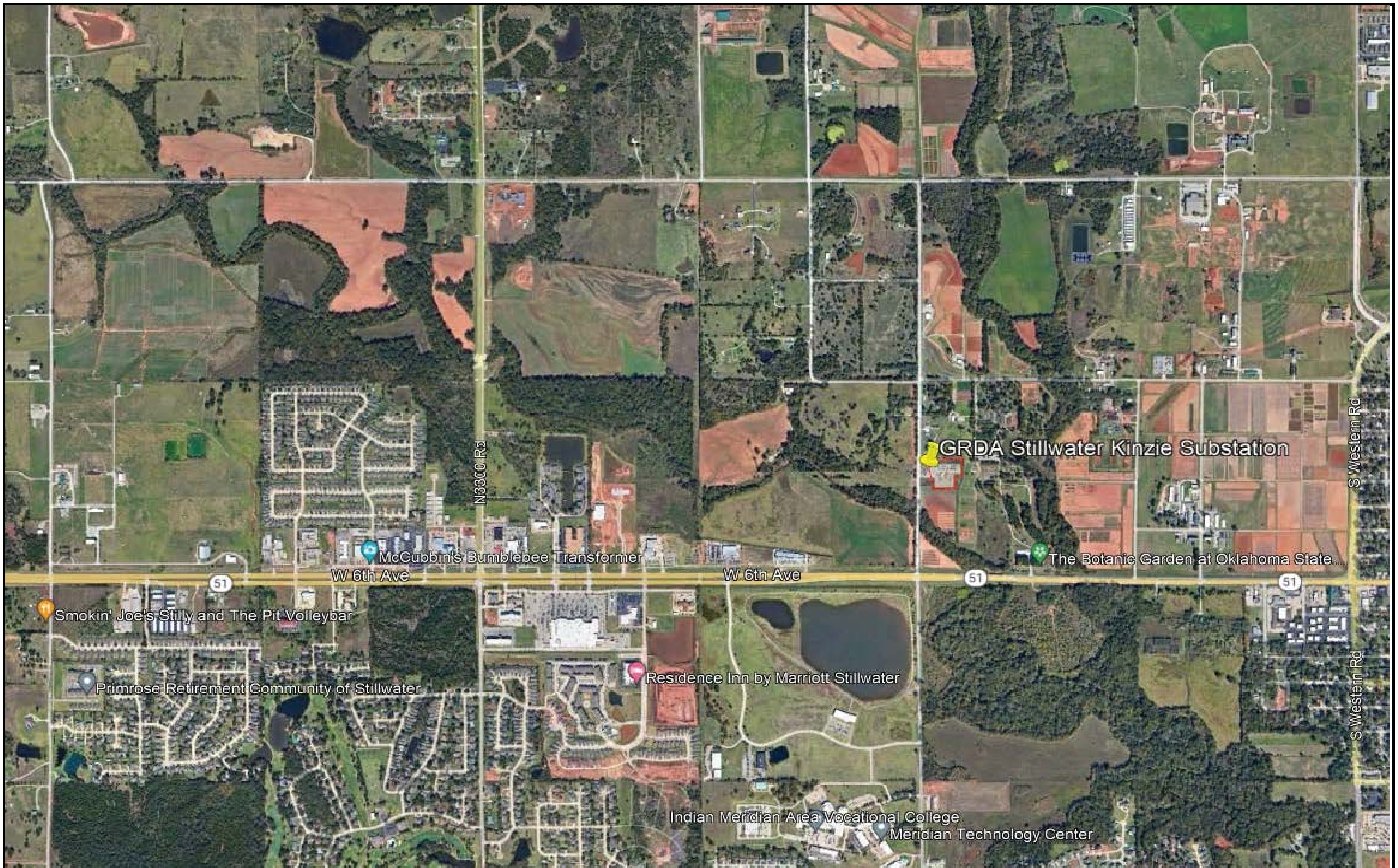
Recommendations provided in this report are based on information from discrete borings (generally 4 to 8 inches in diameter) and, in some cases, from an engineer's general surficial observations. All site conditions cannot be detailed based on a limited number of borings and increasing the number of borings so that all site conditions can be defined is generally not practical. Variations in site conditions between boring locations should be expected and, on occasion, revised recommendations will be required. Hinderliter Geotechnical Engineering, LLC (HGE) should be retained to review final plans and specifications so that comments can be provided regarding the implementation of recommendations provided in this report. HGE should also be retained to provide monitoring of site construction.

This report provides recommendations concerning site construction and, while it may provide limited analysis of soil corrosiveness and / or contaminant content, is not an Environmental Site Assessment (ESA). If the Owner is concerned about environmental and / or biological assessment, a separate study specifically focused on environmental issues should be undertaken.

This report has been prepared specifically for the referenced project and for the exclusive use of our Client. Third-party reliance may be granted upon specific written request of the Client. This report has been prepared using locally specific and generally accepted geotechnical engineering practices based on structural information provided by the Client and information gained from the site. No warranties are implied or granted regarding site recommendations not specifically discussed in this report.

APPENDIX A

SITE VICINITY MAP
APPROXIMATE BORING LOCATION MAP
BORING LOG



SITE VICINITY MAP	HINDERLITER GEOTECHNICAL ENGINEERING	GRDA STILLWATER KINZIE SUBSTATION 3310 RD & W 6TH AVE STILLWATER, OKLAHOMA	ENGINEER MHH	SCALE NOT TO SCALE
			DRAWN BY MHH	PROJECT NO. CEC-22-12
			REVISIONS	DATE JUNE 2022

APPROXIMATE BORING LOCATIONS

HINDERLITER GEOTECHNICAL ENGINEERING

GRDA STILLWATER KINZIE SUBSTATION
3310 RD & W 6TH AVE
STILLWATER, OKLAHOMA

ENGINEER	SCALE
MHH	NOT TO SCALE
DRAWN BY	PROJECT NO.
MHH	CEC-22-12
REVISIONS	DATE
	JUNE 2022

LOG OF BORING B-1

Hinderliter Geotechnical Engineering
4071 NW 3rd Street
Oklahoma City, OK 73107
Telephone: (405) 942-4090
Website: HinderliterGeo.com

CLIENT: CEC Corporation
PROJECT: GRDA Kinzie Substation
LOCATION: Stillwater, Oklahoma
NUMBER: CEC-22-12

DATE(S) DRILLED: 5/27/22

DRILLING METHOD(S):
6" solid flight augers. SPT penetration testing & sampling.

GROUNDWATER INFORMATION:
Groundwater encountered at approximately 19' while drilling and measured at 17'-4" after boring completion. Wet cave in at 18'-3".

SURFACE ELEVATION: 891 Estimated

Depth (ft)	N: Blows/ft; P: Tons/sq ft; T: Blows; R: %; RQD: %	Moisture Content (%)	LL	PL	PI	Dry Density Pounds/cu.ft	Minus No. 4 Sieve (%)	Minus No. 10 Sieve (%)	Minus No. 40 Sieve (%)	Minus No. 200 Sieve (%)	Description of Stratum
0											Gravel Cover
											LEAN CLAY (CL) dark red stiff
~3	N = 14	17.5									
~4			38	10	28		100	100	99	84.1	Lab Resistivity = 1,600 ohm-cm; pH = 7.3
5											LEAN TO FAT CLAY (CL-CH) brown stiff
~6	N = 13	15.0									
~9	N = 8	17.4									
13											LEAN CLAY (CL) light brown stiff
~14	N = 10	18.0	28	15	13		100	100	100	99.0	
18											SILTY CLAY (CL-ML) red, brown soft to hard
~19	N = 4	20.9									
~24	N = 28	14.8									

Depth scale: 5, 10, 15, 20, 25

N - STANDARD PENETRATION TEST RESISTANCE
P - POCKET PENETROMETER RESISTANCE
T - TXDOT CONE PENETRATION RESISTANCE
R - ROCK CORE RECOVERY
RQD - ROCK QUALITY DESIGNATION

REMARKS:
Approximate Boring Location:
Offset due to wet ground.
Lat 36.119695, Lon -97.104548

LOG OF BORING B-1

Hinderliter Geotechnical Engineering
4071 NW 3rd Street
Oklahoma City, OK 73107
Telephone: (405) 942-4090
Website: HinderliterGeo.com

CLIENT: CEC Corporation
PROJECT: GRDA Kinzie Substation
LOCATION: Stillwater, Oklahoma
NUMBER: CEC-22-12

DATE(S) DRILLED: 5/27/22

DRILLING METHOD(S):
6" solid flight augers. SPT penetration testing & sampling.

GROUNDWATER INFORMATION:
Groundwater encountered at approximately 19' while drilling and measured at 17'-4" after boring completion. Wet cave in at 18'-3".

FIELD DATA / LABORATORY DATA

DEPTH (FT)	N: BLOWS/FT P: TONS/SQ FT T: BLOWS R: % RQD: %	MOISTURE CONTENT (%)	LIQUID LIMIT LL	PLASTIC LIMIT PL	PLASTICITY INDEX PI	DRY DENSITY POUNDS/CU.FT	MINUS NO. 4 SIEVE (%)	MINUS NO. 10 SIEVE (%)	MINUS NO. 40 SIEVE (%)	MINUS NO. 200 SIEVE (%)	DESCRIPTION OF STRATUM
											SILTY CLAY (CL-ML) red, brown soft to hard *(continued)*
29.5	N = 14	17.9									
30											
34.5	N = 40	21.6									
35											
38											LEAN CLAY with SAND (CL) dark brown hard
39.5	N = 32	14.9	40	21	19		100	96	95	82.9	
40											
43											LEAN CLAY (CL) red, brown hard to very hard
44.5	N = 56	17.6									
45											
49.5	N = 35/6 50/6	15.4									
50											Bottom of boring 50 feet

N - STANDARD PENETRATION TEST RESISTANCE
P - POCKET PENETROMETER RESISTANCE
T - TXDOT CONE PENETRATION RESISTANCE
R - ROCK CORE RECOVERY
RQD - ROCK QUALITY DESIGNATION

REMARKS:
Approximate Boring Location:
Offset due to wet ground.
Lat 36.119695, Lon -97.104548

APPENDIX B

LABORATORY SUMMARY

CEC

13801 N. Meridian Ave.
Oklahoma City, OK 73134
Phone:(405) 753-6840

Laboratory Summary

Report Date: 06/08/2022
Project: 220454.01
GRDA Stillwater Kinzie Substation

Location: Substation - Stillwater

Client: CEC Corporation

Date Sampled: 05/31/2022
Sampled By: HGE

Lab No: OKC#2323-22

TEST RESULTS

Report No: 0001

Boring ID	Depth	Soil Description	Soil Group	Moisture (%)	Liquid Limit	Plastic Index	- 3/8" Seive	- 4 Sieve	Percent Passing -10 Sieve	- 40 Sieve	- 100 Sieve
B-1 S-1	2' - 3.5'	Dark Red Lean Clay		17.5%							
B-1 S-2	5' - 6.5'	Brown Lean to Fat Clay		15.0%							
B-1 S-3	8.5' - 10'	Brown Lean to Fat Clay		17.4%							
B-1 S-4	13.5' - 15	Light-Brown Lean-Clay	A-6(10)	18.0%	28	13	100	100	100	99.9	99
B-1 S-5	18.5' - 20'	Red Silty Lean Clay		20.9%							
B-1 S-6	23.5' - 25'	Brown Lean Clay w/ Silt		14.8%							
B-1 S-7	28.5' - 30'	Light-Brown Silty Clay		17.9%							
B-1 S-8	33.5' - 35'	Light-Brown Lean Clay w/Silt		21.6%							
B-1 S-9	38.5' - 40'	Dark Brown Sandy Lean Clay	A-6(12)	14.9%	40	19	100	99.5	96	94.9	82.9
B-1 S-10	43.5' - 45'	Red Lean Clay		17.6%							
B-1 S-11	48.5' - 50'	Brown Lean Clay		15.4%							

Remarks: HGE Project No. CEC-22-12
Test Methods: AASHTO T11, T88, T89, T90, T99, T255

1-ec CEC Corporation Attn: Christina Pullampally
1-ec Grand River Dam Authority Attn: Jeff Tullis

Respectfully Submitted,
CEC Materials Testing

LICENSED PROFESSIONAL ENGINEER
ELISABETH RYON
32236
OKLAHOMA

Elisabeth Ryon, Department Head

06/08/2022

APPENDIX C

LPILE v2016 INPUT DESIGN PARAMETERS (UNDRAINED)
AXIAL CAPACITY PARAMETERS (UNDRAINED)

HINDERLITER GEOTECHNICAL ENGINEERING

LPILE v2016 INPUT PARAMETERS (UNDRAINED)

					Soil				Rock			
Layer Number	Depth to Soil/Rock Layer (ft)		Effective Unit Weight, ϒ' (pcf)	LPILE Material Type	Friction Angle, ϕ (degrees)	Undrained Cohesion, c (psf)	Soil Strain Factor, ε_{50}	Soil Modulus, k (pci)	Unconfined Compressive Strength (psi)	Initial Rock Mass Modulus, E_y (psi)	RQD (%)	Rock Strain Factor, k_{rm}
	Top	Bottom										
1	0	10	105	Stiff Clay w/o Free Water		1,225	0.007	100				
2	10	17	105	Stiff Clay w/o Free Water		1,060	0.007	85				
3	17	23	35	Soft Clay		500	0.02	40				
4	23	30	48	Stiff Clay with Free Water		2,185	0.005	175				
5	30	40	48	Stiff Clay with Free Water		2,665	0.005	215				
6	40	50	53	Stiff Clay with Free Water		5,000	0.004	405				

Notes: 1. Empty cell indicates parameter is not applicable to material type.

2. Effective Unit Weight is reduced below the groundwater table.

Boring No: B-1

Depth to Groundwater: 17

Project: GRDA Kinsie Substation

Location: Stillwater, Oklahoma

Project Number: CEC-22-12

HINDERLITER GEOTECHNICAL ENGINEERING

AXIAL CAPACITY PARAMETERS (UNDRAINED)

Layer Number	Depth to Bottom of Layer (ft)	Effective Unit Weight, ϒ' (pcf)	Friction Angle, ϕ (degrees)	Undrained Cohesion, c (psf)	Adhesion Factor	Horizontal Stress Coefficient, K_a	Bearing Capacity Factors N_c	Bearing Capacity Factors N_q	Bearing Capacity Factors N_γ
1	10	105		1,225	62		5.7	1.0	0
2	17	105		1,060	67		9	1.0	0
3	23	35		500	92		9	1.0	0
4	30	48		2,185	43		9	1.0	0
5	40	48		2,665	38		9	1.0	0
6	50	53		5,000	30		9	1.0	0

Notes: 1. Empty cell indicates parameter is not applicable to material type.

2. Effective Unit Weight is reduced below the groundwater table.

3. Appropriate factors of safety should be applied to calculated bearing values.

4. For uplift conditions, the computed side resistance should be multiplied by 1.0 for hard bedrock, 0.9 for clays and clay shales, and 0.7 for granular soils.

5. For drilled shafts in bedrock, disregard side resistance in overburden soils and for at least 3 feet of rock embedment.

Boring No: B-1

Depth to Groundwater: 17

Project: GRDA Kinzie Substation

Location: Stillwater, Oklahoma

Project Number: CEC-22-12

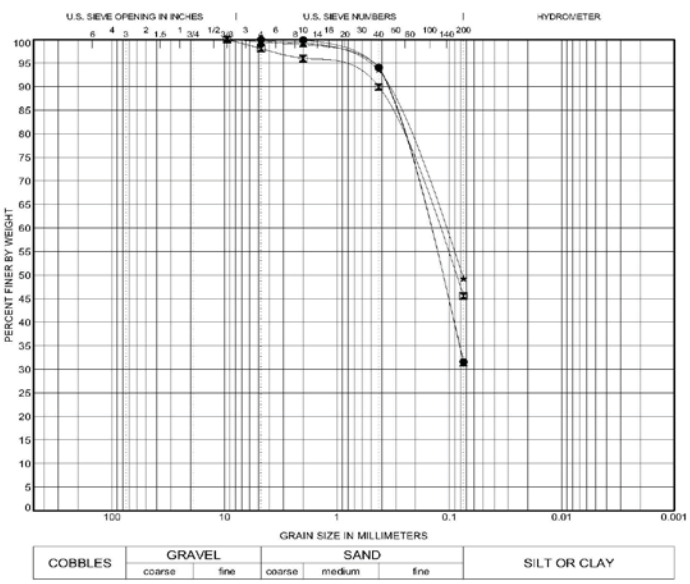
APPENDIX D

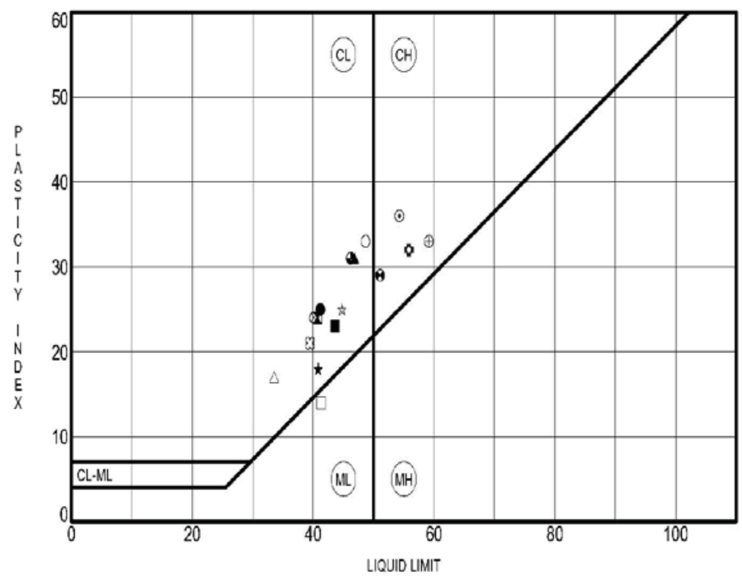
GENERAL NOTES ON SOIL CLASSIFICATION
GENERAL NOTES ON ROCK CLASSIFICATION

GENERAL NOTES ON SOIL CLASSIFICATION

Hinderliter Geotechnical Engineering classifies soils in accordance with the Unified Soil Classification System (USCS). In some cases, the AASHTO Classification System is also used.

USCS soil classifications are derived from soil grain size and material plasticity. Materials with more than 50 percent passing the No. 200 U.S. Sieve (aperture opening = 0.075 mm) are considered to be fine-grained soils (silts or clays). Materials with less than 50 percent passing the No. 200 sieve are considered to be coarse-grained soils (sands, gravels, etc). Coarse-grained soils are classified by the USCS System by plotting the Grain Size in Millimeters vs. Percent Finer by Weight. Depending on the grain size, the materials are classified as cobbles, gravel, sand, or silt / clay. Material plasticity is determined from the Liquid Limit test and the Plastic Limit test. The Liquid Limit (LL) of a soil is the point where, when mixed with water, a pat of soil transitions from a liquid state to a plastic state. The Plastic Limit (PL) is the point where the soil transitions from a plastic state to a solid state. The difference between the LL and PL is known as the Plasticity Index (PI).





Most naturally-occuring materials have some portion of fine-grained and coarse-grained materials. Modifiers are used to describe the relative percentage of minor-occurring materials in the following fashion:

Fine-Grained Soil Modifiers			Coarse-Grained Soil Modifiers	
Modifier	Percentage of Dry Weight		Modifier	Percentage of Dry Weight
Trace	< 15		Trace	< 5
With	15 - 29		With	5-12
Sandy, Gravelly, etc.	> 30		Silty, Clayey, etc.	> 12

The consistency of fine-grained soils and the relative density of coarse-grained soils is generally included on the boring logs as part of the material description. Consistency and relative density are generally defined as follows:

Fine-Grained Soils			Coarse-Grained Soils	
Unconfined Compressive Strength, Qu, psf	Consistency	Standard Penetration Test, N, blows / foot	Standard Penetration Test, N, blows / foot	Relative Density
< 500	Very Soft	< 2	0 - 3	Very Loose
500 - 1000	Soft	2 - 4	4 - 9	Loose
1000 - 2000	Medium	5 - 7	10 - 29	Medium Dense
2000 - 4000	Stiff	8 - 15	30 - 49	Dense
4000 - 8000	Very Stiff	16 - 30	50+	Very Dense
8000+	Hard	30+		

Hinderliter Geotechnical Engineering, LLC
4071 NW 3rd Street
Oklahoma City, OK 73107
Telephone: (405) 942-4090
Fax: (405) 942-4057

General Notes on Soil Classification

HINDERLITER GEOTECHNICAL ENGINEERING

GENERAL NOTES ON ROCK CLASSIFICATION

Sedimentary Rock Classification

Sedimentary rock is classified based on material composition, weathering and hardness. Depending on how samples are obtained, a measure of the degree of jointing can also be determined. Sedimentary rock is composed of clay, silt and/or sand sized particles and is often named based on the soil classification of the deposited material, such as sandstone or siltstone. Limestone, chert and shale are also sedimentary rock types.

Shale

In general, the reddish shales of western and central Oklahoma or Texas tend to be highly weathered and soft. They are composed of cemented clays but frequently contain lesser amounts of silt, sand or caliche. In eastern Oklahoma, Texas and Missouri the shales tend to be dark in color, usually gray, less weathered and harder.

Sandstone

Reddish sandstones in western and central Oklahoma and Texas tend to be highly weathered and soft. These sandstones often have relatively high clay or silt contents. Sandstones in eastern Oklahoma, Texas and Missouri tend to be brownish and hard. Sandstones may be described according to degree of cementation; well-cemented, cemented or poorly-cemented.

Limestone

Generally light colored and hard, limestone reacts readily with hydrochloric acid due to its calcium carbonate content.

Sedimentary rock can be evaluated by sampling and testing or by in-situ evaluation methods. Frequently, soft sedimentary rock is evaluated using penetration testing methods such as the split-barrel (SPT) method or through use of a Texas Cone (TC). Hard rock is often cored and evaluated by cutting or scratching, or by unconfined compressive strength measurements. In-situ methods, such as the Pressuremeter, can also be used.

SPT "N" Values (50 blows / 6" or less)	Hardness	Texas Cone "T" Values (100 blows / 6" or less)
50/6", 50/5"	Soft	100/3" or more
50/4", 50/3"	Moderately Hard	100/2", 100/1"
50/2" or less	Hard, often cored	100/1" or less

Sedimentary rock is generally cored in 5-foot or 10-foot increments or runs. Rock Core Recovery (R) is measured and expressed as a percentage of the total run. The Rock Quality Designation (RQD), defined as in-tact pieces of core 4 inches or more in length, is also measured and expressed as a percentage of the total core run.

RQD (%)	Empirical Quality
90-100	Excellent
75-90	Good
50-75	Fair
25-50	Poor
Below 25	Very Poor

Rock Core Hardness:

- Soft - Can be broken by hand or carved with a knife.
- Moderately Hard - Can be scratched with a penny.
- Hard - Can be scratched with a knife.
- Very Hard - Cannot be scratched with a knife.

Layering or Bedding:

- Fissile - Splits along closely spaced planes 1/16" or less.
- Thin Bedded - Beds 2 inches to 2 feet.
- Thick Bedded - Beds 2 feet to 4 feet.
- Massive - Beds greater than 4 feet.

Joints, Faults or Fractures:

- Very Low Jointing - More than 6-1/2 feet between discontinuities.
- Low Jointing - 2 feet to 6-1/2 feet.
- Medium Jointing - 8 inches to 2 feet.
- High Jointing - 2-1/2 inches to 8 inches.
- Very High Jointing - Less than 2-1/2 inches.

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