Report of Subsurface Exploration
and Geotechnical Evaluation
Tahlequah Overflow Weir
Tahlequah, Oklahoma
Building & Earth Project No.: OK210165

Prepared For:
RK & Associates, PLC

August 30, 2021

BUILDING & EARTH
Geotechnical, Environmental, and Materials Engineers

BUILDING & EARTH
Geotechnical, Environmental, and Materials Engineers

1403 South 70th East Avenue
Tulsa, OK 74112
Ph: (918) 439-9005
www.BuildingAndEarth.com

August 30, 2021

RK & Associates, PLC
4815 South Harvard Avenue, Suite 290
Tulsa, Oklahoma 74135

Attention: Mr. Rick Kosman, P.E.

Subject: Report of Subsurface Exploration and Geotechnical Evaluation
Tahlequah Overflow Weir
Tahlequah, Oklahoma
Building & Earth Project No: OK210165

Dear Mr. Kosman:

Building & Earth Sciences, Inc. has completed the authorized subsurface exploration and geotechnical engineering evaluation for the above referenced project in Tahlequah, Oklahoma.

The purpose of this exploration and evaluation was to determine general subsurface conditions at the site and to address applicable geotechnical aspects of the proposed overflow weir reconstruction. The recommendations in this report are based on a physical reconnaissance of the site and observation and classification of samples obtained from two (2) test borings drilled at the ends of the weir. Confirmation of the anticipated subsurface conditions during construction is an essential part of geotechnical services.

We appreciate the opportunity to provide consultation services for the proposed project. If you have any questions regarding the information in this report or need any additional information, please call us.

Respectfully Submitted,
BUILDING & EARTH SCIENCES, INC.
Certificate of Authorization #3975, Expires 06/30/2022

MARCO V.
VICENTE SILVESTRE
PE21903
8/30/2021

M. Dharmateja

Dharmateja Maganti, E.I.
Project Manager

Marco V. Vicente Silvestre, P.G., P.E.
Regional Vice President - Principal
OK:21903

Table of Contents

1.0 PROJECT & SITE DESCRIPTION

The subject site is located at approximately 1,800 feet north from the intersection of East Willis Road and South Park Hill Road in Tahlequah, Oklahoma. Based on the information provided to our office, we understand that the pond located at the golf course, associated with Cherokee Springs, experienced overflow events that undermined the concrete structure. We also understand that the structure will be demolished to make way for construction of a new weir structure.

Photographs depicting the current site conditions are presented below.

Figure 1: Project site looking south

Figure 2: Void underneath the existing concrete weir structure

At the time of our subsurface exploration, subgrade support of the concrete weir structure was comprised, and voids were noted underneath the slab on the north and south edges. A metal shed was noted to the north of the planned weir reconstruction area.

Tahlequah Overflow Weir Plans, prepared by RK & Associates, PLC, dated 7/27/2021 were provided to our office to assist us with preparation of this report.

2.0 SCOPE OF SERVICES

The authorized subsurface exploration was performed on August 16, 2021, in accordance with our scope of work outlined in an email dated October 16, 2020.

The purpose of the geotechnical exploration was to determine general subsurface conditions at the specific boring locations and to gather data on which to base a geotechnical evaluation with respect to the proposed reconstruction of the weir structure. The subsurface exploration for this project consisted of two (2) test borings. The borings were drilled using a track-mounted Diedrich D50 drill rig equipped with hollow stem augers and an automatic hammer.

The boring locations were determined in the field by a representative of our staff and latitude/longitude coordinates were determined using handheld GPS equipment. As such, the boring locations shown on the Boring Location Plan attached to this report should be considered approximate.

The soil/rock samples recovered during our site investigation were visually classified and specific samples were selected by the project engineer for laboratory analysis. The laboratory analysis consisted of:

Test	ASTM	No. of Tests
Natural Moisture Content	D2216	13
Atterberg Limits	D4318	2

Table 1: Scope of Laboratory Tests

The results of the laboratory analyses are presented on the enclosed Boring Logs and in tabular form in the Appendix of this report. Descriptions of the laboratory tests that were performed are also included in the Appendix.

The information gathered from the exploration was evaluated to help determine if any special subgrade preparation procedures will be required for this project.

The results of the work are presented within this report that addresses:

- Summary of existing surface conditions.
- A description of the subsurface conditions encountered at the boring locations.
- A description of the groundwater conditions observed in the boreholes during drilling. Long-term monitoring was not included in the scope of work.
- Presentation of laboratory test results.
- Site preparation considerations including material types to be expected at the site, treatment of any encountered unsuitable soils, excavation considerations, and surface drainage.
- Compaction requirements and recommended criteria to establish suitable material for structural backfill.

3.0 GEOTECHNICAL SITE CHARACTERIZATION

The following discussion is intended to create a general understanding of the site from a geotechnical engineering perspective. It is not intended to be a discussion of every potential geotechnical issue that may arise, nor to provide every possible interpretation of the conditions identified. The following conditions and subsequent recommendations assume that significant changes in subsurface conditions do not occur at the site and are consistent with that found at the borehole. However, anomalous conditions can occur due to variations in existing fill or the geologic conditions at the site, and it will be necessary to evaluate the assumed conditions during subgrade preparation as part of the weir reconstruction.

3.1 EXISTING SURFACE CONDITIONS

Boring B-01 drilled through the weir structure on the north side encountered concrete with thickness of about 2.5 inches, and boring B-02 drilled in the grass area adjacent to the south edge of the weir encountered topsoil with thickness of about 4 inches. At boring location B-01, a 1.8 feet void was noted underneath the concrete slab.

The concrete and topsoil conditions reported apply only to the specific boring locations. It should be noted that topsoil and concrete thicknesses likely vary at unexplored locations of the project site. For this report, topsoil is defined as the soil horizon which contains the root mat of the noted vegetation.

3.2 SUBSURFACE CONDITIONS

A generalized stratification summary has been prepared using data from the test borings and is presented in the table below. The stratification depicts the general soil/rock conditions and strata encountered during our field investigation.

Stratum No.	Typical Thickness	Description	Consistency/Rock Hardness	Lab Testing Data [2]
1	2.6 to 4.7′	**Fill Materials** comprised of Lean Clays (CL) with roots Various shades and combinations of brown, gray, yellow, and red	Medium stiff to stiff	*Atterberg Limits:* *LL = 37* *PL = 19* *PI = 18* *Moisture content range:* *17 to 25%*
2	8.9 to 9′	**Residual Soils:** Fat Clays (CH) and Lean Clays (CL) with various fine roots, and chert and limestone fragments Various shades and combinations of brown, yellow, and gray	Medium stiff to stiff	*Atterberg Limits:* *LL = 53* *PL = 19* *PI = 34* *Moisture content range:* *22 to 35%*
3	Termination Layer [1]	**Pitkin Limestone Formation** Gray, limestone	Hard	*Moisture content:* *28%*

Table 2: Stratification Summary

Notes:

(1) Borings B-01 and B-02 were terminated on apparent Pitkin Limestone Formation at depths of about 14.5 and 14.1 feet, respectively. A layer of limestone gravel was encountered in boring B-01 at the contact with the limestone unit.

(2) For Atterberg Limits: LL = Liquid Limit, PL = Plastic Limit, and PI = Plasticity Index

For specific details on the information obtained from the borings, please refer to the Boring Logs included in the Appendix.

3.2.1 GROUNDWATER

At the time of drilling, groundwater was encountered in borings B-01 and B-02 at depths of about 13.5 and 13 feet, respectively. Free water was measured in these borings at the time of backfilling at depths of about 12 and 11 feet.

Water levels reported are accurate only for the time and date that the boring was drilled. Long term monitoring of the borehole was not included as part of our subsurface exploration. The boring was backfilled the same day it was drilled.

4.0 SITE DEVELOPMENT CONSIDERATIONS

The primary geotechnical concerns for this project are:

- Fill materials comprised of medium stiff to stiff lean clays were encountered in borings B-01 and B-02, extending to depths of about 4.6 to 5 feet below current grades.
- The lean clay fill is moisture sensitive and prone to losing strength and stability with slight increase in moisture contents.
- Residual fat clays exhibited high plasticity characteristics that have a moderate to high shrink-swell potential.
- Borings B-01 and B-02 were terminated on apparent Pitkin Limestone Formation at depths of about 14.5 and 14.1 feet, respectively. Limestone gravel was encountered in Boring B-01 at the contact with the limestone unit.
- Groundwater seepage was encountered during drilling at depths of about 13 and 13.5 feet, and free water was measured at depths of about 12 and 11 feet.

Recommendations addressing the site conditions are presented in the following sections.

4.1 INITIAL SITE PREPARATION

All concrete slabs, vegetation, roots, topsoil, and any other deleterious materials should be removed from the proposed reconstruction areas. A geotechnical engineer should observe demolition and stripping operations to evaluate that all unsuitable materials are removed from locations for proposed reconstruction areas.

Materials disturbed during demolition and clearing operations should be stabilized in place or, if necessary, undercut to undisturbed materials and backfilled with properly compacted, approved structural fill.

Following demolition of the existing weir structure and removal of any topsoil within the proposed reconstruction areas, we anticipate fill materials comprised of lean clays will be exposed. The onsite fill materials exhibited medium stiff to stiff consistencies and extended to depths of about 4.6 to 5 feet below top of existing concrete slab. ***As part of planned weir reconstruction, we understand that the existing fill materials will be removed full-depth and replaced with approved new structural fill material.***

During site preparation activities, the contractor should identify borrow source materials that will be used as structural fill and provide samples to the testing laboratory so that conformance to the *Structural Fill* requirements outlined below and appropriate moisture-density relationship curves can be determined.

4.2 SUBGRADE EVALUATION AND PREPARATION

Following full-depth removal of fill materials and prior to placement of new structural fill, the exposed residual clay subgrade should be scarified, moisture conditioned, and recompacted to a depth of 8 inches. The subgrade soils should be moisture conditioned within a range of 1 percent below to 3 percent above the material's optimum moisture content, and recompacted to least 95 percent of the material's standard Proctor maximum dry density.

We recommend that the project geotechnical engineer or a qualified representative evaluate the subgrade prior to start of placement of new structural fill. Some unsuitable or unstable areas may be present. Areas that will require fill should be carefully proofrolled with a heavy (25-ton minimum), rubber-tired vehicle at the following times.

- After an area has been undercut, prior to the placement of new structural fill.
- After grading an area to the finished subgrade elevation.
- After areas have been exposed to any precipitation, and/or have been exposed for more than 48 hours.

Some instability may exist during construction, depending on climatic and other factors immediately preceding and during construction. If any soft or otherwise unsuitable soils are identified during the proofrolling process, they must be undercut or stabilized prior to fill placement. All unsuitable material identified during the construction shall be removed and replaced in accordance with the *Structural Fill* section of this report.

Upon completing construction of the new embankment, care should be exercised to maintaining the soil moisture levels within the recommended range to limit the risk of crack development from desiccation of the clay soils when exposed to the elements. During winter construction, the soil seal should be protected from freeze-thaw cycles which can also promote crack development.

4.3 STRUCTURAL FILL

Through conversation with Mr. Kosman, we understand that it is the intent to use onsite available clay soils from a borrow area to the west of the weir structure. Representative bulk samples for any onsite borrow materials should be collected for soil classification and moisture-density relationship determination purposes as part of evaluating suitability for their intended use.

Consideration can be given to the use of onsite fill materials comprised of lean clays (CL) to reconstruct the embankment. If less permeable soils are required for reconstruction the embankment (i.e., hydraulic conductivity of $1x10^{-7}$ cm/sec or less), consideration should be given using onsite residual fat clays (CH). The following tables present recommendations for type of materials to be used for embankment reconstruction, and its placement, and compaction criteria.

Soil Type	USCS Classification	Property Requirements	Placement Location
Imported Lean Clay, Lean to Fat Clay, Fat Clay	CL, CL-CH, CH	LL≤55, 18≤PI≤35, P200>85%, and 100% passing No. 4	**Suitable** for embankment reconstruction
Onsite Fill Materials Lean Clays	CL	Same as above	**Suitable** for embankment reconstruction
Residual Fat Clays 5	CH	50<LL≤55, 18≤PI≤35, P200>85%, 100% passing No. 4, hydraulic conductivity ≤$1x10^{-7}$ cm/sec	**Suitable** for embankment reconstruction when hydraulic conductivity criteria must be met

Table 3: Structural Fill Requirements

Notes:

1. All structural fill should be free of vegetation, topsoil, and any other deleterious materials. The organic content of materials to be used for fill should be less than 3 percent.
2. LL indicates the soil liquid limit; PI indicates the soil plasticity index; P200 indicates the percent of material by weight that passes the #200 sieve; γ_d indicates the maximum dry density as defined by the density standard outlined in the table below.

3. Laboratory testing of the soils proposed for fill must be performed to verify their conformance with the above recommendations.
4. Any fill to be placed at the site should be reviewed by the geotechnical engineer.
5. When specifications include hydraulic conductivity criteria, flexible wall permeability testing must be performed on remolded test specimens to determine the hydraulic conductivity of the fat clays proposed for use as structural fill to reconstruct the embankment.

Placement requirements for structural fill are as follows:

Specification	Requirement
Lift Thickness	Maximum loose lift thickness of 8 inches, depending on type of compaction equipment used.
Density	Minimum 98% of the standard Proctor (ASTM D698) maximum density
Moisture	**Onsite Fill Materials and Residual Lean Clays:** 1% below to 3% above the optimum moisture content as determined by ASTM D698 **Onsite Residual Fat Clays:** 0 to 4% above optimum moisture content
Density Testing Frequency	**Embankment**: One test per 2,500 square feet (SF) per lift with a minimum of three tests performed per lift **Utility trenches**: One test per 150 linear feet per lift with a minimum of two tests performed per lift

Table 4: Structural Fill Placement Requirements

4.4 EXCAVATION CONSIDERATIONS

All excavations performed at the site should follow OSHA guidelines for temporary excavations. Excavated soils should be stockpiled according to OSHA regulations to limit the potential cave-in of soils.

Based on the subsurface conditions encountered in the boring, we anticipate the overburden clay soils can be excavated using a backhoe in good working condition. The contractor should anticipate excavation difficulties when extending into the limestone gravel encountered at about 13.5 to 14 feet below current grades. Borings B-01 and B-02 were terminated on apparent Pitkin Limestone Formation at depths of about 14.5 and 14.1 feet, respectively.

The ability to excavate hard rock is a function of the material, the equipment used, the skill of the operator, the desired rate of removal and other factors. The contractor should review the boring log and should use his own method to evaluate excavation difficulty.

4.5 BENCHING OF SLOPES

Following full-depth removal of existing fill materials, the exposed subgrade soils adjacent to the planned weir structure should be benched prior to placement of new structural fill. Benching of the slopes provides interlocking between the new fill and onsite materials and facilitates compaction of the fill. Benches should be cut as the fill placement progresses and should have a maximum bench height of 2 to 3 feet.

4.6 UTILITY TRENCH BACKFILL

All utility trenches must be backfilled and compacted in the manner specified above for structural fill. It may be necessary to reduce the lift thickness to 4 to 6 inches to achieve compaction using hand-operated equipment.

4.7 WET WEATHER CONSTRUCTION

Excessive movement of construction equipment across the site during wet weather may result in ruts, which will collect rainwater, prolonging the time required to dry the subgrade soils.

During rainy periods, additional effort will be required to properly prepare the site and establish/maintain an acceptable subgrade. The difficulty will increase in areas where clay or silty soils are exposed at the subgrade elevation. ***Likewise, rainwater may become perched on the clayey soils encountered across the site, which could require additional dewatering efforts not needed during dry conditions.***

Grading contractors typically postpone grading operations during wet weather to wait for conditions that are more favorable. Contractors can typically disk or aerate the upper soils to promote drying during intermittent periods of favorable weather. When deadlines restrict postponement of grading operations, additional measures such as undercutting and replacing saturated soils or stabilization can be utilized to facilitate placement of additional fill material.

5.0 CONSTRUCTION MONITORING

Field verification of site conditions is an essential part of the services provided by the geotechnical consultant. To confirm our recommendations, it will be necessary for Building & Earth personnel to make periodic visits to the site during site grading. Typical construction monitoring services are listed below.

- Periodic observations and consultations by a member of our engineering staff during site grading.

- Field density tests during structural fill placement on a continuous basis.
- Reinforcing steel inspections.
- Molding and testing of concrete cylinders.

6.0 CLOSING AND LIMITATIONS

This report was prepared for RK & Associates, PLC, for specific application to the subject project located in Tahlequah, Oklahoma. The information in this report is not transferable. This report should not be used for a different development on the same property without first being evaluated by the engineer.

The recommendations in this report were based on the information obtained from our field exploration and laboratory analysis. The data collected is representative of the locations tested. Variations are likely to occur at other locations throughout the site. Engineering judgment was applied in regard to conditions around the boring. It will be necessary to confirm the anticipated subsurface conditions during construction.

This report has been prepared in accordance with generally accepted standards of geotechnical engineering practice. No other warranty is expressed or implied. If changes are made, or anticipated to be made, to the nature, design, or location of the project as outlined in this report, Building & Earth must be informed of the changes and given the opportunity to either verify or modify the conclusions of this report in writing, or the recommendations of this report will no longer be valid.

The scope of services for this project did not include any environmental assessment of the site or identification of pollutants or hazardous materials or conditions. If the owner is concerned about environmental issues Building & Earth would be happy to provide an additional scope of services to address those concerns.

This report is intended for use during design and preparation of specifications and may not address all conditions at the site during construction. Contractors reviewing this information should acknowledge that this document is for design information only.

An article published by the Geoprofessional Business Association (GBA), titled *Important Information About Your Geotechnical Report*, has been included in the Appendix. We encourage all individuals to become familiar with the article to help manage risk.

Appendix Table of Contents

GEOTECHNICAL INVESTIGATION METHODOLOGIES

The subsurface exploration, which is the basis of the recommendations of this report, has been performed in accordance with industry standards. Detailed methodologies employed in the investigation are presented in the following sections.

DRILLING PROCEDURES – STANDARD PENETRATION TEST (ASTM D1586)

At each boring location, soil samples were obtained at standard sampling intervals with a split-spoon sampler. The borehole was first advanced to the sample depth by augering and the sampling tools were placed in the open hole. The sampler was then driven 18 inches into the ground with a 140-pound automatic hammer free-falling 30 inches. The number of blows required to drive the sampler each 6-inch increment was recorded. The initial increment is considered the “seating” blows, where the sampler penetrates loose or disturbed soil in the bottom of the borehole.

The blows required to penetrate the final two (2) increments are added together and are referred to as the Standard Penetration Test (SPT) N-value. The N-value, when properly evaluated, gives an indication of the soil’s strength and ability to support structural loads. Many factors can affect the SPT N-value, so this result cannot be used exclusively to evaluate soil conditions.

The SPT testing was performed using a drill rig equipped with an automatic hammer. Automatic hammers mechanically control the height of the hammer drop, and doing so, deliver higher energy efficiency (90 to 99 % efficiency) than manual hammers (60 % efficiency) which are dropped using a manually operated rope and cathead system. Because historic data correlations were developed based on use of a manual hammer, it is necessary to adjust the N-values obtained using an automatic hammer to make these correlations valid. Therefore, an energy correction factor of 1.3 was applied to the recorded field N-values from the automatic hammer for the purpose of our evaluation. The N-values discussed or mentioned in this report and shown on the boring logs are recorded field values.

Samples retrieved from the boring locations were labeled and stored in plastic bags at the jobsite before being transported to our laboratory for analysis. The project engineer prepared Boring Logs summarizing the subsurface conditions at the boring locations.

BORING LOG DESCRIPTION

Building & Earth Sciences, Inc. used the gINT software program to prepare the attached boring logs. The gINT program provides the flexibility to custom design the boring logs to include the pertinent information from the subsurface exploration and results of our laboratory analysis. The soil and laboratory information included on our logs is summarized below:

DEPTH AND ELEVATION

The depth below the ground surface and the corresponding elevation are shown in the first two columns.

SAMPLE TYPE

The method used to collect the sample is shown. The typical sampling methods include Split Spoon Sampling, Shelby Tube Sampling, Grab Samples, and Rock Core. A key is provided at the bottom of the log showing the graphic symbol for each sample type.

SAMPLE NUMBER

Each sample collected is numbered sequentially.

BLOWS PER INCREMENT, REC%, RQD%

When Standard Split Spoon sampling is used, the blows required to drive the sampler each 6-inch increment are recorded and shown in column 5. When rock core is obtained the recovery ration (REC%) and Rock Quality Designation (RQD%) is recorded.

SOIL DATA

Column 6 is a graphic representation of four different soil parameters. Each of the parameters use the same graph, however, the values of the graph subdivisions vary with each parameter. Each parameter presented on column 6 is summarized below:

- N-value- The Standard Penetration Test N-value, obtained by adding the number of blows required to drive the sampler the final 12 inches, is recorded . The graph labels range from 0 to 50.
- Qu – Unconfined Compressive Strength estimate from the Pocket Penetrometer test in tons per square foot (tsf). The graph labels range from 0 to 5 tsf.
- Atterberg Limits – The Atterberg Limits are plotted with the plastic limit to the left, and liquid limit to the right, connected by a horizontal line. The difference in the plastic and liquid limits is referred to as the Plasticity Index. The Atterberg Limits test results are also included in the Remarks column on the far right of the boring log. The Atterberg Limits graph labels range from 0 to 100%.
- Moisture – The Natural Moisture Content of the soil sample as determined in our laboratory.

SOIL DESCRIPTION

The soil description prepared in accordance with ASTM D2488, Visual Description of Soil Samples. The Munsel Color chart is used to determine the soil color. Strata changes are indicated by a solid line, with the depth of the change indicated on the left side of the line and the elevation of the change indicated on the right side of the line. If subtle changes within a soil type occur, a broken line is used. The Boring Termination or Auger Refusal depth is shown as a solid line at the bottom of the boring.

GRAPHIC

The graphic representation of the soil type is shown. The graphic used for each soil type is related to the Unified Soil Classification chart. A chart showing the graphic associated with each soil classification is included.

REMARKS

Remarks regarding borehole observations, and additional information regarding the laboratory results and groundwater observations.

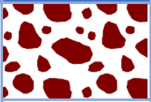
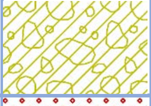
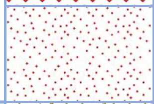
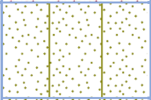
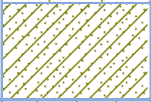
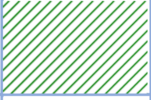
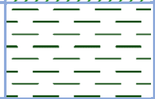
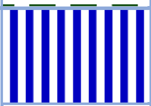
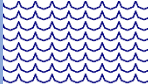
Major Divisions			Symbols		Group Name & Typical Description
			Lithology	Group	
Coarse Grained Soils More than 50% of material is larger than No. 200 sieve size	**Gravel and Gravelly Soils** More than 50% of coarse fraction is larger than No. 4 sieve	**Clean Gravels** (Less than 5% fines)		**GW**	*Well-graded gravels, gravel – sand mixtures, little or no fines*
				**GP**	*Poorly-graded gravels, gravel – sand mixtures, little or no fines*
		Gravels with Fines (More than 12% fines)		**GM**	*Silty gravels, gravel – sand – silt mixtures*
				**GC**	*Clayey gravels, gravel – sand – clay mixtures*
	Sand and Sandy Soils More than 50% of coarse fraction is smaller than No. 4 sieve	**Clean Sands** (Less than 5% fines)		**SW**	*Well-graded sands, gravelly sands, little or no fines*
				**SP**	*Poorly-graded sands, gravelly sands, little or no fines*
		Sands with Fines (More than 12% fines)		**SM**	*Silty sands, sand – silt mixtures*
				**SC**	*Clayey sands, sand – clay mixtures*
Fine Grained Soils More than 50% of material is smaller than No. 200 sieve size	**Silts and Clays** Liquid Limit less than 50	**Inorganic**		**ML**	*Inorganic silts and very find sands, rock flour, silty or clayey fine sands or clayey silt with slight plasticity*
				**CL**	*Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays*
		Organic		**OL**	*Organic silts and organic silty clays of low plasticity*
	Silts and Clays Liquid Limit greater than 50	**Inorganic**		**MH**	*Inorganic silts, micaceous or diatomaceous fine sand, or silty soils*
				**CH**	*Inorganic clays of high plasticity*
		Organic		**OH**	*Organic clays of medium to high plasticity, organic silts*
Highly Organic Soils				**PT**	*Peat, humus, swamp soils with high organic contents*

Table 1: Soil Classification Chart (based on ASTM D2487)

SOIL CLASSIFICATION METHODOLOGY

Building & Earth Sciences classifies soil in general accordance with the Unified Soil Classification System (USCS) presented in ASTM D2487. Table 1 and Figure 1 exemplify the general guidance of the USCS. Soil consistencies and relative densities are presented in general accordance with Terzaghi, Peck, & Mesri's (1996) method, as shown on Table 2, when quantitative field and/or laboratory data is available. Table 2 includes Consistency and Relative Density correlations with N-values obtained using either a manual hammer (60 percent efficiency) or automatic hammer (90 percent efficiency). The *Blows Per Increment* and *SPT N-values* displayed on the boring logs are the unaltered values measured in the field. When field and/or laboratory data is not available, we may classify soil in general accordance with the Visual Manual Procedure presented in ASTM D2488.

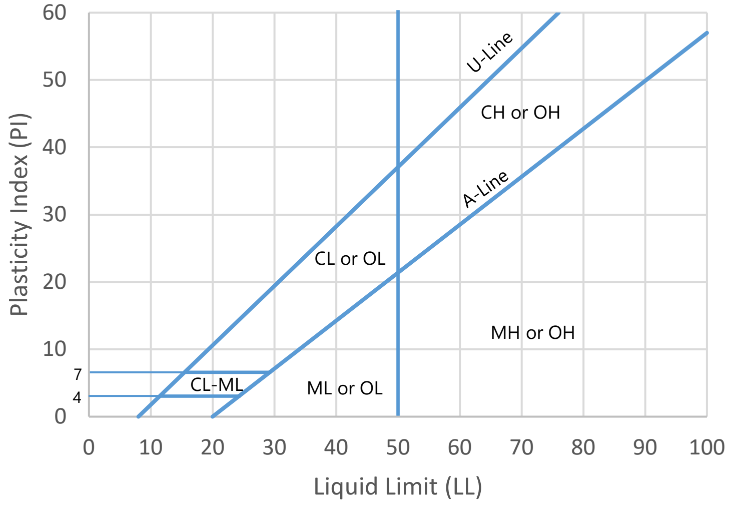


Figure 1: Plasticity Chart (based on ASTM D2487)

Non-cohesive: Coarse-Grained Soil			Cohesive: Fine-Grained Soil			
SPT Penetration (blows/foot)		**Relative Density**	**SPT Penetration (blows/foot)**		**Consistency**	**Estimated Range of Unconfined Compressive Strength (tsf)**
			Automatic Hammer*	Manual Hammer		
Automatic Hammer*	Manual Hammer		< 2	< 2	Very Soft	< 0.25
0 - 3	0 - 4	Very Loose	2 - 3	2 - 4	Soft	0.25 – 0.50
3 - 8	4 - 10	Loose	3 - 6	4 - 8	Medium Stiff	0.50 – 1.00
8 - 23	10 - 30	Medium Dense	6 - 12	8 - 15	Stiff	1.00 – 2.00
23 - 38	30 - 50	Dense	12 - 23	15 - 30	Very Stiff	2.00 – 4.00
> 38	> 50	Very Dense	> 23	> 30	Hard	> 4.00

Table 2: Soil Consistency and Relative Density (based on Terzaghi, Peck & Mesri, 1996)

* - Modified based on 80% hammer efficiency

KEY TO LOGS

☒	Standard Penetration Test ASTM D1586 or AASHTO T-206	⬇	Dynamic Cone Penetrometer (Sower DCP) ASTM STP-399
■	Shelby Tube Sampler ASTM D1587	○	No Sample Recovery
▥	Rock Core Sample ASTM D2113	▽	Groundwater at Time of Drilling
█	Auger Cuttings	▼	Groundwater as Indicated

Table 1: Symbol Legend

Soil	Particle Size	U.S. Standard
Boulders	Larger than 300 mm	N.A.
Cobbles	300 mm to 75 mm	N.A.
Gravel	75 mm to 4.75 mm	3-inch to #4 sieve
Coarse	75 mm to 19 mm	3-inch to ¾-inch sieve
Fine	19 mm to 4.75 mm	¾-inch to #4 sieve
Sand	4.75 mm to 0.075 mm	#4 to #200 Sieve
Coarse	4.75 mm to 2 mm	#4 to #10 Sieve
Medium	2 mm to 0.425 mm	#10 to #40 Sieve
Fine	0.425 mm to 0.075 mm	#40 to #200 Sieve
Fines	Less than 0.075 mm	Passing #200 Sieve
Silt	Less than 5 μm	N.A.
Clay	Less than 2 μm	N.A.

Table 2: Standard Sieve Sizes

N-Value ☐	Standard Penetration Test Resistance calculated using ASTM D1586 or AASHTO T-206. Calculated as sum of original, field recorded values.	Atterberg Limits ├──┤ PL LL	A measure of a soil's plasticity characteristics in general accordance with ASTM D4318. The soil Plasticity Index (PI) is representative of this characteristic and is bracketed by the Liquid Limit (LL) and the Plastic Limit (PL).
Qu ▲	Unconfined compressive strength, typically estimated from a pocket penetrometer. Results are presented in tons per square foot (tsf).	% Moisture ●	Percent natural moisture content in general accordance with ASTM D2216.

Table 3: Soil Data

Hollow Stem Auger	Flights on the outside of the shaft advance soil cuttings to the surface. The hollow stem allows sampling through the middle of the auger flights.
Mud Rotary / Wash Bore	A cutting head advances the boring and discharges a drilling fluid to support the borehole and circulate cuttings to the surface.
Solid Flight Auger	Flights on the outside bring soil cuttings to the surface. Solid stem requires removal from borehole during sampling.
Hand Auger	Cylindrical bucket (typically 3-inch diameter and 8 inches long) attached to a metal rod and turned by human force.

Table 4: Soil Drilling Methods

Descriptor	Meaning
Trace	Likely less than 5%
Few	5 to 10%
Little	15 to 25%
Some	30 to 45%
Mostly	50 to 100%

Table 5: Descriptors

Manual Hammer	The operator tightens and loosens the rope around a rotating drum assembly to lift and drop a sliding, 140-pound hammer falling 30 inches.
Automatic Trip Hammer	An automatic mechanism is used to lift and drop a sliding, 140-pound hammer falling 30 inches.
Dynamic Cone Penetrometer (Sower DCP) ASTM STP-399	Uses a 15-pound steel mass falling 20 inches to strike an anvil and cause penetration of a 1.5-inch diameter cone seated in the bottom of a hand augered borehole. The blows required to drive the embedded cone a depth of 1-3/4 inches have been correlated by others to N-values derived from the Standard Penetration Test (SPT).

Table 6: Sampling Methods

Non-plastic	A 1/8-inch thread cannot be rolled at any water content.
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit.
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be re-rolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be re-rolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

Table 7: Plasticity

Dry	Absence of moisture, dusty, dry to the touch.
Moist	Damp but no visible water.
Wet	Visible free water, usually soil is below water table.

Table 8: Moisture Condition

Stratified	Alternating layers of varying material or color with layers at least ½ inch thick.
Laminated	Alternating layers of varying material or color with layers less than ¼ inch thick.
Fissured	Breaks along definite planes of fracture with little resistance to fracturing.
Slickensides	Fracture planes appear polished or glossy, sometimes striated.
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown.
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay.
Homogeneous	Same color and appearance throughout.

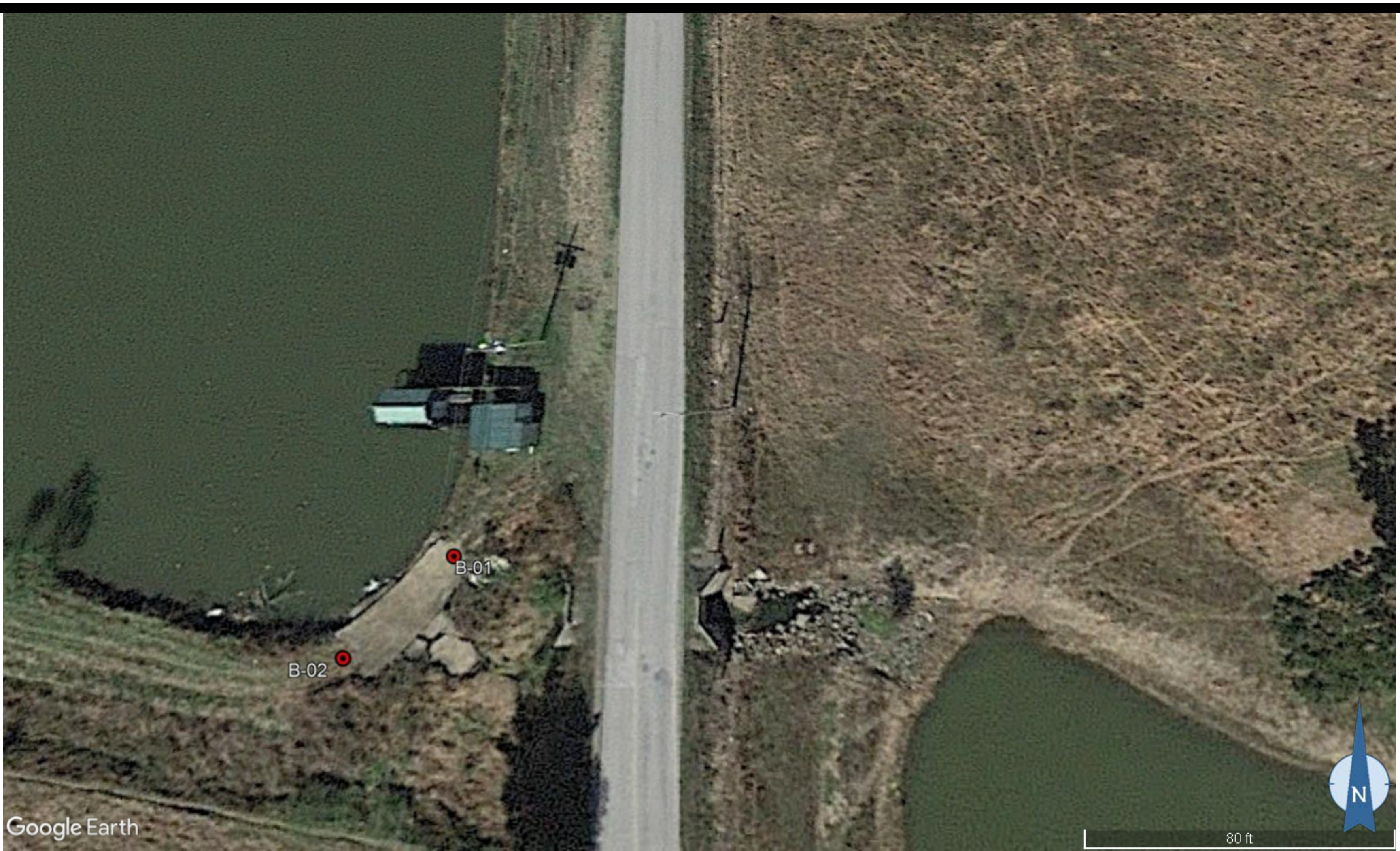
Table 9: Structure

KEY TO HATCHES

Hatch	Description	Hatch	Description	Hatch	Description
▨	***GW*** *- Well-graded gravels, gravel – sand mixtures, little or no fines*	■	*Asphalt*	▨	*Clay with Gravel*
▨	***GP*** *- Poorly-graded gravels, gravel – sand mixtures, little or no fines*	▨	*Aggregate Base*	▨	*Sand with Gravel*
▨	***GM*** *- Silty gravels, gravel – sand – silt mixtures*	▨	*Topsoil*	▨	*Silt with Gravel*
▨	***GC*** *- Clayey gravels, gravel – sand – clay mixtures*	▨	*Concrete*	▨	*Gravel with Sand*
▨	***SW*** *- Well-graded sands, gravelly sands, little or no fines*	▨	*Coal*	▨	*Gravel with Clay*
▨	***SP*** *- Poorly-graded sands, gravelly sands, little or no fines*	▨	***CL-ML*** *- Silty Clay*	▨	*Gravel with Silt*
▨	***SM*** *- Silty sands, sand – silt mixtures*	▨	*Sandy Clay*	▨	*Limestone*
▨	***SC*** *- Clayey sands, sand – clay mixtures*	▨	*Clayey Chert*	▨	*Chalk*
▨	***ML*** *- Inorganic silts and very find sands, rock flour, silty or clayey fine sands or clayey silt with slight plasticity*	▨	*Low and High Plasticity Clay*	▨	*Siltstone*
▨	***CL*** *- Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays*	▨	*Low Plasticity Silt and Clay*	▨	*Till*
▨	***OL*** *- Organic silts and organic silty clays of low plasticity*	▨	*High Plasticity Silt and Clay*	▨	*Sandy Clay with Cobbles and Boulders*
▨	***MH*** *- Inorganic silts, micaceous or diatomaceous fine sand, or silty soils*	▨	*Fill*	▨	*Sandstone with Shale*
▨	***CH*** *- Inorganic clays of high plasticity*	▨	*Weathered Rock*	▨	*Coral*
▨	***OH*** *- Organic clays of medium to high plasticity, organic silts*	▨	*Sandstone*	▨	*Boulders and Cobbles*
▨	***PT*** *- Peat, humus, swamp soils with high organic contents*	▨	*Shale*	▨	*Soil and Weathered Rock*

Table 1: Key to Hatches Used for Boring Logs and Soil Profiles

BORING LOCATION PLAN



REFERENCE USED TO PRODUCE THIS DRAWING: Google Earth Satellite Imagery dated October 2017	**BORING LOCATION PLAN**		**DATE: 8/16/2021**
	PROJECT NO. OK210165	**PROJECT NAME / LOCATION:** Tahlequah Overflow Weir Tahlequah, Oklahoma	**SCALE:** As Shown

BUILDING & EARTH

Geotechnical, Environmental, and Materials Engineers

BORING LOGS

BUILDING & EARTH
Geotechnical, Environmental, and Materials Engineers

LOG OF BORING

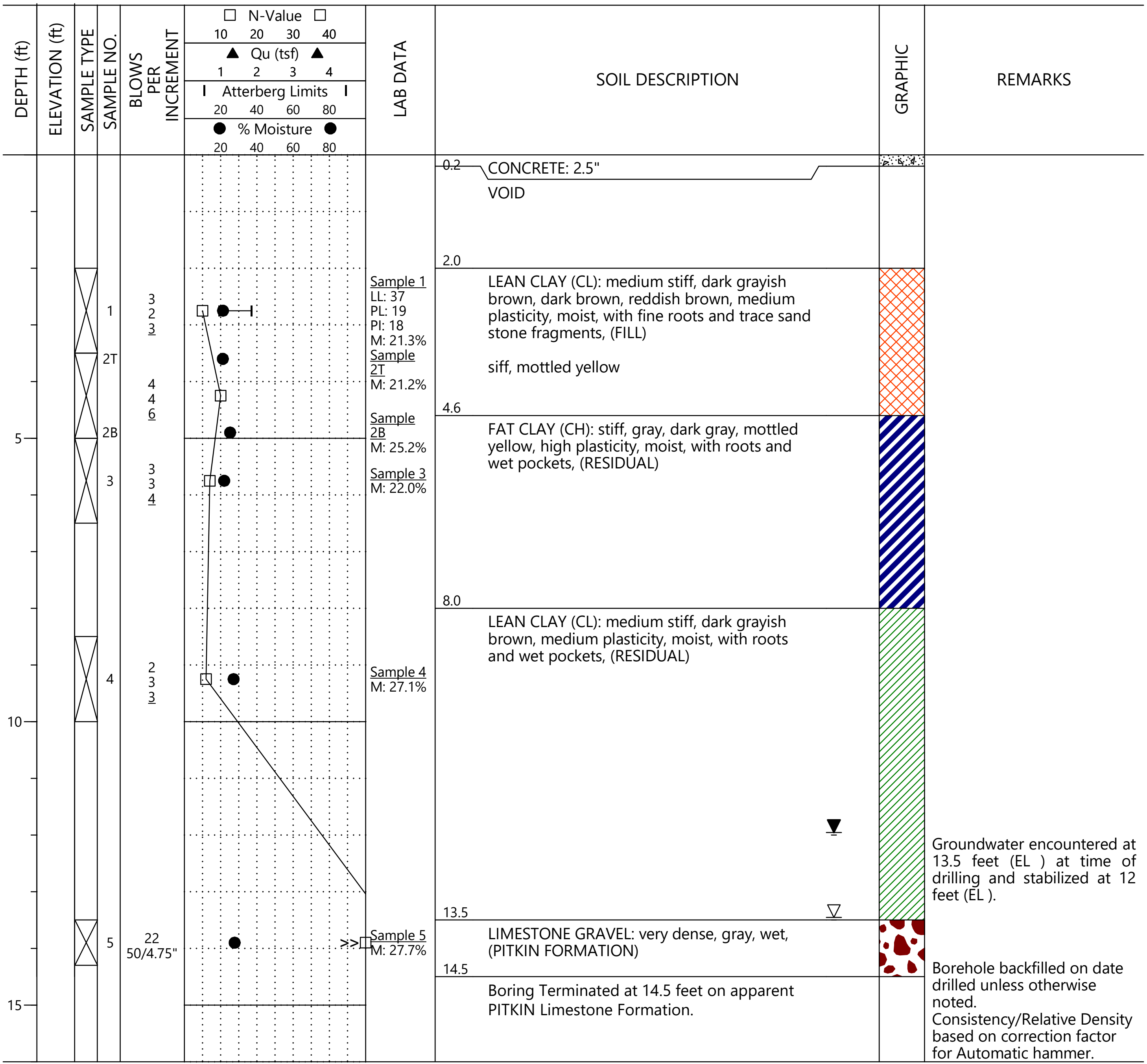
Designation: B-01

Sheet 1 of 1

1403 South 70th East Avenue
Tulsa, OK 74112
Office: (918) 439-9005

PROJECT NAME: Tahlequah Overflow Weir
PROJECT NUMBER: OK210165
DRILLING METHOD: Hollow Stem Auger
EQUIPMENT USED: Diedrich D50
HAMMER TYPE: Automatic
BORING LOCATION: 35.875734°, -94.967614°

LOCATION: Tahlequah, OK
DATE DRILLED: 8/16/21
WEATHER: Sunny
ELEVATION:
DRILL CREW: Aimright
LOGGED BY: Teja Maganti



DEPTH (ft)	SAMPLE NO.	BLOWS PER INCREMENT	LAB DATA	SOIL DESCRIPTION	REMARKS
0.2				CONCRETE: 2.5"	
				VOID	
2.0	1	3 2 3	Sample 1 LL: 37 PL: 19 PI: 18 M: 21.3%	LEAN CLAY (CL): medium stiff, dark grayish brown, dark brown, reddish brown, medium plasticity, moist, with fine roots and trace sand stone fragments, (FILL)	
	2T	4 4 6	Sample 2T M: 21.2%	siff, mottled yellow	
4.6	2B		Sample 2B M: 25.2%	FAT CLAY (CH): stiff, gray, dark gray, mottled yellow, high plasticity, moist, with roots and wet pockets, (RESIDUAL)	
	3	3 3 4	Sample 3 M: 22.0%		
8.0	4	2 3 3	Sample 4 M: 27.1%	LEAN CLAY (CL): medium stiff, dark grayish brown, medium plasticity, moist, with roots and wet pockets, (RESIDUAL)	Groundwater encountered at 13.5 feet (EL) at time of drilling and stabilized at 12 feet (EL).
13.5	5	22 50/4.75"	Sample 5 M: 27.7%	LIMESTONE GRAVEL: very dense, gray, wet, (PITKIN FORMATION)	
14.5				Boring Terminated at 14.5 feet on apparent PITKIN Limestone Formation.	Borehole backfilled on date drilled unless otherwise noted. Consistency/Relative Density based on correction factor for Automatic hammer.

SAMPLE TYPE ☒ Split Spoon

N-VALUE STANDARD PENETRATION RESISTANCE (AASHTO T-206)
% MOISTURE PERCENT NATURAL MOISTURE CONTENT
▽ GROUNDWATER LEVEL IN THE BOREHOLE AT TIME OF DRILLING
▼ STABILIZED GROUNDWATER LEVEL

REC RECOVERY
RQD ROCK QUALITY DESIGNATION
UD UNDISTURBED
Qu POCKET PENETROMETER UNCONFINED COMPRESSIVE STRENGTH

LL: LIQUID LIMIT
PL: PLASTIC LIMIT
PI: PLASTICITY INDEX
M: NATURAL MOISTURE CONTENT
F: PERCENT PASSING NO. 200 SIEVE

BUILDING & EARTH
Geotechnical, Environmental, and Materials Engineers

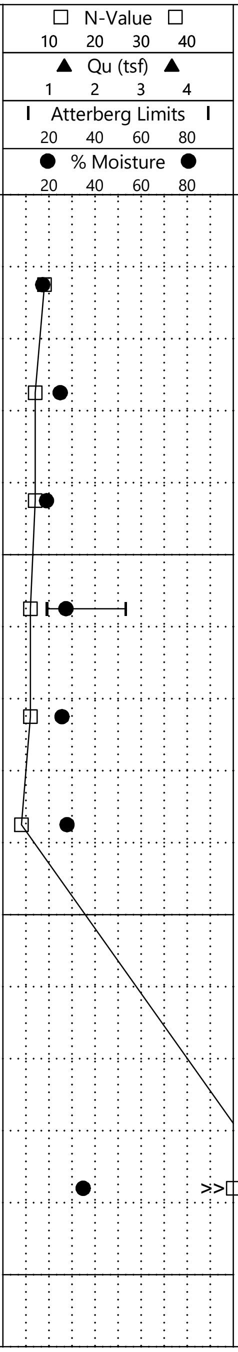
1403 South 70th East Avenue
Tulsa, OK 74112
Office: (918) 439-9005

LOG OF BORING

Designation: B-02

Sheet 1 of 1

PROJECT NAME:	Tahlequah Overflow Weir	LOCATION:	Tahlequah, OK
PROJECT NUMBER:	OK210165	DATE DRILLED:	8/16/21
DRILLING METHOD:	Hollow Stem Auger	WEATHER:	Sunny
EQUIPMENT USED:	Diedrich D50	ELEVATION:	
HAMMER TYPE:	Automatic	DRILL CREW:	Aimright
BORING LOCATION:	35.875647°, -94.967705°	LOGGED BY:	Teja Maganti



DEPTH (ft)	ELEVATION (ft)	SAMPLE TYPE	SAMPLE NO.	BLOWS PER INCREMENT	LAB DATA	SOIL DESCRIPTION	GRAPHIC	REMARKS
0.3						TOPSOIL: 4"		
		☒	1	5 5 4	Sample 1 M: 17.3%	LEAN CLAY (CL): stiff, grayish brown, reddish brown, pale brown, low plasticity, dry to moist, with silt pockets and roots, (FILL) increasing silt		
		☒	2	3 3 4	Sample 2 M: 24.9%	dark brown, medium plasticity		
		☒	3	2 3 4	Sample 3 M: 18.9%			
5.0								
5		☒	4	2 3 3	Sample 4 LL: 53 PL: 19 PI: 34 M: 27.4%	FAT CLAY (CH): medium stiff to stiff, gray, dark gray, yellow, high plasticity, moist, with wet pockets, (RESIDUAL)		
		☒	5	2 2 4	Sample 5 M: 25.6%			
		☒	6	2 2 2	Sample 6 M: 27.8%	medium stiff, with limestone and chert fragments		
10						▼ ▽		Groundwater encountered at 13 feet (EL) at time of drilling and stabilized at 11 feet (EL).
14.1		☒	7	3 50/1.5"	Sample 7 M: 34.8%			
15						Boring Terminated at 14.1 feet on apparent PITKIN Limestone Formation.		Borehole backfilled on date drilled unless otherwise noted. Consistency/Relative Density based on correction factor for Automatic hammer.

SAMPLE TYPE ☒ Split Spoon

N-VALUE STANDARD PENETRATION RESISTANCE (AASHTO T-206)
% MOISTURE PERCENT NATURAL MOISTURE CONTENT
▽ GROUNDWATER LEVEL IN THE BOREHOLE AT TIME OF DRILLING
▼ STABILIZED GROUNDWATER LEVEL
REC RECOVERY
RQD ROCK QUALITY DESIGNATION
UD UNDISTURBED
Qu POCKET PENETROMETER UNCONFINED COMPRESSIVE STRENGTH
LL: LIQUID LIMIT
PL: PLASTIC LIMIT
PI: PLASTICITY INDEX
M: NATURAL MOISTURE CONTENT
F: PERCENT PASSING NO. 200 SIEVE

LABORATORY TEST PROCEDURES

A brief description of the laboratory tests performed is provided in the following sections.

DESCRIPTION OF SOILS (VISUAL-MANUAL PROCEDURE) (ASTM D2488)

The soil samples were visually examined by our engineer and soil descriptions were provided. Representative samples were then selected and tested in accordance with the aforementioned laboratory-testing program to determine soil classifications and engineering properties. This data was used to correlate our visual descriptions with the Unified Soil Classification System (USCS).

NATURAL MOISTURE CONTENT (ASTM D2216)

Natural moisture contents (M%) were determined on selected samples. The natural moisture content is the ratio, expressed as a percentage, of the weight of water in a given amount of soil to the weight of solid particles.

ATTERBERG LIMITS (ASTM D4318)

The Atterberg Limits test was performed to evaluate the soil's plasticity characteristics. The soil Plasticity Index (PI) is representative of this characteristic and is bracketed by the Liquid Limit (LL) and the Plastic Limit (PL). The Liquid Limit is the moisture content at which the soil will flow as a heavy viscous fluid. The Plastic Limit is the moisture content at which the soil is between "plastic" and the semi-solid stage. The Plasticity Index (PI = LL - PL) is a frequently used indicator for a soil's potential for volume change. Typically, a soil's potential for volume change increases with higher plasticity indices.

LABORATORY TEST RESULTS

The results of the laboratory testing are presented in the following tables.

BORING NO.	DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	% PASSING #200 SIEVE	CLASSIFICATION
B-01	2.5 - 4.0	21.3	37	19	18		
B-01	3.6	21.2					
B-01	4.9	25.2					
B-01	5.0 - 6.5	22.0					
B-01	8.5 - 10.0	27.1					
B-01	13.5 - 15.0	27.7					
B-02	0.5 - 2.0	17.3					
B-02	2.0 - 3.5	24.9					
B-02	3.5 - 5.0	18.9					
B-02	5.0 - 6.5	27.4	53	19	34		
B-02	6.5 - 8.0	25.6					
B-02	8.0 - 9.5	27.8					
B-02	13.5 - 15.0	34.8					

TABLE L-1: General Soil Classification Test Results

Soils with a Liquid Limit (LL) greater than 50 and Plasticity Index (PI) greater than 25 usually exhibit significant volume change with varying moisture content and are considered to be highly plastic

(1) Indicates visual classification. WR indicates weathered rock.

Important Information about This

Geotechnical-Engineering Report

Subsurface problems are a principal cause of construction delays, cost overruns, claims, and disputes.

While you cannot eliminate all such risks, you can manage them. The following information is provided to help.

Geotechnical Services Are Performed for Specific Purposes, Persons, and Projects

Geotechnical engineers structure their services to meet the specific needs of their clients. A geotechnical-engineering study conducted for a civil engineer may not fulfill the needs of a constructor — a construction contractor — or even another civil engineer. Because each geotechnical- engineering study is unique, each geotechnical-engineering report is unique, prepared *solely* for the client. No one except you should rely on this geotechnical-engineering report without first conferring with the geotechnical engineer who prepared it. *And no one — not even you* — should apply this report for any purpose or project except the one originally contemplated.

Read the Full Report

Serious problems have occurred because those relying on a geotechnical-engineering report did not read it all. Do not rely on an executive summary. Do not read selected elements only.

Geotechnical Engineers Base Each Report on a Unique Set of Project-Specific Factors

Geotechnical engineers consider many unique, project-specific factors when establishing the scope of a study. Typical factors include: the client's goals, objectives, and risk-management preferences; the general nature of the structure involved, its size, and configuration; the location of the structure on the site; and other planned or existing site improvements, such as access roads, parking lots, and underground utilities. Unless the geotechnical engineer who conducted the study specifically indicates otherwise, do not rely on a geotechnical-engineering report that was:

- not prepared for you;
- not prepared for your project;
- not prepared for the specific site explored; or
- completed before important project changes were made.

Typical changes that can erode the reliability of an existing geotechnical-engineering report include those that affect:

- the function of the proposed structure, as when it's changed from a parking garage to an office building, or from a light-industrial plant to a refrigerated warehouse;
- the elevation, configuration, location, orientation, or weight of the proposed structure;
- the composition of the design team; or
- project ownership.

As a general rule, *always* inform your geotechnical engineer of project changes—even minor ones—and request an assessment of their impact. *Geotechnical engineers cannot accept responsibility or liability for problems that occur because their reports do not consider developments of which they were not informed.*

Subsurface Conditions Can Change

A geotechnical-engineering report is based on conditions that existed at the time the geotechnical engineer performed the study. *Do not rely on a geotechnical-engineering report whose adequacy may have been affected by*: the passage of time; man-made events, such as construction on or adjacent to the site; or natural events, such as floods, droughts, earthquakes, or groundwater fluctuations. *Contact the geotechnical engineer before applying this report to determine if it is still reliable.* A minor amount of additional testing or analysis could prevent major problems.

Most Geotechnical Findings Are Professional Opinions

Site exploration identifies subsurface conditions only at those points where subsurface tests are conducted or samples are taken. Geotechnical engineers review field and laboratory data and then apply their professional judgment to render an opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ — sometimes significantly — from those indicated in your report. Retaining the geotechnical engineer who developed your report to provide geotechnical-construction observation is the most effective method of managing the risks associated with unanticipated conditions.

A Report's Recommendations Are Not Final

Do not overrely on the confirmation-dependent recommendations included in your report. *Confirmation-dependent recommendations are not final,* because geotechnical engineers develop them principally from judgment and opinion. Geotechnical engineers can finalize their recommendations *only* by observing actual subsurface conditions revealed during construction. *The geotechnical engineer who developed your report cannot assume responsibility or liability for the report's confirmation-dependent recommendations if that engineer does not perform the geotechnical-construction observation required to confirm the recommendations' applicability.*

A Geotechnical-Engineering Report Is Subject to Misinterpretation

Other design-team members' misinterpretation of geotechnical-engineering reports has resulted in costly problems. Confront that risk by having your geotechnical engineer confer with appropriate members of the design team after submitting the report. Also retain your geotechnical engineer to review pertinent elements of the design team's plans and specifications. Constructors can also misinterpret a geotechnical-engineering report. Confront that risk by having your geotechnical engineer participate in prebid and preconstruction conferences, and by providing geotechnical construction observation.

Do Not Redraw the Engineer's Logs

Geotechnical engineers prepare final boring and testing logs based upon their interpretation of field logs and laboratory data. To prevent errors or omissions, the logs included in a geotechnical-engineering report should *never* be redrawn for inclusion in architectural or other design drawings. Only photographic or electronic reproduction is acceptable, *but recognize that separating logs from the report can elevate risk.*

Give Constructors a Complete Report and Guidance

Some owners and design professionals mistakenly believe they can make constructors liable for unanticipated subsurface conditions by limiting what they provide for bid preparation. To help prevent costly problems, give constructors the complete geotechnical-engineering report, *but* preface it with a clearly written letter of transmittal. In that letter, advise constructors that the report was not prepared for purposes of bid development and that the report's accuracy is limited; encourage them to confer with the geotechnical engineer who prepared the report (a modest fee may be required) and/or to conduct additional study to obtain the specific types of information they need or prefer. A prebid conference can also be valuable. *Be sure constructors have sufficient time* to perform additional study. Only then might you be in a position to give constructors the best information available to you, while requiring them to at least share some of the financial responsibilities stemming from unanticipated conditions.

Read Responsibility Provisions Closely

Some clients, design professionals, and constructors fail to recognize that geotechnical engineering is far less exact than other engineering disciplines. This lack of understanding has created unrealistic expectations that have led to disappointments, claims, and disputes. To help reduce the risk of such outcomes, geotechnical engineers commonly include a variety of explanatory provisions in their reports. Sometimes labeled "limitations," many of these provisions indicate where geotechnical engineers' responsibilities begin and end, to help others recognize their own responsibilities and risks. *Read these provisions closely.* Ask questions. Your geotechnical engineer should respond fully and frankly.

Environmental Concerns Are Not Covered

The equipment, techniques, and personnel used to perform an *environmental* study differ significantly from those used to perform a *geotechnical* study. For that reason, a geotechnical-engineering report does not usually relate any environmental findings, conclusions, or recommendations; e.g., about the likelihood of encountering underground storage tanks or regulated contaminants. *Unanticipated environmental problems have led to numerous project failures.* If you have not yet obtained your own environmental information, ask your geotechnical consultant for risk-management guidance. *Do not rely on an environmental report prepared for someone else.*

Obtain Professional Assistance To Deal with Mold

Diverse strategies can be applied during building design, construction, operation, and maintenance to prevent significant amounts of mold from growing on indoor surfaces. To be effective, all such strategies should be devised for the *express purpose* of mold prevention, integrated into a comprehensive plan, and executed with diligent oversight by a professional mold-prevention consultant. Because just a small amount of water or moisture can lead to the development of severe mold infestations, many mold- prevention strategies focus on keeping building surfaces dry. While groundwater, water infiltration, and similar issues may have been addressed as part of the geotechnical- engineering study whose findings are conveyed in this report, the geotechnical engineer in charge of this project is not a mold prevention consultant; *none of the services performed in connection with the geotechnical engineer's study were designed or conducted for the purpose of mold prevention. Proper implementation of the recommendations conveyed in this report will not of itself be sufficient to prevent mold from growing in or on the structure involved.*

Rely, on Your GBC-Member Geotechnical Engineer for Additional Assistance

Membership in the Geotechnical Business Council of the Geoprofessional Business Association exposes geotechnical engineers to a wide array of risk-confrontation techniques that can be of genuine benefit for everyone involved with a construction project. Confer with you GBC-Member geotechnical engineer for more information.

GBC
GEOTECHNICAL
BUSINESS COUNCIL
of the Geoprofessional Business Association

8811 Colesville Road/Suite G106, Silver Spring, MD 20910
Telephone: 301/565-2733 Facsimile: 301/589-2017
e-mail: info@geoprofessional.org www.geoprofessional.org