Geotechnical Recommendation Report

Date:	May 30, 2025
Project Name:	Replacement of South Rim Wastewater Treatment Plant (GRCA 257282)
Project No.:	D3167666
Attention:	Mike Ryan/NPS Christopher Carpenter/NPS
Client:	National Park Service- Grand Canyon National Park
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1. Introduction

This report was prepared for the GRCA 257282 Replace Wastewater Plant South Rim Village project. As part of the geotechnical evaluation, two geotechnical explorations were conducted for the project, one focused on wastewater treatment plant area, and one based on the access road improvement.

The *Preliminary Geotechnical Recommendation Report* for Replace Wastewater Plant South Rim Village was prepared by Shannon & Wilson in April 2022 (Attachment 1) for the wastewater treatment plant area. The report summarizes:

- Subsurface conditions encountered during the exploration program completed on January 17 and 18, 2022
- Laboratory test results
- The geotechnical engineering recommendations

Shannon & Wilson completed the work as a subconsultant to Jacobs Government Services Company (Jacobs) under Professional Service Task Order 148027714 dated October 1, 2021.

The *Preliminary Geotechnical Report* (Shannon & Wilson 2022) was prepared during the early phase of the project. Because Jacobs is the engineer of record for the final design, Jacobs has reviewed the *Preliminary Geotechnical Report* and prepared this technical memorandum (TM) to document updates and design decision changes that affect the *Preliminary Geotechnical Report*.

The following items in the *Preliminary Geotechnical Report* have changed, and are documented herein:

- The list of proposed new facilities in the *Preliminary Geotechnical Report* was updated to the current facility list documented in Table 1 and Figures 1 and 2.
- The Construction Considerations - Earthwork recommendations of the *Preliminary Geotechnical Report* have been modified as discussed in Section 3.

All other engineering recommendations are as presented by Shannon & Wilson.

The *Geotechnical Report* for South Rim WWTP Access Road was prepared by Shannon & Wilson in January 2025 (Attachment 2) for the access road improvement. The report summarizes:

- Subsurface conditions encountered during the exploration program completed on September 18 and 19, 2024
- Laboratory test results
- The geotechnical engineering recommendations for the access road

Shannon & Wilson completed the work as a subconsultant to Jacobs Government Services Company (Jacobs) under Professional Service Task Order 148052738 dated May 20, 2024. Jacobs has reviewed the *Geotechnical Report* and confirms all recommendations as presented by Shannon & Wilson.

2. Proposed New Facilities

The project includes the construction of 15 new facilities at the wastewater treatment plant site, and the construction of a new gravel access road that extends from the wastewater treatment plant to the existing Arizona Public Service (APS) Substation. All new facilities will be within the existing plant, except the drying beds (facility number 85) that will be constructed south of the existing plant fence and the access road constructed to the east of the plant. Table 1 provides a summary of the new facilities, the foundation type, approximate foundation depth and the approximate foundation elevation based on 90 percent design drawings. Figures 1 and 2 show the existing site plan and the proposed facilities plan, respectively.

Table 1. Proposed New Plant Facilities (to replace Table 2-1 in Shannon & Wilson's Preliminary Geotechnical Report, dated April 2022)

New Facilities	Facility Number	Foundation Type	Approximate Foundation Depth Below Existing Grade (feet)	Approximate Foundation Elevation (feet)
Administration Building	10	Strip footings for CMU walls with floating slab-on-grade	1.75 to 9.25	6,774.75
Generator and Fuel Tanks	11	Slab-on-grade	2.1 to 6.6	6,776.4
Maintenance Building	12	Strip footings for CMU walls with floating slab-on-grade	2	6,773
Maintenance Building – Covered Exterior Storage	12	Slab-on-grade with thicken footing	3	6,672
Receiving Station	18	Slab-on-grade Precast concrete vault	2 feet (slab-on-grade) 12 feet (Vault)	6,786 to 6,787 6,778 (Vault)
Headworks	20	Strip footings for CMU walls with floating slab-on-grade Mat slab	3 to 12 f	6,777 to 6,786
Odor Control	22	Mat slab	2 to 3	6,789.5
Process Tanks	25	Mat Slab	10 to 15	6,764.4 to 6,759.4
Process Building	32	Mat Slab (basement), Strip footings for CMU walls with floating slab-on-grade (ground floor)	20 feet Up to 4.5 feet of fill	6,764.9 to 6,782.5
Reclaimed Water Tank	70	Mat slab	0 to 2	6,777
Digester Facility	80	Mat slab	1 to 6.5	6,782
Drying Beds	85	Slab-on-grade	5 feet Up to 12.5 feet of fill	6,773.6 to 6,777.8
Plant Drain Pump Station	86	Precast manhole	15	6,751
Compost Facility	87	Mat slab	0 to 1	6,788.5
Covered Storage	88	Strip footings for CMU walls with floating slab-on-grade	2 to 4	6,787

CMU = concrete masonry unit

3. Geotechnical Design Recommendations

The recommendations provided by Shannon & Wilson (2022 and 2025) have been reviewed and are applicable to the design of the facilities and access road and they will be used in the design of the foundations, slopes, and wall for the facilities and access road, with the following exceptions.

Revise and/or add the following construction considerations to the Earthwork Section (Section 7.2) of Shannon & Wilson's Preliminary Geotechnical Report, dated April 2022:

- The Use of explosive is not allowed for the project.
- Soil and bedrock subgrade preparation should meet the requirements of Specification Section 31 23 13.
- Foundation slab, slabs-on-grade and wall and column foundations should bear on a minimum of 8 inches of compacted granular fill or undisturbed bedrock. If foundations partially bear on undisturbed bedrock, the portion of foundation that is on soil shall bear on 18 inches of compacted granular fill above native soils. If undisturbed bedrock is shallower than 18-inches, then the thickness of compacted granular fill shall be equal to the depth to undisturbed bedrock.
- Granular fill should consist of 1-inch minus crushed gravel and or crushed rock. Granular fill should be well-graded from coarse to fine and containing sufficient fines to bind material when compacted, but with maximum 8 percent by weight passing No. 200 sieve.

4. References

Shannon & Wilson. 2022. *Preliminary Geotechnical Report.* National Park Services – Replace Wastewater Plant South Rim Village: GRCA – 257282. April.

Shannon & Wilson. 2025. *Geotechnical Report.* Grand Canyon National Park – South Rim WWTP Access Road. January.

Figure 1. Existing Site Plan

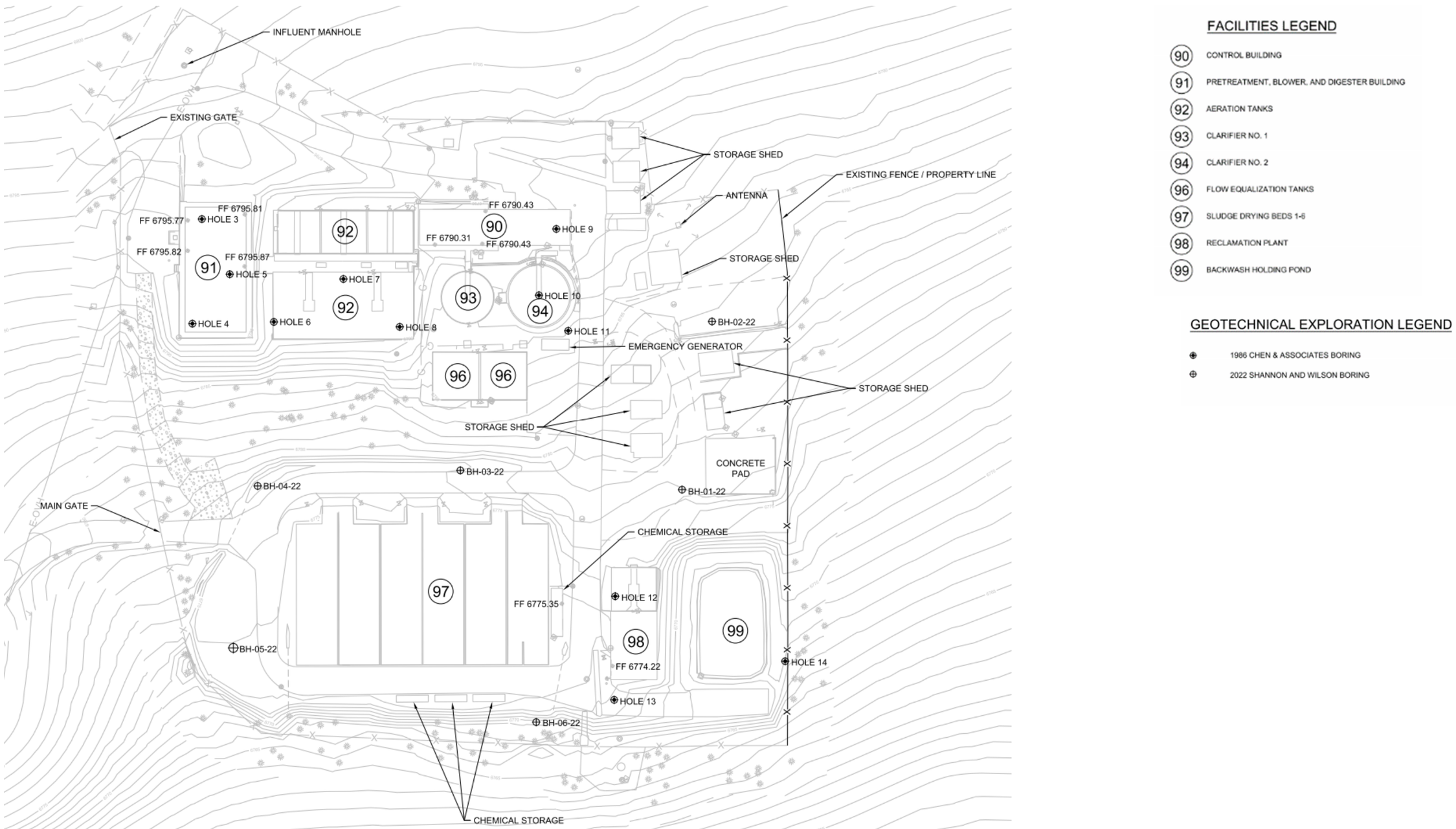
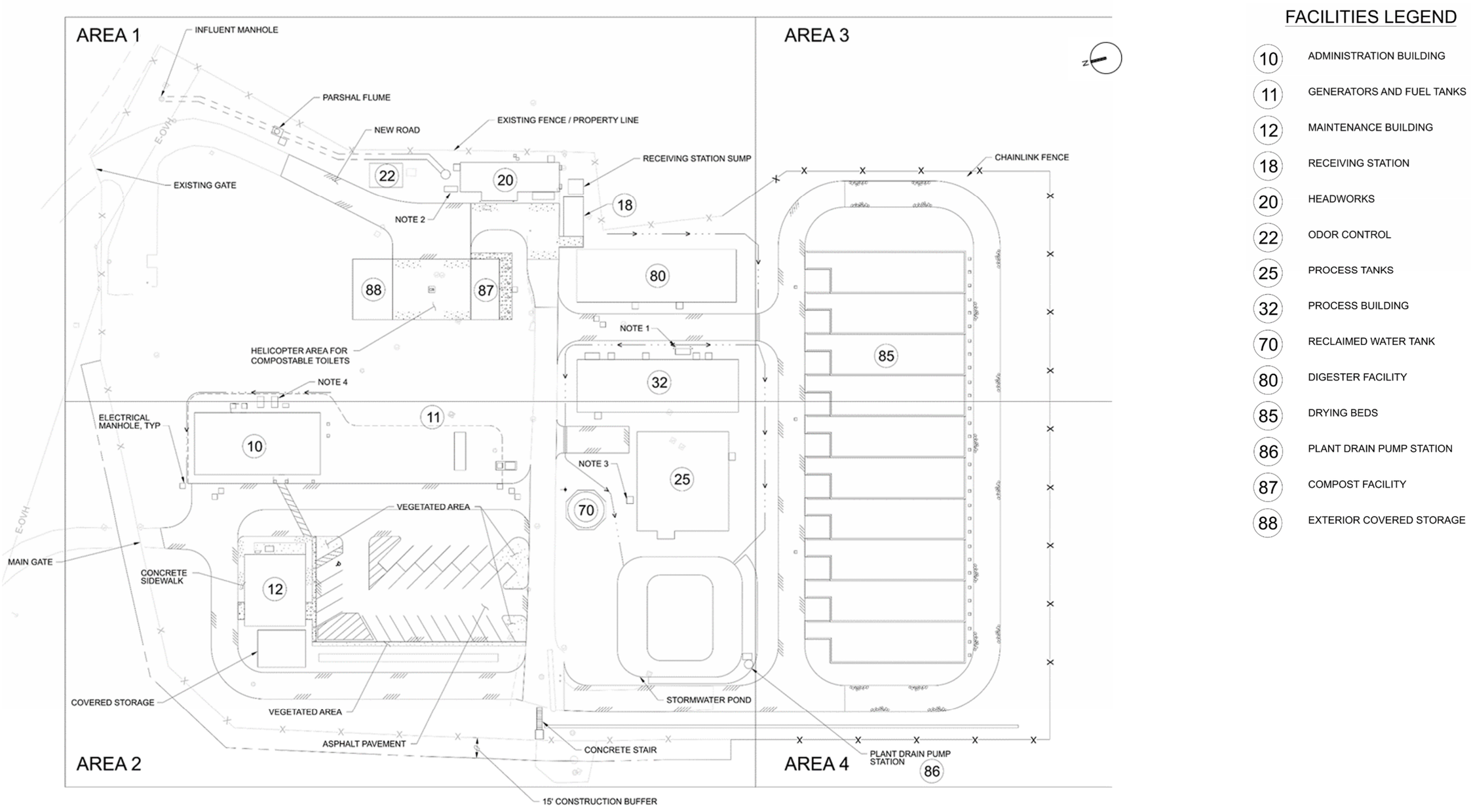


Figure 2. Overall Site Plan



Attachment 1
Preliminary Geotechnical Report – Shannon & Wilson 2022

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PRELIMINARY GEOTECHNICAL REPORT

National Park Service - GRCA - 257282, Replace Wastewater Plant South Rim Village

GRAND CANYON VILLAGE, ARIZONA

SHANNON & WILSON

April 2022

Shannon & Wilson No: 107528-001

Submitted To: Jacobs Engineering Group, Inc.
9191 Jamaica Street
Englewood, CO 80112
Attn: Kathy Rosinski, P.E.

Subject: PRELIMINARY GEOTECHNICAL REPORT, NATIONAL PARK SERVICE - GRCA - 257282, REPLACE WASTEWATER PLANT SOUTH RIM VILLAGE , GRAND CANYON VILLAGE, ARIZONA

We are pleased to submit our preliminary geotechnical report for the above-referenced project. The enclosed report summarizes subsurface conditions encountered in our exploration program, laboratory test results, and geotechnical engineering recommendations for the proposed project. Shannon & Wilson participated in this project as a subconsultant to Jacobs Engineering Group, Inc. (Jacobs). Our scope of services for the project was specified in our Professional Services Task Order 148027714 dated October 1, 2021.

We appreciate the opportunity to be of service to you on this project. If you have questions concerning this report, or we may be of further service, please contact us.

Sincerely,

SHANNON & WILSON

Gregory R. Fischer, Ph.D., P.E
President

CRC:JCG:GRF/jma

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1 INTRODUCTION

This report presents the results of our subsurface exploration and testing program and preliminary geotechnical engineering recommendations for the proposed South Rim Wastewater Treatment Plant (WWTP) Project (the Project) in Grand Canyon National Park, Arizona (Figure 1).

Our conclusions and recommendations are based on:

- Our understanding of the Project and information provided by Jacobs;
- Subsurface conditions observed in the explorations; and
- The results of testing performed on samples collected from the explorations.

The objective of our studies was to provide geotechnical recommendations and construction considerations, as presented herein, for the proposed new facilities. This report should not be used for other purposes without Shannon & Wilson's review. If a service is not specifically indicated in this report, do not assume that it was performed.

This report is preliminary. It will be necessary for the design-build contractor to develop final geotechnical recommendations for the Project.

2 PROJECT AND SITE DESCRIPTION

The Project is located in Grand Canyon National Park in Coconino County, Arizona (Figure 1). The Project site is approximately 2.5 miles west-southwest of Grand Canyon National Park South Rim Visitors Center at the existing Wastewater Treatment Plant (WWTP). The Project includes the construction of 11 new facilities within the existing plant site. Exhibit 2-1 provides a summary of the new facilities proposed for the Project, the proposed foundation type, approximate foundation depth and the approximate foundation elevation based on preliminary plans provided by Jacobs (2022) and email correspondence.

The existing WWTP facility sits on approximately 4.5 acres that gently slopes from east to west. We understand that the existing site grades were modified during the original construction of the treatment plant. It appears that fill for construction on west side of the site was placed, however no plans or as-builts were provided documenting the materials or placement methods used. The existing grades slope from approximate elevation 6,790 to 6,769. The site is generally surrounded by undeveloped land. Refer to Figure 2 for a Project map.

Exhibit 2-1: Proposed New Facilities

New Facilities	Foundation Type	Approx. Foundation Depth below Existing Grade	Approx. Foundation Elevation
Administration	Mat	2.5 ft	6774
Maintenance	Mat	2.5 ft	6772
Vault Waste / Septage Receiving	Mat	2.5 ft, with adjacent 10-ft deep vault	6785 6779
Headworks	Footings	4 to 11 ft	6778.5 to 6784.5
Odor Control	Mat	2.5 ft	6779
Process Tanks	Footings	12 to 16 ft	6764
Process Building	Mat	2.5 ft (east and west sections) 15 to 20 ft (center section)	6778 6761 to 6766
Reclaimed Water Tank	Footings	2.5 to 5 ft	6780
Decant Thickened Digester	Mat	2.5 ft	6782
Dewatering and Reclaimed Water Pump Station	Mat	2.5 ft	6773
Composter Facility	Mat	2.5 ft	6785

NOTES:
ft = feet

3 SUBSURFACE EXPLORATIONS AND LABORATORY TESTING

3.1 Field Investigation

Shannon & Wilson conducted a field exploration program on January 17 and 18, 2022, to explore subsurface conditions at the Project site. The subsurface exploration program consisted of drilling and sampling 6 borings, designated as borings BH-01-22 to BH-06-22 to depths selected by Jacobs. Refer to Figure 2 for the approximate boring locations. Exhibit 3-1 provides a summary of the borings completed for the Project.

Exhibit 3-1: Boring Summary

Boring Name	Elevation (ft)	Depth (ft)
BH-01-22	6,777.8	22
BH-02-22	6,783.7	9
BH-03-22	6,777.1	22
BH-04-22	6,775.7	26
BH-05-22	6,774.8	17
BH-06-22	6,769.3	13.5

Appendix A presents a discussion of the drilling and sampling procedures used to complete the borings. Appendix A also presents the individual exploration logs and an explanation of the symbols and terminology used to classify soil and rock samples recovered from the borings.

3.2 Geotechnical Laboratory Testing

Geotechnical laboratory tests were completed on selected samples retrieved from the borings. Index tests included natural water content, grain size analysis, and Atterberg limits. Engineering properties tests included corrosion and unconfined compressive strength. Laboratory test results and a discussion of the testing procedures are included in Appendix B. The natural water content and fines content are also shown on the individual boring logs included in Appendix A.

3.3 Previous Explorations

Existing subsurface data available for the site includes logs for 12 borings by Chen & Associates (1986) and associated laboratory testing. Appendix C includes these logs, laboratory testing results and a site plan showing the approximate boring locations.

4 REGIONAL GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

A regional geologic map of the Bright Angel quadrangle (Maxson, 1961) indicates that the near surface geology in the Project area is dominated by the limestone member of the Kaibab Formation (Permian) and consists of massive, fine-grained limestone containing

beds of sandstone, siltstone, and nodules of white chert. The Kaibab Formation forms the uppermost cliffs along the north and south rims of the Grand Canyon.

4.2 Subsurface Conditions

Borings BH-01-22 to BH-04-22, completed along the center and southern portions of the site, encountered 1 to 2 feet of overburden soil overlying limestone bedrock. The overburden soil consisted of clayey gravel with sand. The limestone bedrock was observed to be slightly weathered to fresh and medium strong to medium strong. Interbedded layers of weak, moderately to highly weathered limestone was encountered ranging in thickness from approximately 1 to 2.5 feet thick. Sandstone bedrock was encountered in BH-03-22 from approximately 18.7 to 19.7 feet and was observed to be fresh and medium strong.

Borings BH-05-22 and BH-06-22, completed along the western side of the existing drying beds, encountered 6 to 7 feet of undocumented fill soil overlying limestone bedrock. The undocumented fill soil consisted of loose to dense, clayey sand with gravel to clayey gravel with sand and sandy lean clay with gravel. The limestone bedrock was observed to be slightly weathered and medium strong.

The previous borings completed by Chen and Associates (1986), indicated 1 to 3 feet of overburden soil, consisting primarily of gravel with varying amounts of clay and sand, overlying limestone bedrock.

4.3 Groundwater

Groundwater was not encountered in any of our borings or in the previous borings (Chen & Associates, 1986). Groundwater was not encountered prior to coring in borings BH-01-22, BH-03-22, and BH-04-22; therefore, groundwater was not able to be identified if it was encountered. Groundwater fluctuations are possible and will depend on many factors, including seasonal variations, local precipitation, runoff, and snow melt.

4.4 Subsurface Variations

The explorations were performed to evaluate subsurface conditions beneath the Project site. Our observations are specific to the locations, depths, and times noted on the logs and may not be applicable to all areas of the site. No amount of explorations or testing can precisely predict the characteristics, quality, or distribution of subsurface and site conditions. Potential variation includes, but is not limited to:

- The conditions between explorations may be different, especially due to the presence of boulders and cobbles, differences in densities or gradations of fill.

- The passage of time or intervening causes (natural and manmade) may result in changes to site and subsurface conditions.

If conditions different from those described herein are encountered during construction, we should review our description of the subsurface conditions and reconsider our conclusions and recommendations.

5 GEOLOGIC HAZARD EVALUATION

5.1 Seismic Hazards

Based on a database by the U.S. Geological Survey (USGS), the nearest confirmed fault, to the Project, is the Bright Angel fault zone (undifferentiated Quaternary fault), approximately 0.2 miles to the northwest (USGS, 2021). The Bright Angel Fault is a normal fault that runs roughly parallel to Rowe Well Road and has movements of less than 0.2 mm per year (Pearthree, 1997). Although the Bright Angel Fault is close to the Project site, the location is well defined (Pearthree, 1997) and therefore, it is our opinion that the potential for ground surface fault rupture at the Project site is low.

5.2 Corrosion

The soil encountered at the Project site can be corrosive to substructure elements. Due to the prevalence of bedrock at the site, a single soil sample was tested for pH, resistivity, water soluble sulfates, and chlorides. The results are presented in Table B-1 in Appendix B.

The resistivity measured in the sample was 4,000 ohm-centimeters. Based on correlations developed by Roberge (2012) as shown in Exhibit 5-1, this value suggests corrosive subsurface conditions for metallic pipe in contact with subsurface materials across the site.

Exhibit 5-1: Corrosivity Ratings Based on Soil Resistivity

Soil Resistivity (ohm-cm)	Corrosivity Rating
>20,000	Essentially Noncorrosive
10,000-20,000	Mildly Corrosive
5,000-10,000	Moderately Corrosive
3,000-5,000	Corrosive
1,000-3,000	Highly Corrosive
<1,000	Extremely Corrosive

The concentration of water-soluble sulfates measured in the sample was 0.01% by weight. Based on classifications as defined by ACI-318-19 (ACI, 2019), as shown in Exhibit 5-2, this test result suggests an exposure class S0 on concrete exposed to site soils.

Exhibit 5-2: Corrosivity Ratings Based on Water Soluble Sulfate Exposure

Water Soluble Sulfate in Soil (Percent by Weight)	Sulfate Severity (Class)
<0.10	Negligible (S0)
0.10-<0.20	Moderate (S1)
0.20-2.00	Severe (S2)
>2.00	Very Severe (S3)

The test results and the above discussion are provided to assist the designer in the selection of Project materials, concrete type, or other features with respect to corrosion. As appropriate, the designer should consider protective measures, such as coatings, upsizing for section loss, or using alternative materials to reduce the corrosion potential.

6 PRELIMINARY GEOTECHNICAL RECOMMENDATIONS

The preliminary recommendations presented in the following sections are based on our understanding of the Project, conversations with Jacobs, and our subsurface exploration and laboratory testing program.

6.1 Ground Motion Design Parameters

We understand that design ground motion parameters will be based on the requirements of the 2021 International Building Code (International Code Council, 2020), which has adopted the ASCE 7-16 design code for minimum design loads on buildings (ASCE, 2017). These design loads are in turn based on the USGS National Seismic Hazard Maps that were updated in 2008 (Petersen and others, 2008). We characterized the site class using Standard Penetration Test (SPT) N-values (blow counts) noted in our exploration logs and our characterization of geologic conditions at the site. Based on not having shear wave velocity data, we recommend using Site Class C. A site classification of A or B may be appropriate if direct shear wave velocity measurements are obtained. Seismic design parameters for Site Class C are provided in Exhibit 6-1.

Exhibit 6-1: Seismic Design Ground Motion Parameters

Parameter	Value
Peak Ground Acceleration, PGA (g) (Site Class B)	0.169
Short-period Spectral Acceleration, S_S (g)	0.374
Long-period Spectral Acceleration, S_1 (g)	0.114
Site Class	C
PGA Site Factor, F_{pga}	1.23
Short-period Site Factor, F_a	1.3
Long-period Site Factor, F_v	1.5
Site Modified Peack Ground Acceleration, PGA_M (PGA x F_{pga}) (g)	0.208
Site Modified Spectral Acceleration - 0.2 s, S_{MS} (S_S x F_a) (g)	0.487
Site Modified Spectral Acceleration - 1.0 s, S_{M1} (S_1 x F_v) (g)	0.17
Seismic Design Value - 0.2 s, S_{DS} (2/3 x S_{MS}) (g)	0.324
Seismic Design Value - 1.0 s, S_{D1} (2/3 x S_{M1}) (g)	0.114

NOTES:
Calculated in accordance with IBC 2021 (2020) and ASCE 7-16 (2016).
g = gravity; PGA = peak ground acceleration, s = second

6.2 Foundations

We recommend that the proposed structures be supported by either spread/strip footings or mat foundations. Based on the available subsurface data, bedrock was generally encountered at a depth of 1 to 2 feet. Deeper soil, undocumented fill, on the order of 7 feet was encountered on the east side of the existing drying beds in borings BH-05-22 and BH-06-22. The undocumented fill consisted of clayey sands and gravels and sandy clays. We do not recommend placing foundation elements on undocumented fill. Based on preliminary plans provided by Jacobs (2022) and email correspondence, we anticipate the structures will be generally founded on bedrock.

If structures will be founded above the bedrock elevation, we recommend that undocumented fill be removed to the competent bedrock depth and replaced with Granular Fill (Section 7.2.5). The overexcavated fill can be used for general grading purposes; however, we do not recommend placing the material beneath structure foundations (see below).

6.2.1 Spread/Strip Footings

We recommend designing spread/strip footings for a net allowable bearing capacities of 10,000 pounds per square foot (psf) and 4,000 psf for foundations on bedrock and properly

compacted Granular Fill, respectively. These capacities can be increased by 33% for transient wind or seismic loads. Strip footings should have a minimum width of 2 feet and rectangular (spread) footings a minimum width of 4 feet. We recommend foundation elements be founded a minimum embedment of 30 inches below finished grade (Coconino County, 2016). If competent bedrock is encountered at a depth shallower than 30 inches below finished grade, the foundations or slab-on-grade may be founded at that depth We anticipate a potential total settlement of footings to be on the order of 1 inch and differential settlement on the order of 0.5 inch over a span of 30 feet on soil and half those settlements for foundations on bedrock. The majority of the settlement is expected to occur as the load is applied.

6.2.2 Mat Foundations

We recommend designing mat foundations for the bearing pressure discussed for spread footings. For the bearing values discussed in Section 6.2.1, we anticipate a settlement of about 1 inch for mats on compacted Granular Fill and 0.5 inch for mats on bedrock. However, we do not anticipate that bearing capacity will control the mat foundation design. Instead, we anticipate that the design will be governed by soil-structure interaction and the evaluation of calculated mat settlement (deflections), shears, and moments. Geotechnical information required for this analysis is the subgrade reaction modulus, which is analogous to a spring that can be applied in the structural model to represent the soil/rock response to applied stress. This value is a function of the dimensions of the mat and the stiffness of the underlying soil. Recommended values for subgrade reaction moduli (k) are provided in Exhibit 6-2.

Exhibit 6-2: Recommended Subgrade Reaction Moduli

Subgrade Material	Value
Competent Limestone Bedrock	100 - 250 pci
Compacted Granular Fill	25 - 75 pci

NOTES:
pci = pounds per square inch

We recommend evaluating a range of k values and designing for the worst-case conditions to account for potential variability of the bedrock strength and granular fill thickness.

6.3 Lateral Earth Pressures and Lateral Resistance

The lateral earth pressures acting on structure walls depend on many factors, including surcharge loads, the backfill soil type/consistency, and whether the top of the wall is free to yield or deflect laterally during and after excavation. If the top of the wall is free to yield a

minimum of 0.1% of the wall height (i.e., 0.001 times the height [H]), the soil pressures will generally be less (i.e., active condition) than if the wall is not able to yield this amount due to stiffness or resistance of the wall (i.e., at-rest condition). We anticipate that at-rest earth pressures will be appropriate for the structures. Our static earth pressure recommendations for soil backfill are presented in Exhibit 6-3. The static lateral earth pressures assume the structure walls are backfilled with properly compacted granular material in a 1 horizontal to 1 vertical (1H:1V) zone extending upward from the base of the structure from a point 1.5 feet behind the wall. These pressures also assume a vertical wall face and a flat backslope. As discussed previously, onsite undocumented fill materials are not suitable for reuse as backfill.

Seismic active lateral earth pressure coefficients were determined based on the Mononabe-Okabe method (AASHTO, 2020), and seismic at-rest earth pressure coefficients were determined based on methods developed by Zhang and others (1998). Per AASHTO (2020), the pressure distribution shape for dynamic active earth pressures is triangular, with the resultant force (P_{AE}) acting at the lower third of the wall height (h/3). The parameters are provided in Exhibit 6-3.

Exhibit 6-3: Recommended Lateral Earth Pressure (LEP) Values

Parameter	Coefficient	Drained Equivalent Fluid Pressure (pcf)[1,2]	Undrained Equivalent Fluid Pressure (pcf)[3]
Static Active Earth Pressure	K_A = 0.28	36	80
Static At-rest Earth Pressure	K_o = 0.44	56	90
Static Allowable Passive Earth Pressure[4]	K_p = 3.3	410	270
Dynamic Active Earth Pressure	K_{AE} = 0.34	43	85
Dynamic At-rest Earth Pressure	K_{oe} = 0.59	74	100
Dynamic Passive Earth Pressure	K_{pe} = 3.1	390	250

NOTES:

1 Based on granular soil with an assumed unit weight of 125 pcf and a friction angle of 34 degrees for the retained soil.

2 Drained equivalent fluid pressure parameters assume no hydrostatic pressure.

3 Undrained equivalent fluid pressure parameters assume hydrostatic pressures behind wall.

4 Static Passive Earth Pressure coefficient includes a factor of safety of 2.

pcf = pounds per cubic foot

If narrow backfill zones are utilized between structure walls and the limestone bedrock, updated earth pressures should be evaluated during final design:

- If flow fill is utilized as structure backfill, the flow fill may need to be placed incrementally and the walls should be designed for hydrostatic pressures associated with the maximum incremental flow fill lift height.

- If Granular Fill can be utilized within a narrow backfill zone, the earth pressures could also be reduced for bin conditions and should be evaluated during final design.

Exhibit 6-4 provides recommended lateral earth pressure (LEP) reduction values based on the backfill aspect ratio (b/H, with b = backfill width and H = backfill height). The reduction values can be applied directly to the drained equivalent fluid pressure from Exhibit 6-3. For undrained conditions (i.e., with hydrostatic pressures behind wall), the reduction values should be applied to only the soil portion of the undrained equivalent fluid pressure (i.e. [Value - 62.4 pcf]*[Reduction Value] + 62.4 pcf) from Exhibit 6-3. The reduction values can be linearly interpolated between the listed values.

Exhibit 6-4: Recommended LEP Reduction Values for Narrow Backfill Zones

Aspect Ratio (b/H)	Reduction Value
≥ 0.50	1.0
0.40	0.95
≤ 0.25	0.75

NOTES:
b = fill width, H = fill height

Surcharge loads from vehicles/traffic and construction equipment will induce additional lateral loads on structure walls. The pressures provided above do not account for surcharge loads. Lateral loads due to various types of surcharges may be calculated by multiplying the surcharge by the provided pressure coefficient. Surcharge loads should be applied as recommended in Figure 3.

Lateral loads can be resisted by friction along the base of the foundation using an allowable coefficient of sliding resistance of 0.35 for granular fill and 0.45 for bedrock. This allowable value for coefficient of sliding resistance includes a factor of safety of 1.5. In addition, we recommend an allowable passive pressure as provided in Exhibit 6-3. The allowable passive earth pressure coefficient includes a factor of safety of 2 to account for uncertainty in soil properties and to limit the lateral deflection necessary to mobilize the passive resistance. Passive resistance should be ignored in the upper 30 inches; however, the equivalent fluid pressure line may be projected down from the ground surface.

6.4 Surface Drainage

Surface drainage control is critical in reducing the potential for hydrostatic pressures and soil movements. The ground surface around the structures should be sloped to provide positive drainage away from foundations and structures. We recommend providing a slope of at least 10% for the first 5 feet surrounding the structures. Roof downspouts should

discharge into the storm drain system. If this is not possible, roof downspouts should discharge beyond the limits of foundation backfill or a minimum of 5 feet. We recommend providing splash blocks and downspout extenders, or tightlining downspouts away from the building. Roof downspouts should not be connected into a perimeter foundation drain system.

7 CONSTRUCTION CONSIDERATIONS

The applicability of the design recommendations provided in this report is contingent on good construction practice. Poor construction techniques may alter conditions from those on which our recommendations are based, resulting in reduced foundation capacity and increased settlement. The following sections present construction considerations for this Project.

7.1 Dewatering

Groundwater was not encountered during our subsurface exploration program. Should dewatering be required for some of the deeper facilities, we recommend that a dewatering designer and contractor be obtained for the Project design.

7.2 Earthwork

7.2.1 Site Preparation

We recommend that pavement, brush, and other vegetation be cleared, and roots and stumps be removed from all areas to be improved. Any existing surficial organic topsoil and any soil containing organics also should be stripped and removed. The depth of this removal is anticipated to vary over the site. Pavement, topsoil, and organic-rich soils are not considered suitable for reuse as fill and should be removed from the site or stockpiled for reuse in landscaping areas.

As discussed previously, undocumented fill soils may exist below the facilities. We recommend that all undocumented fill soils be removed beneath all areas of the site where structures are to be constructed.

7.2.2 Excavation

Excavations on the order of 30 feet are expected at the site. In general, excavations greater than 3 feet will encounter bedrock material. Excavation of bedrock material using conventional excavating equipment is anticipated to be limited due to the unconfined

compressive strengths and RQD. Other forms of rock excavation, such as ripping, jackhammer or impact hammer, and blasting will likely be required at the Project site. The chosen method of excavation will largely be dependent on available space and impacts on adjacent structures.

Jackhammers or impact hammers may be used to breakup and chip away the rock with minor impact to adjacent structures. Although mechanized equipment may expedite the work, this method is still relatively slow and may be best for detailed excavation work.

Blasting is likely the most efficient way to break up the bedrock sufficiently for conventual excavation methods. Blasting is also the most likely to have an impact on surrounding structures. We recommend that an experienced blasting contractor be retained to evaluate the use of explosives at the site.

7.2.3 Foundation and Slab Subgrade Preparation

Subgrade excavations should be cleaned of all undocumented fill, debris, or loose/soft material prior to concrete placement and should be kept free of water at all times. All undocumented fill beneath proposed structures should be overexcavated to the bedrock depth and replaced with compacted Granular Fill (Section 7.2.5) to establish adequate foundation support.

Excavations for mat or shallow foundations should be observed by a geotechnical engineering representative familiar with the subsurface conditions to evaluate the adequacy of the bearing stratum and confirm that the subsurface conditions at and below the bearing elevations are consistent with design assumptions and all undocumented fill has been removed.

7.2.4 Fill Placement and Compaction

Fill materials should be placed in horizontal lifts, with the loose lift thickness not to exceed 12 inches for heavy equipment compactors and 6 inches for hand-operated compactors. Compaction of backfill adjacent to walls can result in higher lateral earth pressures against the wall. As such, small equipment that is hand-operated shall only be used within a line extending upward from the base of the structure at 0.5H:1V, or at least 3 feet from the wall, whichever is greater.

All fill materials shall be compacted to a dense/hard and unyielding condition. Granular Fill should be compacted to a minimum of 95% of its Modified Proctor maximum dry density (ASTM D1557 (ASTM International, 2021)). The moisture content of Granular Fill should be within plus or minus 2% of the optimum moisture content.

For soil subgrades, the compacted surface should be proof-rolled with a fully-loaded, tandem-axle, 10-yard dump truck or equivalent. Areas that are identified as being loose, soft, or yielding during proof-rolling should be recompacted in place. Care should be taken during proof-rolling and subgrade preparation to avoid disturbing subgrade soils and supporting soils that will remain in place, as they can rut under repeated construction traffic.

7.2.5 Granular Fill

Granular Fill should consist of material that is free of organics, contaminants, debris, and rock fragments larger than 3 inches, and have a plasticity index (PI) of less than 10. We recommend that Granular Fill contain a maximum fines content of 20%. It should be noted that as the amount of fines (portion of soil particles passing a U.S. Standard No. 200 sieve, based on the minus ¾-inch fraction) increases, soil becomes more sensitive to small changes in moisture content, and adequate compaction becomes more difficult to achieve. Based our laboratory testing the onsite fill will not meet these requirements. Excavated bedrock, that has been crushed and process to meet the standards in this section, may be used as Granular Fill.

7.3 Temporary Slopes

Temporary excavations will be required to construct the proposed structures. The Contractor will be responsible for excavation stability during construction. As such, the Contractor should evaluate the stability of temporary slope and excavation configurations that may be required during construction.

The safe slope for the excavation of subsurface materials depends on many factors, including: (1) the presence of groundwater; (2) the type, density, and shear strength of the subsurface materials; (3) the depth of excavation; (4) the presence of adjacent structures; (5) surcharge loading adjacent to the excavation (including excavated material, existing dead or live loads, and construction equipment); and (6) time of construction.

To the extent that temporary excavation slopes are feasible, the following slope conditions are for cost estimating and planning purposes only and limited to slopes up to 20 feet in height. We anticipate that temporary excavations can be made at slopes of 1.5H:1V in granular cohesionless soils. We anticipate that vertical or near vertical excavations can be made in the bedrock material. If temporary slopes will be made, they should be consistent with the Occupational Safety and Health Administration (OSHA) guidelines contained in 29 CFR 1926, Subpart P (OSHA, 1999).

Consistent with conventional practice, the Contractor should be responsible for the actual temporary excavation slopes and shoring, including methods, sequence, and schedule of construction. The Contractor is able to observe the nature and conditions of the subsurface materials encountered and should evaluate the factors discussed above. If instability is observed, slopes should be flattened or shored. All excavations should be accomplished in accordance with local, state, and federal safety regulations.

8 LIMITATIONS

This preliminary report was prepared for the exclusive use of Jacobs and the National Park Service specific application to their design of the Project at this site as it relates to the geotechnical aspects discussed herein. The purpose of this report was to provide information on factual data only, and it should not be construed as a warranty of subsurface conditions, such as those interpreted from the logs and discussions of subsurface conditions in this report. This report is preliminary and is not suitable for final design. It will be necessary for the design-build contractor to develop final geotechnical recommendations for the Project, including completing additional explorations, as necessary.

The conclusions and recommendations presented in this report are based on the site conditions as they presently exist. These opinions further assume that explorations are representative of the subsurface conditions beneath the site; that is, the subsurface conditions everywhere are not significantly different than those disclosed by the explorations.

Within the limitations of the scope, schedule, and budget, the analyses, conclusions, and recommendations presented in this report were prepared in accordance with generally accepted professional geotechnical engineering principles and practice in this area at the time this report was prepared. We make no other warranty, either express or implied.

Shannon & Wilson has prepared the attached "Important Information About Your Geotechnical Report," to assist you and others in understanding the use and limitations of our reports.

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0 0.5 1
Miles

N

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VICINITY MAP

April 2022 107528-001

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FIG. 1

LEGEND

- ● Chen & Associates 1986 Geotechnical Boring Designation and Approximate Location
- ⊕ Shannon & Wilson 2022 Geotechnical Boring Designation and Approximate Location

NOTES

1. Existing borings based on Chen & Associates (1986)

N

0 100 200

Approximate Scale In Feet

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SITE AND EXPLORATION PLAN

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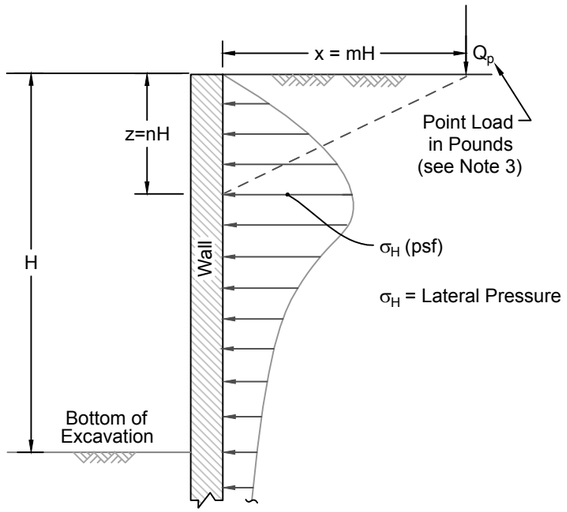
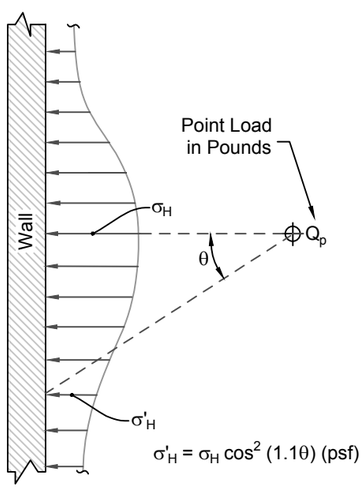
FIG. 2



ELEVATION VIEW

For m ≤ 0.4: $\sigma_H = 0.28 \frac{Q_p}{H^2} \frac{n^2}{(0.16 + n^2)^3}$ (psf) (see Note 3)

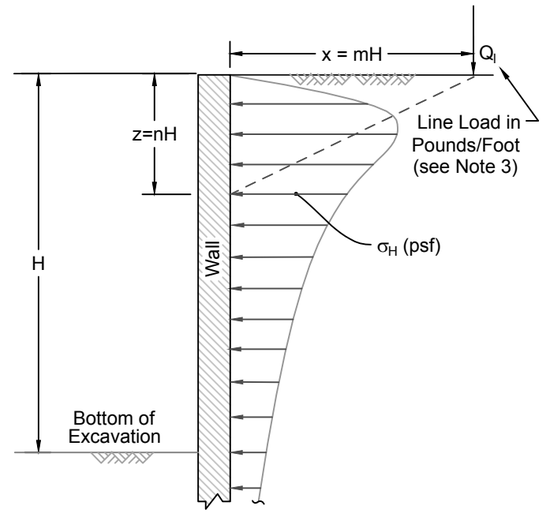
For m > 0.4: $\sigma_H = 1.77 \frac{Q_p}{H^2} \frac{m^2 n^2}{(m^2 + n^2)^3}$ (psf)



PLAN VIEW

A) LATERAL PRESSURE DUE TO POINT LOAD i.e. SMALL ISOLATED FOOTING OR WHEEL LOAD

(NAVFAC DM 7.2, 1986)



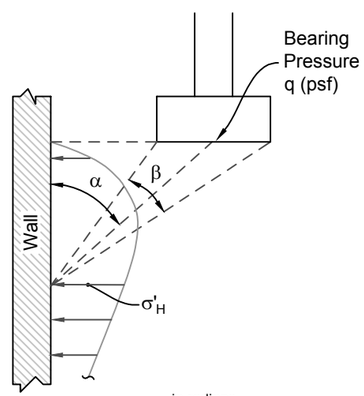
ELEVATION VIEW

For m ≤ 0.4: $\sigma_H = 0.20 \frac{Q_l}{H} \frac{n}{(0.16 + n^2)^2}$ (psf) (see Note 3)

For m > 0.4: $\sigma_H = 1.28 \frac{Q_l}{H} \frac{m^2 n}{(m^2 + n^2)^2}$ (psf)

B) LATERAL PRESSURE DUE TO LINE LOAD i.e. NARROW CONTINUOUS FOOTING PARALLEL TO WALL

(NAVFAC DM 7.02, 1986)

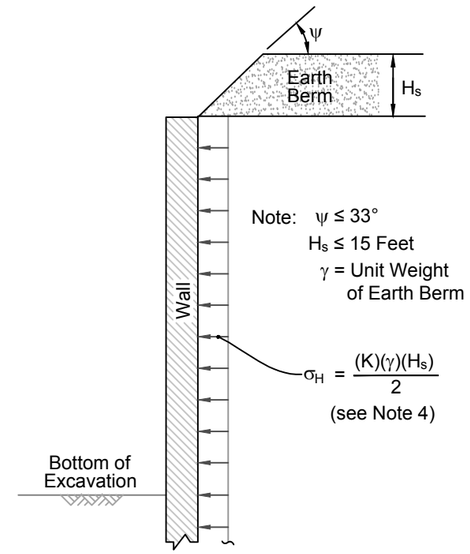


in radians

$\sigma_H = \frac{2q}{\pi} (\beta - \sin \beta \cos 2\alpha)$ (psf)

C) LATERAL PRESSURE DUE TO STRIP LOAD

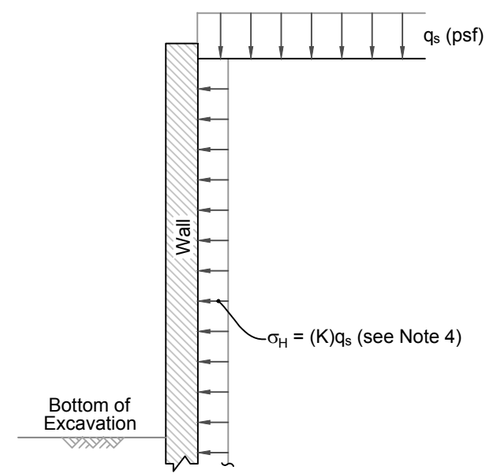
(derived from Fang, *Foundation Engineering Handbook*, 1991)



Note: ψ ≤ 33°
H_s ≤ 15 Feet
γ = Unit Weight of Earth Berm

$\sigma_H = \frac{(K)(\gamma)(H_s)}{2}$ (see Note 4)

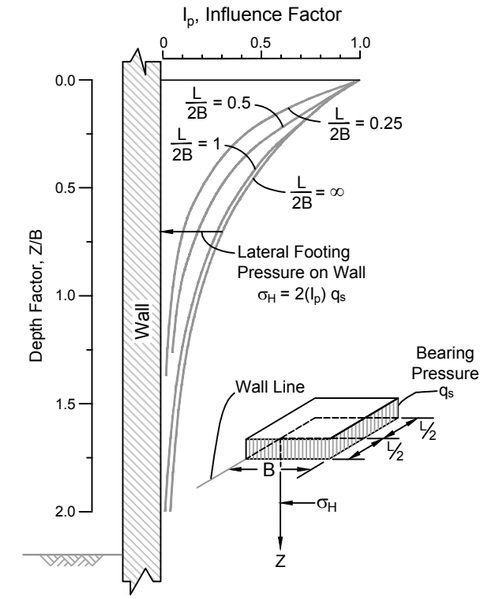
EARTH BERM



UNIFORM SURCHARGE

D) LATERAL PRESSURE DUE TO EARTH BERM OR UNIFORM SURCHARGE

(derived from Poulos and Davis, *Elastic Solutions for Soil and Rock Mechanics*, 1974; and Terzaghi and Peck, *Soil Mechanics in Engineering Practice*, 1967)



E) LATERAL PRESSURE DUE TO ADJACENT FOOTING
(see Notes 5 and 6)

(derived from NAVFAC DM 7.02, 1986; and Sandhu, *Earth Pressure on Walls Due to Surcharge*, 1974)

NOTES

1. Figures are not drawn to scale.
2. Applicable surcharge pressures should be added to appropriate temporary and permanent wall lateral earth and water pressure.
3. If point or line loads are close to the back of the wall such that m ≤ 0.4, it may be more appropriate to model the actual load distribution (i.e., Detail E) or use more rigorous analysis methods.
4. See text for recommended K values.
5. The stress is estimated on the back of the wall at the center of the length, L, of loading.
6. The estimated stress is based on a Poisson's ratio of 0.5.

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RECOMMENDED SURCHARGE LOADING FOR TEMPORARY AND PERMANENT WALLS

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FIG. 3

APPENDIX A: SUBSURFACE EXPLORATIONS

Appendix A

Subsurface Explorations

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A.2.4 Rock Core Sampling A-2

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Figure A-3 to A-8: Log of Borings BH-01-22 through BH-06-22
Figure A-9 to A-11: Rock Core Photographs: BH-01-22, BH-03-22, and BH-04-22

APPENDIX A: SUBSURFACE EXPLORATIONS

A.1 INTRODUCTION

Shannon & Wilson's field exploration program was conducted from January 17 to January 19, 2022 and consisted of drilling six borings at the locations shown on Figure 2. The methods used to conduct the field exploration program are described below.

A.2 EXPLORATIONS

The borings were coordinated (including subcontractor coordination and utility locates) and observed by Shannon & Wilson. The boring logs are presented in Figures A-3 through A-8. The exploration logs represent our interpretation of the contents of the field logs and select results of laboratory testing.

The borings were drilled by Vine Laboratories of Commerce City, Colorado (under subcontract to Shannon & Wilson) using a buggy-mounted CME 750X drill rig. The borings were advanced to depths ranging from 9 to 26 feet below existing site grade. The borings were advanced utilizing solid-stem auger, hollow-stem auger, and NQ rock coring methods. Groundwater was not encountered during drilling in any of the borings. On completion of drilling, the borings were backfilled with drill cuttings and bentonite chips.

A.2.1 Soil Classification System

During exploration, our representative collected samples and prepared field logs of the explorations. Soil classification for this project was based on ASTM D2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), and ASTM D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure). The Unified Soil Classification System is summarized in Figure A-1.

A.2.2 Rock Classification System

The Shannon & Wilson representative classified rock samples in general accordance with the International Society of Rock Mechanics (ISRM) classification method. According to this system, rocks are classified based on the stratigraphic structure, rock strength, degree of weathering, and other properties. The rock classification system is summarized in Figure A-2.

A.2.3 Standard Penetration Test (SPT)

Disturbed samples were obtained in general accordance with the Standard Penetration Test (SPT) (ASTM Designation: D1586). The SPT consists of driving a 2-inch outside diameter (O.D.), 1.375-inch inside diameter split-spoon sampler a distance of 18 inches with a 140-pound hammer free-falling a distance of 30 inches. An automatic hammer system was used to advance the samplers. During sampling, the Shannon & Wilson field representative recorded the number of blows for each 6-inch increment of penetration and summed the blow counts for the last two 6-inch increments. This sum is recorded as the penetration resistance number, or N-value. If high penetration resistance prevented driving the total length of the sampler, the Shannon & Wilson field representative recorded the partial penetration depth and blow count. The N-values provide a means for evaluating the relative density or compactness of cohesionless (granular) soils and consistency or stiffness of cohesive (fine-grained) soils (see Figure A-1). The N-values are shown in the individual boring logs. Representative portions of the split-spoon sample obtained in conjunction with the SPT were placed in a screw-top plastic jar and transported to our laboratory.

A.2.4 Rock Core Sampling

Rock samples were collected using NQ wireline coring methods (1.875-inch-nominal-diameter rock core). During coring, cuttings were removed from the borehole by circulating water down through the drill rods and back up the annulus of the boring. Core runs were 5 feet in length, except for the first core run, which reamed out disturbed material at the bottom of the borehole.

Percent recovery and rock quality designation (RQD) values are shown on the boring log where coring was completed. Percent recovery is the ratio of the length of recovered core to the total length of the core run. RQD is the ratio, expressed as a percent, of the sum of the length of intact core pieces greater than 4 inches long in a run to the total length of the core run. Following drilling, the core was logged by the Shannon & Wilson field representative, then stored in cardboard core boxes and transported to the Shannon & Wilson laboratory. Photographs of cores are presented in Figures A-9 through A-11.

Shannon & Wilson, Inc. (S&W), uses a soil identification system modified from the Unified Soil Classification System (USCS). Elements of the USCS and other definitions are provided on this and the following pages. Soil descriptions are based on visual-manual procedures (ASTM D2488) and laboratory testing procedures (ASTM D2487), if performed.

S&W INORGANIC SOIL CONSTITUENT DEFINITIONS

CONSTITUENT[2]	FINE-GRAINED SOILS (50% or more fines)[1]	COARSE-GRAINED SOILS (less than 50% fines)[1]
Major	***Silt, Lean Clay, Elastic Silt,*** or ***Fat Clay***[3]	***Sand*** or ***Gravel***[4]
Modifying (Secondary) Precedes major constituent	30% or more coarse-grained: ***Sandy*** or ***Gravelly***[4]	More than 12% fine-grained: ***Silty*** or ***Clayey***[3]
Minor Follows major constituent	15% to 30% coarse-grained: ***with Sand*** or ***with Gravel***[4]	5% to 12% fine-grained: ***with Silt*** or ***with Clay***[3]
	30% or more total coarse-grained *and* lesser coarse-grained constituent is 15% or more: ***with Sand*** or ***with Gravel***[5]	15% or more of a second coarse-grained constituent: ***with Sand*** or ***with Gravel***[5]

[1]All percentages are by weight of total specimen passing a 3-inch sieve.
[2]The order of terms is: *Modifying Major with Minor*.
[3]Determined based on behavior.
[4]Determined based on which constituent comprises a larger percentage.
[5]Whichever is the lesser constituent.

MOISTURE CONTENT TERMS

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

STANDARD PENETRATION TEST (SPT) SPECIFICATIONS

Hammer: 140 pounds with a 30-inch free fall. Rope on 6- to 10-inch-diam. cathead 2-1/4 rope turns, > 100 rpm

NOTE: If automatic hammers are used, blow counts shown on boring logs should be adjusted to account for efficiency of hammer.

Sampler: 10 to 30 inches long
Shoe I.D. = 1.375 inches
Barrel I.D. = 1.5 inches
Barrel O.D. = 2 inches

N-Value: Sum blow counts for second and third 6-inch increments.
Refusal: 50 blows for 6 inches or less; 10 blows for 0 inches.

NOTE: Penetration resistances (N-values) shown on boring logs are as recorded in the field and have not been corrected for hammer efficiency, overburden, or other factors.

PARTICLE SIZE DEFINITIONS

DESCRIPTION	SIEVE NUMBER AND/OR APPROXIMATE SIZE
FINES	< #200 (0.075 mm = 0.003 in.)
SAND	
Fine	#200 to #40 (0.075 to 0.4 mm; 0.003 to 0.02 in.)
Medium	#40 to #10 (0.4 to 2 mm; 0.02 to 0.08 in.)
Coarse	#10 to #4 (2 to 4.75 mm; 0.08 to 0.187 in.)
GRAVEL	
Fine	#4 to 3/4 in. (4.75 to 19 mm; 0.187 to 0.75 in.)
Coarse	3/4 to 3 in. (19 to 76 mm)
COBBLES	3 to 12 in. (76 to 305 mm)
BOULDERS	> 12 in. (305 mm)

RELATIVE DENSITY / CONSISTENCY

COHESIONLESS SOILS		COHESIVE SOILS	
N, SPT, BLOWS/FT.	RELATIVE DENSITY	N, SPT, BLOWS/FT.	RELATIVE CONSISTENCY
< 4	Very loose	< 2	Very soft
4 - 10	Loose	2 - 4	Soft
10 - 30	Medium dense	4 - 8	Medium stiff
30 - 50	Dense	8 - 15	Stiff
> 50	Very dense	15 - 30	Very stiff
		> 30	Hard

WELL AND BACKFILL SYMBOLS

Bentonite Cement Grout	Surface Cement Seal
Bentonite Grout	Asphalt or Cap
Bentonite Chips	Slough
Silica Sand	Inclinometer or Non-perforated Casing
Perforated or Screened Casing	Vibrating Wire Piezometer

PERCENTAGES TERMS[1, 2]

Trace	< 5%
Few	5 to 10%
Little	15 to 25%
Some	30 to 45%
Mostly	50 to 100%

[1]Gravel, sand, and fines estimated by mass. Other constituents, such as organics, cobbles, and boulders, estimated by volume.

[2]Reprinted, with permission, from ASTM D2488 - 09a Standard Practice for Description and Identification of Soils (Visual-Manual Procedure), copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM International, www.astm.org.

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SOIL CLASSIFICATION AND LOG KEY

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FIG. A-1
Sheet 1 of 3

2013 BORING CLASS1 107528-001 WWTP SOUTH RIM.GPJ SWNEW.GDT 4/28/22

UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)
(Modified From USACE Tech Memo 3-357, ASTM D2487, and ASTM D2488)

MAJOR DIVISIONS			GROUP/GRAPHIC SYMBOL		TYPICAL IDENTIFICATIONS
COARSE-GRAINED SOILS *(more than 50% retained on No. 200 sieve)*	Gravels *(more than 50% of coarse fraction retained on No. 4 sieve)*	Gravel *(less than 5% fines)*	GW		Well-Graded Gravel; Well-Graded Gravel with Sand
			GP		Poorly Graded Gravel; Poorly Graded Gravel with Sand
		Silty or Clayey Gravel *(more than 12% fines)*	GM		Silty Gravel; Silty Gravel with Sand
			GC		Clayey Gravel; Clayey Gravel with Sand
	Sands *(50% or more of coarse fraction passes the No. 4 sieve)*	Sand *(less than 5% fines)*	SW		Well-Graded Sand; Well-Graded Sand with Gravel
			SP		Poorly Graded Sand; Poorly Graded Sand with Gravel
		Silty or Clayey Sand *(more than 12% fines)*	SM		Silty Sand; Silty Sand with Gravel
			SC		Clayey Sand; Clayey Sand with Gravel
FINE-GRAINED SOILS *(50% or more passes the No. 200 sieve)*	Silts and Clays *(liquid limit less than 50)*	Inorganic	ML		Silt; Silt with Sand or Gravel; Sandy or Gravelly Silt
			CL		Lean Clay; Lean Clay with Sand or Gravel; Sandy or Gravelly Lean Clay
		Organic	OL		Organic Silt or Clay; Organic Silt or Clay with Sand or Gravel; Sandy or Gravelly Organic Silt or Clay
	Silts and Clays *(liquid limit 50 or more)*	Inorganic	MH		Elastic Silt; Elastic Silt with Sand or Gravel; Sandy or Gravelly Elastic Silt
			CH		Fat Clay; Fat Clay with Sand or Gravel; Sandy or Gravelly Fat Clay
		Organic	OH		Organic Silt or Clay; Organic Silt or Clay with Sand or Gravel; Sandy or Gravelly Organic Silt or Clay
HIGHLY-ORGANIC SOILS	Primarily organic matter, dark in color, and organic odor		PT		Peat or other highly organic soils (see ASTM D4427)

NOTE: No. 4 size = 4.75 mm = 0.187 in.; No. 200 size = 0.075 mm = 0.003 in.

NOTES

1. Dual symbols *(symbols separated by a hyphen, i.e., SP-SM, Sand with Silt)* are used for soils with between 5% and 12% fines or when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart. Graphics shown on the logs for these soil types are a combination of the two graphic symbols (e.g., SP and SM).

2. Borderline symbols *(symbols separated by a slash, i.e., CL/ML, Lean Clay to Silt; SP-SM/SM, Sand with Silt to Silty Sand)* indicate that the soil properties are close to the defining boundary between two groups.

National Park Service - GRCA-257282
Replace Wastewater Plant South Rim Village
Grand Canyon Village, Arizona

SOIL CLASSIFICATION AND LOG KEY

April 2022 | 107528-001

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FIG. A-1
Sheet 2 of 3

2013_BORING_CLASS2 107528-001 WWTP SOUTH RIM.GPJ SWNEW.GDT 4/28/22

GRADATION TERMS

Poorly Graded	Narrow range of grain sizes present or, within the range of grain sizes present, one or more sizes are missing (Gap Graded). Meets criteria in ASTM D2487, if tested.
Well-Graded	Full range and even distribution of grain sizes present. Meets criteria in ASTM D2487, if tested.

CEMENTATION TERMS[1]

Weak	Crumbles or breaks with handling or slight finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

PLASTICITY[2]

DESCRIPTION	VISUAL-MANUAL CRITERIA	APPROX. PLASITICTY INDEX RANGE
Nonplastic	A 1/8-in. thread cannot be rolled at any water content.	< 4
Low	A thread can barely be rolled and a lump cannot be formed when drier than the plastic limit.	4 to 10
Medium	A thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. A lump crumbles when drier than the plastic limit.	10 to 20
High	It take considerable time rolling and kneading to reach the plastic limit. A thread can be rerolled several times after reaching the plastic limit. A lump can be formed without crumbling when drier than the plastic limit.	> 20

ADDITIONAL TERMS

Mottled	Irregular patches of different colors.
Bioturbated	Soil disturbance or mixing by plants or animals.
Diamict	Nonsorted sediment; sand and gravel in silt and/or clay matrix.
Cuttings	Material brought to surface by drilling.
Slough	Material that caved from sides of borehole.
Sheared	Disturbed texture, mix of strengths.

PARTICLE ANGULARITY AND SHAPE TERMS[1]

Angular	Sharp edges and unpolished planar surfaces.
Subangular	Similar to angular, but with rounded edges.
Subrounded	Nearly planar sides with well-rounded edges.
Rounded	Smoothly curved sides with no edges.
Flat	Width/thickness ratio > 3.
Elongated	Length/width ratio > 3.

[1]Reprinted, with permission, from ASTM D2488 - 09a Standard Practice for Description and Identification of Soils (Visual-Manual Procedure), copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM International, www.astm.org.
[2]Adapted, with permission, from ASTM D2488 - 09a Standard Practice for Description and Identification of Soils (Visual-Manual Procedure), copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM International, www.astm.org.

ACRONYMS AND ABBREVIATIONS

ATD	At Time of Drilling
Diam.	Diameter
Elev.	Elevation
ft.	Feet
FeO	Iron Oxide
gal.	Gallons
Horiz.	Horizontal
HSA	Hollow Stem Auger
I.D.	Inside Diameter
in.	Inches
lbs.	Pounds
MgO	Magnesium Oxide
mm	Millimeter
MnO	Manganese Oxide
NA	Not Applicable or Not Available
NP	Nonplastic
O.D.	Outside Diameter
OW	Observation Well
pcf	Pounds per Cubic Foot
PID	Photo-Ionization Detector
PMT	Pressuremeter Test
ppm	Parts per Million
psi	Pounds per Square Inch
PVC	Polyvinyl Chloride
rpm	Rotations per Minute
SPT	Standard Penetration Test
USCS	Unified Soil Classification System
q_u	Unconfined Compressive Strength
VWP	Vibrating Wire Piezometer
Vert.	Vertical
WOH	Weight of Hammer
WOR	Weight of Rods
Wt.	Weight

STRUCTURE TERMS[1]

Interbedded	Alternating layers of varying material or color with layers at least 1/4-inch thick; singular: bed.
Laminated	Alternating layers of varying material or color with layers less than 1/4-inch thick; singular: lamination.
Fissured	Breaks along definite planes or fractures with little resistance.
Slickensided	Fracture planes appear polished or glossy; sometimes striated.
Blocky	Cohesive soil that can be broken down into small angular lumps that 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.

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SOIL CLASSIFICATION AND LOG KEY

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FIG. A-1
Sheet 3 of 3

2013 BORING CLASS3 107528-001 WWTP SOUTH RIM.GPJ SWNEW.GDT 4/28/22

WEATHERING

TERM	DESCRIPTION
Fresh	No visible sign of rock material weathering
Slightly Weathered	Slight discoloration on surface
Moderately Weathered	Discoloring evident; Less than half of the rock material is decomposed
Highly Weathered	Entire rock mass discolored; More than half of the rock material is decomposed
Completely Weathered	Rock reduced to a soil with relict rock texture
Residual Soil	All rock material is converted to soil

STRENGTH

GRADE	DESCRIPTION	APPROX. UCS (psi)
R0	Extremely Weak Rock	36 to 145
R1	Very Weak Rock	145 to 700
R2	Weak Rock	700 to 3,600
R3	Medium Strong Rock	3,600 to 7,200
R4	Strong Rock	7,200 to 14,500
R5	Very Strong Rock	14,500 to 36,250
R6	Extremely Strong Rock	>36,250

JOINT ROUGHNESS COEFFICIENT (JRC)

COEFFICIENT	DESCRIPTION
14 to 20	VERY ROUGH: Near vertical edges evident
10 to 14	ROUGH: Smooth ridges, surface abrasion
6 to 10	SLIGHTLY ROUGH: Asperities on surface can be felt
2 to 6	SMOOTH: Appears and feels smooth
0 to 2	SLICKENSIDED: Visible polishing, striated surface

DISCONTINUITY DATA

SPACING	
DESCRIPTION	SPACING
Extremely Close	< 1 in
Very Close	1 to 2.5 in
Close	2.5 to 8 in
Moderate	8 to 24 in
Wide	24 in to 6 ft
Very Wide	6 to 20 ft
Extremely Wide	> 20 ft

DISCONTINUITY TERMS

FRACTURE - Collective term for any natural break excluding shears, shear zones, and faults

JOINT (JT) - Planar break with little or no displacement

FOLIATION JOINT (FJ) or BEDDING JOINT (BJ) - Joint along foliation or bedding

INCIPIENT JOINT (IJ) or INCIPIENT FRACTURE (IF) - Joint or fracture not evident until wetted and dried; breaks along existing surface

RANDOM FRACTURE (RF) - Natural, very irregular fracture that does not belong to a set

BEDDING PLANE SEPARATION or PARTING - A separation along bedding after extraction from stress relief or slaking

FRACTURE ZONE (FZ) - Planar zone of broken rock without gouge

MECHANICAL BREAK (MB) - Breaks due to drilling or handling; drilling break (DB), hammer break (HB)

SHEAR (SH) - Surface of differential movement evident by presence of slickensides, striations, or polishing

SHEAR ZONE (SZ) - Zone of gouge and rock fragments bounded by planar shear surfaces

FAULT (FT) - Shear zone of significant extent; differentiation from shear zone may be site-specific

APERTURE WIDTH	
TERM	SPACING
Very Tight	<0.1mm
Tight	0.1 to 0.25mm
Partly Open	0.25 to 0.5mm
Open	0.5 to 2.5mm
Moderately Wide	2.5 to 10mm
Wide	10mm to 1cm
Very Wide	1 to 10cm
Extremely Wide	10 to 100cm
Cavernous	>1m

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Replace Wastewater Plant South Rim Village
Grand Canyon Village, Arizona

ROCK CLASSIFICATION AND LOG KEY

April 2022 107528-001

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FIG. A-2
Sheet 1 of 2

ROCK CLASS KEY - P1 (NEW STRENGTHS) 107528-001_WWTP SOUTH RIM.GPJ SHAN_WIL.GDT 4/28/22

ROCK CLASSIFICATION SYMBOLS

BEDROCK TYPE	GRAPHIC SYMBOL	ROCK NAME
Clastic Sedimentary Rocks		Breccia
		Conglomerate
		Sandstone
		Siltstone
		Claystone
		Shale
		Coal
Carbonate Sedimentary Rocks		Limestone
		Dolomite
		Coral
Evaporite Rocks		Gypsum
		Halite
		Calcite
Extrusive Igneous Rocks		Tuff
		Rhyolite
		Dacite
		Andesite
		Basalt
Intrusive Igneous Rocks		Granite
		Grano-diorite
		Diorite
		Gabbro
Metamorphic Rocks		Marble
		Quartzite
		Slate
		Phyllite
		Schist
		Gneiss

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Replace Wastewater Plant South Rim Village
Grand Canyon Village, Arizona

ROCK CLASSIFICATION AND LOG KEY

April 2022 107528-001

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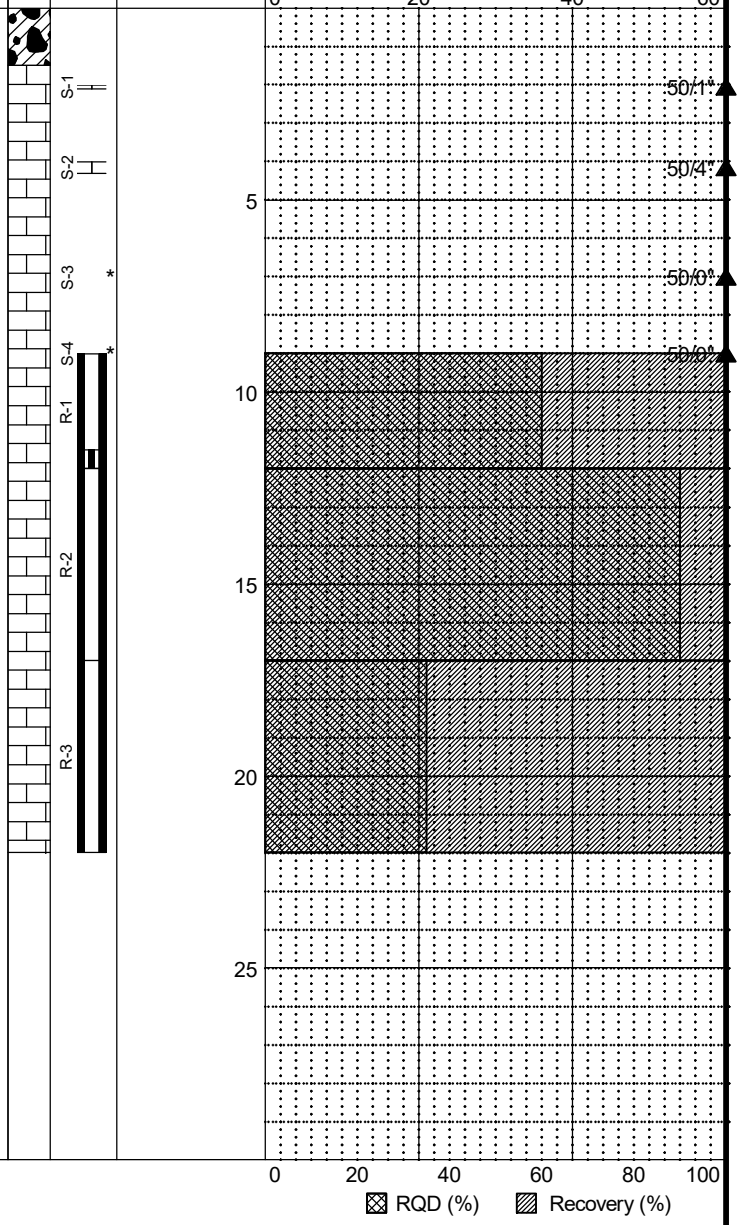
FIG. A-2
Sheet 2 of 2

ROCK CLASS KEY - P2 107528-001 WWTP SOUTH RIM.GPJ SHAN WIL.GDT 4/28/22

Total Depth:	22 ft.	Latitude:	36.04936°	Drilling Method:	HSA and Rock Core	Hole Diam.:	6 in.
Top Elevation:	6777.8 ft.	Longitude:	-112.15051°	Drilling Company:	Vine Laboratories	Rod Type.:	AWJ
Vert. Datum:		Station:		Drill Rig Equipment:	CME 750X Buggy	Hammer Type:	Automatic
Horiz. Datum:		Offset:	-	Other Comments:			

SOIL DESCRIPTION *Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.*	Depth, ft.
Brown, *Clayey Gravel with Sand (GC);* moist.	
LIMESTONE: medium strong to strong, yellow to red-yellow; fine grained; slightly weathered to fresh. [Kaibab Formation] - Weak, moderately weathered from 3.5 feet to 6 feet. - Weak, moderately weathered from 9 feet to 10.5 feet. - R-1 Sample UCS = 6,650 psi - Weak, moderately weathered from 16.1 feet to 17.4 feet. - Highly fractured below 18.4 feet. - Highly fractured below 21 feet.	1.5
BOTTOM OF BORING COMPLETED ON 01/18/2022	22.0



LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Rock Core
- Rock Core Sample

NOTES

1. Refer to Figures A-1 and A-2 for explanation of symbols, codes, abbreviations and definitions.
2. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
3. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
4. Groundwater level, if indicated above, is for the date specified and may vary.
5. USCS designation is based on visual-manual classification and selected lab testing.

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LOG OF BORING BH-01-22

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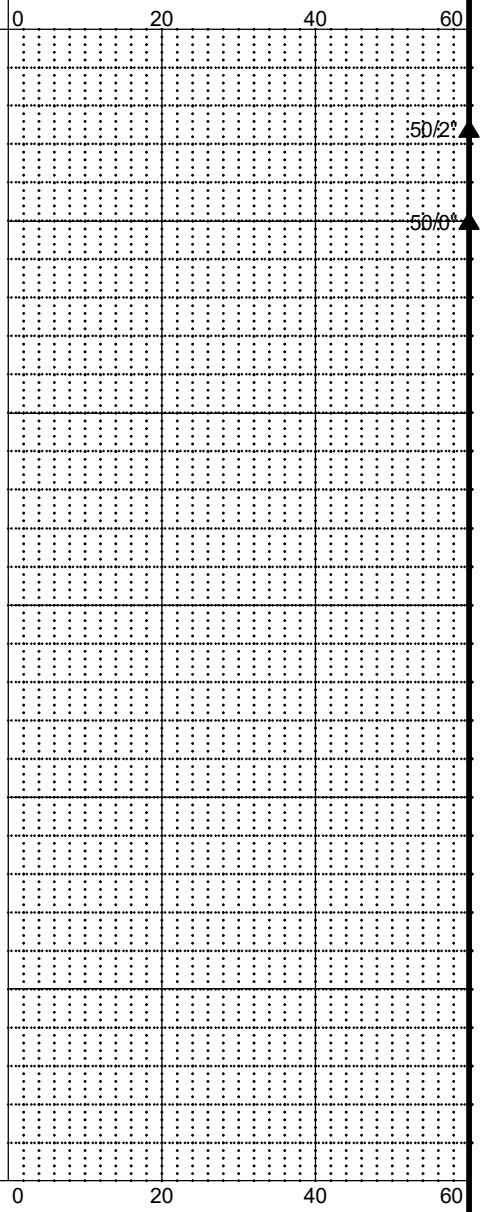
FIG. A-3

MASTER LOG E POCKETPEN LAT&LONG 107528-001 WWTP SOUTH RIM.GPJ 4/28/22

Total Depth:	9 ft.	Latitude:	36.04922°	Drilling Method:	Solid-Stem Auger	Hole Diam.:	6 in.
Top Elevation:	6783.7 ft.	Longitude:	-112.15013°	Drilling Company:	Vine Laboratories	Rod Type.:	AWJ
Vert. Datum:		Station:		Drill Rig Equipment:	CME 750X Buggy	Hammer Type:	Automatic
Horiz. Datum:		Offset:	-	Other Comments:			

SOIL DESCRIPTION *Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.*	Depth, ft.	Symbol	Samples	Ground Water	Depth, ft.	PENETRATION RESISTANCE (blows/foot) ▲ Hammer Wt. & Drop: 140 lbs / 30 inches
Brown, *Clayey Gravel with Sand (GC);* moist.						
LIMESTONE: medium strong to strong, yellow; fine grained; slightly weathered to fresh. [Kaibab Formation]	2.0		S-1 SG-1 * G-2		5 10 15 20 25	50/2" 50/0"
- Auger refusal at 9 feet.	9.0					
BOTTOM OF BORING COMPLETED ON 01/19/2022						



LEGEND

* Sample Not Recovered

Standard Penetration Test

Grab Sample

NOTES

1. Refer to Figures A-1 and A-2 for explanation of symbols, codes, abbreviations and definitions.
2. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
3. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
4. Groundwater level, if indicated above, is for the date specified and may vary.
5. USCS designation is based on visual-manual classification and selected lab testing.

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LOG OF BORING BH-02-22

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FIG. A-4

MASTER LOG E POCKETPEN LAT&LONG 107528-001 WWTP SOUTH RIM.GPJ 4/28/22

Total Depth:	23 ft.	Latitude:	36.04977°	Drilling Method:	HSA and Rock Core	Hole Diam.:	6 in.
Top Elevation:	6777.1 ft.	Longitude:	-112.15035°	Drilling Company:	Vine Laboratories	Rod Type.:	AWJ
Vert. Datum:		Station:		Drill Rig Equipment:	CME 750X Buggy	Hammer Type:	Automatic
Horiz. Datum:		Offset:	-	Other Comments:			

SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

Brown, *Clayey Gravel with Sand (GC);* moist.

1.0

LIMESTONE: medium strong to strong, yellow to red-yellow; fine grained; slightly weathered to fresh.
[Kaibab Formation]

- Highly fractured from 5.8 feet to 6.6 feet.

- Highly fractured with low RQD from 9.5 feet to 11.5 feet.

- R-3 Sample UCS = 4,999 psi

- Moderately weathered from 15.3 feet to 17.3 feet.
- R-3 Sample UCS = 6,512 psi

18.7

SANDSTONE: medium strong, yellow; fine grained; fresh.
[Kaibab Formation]

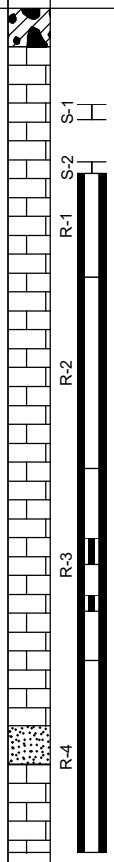
19.7

LIMESTONE: medium strong to strong, yellow to red-yellow; fine grained; slightly weathered to fresh.
[Kaibab Formation]
- Highly weathered below 21.2 feet.

22.0

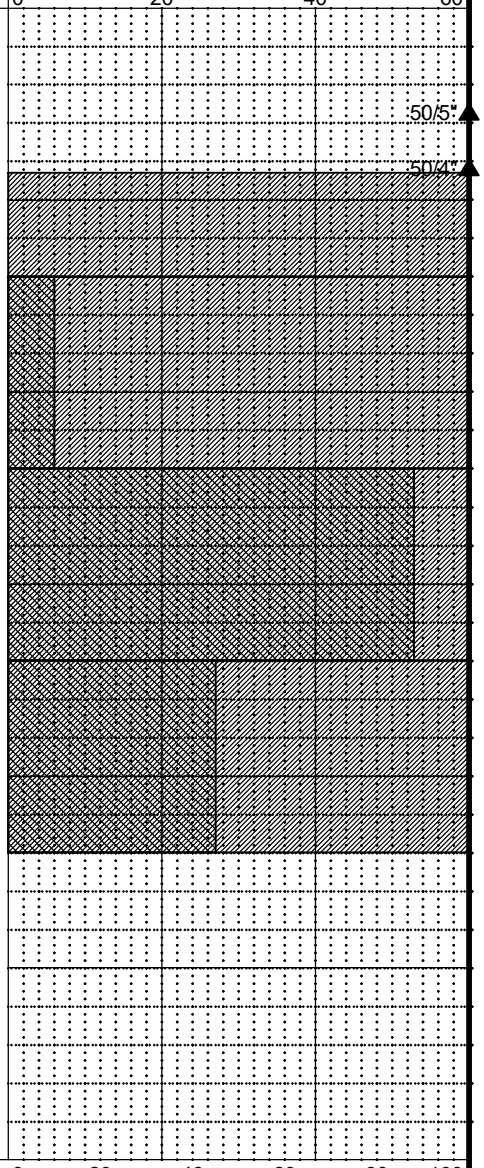
BOTTOM OF BORING
COMPLETED ON 01/18/2022

Depth, ft. | Symbol | Samples | Ground Water | Depth, ft.



PENETRATION RESISTANCE (blows/foot)

▲ Hammer Wt. & Drop: 140 lbs / 30 inches



LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Rock Core
- Rock Core Sample

NOTES

1. Refer to Figures A-1 and A-2 for explanation of symbols, codes, abbreviations and definitions.
2. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
3. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
4. Groundwater level, if indicated above, is for the date specified and may vary.
5. USCS designation is based on visual-manual classification and selected lab testing.

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LOG OF BORING BH-03-22

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FIG. A-5

MASTER LOG E POCKETPEN LAT&LONG 107528-001 WWTP SOUTH RIM.GPJ 4/28/22

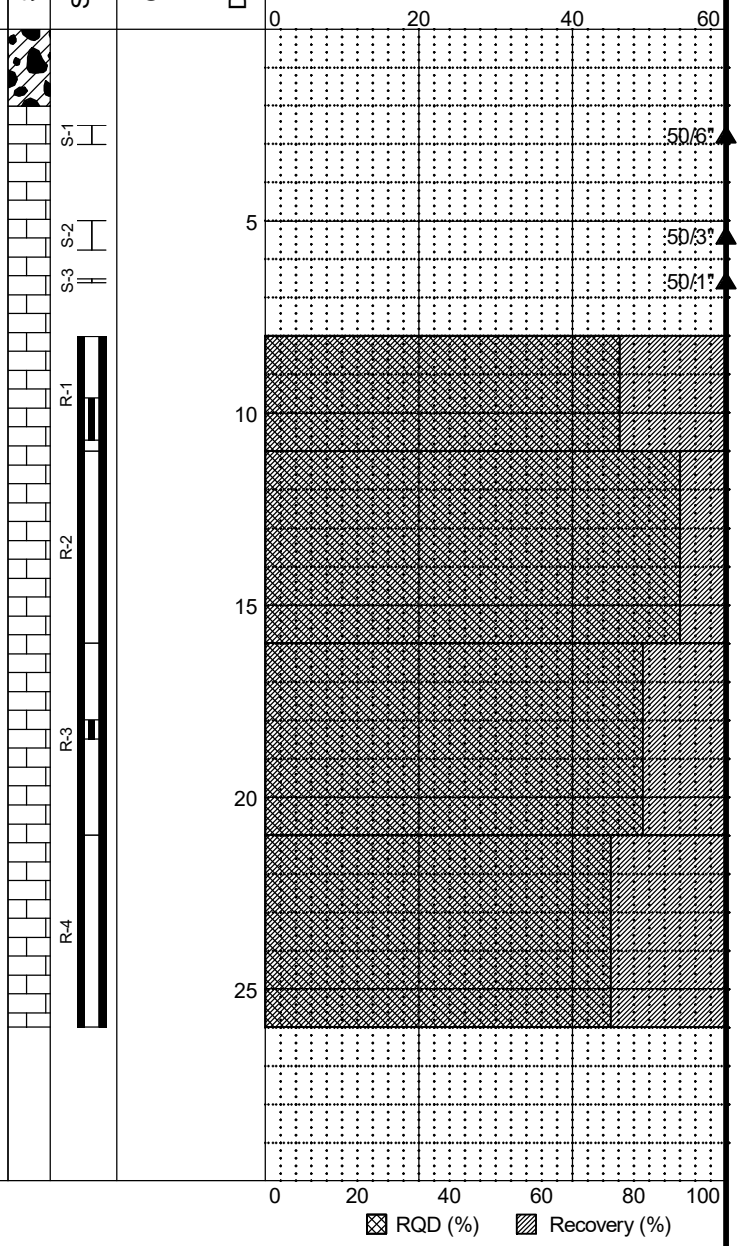
Total Depth:	26 ft.	Latitude:	36.05016°	Drilling Method:	HSA and Rock Core	Hole Diam.:	6 in.
Top Elevation:	6775.7 ft.	Longitude:	-112.15027°	Drilling Company:	Vine Laboratories	Rod Type.:	AWJ
Vert. Datum:		Station:		Drill Rig Equipment:	CME 750X Buggy	Hammer Type:	Automatic
Horiz. Datum:		Offset:	-	Other Comments:			

SOIL DESCRIPTION *Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.*	Depth, ft.
Brown, *Clayey Gravel with Sand (GC);* moist.	
LIMESTONE: medium strong to strong, yellow; fine grained; slightly weathered to fresh. [Kaibab Formation]	2.0
- R-1 Sample UCS = 3,666 psi	
- Weak, moderately weathered from 13.4 feet to 14.6 feet.	
- Weak, moderately weathered from 17.6 feet to 18.7 feet.	
- R-3 Sample UCS = 7,886 psi	
- Weak, moderately fractured from 21 feet to 22.5 feet.	
BOTTOM OF BORING COMPLETED ON 01/18/2022	26.0

Symbol | Samples | Ground Water | Depth, ft.

PENETRATION RESISTANCE (blows/foot)

▲ Hammer Wt. & Drop: *140 lbs / 30 inches*



LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Rock Core
- Rock Core Sample

NOTES

1. Refer to Figures A-1 and A-2 for explanation of symbols, codes, abbreviations and definitions.
2. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
3. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
4. Groundwater level, if indicated above, is for the date specified and may vary.
5. USCS designation is based on visual-manual classification and selected lab testing.

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LOG OF BORING BH-04-22

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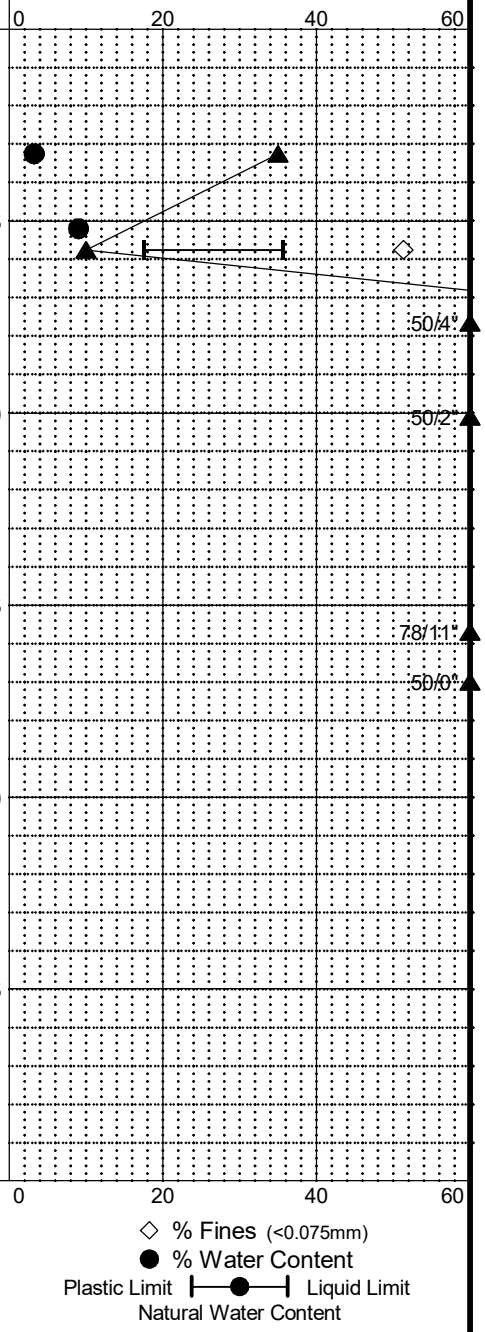
FIG. A-6

Total Depth:	17 ft.	Latitude:	36.05028°	Drilling Method:	Hollow-Stem Auger	Hole Diam.:	6 in.
Top Elevation:	6774.8 ft.	Longitude:	-112.15064°	Drilling Company:	Vine Laboratories	Rod Type.:	AWJ
Vert. Datum:		Station:		Drill Rig Equipment:	CME 750X Buggy	Hammer Type:	Automatic
Horiz. Datum:		Offset:	-	Other Comments:			

SOIL DESCRIPTION *Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.*	Depth, ft.
Medium dense to dense and stiff to hard, brown to yellow, *Clayey Sand with Gravel (SC)* to *Sandy Lean Clay with Gravel (CL);* moist; cobbles inferred from drill action. Fill	
LIMESTONE: medium strong to strong, yellow; fine grained; slightly weathered to fresh. [Kaibab Formation]	7.0
- Auger refusal at 17 feet.	17.0
BOTTOM OF BORING COMPLETED ON 01/17/2022	

Symbol | Samples: S-1, S-2, S-3, S-4, S-5, S-6 | Ground Water | Depth, ft.



LEGEND

* Sample Not Recovered

Standard Penetration Test

◇ % Fines (<0.075mm)

● % Water Content

Plastic Limit ⊢●⊣ Liquid Limit

Natural Water Content

NOTES

1. Refer to Figures A-1 and A-2 for explanation of symbols, codes, abbreviations and definitions.
2. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
3. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
4. Groundwater level, if indicated above, is for the date specified and may vary.
5. USCS designation is based on visual-manual classification and selected lab testing.

National Park Service - GRCA-257282
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LOG OF BORING BH-05-22

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FIG. A-7

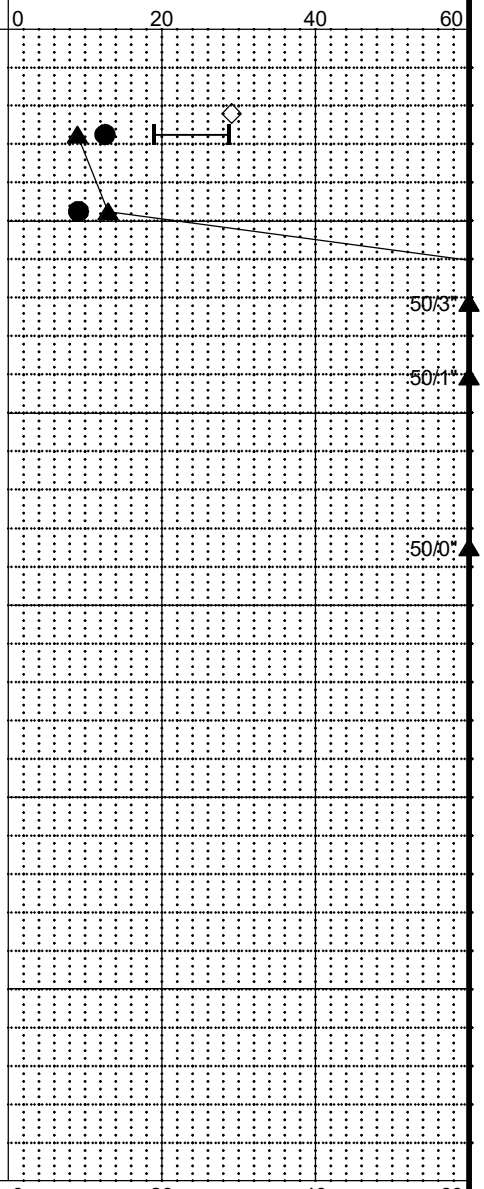
MASTER LOG E POCKETPEN LAT&LONG 107528-001 WWTP SOUTH RIM.GPJ 4/28/22

Total Depth:	13.5 ft.	Latitude:	36.04975°	Drilling Method:	Solid-Stem Auger	Hole Diam.:	6 in.
Top Elevation:	6769.3 ft.	Longitude:	-112.15094°	Drilling Company:	Vine Laboratories	Rod Type.:	AWJ
Vert. Datum:		Station:		Drill Rig Equipment:	CME 750X Buggy	Hammer Type:	Automatic
Horiz. Datum:		Offset:	-	Other Comments:			

SOIL DESCRIPTION *Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.*	Depth, ft.	Symbol	Samples	Ground Water	Depth, ft.
Loose to medium dense, brown to yellow-brown, *Clayey Sand with Gravel (SC)* to *Clayey Gravel with Sand (GC);* moist. Fill			S-1 S-2		
LIMESTONE: medium strong to strong, yellow; fine grained; slightly weathered to fresh. [Kaibab Formation]	6.0		S-3 S-4		
- Auger refusal at 13.5 feet.	13.5		S-5 G		
BOTTOM OF BORING COMPLETED ON 01/17/2022					

PENETRATION RESISTANCE (blows/foot)

▲ Hammer Wt. & Drop: *140 lbs / 30 inches*



LEGEND

* Sample Not Recovered

Standard Penetration Test

G Grab Sample

◇ % Fines (<0.075mm)

● % Water Content

Plastic Limit ⊢●⊣ Liquid Limit

Natural Water Content

NOTES

1. Refer to Figures A-1 and A-2 for explanation of symbols, codes, abbreviations and definitions.
2. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
3. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
4. Groundwater level, if indicated above, is for the date specified and may vary.
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LOG OF BORING BH-06-22

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FIG. A-8

MASTER LOG E POCKETPEN LAT&LONG 107528-001 WWTP SOUTH RIM.GPJ 4/28/22

Boring BH-01-22, Core Run #1: 9.0 to 12.0 feet.

Top Of Core

Boring BH-01-22, Core Run #2: 12.0 to 17.0 feet

Top Of Core

Photo Match Line

Photo Match Line

Boring	Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
BH-01-22	R-1	9.0	12.0	100	60
BH-01-22	R-2	12.0	17.0	100	90

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ROCK CORING PHOTOGRAPHS
BORING BH-01-22

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FIG. A-9
Sheet 1 of 2

FIG. A-9
Sheet 1 of 2

Boring BH-01-22, Core Run #3: 17.0 to 22.0 feet.

Top Of Core

Photo Match Line

Photo Match Line

Boring	Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
BH-01-22	R-3	17.0	22.0	100	35

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ROCK CORING PHOTOGRAPHS
BORING BH-01-22

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FIG. A-9
Sheet 2 of 2

FIG. A-9
Sheet 2 of 2

Boring BH-03-22, Core Run #1: 4.3 to 7.0 feet.

Top Of Core

Boring BH-03-22, Core Run #2: 7.0 to 12.0 feet

Top Of Core

Photo Match Line

Photo Match Line

Boring	Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
BH-03-22	R-1	4.3	7.0	100	0
BH-03-22	R-2	7.0	12.0	100	10

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Grand Canyon Village, Arizona

ROCK CORING PHOTOGRAPHS
BORING BH-03-22

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FIG. A-10
Sheet 1 of 2

FIG. A-10
Sheet 1 of 2

Boring BH-03-22, Core Run #3: 12.0 to 17.0 feet.

Top Of Core

Photo Match Line

Photo Match Line

Boring BH-03-22, Core Run #4: 17.0 to 22.0 feet

Top Of Core

Photo Match Line

Photo Match Line

Boring	Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
BH-03-22	R-3	12.0	17.0	100	88
BH-03-22	R-4	17.0	22.0	100	45

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Grand Canyon Village, Arizona

ROCK CORING PHOTOGRAPHS
BORING BH-03-22

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FIG. A-10
Sheet 2 of 2

FIG. A-10
Sheet 2 of 2

Boring BH-04-22, Core Run #1: 8.0 to 11.0 feet.

Top Of Core

Boring BH-04-22, Core Run #2: 11.0 to 16.0 feet

Top Of Core

Photo Match Line

Photo Match Line

Boring	Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
BH-04-22	R-1	8.0	11.0	100	77
BH-04-22	R-2	11.0	16.0	100	90

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ROCK CORING PHOTOGRAPHS
BORING BH-04-22

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FIG. A-11
Sheet 1 of 2

FIG. A-11
Sheet 1 of 2

Boring BH-04-22, Core Run #3: 16.0 to 21.0 feet.

Top Of Core

Photo Match Line

Photo Match Line

Boring BH-04-22, Core Run #4: 21.0 to 26.0 feet

Top Of Core

Photo Match Line

Photo Match Line

Boring	Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
BH-04-22	R-3	16.0	21.0	100	82
BH-04-22	R-4	21.0	26.0	100	75

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ROCK CORING PHOTOGRAPHS
BORING BH-04-22

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FIG. A-11
Sheet 2 of 2

FIG. A-11
Sheet 2 of 2

APPENDIX B: LABORATORY TEST RESULTS

Appendix B

Laboratory Test Results

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B.1 Introduction B-1
B.2 Geotechnical Index Tests B-1
B.2.1 Water Content B-1
B.2.2 Grain Size Analysis B-1
B.2.3 Atterberg Limits B-1
B.3 Geotechnical Engineering Property Tests B-2
B.3.1 Corrosion B-2
B.3.2 Unconfined Compressive Strength B-2

Tables

Table B-1: Summary of Laboratory Test Results by Boring

Figures

Figure B-1: Grain Size Distribution
Figure B-2: Plasticity Chart

B.1 INTRODUCTION

Laboratory tests were completed on soil samples retrieved from the borings in general accordance with the American Society of Testing and Materials International (ASTM) testing methods. The laboratory testing program was performed to classify the materials into similar geologic groups and provide data that can be used for design of the project. The geotechnical laboratory testing was performed by Vine Laboratories, Inc. of Commerce City, Colorado. A summary of the laboratory test results is presented in Table B-1. The following sections describe the laboratory testing procedures.

B.2 GEOTECHNICAL INDEX TESTS

B.2.1 Water Content

Water content was determined for selected samples in general accordance with ASTM Designation: D2216, Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. To perform this test, a sample was weighed before and after oven-drying, and the water content was calculated. Water content determinations are shown graphically on the boring logs and are also summarized in Table B-1.

B.2.2 Grain Size Analysis

The grain size distribution of selected samples was determined in general accordance with ASTM D 422, Standard Test Method for Particle-Size Analysis of Soils. Results of these analyses are presented as grain size distribution curves presented in Figure B-1 and summarized in Table B-1.

B.2.3 Atterberg Limits

Soil plasticity was determined by performing Atterberg limits tests on selected fine-grained samples. The tests were completed in general accordance with ASTM D4318, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. The Atterberg limits include liquid limit (LL), plastic limit (PL), and plasticity index (PI equals LL minus PL) and are generally used to assist in classification of soils, to indicate soil consistency (when compared to natural water content), and to provide correlation to soil properties. The results of the Atterberg limits tests are summarized in Table B-1, plotted on a plasticity chart (Figure B-2), and shown graphically on the boring logs in Appendix A.

B.3 GEOTECHNICAL ENGINEERING PROPERTY TESTS

B.3.1 Corrosion

Corrosion testing of select samples was performed for pH, resistivity, sulfate content, and chloride content by Vine Laboratories. Testing for pH was completed in general accordance with ASTM D4972, Standard Test Methods for pH of Soils. Resistivity testing was completed in accordance with ASTM G57, Standard Test Method for Measurement of Soil Resistivity Using the Wenner Four-Electrode Method. Sulfate content testing was completed in general accordance with ASTM C1580, Standard Test Method for Water-Soluble Sulfate in Soil. Chloride content testing was completed in general accordance with ASTM D1411, Standard Test Methods for Water-Soluble Chlorides Present as Admixtures in Graded Aggregate Road Mixes. Test results for sulfate and chloride content are given in units of part per million. The test results are summarized in Table B-1.

B.3.2 Unconfined Compressive Strength

Unconfined Compressive Strength of intact rock samples was performed by Vine Laboratories. The unconfined compressive strength testing was completed in general accordance with ASTM D7012 (Method C), Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures. The test results are summarized in Table B-1.

Table B-1 - Summary of Laboratory Test Results by Boring

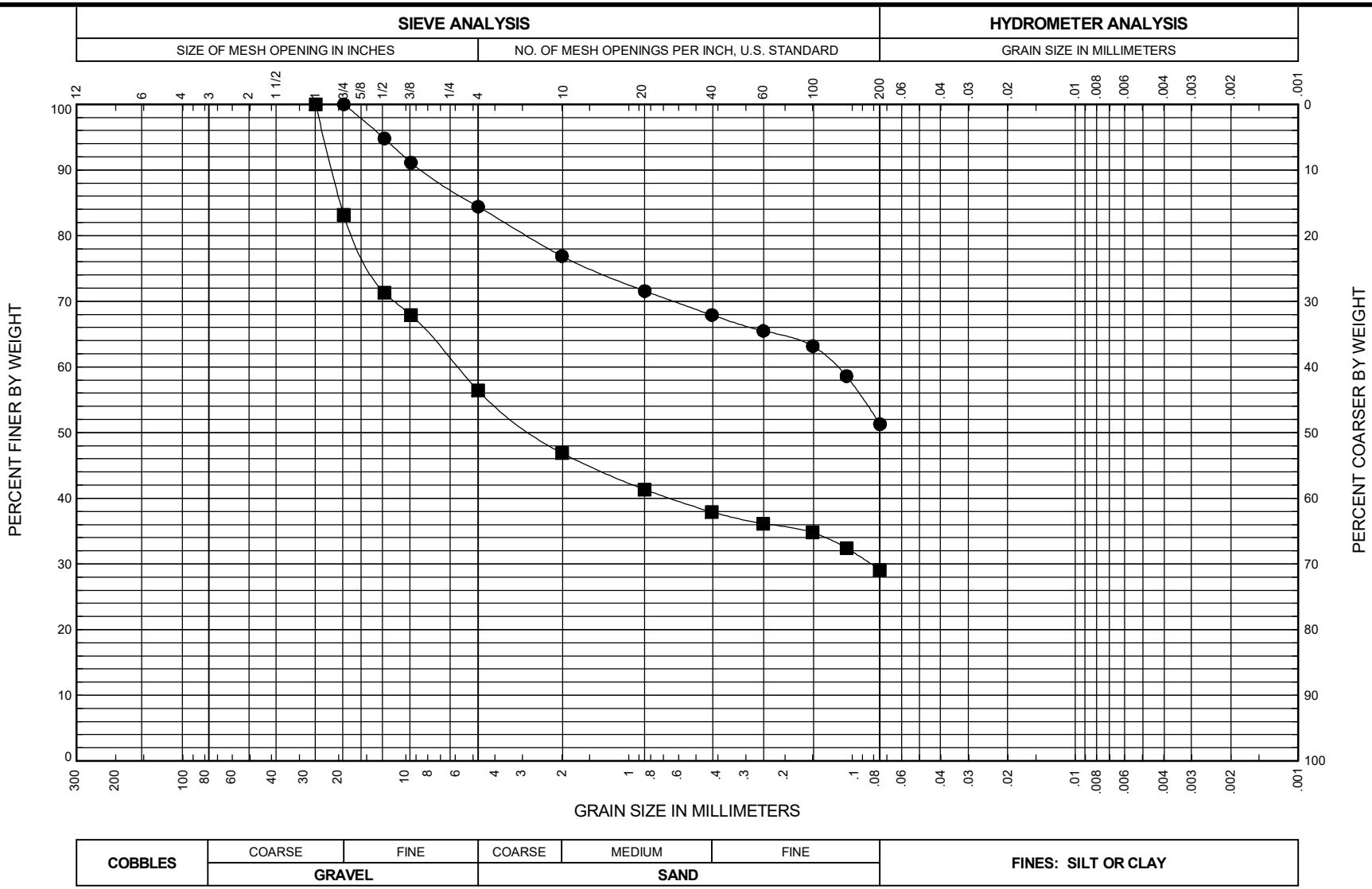
SAMPLE DATA							GRAIN-SIZE ANALYSES			ATTERBERG LIMITS				CORROSION			
Boring	Sample	Depth (feet) Top	Depth (feet) Bottom	USCS Symbol[1]	Water Content (%)	Unit Weight (pcf)	Gravel (%)	Sand (%)	Fines (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Unconfined Compressive Strength (psi)	pH	Resistivity (ohm-cm)	Sulfate Content (%)	Chloride Content (%)
BH-01-22	R-1	11.5	12.0			148.6							6,650				
BH-03-22	R-3	13.8	14.5			147.5							4,999				
	R-4	15.3	15.7			148.3							6,512				
BH-04-22	R-1	9.6	10.7			146.3							3,666				
	R-3	18.0	18.5			148.3							7,886				
BH-05-22	S-1	2.5	4.0		3.2												
	S-2	5.0	6.5	CL	9.0		16	33	51	36	18	18					
BH-06-22	S-1	2.0	3.5	GC	12.6		44	27	29	29	19	10					
	S-2	4.0	5.5		9.1									7.5	4,000	0.01	0.008

NOTES:

1 Refer to Appendix A, Figure A-1 for definitions.

2 Gravel defined as particles larger than the No. 4 sieve size, Sand as particles between the No. 4 and No. 200 sieve sizes, and Fines as particles passing the No. 200 sieve.

ohm-cm = ohm centimeters; psi = pounds per square inch; pcf = pounds per cubic foot; ppm = parts per million



SAMPLE ID	DEPTH (feet)	U.S.C.S. SYMBOL	SAMPLE DESCRIPTION	FINES %	NAT. W.C. %	LL %	PL %	PI %
● BH-05-22, S-2	5.0	CL	Sandy Lean Clay with Gravel	51.3	9.0	36	18	18
■ BH-06-22, S-1	2.0	GC	Clayey Gravel with Sand	29.1	12.6	29	19	10

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GRAIN SIZE DISTRIBUTION

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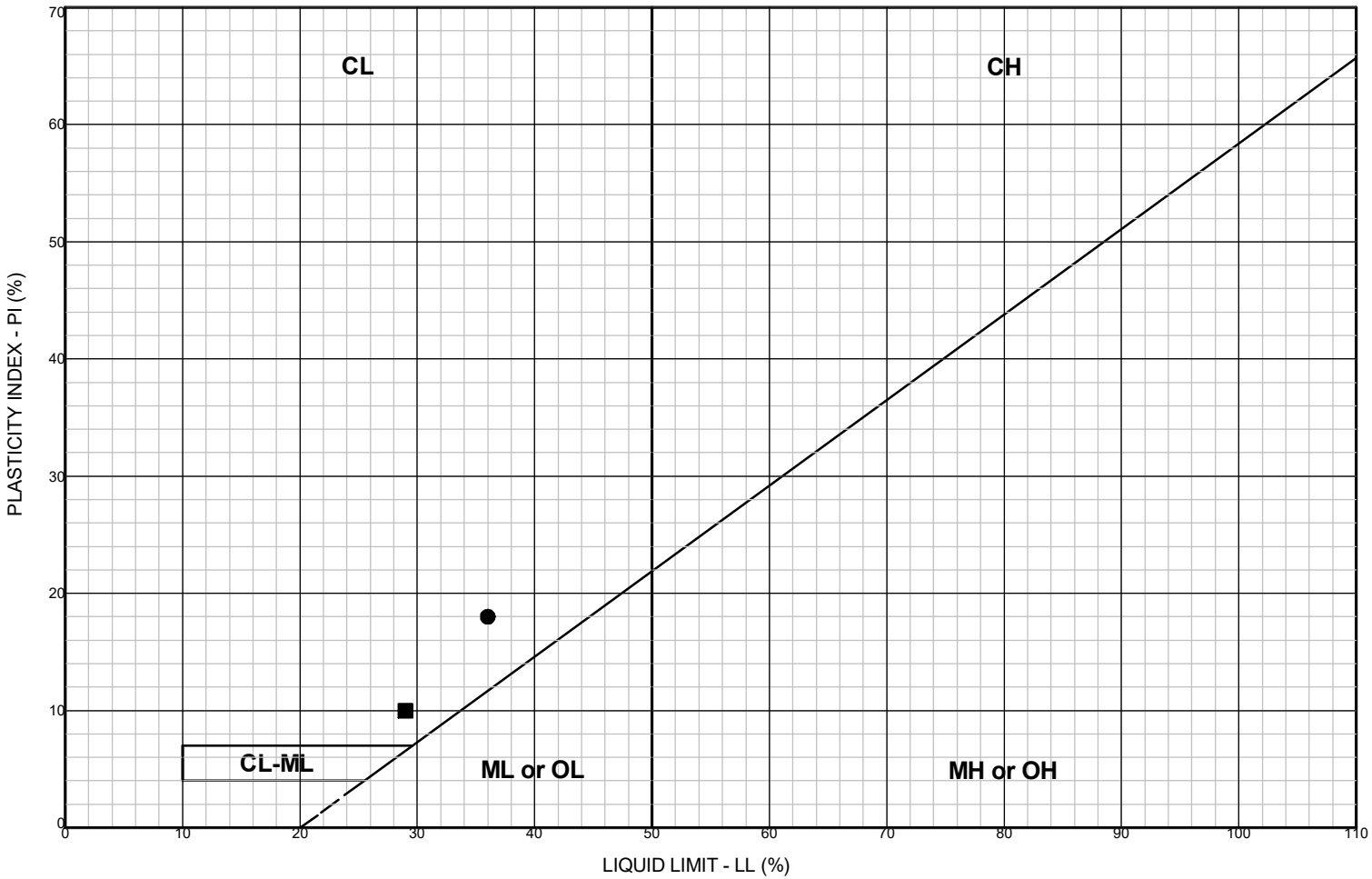
FIG. B-1

FIG. B-1

GSA MAIN 107528-001 WWTP SOUTH RIM.GPJ 3/4/22

National Park Service



LEGEND

CL: Low plasticity inorganic clays; sandy and silty clays

CH: High plasticity inorganic clays

ML or OL: Inorganic and organic silts and clayey silts of low plasticity

MH or OH: Inorganic and organic silts and clayey silts of high plasticity

CL-ML: Silty clays and clayey silts

SAMPLE ID	DEPTH (feet)	U.S.C.S. SYMBOL	SOIL CLASSIFICATION	LL %	PL %	PI %	NAT. W.C. %	PASS. #200, %
● BH-05-22, S-2	5.0	CL	Sandy Lean Clay with Gravel	36	18	18	9.0	51.3
■ BH-06-22, S-1	2.0	GC	Clayey Gravel with Sand	29	19	10	12.6	29.1

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PLASTICITY CHART

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FIG. B-2

ATT_MAIN 107528-001 WWTP SOUTH RIM.GPJ 3/4/22

FIG. B-2

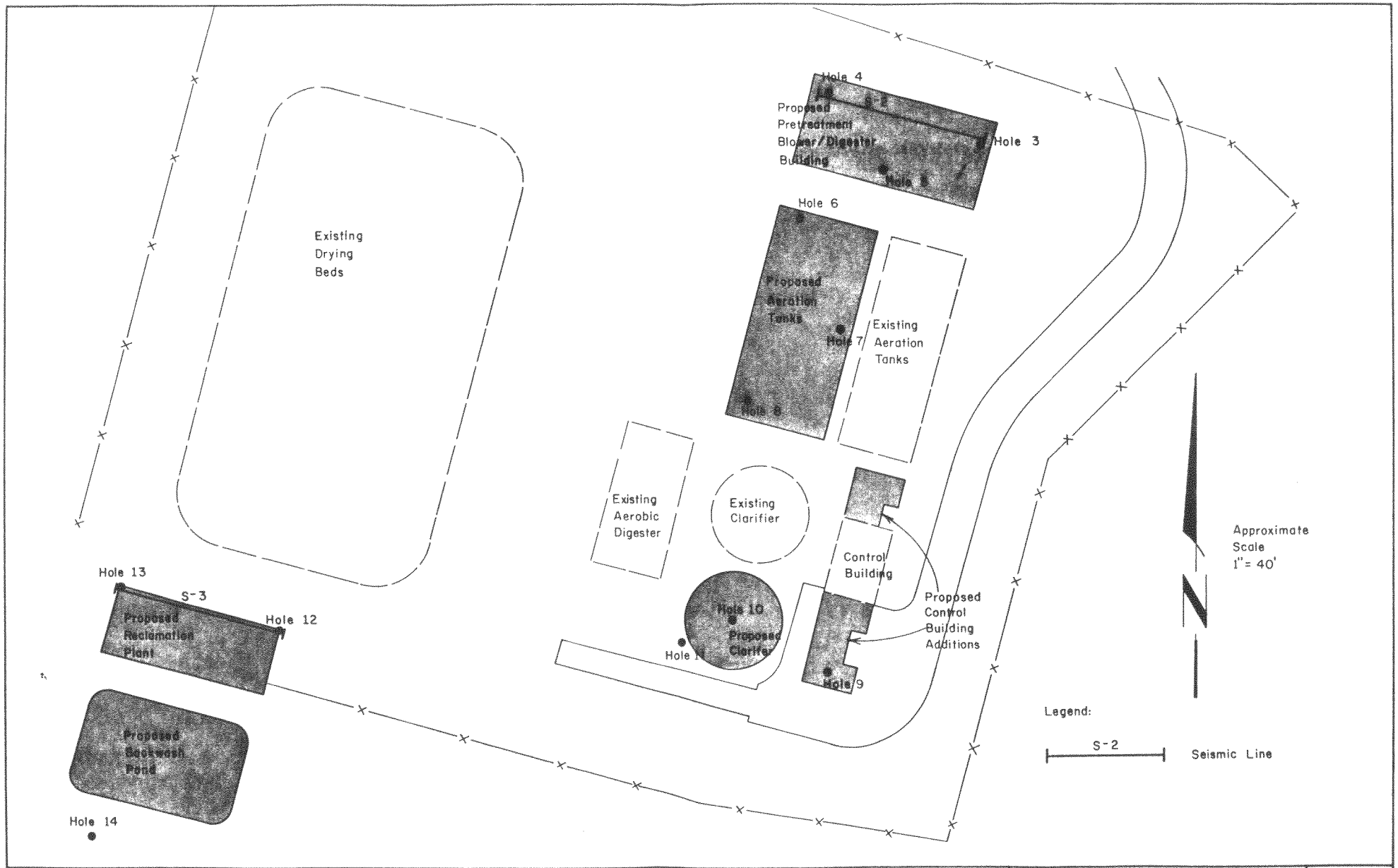
APPENDIX C: PREVIOUS MONITORING WELLS

Appendix C

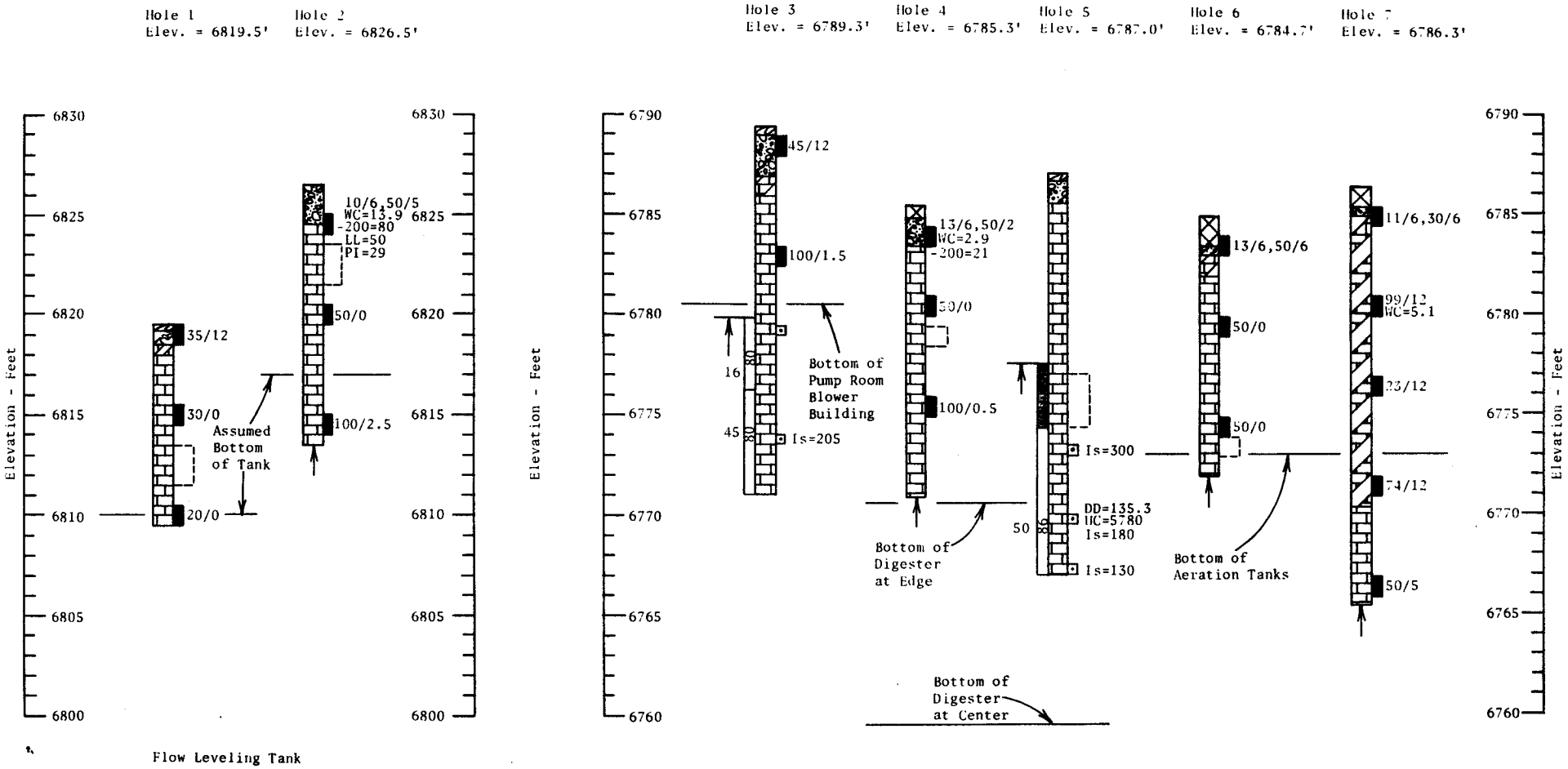
Previous Explorations

FIGURES (Chen & Associates, 1986)

Figure C-1: Location of Test Holes
Figure C-2: Log of Exploratory Borings
Figure C-3: Log of Exploratory Borings, Continued
Figure C-4: Legend and Notes
Figure C-5: Core Log, Hole 3
Figure C-6: Core Log, Hole 5
Figure C-7: Core Log, Hole 10
Figure C-8: Gradation Test Results
Figure C-9: Table 1, Summary of Laboratory Test Results



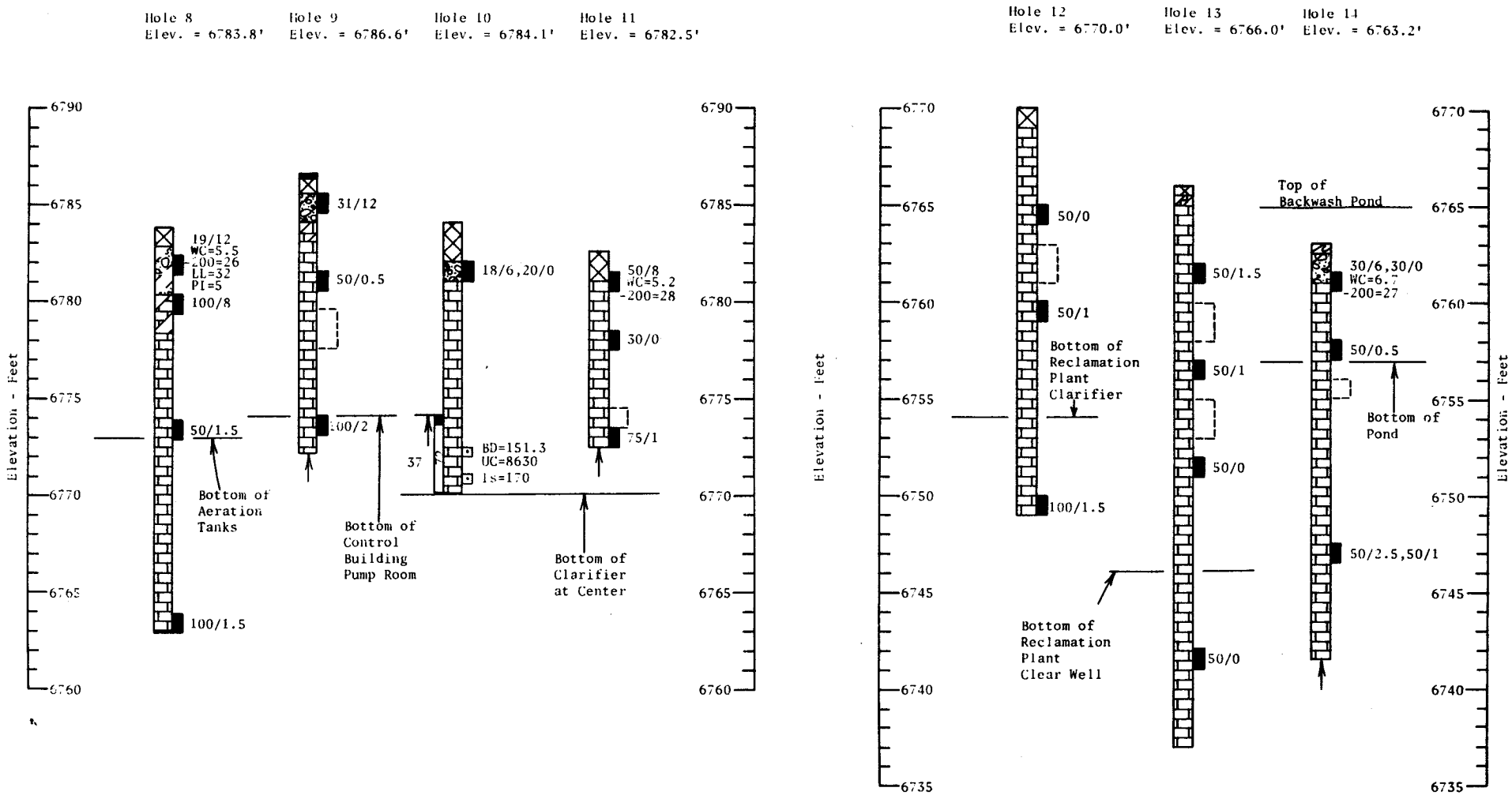
4 406 85	**Chen & Associates**	LOCATION OF EXPLORATORY BORINGS, WASTEWATER TREATMENT PLANT	Fig. 2A



Note: Explanation of symbols presented on Fig. 5.

4 406 85	**Chen & Associates**	Logs of Exploratory Borings	Fig. 3

FIG. C-2



Note: Explanation of symbols presented on Fig. 5.

4 406 85	**Chen & Associates**	Logs of Exploratory Borings	Fig. 4

FIG. C-3

Legend:

Asphalt Pavement.

Topsoil; sandy gravel with organics, roots, slightly moist, dark brown.

Fill; gravel with cobbles, sandy, silty to clayey, occasional limestone boulders (up to 3 feet), occasional topsoil, wood debris, loose to medium dense, slightly moist, dark brown.

Gravel (GC-CL); clayey to gravelly clay, occasional clay pockets, occasional cobbles, probable boulders, medium dense to very dense (clay very stiff), slightly moist, medium brown to light brown. (residual soil)

Gravel (GM-GC); and cobbles, sandy, silty with occasional clay zones, boulders, dense, slightly moist to moist, reddish-brown to light brown. (residual soil)

Weathered Limestone; moderately to highly weathered, sandy, thin bedding, fractured, medium hard to hard, slightly moist to moist, light brown.

Limestone; occasionally weathered zones, sandy, thin to thick bedding, some thin laminated bedding, weakly to highly cemented, hard to very hard, slightly moist, light brown to white-brown, chert and quartz. inclusions.

Drive sample; standard penetration test (SPT), 1 3/8-inch split spoon sample.

25/12 Drive sample blow count; indicates that 25 blows of a 140-pound hammer falling 30 inches were required to drive the SPT sampler 12 inches.

Disturbed bulk sample

Practical rig refusal

Boring advanced by rotary rock bit.

50 Boring advanced with NX core bit, RQD = 50%, core recovery = 86%.

Core sample tested

Notes:

1) Exploratory borings were drilled on November 8, 9 and 10, 1985 with 4-inch and 6-inch diameter continuous flight power augers. Holes 3, 5 and 10 were deepened with 3 1/8" rotary bit and NX diamond bit using air for circulation.

2) Locations of exploratory borings were measured approximately by taping from features shown on site plan provided.

3) Elevations of exploratory borings were provided by MWE based on the drilled locations.

4) The exploratory boring locations and elevations should be considered accurate only to the degree implied by the method used.

5) The lines between materials shown on the exploratory boring logs represent the approximate boundaries between material types and transitions may be gradual.

6) No free water was observed in the borings at the time of drilling.

7) Laboratory Testing Results:

WC = Water Content (%)
BD = Bulk Density Limestone (pcf)
-200 = Percent passing No. 200 sieve
LL = Liquid Limit (%)
PI = Plasticity Index (%)
UC = Unconfined Compressive Strength (psi)
I_s = Point Load Index (psi)

4 406 85	Chen & Associates	Legend and Notes	Fig. 5

FIG. C-4

CORE LOG

Job No. 4 406 85 **Sheet** 1 **of** 1

Project Grand Canyon Waste Water Treatment Plant **Location** See Figure 2A

Hole 3 **Ground Elevation** 6789.3' **Total Depth** 18.4' **Depth of Overburden** 2.5'

Angle from Horizontal 90° **Bearing of Angle Hole** ---- **Depth of Water Table** not encountered **Begun** 11-9-85 **Finished** 11-9-85

GEOLOGIC LOG	GRAPHIC LOG	DISCONTINUITY LOG	% RQD/ % Recovery

Depth and Elevation (Feet) 0 50 100

Test Results

Topsoil

Gravel (GC-GM); sandy with cobbles and boulders, clayey to silty, dense, slightly moist, mixed brown and red-brown.

Weathered Limestone; highly jointed and fractured, light brown.

Limestone; light brown to white brown, moderately effervescent, very hard to hard, thin to thick bedding, occasional quartz lined vugs, moderately to closely jointed.

45/12

100/1.5

I_s = 460

I_s = 205

Hole advanced from 0 to 9.4' through topsoil, weathered Limestone and Limestone bedrock with 7-inch diameter hollow-stem auger.

Coring began at 9.4' with NX diamond bit

10 90° 80° 70° 40° 30° 50° 60° 70° 50°

15 90° 25°

90° Friable zone, poor recovery

80° Total Hole Depth = 18.4'

16/80

45/80

0 5 10 15 20 25 30 35 40 45 50

0 50 100

Notes:

1) Drive sample; standard penetration test (SPT), ASTM D-1586, 1 3/8-inch I.D. split spoon sample.
2) 45/12 Drive sample blow count; indicates that 45 blows of a 140-pound hammer falling 30 inches were required to drive the SPT sampler 12 inches.
3) Angles of joints are measured from core axis in degrees.
4) RQD (Rock Quality Designation) is percentage of core 4 inches or larger in each core run. Core breakage only along bedding or joints is utilized in calculation of RQD.

Core sample tested

I_s = Point Load Index (psi)

Chen and Associates
Core Log
Hole 3
Job No. 4 406 85
Fig. 6

FIG. C-5

CORE LOG

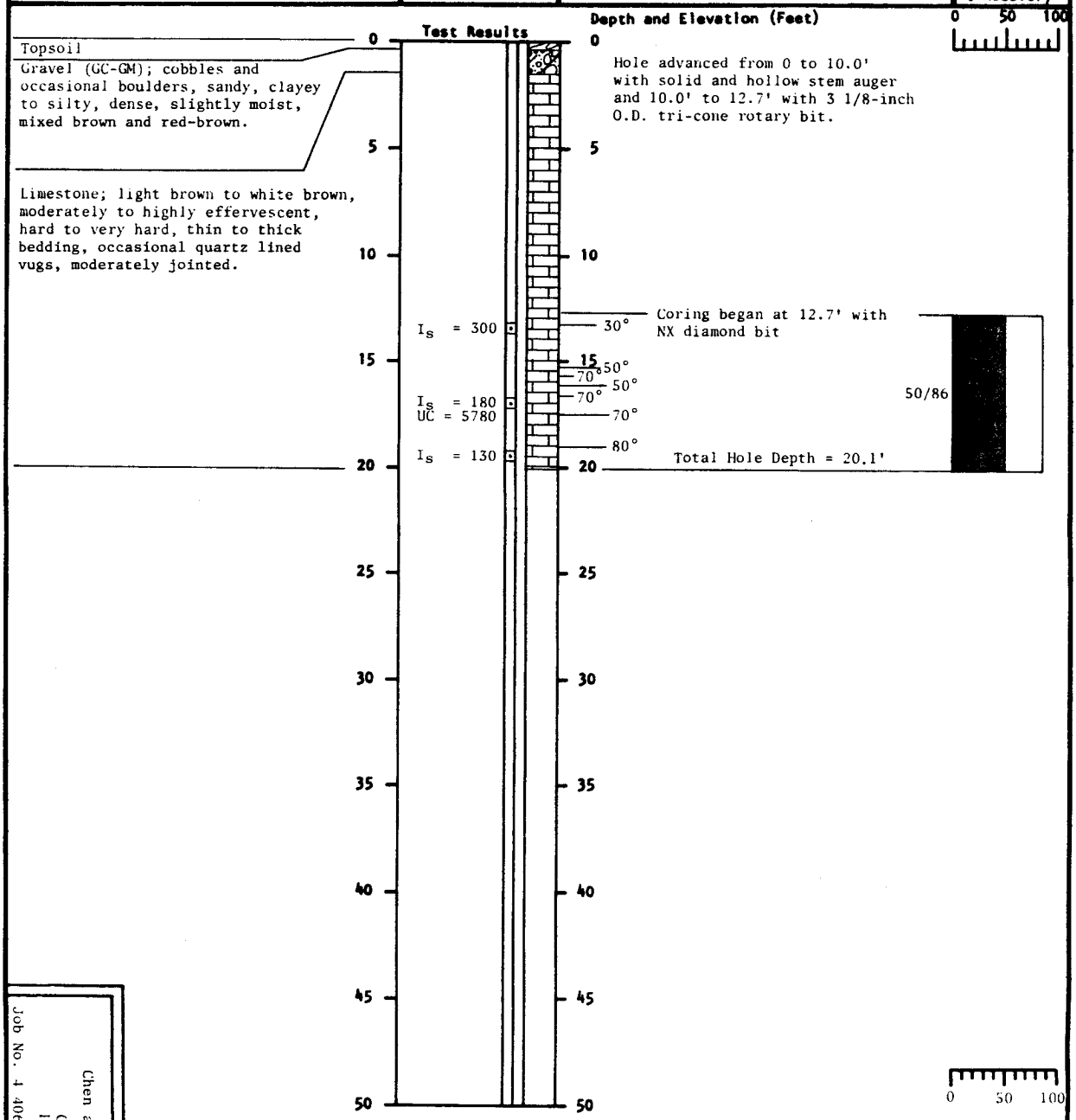
Job No. 4 406 85 **Sheet** 1 **of** 1

Project Grand Canyon Waste Water Treatment Plant **Location** See Figure 2A

Hole 5 **Ground Elevation** 6787.0' **Total Depth** 20.1' **Depth of Overburden** 1.5'

Angle from Horizontal 90° **Bearing of Angle Hole** --- **Depth of Water Table** not encountered **Begun** 11-9-85 **Finished** 11-10-85

GEOLOGIC LOG	GRAPHIC LOG	DISCONTINUITY LOG	% RQD/ % Recovery



Notes:

1) Angles of joints are measured from core axis in degrees.

2) RQD (Rock Quality Designation) is percentage of core 4 inches or larger in each core run. Core breakage only along bedding or joints is utilized in calculation of RQD.

Core sample tested

I_s = Point Load Index (psi)

UC = Unconfined Compressive Strength (psi)

Chen and Associates
Core Log
Hole 5
Job No. 4 406 85
Fig. 7

FIG C-6

CORE LOG

Job No. 4 406 85 **Sheet** 1 **of** 1

Project Grand Canyon Waste Water Treatment Plant **Location** See Figure 2A

Hole 10 **Ground Elevation** 6784.1 **Total Depth** 13.8' **Depth of Overburden** 3.0'

Angle from Horizontal 90° **Bearing of Angle Hole** --- **Depth of Water Table** not encountered **Begun** 11-8-85 **Finished** 11-9-85

GEOLOGIC LOG	GRAPHIC LOG	DISCONTINUITY LOG	% RQD/ % Recovery

Depth and Elevation (Feet)

Test Results

Fill; gravel, cobbles and boulders, silty, sandy, firm, slightly moist, dark brown, trace topsoil, on-site material.

Gravel (GC-GM); cobbles, clayey to very clayey, silty, sandy, dense, slightly moist, medium brown.

Limestone; light brown to white brown, moderately effervescent, hard to very hard, thin bedding, occasional thin quartz zones and quartz lined vugs, moderately to highly jointed

UC = 8630

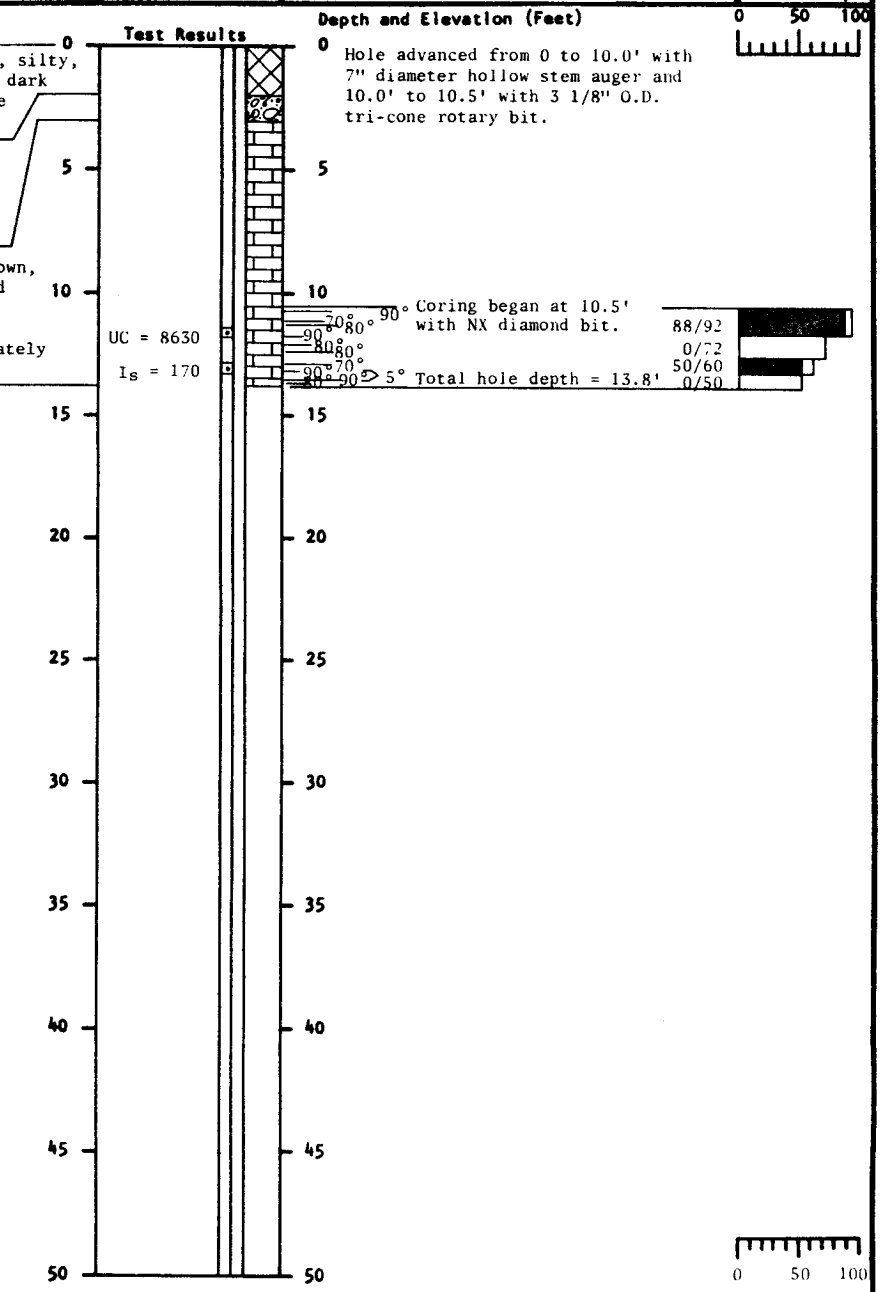
I_s = 170

Hole advanced from 0 to 10.0' with 7" diameter hollow stem auger and 10.0' to 10.5' with 3 1/8" O.D. tri-cone rotary bit.

Coring began at 10.5' with NX diamond bit.

Total hole depth = 13.8'

% RQD/ % Recovery: 88/92, 0/72, 50/60, 0/50



Notes:

1) Angles of joints are measured from core axis in degrees.

2) RQD (Rock Quality Designation) is percentage of core 4 inches or larger in each core run. Core breakage only along bedding or joints is utilized in calculation of RQD.

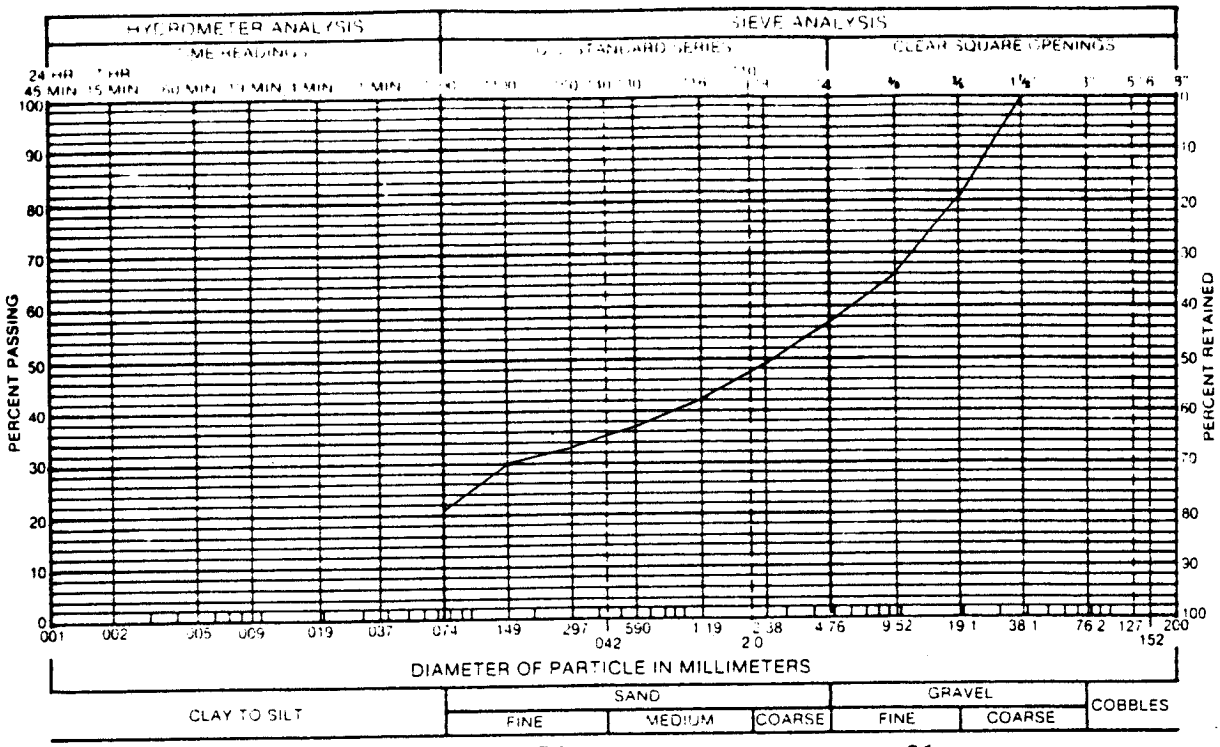
Core sample tested

I_s = Point Load Index (psi)
UC = Unconfined Compressive Strength (psi)

Chen and Associates
Core log
hole 10
Job No. 4 406 85
Fig. 8

FIG. C-7

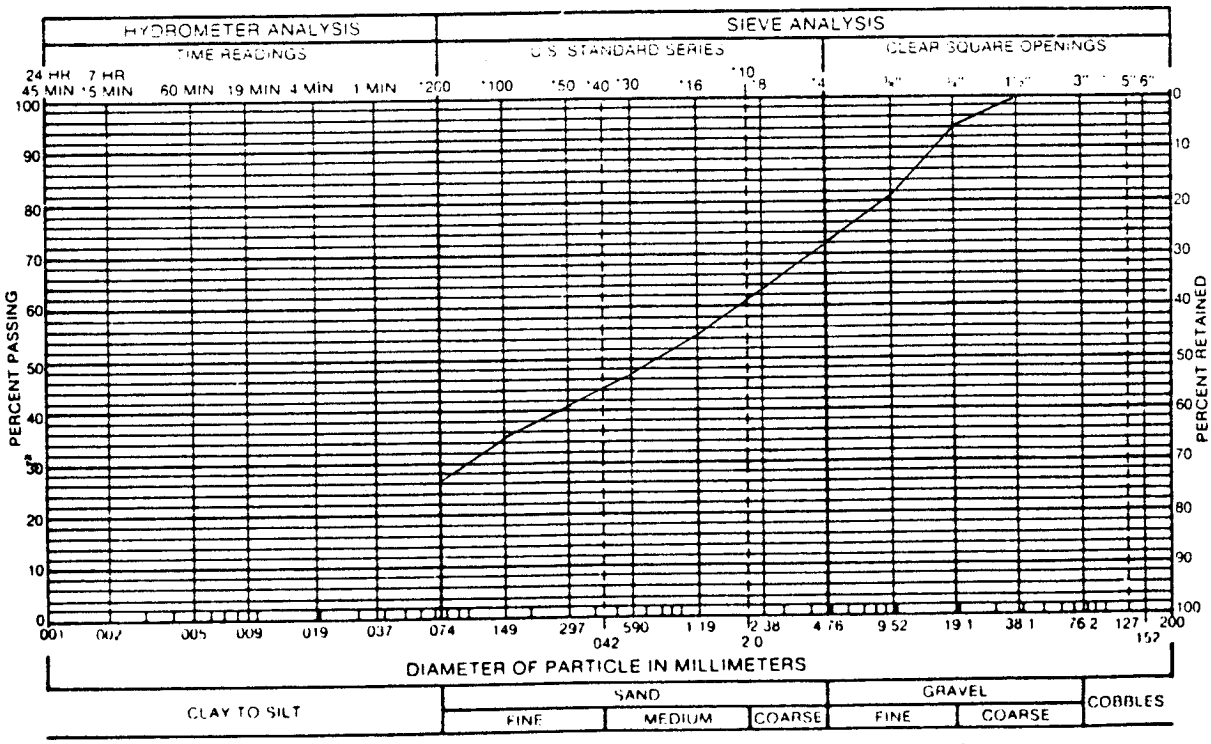
chen and associates, inc.



GRAVEL 43 % SAND 36 % SILT AND CLAY 21 %

LIQUID LIMIT % PLASTICITY INDEX %

SAMPLE OF silty sandy gravel FROM Hole 4 at 1 foot



GRAVEL 28 % SAND 46 % SILT AND CLAY 26 %

LIQUID LIMIT 32 % PLASTICITY INDEX 5 %

SAMPLE OF silty, clayey sandy gravel FROM Hole 8 at 1.5 feet

4 406 85 GRADATION TEST RESULTS Fig. 10

FIG C-8

CHEN AND ASSOCIATES

4 406 85

TABLE I

SUMMARY OF LABORATORY TEST RESULTS

SAMPLE LOCATION		NATURAL MOISTURE CONTENT (%)	BULK DENSITY (PCF)	GRADATION		PERCENT PASSING NO. 200 SIEVE	ATTERBERG LIMITS		UNCONFINED COMPRESSIVE STRENGTH (psi)	POINT LOAD INDEX (psi)	SOIL OR BEDROCK TYPE
	DEPTH (FEET)			GRAVEL (%)	SAND (%)		LIQUID LIMIT (%)	PLASTICITY INDEX (%)			
2	1.5	13.9				80	50	29			sandy, silty clay
3	10									460	limestone
	15.5									205	limestone
4	1	2.9		43	36	21					silty, sandy gravel
5	13.5									300	limestone
	17		135.3						5780	180	limestone
	19.5									130	limestone
7	5	5.1									sandy, silty gravel
8	1.5	5.5		28	46	26	32	5			silty, clayey, sandy gravel
10	11.5		151.3						8630		limestone
	13									170	limestone
11	1	5.2		36	36	28					silty sand & gravel
14	1.5	6.7				27					silty sand & gravel

FIG. C-9

IMPORTANT INFORMATION

Important Information

About Your Geotechnical Report

IMPORTANT INFORMATION

CONSULTING SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES AND FOR SPECIFIC CLIENTS.

Consultants prepare reports to meet the specific needs of specific individuals. A report prepared for a civil engineer may not be adequate for a construction contractor or even another civil engineer. Unless indicated otherwise, your consultant prepared your report expressly for you and expressly for the purposes you indicated. No one other than you should apply this report for its intended purpose without first conferring with the consultant. No party should apply this report for any purpose other than that originally contemplated without first conferring with the consultant.

THE CONSULTANT'S REPORT IS BASED ON ONE-SPECIFIC FACTORS.

A geotechnical/environmental report is based on a subsurface exploration plan designed to consider a unique set of project-specific factors. Depending on the project, these may include the general nature of the structure and property involved; its size and configuration; its historical use and practice; the location of the structure on the site and its orientation; other improvements such as access roads, parking lots, and underground utilities; and the additional risk created by scope-of-service limitations imposed by the client. To help avoid costly problems, ask the consultant to evaluate how any factors that change subsequent to the date of the report may affect the recommendations. Unless your consultant indicates otherwise, your report should not be used (1) when the nature of the proposed project is changed (for example, if an office building will be erected instead of a parking garage, or if a refrigerated warehouse will be built instead of an unrefrigerated one, or chemicals are discovered on or near the site); (2) when the size, elevation, or configuration of the proposed project is altered; (3) when the location or orientation of the proposed project is modified; (4) when there is a change of ownership; or (5) for application to an adjacent site. Consultants cannot accept responsibility for problems that may occur if they are not consulted after factors that were considered in the development of the report have changed.

SUBSURFACE CONDITIONS CAN CHANGE.

Subsurface conditions may be affected as a result of natural processes or human activity. Because a geotechnical/environmental report is based on conditions that existed at the time of subsurface exploration, construction decisions should not be based on a report whose adequacy may have been affected by time. Ask the consultant to advise if additional tests are desirable before construction starts; for example, groundwater conditions commonly vary seasonally.

Construction operations at or adjacent to the site and natural events such as floods, earthquakes, or groundwater fluctuations may also affect subsurface conditions and, thus, the continuing adequacy of a geotechnical/environmental report. The consultant should be kept apprised of any such events and should be consulted to determine if additional tests are necessary.

MOST RECOMMENDATIONS ARE PROFESSIONAL JUDGMENTS.

Site exploration and testing identifies actual surface and subsurface conditions only at those points where samples are taken. The data were extrapolated by your consultant, who then applied judgment to render an opinion about overall subsurface conditions. The actual interface between materials may be far more gradual or abrupt than your report indicates. Actual conditions in areas not sampled may differ from those predicted in your report. While nothing can be done to prevent

IMPORTANT INFORMATION

such situations, you and your consultant can work together to help reduce their impacts. Retaining your consultant to observe subsurface construction operations can be particularly beneficial in this respect.

A REPORT'S CONCLUSIONS ARE PRELIMINARY.

The conclusions contained in your consultant's report are preliminary, because they must be based on the assumption that conditions revealed through selective exploratory sampling are indicative of actual conditions throughout a site. Actual subsurface conditions can be discerned only during earthwork; therefore, you should retain your consultant to observe actual conditions and to provide conclusions. Only the consultant who prepared the report is fully familiar with the background information needed to determine whether or not the report's recommendations based on those conclusions are valid and whether or not the contractor is abiding by applicable recommendations. The consultant who developed your report cannot assume responsibility or liability for the adequacy of the report's recommendations if another party is retained to observe construction.

THE CONSULTANT'S REPORT IS SUBJECT TO MISINTERPRETATION.

Costly problems can occur when other design professionals develop their plans based on misinterpretation of a geotechnical/environmental report. To help avoid these problems, the consultant should be retained to work with other project design professionals to explain relevant geotechnical, geological, hydrogeological, and environmental findings, and to review the adequacy of their plans and specifications relative to these issues.

BORING LOGS AND/OR MONITORING WELL DATA SHOULD NOT BE SEPARATED FROM THE REPORT.

Final boring logs developed by the consultant are based upon interpretation of field logs (assembled by site personnel), field test results, and laboratory and/or office evaluation of field samples and data. Only final boring logs and data are customarily included in geotechnical/environmental reports. These final logs should not, under any circumstances, be redrawn for inclusion in architectural or other design drawings, because drafters may commit errors or omissions in the transfer process.

To reduce the likelihood of boring log or monitoring well misinterpretation, contractors should be given ready access to the complete geotechnical engineering/environmental report prepared or authorized for their use. If access is provided only to the report prepared for you, you should advise contractors of the report's limitations, assuming that a contractor was not one of the specific persons for whom the report was prepared, and that developing construction cost estimates was not one of the specific purposes for which it was prepared. While a contractor may gain important knowledge from a report prepared for another party, the contractor should discuss the report with your consultant and perform the additional or alternative work believed necessary to obtain the data specifically appropriate for construction cost estimating purposes. Some clients hold the mistaken impression that simply disclaiming responsibility for the accuracy of subsurface information always insulates them from attendant liability. Providing the best available information to contractors helps prevent costly construction problems and the adversarial attitudes that aggravate them to a disproportionate scale.

IMPORTANT INFORMATION

READ RESPONSIBILITY CLAUSES CLOSELY.

Because geotechnical/environmental engineering is based extensively on judgment and opinion, it is far less exact than other design disciplines. This situation has resulted in wholly unwarranted claims being lodged against consultants. To help prevent this problem, consultants have developed a number of clauses for use in their contracts, reports, and other documents. These responsibility clauses are not exculpatory clauses designed to transfer the consultant's liabilities to other parties; rather, they are definitive clauses that identify where the consultant's responsibilities begin and end. Their use helps all parties involved recognize their individual responsibilities and take appropriate action. Some of these definitive clauses are likely to appear in your report, and you are encouraged to read them closely. Your consultant will be pleased to give full and frank answers to your questions.

The preceding paragraphs are based on information provided by the ASFE/Association of Engineering Firms Practicing in the Geosciences, Silver Spring, Maryland

Attachment 2
Geotechnical Report – Shannon & Wilson 2025

SUBMITTED TO:
Jacobs
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San Jose, CA 95112

BY:
Shannon & Wilson
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GEOTECHNICAL REPORT

Grand Canyon National Park South Rim WWTP Access Road

SOUTH RIM VILLAGE, ARIZONA

SHANNON & WILSON

January 10. 2025

Shannon & Wilson No: 112557-001

Submitted To: Jacobs
1737 North First Street, Ste 350
San Jose, CA 95112
Attn: Ms. Kathy Rosinski, PE

Subject: GEOTECHNICAL REPORT, GRAND CANYON NATIONAL PARK SOUTH RIM WWTP ACCESS ROAD, SOUTH RIM VILLAGE, ARIZONA

This geotechnical report presents the results of our geotechnical exploration performed during the Design Development/Construction Document phase of work for a new access road to the South Rim Wastewater Treatment Plant located in the Grand Canyon National Park. Our work was completed in accordance with our signed Professional Services Task Order Number 148052738 with Jacobs Government Services Company (Jacobs) dated May 20, 2024.

We appreciate the opportunity to be of service to you on this project. If you have any questions or require further information, please contact me at 303-825-3800.

Sincerely,

SHANNON & WILSON

Registered Professional Engineer (Civil)
CERTIFICATE NO. 77306
DAVID VARATHUNGARAJAN
DATE SIGNED Jan. 10, 2025
ARIZONA U.S.A.

Margaret A. (Peggy) Ganse
Vice President

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BTM:MAG:DAV/ajg

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1 INTRODUCTION

This report presents the results of our geotechnical explorations and provides our geotechnical engineering recommendations for a proposed access road at the South Rim Wastewater Treatment Plant located in the Grand Canyon National Park (GRCA 257282). Our work was completed in accordance with our signed Professional Services Task Order Number 148052738 with Jacobs Government Services Company (Jacobs) dated May 20, 2024. Under this agreement we:

- Performed a subsurface investigation, including completing utility locates and observation and logging of nine borings;
- Completed geotechnical laboratory tests on selected soil and bedrock samples;
- Evaluated potential geologic hazards;
- Evaluated site subsurface conditions with respect to the proposed improvements;
- Provided recommendations for geotechnical aspects of the project; and
- Prepared this geotechnical report.

The scope of our services did not include any environmental assessment or evaluation regarding the presence or absence of wetlands or toxic materials in the soil, surface water, or air, on or below the site. If a service is not specifically indicated in this report, do not assume it was performed.

2 SITE AND PROJECT DESCRIPTION

The Project is located in Grand Canyon National Park in Coconino County, Arizona (Figure 1). The Project site is approximately 2.5 miles west-southwest of the Grand Canyon National Park South Rim Visitors Center, at the existing Wastewater Treatment Plant (WWTP). The existing WWTP facility sits on approximately 4.5 acres and is generally surrounded by undeveloped land (see Exhibit 2-1). Two sensitive resource areas have been identified in the Project area, as shown in Figure 2.

Exhibit 2-1: Looking West Across Site Showing Boring BH04-24 in the Foreground and Power Line Road in the Background

The Project includes a proposed access road, a connector road, and drainage culverts; geotechnical recommendations are being provided for the access road and connector road. The width of each proposed roadway will be 16 feet plus an additional 4 feet for the shoulders. Roadway surfacing will consist of either aggregate surfacing or flexible pavement.

We understand the National Park Service (NPS) suggested surfacing the roadway using roller compacted concrete. We typically recommend roller compacted concrete for intermodal railroad yards or pavements expected to perform under heavy industrial loading. Based on discussions with Jacobs, we understand the Project will not experience heavy loading; therefore, we did not consider roller compacted concrete for the Project.

Based on design plans provided by Jacobs (Jacobs, 2024), the access road will begin east of the WWTP and extend approximately 4,823 feet southeast to the Arizona Public Service (APS) Substation (Station 10+67.80 to Station 58+90.84). The access road will generally parallel the existing unimproved Power Line Road. The access road grade will range from

approximately Elev. 6,800 feet to Elev. 6,913 feet; the roadway will slope up towards the southeast.

The proposed connector road will begin south of the WWTP and extend approximately 989 feet east towards the access road (Station 100+47 to Station 109+78.89). The connector road will connect future drying beds south of the existing WWTP to the gravel access road. The connector road grade will range from approximately Elev. 6,785 feet to Elev. 6,840 feet; the roadway will slope up towards the east.

Based on a review of the plans (Jacobs, 2024), we understand the proposed access road and connector road will be constructed at grade or on shallow fill (generally < 1 foot) placed on native ground. Between approximate Station 34+00 and Station 42+00 along the proposed access road, taller fills are planned (up to 5 feet) in some locations. Taller fills (up to 5 feet) are also planned between approximate Station 100+00 and Station 101+50 along the proposed connector road.

Six 24-inch inside diameter (I.D) culverts are included in the Project. Five of the culverts are associated with the proposed access road (at approximate Stations 20+00, 26+00, 29+50, 36+50, and 49+65), and one culvert is associated with the proposed connector road (approximate Station 100+75). At this stage of the design, the proposed culverts will be comprised of metal and may have a round or elliptical cross section. The length of the culverts will be on the order of 40 to 50 feet.

3 FIELD EXPLORATIONS AND LABORATORY TESTING

3.1 Field Investigation

Shannon & Wilson conducted a field exploration program on September 18 and September 19, 2024, to explore subsurface conditions at the Project site. The subsurface exploration program consisted of drilling and sampling nine borings, designated BH01-24 to BH09-24. Refer to Figure 2 for the approximate boring locations. No borings were drilled in the sensitive resource areas at the request of NPS. Additionally, no borings were drilled along the connector road alignment, as it was not included in initial design concepts. Exhibit 3-1 provides a summary of the borings completed for the Project.

Exhibit 3-1: Boring Summary

Boring Name	Elevation (ft)	Boring Depth (ft)	Rock Coring Depth (ft)
BH01-24	6802	15.0	10.0-15.0
BH02-24	6785	5.1	N/A
BH03-24	6834	10.0	2.5-10.0
BH04-24	6856	10.2	N/A
BH05-24	6870	10.0	2.5-10.0
BH06-24	6872	15.2	10.2-15.2
BH07-24	6886	15.1	5.1-10.1
BH08-24	6898	10.8	10.1-15.1
BH09-24	6902	12.6	5.8-10.8

NOTES:
N/A = not applicable

Appendix A presents a discussion of the drilling and sampling procedures used to complete the borings. Appendix A also presents the individual exploration logs, an explanation of the symbols and terminology used to classify soil and rock samples recovered from the borings, and rock core photographs.

3.2 Geotechnical Laboratory Testing

Geotechnical laboratory tests were completed on selected samples retrieved from the borings. Index tests included natural water content, grain size analysis, and Atterberg limits. Engineering properties tests included corrosion and unconfined compressive strength (UCS). Laboratory test results and a discussion of the testing procedures are included in Appendix B. The natural water content, fines content, and UCS values are also shown on the individual boring logs included in Appendix A.

4 GEOLOGIC SETTING AND SUBSURFACE CONDITIONS

We based our understanding of the geology and subsurface conditions at the site on regional geologic maps, our field reconnaissance, and the results of our field exploration program.

A regional geologic map of the Bright Angel quadrangle (Maxson, 1961) indicates that the near surface geology in the Project area is dominated by the limestone member of the Kaibab Formation (Permian) and consists of massive, fine-grained limestone containing

beds of sandstone, siltstone, and nodules of white chert. The Kaibab Formation forms the uppermost cliffs along the north and south rims of the Grand Canyon.

4.1 Subsurface Conditions

Except for BH02-24 which encountered bedrock at the surface, the borings encountered between 0.5 and 1.5 feet of overburden overlying limestone bedrock. The overburden soils consisted of silty clay with sand (CL-ML) (American Association of State Highway and Transportation Officials [AASHTO] soil classification A-4).

The limestone bedrock was observed to be completely weathered to fresh and extremely weak to strong but was typically moderately to slightly weathered and medium strong. The upper portion of the limestone was generally comparatively weaker and more weathered. Core recovery ranged from 56% to 100%, but was typically 80% or greater.

The Rock Quality Index (RQD) of the rock core was measured to gain an understanding of rock mass quality based upon the degree of fracturing. RQD characterizes the rock core by adding up the pieces of core which are greater than 4 inches in length, to gain an appreciation of the degree of fracturing in the rock mass. RQD values were variable, ranging from 0 to 79 (very poor to good rock quality). The weighted average RQD value of 43 is representative of poor rock quality.

Exhibit 4-1: Rock Quality Index

Range of RQD	Rock Quality[1]
90-100	Excellent
75-90	Good
50-75	Fair
25-50	Poor
0-25	Very Poor

NOTES:

1 Rock Quality as defined by Deere, 1963

4.2 Groundwater

Groundwater was not encountered in any of our borings. Note that water was added during rock coring operations, but does not reflect native conditions.

These dry conditions are only representative of conditions at the time of drilling. Fluctuations of groundwater levels at the site are possible and will depend on many factors, such as seasonal variations, local precipitation, and runoff.

4.3 Subsurface Variations

The explorations were performed to evaluate subsurface conditions beneath the Project site. Our observations are specific to the locations, depths, and times noted on the logs and may not be applicable to all areas of the site. No amount of explorations or testing can precisely predict the characteristics, quality, or distribution of subsurface and site conditions. Potential variation includes, but is not limited to:

- The conditions between explorations may be different, especially due to the presence of boulders and cobbles, differences in densities or gradations.
- The passage of time or intervening causes (natural and manmade) may result in changes to site and subsurface conditions.

If conditions different from those described herein are encountered during construction, we should review our description of the subsurface conditions and reconsider our conclusions and recommendations.

5 GEOLOGIC HAZARD EVALUATION

5.1 Seismic Hazards

Based on a database by the U.S. Geological Survey (USGS), the nearest confirmed fault, to the Project, is the Bright Angel fault zone (undifferentiated Quaternary fault), approximately 0.2 miles to the northwest (USGS, 2021). The Bright Angel Fault is a normal fault that runs roughly parallel to Rowe Well Road and has movements of less than 0.2 mm per year (Pearthree, 1997). Although the Bright Angel Fault is close to the Project site, the location is well defined (Pearthree, 1997), and therefore, it is our opinion that the potential for ground surface fault rupture at the Project site is low.

5.2 Corrosive Soil and Bedrock

The soil/rock encountered at the project site can be corrosive to substructure elements. To assist in estimating the corrosion potential at the site, selected samples were tested for pH, resistivity, water soluble sulfates, and chlorides. The results are summarized below in Exhibit 5-1.

Exhibit 5-1: Corrosion Testing Results

Boring	Depth (feet)	Material	pH	Resistivity (ohm-cm)	Sulfate Content (%)	Chloride Content (%)
BH01-24	2.4-4.0	Limestone	8.0	41,000	<0.01	0.088
BH04-24	0.0-1.0	Silty Clay with Sand	7.0	7,700	<0.01	0.091
BH06-24	2.5-3.0	Limestone	7.9	26,000	<0.01	0.050
BH08-24	5.0-5.8	Limestone	7.4	17,000	0.01	0.081

NOTES:

1 Water-soluble sulfate and chloride content values are shown as percent weight in dry soil.

ohm-cm = ohm-centimeter

The resistivity measured in the samples ranged from 7,700 to 41,000 ohm-centimeters. Based on correlations developed by Roberge (2012) as shown in Exhibit 5-2, these values suggest moderately corrosive to essentially noncorrosive subsurface conditions for metals in contact with subsurface materials across the site.

Exhibit 5-2: Corrosivity Ratings Based on Soil Resistivity

Soil Resistivity (ohm-cm)	Corrosivity Rating
>20,000	Essentially Noncorrosive
10,000-20,000	Mildly Corrosive
5,000-10,000	Moderately Corrosive
3,000-5,000	Corrosive
1,000-3,000	Highly Corrosive
<1,000	Extremely Corrosive

The concentration of water-soluble sulfates measured in the samples was <0.01% to 0.01% by weight. Based on classifications as defined by ACI-318-19 (ACI, 2019) as shown in Exhibit 5-3, these test results classified as Moderate (S1) to Negligible (S0) for concrete exposed to site soils.

Exhibit 5-3: Corrosivity Ratings Based on Water Soluble Sulfate Exposure

Water Soluble Sulfate in Soil (Percent by Weight)	Sulfate Severity (Class)
<0.10	Negligible (S0)
0.10-<0.20	Moderate (S1)
0.20-2.00	Severe (S2)
>2.00	Very Severe (S3)

The test results and the above discussion are provided to assist the designer in the selection of project materials, concrete type, or other features with respect to corrosion. As appropriate, the designer should consider protective measures, such as coatings, upsizing for section loss, or using alternative materials to reduce the corrosion potential.

6 AGGREGATE SURFACING AND FLEXIBLE PAVEMENT RECOMMENDATIONS

6.1 Design Requirements

We understand the access road and connector road will be constructed using either aggregate surfacing or flexible pavement. Our pavement design analysis and recommendations are based on the design procedures presented in the 1993 AASHTO Guide for the Design of Pavement Structures (AGDPS) (AASHTO, 1993), with additional guidance from the Arizona Department of Transportation (ADOT) Pavement Design Manual (PDM) (ADOT, 2017).

6.2 Aggregate Surfacing

6.2.1 Subgrade Design Strength

As discussed in Section 4.1, our borings encountered limestone bedrock at the ground surface or within 18 inches of the ground surface. Overburden soils consisted of up to 18 inches of silty clay with sand (CL-ML) (AASHTO soil classification A-4). Considering the relatively shallow bedrock along the proposed aggregate surfacing road, we assumed "Good" subgrade soil strength as described in Chapter 4 of AGDPS in our analysis.

6.2.2 Traffic Loading

Based on discussions with Jacobs, traffic counts are not available for the Project, but they are considered to be low volume during normal operations. The AGDPS (AASHTO, 1993) recommends an 18-kip equivalent single axle loading (ESAL) of 10,000 to 30,000 for low volume roadways and 30,000 to 60,000 ESALs for medium volume roadway. To be consistent with the flexible pavement design, we also evaluated an aggregate surfacing roadway section with an ESAL of 50,000 (refer to Section 6.3.2).

In addition to normal operating traffic, the access road will be subjected to construction traffic over a period of at least 12 months. According to Jacobs, construction traffic may include up to 1,500 truckloads of excavation/fill material. The assumed minimum ESALs used for design are greater than the ESALs calculated based on the provided construction

loading. For this reason, the design is anticipated to be adequate for this construction traffic.

6.2.3 Recommended Aggregate Surfacing Section

Our recommendations for minimum aggregate surfacing thicknesses are presented below in Exhibit 6-1, based on design ESAL. Based on the anticipated traffic volume, we recommend 5 inches of aggregate surfacing. However, 9 inches would be required if it is desired to utilize the same design ESAL for both pavement types. The recommended surfacing thickness assumes the aggregate surface will be regraded a minimum of every five years. Additional surfacing maintenance may be required when the roadway is subjected to the proposed construction loading.

Exhibit 6-1: Recommended Aggregate Surfacing Thickness

Design ESALs	Aggregate Road Surfacing Thickness (inches)
< 30,000 (Low Volume)	5
Up to 50,000 (Medium Volume)	9

6.2.4 Aggregate Road Surfacing Maintenance

In our opinion, the most efficient way to avoid excessive maintenance is to have a properly graded road with a crowned driving surface, a shoulder area that slopes directly away from the edge of the driving surface, and a ditch. Corrugation occurs in areas where water collects in the roadway wheel path and saturates the subgrade. Directing surface water away from the road reduces the potential for corrugation. We understand this may not be feasible in all areas due to the roadway geometry. In those cases, frequent maintenance of infilling of ruts and regrading may be required, or a more permanent surface treatment should be considered.

Potholes (occurring in the aggregate surfacing) form from the loss of the fine particulate within the aggregate material. The fine particles within the gradation of the aggregate surfacing act as a binder that prevents the coarser sand and gravel sized particles from migrating. The loss of the fine material increases the roadway surface raveling and eventually leads to rutting. One common maintenance method (other than importing new aggregate surfacing material and regrading) is applying a dust suppressant product (or dust palliative). Dust suppressants work by either adhering or binding the surficial aggregate, chemically changing the fines properties within the aggregate, or increasing the density of the road surface material to prevent fines migration.

6.2.5 Geotextile Separator

The overburden soils that will serve as the roadway subgrade are expected to consist of silty clay with sand (CL-ML or AASHTO soil classification A-4). A geotextile separation fabric can be used to improve the long-term performance of a pavement section where clayey soils are present in the subgrade by preventing the fines from migrating into the overlying aggregate. However, we do not recommend use of a geotextile separator under the aggregate road surfacing material since it would likely be damaged during routine maintenance (scarification and regrading).

6.3 Flexible Pavement

6.3.1 Subgrade Design Strength

Sections 4.1 and 6.2.1 discuss subgrade composition and classification. Based on soil plasticity index and fines content (portion of soil particles passing the U.S. Standard No. 200 sieve) laboratory results and Table 2-3 of the ADOT PDM (2017), we estimated an R-value of 32 for overburden soils. Considering the anticipated presence of shallow bedrock throughout the Project, we used a design R-value of 35. Using the resilient modulus equation in the ADOT PDM (2017), we calculated a subgrade resilient modulus of 12,000 psi and used this value for our analysis.

6.3.2 Traffic Loading

As discussed in Section 6.2.2, the Project is considered to be low volume during normal operations and during construction. The AGDPS (AASHTO, 1993) recommends a minimum ESAL of 50,000 for flexible pavement design of low volume roadways.

6.3.3 Recommended Flexible Pavement Section

Exhibit 6-2 summarizes our recommended pavement sections.

Exhibit 6-2: Recommended Pavement Section

Paving Alternative	Recommended Pavement Section
1	4 in. HMA
2	3 in. HMA over 4 in. ABC

NOTE:

1 A geotextile separator is recommended below the ABC to improve long-term performance.

ABC = Aggregate Base Course; HMA = Hot Mix Asphalt; in. = inches

6.3.4 Geotextile Separator

As previously described, a geotextile separation fabric can be used to improve the long-term performance of a pavement section where clayey soils are present in the subgrade (such as those along the project alignment) by preventing the fines from migrating into the overlying aggregate. While installing a geotextile separator does not directly improve the structural capacity of the pavement section, doing so should reduce the fines migration as described above, as well as lower the risk of long-term drainage issues and poor pavement performance.

For these reasons, we recommend a Class 1 geotextile fabric separator under flexible pavement in the sensitive resource areas to improve the performance of the pavement section. Placing the geotextile fabric separator could reduce the need for additional maintenance and repairs. A geotextile separator could also be utilized under the flexible pavement along the entire alignment to reduce the frequency of additional maintenance and repairs. The design team should evaluate the potential benefits of reduced maintenance against the additional capital costs that would be incurred during construction.

7 CONSTRUCTION CONSIDERATIONS

The applicability of the design recommendations provided in this report is contingent on good construction practice. Poor construction techniques may alter conditions from those on which our recommendations are based, resulting in decreased pavement performance. The following sections present construction considerations for this project.

7.1 Excavatability

We anticipate that the overburden materials can be excavated with conventional construction equipment. Shallow limestone bedrock was encountered in our explorations and can be expected to be encountered throughout the roadway alignment. We generally anticipate that the limestone at the surface can be excavated using conventional excavating equipment, such as a rubber-tired backhoe or a tracked hydraulic excavator with ripper attachments; however, production may be slower in comparatively stronger layers present beneath the ground surface, which may require excavation with a hydraulic rock breaker or ripping with a dozer.

7.2 Subgrade Preparation and Fill Placement

7.2.1 Site Preparation

Deleterious material should be removed and any existing surficial topsoil and soil containing visible organics should be stripped and removed from all areas to be surfaced or paved. Topsoil and organic-rich soils are not considered suitable for reuse as fill and should be removed from the site or stockpiled for use as topsoil material.

7.2.2 Fill Materials

Fill should consist of soils that are free of organics, contaminants, debris, rock fragments larger than 3 inches, should contain less than 30 percent fines, and should have a minimum R-value of 35. It should be noted that as the percentage of fines increases, soil becomes more sensitive to small changes in moisture content, and adequate compaction becomes more difficult to achieve. Fill should be placed in uniform, horizontal layers not exceeding 8 inches in loose thickness for heavy, self-propelled compactors, or 4 inches for hand-operated mechanical compactors. The appropriate lift thickness will depend on the Contractor's equipment as well as the moisture content and quality of the fill material.

7.2.3 Subgrade Treatment and Compaction

Areas of exposed roadway subgrade should be scarified to a depth of 8 inches, moisture treated, and recompacted (this treatment is not required where rock is exposed in subgrade). Through discussions with Jacobs, we understand scarification of the subgrade in the two sensitive resource areas is acceptable. Subgrade soil and fill should be moisture treated within 2% of the optimum moisture content and compacted to a dense and unyielding condition and at least 95% of maximum dry density determined in accordance with AASHTO T180 (modified compaction effort). Additionally, we recommend that the subgrade be compacted to a firm and unyielding condition.

7.2.4 Proof Rolling

The compacted surface should be proof rolled with a fully loaded, tandem-axle, 10-yard dump truck or equivalent. We recommend that the proof-rolling be observed by a representative of Shannon & Wilson. If areas are identified as being loose, soft, or yielding during proof-rolling, these areas of the subgrade should be improved by further compaction or overexcavation to bedrock.

7.3 Cut and Fill Slopes

We understand that permanent cut/fill slopes will generally be 4H:1V (horizontal to vertical) or flatter. Based on conditions encountered in our explorations, we anticipate that such cut and fill slopes will have adequate global stability. We recommend that slopes be seeded and/or planted with relatively fast-growing vegetation to reduce the potential for surface sloughing and erosion. Natural or geosynthetic erosion control blankets may be necessary to assist in erosion protection during vegetation growth.

7.4 Temporary Slopes and Shoring

Where possible, contractors typically use temporary excavation slopes for installation of shallow structures. If it is possible to slope the excavation, we recommend the temporary slopes be consistent with the Occupational Safety & Health Administration (OSHA) guidelines contained in 29 CFR 1926, Subpart P (1999). For cost estimating and planning purposes only, we anticipate that most of the temporary excavations will require slopes of 1.5H:1V in the overburden, consistent with OSHA Type B soils, and 1H:1V in the bedrock, consistent with OSHA Type A soils. The Contractor should continually classify the soils that are encountered as excavation progresses with respect to the OSHA system.

In areas where site conditions preclude the use of temporary slopes, temporary shoring should be used. Temporary shoring should be designed by the Contractor and include surcharge loading, as appropriate. The Contractor should be made responsible for design of temporary excavation support systems.

Regardless of the method selected, the sloped/shored system should provide adequate protection for workers and against damage to adjacent facilities. Consistent with conventional practice, the final selection of shoring type or slope angle, temporary shoring design, methods, sequence, and schedule of construction should be the responsibility of the Contractor. Further, it should be the Contractor's responsibility to monitor the stability of shored/sloped excavations and take corrective action if any potentially unstable conditions are encountered. If instability is observed, slopes should be flattened or shored. All excavations should be accomplished in accordance with local, state, and federal safety regulations.

7.5 Aggregate Surfacing Materials

The ADOT PDM (2017) states that, "ADOT's standard aggregate base is generally not suitable due to lack of cohesive strength" for use as aggregate surfacing on gravel roadways. The ADOT PDM does not provide additional guidance on aggregate surfacing material properties. We recommend the aggregate surfacing material meet the surface coarse

aggregate requirements listed in Section 703.05 in FP-24 (U.S. Department of Transportation and Federal Highway Administration, 2024), as shown below in Exhibit 7-1.

Exhibit 7-1: Recommended Aggregate Surfacing Material

Sieve Size	Gradation F	Gradation G	Gradation H
2-1/2 inch	-	-	-
2 inch	-	-	-
1-1/2 inch	-	-	-
1 inch	-	100	-
¾ inch	100	-	100
½ inch	-	70 to 80	-
3/8 inch	62 to 90	-	-
No. 4	36 to 74	40 to 50	41 to 71
No. 10	-	25 to 40	-
No. 40	12 to 26	15 to 25	12 to 28
No. 200	4 to 7	8 to 14	9 to 16

NOTES:

1 Values shown are percent passing the sieve

2 From FP-24 (U.S. Department of Transportation and Federal Highway Administration, 2024.

"-" = no requirement

7.6 Flexible Pavement Materials

7.6.1 Hot Mix Asphalt (HMA)

The HMA mix design should be in accordance with ADOT Standard Specifications for Road and Bridge Construction (2021) and Superpave standards. Our HMA material recommendations are based on the 2017 ADOT PDM and our experience on similar projects. HMA lift thicknesses should generally be within 3 to 4½ times the nominal maximum aggregate size. Binder selection is based on the anticipated pavement temperatures and traffic loading. We recommend a PG 64-22 binder and paving the roadway in two lifts. We recommend a lift of ADOT ½-inch mix over a lift of ¾-inch mix or two lifts of ADOT ½-inch mix. A tack coat should be placed between subsequent lifts.

7.6.2 Aggregate Base Course (ABC)

The ABC should conform to Class 1 Aggregate of Section 303 of the ADOT Standard Specifications for Road and Bridge Construction (2021). ABC material should be placed in maximum 6-inch-thick lifts, moisture conditioned to within 2 percent of the optimum moisture content and compacted to at least 95 percent of the maximum dry density as determined by AASHTO T180 (modified compaction effort).

7.7 Geotextile Separator

If used, the geotextile separator should conform to Section 208 in the ADOT Standard Specifications for Road and Bridge Construction (2021).

7.8 Construction Observation

We developed our geotechnical design recommendations based on a limited number of borings and laboratory testing. Our recommendations may need to be adjusted in the field based on the conditions encountered during construction. We recommend that we be retained during the construction portion of this project to perform a construction observation and monitoring program related to the geotechnical aspects of this project. Monitoring would allow us to confirm that conditions encountered are consistent with those indicated by the explorations and provide expedient recommendations should conditions be revealed during construction that are different from those anticipated.

8 CLOSURE

This report was prepared for the exclusive use of the National Park Service and Jacobs for use in design of the project. Once the remaining borings have been completed, this interim report will be updated. It should be made available to prospective contractors for information on factual data only, and not as a warranty of subsurface conditions.

Our evaluations, analyses, conclusions, and recommendations are based on:

- The limitations of our approved scope, schedule, and budget described in our Professional Services Task Order.
- Our understanding of the project and information provided by Jacobs.

This report should not be used without our approval if any of the following occurs:

- Conditions change due to natural forces or human activity under, at, or adjacent to the site.
- Assumptions stated in this report have changed.
- Project details change or new information becomes available such that our analyses, conclusions, and recommendations may be affected.
- If the site ownership or land use has changed.
- More than 5 years has passed since the date of this report.

If any of these occur, we should be retained to review the applicability of our analyses, conclusions, and recommendations.

Unanticipated soil conditions are commonly encountered and cannot be fully determined by a limited boring and testing program. Such unexpected conditions frequently require that additional expenditures be made to attain a properly constructed project. Therefore, some contingency fund is recommended to accommodate such potential extra costs.

Within the limitations of scope, schedule, and budget, the analyses, conclusions, and recommendations presented in this report were prepared in accordance with generally accepted professional geotechnical and geological principles and practice in this area at the time this report was prepared. We make no other warranty, either express or implied.

Shannon & Wilson has prepared the attached document, "Important Information about Your Geotechnical and Environmental Report," to assist you and others in understanding the use and limitations of our reports.

9 REFERENCES

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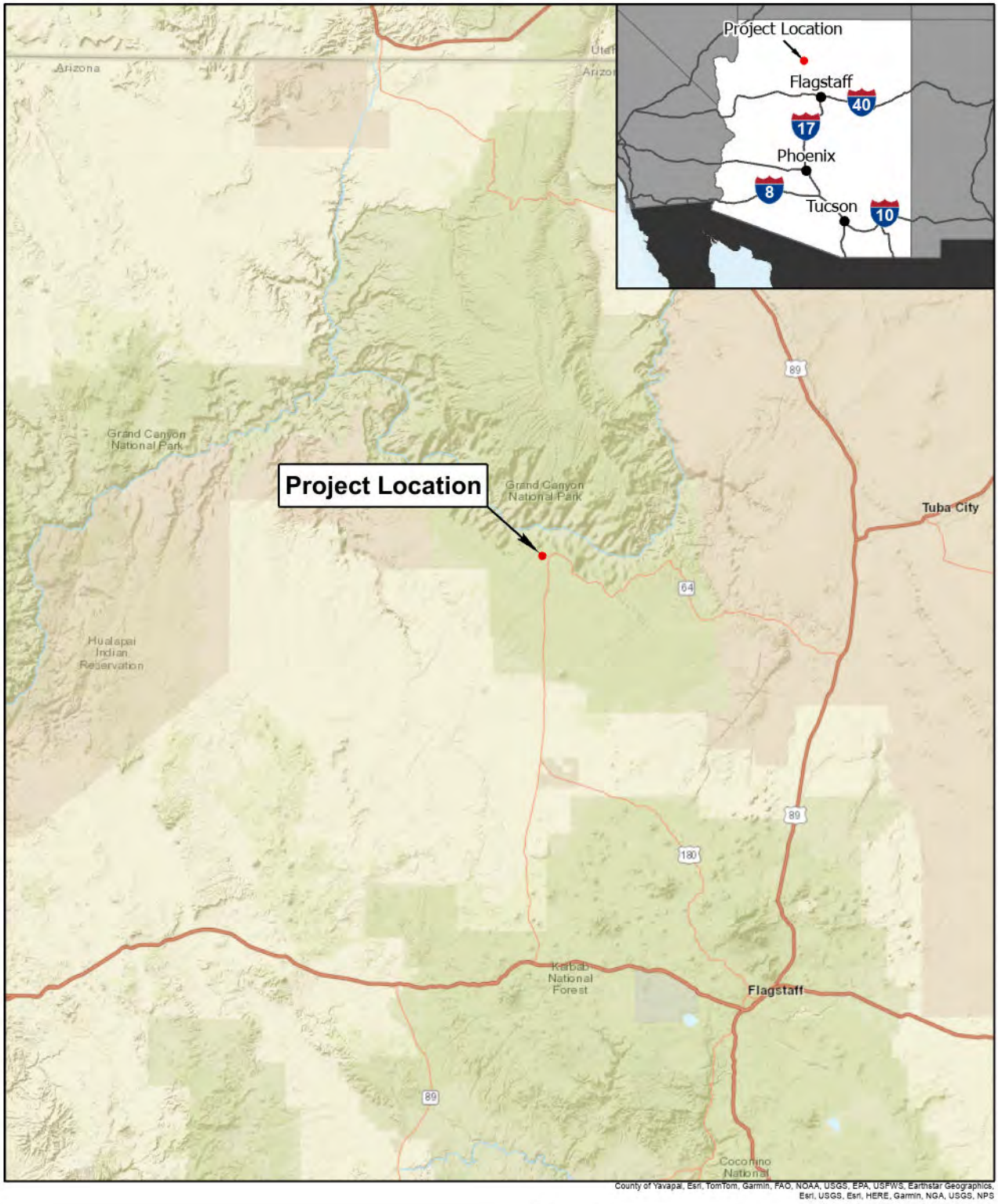


N

0 20 40

Scale in Miles

Grand Canyon National Park
South Rim WWTP Access Road
South Rim Village, Arizona

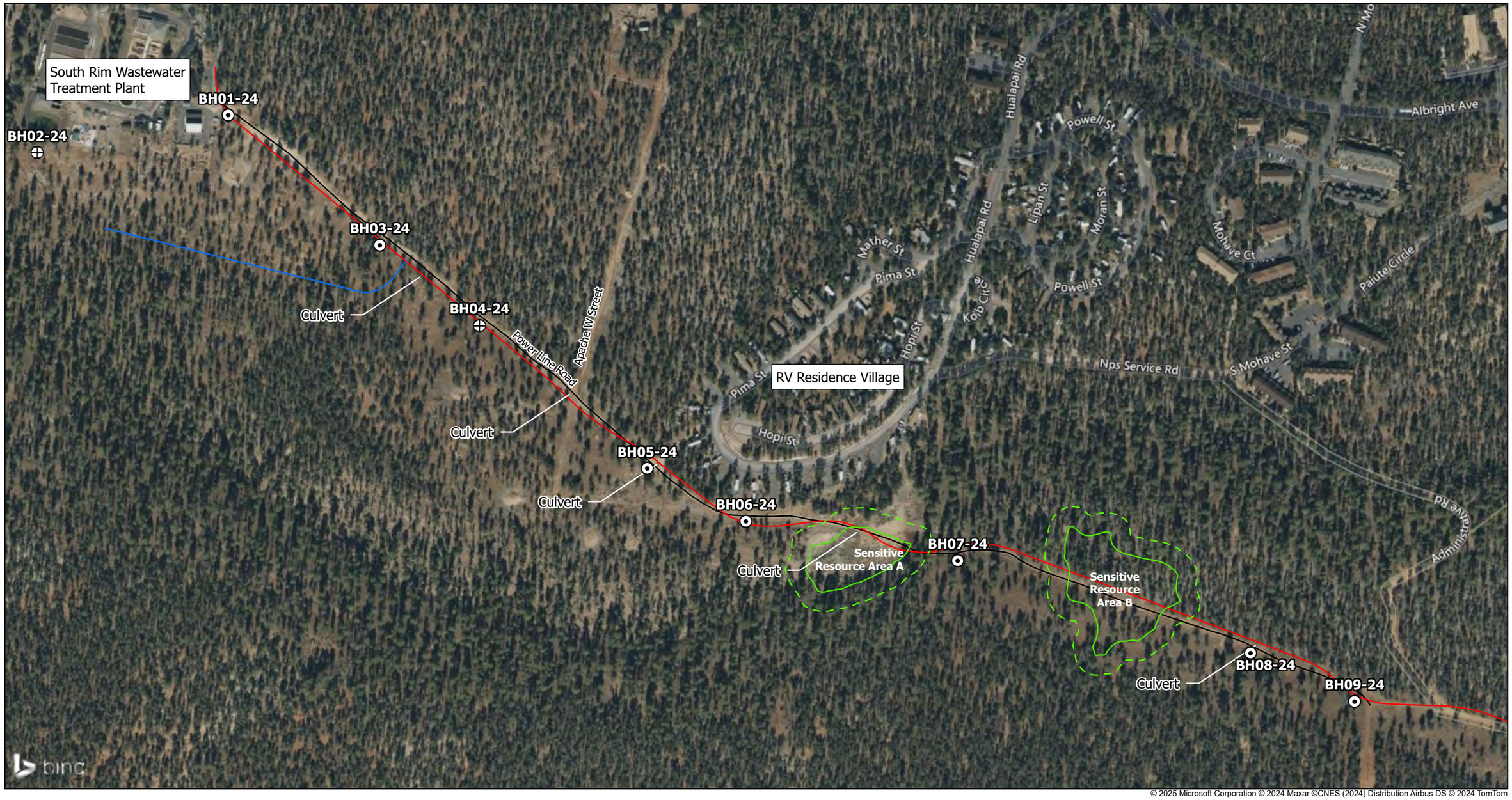
VICINITY MAP

January 2025

112557-001

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. 1



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LEGEND

- Auger Boring Designation and Approximate Location
- Rock Core Boring Designation and Approximate Location
- Sensitive Resource Area
- 30-Foot Buffer
- Proposed Access Road
- Proposed Connector Road
- Existing Power Line Road

NOTES

1. Locations of borings were collected using a recreational grade GPS and should be considered approximate. No survey was performed.
2. Map features are projected using NAD 1983 2011 StatePlane Arizona Central FIPS 0202 Ft Intl.
3. Alignment and site features are adapted from file titled 'GRCA247282_2024.10.08_DD_RoadwayDrawings' provided by Jacobs on October 16, 2024.
4. Connector road alignment is preliminary and subject to refinement as the design progresses.

0 300 600

Approximate Scale In Feet

N

Grand Canyon National Park
South Rim WWTP Access Road
South Rim Village, Arizona

SITE AND EXPLORATION PLAN

January 2025 112557-001

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FIG. 2

APPENDIX A: SUBSURFACE EXPLORATIONS

Appendix A

Subsurface Explorations

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A.1 Introduction A-1
A.2 Explorations A-1
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A.2.2 Rock Classification System A-1
A.2.3 Standard Penetration Test (SPT) A-2
A.2.4 Rock Core Sampling A-2

Attachments

Log Key
Log of Borings BH01-24 through BH09-24

Figures

Figure A-1 to A-7: Rock Core Photographs: BH01-24, BH03-24, BH05-24, BH06-24, BH07-24, BH08-24, and BH09-24

APPENDIX A: SUBSURFACE EXPLORATIONS

A.1 INTRODUCTION

Shannon & Wilson's field exploration program was conducted from September 18-19, 2024, and consisted of drilling nine borings (designated BH01-24 through BH09-24) at the locations shown in Figure 2. The methods used to conduct the field exploration program are described below.

A.2 EXPLORATIONS

The borings were coordinated (including subcontractor coordination and utility locates) and observed by a representative from Shannon & Wilson. The boring logs are attached. These exploration logs represent our interpretation of the contents of the field logs and select results of laboratory testing.

The borings were drilled by Vine Laboratories of Commerce City, Colorado (under subcontract to Shannon & Wilson) using a buggy-mounted CME 750X drill rig. The borings were advanced to depths ranging from 5.1 to 15.3 feet below existing ground surface. The borings were advanced utilizing 4-inch-outside-diameter (O.D.) solid-stem auger and NQ rock coring methods. Groundwater was not encountered during drilling in any of the borings. On completion of drilling, the borings were backfilled with drill cuttings and bentonite chips.

A.2.1 Soil Classification System

During drilling, our representative collected samples and prepared field logs of the explorations. Soil classification for this project was based on ASTM D2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), and ASTM D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure). The Unified Soil Classification System is summarized in the attached Log Key.

A.2.2 Rock Classification System

The Shannon & Wilson representative classified rock samples in general accordance with the International Society of Rock Mechanics (ISRM) classification method. According to this system, rock is classified based on the stratigraphic structure, rock strength, degree of weathering, and other properties. The rock classification system is summarized in the attached Log Key.

A.2.3 Standard Penetration Test (SPT)

Disturbed samples were obtained in the borings in general accordance with the Standard Penetration Test (SPT) (ASTM Designation: D1586). The SPT consists of driving a 2-inch-outside-diameter (O.D.), 1.375-inch I.D. split-spoon sampler 18 inches. An automatic, free-falling 140-pound hammer was used to advance the split spoon sampler. During sampling, the Shannon & Wilson field representative recorded the number of blows for each 6-inch increment of penetration and summed the blow counts for the last two 6-inch increments. This sum is recorded as the penetration resistance number, or N-value. If high penetration resistance prevented driving the total length of the sampler, the Shannon & Wilson field representative recorded the partial penetration depth and blow count. The N-values provide a means for evaluating the relative density or compactness of cohesionless (granular) soils and consistency or stiffness of cohesive (fine-grained) soils (see attached Log Key). The raw N-values are shown on the individual boring logs. Representative portions of the split-spoon sample obtained in conjunction with the SPT were placed in a screw-top plastic jar and transported to our laboratory.

A.2.4 Rock Core Sampling

Rock samples were collected using NQ wireline coring methods (1.875-inch-nominal-diameter rock core). During coring, cuttings were removed from the borehole by circulating water down through the drill rods and back up the annulus of the boring. Core runs were generally 5 feet in length, except for the first core run, which reamed out disturbed material at the bottom of the borehole.

Percent recovery and rock quality designation (RQD) values are shown on the boring log where coring was completed. Percent recovery is the ratio of the length of recovered core to the total length of the core run. RQD is the ratio, expressed as a percent, of the sum of the length of intact core pieces greater than 4 inches long in a run to the total length of the core run. Following drilling, the core was logged by the Shannon & Wilson field representative, then stored in cardboard core boxes and transported to the Shannon & Wilson laboratory. Photographs of cores are presented in Figures A-1 through A-7.

SOIL CLASSIFICATION

Shannon & Wilson uses a soil identification system modified from the Unified Soil Classification System (USCS) as described on this Key. Soil descriptions are based on visual-manual procedures (ASTM D2488) and available laboratory index test results (ASTM D2487).

Exhibit A: Unified Soil Classification System (USCS)[1]

Major Divisions			Symbol	Typical Identifications (USCS Group Names)[2,4]
COARSE-GRAINED SOILS *(> 50% of soil is retained on the No. 4 sieve[3])*	**GRAVELS** *(> 50% of coarse fraction retained on the No. 4 sieve[3])*	**Gravel** *(< 5% fines[3])*	GW	Well-graded Gravel; Well-Graded Gravel with Sand
			GP	Poorly Graded Gravel; Poorly Graded Gravel with Sand
		Silty or Clayey Gravel *(> 12% fines[3])*	GM	Silty Gravel; Silty Gravel with Sand
			GC	Clayey Gravel; Clayey Gravel with Sand
	SANDS *(≥ 50% of coarse fraction passes the No. 4 sieve[3])*	**Sand** *(< 5% fines[3])*	SW	Well-graded Sand; Well-graded Sand with Gravel
			SP	Poorly Graded Sand; Poorly Graded Sand with Gravel
		Silty or Clayey Sand *(> 12% fines[3])*	SM	Silty Sand; Silty Sand with Gravel
			SC	Clayey Sand; Clayey Sand with Gravel
FINE-GRAINED SOILS *(≥ 50% of soil passes the No. 200 sieve[3])*	**SILTS AND CLAYS** *(liquid limit < 50)*	**Inorganic**	ML	Silt; Silt with Sand or Gravel; Sandy or Gravelly Silt
			CL	Lean Clay; Lean Clay with Sand or Gravel; Sandy or Gravelly, Lean Clay
		Organic	OL	Organic Silt or Clay; Organic Silt or Clay with Sand or Gravel; Sandy or Gravelly, Organic Silt or Clay
	SILTS AND CLAYS *(liquid limit ≥ 50)*	**Inorganic**	MH	Elastic Silt; Elastic Silt with Sand or Gravel; Sandy or Gravelly, Elastic Silt
			CH	Fat Clay; Fat Clay with Sand or Gravel; Sandy or Gravelly, Fat Clay
		Organic	OH	Organic Silt or Clay; Organic Silt or Clay with Sand or Gravel; Sandy or Gravelly, Organic Silt or Clay
HIGHLY ORGANIC SOILS	*Primarily organic matter, dark in color, and organic odor*		PT	Peat or other Highly Organic Soils (see ASTM D4427)

NOTE: *For gravels and sands with 5 to 12% fines[3], the following are added to the Group Name:* with Silt and/or Clay or Silty Clay. *Dual Symbols are used:* GW-GM, GP-GM, SW-SM, SP-SM GW-GC, GP-GC, SW-SC, SP-SC

EXHIBIT A NOTES:
1. Adapted, with permission, from USACE Tech Memo 3-357, ASTM D2487, and ASTM D2488.
2. Borderline symbols (symbols separated by a slash) indicate that the soil characteristics are close to the defining boundary between two groups (e.g., CL/ML = Lean Clay to Silt; SP-SM/SM = Sand with Silt to Silty Sand).
3. No. 4 size = 4.75 millimeters (mm) = 0.187 inch; No. 200 sieve size = 0.075 mm = 0.003 inch. Particles smaller 0.075 mm are termed "fines".
4. Poorly graded indicates a narrow range or missing grain sizes. Well-graded indicates a full-range and even distribution of grain sizes.
5. If cobbles and/or boulders are observed, "with cobbles" or "with boulders" or "with cobbles and boulders" is added to the Group Name.

Exhibit B-1: Standard Penetration Test (SPT)

Term	Description
Hammer	140-pound weight with a 30-inch free fall. Hammer types vary (e.g., automatic, rope and cathead). If available, the hammer type and energy ratio (E-ratio) is noted on the boring log.
Sampler	Barrel I.D. / O.D. = 1.5 inches / 2 inches (liner not used) Barrel Length = 30 inches; Shoe I.D. = 1.375 inches
N-Value (N)[1]	Sum of the count of hammer blows to penetrate the second and third 6-inch increments in blows per foot (bpf). **Refusal**: 50 blows for 6 inches or less or 10 blows for 0 inch.

Exhibit B-2: Relative Consistency of Cohesive Soils

Term	N[2] (bpf)	PP[3] (tsf)	TV[3] (tsf)
Very Soft	0 - 2	0 - 0.25	0 - 0.12
Soft	2 - 4	0.25 - 0.5	0.12 - 0.25
Medium Stiff	4 - 8	0.5 - 1	0.25 - 0.5
Stiff	8 - 15	1 - 2	0.5 - 1
Very Stiff	15 - 30	2 - 4	1 - 2
Hard	> 30	> 4	> 2

Exhibit B-3: Relative Density of Cohesionless Soils

Term	N[2] (bpf)
Very Loose	0 - 4
Loose	4 - 10
Medium Dense	10 - 30
Dense	30 - 50
Very Dense	> 50

EXHIBIT B NOTES:
1. N-values shown on boring logs are as recorded in the field and have not been corrected for hammer energy, overburden, or other factors. Where the hammer E-ratio is available, the N-value normalized to a ratio of 60% (N_{60}) is listed.
2. Based on ASTM Standard D1586. Relative densities/consistencies noted on the boring logs are based on uncorrected N-values.
3. PP = pocket penetrometer; TV = torvane, tsf = tons per square foot. Correlations based on experience and multiple published references.

Exhibit C: Soil Structure[1]

Term	Description
Blocky	Cohesive soil that can be broken down into small angular lumps that resist further breakdown.
Fissured	Breaks along definite planes or fractures with little resistance.
Homogeneous	Same color and appearance throughout.
Interbedded	Alternating layers at least 1/4 inch thick of varying material or color. *Singular: bed*
Laminated	Alternating layers less than 1/4 inch thick of varying material or color. *Singular: lamination*
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay.
Slickensided	Fracture planes appear polished or glossy, sometimes striated.

EXHIBIT C NOTE:
1. Adapted, with permission, from ASTM D2488.

Exhibit D: Soil Plasticity[1]

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

EXHIBIT D NOTE:
1. Adapted, with permission, from ASTM D2488.

Exhibit E: Soil Moisture Content[1]

Term	Description
Dry	Absence of moisture, dusty, dry to the touch.
Moist	Damp but no visible water.
Wet	Visible free water, from below water table.

EXHIBIT E NOTE:
1. Adapted, with permission, from ASTM D2488 (Figure 2).

Exhibit F: Soil Cementation[1]

Term	Description
Weak	Crumbles or breaks with handling or slight finger pressure.
Moderate	Crumbles or breaks with considerable finger pressure.
Strong	Will not crumble or break with finger pressure.

EXHIBIT F NOTE:
1. Adapted, with permission, from ASTM D2488.

Exhibit G: Percentages

Term	Percent[1]
Trace	<5
Few	5 to 10
Little	15 to 25
Some	30 to 45
Mostly	>50

EXHIBIT G NOTE:
1. Percent estimated by weight for sand and gravel, and by volume for cobbles, organics, and other non-soil material (e.g., rubble, debris).

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SOIL CLASSIFICATION *(continued)*

See Page 1 for Soil Classification Exhibits A through G

Exhibit H: Particle Angularity and Shape[1]

Term	Description
Angular	Sharp edges and unpolished planar surfaces.
Subangular	Similar to angular, but with rounded edges.
Subrounded	Nearly planar sides with well-rounded edges.
Rounded	Smoothly curved sides with no edges.
Flat	Width to thickness ratio > 3.
Elongated	Width to thickness ratio < 3.

EXHIBIT H NOTE:
1. Adapted, with permission, from ASTM D2488.

Exhibit I: Additional Descriptive Terms

Term	Description
Mottled	Irregular patches of different colors.
Bioturbated	Soil disturbance or mixing by plants or animals.
Diamict	Nonsorted sediment; sand and gravel in silt and/or clay matrix.
Cuttings	Material brought to surface by drilling action.
Slough	Material that caved from sides of borehole.
Sheared	Disturbed texture, mix of strengths.

SOIL CLASSIFICATION REFERENCES:
ASTM International, [current edition], Annual book of standards, v. 04.08, soil and rock (I): D420 - D5876, available: www.astm.org.
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SYMBOLOGY AND GRAPHICS

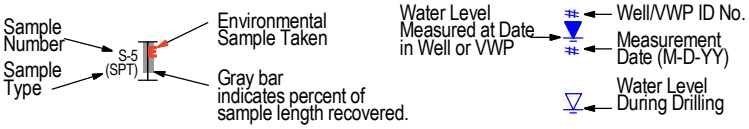
Exhibit J: Sample and Run Graphics

Graphic	Description	Graphic	Description	Graphic	Description
	SPT split spoon (2-inch OD)		Split spoon (SS) (diameters vary)		Core run (typically rock)
	Grab (GB) from cuttings or excavation		Modified California (MC) sampler		Sheath (SH) (used for geoprobes)
	Tube (TB) (e.g., Shelby, piston)		Sonic core (SC) run (typically soil)		

Exhibit K: Hole Backfill and Instrument Graphics

Graphic	Description	Graphic	Description	Graphic	Description
	Bentonite-cement grout		Cement Seal		Blank pipe or instrument casing
	Bentonite grout		Sand filter pack		Perforated or slotted pipe
	Bentonite chips		Slough *(hole caved)*		VWP and electric lead

Exhibit L: Other Log Symbols



ROCK CLASSIFICATION

Shannon & Wilson uses a rock classification system modified from the system recommended by the International Society for Rock Mechanics (ISRM). Copyright limitations prevent us from reproducing summary tables from the ISRM system on this Key. General descriptions are provided in Exhibit M.

Exhibit M: General Rock Descriptive Terms - ISRM

Term	General Description
Strength	Ranges from extremely weak (q_u = 36 to 135 psi) to extremely strong (q_u > 36,250 psi), and is based on the ability to break the rock with a hammer or scrape the rock with a knife.
Weathering	Ranges from fresh (no visible signs of weathering) to completely weathered, based on observed degree of discoloration, decomposition, and/or disintegration. When the rock material has completely converted to soil, it is termed a residual soil.
Fabric	Describes the rock structure based on observed layering, tendency to break, and distribution of minerals (e.g., massive, bedded, foliated).
Roughness	For discontinuities: Includes rough, smooth, and slickensided, and includes other descriptive terms (e.g., stepped, undular, irregular, planar).
Spacing	For discontinuities: Ranges from extremely close (< 1 inch) to extremely wide (> 20 feet).
Persistence	For discontinuities: Ranges from very low to very high.
Other	Description of discontinuities (joints, fractures, bedding planes, etc.), observations of potential displacement, gouge, shear, etc.

REFERENCE: Brown, E. T., ed., 1981, Rock characterization, testing & monitoring: International Society of Rock Mechanics (ISRM) suggested methods: Oxford, Pergamon Press, 211 p.

Exhibit N: Rock Name Graphics

Graphic	Description	Graphic	Description
	Limestone		

Exhibit O: Recovery and RQD Equations[1]

Term	Equation
Core Recovery (REC) in %	$100\% \times \frac{\text{Length of Core Recovered}}{\text{Length of Core Run}}$
Rock Quality Designation (RQD) in %	$100\% \times \frac{\text{Length of Core in Pieces} > 4\text{ in}}{\text{Length of Core Run}}$

REFERENCE: Loehr, J. E.; Lutenegger, A.; Rosenblad, B.; and Boeckmann, A., 2016, Geotechnical site characterization: U.S. Federal Highway Administration Report FHWA NHI-16-072, Geotechnical Engineering Circular no. 5, 1 v.

ACRONYMS AND ABBREVIATIONS

ATD	at time of drilling	N	field (uncorrected) SPT N-value	REF	refusal
bpf	blows per foot	N_{60}	SPT N-value corrected for 60% ETR	RQD	rock quality designation (ASTM D6032)
dia, diam	diameter	NA, n/a	not applicable or not available	SC	sonic core
Elev.	elevation	NE	northeast	SE	southeast
ENV	environmental sample	NP	nonplastic	SPT	Standard Penetration Test (ASTM D1586)
ETR	energy transfer ratio (hammer)	NR	no recovery	SW	southwest
FC	fines content (< 0.075 mm)	NW	northwest	TP	test pit
FeO	iron oxide	OC	organic content	tsf	tons per square foot
ft or '	foot or feet	OD	outside diameter	TV	tor vane reading
gal	gallons	OW	observation well	UCS, q_u	unconfined compressive strength
GP	geoprobe	pcf	pounds per cubic foot	USCS	Unified Soil Classification System
GWT	groundwater table	PI	plasticity index	VST	vane shear test
HSA	hollow-stem auger	PID	photoionization detector	VWP	vibrating wire piezometer
ID	inside diameter or identification	PL	plastic limit	WC	natural water content
in or "	inch	PMT	pressuremeter test	WOH	weight of hammer
incl	inclinometer	PP	pocket penetrometer reading	WOR	weight of rods
ksf	kips per square foot	ppm	parts per million		
lbs	pounds	psi	pounds per square inch		
LL	liquid limit	PT	nonstandard penetration test N-value		
mm	millimeter	REC	recovery		

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SHANNON & WILSON

BORING LOG

Grand Canyon National Park South Rim WWTP Access Road
South Rim Village, Arizona

BH01-24

EXPLORATION INFORMATION

Total Depth:	*15.0 feet*
Top Elevation:	*~6802 feet*
Vertical Datum:	*n/a*
Latitude:	*~ 36.0494 degrees*
Longitude:	*~ -112.1489 degrees*
Horizontal Datum:	*WGS [GCS1984]*
Hole Start Date:	*September 19, 2024*
Hole Finish Date:	*September 19, 2024*

DRILLING INFORMATION

Drilling Method:	*varies - see log*
Drilling Company:	*Vine Laboratories, Inc.*
Drill Rig Equipment:	*CME 750x Buggy Rig*
Hole Size:	*varies - see log*
Rod Type/Dia.:	*AWJ 1.75 inch*
Hammer Wt. / Drop:	*140 lbs/30 inches*
Hammer ETR:	*n/a*

BASIC LEGEND

(See separate LOG KEY for additional symbols, acronyms, and definitions)

Abbreviations

N	Standard Penetration Test (SPT) blows per 6-inch increment
PT	Penetration test (not SPT) blows per 6-inch increment
bpf	Blows per foot for penetration test
WC	Natural water content (%)
FC	Fines content (% grains smaller than 0.075 mm)
PI	Plasticity index (Atterberg Limits)

Symbols

Sample Number → S-5
Sample Type → (SPT)
Gray bar indicates percent of sample length recovered.

Approx. Elev. (feet)	Depth (feet)	Material Description and Other Observations	Graphic	Depth (feet)	Samples	Field Data	Lab Data	Multiple Items Plotted *(see bottom legend on Page 1)* 0 50 100	Depth (feet)
		Brown, ***SILTY CLAY WITH SAND*** (CL-ML); moist; few gravel.		0.5					
6800		***LIMESTONE***: extremely weak to medium strong, light red to red-yellow; completely to highly weathered. Kaibab Formation			S-1 (SPT)	N = 35,40,50	WC=10% FC=69% pH=8 RES=10000 OhmCm		
	5				S-2 (SPT)	N = 39,50/3"	WC=14% FC=68%	>>	5
6795		*-Slightly to moderately weathered below 6 feet.*							
	10				S-3 (SPT)	N = 50/1" REC = 86% RQD = 1%		>>	10
6790		*-Dissolution weathering pit at 12.0 feet.* *-Iron oxide stained from 12.2 to 12.6 feet.* *-Slightly weathered and contains calcite nodules below 12.6 feet.*			R-1		UCS=3835		
	15	BOTTOM OF HOLE AT 15 FEET		15.0					15

Method: Solid Auger; Hole Size: 4"
Method: Rock Core; Hole Size: 3"

NOTES:
- Refer to LOG KEY for explanation of symbols, codes, abbreviations, and definitions.
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- Group symbol is based on visual-manual identification and selected lab testing.
- Report text contains limitations and information needed to contextually understand this log.
- Boring location was estimated using existing site features as well as recreational grade GPS and should be considered approximate.
- Boring elevation was estimated using the topographic map provided by Jacobs and should be considered approximate.

▲ Uncorrected N-value, bpf
▼ Uncorrected, Penetration N-value, bpf
● = WC% ◇ = FC%
RQD (%) Recovery (%)

FINAL

Logged by:	ZAB
Review by:	BTM
Version:	1

SHANNON & WILSON

BORING LOG

Grand Canyon National Park South Rim WWTP Access Road
South Rim Village, Arizona

BH02-24

EXPLORATION INFORMATION

Total Depth:	*5.1 feet*
Top Elevation:	*~6785 feet*
Vertical Datum:	*n/a*
Latitude:	*~ 36.0491 degrees*
Longitude:	*~ -112.1509 degrees*
Horizontal Datum:	*WGS [GCS1984]*
Hole Start Date:	*September 19, 2024*
Hole Finish Date:	*September 19, 2024*

DRILLING INFORMATION

Drilling Method:	*Solid Auger*
Drilling Company:	*Vine Laboratories, Inc.*
Drill Rig Equipment:	*CME 750x Buggy Rig*
Hole Size:	*4 inch*
Rod Type/Dia.:	*AWJ 1.75 inch*
Hammer Wt. / Drop:	*140 lbs/30 inches*
Hammer ETR:	*n/a*

BASIC LEGEND

(See separate LOG KEY for additional symbols, acronyms, and definitions)

Abbreviations

N	Standard Penetration Test (SPT) blows per 6-inch increment
PT	Penetration test (not SPT) blows per 6-inch increment
bpf	Blows per foot for penetration test
WC	Natural water content (%)
FC	Fines content (% grains smaller than 0.075 mm)
PI	Plasticity index (Atterberg Limits)

Symbols

Sample Number → S-5
Sample Type → (SPT)
Gray bar indicates percent of sample length recovered.

Approx. Elev. (feet)	Depth (feet)	Material Description and Other Observations	Graphic	Depth (feet)	Samples	Field Data	Lab Data	Multiple Items Plotted *(see bottom legend on Page 1)* 0 50 100	Depth (feet)
6780	5.5	***LIMESTONE***: medium strong to strong, light red to yellow; slightly weathered to fresh. Kaibab Formation *-Auger refusal at 5.5 feet.*		5.1	S-1 (SPT) S-2 (SPT)	N = 50/1" N = 50/1"	WC=1%	● >> ▲ >> ▲	5

BOTTOM OF HOLE AT 5.1 FEET

NOTES:
- Refer to LOG KEY for explanation of symbols, codes, abbreviations, and definitions.
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- Report text contains limitations and information needed to contextually understand this log.
- Boring location was estimated using existing site features as well as recreational grade GPS and should be considered approximate.
- Boring elevation was estimated using the topographic map provided by Jacobs and should be considered approximate.

▲ Uncorrected N-value, bpf
▼ Uncorrected, Penetration N-value, bpf
● = WC%

FINAL

Logged by:	ZAB
Review by:	BTM
Version:	1

SHANNON & WILSON

BORING LOG

Grand Canyon National Park South Rim WWTP Access Road
South Rim Village, Arizona

BH03-24

EXPLORATION INFORMATION

Total Depth:	*10.0 feet*
Top Elevation:	*~6834 feet*
Vertical Datum:	*n/a*
Latitude:	*~ 36.0483 degrees*
Longitude:	*~ -112.1473 degrees*
Horizontal Datum:	*WGS [GCS1984]*
Hole Start Date:	*September 19, 2024*
Hole Finish Date:	*September 19, 2024*

DRILLING INFORMATION

Drilling Method:	*varies - see log*
Drilling Company:	*Vine Laboratories, Inc.*
Drill Rig Equipment:	*CME 750x Buggy Rig*
Hole Size:	*varies - see log*
Rod Type/Dia.:	*AWJ 1.75 inch*
Hammer Wt. / Drop:	*140 lbs/30 inches*
Hammer ETR:	*n/a*

BASIC LEGEND

(See separate LOG KEY for additional symbols, acronyms, and definitions)

Abbreviations

N	Standard Penetration Test (SPT) blows per 6-inch increment
PT	Penetration test (not SPT) blows per 6-inch increment
bpf	Blows per foot for penetration test
WC	Natural water content (%)
FC	Fines content (% grains smaller than 0.075 mm)
PI	Plasticity index (Atterberg Limits)

Symbols

Sample Number → S-5
Sample Type → (SPT)
Gray bar indicates percent of sample length recovered.

Approx. Elev. (feet)	Depth (feet)	Material Description and Other Observations	Graphic	Depth (feet)	Samples	Field Data	Lab Data	Multiple Items Plotted *(see bottom legend on Page 1)* 0 50 100	Depth (feet)
		Brown, ***SILTY CLAY WITH SAND*** (CL-ML); moist; few gravel.		0.5	Method: Solid Auger; Hole Size: 4"				
6830	5	***LIMESTONE***: medium strong, yellow to red-yellow; slightly weathered to fresh; iron oxide and manganese stained. Kaibab Formation			Method: Rock Core; Hole Size: 3"; R-1 S-1 (SPT)	N = 50/1" REC = 60% RQD = 0%		>>	5
		-Highly oxidized from 6.2 to 7 feet. *-Extremely weak and highly weathered below 7 feet.*			R-2	REC = 100% RQD = 47%			
6825	10	*-Medium strong to strong and slightly to moderately weathered below 8.7 feet.* *-Light gray to red-yellow, extremely weak, and moderately to highly weathered with iron oxide staining below 9.6 feet.*		10.0			UCS=6380		10

BOTTOM OF HOLE AT 10 FEET

NOTES:
- Refer to LOG KEY for explanation of symbols, codes, abbreviations, and definitions.
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- Report text contains limitations and information needed to contextually understand this log.
- Boring location was estimated using existing site features as well as recreational grade GPS and should be considered approximate.
- Boring elevation was estimated using the topographic map provided by Jacobs and should be considered approximate.

▲ Uncorrected N-value, bpf
▼ Uncorrected, Penetration N-value, bpf

RQD (%) Recovery (%)

FINAL

Logged by:	ZAB
Review by:	BTM
Version:	1

SHANNON & WILSON

BORING LOG

Grand Canyon National Park South Rim WWTP Access Road
South Rim Village, Arizona

BH04-24

EXPLORATION INFORMATION

Total Depth:	*10.2 feet*
Top Elevation:	*~6856 feet*
Vertical Datum:	*n/a*
Latitude:	*~ 36.0476 degrees*
Longitude:	*~ -112.1463 degrees*
Horizontal Datum:	*WGS [GCS1984]*
Hole Start Date:	*September 19, 2024*
Hole Finish Date:	*September 19, 2024*

DRILLING INFORMATION

Drilling Method:	*Solid Auger*
Drilling Company:	*Vine Laboratories, Inc.*
Drill Rig Equipment:	*CME 750x Buggy Rig*
Hole Size:	*4 inch*
Rod Type/Dia.:	*AWJ 1.75 inch*
Hammer Wt. / Drop:	*140 lbs/30 inches*
Hammer ETR:	*n/a*

BASIC LEGEND

(See separate LOG KEY for additional symbols, acronyms, and definitions)

Abbreviations

N	Standard Penetration Test (SPT) blows per 6-inch increment
PT	Penetration test (not SPT) blows per 6-inch increment
bpf	Blows per foot for penetration test
WC	Natural water content (%)
FC	Fines content (% grains smaller than 0.075 mm)
PI	Plasticity index (Atterberg Limits)

Symbols

Sample Number → S-5
Sample Type → (SPT)
Gray bar indicates percent of sample length recovered.

Approx. Elev. (feet)	Depth (feet)	Material Description and Other Observations	Graphic	Depth (feet)	Samples	Field Data	Lab Data	Multiple Items Plotted *(see bottom legend on Page 1)* 0 50 100	Depth (feet)
6855		Brown, ***SILTY CLAY WITH SAND*** (CL-ML); moist; few gravel.		0.5	G-1 (GB)		WC=5% FC=71% LL/PI=25/4 pH=7 RES=7700 OhmCm WC=3%		
		LIMESTONE: medium strong, light red to red-yellow; moderately to slightly weathered; iron oxide stained. Kaibab Formation			S-1 (SPT)	N = 50/2"		>>	
6850	5				S-2 (SPT)	N = 42,50/5"	WC=3%	>>	5
	10			10.2	S-3 (SPT)	N = 50/2"	WC=4%	>>	10

BOTTOM OF HOLE AT 10.2 FEET

NOTES:
- Refer to LOG KEY for explanation of symbols, codes, abbreviations, and definitions.
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- Report text contains limitations and information needed to contextually understand this log.
- Boring location was estimated using existing site features as well as recreational grade GPS and should be considered approximate.
- Boring elevation was estimated using the topographic map provided by Jacobs and should be considered approximate.

▲ Uncorrected N-value, bpf
▼ Uncorrected, Penetration N-value, bpf
● = WC% ◇ = FC%
Plastic Limit ├──●──┤ Liquid Limit

FINAL

Logged by:	ZAB
Review by:	BTM
Version:	1

SHANNON & WILSON

BORING LOG

Grand Canyon National Park South Rim WWTP Access Road
South Rim Village, Arizona

BH05-24

EXPLORATION INFORMATION		DRILLING INFORMATION	
Total Depth:	*10.0 feet*	Drilling Method:	*varies - see log*
Top Elevation:	*~6870 feet*	Drilling Company:	*Vine Laboratories, Inc.*
Vertical Datum:	*n/a*	Drill Rig Equipment:	*CME 750x Buggy Rig*
Latitude:	*~ 36.0464 degrees*	Hole Size:	*varies - see log*
Longitude:	*~ -112.1445 degrees*	Rod Type/Dia.:	*AWJ 1.75 inch*
Horizontal Datum:	*WGS [GCS1984]*	Hammer Wt. / Drop:	*140 lbs/30 inches*
Hole Start Date:	*September 19, 2024*	Hammer ETR:	*n/a*
Hole Finish Date:	*September 19, 2024*		

BASIC LEGEND
(See separate LOG KEY for additional symbols, acronyms, and definitions)

Abbreviations

N	Standard Penetration Test (SPT) blows per 6-inch increment
PT	Penetration test (not SPT) blows per 6-inch increment
bpf	Blows per foot for penetration test
WC	Natural water content (%)
FC	Fines content (% grains smaller than 0.075 mm)
PI	Plasticity index (Atterberg Limits)

Symbols

Sample Number → S-5
Sample Type → (SPT)
Gray bar indicates percent of sample length recovered.

Approx. Elev. (feet)	Depth (feet)	Material Description and Other Observations	Graphic	Depth (feet)	Samples	Field Data	Lab Data	Multiple Items Plotted *(see bottom legend on Page 1)* 0 50 100	Depth (feet)
		Brown, ***SILTY CLAY WITH SAND*** (CL-ML); moist; few gravel.		1.0	Method: Solid Auger; Hole Size: 4"				
		LIMESTONE: weak to medium strong, light red to red-yellow; slightly to moderately weathered. Kaibab Formation *-Highly fractured and iron oxide and magnesium oxide stained above 5 feet.*			Method: Rock Core; Hole Size: 3"; R-1; S-1 (SPT); R-2	N = 50/2" REC = 80% RQD = 20% REC = 80% RQD = 36%	WC=12% UCS=3939	>>	
6865	5								5
6860	10			10.0					10

BOTTOM OF HOLE AT 10 FEET

NOTES:
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- Boring location was estimated using existing site features as well as recreational grade GPS and should be considered approximate.
- Boring elevation was estimated using the topographic map provided by Jacobs and should be considered approximate.

▲ Uncorrected N-value, bpf
▼ Uncorrected, Penetration N-value, bpf
● = WC%
RQD (%) Recovery (%)

FINAL

Logged by:	ZAB
Review by:	BTM
Version:	1

SHANNON & WILSON

BORING LOG

Grand Canyon National Park South Rim WWTP Access Road
South Rim Village, Arizona

BH06-24

EXPLORATION INFORMATION

Total Depth:	*15.2 feet*
Top Elevation:	*~6872 feet*
Vertical Datum:	*n/a*
Latitude:	*~ 36.0460 degrees*
Longitude:	*~ -112.1435 degrees*
Horizontal Datum:	*WGS [GCS1984]*
Hole Start Date:	*September 18, 2024*
Hole Finish Date:	*September 18, 2024*

DRILLING INFORMATION

Drilling Method:	*varies - see log*
Drilling Company:	*Vine Laboratories, Inc.*
Drill Rig Equipment:	*CME 750x Buggy Rig*
Hole Size:	*varies - see log*
Rod Type/Dia.:	*AWJ 1.75 inch*
Hammer Wt. / Drop:	*140 lbs/30 inches*
Hammer ETR:	*n/a*

BASIC LEGEND

(See separate LOG KEY for additional symbols, acronyms, and definitions)

Abbreviations

N	Standard Penetration Test (SPT) blows per 6-inch increment
PT	Penetration test (not SPT) blows per 6-inch increment
bpf	Blows per foot for penetration test
WC	Natural water content (%)
FC	Fines content (% grains smaller than 0.075 mm)
PI	Plasticity index (Atterberg Limits)

Symbols

Sample Number → S-5
Sample Type → (SPT)
Gray bar indicates percent of sample length recovered.

Approx. Elev. (feet)	Depth (feet)	Material Description and Other Observations	Graphic	Depth (feet)	Samples	Field Data	Lab Data	Multiple Items Plotted *(see bottom legend on Page 1)* 0 50 100	Depth (feet)
6870		Brown, ***SILTY CLAY WITH SAND*** (CL-ML); moist; few gravel.		1.5					
		LIMESTONE: medium strong, red-yellow to light gray; slightly weathered. Kaibab Formation			S-1 (SPT)	N = 50/6"	WC=7% FC=55% pH=7.9 RES=10000 OhmCm WC=4%	>>	
	5				S-2 (SPT)	N = 50/4"		>>	5
6865					Method: Solid Auger; Hole Size: 4"				
	10	*-Light red to red-yellow, slightly to moderately weathered, iron oxide stained, and contains calcite nodules below 10.2 feet.*			S-3 (SPT); R-1; Method: Rock Core; Hole Size: 3"	N = 50/2" REC = 100% RQD = 54%	WC=9% UCS=5765	>>	10
6860									
	15			15.2					15

BOTTOM OF HOLE AT 15.2 FEET

NOTES:
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- Boring elevation was estimated using the topographic map provided by Jacobs and should be considered approximate.

▲ Uncorrected N-value, bpf
▼ Uncorrected, Penetration N-value, bpf
● = WC% ◇ = FC%
RQD (%) Recovery (%)

FINAL

Logged by:	ZAB
Review by:	BTM
Version:	1

SHANNON & WILSON

BORING LOG

Grand Canyon National Park South Rim WWTP Access Road
South Rim Village, Arizona

BH07-24

EXPLORATION INFORMATION

Total Depth:	*15.1 feet*
Top Elevation:	*~6886 feet*
Vertical Datum:	*n/a*
Latitude:	*~ 36.0456 degrees*
Longitude:	*~ -112.1413 degrees*
Horizontal Datum:	*WGS [GCS1984]*
Hole Start Date:	*September 18, 2024*
Hole Finish Date:	*September 18, 2024*

DRILLING INFORMATION

Drilling Method:	*varies - see log*
Drilling Company:	*Vine Laboratories, Inc.*
Drill Rig Equipment:	*CME 750x Buggy Rig*
Hole Size:	*varies - see log*
Rod Type/Dia.:	*AWJ 1.75 inch*
Hammer Wt. / Drop:	*140 lbs/30 inches*
Hammer ETR:	*n/a*

BASIC LEGEND

(See separate LOG KEY for additional symbols, acronyms, and definitions)

Abbreviations

N	Standard Penetration Test (SPT) blows per 6-inch increment
PT	Penetration test (not SPT) blows per 6-inch increment
bpf	Blows per foot for penetration test
WC	Natural water content (%)
FC	Fines content (% grains smaller than 0.075 mm)
PI	Plasticity index (Atterberg Limits)

Symbols

Sample Number → S-5
Sample Type → (SPT)
Gray bar indicates percent of sample length recovered.

Approx. Elev. (feet)	Depth (feet)	Material Description and Other Observations	Graphic	Depth (feet)	Samples	Field Data	Lab Data	Multiple Items Plotted *(see bottom legend on Page 1)* 0 50 100	Depth (feet)
6885		Brown, ***SILTY CLAY WITH SAND*** (CL-ML); moist; few gravel.		1.0					
		LIMESTONE: medium strong, red-yellow to light red; slightly weathered. Kaibab Formation			Method: Solid Auger; Hole Size: 4"; S-1 (SPT)	N = 50/2"		>>	
6880	5	*-Strong, slightly to moderately weathered, and iron oxide stained below 5 feet.*			Method: Rock Core; Hole Size: 3"; S-2 (SPT); R-1	N = 50/1" REC = 100% RQD = 79%	UCS=8134	>>	5
6875	10				R-2	REC = 100% RQD = 64%			10
	15			15.1					15

BOTTOM OF HOLE AT 15.1 FEET

NOTES:
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- Report text contains limitations and information needed to contextually understand this log.
- Boring location was estimated using existing site features as well as recreational grade GPS and should be considered approximate.
- Boring elevation was estimated using the topographic map provided by Jacobs and should be considered approximate.

▲ Uncorrected N-value, bpf
▼ Uncorrected, Penetration N-value, bpf

RQD (%) Recovery (%)

FINAL

Logged by:	ZAB
Review by:	BTM
Version:	1

SHANNON & WILSON

BORING LOG

Grand Canyon National Park South Rim WWTP Access Road
South Rim Village, Arizona

BH08-24

EXPLORATION INFORMATION

Total Depth:	*10.8 feet*
Top Elevation:	*~6898 feet*
Vertical Datum:	*n/a*
Latitude:	*~ 36.0448 degrees*
Longitude:	*~ -112.1382 degrees*
Horizontal Datum:	*WGS [GCS1984]*
Hole Start Date:	*September 18, 2024*
Hole Finish Date:	*September 18, 2024*

DRILLING INFORMATION

Drilling Method:	*varies - see log*
Drilling Company:	*Vine Laboratories, Inc.*
Drill Rig Equipment:	*CME 750x Buggy Rig*
Hole Size:	*varies - see log*
Rod Type/Dia.:	*AWJ 1.75 inch*
Hammer Wt. / Drop:	*140 lbs/30 inches*
Hammer ETR:	*n/a*

BASIC LEGEND

(See separate LOG KEY for additional symbols, acronyms, and definitions)

Abbreviations

N	Standard Penetration Test (SPT) blows per 6-inch increment
PT	Penetration test (not SPT) blows per 6-inch increment
bpf	Blows per foot for penetration test
WC	Natural water content (%)
FC	Fines content (% grains smaller than 0.075 mm)
PI	Plasticity index (Atterberg Limits)

Symbols

Sample Number → S-5
Sample Type → (SPT)
Gray bar indicates percent of sample length recovered.

Approx. Elev. (feet)	Depth (feet)	Material Description and Other Observations	Graphic	Depth (feet)	Samples	Field Data	Lab Data	Multiple Items Plotted *(see bottom legend on Page 1)* 0 50 100	Depth (feet)
		Brown, ***SILTY CLAY WITH SAND*** (CL-ML); moist; few gravel.		1.5	Method: Solid Auger; Hole Size: 4"; S-1 (SPT)	N = 50/4"	WC=10%		
6895	5	***LIMESTONE***: medium strong to strong, light red to red-yellow; moderately to slightly weathered. Kaibab Formation			Method: Rock Core; Hole Size: 3"; S-2 (SPT); R-1	N = 46,50/4" REC = 56% RQD = 16%	WC=5% FC=54% pH=7.4 RES=10000 OhmCm UCS=9086		5
6890	10	*-Extremely weak and highly to moderately weathered from 6.9 to 7.3 feet.* *-Medium strong and moderately to slightly weathered from 7.3 to 8.1 feet.* *-Extremely weak and highly to moderately weathered below 8.1 feet.*		10.8					10
10.8		BOTTOM OF HOLE AT 10.8 FEET							

NOTES:
- Refer to LOG KEY for explanation of symbols, codes, abbreviations, and definitions.
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- Report text contains limitations and information needed to contextually understand this log.
- Boring location was estimated using existing site features as well as recreational grade GPS and should be considered approximate.
- Boring elevation was estimated using the topographic map provided by Jacobs and should be considered approximate.

▲ Uncorrected N-value, bpf
▼ Uncorrected, Penetration N-value, bpf
● = WC% ◇ = FC%
RQD (%) Recovery (%)

FINAL

Logged by:	ZAB
Review by:	BTM
Version:	1

SHANNON & WILSON

BORING LOG

Grand Canyon National Park South Rim WWTP Access Road
South Rim Village, Arizona

BH09-24

EXPLORATION INFORMATION

Total Depth:	*12.6 feet*
Top Elevation:	*~6902 feet*
Vertical Datum:	*n/a*
Latitude:	*~ 36.0444 degrees*
Longitude:	*~ -112.1371 degrees*
Horizontal Datum:	*WGS [GCS1984]*
Hole Start Date:	*September 18, 2024*
Hole Finish Date:	*September 18, 2024*

DRILLING INFORMATION

Drilling Method:	*varies - see log*
Drilling Company:	*Vine Laboratories, Inc.*
Drill Rig Equipment:	*CME 750x Buggy Rig*
Hole Size:	*varies - see log*
Rod Type/Dia.:	*AWJ 1.75 inch*
Hammer Wt. / Drop:	*140 lbs/30 inches*
Hammer ETR:	*n/a*

BASIC LEGEND

(See separate LOG KEY for additional symbols, acronyms, and definitions)

Abbreviations

N	Standard Penetration Test (SPT) blows per 6-inch increment
PT	Penetration test (not SPT) blows per 6-inch increment
bpf	Blows per foot for penetration test
WC	Natural water content (%)
FC	Fines content (% grains smaller than 0.075 mm)
PI	Plasticity index (Atterberg Limits)

Symbols

Sample Number → S-5
Sample Type → (SPT)
Gray bar indicates percent of sample length recovered.

Approx. Elev. (feet)	Depth (feet)	Material Description and Other Observations	Graphic	Depth (feet)	Samples	Field Data	Lab Data	Multiple Items Plotted *(see bottom legend on Page 1)* 0 50 100	Depth (feet)
		Brown, ***SILTY CLAY WITH SAND*** (CL-ML); moist; few gravel.		1.5					
6900		***LIMESTONE***: medium strong to strong, light red to red-yellow; slightly weathered to fresh. Kaibab Formation *-Iron oxide stained from 1.5 to 11.4 feet.*			S-1 (SPT)	N = 50/4"	WC=3%		
	5				S-2 (SPT)	N = 50/1"			5
6895									
	10				S-3 (SPT)	N = 50/1" REC = 100% RQD = 54%	UCS=8113		10
6890		*-Slightly to moderately weathered and more heavily stained from 11.4 to 12 feet.*							
	12.6			12.6					

Method: Hollow Stem Auger; Hole Size: 4"
Method: Rock Core; Hole Size: 3"
R-1

BOTTOM OF HOLE AT 12.6 FEET

NOTES:
- Refer to LOG KEY for explanation of symbols, codes, abbreviations, and definitions.
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- Report text contains limitations and information needed to contextually understand this log.
- Boring location was estimated using existing site features as well as recreational grade GPS and should be considered approximate.
- Boring elevation was estimated using the topographic map provided by Jacobs and should be considered approximate.

▲ Uncorrected N-value, bpf
▼ Uncorrected, Penetration N-value, bpf
● = WC%
RQD (%) Recovery (%)

FINAL

Logged by:	ZAB
Review by:	BTM
Version:	1

Top of Core

Run 1: 10.0 – 15.0 feet

Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
R-1	10.0	15.0	86	26

Grand Canyon National Park
South Rim WWTP Access Road
South Rim Village, Arizona

ROCK CORE PHOTOGRAPHS
BORING BH01-24

January 2025 112557-001

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FIG. A-1

FIG. A-1

Top of Core

Run 1: 2.5 – 5.0 feet

Photo Match Line

Top of Core

Photo Match Line

Run 2: 5.0 – 10.0 feet

Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
R-1	2.5	5.0	60	0
R-2	5.0	10.0	100	47

Grand Canyon National Park
South Rim WWTP Access Road
South Rim Village, Arizona

ROCK CORE PHOTOGRAPHS
BORING BH03-24

January 2025 112557-001

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FIG. A-2

FIG. A-2

Top of Core

Run 1: 2.5 – 5.0 feet

Top of Core

Photo Match Line

Photo Match Line

Run 2: 5.0 – 10.0 feet

Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
R-1	2.5	5.0	80	20
R-2	5.0	10.0	80	36

Grand Canyon National Park
South Rim WWTP Access Road
South Rim Village, Arizona

ROCK CORE PHOTOGRAPHS
BORING BH05-24

January 2025 112557-001

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FIG. A-3

FIG. A-3

Top of Core

Photo Match Line

Photo Match Line

Run 1: 10.2 – 15.2 feet

Photo Match Line
(next sheet)

Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
R-1	10.2	15.2	100	54

Grand Canyon National Park
South Rim WWTP Access Road
South Rim Village, Arizona

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FIG. A-4
Sheet 1 of 2

FIG. A-4
Sheet 1 of 2

Run 1 (continued): 10.2 – 15.2 feet

Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
R-1	10.2	15.2	100	54

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FIG. A-4
Sheet 2 of 2

FIG. A-4
Sheet 2 of 2

Top of Core

Photo Match Line

Photo Match Line

Run 1: 5.1 – 10.1 feet

Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
R-1	5.1	10.1	100	79

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FIG. A-5
Sheet 1 of 2

FIG. A-5
Sheet 1 of 2

Top of Core

Run 2: 10.1 – 15.1 feet

Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
R-2	10.1	15.1	100	64

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FIG. A-5
Sheet 2 of 2

FIG. A-5
Sheet 2 of 2

Top of Core

Photo Match Line

Photo Match Line

Run 1: 5.8 – 10.8 feet

Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
R-1	5.8	10.8	56	16

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FIG. A-6

FIG. A-6

Top of Core

Photo Match Line

Photo Match Line

Run 1: 10.1 – 12.6 feet

Run	Top (feet)	Bottom (feet)	Recovery (%)	RQD (%)
R-1	10.1	12.6	100	54

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South Rim WWTP Access Road
South Rim Village, Arizona

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FIG. A-7

FIG. A-7

APPENDIX B: LABORATORY TEST RESULTS

Appendix B

Laboratory Test Results

CONTENTS

B.1 Introduction B-1
B.2 Geotechnical Index Tests B-1
B.2.1 Water Content B-1
B.2.2 Grain Size Distribution B-1
B.2.3 Atterberg Limits B-1
B.3 Geotechnical Property Tests B-2
B.3.1 Corrosion B-2
B.3.2 Unconfined Compressive Strength B-2

Tables

Table B-1: Summary of Laboratory Test Results by Boring

Attachments

Grain Size Distribution Test Results
Atterberg Limits Test Results
Uniaxial Compressive Strength of Intact Rock Core Specimens (7 sheets)

B.1 INTRODUCTION

Laboratory tests were completed on select soil and bedrock samples retrieved from the borings in general accordance with the American Association of State Highway and Transportation Officials (AASHTO), American Society of Testing and Materials International (ASTM), and Colorado Department of Transportation (CDOT) Colorado Procedure - Laboratory (CP-L) testing methods. The laboratory testing program was performed to classify the materials into similar geologic groups and provide data that can be used for design of the project. The geotechnical laboratory testing was performed at our laboratory in Denver, Colorado. Test results are summarized in Table B-1. The following sections describe the laboratory testing procedures.

B.2 GEOTECHNICAL INDEX TESTS

B.2.1 Water Content

Water content was determined for selected samples in general accordance with ASTM D2216, Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. To perform this test, a sample was weighed before and after oven-drying, and the water content was calculated. Water content determinations are shown graphically on the boring logs and are also summarized in Table B-1.

B.2.2 Grain Size Distribution

The grain size distribution of selected samples was determined in general accordance with ASTM D6913, Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. Results of these analyses are attached as grain size distribution curves and are summarized in Table B-1. Selected samples were also tested for the percentage of material passing the No. 200 sieve in general accordance with ASTM D1140, Standard Method for Amount of Material in Soils Finer than the No. 200 Sieve. The percent fines (silt- and clay-sized particles passing the No. 200 sieve) are shown graphically in the boring logs in Appendix A and are also summarized in Table B-1.

B.2.3 Atterberg Limits

Soil plasticity was determined by performing Atterberg limits tests on selected fine-grained samples. The tests were completed in general accordance with ASTM D4318, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. The Atterberg limits include liquid limit (LL), plastic limit (PL), and plasticity index (PI equals LL minus PL) and

are generally used to assist in classification of soils, to indicate soil consistency (when compared to natural water content), and to provide correlation to soil properties. The results of the Atterberg limits tests are plotted on the attached plasticity chart, shown graphically in the boring logs in Appendix A, and summarized in Table B-1.

B.3 GEOTECHNICAL PROPERTY TESTS

B.3.1 Corrosion

Corrosion testing of select samples was performed for pH, resistivity, sulfate content, and chloride content. Testing for pH and resistivity were done in general accordance with AASHTO T289, Standard Method of Test for Determining pH of Soil for Use in Corrosion Testing and ASTM G57, Standard Method of Test for Determining Minimum Laboratory Soil Resistivity, respectively. Sulfate content testing was done in accordance with CDOT laboratory procedure CP-L 2103, Sulfate Ion Content in Soil. Chloride content was done in accordance with CDOT laboratory procedure CP-L 2014, Determining Water-Soluble Chloride Content in Soil. Test results for sulfate and chloride content are reported in units of percent by weight. The test results are summarized in Table B-1.

B.3.2 Unconfined Compressive Strength

Unconfined Compressive Strength of intact rock samples was performed by Vine Laboratories. The unconfined compressive strength testing was completed in general accordance with ASTM D7012 (Method C), Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures. The test results are summarized in Table B-1 and attached.

Table B-1 - Summary of Laboratory Test Results by Boring

SAMPLE DATA								GRAIN SIZE ANALYSIS[2]			ATTERBERG LIMITS			CORROSION				
Boring	Sample	Depth (feet) Top	Depth (feet) Bottom	USCS Symbol[1]	AASHTO Soil Classification (Group Index)	Natural Moisture Content (%)	Moist Unit Weight (pcf)	Gravel (%)	Sand (%)	Fines (%)	Liquid Limit	Plastic Limit	Plasticity Index	pH	Resistivity (ohm-cm)	Sulfates (%)	Chlorides (%)	Uniaxial Compressive Strength (psi)
BH01-24	S-1	2.5	4.0			10.3		6	25	69				8.0	41,000	<0.01	0.088	
	S-2	5.0	5.9			13.9				68								
	R-1	13.1	14.0			6.9	150.7											3,800
BH02-24	S-1	2.5	2.6			1.2												
BH03-24	R-2	8.5	9.2				145.6											6,400
BH04-24	G-1	0.0	1.0	CL-ML	A-4 (1)	4.5		6	23	71	25	21	4	7.0	7,700	<0.01	0.091	
	S-1	2.5	2.7			3.0												
	S-2	5.0	5.9			3.2												
	S-3	10.0	10.2			4.1												
BH05-24	S-1	2.5	2.7			12.2												
	R-2	5.8	6.5				140.2											3,900
BH06-24	S-1	2.5	3.0			6.9				55				7.9	26,000	<0.01	0.050	
	S-2	5.0	5.3			4.2												
	S-3	10.0	10.2			8.9												
	R-1	10.2	15.2				157.1											5,800
BH07-24	R-1	6.2	7.0				144.9											8,100
BH08-24	S-1	2.5	2.8			9.6												
	S-2	5.0	5.8			4.9		16	30	54				7.4	17,000	0.01	0.081	
	R-1	6.2	6.8				150.1											9,100
BH09-24	S-1	2.5	2.8			2.8												
	R-1	10.4	11.2				150.1											8,100

NOTES:

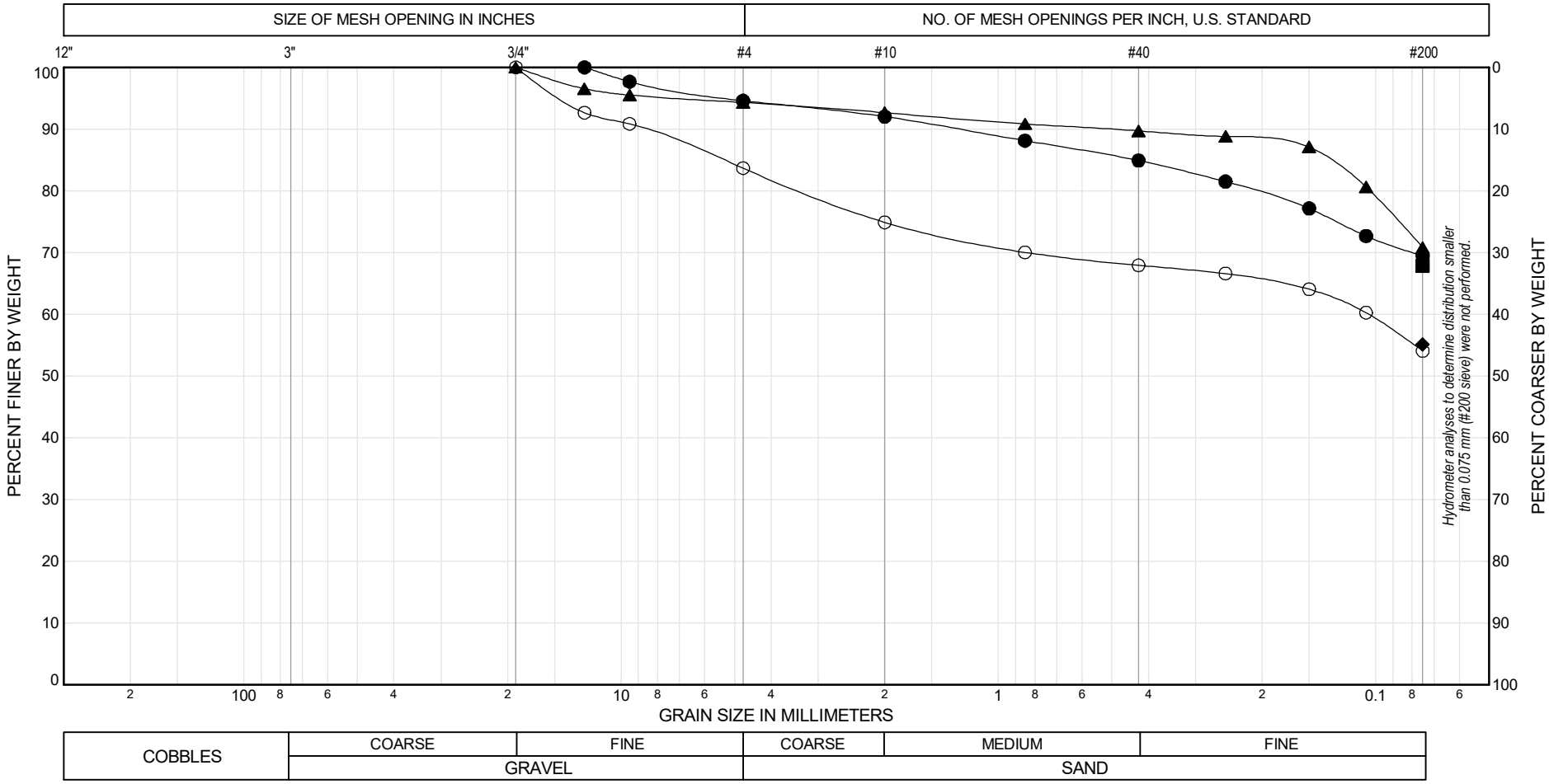
1 Refer to Appendix A, Log Key for definitions.

2 Gravel defined as particles larger than the No. 4 sieve size, Sand as particles between the No. 4 and No. 200 sieve sizes, and Fines as particles passing the No. 200 sieve.

ohm-cm = ohm centimeters; pcf = pounds per cubic foot; psi = pounds per square inch

Grand Canyon National Park South Rim WWTP Access Road
South Rim Village, Arizona

Gradation Chart



EXPLORATION AND SAMPLE NUMBER	DEPTH (feet)	UNIFIED SOIL CLASSIFICATION SYSTEM (USCS) GROUP NAME	USCS SYMBOL	GRAVEL %	SAND %	FINES %	NAT WC %	TEST BY/RVW	TEST STD	TEST NOTE
● BH01-24, S-1	2.5	LIMESTONE		5	25	69	10.3	JDT ASW	D6913	
■ BH01-24, S-2	5.0	LIMESTONE				68	13.9	JDT ASW	D1140	
▲ BH04-24, G-1	0.0	SILTY CLAY with SAND	CL-ML	6	23	71	4.5	JDT ASW	D6913	
◆ BH06-24, S-1	2.5	LIMESTONE				55	6.9	JDT ASW	D1140	
○ BH08-24, S-2	5.0	LIMESTONE		16	30	54	4.9	JDT ASW	D6913	

* Where indicated by *, the USCS Group Name was based on visual-manual examination procedures (ASTM D2488) and the grain size distribution test results.
ABBREVIATIONS: NAT WC = natural moisture content; RVW = reviewed by; STD = Standard; USCS = Unified Soil Classification System code; ~ = approximately (used when measured but not greater than 0.5%)

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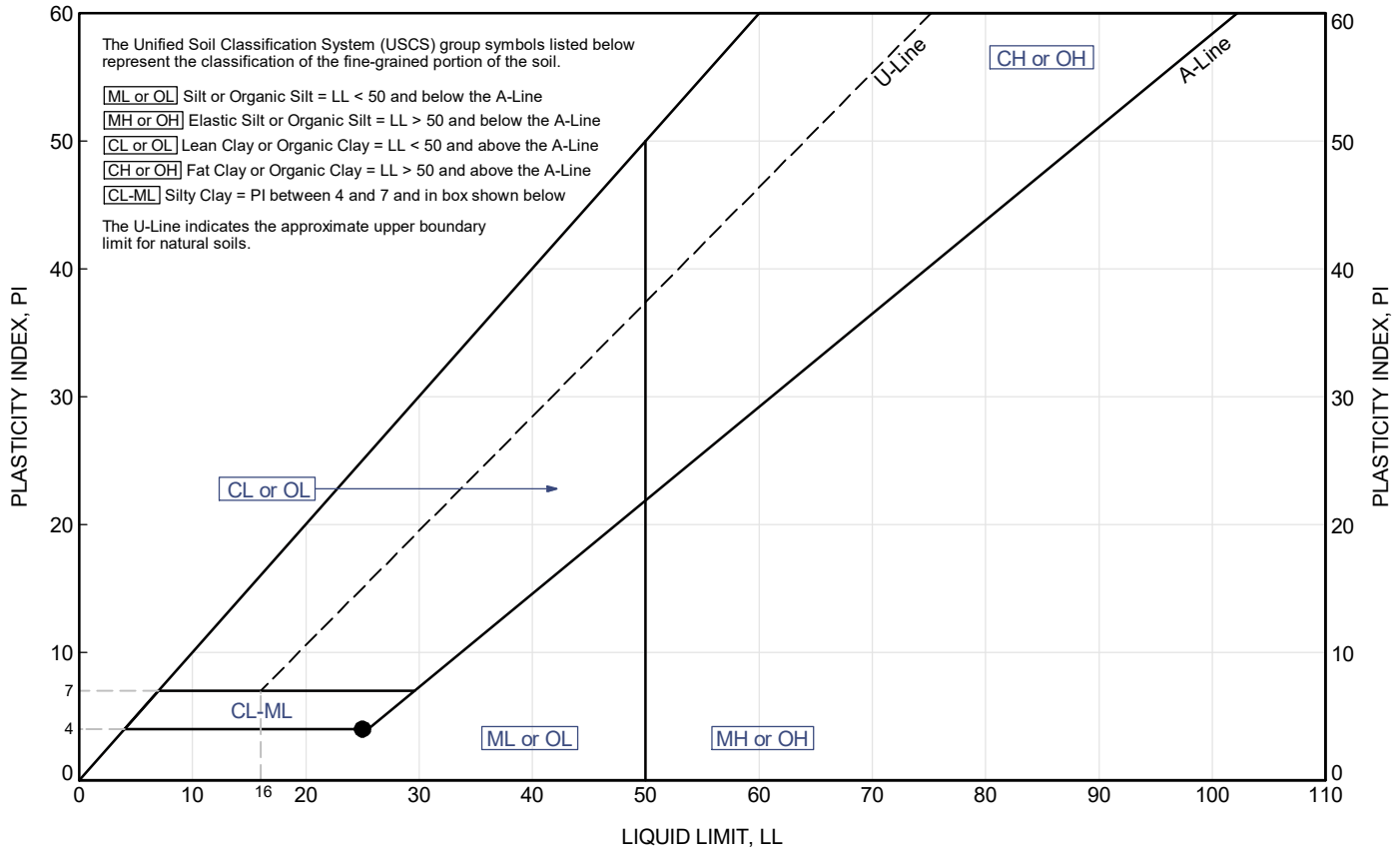
Grand Canyon National Park South Rim WWTP Access Road
South Rim Village, Arizona

Plasticity Chart



EXPLORATION AND SAMPLE NUMBER	DEPTH (feet)	UNIFIED SOIL CLASSIFICATION SYSTEM (USCS) GROUP NAME	USCS SYMBOL	LL	PL	PI	FINES (%)	NAT MC %	TEST BY/RVW	TEST STD	TEST NOTE
● BH04-24, G-1	0.0	SILTY CLAY with SAND	CL-ML	25	21	4	71	4.5	JYS ASW	D4318	

* Where indicated by *, the USCS Group Name was based on visual-manual examination procedures (ASTM D2488) and the Atterberg Limits test results.
ABBREVIATIONS: LL = liquid limit; NAT MC = natural moisture content; n/a = test attempted; NP = nonplastic; PI = plasticity index; PL = plastic limit; STD = standard; RVW = reviewed by; USCS = Unified Soil Classification System symbol

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UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS

ASTM D7012-14, Method C

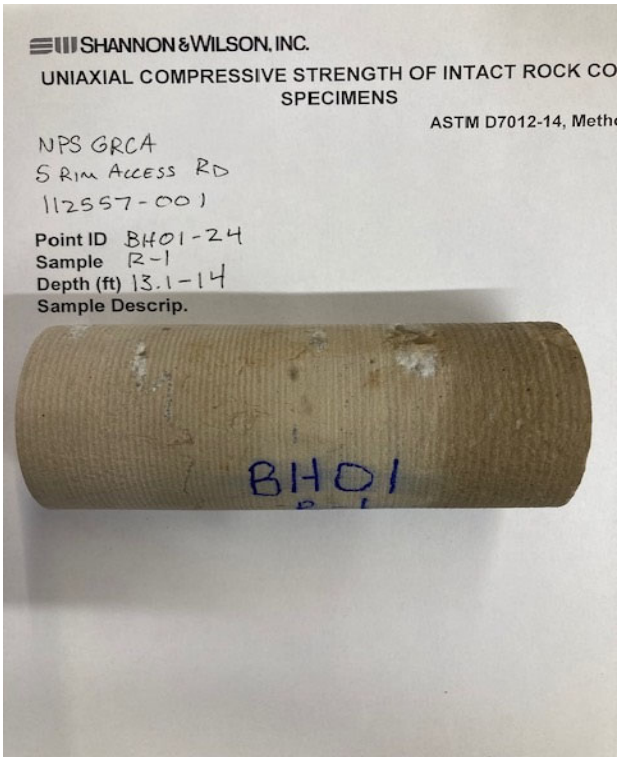
Grand Canyon National Park South Rim WWTP Access Road	**Point ID**	**BH01-24**
	Sample	**R-1**
	Depth	**13.1' - 14'**
	Sample Descrip.	**Limestone**

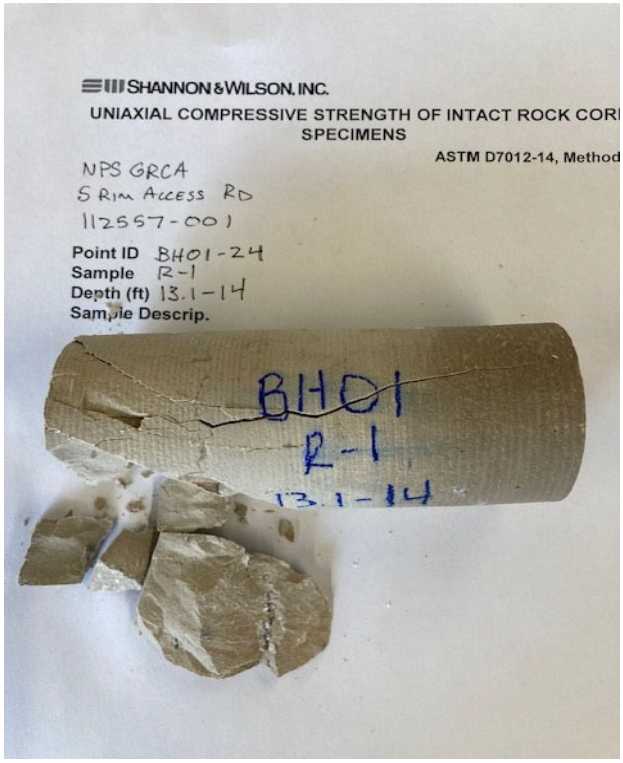
Specimen Data and Test Results

Specimen Data:		
Diameter	1.86	in
Length	4.58	in
L/D Ratio	2.46	
Area	2.73	in^2
Mass	494.08	g
Water Content	6.9	%
Bulk S.G.	2.41	
Unit Weight*	150.7	pcf
*estimated		

Specimen Test Results:			
Maximum Load		10,455	lbs
Compressive Strength		3,800	psi
Compressive Strength		26	Mpa
Time to Break			
	Minutes	1	
	Seconds	57	
Sample Break Type	Intact	X	
	Fracture		
	Stress Rate	0.22	Mpa/s

Specimen Photographs





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UCS_Rock_ASTM_D7012_No Strain_BH01-24, Run-1.xlsx

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UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS

ASTM D7012-14, Method C

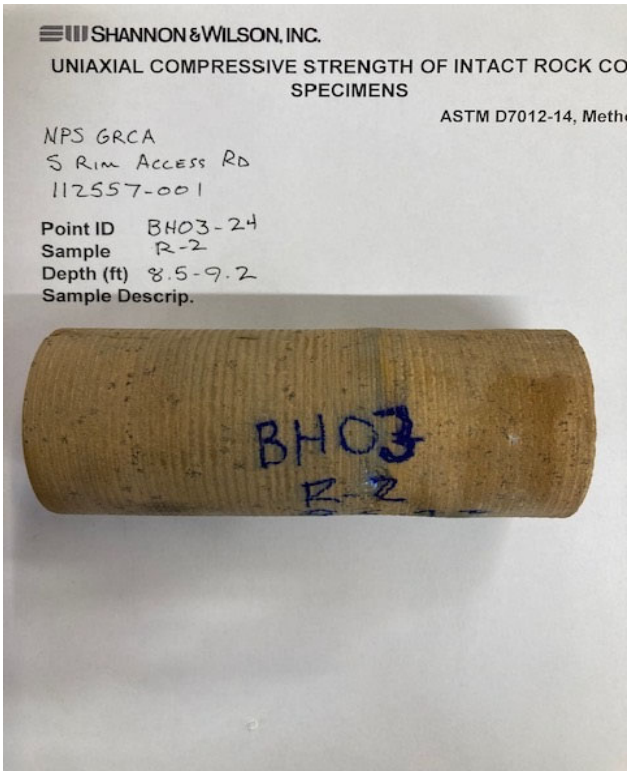
Grand Canyon National Park **South Rim WWTP Access Road**	**Point ID** BH03-24 **Sample** R-2 **Depth** 8.5' - 9.2' **Sample Descrip.** Limestone

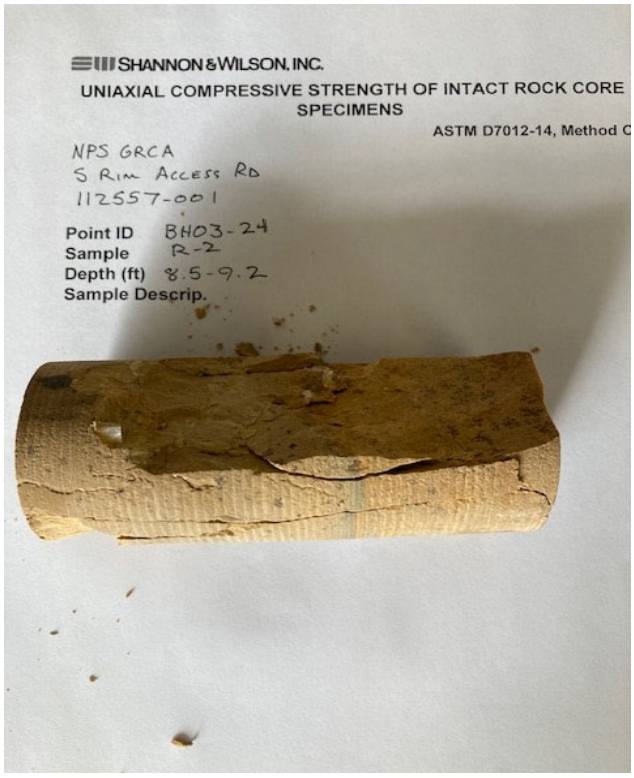
Specimen Data and Test Results

Specimen Data:		
Diameter	1.87	in
Length	4.59	in
L/D Ratio	2.46	
Area	2.73	in^2
Mass	479.45	g
Water Content	5.5	%
Bulk S.G.	2.33	
Unit Weight*	145.6	pcf
*estimated		

Specimen Test Results:			
Maximum Load		17,430	lbs
Compressive Strength		6,400	psi
Compressive Strength		44	Mpa
Time to Break			
	Minutes	2	
	Seconds	50	
Sample Break Type	Intact	X	
	Fracture		
	Stress Rate	0.26	Mpa/s

Specimen Photographs





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UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS

ASTM D7012-14, Method C

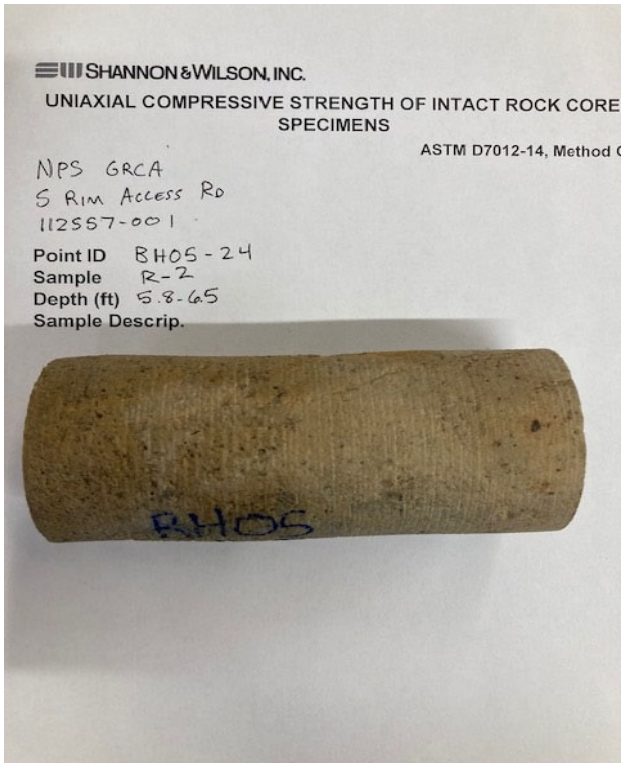
Grand Canyon National Park South Rim WWTP Access Road	**Point ID**	**BH05-24**
	Sample	**R-2**
	Depth	**5.8' - 6.5'**
	Sample Descrip.	**Limestone**

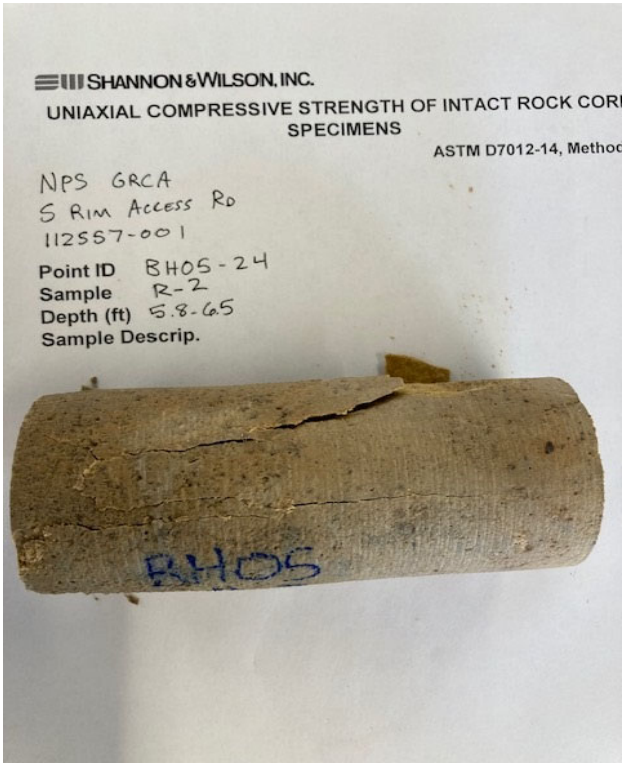
Specimen Data and Test Results

Specimen Data:		
Diameter	1.87	in
Length	4.58	in
L/D Ratio	2.46	
Area	2.73	in^2
Mass	460.39	g
Water Content	2.6	%
Bulk S.G.	2.25	
Unit Weight*	140.2	pcf
*estimated		

Specimen Test Results:			
Maximum Load		10,760	lbs
Compressive Strength		3,900	psi
Compressive Strength		27	Mpa
Time to Break			
	Minutes	1	
	Seconds	24	
Sample Break Type	Intact	X	
	Fracture		
	Stress Rate	0.32	Mpa/s

Specimen Photographs





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UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS

ASTM D7012-14, Method C

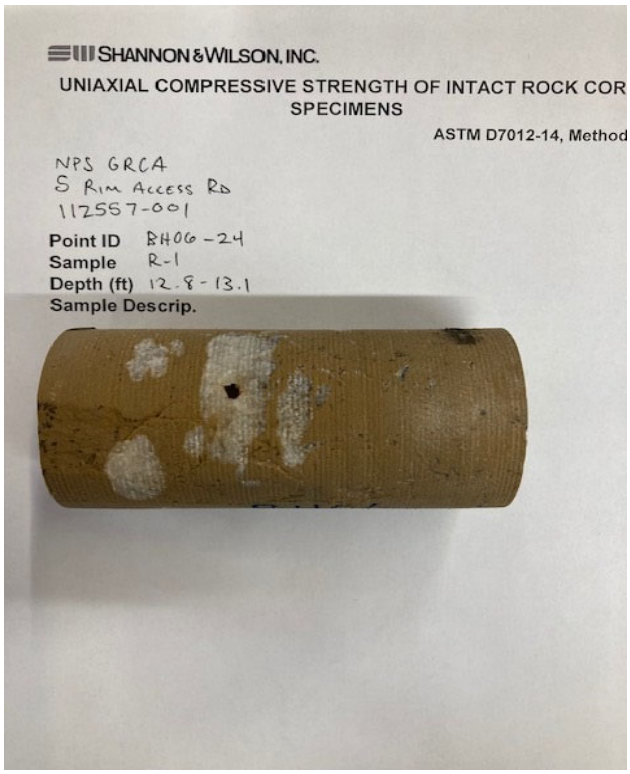
Grand Canyon National Park South Rim WWTP Access Road	**Point ID**	**BH06-24**
	Sample	**R-1**
	Depth	**12.8' - 13.1'**
	Sample Descrip.	**Limestone**

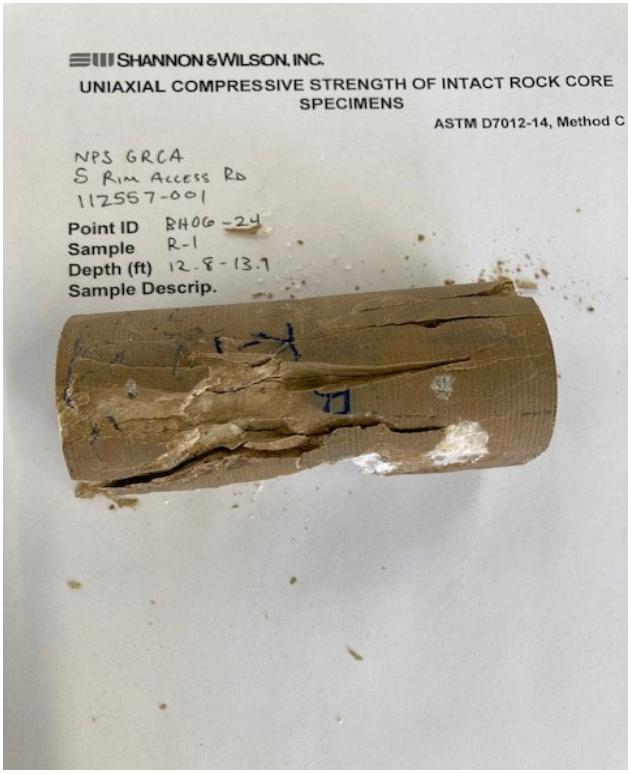
Specimen Data and Test Results

Specimen Data:		
Diameter	1.87	in
Length	4.12	in
L/D Ratio	2.21	
Area	2.73	in^2
Mass	463.80	g
Water Content	1.7	%
Bulk S.G.	2.52	
Unit Weight*	157.1	pcf
*estimated		

Specimen Test Results:			
Maximum Load		15,750	lbs
Compressive Strength		5,800	psi
Compressive Strength		40	Mpa
Time to Break			
	Minutes	2	
	Seconds	30	
Sample Break Type	Intact	X	
	Fracture		
	Stress Rate	0.27	Mpa/s

Specimen Photographs





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UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS

ASTM D7012-14, Method C

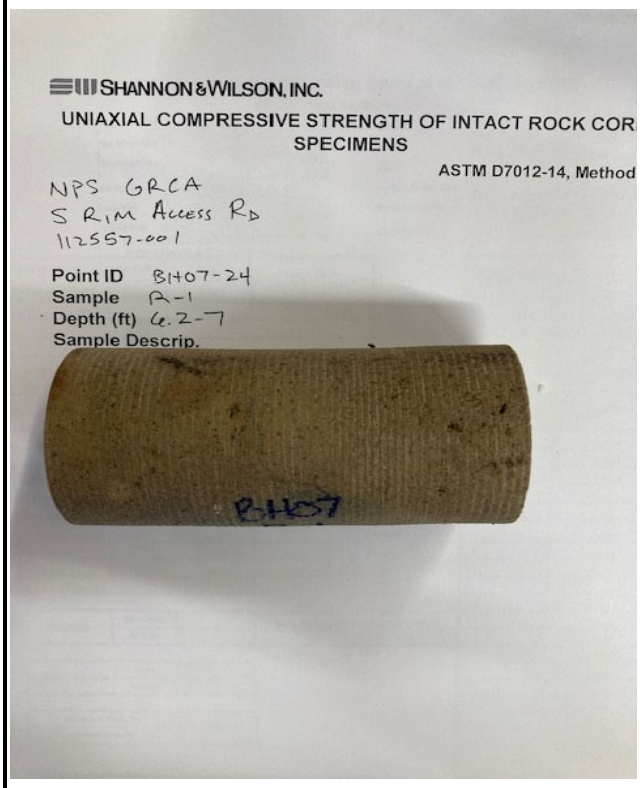
Grand Canyon National park **South Rim WWTP Access Road**	**Point ID** BH07-24 **Sample** R-1 **Depth** 6.2' - 7' **Sample Descrip.** Limestone

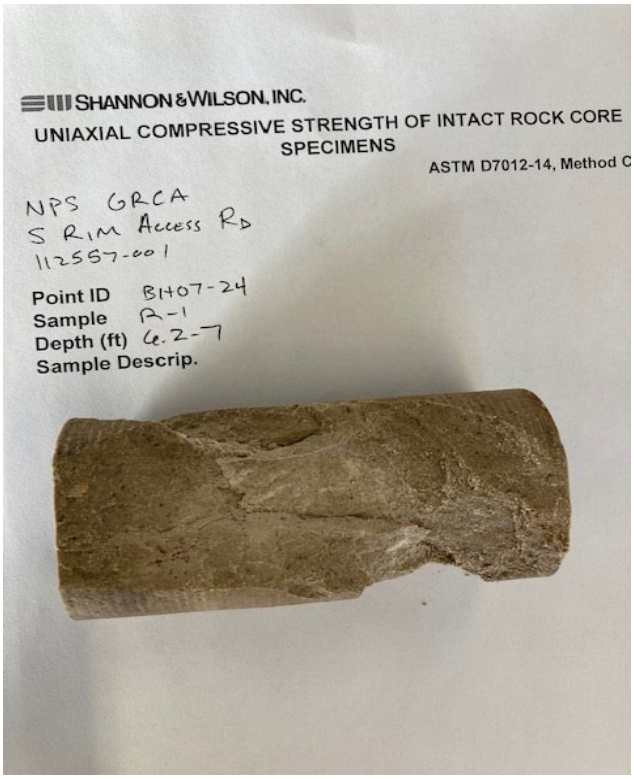
Specimen Data and Test Results

Specimen Data:		
Diameter	1.86	in
Length	4.12	in
L/D Ratio	2.21	
Area	2.72	in^2
Mass	426.71	g
Water Content	1.9	%
Bulk S.G.	2.32	
Unit Weight*	144.9	pcf
*estimated		

Specimen Test Results:			
Maximum Load		22,150	lbs
Compressive Strength		8,100	psi
Compressive Strength		56	Mpa
Time to Break			
	Minutes	1	
	Seconds	5	
Sample Break Type	Intact	X	
	Fracture		
	Stress Rate	0.86	Mpa/s

Specimen Photographs





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UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS

ASTM D7012-14, Method C

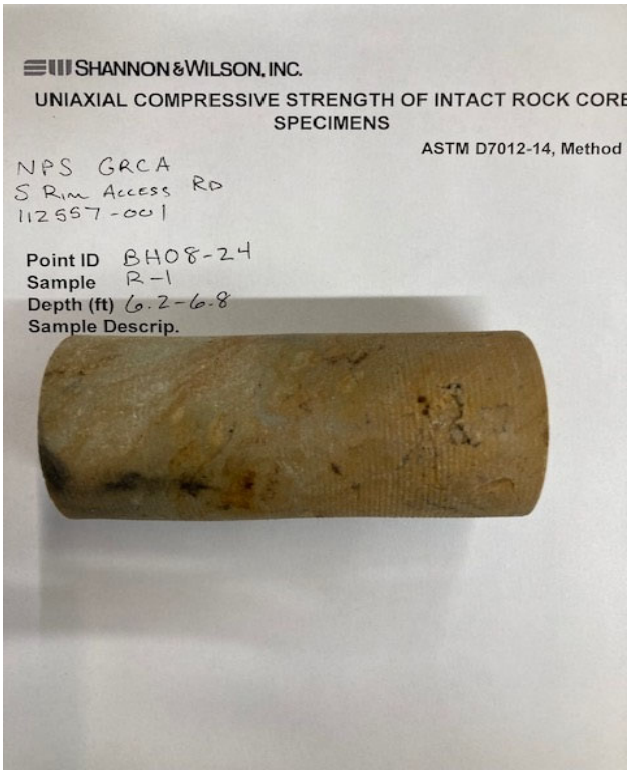
Grand Canyon National Park **South Rim WWTP Access Road**	**Point ID** BH08-24 **Sample** R-1 **Depth** 6.2' - 6.8' **Sample Descrip.** Limestone

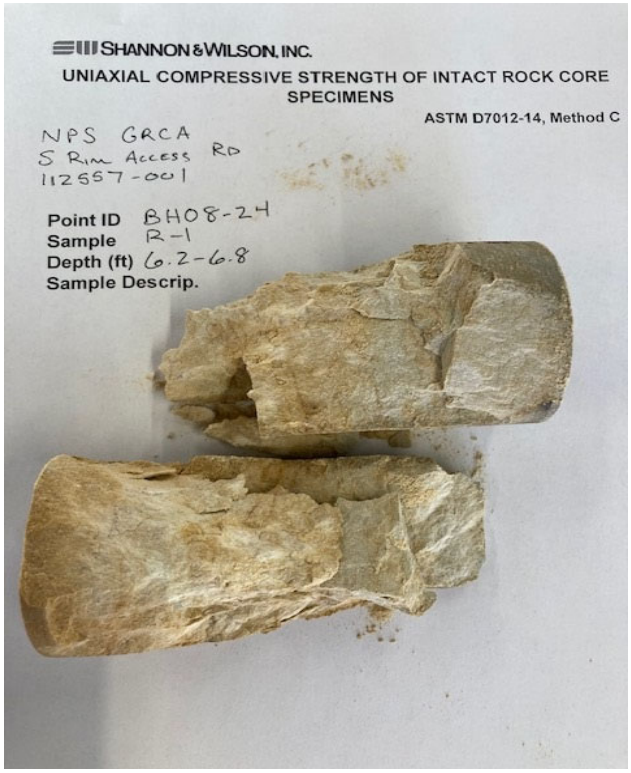
Specimen Data and Test Results

Specimen Data:		
Diameter	1.86	in
Length	4.11	in
L/D Ratio	2.21	
Area	2.73	in^2
Mass	442.27	g
Water Content	1.1	%
Bulk S.G.	2.40	
Unit Weight*	150.1	pcf
*estimated		

Specimen Test Results:			
Maximum Load		24,795	lbs
Compressive Strength		9,100	psi
Compressive Strength		63	Mpa
Time to Break			
	Minutes	3	
	Seconds	7	
Sample Break Type	Intact	X	
	Fracture		
	Stress Rate	0.34	Mpa/s

Specimen Photographs





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UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS

ASTM D7012-14, Method C

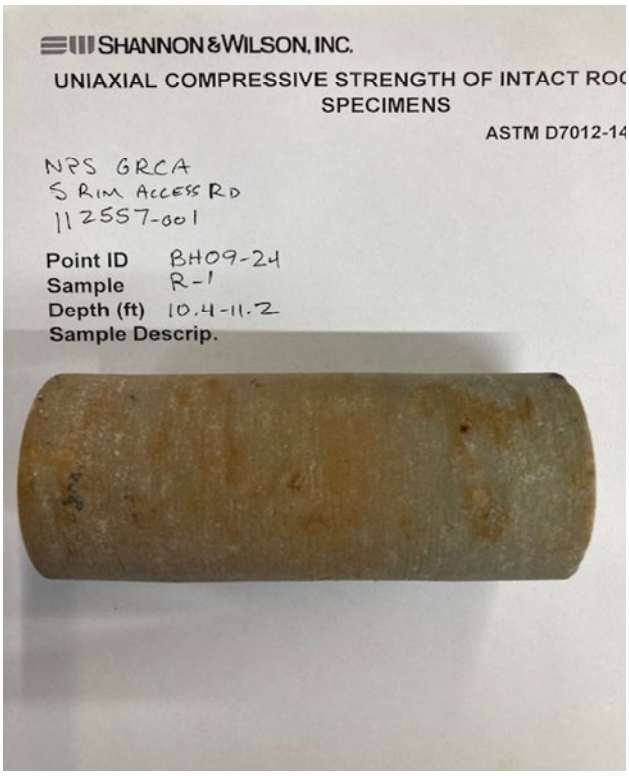
Grand Canyon National Park **South Rim WWTP Access Road**	**Point ID** BH09-24 **Sample** R-1 **Depth** 10.4' - 11.2' **Sample Descrip.** Limestone

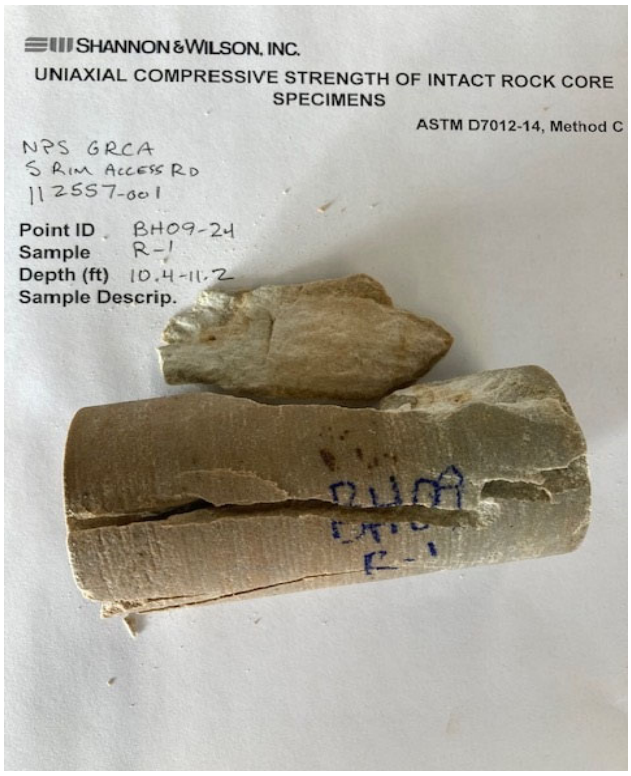
Specimen Data and Test Results

Specimen Data:		
Diameter	1.86	in
Length	4.11	in
L/D Ratio	2.21	
Area	2.72	in^2
Mass	440.39	g
Water Content	1.1	%
Bulk S.G.	2.40	
Unit Weight*	150.1	pcf
*estimated		

Specimen Test Results:			
Maximum Load		22,045	lbs
Compressive Strength		8,100	psi
Compressive Strength		56	Mpa
Time to Break			
	Minutes	1	
	Seconds	44	
Sample Break Type	Intact	X	
	Fracture		
	Stress Rate	0.54	Mpa/s

Specimen Photographs





Checked By: ASW Date: 10/29/24

Tested By: JYS Date: 10/24/24

UCS_Rock_ASTM_D7012_No Strain_BH09-24, Run-1.xlsx

112557-001

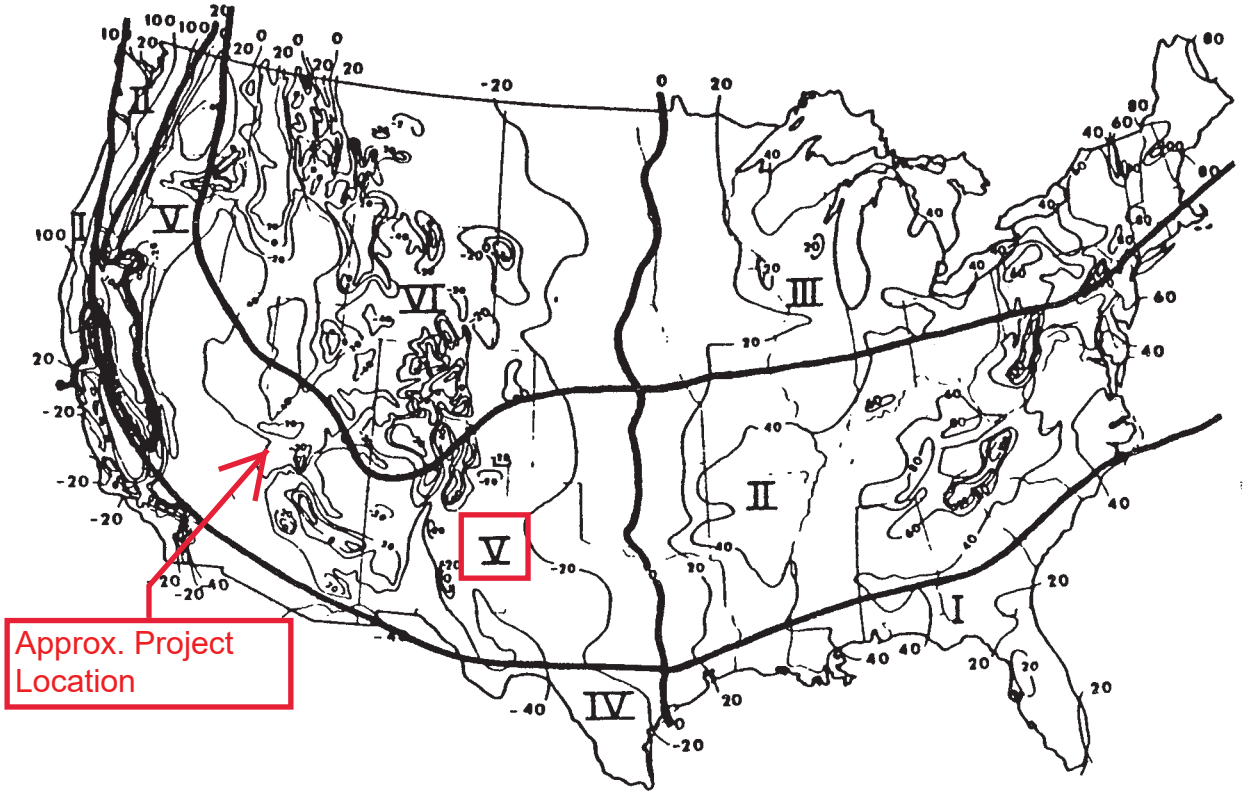
APPENDIX C: PAVEMENT DESIGN CALCULATIONS

Appendix C

Pavement Design Calculations

Exhibits

Exhibit C-1: AASHTO 1993 AGDPS – The Six Climate Regions in the United States
Exhibit C-2: CFLHD Supplement 11.4.2-1 – AASHTO and ASTM Soil Classification
Exhibit C-3: AASHTO 1993 AGDPS – Recommended Aggregate Base Thickness
Exhibit C-4: Flexible Pavement Design Worksheets (30,000 ESALs)
Exhibit C-5: Flexible Pavement Design Worksheets (50,000 ESALs)
Exhibit C-6: LTPPBind Output



REGION	CHARACTERISTICS
I	Wet, no freeze
II	Wet, freeze – thaw cycling
III	Wet, hard-freeze, spring thaw
IV	Dry, no freeze
V	Dry, freeze – thaw cycling
VI	Dry, hard freeze, spring thaw

Figure 4.1. The Six Climatic Regions in the United States (*12*)

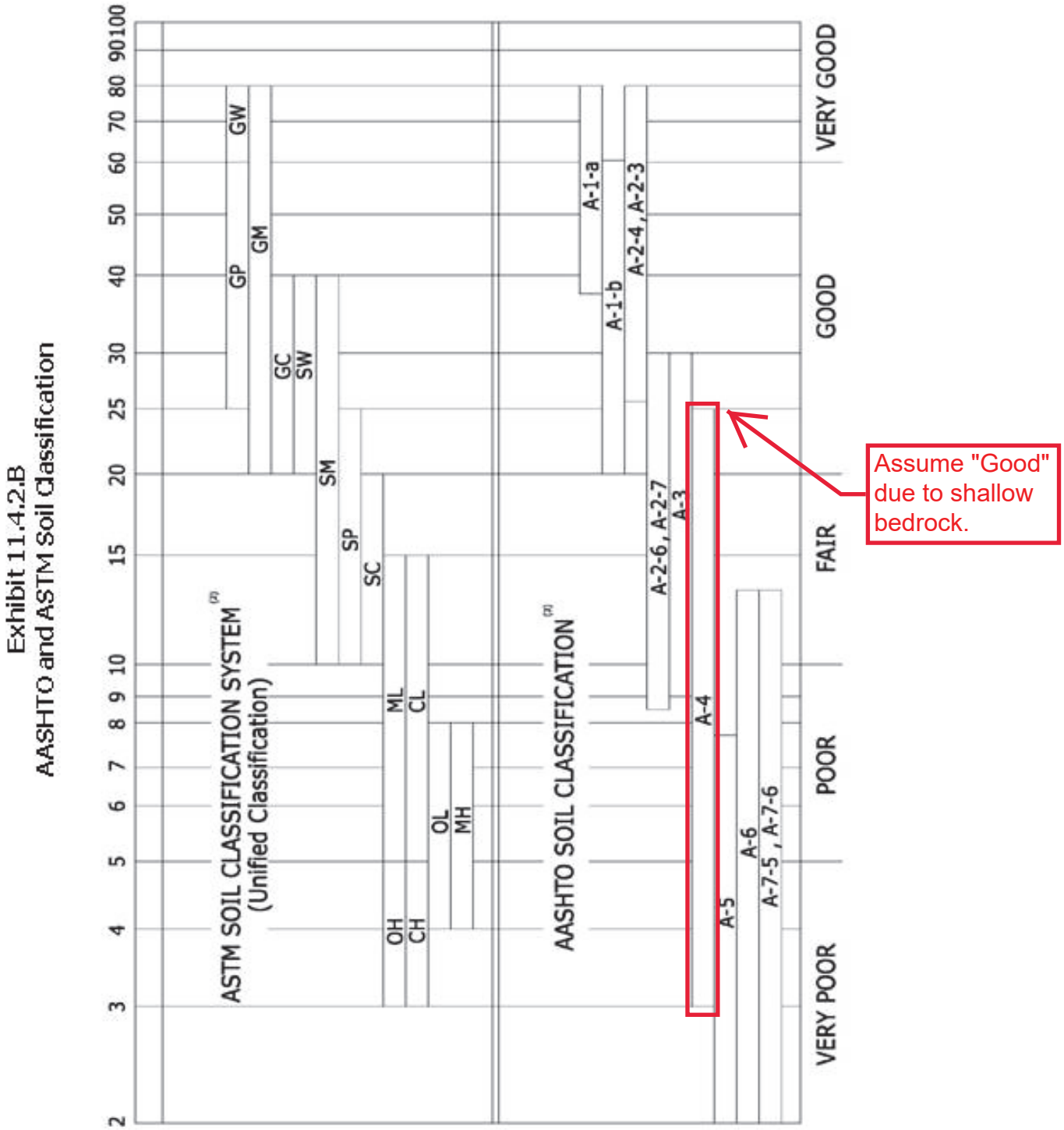


Exhibit 11.4.2.B
AASHTO and ASTM Soil Classification
ASTM SOIL CLASSIFICATION SYSTEM
(Unified Classification)
AASHTO SOIL CLASSIFICATION
GW
GP
GM
GC
SW
SM
SP
SC
ML
CL
OL
MH
OH
CH
A-1-a
A-1-b
A-2-4, A-2-3
A-2-6, A-2-7
A-3
A-4
A-5
A-6
A-7-5, A-7-6
2 3 4 5 6 7 8 9 10 15 20 25 30 40 50 60 70 80 90 100
VERY POOR
POOR
FAIR
GOOD
VERY GOOD
Assume "Good" due to shallow bedrock.

Table 4.10. Aggregate Surfaced Road Design Catalog: Recommended Aggregate Base Thickness (in Inches) for the Six U.S. Climatic Regions, Five Relative Qualities of Roadbed Soil and Three Levels of Traffic

Relative Quality of Roadbed Soil	Traffic Level	U.S. Climatic Region					
		I	II	III	IV	V	VI
Very good	High	8*	10	15	7	9	15
	Medium	6	8	11	5	7	11
	Low	4	4	6	4	4	6
Good	High	11	12	17	10	11	17
	Medium	8	9	12	7	9	12
	Low	4	5	7	4	5	7
Fair	High	13	14	17	12	13	17
	Medium	11	11	12	10	10	12
	Low	6	6	7	5	5	7
Poor	High	**	**	**	**	**	**
	Medium	**	**	**	15	15	**
	Low	9	10	9	8	8	9
Very poor	High	**	**	**	**	**	**
	Medium	**	**	**	**	**	**
	Low	11	11	10	8	8	9

*Thickness of aggregate base required (in inches)

**Higher type pavement design recommended

Flexible Pavement Design Worksheet

Job No.: 112557-001
Location: Grand Canyon National Park South Rim WWTP Access Road
Comment: Analysis based on the 1993 AASHTO Guide for the Design of Pavement Structures with parameter guidelines from the 2017 Arizona DOT Pavement Design Manual.
Analysis 1: Full Depth HMA (Hot Mix Asphalt)

1. Pavement Design Life: Section 2.0 (ADOT, 2017) — 20.0 years

2. Traffic Loading (W_{18}): Per request from Jacobs — 18k ESALs: 30,000 per lane

3. Serviceability:
   - p_0: 4 — Table 2-2 for <= 500 ADT (ADOT, 2017)
   - p_t: 2.4 — Table 2-2 for <= 500 ADT (ADOT, 2017)
   - ΔPSI: 1.6

4. Subgrade Resilient Modulus (M_R):
   - R-value: 35.0 — Equation in Section 2.1.5.2 (ADOT, 2017)

   MR = [1815 + 225 * (R-value) + 2.40 * (R-value)^2] / [0.6 * (SVF)^0.6] = 11,865 psi
   SVF = 2.6 — Table 2-4 (ADOT, 2017)
   M_R: 12,000 psi

5. Reliability:
   - R: 75 % — Table 2-1 for <= 500 ADT (ADOT, 2017)
   - Z_R: -0.674

6. Design Standard Deviation (S_o):
   - S_o: 0.45 — Section 2.1.3 (ADOT, 2017)

7. Required Structural Numbers (SN_i):

Analysis M_R	
12,000	SN_1: **1.429**
-NA-	SN_2: **-NA-**
-NA-	SN_3: **-NA-**

$$\log_{10}(W_{18}) = Z_R\ S_o + 9.36\ \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32\ \log_{10}(M_R) - 8.07$$

Layer Analysis

8. Pavement Materials Characterization:

Layer	Material	Structural Layer Coefficients	Drainage Coefficients	Layer Modulus (psi)
1	HMA	a_1: 0.44	-	-
2		a_2:	m_2:	
3		a_3:	m_3:	

9. Solutions for thicknesses: [Figure 3.2, Part II of 1993 AASHTO]

$SN^*_1 = a_1D^*_1 >= SN_1$
$SN^*_2 = a_1D^*_1 + a_2D^*_2m_2 >= SN_2$
$SN^*_3 = a_1D^*_1 + a_2D^*_2m_2 + a_3D^*_3m_3 >= SN_3$

Recommended Thicknesses				
Layer	Material	Thickness (D^*_i)	SN^*_i	SN_i
1	HMA	4.0 inches	1.760	1.429
2		inches		
3		inches		

Note: Required SN <= Pavement SN, Design is Acceptable

Flexible Pavement Design Worksheet

Job No.: 112557-001
Location: Grand Canyon National Park South Rim WWTP Access Road
Comment: Analysis based on the 1993 AASHTO Guide for the Design of Pavement Structures with parameter guidelines from the 2017 Arizona DOT Pavement Design Manual.
Analysis 2: HMA (Hot Mix Asphalt) over ABC (Aggregate Base Course)

1. Pavement Design Life: Section 2.0 (ADOT, 2017) — 20.0 years

2. Traffic Loading (W_{18}): Per request from Jacobs — 18k ESALs: 30,000 per lane

3. Serviceability:
   - p_0: 4 — Table 2-2 for <= 500 ADT (ADOT, 2017)
   - p_t: 2.4 — Table 2-2 for <= 500 ADT (ADOT, 2017)
   - ΔPSI: 1.6

4. Subgrade Resilient Modulus (M_R):
   - R-value: 35.0 — Equation in Section 2.1.5.2 (ADOT, 2017)

   MR = [1815 + 225 * (R-value) + 2.40 * (R-value)^2] / [0.6 * (SVF)^0.6] = 11,865 psi
   SVF = 2.6 — Table 2-4 (ADOT, 2017)
   M_R: 12,000 psi

5. Reliability:
   - R: 75 % — Table 2-1 for <= 500 ADT (ADOT, 2017)
   - Z_R: -0.674

6. Design Standard Deviation (S_o):
   - S_o: 0.45 — Section 2.1.3 (ADOT, 2017)

7. Required Structural Numbers (SN_i):

Analysis M_R		
30,000	SN_1:	**0.929**
12,000	SN_2:	**1.429**
-NA-	SN_3:	**-NA-**

$$\log_{10}(W_{18}) = Z_R\ S_o + 9.36\ \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32\ \log_{10}(M_R) - 8.07$$

Layer Analysis

8. Pavement Materials Characterization:

Layer	Material	Structural Layer Coefficients	Drainage Coefficients	Layer Modulus (psi)
1	HMA	a_1: 0.44	-	-
2	ABC	a_2: 0.10	m_2: 0.92	30,000
3		a_3:	m_3:	

9. Solutions for thicknesses: [Figure 3.2, Part II of 1993 AASHTO]

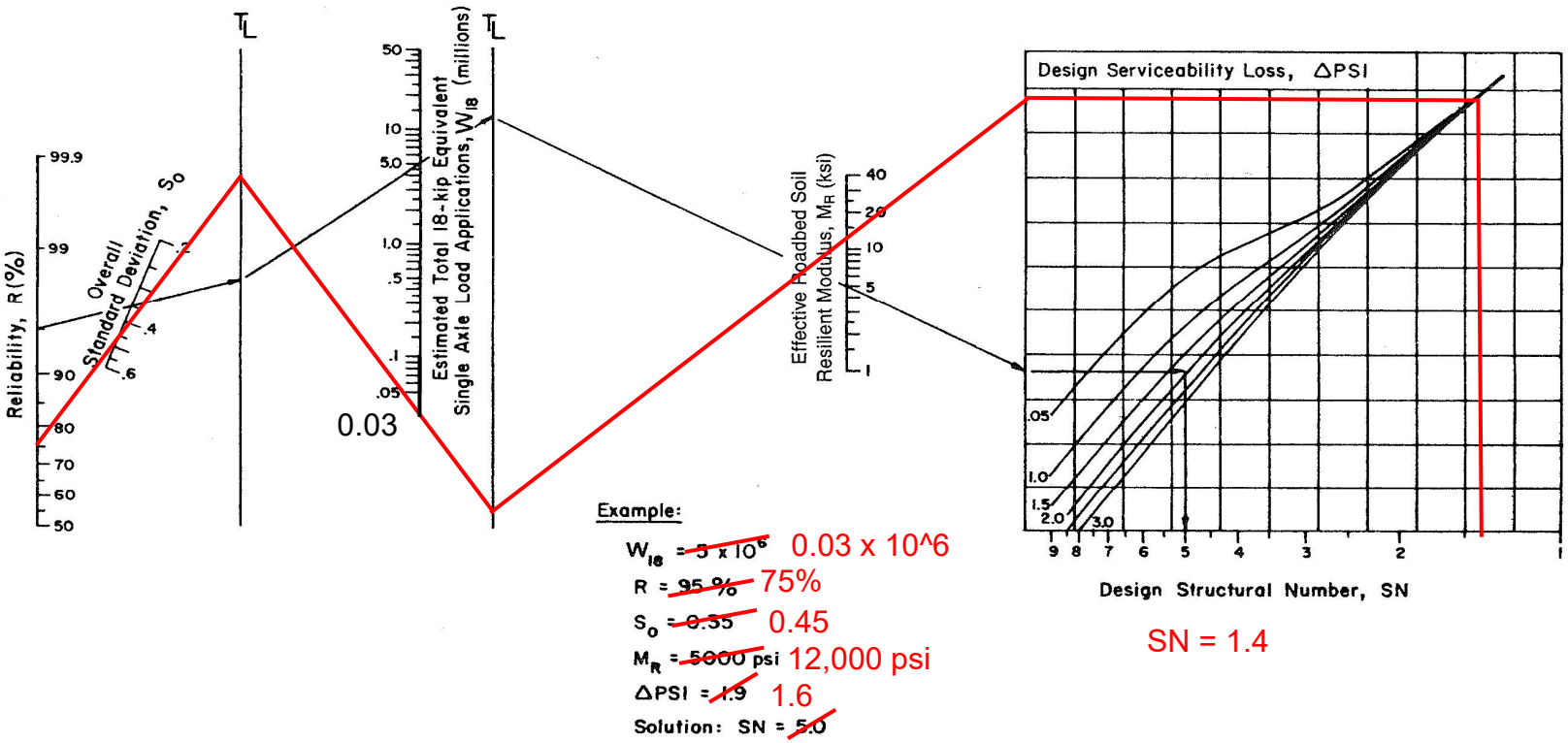
$SN^*_1 = a_1D^*_1 >= SN_1$
$SN^*_2 = a_1D^*_1 + a_2D^*_2m_2 >= SN_2$
$SN^*_3 = a_1D^*_1 + a_2D^*_2m_2 + a_3D^*_3m_3 >= SN_3$

Recommended Thicknesses				
Layer	Material	Thickness (D^*_i)	SN^*_i	SN_i
1	HMA	3.0 inches	1.320	0.929
2	ABC	4.0 inches	1.688	1.429
3		inches		

Note: Required SN <= Pavement SN, Design is Acceptable

NOMOGRAPH SOLVES:

$$\log_{10} W_{18} = Z_R * S_o + 9.36 * \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 * \log_{10} M_R - 8.07$$



Example:

W_{18} = ~~5 x 10^6~~ 0.03 x 10^6

R = ~~95 %~~ 75%

S_o = ~~0.35~~ 0.45

M_R = ~~5000 psi~~ 12,000 psi

ΔPSI = ~~1.9~~ 1.6

Solution: SN = ~~5.0~~

Figure 3.1. Design Chart for Flexible Pavements Based on Using Mean Values for Each Input

0.45 Section 2.1.3 (ADOT, 2017)

#REF!

Flexible Pavement Design Worksheet

Job No.: 112557-001
Location: Grand Canyon National Park South Rim WWTP Access Road
Comment: Analysis based on the 1993 AASHTO Guide for the Design of Pavement Structures with parameter guidelines from the 2017 Arizona DOT Pavement Design Manual.
Analysis 1: Full Depth HMA (Hot Mix Asphalt)

1. Pavement Design Life: Section 2.0 (ADOT, 2017) — 20.0 years

2. Traffic Loading (W_{18}): Per 1993AGDPS minimum — 18k ESALs: 50,000 per lane

3. Serviceability:
   - p_0: 4 — Table 2-2 for <= 500 ADT (ADOT, 2017)
   - p_t: 2.4 — Table 2-2 for <= 500 ADT (ADOT, 2017)
   - ΔPSI: 1.6

4. Subgrade Resilient Modulus (M_R):
   - R-value: 35.0 — Equation in Section 2.1.5.2 (ADOT, 2017)

   MR = [1815 + 225 * (R-value) + 2.40 * (R-value)^2] / [0.6 * (SVF)^0.6] = 11,865 psi
   SVF = 2.6 — Table 2-4 (ADOT, 2017)
   M_R: 12,000 psi

5. Reliability:
   - R: 75 % — Table 2-1 for <= 500 ADT (ADOT, 2017)
   - Z_R: -0.674

6. Design Standard Deviation (S_o):
   - S_o: 0.45 — Section 2.1.3 (ADOT, 2017)

7. Required Structural Numbers (SN_i):

Analysis M_R		
12,000	SN_1:	**1.569**
-NA-	SN_2:	**-NA-**
-NA-	SN_3:	**-NA-**

$$\log_{10}(W_{18}) = Z_R\ S_o + 9.36\ \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32\ \log_{10}(M_R) - 8.07$$

Layer Analysis

8. Pavement Materials Characterization:

Layer	Material	Structural Layer Coefficients	Drainage Coefficients	Layer Modulus (psi)
1	HMA	a_1: 0.44	-	-
2		a_2:	m_2:	
3		a_3:	m_3:	

9. Solutions for thicknesses: [Figure 3.2, Part II of 1993 AASHTO]

$SN^*_1 = a_1D^*_1 >= SN_1$
$SN^*_2 = a_1D^*_1 + a_2D^*_2m_2 >= SN_2$
$SN^*_3 = a_1D^*_1 + a_2D^*_2m_2 + a_3D^*_3m_3 >= SN_3$

Recommended Thicknesses				
Layer	Material	Thickness (D^*_i)	SN^*_i	SN_i
1	HMA	4.0 inches	1.760	1.569
2		inches		
3		inches		

Note: Required SN <= Pavement SN, Design is Acceptable

Flexible Pavement Design Worksheet

Job No.: 112557-001
Location: Grand Canyon National Park South Rim WWTP Access Road
Comment: Analysis based on the 1993 AASHTO Guide for the Design of Pavement Structures with parameter guidelines from the 2017 Arizona DOT Pavement Design Manual.
Analysis 2: HMA (Hot Mix Asphalt) over ABC (Aggregate Base Course)

1. Pavement Design Life: Section 2.0 (ADOT, 2017) — 20.0 years

2. Traffic Loading (W_{18}): Per 1993AGDPS minimum — 18k ESALs: 50,000 per lane

3. Serviceability:
   - p_0: 4 — Table 2-2 for <= 500 ADT (ADOT, 2017)
   - p_t: 2.4 — Table 2-2 for <= 500 ADT (ADOT, 2017)
   - ΔPSI: 1.6

4. Subgrade Resilient Modulus (M_R):
   - R-value: 35.0 — Equation in Section 2.1.5.2 (ADOT, 2017)

   MR = [1815 + 225 * (R-value) + 2.40 * (R-value)^2] / [0.6 * (SVF)^0.6] = 11,865 psi
   SVF = 2.6 — Table 2-4 (ADOT, 2017)
   M_R: 12,000 psi

5. Reliability:
   - R: 75 % — Table 2-1 for <= 500 ADT (ADOT, 2017)
   - Z_R: -0.674

6. Design Standard Deviation (S_o):
   - S_o: 0.45 — Section 2.1.3 (ADOT, 2017)

7. Required Structural Numbers (SN_i):

Analysis M_R	
30,000	SN_1: **1.038**
12,000	SN_2: **1.568**
-NA-	SN_3: **-NA-**

$$\log_{10}(W_{18}) = Z_R\ S_o + 9.36\ \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32\ \log_{10}(M_R) - 8.07$$

Layer Analysis

8. Pavement Materials Characterization:

Layer	Material	Structural Layer Coefficients	Drainage Coefficients	Layer Modulus (psi)
1	HMA	a_1: 0.44	-	-
2	ABC	a_2: 0.10	m_2: 0.92	30,000
3		a_3:	m_3:	

9. Solutions for thicknesses: [Figure 3.2, Part II of 1993 AASHTO]

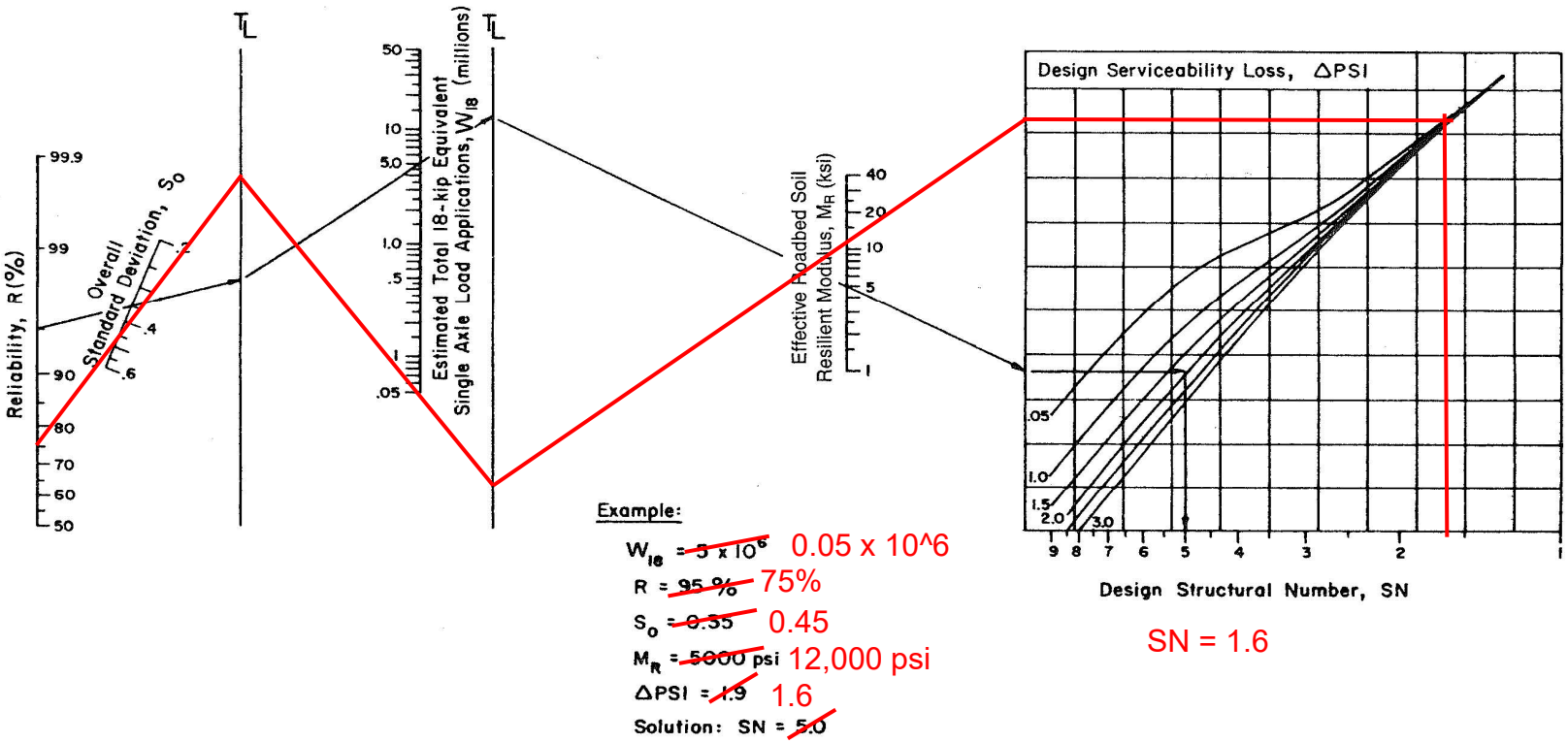
$SN^*_1 = a_1D^*_1 >= SN_1$
$SN^*_2 = a_1D^*_1 + a_2D^*_2m_2 >= SN_2$
$SN^*_3 = a_1D^*_1 + a_2D^*_2m_2 + a_3D^*_3m_3 >= SN_3$

Recommended Thicknesses				
Layer	Material	Thickness (D^*_i)	SN^*_i	SN_i
1	HMA	3.0 inches	1.320	1.038
2	ABC	4.0 inches	1.688	1.568
3		inches		

Note: Required SN <= Pavement SN, Design is Acceptable

NOMOGRAPH SOLVES:

$$\log_{10} W_{18} = Z_R * S_o + 9.36 * \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 * \log_{10} M_R - 8.07$$



Example:

W_{18} = ~~5 x 10^6~~ 0.05 x 10^6

R = ~~95 %~~ 75%

S_o = ~~0.35~~ 0.45

M_R = ~~5000 psi~~ 12,000 psi

ΔPSI = ~~1.9~~ 1.6

Solution: SN = ~~5.0~~

SN = 1.6

Figure 3.1. Design Chart for Flexible Pavements Based on Using Mean Values for Each Input

0.45 Section 2.1.3 (ADOT, 2017)

#REF!

LTPPBind Version 3.1 Beta

Depth = 0 mm

PG Binder Selection

Parameter	A=0 km	B=8 km	C=20 km	D=52 km	E=70 km
Station ID	✓AZ3596	✓AZ6471	✓AZ1001	✗AZ8343	✗AZ1169
Elevation, m	6303	2387	7803	2976	3868
Degree-Days >10 C	2618	4948	1910	4332	4006
Low Air Temperature, C	-20.8	-3	-22.1	-9.9	-15.7
Low Air Temp. Std Dev	4.5	3	4.4	3.9	3.1

Input Data

Latitude, Degree: 36.05
Lowest Yearly Air Temperature, C: -15.3
Yearly Degree-Days>10 Deg.C: 3159
Low Air Temp. Standard Dev., Deg C: 4.0

Temperature Adjustments

Base HT PG: 58
Desired Reliability, %: 98
Depth of Layer, mm: 0

Traffic Adjustments for HT

Traffic Loading	Traffic Speed Fast	Traffic Speed Slow
Up to 3 M. ESAL	0.0	2.7
3 to 10 M. ESAL	7.1	9.5
10 to 30 M. ESAL	12.3	14.5
Above 30 M. ESAL	14.5	16.6

PG Temperature	HIGH	LOW
PG Temp. at 50% Reliability	57.8	-9.0
PG Temp. at Desired Reliability	59.5	-16.3
Adjustments for Traffic	2.7	
Adjustments for Depth	0.0	0.0
Adjusted PG Temperature	62.2	-16.3
Selected PG Binder Grade	64	-22

? Recalculate PG Save Cancel

Depth = 50 mm (~2 inches)

PG Binder Selection

Parameter	A=0 km	B=8 km	C=20 km	D=52 km	E=70 km
Station ID	✓AZ3596	✓AZ6471	✓AZ1001	✗AZ8343	✗AZ1169
Elevation, m	6303	2387	7803	2976	3868
Degree-Days >10 C	2618	4948	1910	4332	4006
Low Air Temperature, C	-20.8	-3	-22.1	-9.9	-15.7
Low Air Temp. Std Dev	4.5	3	4.4	3.9	3.1

Input Data

Latitude, Degree: 36.05
Lowest Yearly Air Temperature, C: -15.3
Yearly Degree-Days>10 Deg.C: 3159
Low Air Temp. Standard Dev., Deg C: 4.0

Temperature Adjustments

Base HT PG: 58
Desired Reliability, %: 98
Depth of Layer, mm: 50

Traffic Adjustments for HT

Traffic Loading	Traffic Speed Fast	Traffic Speed Slow
Up to 3 M. ESAL	0.0	2.7
3 to 10 M. ESAL	7.1	9.5
10 to 30 M. ESAL	12.3	14.5
Above 30 M. ESAL	14.5	16.6

PG Temperature	HIGH	LOW
PG Temp. at 50% Reliability	57.8	-9.0
PG Temp. at Desired Reliability	59.5	-16.3
Adjustments for Traffic	2.7	
Adjustments for Depth	-4.9	3.0
Adjusted PG Temperature	57.3	-13.3
Selected PG Binder Grade	58	-16

? Recalculate PG Save Cancel

Use PG 64-22 for both lifts

Grand Canyon National Park South Rim WWTP Access Road
Latitude = 36.0460 deg.
Longitude = -112.1435 deg.

IMPORTANT INFORMATION

Important Information

About Your Geotechnical Report

IMPORTANT INFORMATION

CONSULTING SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES AND FOR SPECIFIC CLIENTS.

Consultants prepare reports to meet the specific needs of specific individuals. A report prepared for a civil engineer may not be adequate for a construction contractor or even another civil engineer. Unless indicated otherwise, your consultant prepared your report expressly for you and expressly for the purposes you indicated. No one other than you should apply this report for its intended purpose without first conferring with the consultant. No party should apply this report for any purpose other than that originally contemplated without first conferring with the consultant.

THE CONSULTANT'S REPORT IS BASED ON PROJECT-SPECIFIC FACTORS.

A geotechnical/environmental report is based on a subsurface exploration plan designed to consider a unique set of project-specific factors. Depending on the project, these may include the general nature of the structure and property involved; its size and configuration; its historical use and practice; the location of the structure on the site and its orientation; other improvements such as access roads, parking lots, and underground utilities; and the additional risk created by scope-of-service limitations imposed by the client. To help avoid costly problems, ask the consultant to evaluate how any factors that change subsequent to the date of the report may affect the recommendations. Unless your consultant indicates otherwise, your report should not be used (1) when the nature of the proposed project is changed (for example, if an office building will be erected instead of a parking garage, or if a refrigerated warehouse will be built instead of an unrefrigerated one, or chemicals are discovered on or near the site); (2) when the size, elevation, or configuration of the proposed project is altered; (3) when the location or orientation of the proposed project is modified; (4) when there is a change of ownership; or (5) for application to an adjacent site. Consultants cannot accept responsibility for problems that may occur if they are not consulted after factors that were considered in the development of the report have changed.

SUBSURFACE CONDITIONS CAN CHANGE.

Subsurface conditions may be affected as a result of natural processes or human activity. Because a geotechnical/environmental report is based on conditions that existed at the time of subsurface exploration, construction decisions should not be based on a report whose adequacy may have been affected by time. Ask the consultant to advise if additional tests are desirable before construction starts; for example, groundwater conditions commonly vary seasonally.

Construction operations at or adjacent to the site and natural events such as floods, earthquakes, or groundwater fluctuations may also affect subsurface conditions and, thus, the continuing adequacy of a geotechnical/environmental report. The consultant should be kept apprised of any such events and should be consulted to determine if additional tests are necessary.

MOST RECOMMENDATIONS ARE PROFESSIONAL JUDGMENTS.

Site exploration and testing identifies actual surface and subsurface conditions only at those points where samples are taken. The data were extrapolated by your consultant, who then applied judgment to render an opinion about overall subsurface conditions. The actual interface between materials may be far more gradual or abrupt than your report indicates. Actual conditions in areas not sampled may differ from those predicted in your report. While nothing can be done to prevent such situations, you and your consultant can work together to help reduce their impacts. Retaining

IMPORTANT INFORMATION

your consultant to observe subsurface construction operations can be particularly beneficial in this respect.

A REPORT'S CONCLUSIONS ARE PRELIMINARY.

The conclusions contained in your consultant's report are preliminary, because they must be based on the assumption that conditions revealed through selective exploratory sampling are indicative of actual conditions throughout a site. Actual subsurface conditions can be discerned only during earthwork; therefore, you should retain your consultant to observe actual conditions and to provide conclusions. Only the consultant who prepared the report is fully familiar with the background information needed to determine whether or not the report's recommendations based on those conclusions are valid and whether or not the contractor is abiding by applicable recommendations. The consultant who developed your report cannot assume responsibility or liability for the adequacy of the report's recommendations if another party is retained to observe construction.

THE CONSULTANT'S REPORT IS SUBJECT TO MISINTERPRETATION.

Costly problems can occur when other design professionals develop their plans based on misinterpretation of a geotechnical/environmental report. To help avoid these problems, the consultant should be retained to work with other project design professionals to explain relevant geotechnical, geological, hydrogeological, and environmental findings, and to review the adequacy of their plans and specifications relative to these issues.

BORING LOGS AND/OR MONITORING WELL DATA SHOULD NOT BE SEPARATED FROM THE REPORT.

Final boring logs developed by the consultant are based upon interpretation of field logs (assembled by site personnel), field test results, and laboratory and/or office evaluation of field samples and data. Only final boring logs and data are customarily included in geotechnical/environmental reports. These final logs should not, under any circumstances, be redrawn for inclusion in architectural or other design drawings, because drafters may commit errors or omissions in the transfer process.

To reduce the likelihood of boring log or monitoring well misinterpretation, contractors should be given ready access to the complete geotechnical engineering/environmental report prepared or authorized for their use. If access is provided only to the report prepared for you, you should advise contractors of the report's limitations, assuming that a contractor was not one of the specific persons for whom the report was prepared, and that developing construction cost estimates was not one of the specific purposes for which it was prepared. While a contractor may gain important knowledge from a report prepared for another party, the contractor should discuss the report with your consultant and perform the additional or alternative work believed necessary to obtain the data specifically appropriate for construction cost estimating purposes. Some clients hold the mistaken impression that simply disclaiming responsibility for the accuracy of subsurface information always insulates them from attendant liability. Providing the best available information to contractors helps prevent costly construction problems and the adversarial attitudes that aggravate them to a disproportionate scale.

READ RESPONSIBILITY CLAUSES CLOSELY.

Because geotechnical/environmental engineering is based extensively on judgment and opinion, it is far less exact than other design disciplines. This situation has resulted in wholly unwarranted claims

IMPORTANT INFORMATION

being lodged against consultants. To help prevent this problem, consultants have developed a number of clauses for use in their contracts, reports, and other documents. These responsibility clauses are not exculpatory clauses designed to transfer the consultant's liabilities to other parties; rather, they are definitive clauses that identify where the consultant's responsibilities begin and end. Their use helps all parties involved recognize their individual responsibilities and take appropriate action. Some of these definitive clauses are likely to appear in your report, and you are encouraged to read them closely. Your consultant will be pleased to give full and frank answers to your questions.

The preceding paragraphs are based on information provided by the ASFE/Association of Engineering Firms Practicing in the Geosciences, Silver Spring, Maryland