SPECIAL GEOTECHNICAL EXPLORATION

ROUTE 19 BRIDGES KARST REVIEW SHANNON COUNTY, MO

MODOT PROJECT NO. J9P3305

Prepared for:

HG Consult, Inc.
9111 NE. 79th Street
Kansas City, Missouri

August 19, 2022

Olsson Project No. 020-1986

olsson®

olsson®

August 19, 2022

HG. Consult, Inc.
Attn: Mr. Dave Kocour, V.P.
7733 N Wallace Avenue
Kansas City, MO 64158

Re: **Preliminary Geotechnical Study**
Route 19 Bridges Karst Review
Shannon County, Missouri
MoDOT Project No. J9P3305
Olsson Project No. 020-01986

Dear Mr. Kocour:

Olsson, Inc. (***Olsson***) has completed our review of the geophysical studies that were performed for the above referenced project. The enclosed report summarizes the findings from the Geophysical Letter Report prepared by Collier Geophysics, LLC and the Geophysics Investigation Karst Review report prepared by GeoEngineers, Inc. In addition, the report provides our supplemental geotechnical opinions regarding the bridge in relation to impacting Round Spring based on our review of the reports.

We appreciate the opportunity to provide our geotechnical engineering services for this project. If you have any questions or need further assistance, please contact us at your convenience.

Respectfully submitted,
Olsson

STATE OF MISSOURI
JAMES M. LANDRUM
NUMBER
E-28954
REGISTERED PROFESSIONAL ENGINEER
6/5/2024

Robert R. Sherwood, EI **James M. Landrum, PE**

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APPENDICES

1. PROJECT UNDERSTANDING

1.1 Geotechnical Scope

The conceptual replacement alternatives of the bridge over Spring Valley Creek (Bridge J0420) include a temporary bridge, demolition of all or part of the existing bridge, installation of new foundations, and re-alignment of the bridge approaches. The most probable alignment is presented in Attachment A of this summary report. Olsson was previously retained to complete a desktop geotechnical study of the most probable bridge alignments (Olsson Report No., 020-1986, dated March 2, 2021). This report is provided in Attachment B of this summary report. During our preliminary geotechnical study for the Route 19 Bridges project, we identified three karst features within the study area, two of which were near Bridge J0420 and warranted further study: Round Spring and Spring Valley Creek. Round Spring is a primary sinkhole located northeast of Bridge J0420. The basin has an explored well depth of 55 feet and an average flow of approximately 26 million gallons per day. Spring Valley Creek is a losing stream, having solution-enlarged openings beneath the streambed that allow surface water to rapidly enter the subsurface resulting in significant loss of the stream flow into the groundwater system.

HG Consult, Inc. (HG Consult) subsequently retained Collier Geophysics, LLC (Collier) to perform a limited geophysical survey of the area. Missouri Department of Transportation (MoDOT) and HG Consult also retained GeoEngineers, Inc. (GeoEngineers) to perform borings and to assist with karst interpretation of the Round Spring area. The reports prepared by GeoEngineers, and the report prepared by Collier are provided in Attachments C, D, and E of this summary report, respectively.

This report summarizes the findings of our preliminary geotechnical desktop study and the findings of the reports prepared by GeoEngineers and Collier and provides supplemental geotechnical opinions on how the results from these studies impact the proposed bridge location.

1.2 Study Area and Location

The roughly seven-acre geophysical study area is located in the Ozark National Scenic Riverways (ONSR) in Shannon County, Missouri. The study area included approximately 1,000 feet of Missouri Route 19, including Bridge J0420, and generally extended 100 feet (+/-) laterally from the pavement edges. The study area also extended approximately 200 feet to the southeast from the pavement edge near Round Spring. An overview map of the study area is presented below.

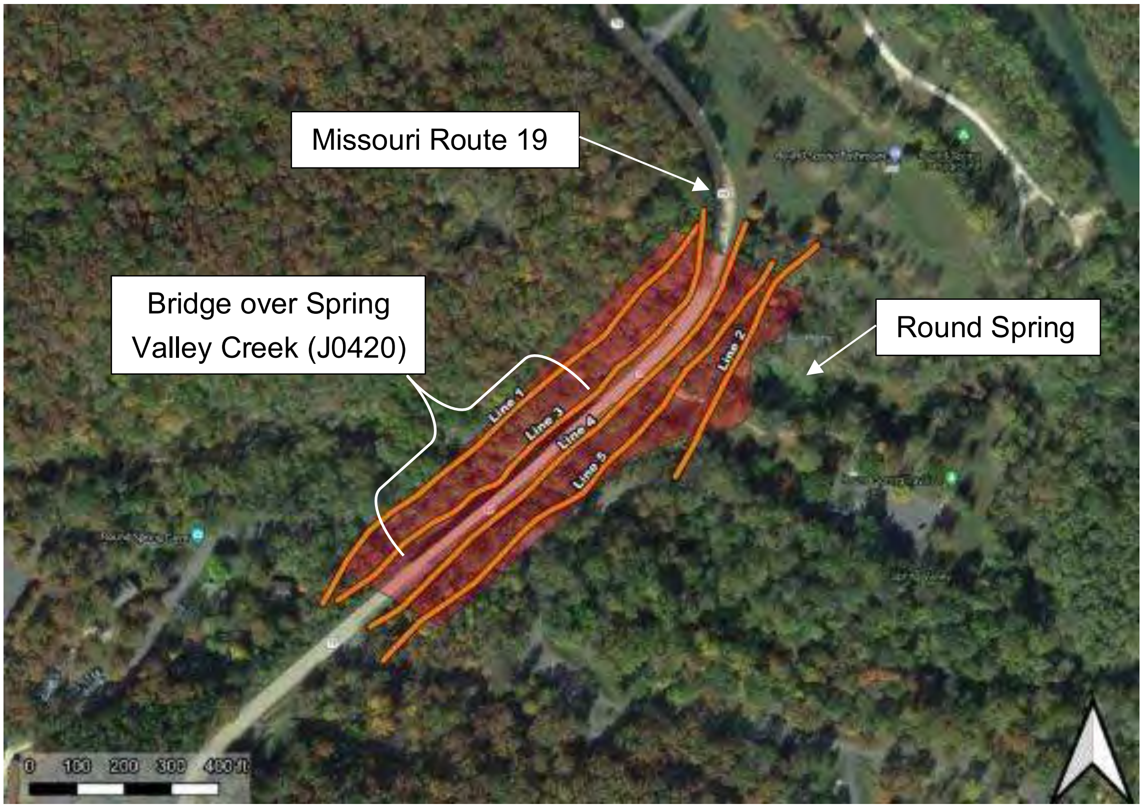


Figure 1. Overview Map of the Study Area (Adapted from Collier, 2021)

Bridge J0420 is a 523-foot-long, 20-foot-wide bridge with one 155-foot open-spandrel concrete arch span and seven concrete girder approach spans ranging between 51 and 54 feet, Figure 2 (upstream view). The bridge is generally supported on spread footing foundations bearing on bedrock at approximate elevations ranging from 651 feet to 665 feet.

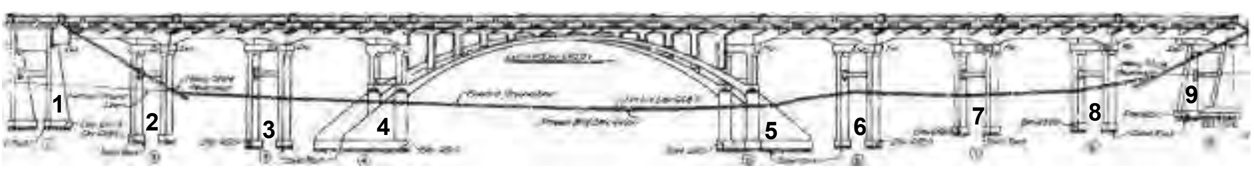


Figure 2. Diagram of Bridge J0420 (upstream view).

2. DESKTOP GEOTECHNICAL STUDY SUMMARY

In our desktop study, we identified the following geologic and geotechnical conditions near Bridge J0420:

Topography is generally mountainous, with hillslopes and ridges bedded in the river drained valley. The hillslope and ridge stratigraphy generally consists of residuum and colluvium over dolomite bedrock. Soil stratigraphy of the lower laying stream terraces, flood plains, flood-plain steps, and the drainageways generally consists of unconsolidated terrace deposits and alluvium over dolomite. The alluvial soils within and adjacent to Spring Valley Creek have the potential to liquify during an earthquake event.

The bedrock formation at the existing bridge piers and spread footings appears to be Early Cambrian aged Eminence Dolomite: generally light gray, medium- to course-grained, massive- to thick-bedded and commonly stromatic with variable amounts of chert throughout. Bedrock strata across the study area are expected to consist of Eminence Dolomite over Potosi Dolomite. Potosi Dolomite is generally light brown, brown, and light gray, fine- to medium-grained, massive- to thick-bedded with light-gray chert and quartz druse throughout and possibly a 1- to 3-foot-thick (+/-) bed of rusty-weathering porous chert close to the contact with overlying Eminence Dolomite.

Approximate bedrock elevations at the pier locations for Bridge J0420 are presented in Table 1.

Table 1. General Bedrock Elevation at Bridge J0420 Piers, starting at the Left Abutment and moving to the Right Abutment of Bridge J0420 as shown in Figure 2.

Peir No.	1	2	3	4	5	6	7	8	9
Elevation (ft)	660	654	652	651	651	652	658	659	665

Karst features exist within the bedrock strata in the study area, and known karst features include Round Spring, Spring Valley Creek, and Round Spring Cavern. More features could be present in the project study area. Round Spring is a primary sinkhole formed in the Eminence Dolomite strata and groundwater in Round Spring rises to an approximate elevation of 715 feet under artesian conditions. Optimized paths of groundwater flow (a straight line between dye injection and the spring) indicate that a portion of the recharge for Round Spring crosses Route 19; this path likely does not accurately represent the actual groundwater flow path and location of subsurface karst features.

3. GEOPHYSICAL AND KARST REVIEW SUMMARY

Collier identified two anomalous conditions within the bedrock in this study area: the first exhibited a very high resistivity and was generally located within the streambed of Spring Valley Creek and throughout most of the length of Bridge J0420, the second exhibited a low-resistivity value and was generally located in isolated areas within the streambed of Spring Valley Creek, near the north abutment of Bridge J0420, and near Round Spring. As indicated by Collier, generally, high-resistivity anomalies can either be a signature of potential air-filled voids, or competent limestone with near-zero porosity and low saturation. Similarly, low resistivity anomalies are generally a signature of a number of conditions including a high degree of weathering, fluid filled fractures, residuum, or a groundwater condition with elevated hydraulic conductivity or dissolved solids.

3.1 High Resistivity Anomalies Beneath Bridge J0420

In their 2021 report, Collier indicated the general surface elevation of the high-resistivity anomalies ranged from 663 feet to 667 feet beneath the streambed of Spring Valley Creek, with additional high-resistivity anomalies located between elevations 600 feet and 637 feet. In their 2021 report, GeoEngineers interpreted the data collected by Collier and indicated that it was unlikely that a major karst void existed within the immediate vicinity of Bridge J0420 but opined that the geophysical techniques used by Collier were inconclusive on whether a void is present beneath Bridge J0420. GeoEngineers and Collier subsequently recommended borings be used to evaluate this area.

3.2 Low Resistivity Anomalies Beneath Bridge J0420

The low-resistivity anomalies identified by Collier were generally located in isolated areas within the streambed of Spring Valley Creek, near the north abutment of Bridge J0420, and near Round Spring. Using the data collected by Collier, GeoEngineers identified a potentially water filled conduit located outside the immediate vicinity of the existing Bridge J0420. Additionally, GeoEngineers identified multiple solution widened joints that could be interconnected throughout the project area. The surface extents of the low-resistivity anomalies indicative of two major vertical joints generally overlap the north abutment and the archway of Bridge J0420; varying degrees of excavation and disturbance are anticipated at or near these major vertical joints. Based on data provided by Collier and the interpretation provided by GeoEngineers, the general surface elevation of the major vertical joint near the north abutment of the existing bridge appears to range from 698 feet to 704 feet and extends to approximate depths ranging from 35 feet to 146 feet. The general surface elevation of the major vertical joint near the arch of the existing bridge appears to range from 673 feet to 674 feet and extends to approximate depths ranging from 35 feet to 40 feet.

GeoEngineers opined that these joints, if impacted by future construction, could facilitate flow of dissolved or suspended solids down to horizontal conduits that feed Round Spring. GeoEngineers indicated that transport of dissolved or suspended solids into Round Spring will depend on a number of factors including, but not limited to, the direction and magnitude of water flow, the actual joint connections, groundwater levels and weather conditions at the time of construction.

3.3 Preliminary Geotechnical Borings at Bridge J0420

In April and May 2022, GeoEngineers completed four borings at the site to explore the high resistivity geophysical anomaly identified by Collier as “V” and the low resistivity geophysical anomalies identified by Collier as “Q” and “W”, as shown in Figures 3 and 4. These three geophysical anomalies were located beneath Bridge J0420, as shown in Figure 5. GeoEngineers denoted their borings as B-1, B-2, B-3, And B-4 as shown in Figure 5.

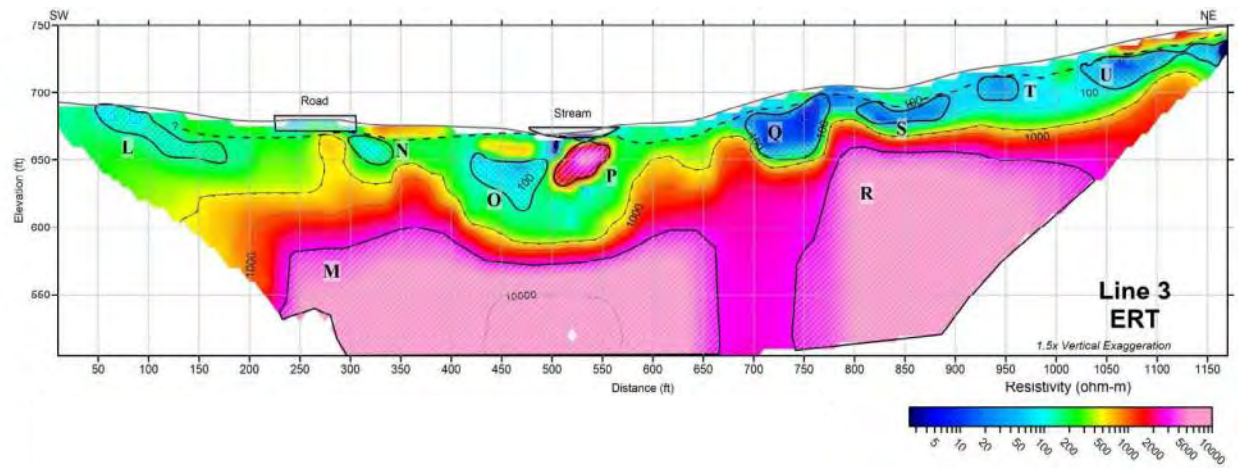


Figure 3. Resistivity Results – Line 3 (Ref. Collier, 2021)

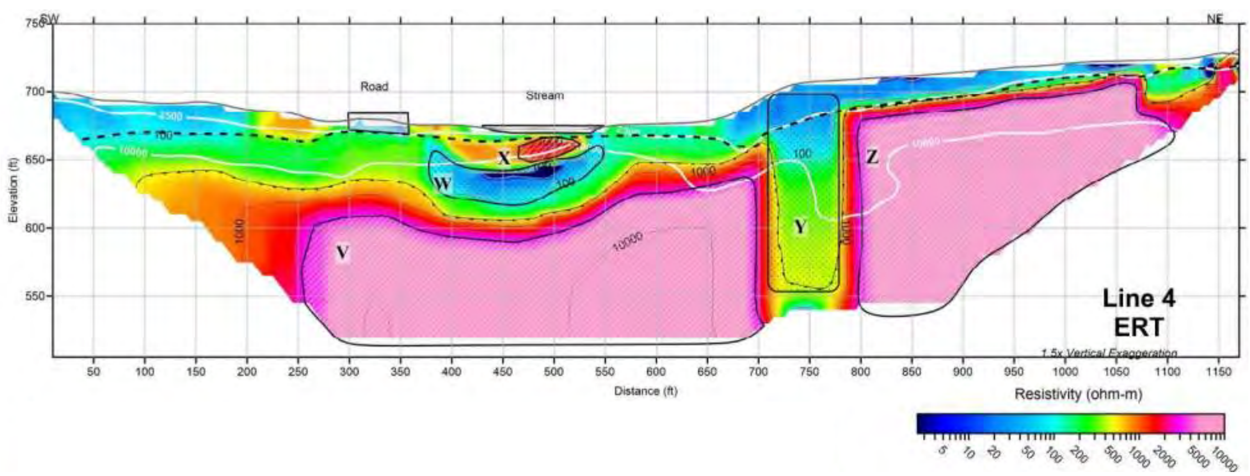


Figure 4. Resistivity Results – Line 4 (Ref. Collier, 2021).

Based on Colliers findings, high resistivity anomaly “V” is much larger and deeper than low resistivity anomaly “W”, as shown in Figure 4.

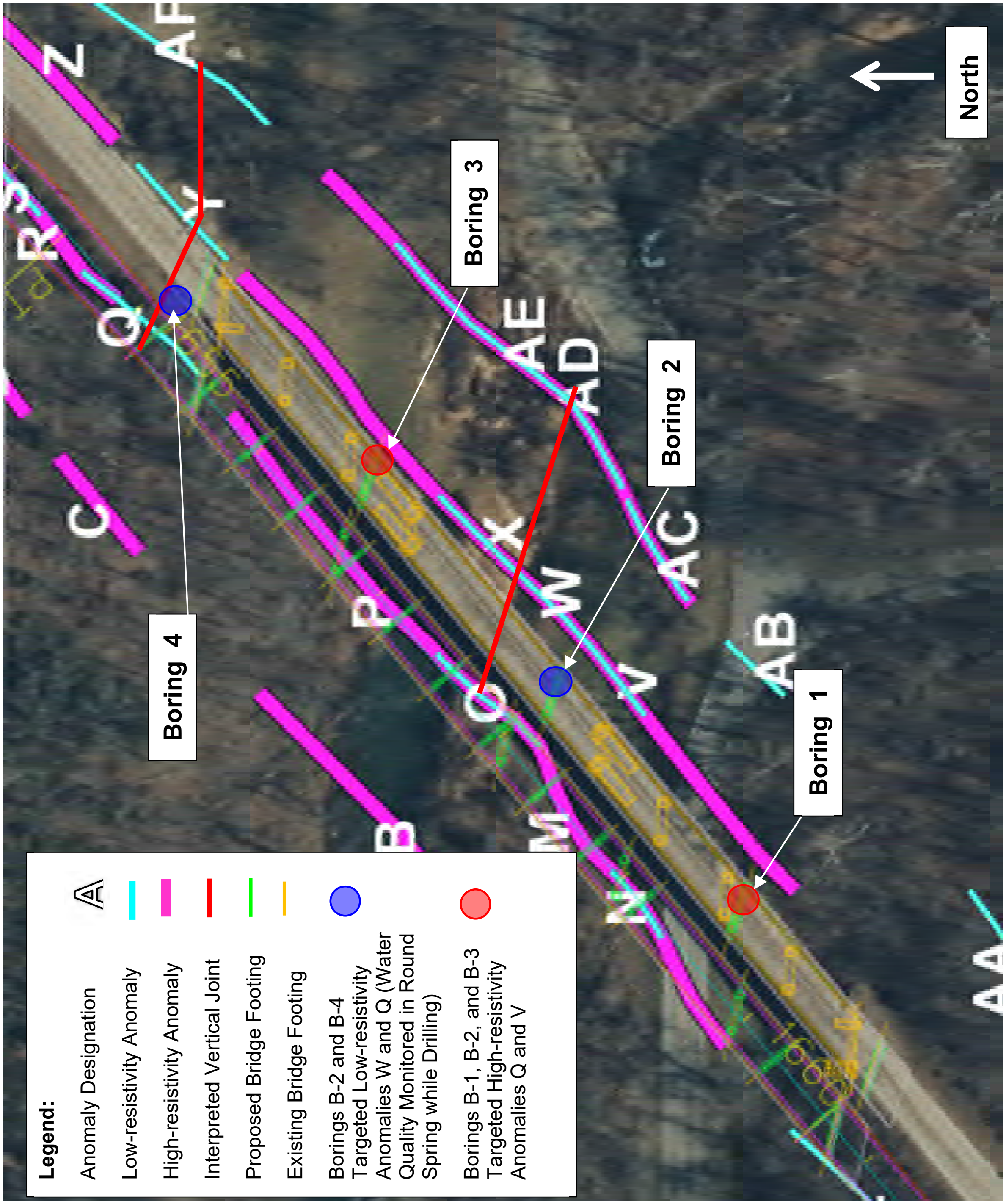


Figure 5. Map of Geophysical Anomalies and Approximate Boring Locations (Adapted from GeoEngineers, 2022).

GeoEngineers advanced Boring B-1 into high resistivity anomaly "V", Boring B-2 into low resistivity anomaly "W" and high resistivity anomaly "V", Boring B-3 into high resistivity anomaly "V", and Boring B-4 into low resistivity anomaly "Q". Boring B-4 was the closest to Round Spring compared to B-2. The Results of GeoEngineers exploration are summarized in Table 2.

Table 2. Geotechnical Borings Correlation to Geophysical Anomalies (Adapted from GeoEngineers, 2022).

Boring No.	Geophysics Line[1]	Geophysics Anomaly Identifier[1]	Type of Geophysics Anomaly[1]	Anomaly Top Depth (ft bgs)	Anomaly Depth Extent (ft)	Boring Description
B-1	Line 4	V	High resistivity	37	124	Soft to hard dolomite with some vugs and quartz druse
B-2	Line 4	W	Low resistivity	18	40	Medium hard to hard dolomite, slightly weathered with some vugs and clay lenses
B-2	Line 4	V	High resistivity	84	>50	Soft to hard dolomite, slightly weathered with some vugs and quartz druse; void identified 83 to 85 ft bgs.
B-3	Line 4	V	High resistivity	50	>75	Soft to hard dolomite, slightly weathered with some vugs and quartz druse
B-4	Line 3	Q	Low resistivity	13	35	Clay and clay with sand, moist and stiff (fill)

Note 1: From Collier, 2021. See Figures 3 and 4 of this summary report.

GeoEngineers correlated the rock core samples obtained from borings within high resistivity anomaly "V" to slightly weathered, soft to hard dolomite. GeoEngineers noted a two-foot-deep void located near the top of the anomaly at Boring B-2 (approximately 65 feet below top-of-bedrock; elev. 590 feet) and opined that it is unlikely that this void would produce the large high resistivity anomaly. GeoEngineers interpreted the high resistivity anomaly to be dense bedrock with low moisture content and that it was unlikely that a major karst void existed within the immediate vicinity of Bridge J0420.

GeoEngineers observed fractures and clay seams in the rock core samples obtained from anomaly "W". GeoEngineers correlated the rock core samples obtained from the boring within low resistivity anomaly "Q" to moist clays and clay with sand. GeoEngineers measured and monitored the water quality in Round Spring during drilling of borings within anomalies "W" and "Q". GeoEngineers noted that they observed no impact to the water quality at Round Spring during drilling operations. GeoEngineers report cautions that their results should not be misconstrued as conclusive evidence that there would be no impact to Round Spring during the construction of the new bridge over Spring Valley Creek.

4. GEOTECHNICAL CONSIDERATIONS

GeoEngineers opined in their 2021 report that the geophysical techniques used by Collier were inconclusive on whether a void was present beneath Bridge J0420 and whether joints, if encountered, would facilitate adverse impact of Round Spring during construction. GeoEngineers recommend and Olsson concurred that soil borings in conjunction with a down hole camera and dye testing could be used to further explore the identified anomalies. GeoEngineers performed the recommended borings and downhole camera evaluation as summarized in their 2022 report. Dye testing was not completed.

Based on GeoEngineers findings from the borings performed within high resistivity anomaly "V" and low resistivity anomalies "Q" and "W", GeoEngineers opined in their 2022 report that the geophysical anomalies identified by Collier represent no significant risk for further development of foundation plans for Bridge J0420. However, GeoEngineers did note relatively minor voids in the upper 10 feet of the bedrock strata, and it is possible these voids could extend deeper. In our opinion, foundations for the new bridge would generally need to extend through the voided bedrock to bear on sound, competent bedrock. GeoEngineers also opined that while the results from monitoring water quality in Round Spring during drilling operations indicate no impact to Round Spring, these results are not conclusive evidence that there would be no impact to Round Spring during the design phase geotechnical exploration and/or during construction of a new bridge over Spring Valley Creek.

Additional geotechnical borings will be needed at the bridge abutments and the bridge bent locations for design of the new bridge foundations. We recommend that ***Olsson*** be retained to conduct a design phase geotechnical exploration. The geotechnical exploration should be conducted in accordance with MoDOT Guidelines. We also recommend that a downhole camera be used in core holes to visually identify the occurrence and extents of voids, joints, and fractures at the core holes.

The geotechnical borings and water quality results discussed herein are limited. Conditions encountered during GeoEngineers field exploration could vary from conditions encountered during the design phase geotechnical exploration and during construction. Therefore, as recommended by GeoEngineers, a hydrogeologist should also be on site during the geotechnical exploration and during construction of the bridge to monitor water quality at Round Spring. In a supplemental email to MoDOT regarding GeoEngineers' 2022 report, GeoEngineers recommended that additional water quality monitoring be conducted during the design phase geotechnical exploration and during construction. GeoEngineers also opined that die tracing and/or other techniques for monitoring groundwater flow may be considered to help understand the effect that construction may have on Round Spring.

5. LIMITATIONS

The conclusions and recommendations presented in this report are based on the information available regarding the proposed construction, our review of the geophysical/geophysics/geo-technical reports for the project, and our experience with similar projects. As indicated by GeoEngineers, the geophysical techniques used by Collier are limited by a number of factors (e.g., terrain, data resolution, and subsurface conditions at the time the study was performed); therefore, they are not definitive. The preliminary geotechnical borings and field testing conducted by GeoEngineers represents a very small statistical sampling of subsurface conditions. It is possible that conditions may be encountered during design phase geotechnical exploration and construction that are substantially different from those indicated by the ERT and SRT surveys and exploratory borings. In these instances, adjustments to the bridge design and construction may be necessary.

This geotechnical report is based on the Bridge J0420 concept plans and our understanding of the project's information as provided to ***Olsson***. Changes in the location or design of new structures could significantly affect the conclusions and recommendations presented in this geotechnical report. ***Olsson*** should be contacted in the event of such changes to determine if the recommendations of this report remain appropriate for the revised bridge design.

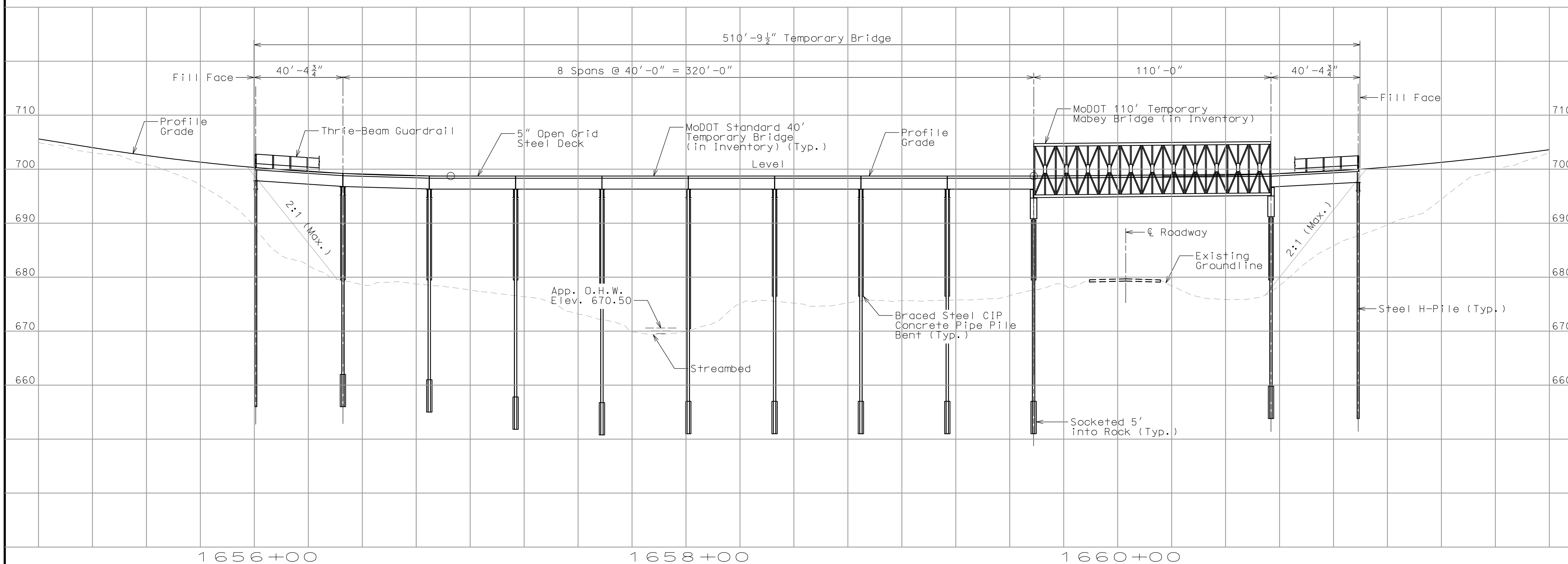
This report was prepared under the direction and supervision of a Professional Engineer registered in the State of Missouri with the firm of **Olsson, Inc.** The conclusions and recommendations contained herein are based on generally accepted, professional, geotechnical engineering practices at the time of this report, within this geographic area. No warranty, express or implied, is intended or made. This report has been prepared for the exclusive use of **HG Consult, Inc.**, and the **Missouri Department of Transportation (MoDOT)** and their authorized representatives for the specific application to proposed project described herein.

ATTACHMENT A

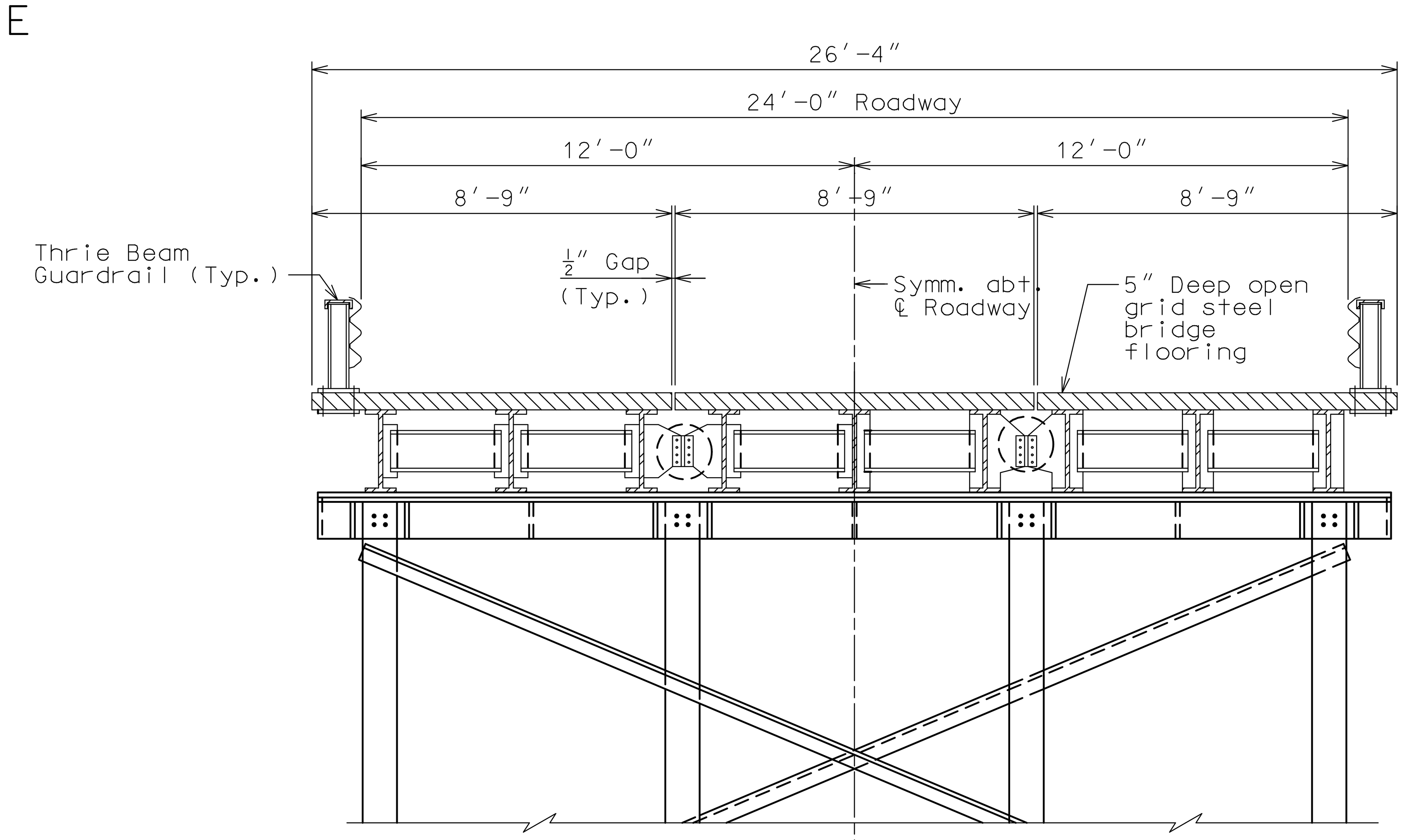
Conceptual Bridge Alternatives (Prepared by HDR Engineering, Inc., and Olsson Inc., 2019)

ROUTE 19 ℄ TEMPORARY ROADWAY PROFILE

- - - - - - - - EXISTING GROUNDLINE



PROFILE



TEMPORARY ROUTE 19 BRIDGE
PROP. TYP. SECTION @ INT. BENT

SPRING VALLEY - TEMPORARY BRIDGE

Note: This drawing is not to scale. Follow dimensions.

Sheet No. 1 of 1

NOT FOR CONSTRUCTION

DATE PREPARED	
9/17/2019	
ROUTE 19	STATE MO
DISTRICT BR	SHEET NO. 12
COUNTY SHANNON	
JOB NO. J9P3305	
CONTRACT ID.	
PROJECT NO.	
BRIDGE NO. TEMP. BR.	

DESCRIPTION

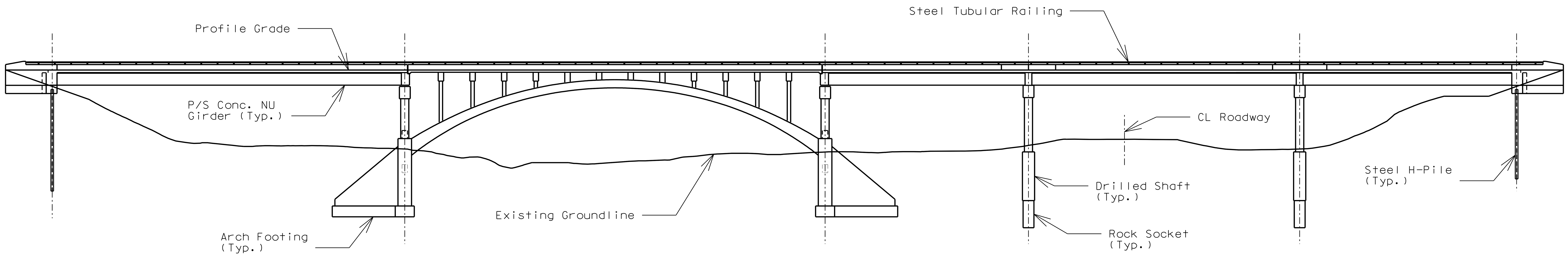
DATE

MISSOURI HIGHWAYS AND TRANSPORTATION COMMISSION
105 WEST CAPITOL
JEFFERSON CITY, MO 65102
1-888-ASK-MODOT (1-888-275-6636)

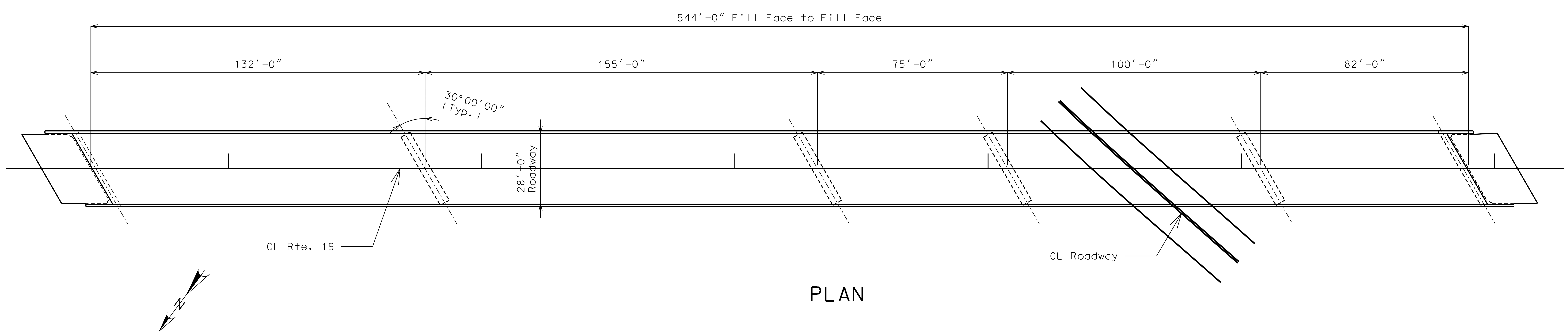
olsson
7301 WEST 133RD STREET
OVERLAND PARK, KS 66213
CERTIFICATE OF
AUTHORITY NO. 001592

REV.

9:46:22 PM 9/17/2019



ELEVATION



PLAN

SPRING VALLEY - REPLACE IN KIND ON OFFSET ALIGNMENT OPTION

GENERAL PLAN AND ELEVATION

Note: This drawing is not to scale. Follow dimensions.

Sheet No. of

DATE PREPARED	
9/18/2019	
ROUTE 19	STATE MO
DISTRICT BR	SHEET NO. 10
COUNTY SHANNON	
JOB NO. J9P3305	
CONTRACT ID.	
PROJECT NO.	
BRIDGE NO.	

DATE	DESCRIPTION

MISSOURI HIGHWAYS AND TRANSPORTATION COMMISSION

105 WEST CAPITOL
JEFFERSON CITY, MO 65102
1-888-ASK-MODOT (1-888-275-6636)

HDR Engineering, Inc.
4435 Main Street
Suite 1000
Kansas City, MO 64111-1856
816-360-2700
Certificate of Authority: 000856

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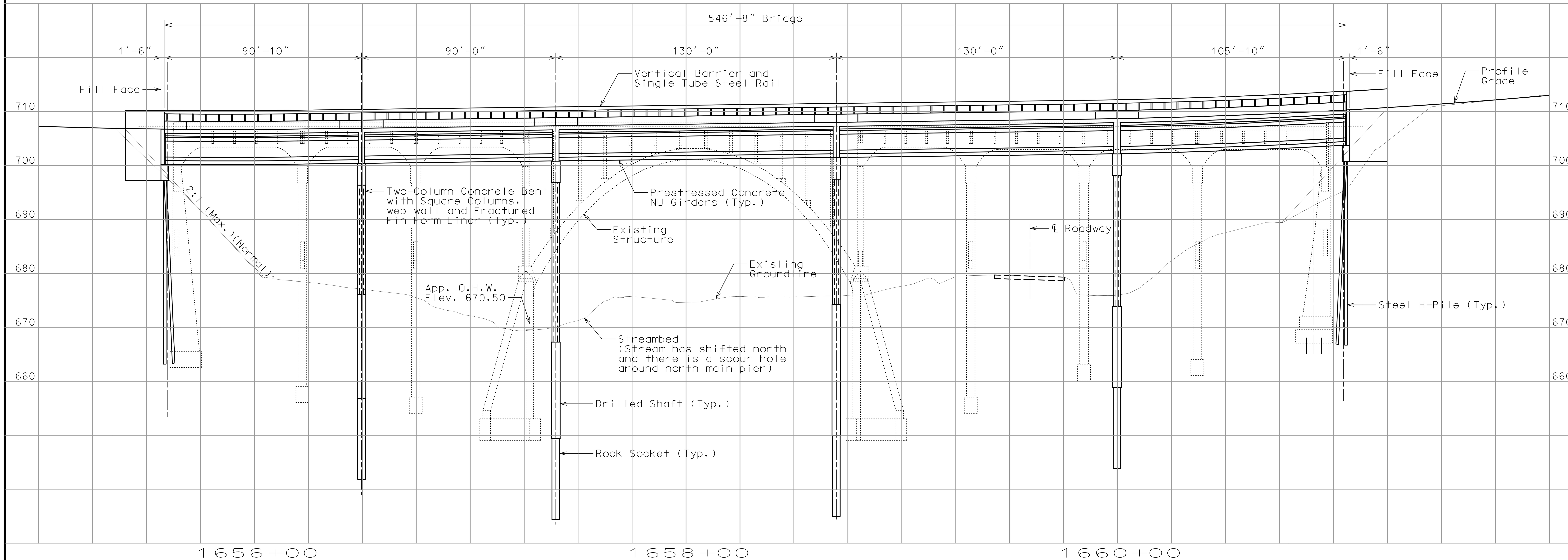

PROFILE

A new girder bridge option would likely use parabolically haunched steel plate girders similar to those over Sinking Creek instead of the concrete girders as shown.

SPRING VALLEY - GIRDER BRIDGE REPLACEMENT OPTION

Note: This drawing is not to scale. Follow dimensions.

Sheet No. 1 of 1

NOT FOR CONSTRUCTION

DATE PREPARED	
9/18/2019	
ROUTE 19	STATE MO
DISTRICT BR	SHEET NO. 14
COUNTY SHANNON	
JOB NO. J9P3305	
CONTRACT ID.	
PROJECT NO.	
BRIDGE NO. BRIDGE	

DATE | DESCRIPTION

MISSOURI HIGHWAYS AND TRANSPORTATION COMMISSION
105 WEST CAPITOL
JEFFERSON CITY, MO 65102
1-888-ASK-MODOT (1-888-275-6636)

olsson
7301 WEST 133RD STREET
OVERLAND PARK, KS 66213
CERTIFICATE OF AUTHORITY NO. 001592

REV.

4:13:54 PM 9/18/2019

ATTACHMENT B

Route 19 Bridges Geotechnical Study (Prepared by Olsson, Inc., 2021)

PRELIMINARY GEOTECHNICAL STUDY

ROUTE 19 BRIDGES
CURRENT RIVER TO ROUND SPRING
SHANNON COUNTY, MO

Prepared For:

Hg Consult, Inc.
18963 W 117th Street
Olathe, Kansas

March 2, 2021
Olsson Project No. 020-1986

olsson

March 2, 2021

Hg. Consult, Inc.
Attn: Mr. Dave Kocour, V.P.
18963 W 117th St.
Olathe, KS 66061

Re: Preliminary Geotechnical Study
Route 19 Bridge Current River to Round Spring
Shannon County, Missouri
Olsson Project No. 020-1986

Dear Mr. Kocour,

Olsson Inc. has completed the preliminary geotechnical study for the above referenced project. The enclosed report summarizes the findings from our literature review of the site surface and subsurface conditions as well as our review of mining operations and mineral deposits in the study area.

We appreciate the opportunity to provide our preliminary geotechnical study for this project. If you have any questions or need further assistance, please contact us at your convenience.

Respectfully submitted,
Olsson, Inc.

Robert Sherwood, E.I.
Assistant Engineer

James M. Landrum, P.E.
Vice President

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Appendices

A. PROJECT UNDERSTANDING

A.1. GEOTECHNICAL SCOPE

This report presents the results of our literature search of existing surface and subsurface information and our records search relating to mining operations and mineral deposits in the study area for the Route 19 Bridges over the Current River in Shannon County, Missouri.

A.2. STUDY AREA LOCATION AND DESCRIPTION

The study area extends from approximately 0.25 miles north of the existing Route 19 bridge over the Current River south on Route 19 to approximately 0.25 miles south of the existing Route 19 bridge over Spring Valley extending approximately 300 feet east and west on either side of existing Route 19, as depicted in Figure 1. The study area lies entirely within the National Parks Services (NPS) Ozark National Scenic Riverway (ONSR). Largely undeveloped, the land use descriptions of the study region include NPS ONSR Section 4f, large public use, and one private business. Route 19 is a rural, minor arterial paved road. NPS utilities and facilities within the study area include a treatment plant, water tower, pedestrian and utility bridge, ranger station, parking and river access points, service roads, trails, and spring/cave/camping/residence access points. The private business is located approximately 180 feet north of the Current river bridge and 50 feet west of Route 19.

Figure 1: Study Area Limits

The study area generally slopes down from the northwest to the southeast with approximate elevations ranging from 840 to 660 feet. Route 19 is a two-lane asphaltic concrete road generally bordered on the east and west sides by dense deciduous forest growing on moderately to steeply sloped terrain. Route 19 appears to hug ridges and hillslopes navigating approximate elevations between 700 and 800 feet in the study area. The Current River is a pristine, spring fed, multiuse waterway and is the major river unit within the ONSR.

Two existing bridges carry Route 19 over the Current River and Spring Valley Creek north and west of Round Spring, respectively. The Current River Bridge (G0804) is a five-span, closed-spandrel concrete arch bridge with three main spans of approximately 130 feet and two 60-foot approach spans. The bridge was built in 1924. The 601-foot-long, 18-foot-wide bridge supports a single traffic lane over the Current River (Figure 2). Plans that we reviewed indicate that the existing footings were keyed 6 to 18 inches into bedrock.

The Spring Valley Bridge (J0420) is a 523-foot-long, 20-foot-wide bridge comprised of one 155-foot open-spandrel concrete arch span and seven concrete girder approach spans ranging between 51 and 54 feet (Figure 3). Built in 1930, the concrete arches support rectangular concrete columns and cap beams. The bridge carries two traffic lanes over Spring Valley. The plans we reviewed indicate that the north abutment is supported by two spread footings keyed 6 inches into bedrock. The south abutment is reportedly supported on the east side by a spread footing keyed 6 inches into bedrock and supported on the west side by 25-foot-long timber piles. The plans show that the remaining pier footings and bent footings are keyed 6 to 18 inches into bedrock.

Figure 2: Current River Bridge Diagram and Photograph (G0804)

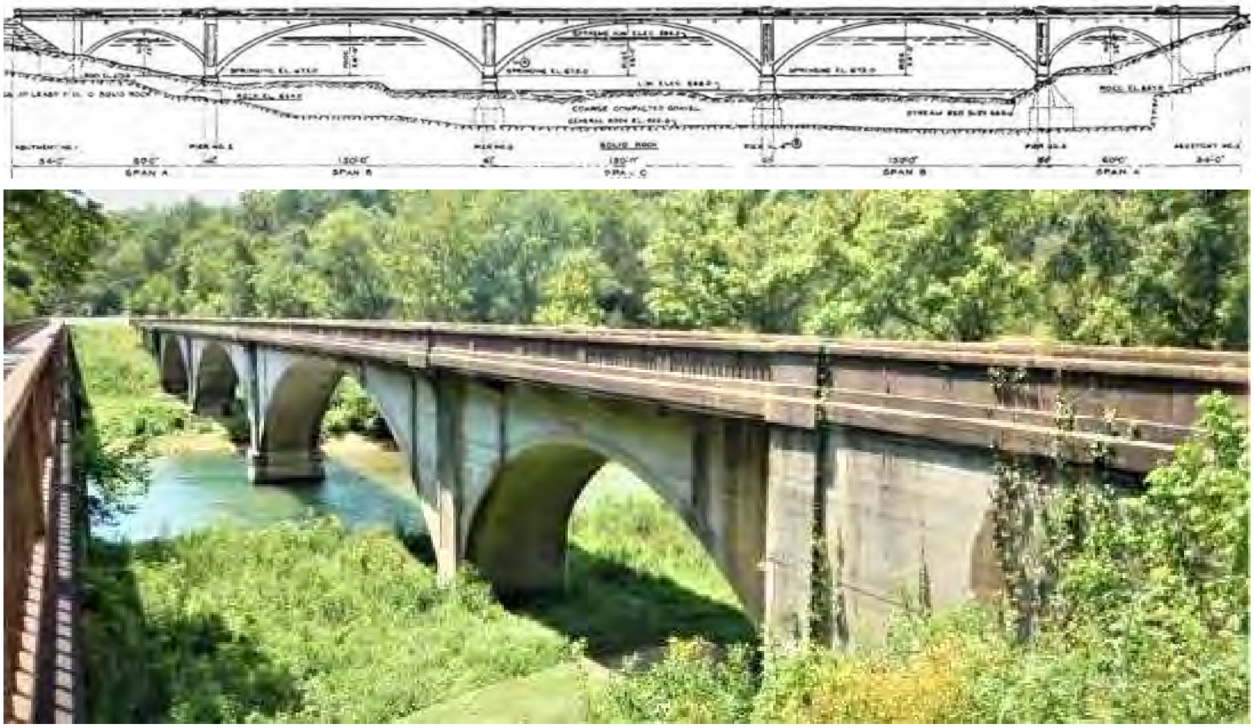
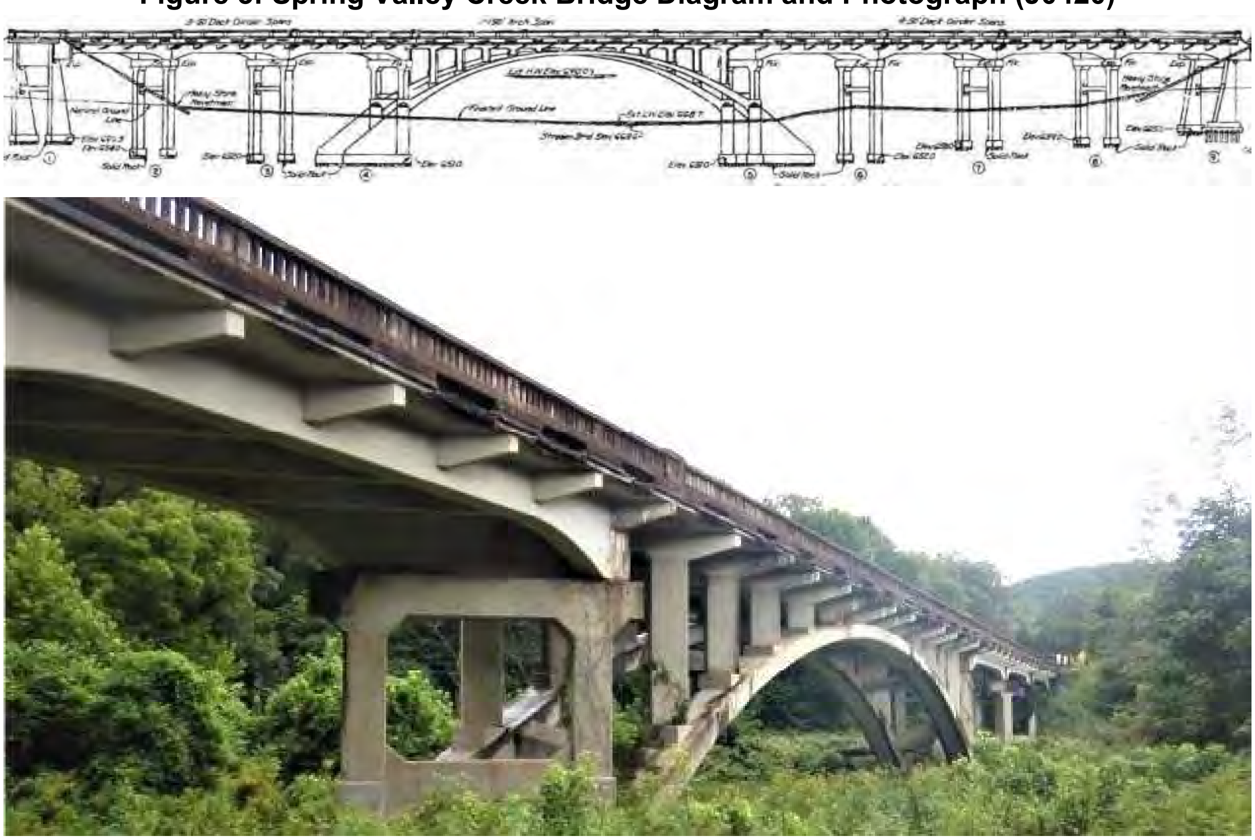


Figure 3: Spring Valley Creek Bridge Diagram and Photograph (J0420)



Based on the United States Geological Survey (USGS), relatively steep slopes occur along the south-facing hillslopes of Spring Valley Creek, west of Bridge J0420; an average slope gradient of 53 percent is reported with gradients ranging between 30 and 90 percent. Across the study area, hillslopes, stony ridges, and benched slopes generally have gradients ranging from 15 to 30 percent. Ground surfaces east of Route 19, between Bridge G8040 and J0420, consist of rocky and stony ridges with approximate slope gradients ranging from 8 to 15 percent which transition to gently sloping, alluvial stream terraces approaching the NPS campgrounds (3-8 percent gradient). Slope gradients gradually increase, and topography becomes increasingly rocky and stony as one moves south from Bridge J0420 within the study area. A topographic map of the study area is presented in Appendix B.

A.3. Summary of Previous Study

Due to the continued degradation of the existing bridges, we understand that replacement bridges are being considered in this area. Alternative bridge alignments, profiles, and structure types for Bridges G0804 and J0420 were presented in the October 2019 Bridge Rehabilitation/ Replacement Alternatives Study Report prepared by HDR and ***Olsson***. Issues identified in the HDR report that pertains to the geotechnical aspects of the project are summarized below:

- Retaining walls or reinforced steepened slopes will likely be needed south of Spring Valley.
- Rock benching will likely be needed north of the Current River.
- Rock benching north of the Current River may encounter buried utilities.
- Cofferdams will be required in streams if spread footings are to be constructed on bedrock.
- Shallow cofferdams will likely require drilling of structural steel piles to support cofferdam walls.
- Cofferdams will increase the area of impact on the streambed.
- The region of the state is known to have karstic bedrock conditions.
- The extents of the Round Spring Cavern were unknown at the time of the 2019 study and may limit use of driven piles or drilled shafts.
- The nearby cave system my prevent the use of explosive charges for demolition of the existing bridges.

We understand conceptual plans for remediation and/or replacement alternatives of Bridges G0804 and J0420 include construction of temporary bridges, demolition of all or part of the existing bridges, installation of new foundations, and re-alignment of the bridge approaches.

B. SUBSURFACE CONDITIONS

B.1. Geologic Conditions

The study area is located southwest of the St. Francois Mountains in south-central Missouri, within the Round Spring Quadrangle in the Salem Plateau geomorphic subdivision of the Ozark Plateaus physiographic province (Fenneman, 1938; Imes and Emmett, 1994). Topography across the study area is generally mountainous, with convex and quasilinear hillslopes and ridges bedded in river drained valleys.

Near surface soils in the study area are expected to consist of the following units as defined by the Geologic Resources Inventory program (GRI) and Orndorff & Weary, 2009:

Alluvium – Holocene aged. Gravel, sand, and clay along the bed and active flood plains of modern stream valleys. Material consists mostly of subrounded to subangular chert, sandstone, and quartzite clasts in a matrix of sand containing silt and clay. Typical thicknesses range from 0 to 20 feet.

Colluvium – Holocene and Pleistocene aged. Boulders, cobbles, and pebbles of sandstone derived from weathering of bedrock, forms gravity-creep deposits generally up to 3 feet thick on steep slopes. Widely distributed and common on steep slopes.

Terrace Deposits – Likely Holocene and Pleistocene aged. Large cobble-size to sand-size, subrounded to subangular chert, sandstone, and quartzite clasts within a matrix of sand, silt, and clay. In some locations a significant fraction of the matrix is silt-size reworked loess [windblown]. Deposited on relatively flat areas along floors and walls of modern stream valleys, but above normal seasonal floods of present streams. Terraces may stand 6 to 10 feet above stream level. Typical thickness is at least 10 feet.

Residuum – Quaternary and Tertiary aged. Red and reddish-orange sandy clay containing angular sandstone and chert cobbles and boulders as much as 6 feet in diameter. Sandstone cobbles and boulders, fine- to course-grained, poorly sorted, and locally containing symmetrical and asymmetrical ripple marks. Chert cobbles and boulders, light- to medium-gray consisting of banded, sandy, oolitic, and porcelaneous varieties. Thicknesses can be as much as 40 feet.

Based on data available through the NRCS Websoil Survey (USDA), the US Geological Survey (USGS), construction documents, and the Missouri Department of Natural Resources (MoDNR) subsurface stratigraphy databases, the hillslope and ridge stratigraphy in the study area consists of residuum and colluvium over dolomite bedrock. Soil stratigraphy of the lower lying stream terraces, flood plains, flood-plain steps, and the drainageways generally consists of unconsolidated terrace deposits and alluvium over dolomite bedrock.

Based on our review of the Bridge G0804 and J0420 construction drawings, the general depth to bedrock ranges from 10 to 20+ feet across the Current River riverbed, Spring Valley and Spring Valley Creek, with occasional bedrock outcroppings located along the ridge lines. In 1970, a water well, now owned by the ONSR NPS, was drilled adjacent to the study area south of Bridge J0420; a copy of the well log (No. 26637) obtained from the Missouri Geology Survey (MGS) is presented in Appendix A. This well log shows approximately 20 feet of overburden overlaying the Eminence Dolomite bedrock (encountered at elev. 725 feet +/-) which overlays Potosi Dolomite (encountered at 565 feet +/-).

In 2013, MoDNR produced a survey of the liquefaction potential of near surface soils across the study area. Based on the results of that survey, the alluvial soils within and adjacent to the Current River and Spring Valley Creek have the potential to liquefy during an earthquake event.

The bedrock strata in the Salem Plateau are generally flat-laying, dipping slightly (approximately 1 to 3 degrees) toward the east and southeast (Weary and Orndorff, 2016; GRI, 2016). The bedrock map units across the study area are expected to consist of the of Late Ordovician aged Gasconade Dolomite (lower unit), Early Cambrian aged Eminence Dolomite, and Potosi Dolomite. The Gasconade Dolomite map unit is divided into three informal units, the upper, middle, and lower units; the lower unit is also called the Gunter Sandstone Member. Geologic maps for the study area are presented in Appendix B. Bedrock surface elevations are expected to vary across the study area as downcutting streams have eroded the soluble carbonate bedrocks lowering the ground surface.

The Gunter Sandstone Member, generally located at the higher elevations along ridgelines, is a light gray to white relatively impermeable silica-cemented quartz sandstone, sandy dolomite, or orthoquartzite interbedded with light gray to tan, fine-grained, thin-bedded dolomite, with typical thicknesses ranging from 10 to 25 feet (Weary and Orndorff et al, 2017; GRI, 2016). The Eminence Dolomite is generally light gray, medium- to coarse-grained, massive- to thick-bedded and commonly stromatolitic with variable amounts of chert throughout (Orndorff & Weary, 2009; GRI, 2016). The Potosi Dolomite is generally light brown, brown, and light gray, fine- to medium-grained, and massive- to thick-bedded with light-gray chert and quartz druse throughout. Quartz druse typically develops in vugs as botryoidal masses of chalcedony with small quartz crystals coating surfaces. The Potosi Dolomite can have a 1- to 3-ft thick (+/-) bed of rusty-weathering porous chert close to the contact with overlying Eminence Dolomite (Orndorff & Weary, 2009; GRI, 2016).

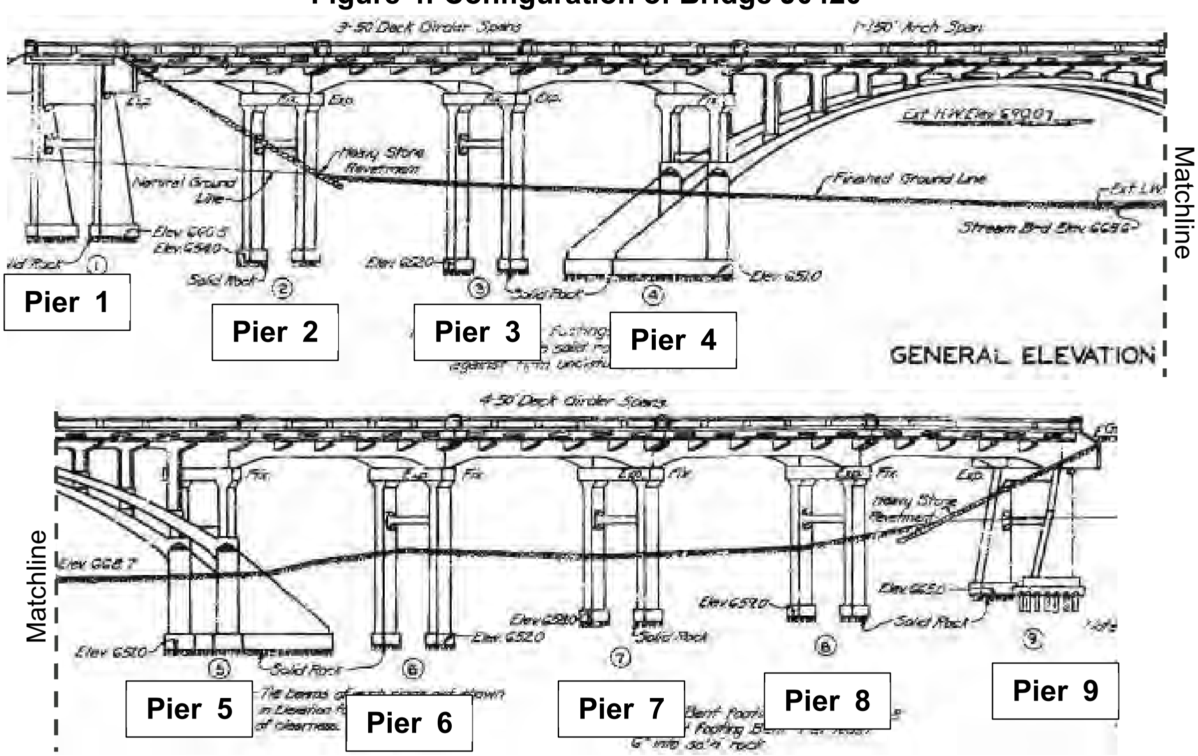
The Gasconade, Eminence and Potosi Dolomite bedrock layers across the site are within the Ozark Aquifer Geohydrologic Unit. Artesian conditions occur at Round Spring where ground water rises to an approximate elevation of 715 feet. Groundwater was observed in well 26637 in September of 1970 and was recorded at 80 feet below the ground surface at that time (approximate elevation of 665 feet). Localized perched water conditions can also be present in the soils.

The bedrock formation at existing bridge piers and spread footings appears to be the Eminence Dolomite. The approximate bedrock elevations at the pier locations, reported on the construction drawings of the existing bridges for Spring Valley and Current River Bridges (J0420 and G0804, respectively), are listed in Table 1 and 2. The corresponding piers are marked in Figure 4 and 5.

Table 1: General Bedrock Elevation at Bridge J0420 Piers

Pier No.	1	2	3	4	5	6	7	8	9
Elevation (ft)	660	654	652	651	651	652	658	659	665

Figure 4: Configuration of Bridge J0420

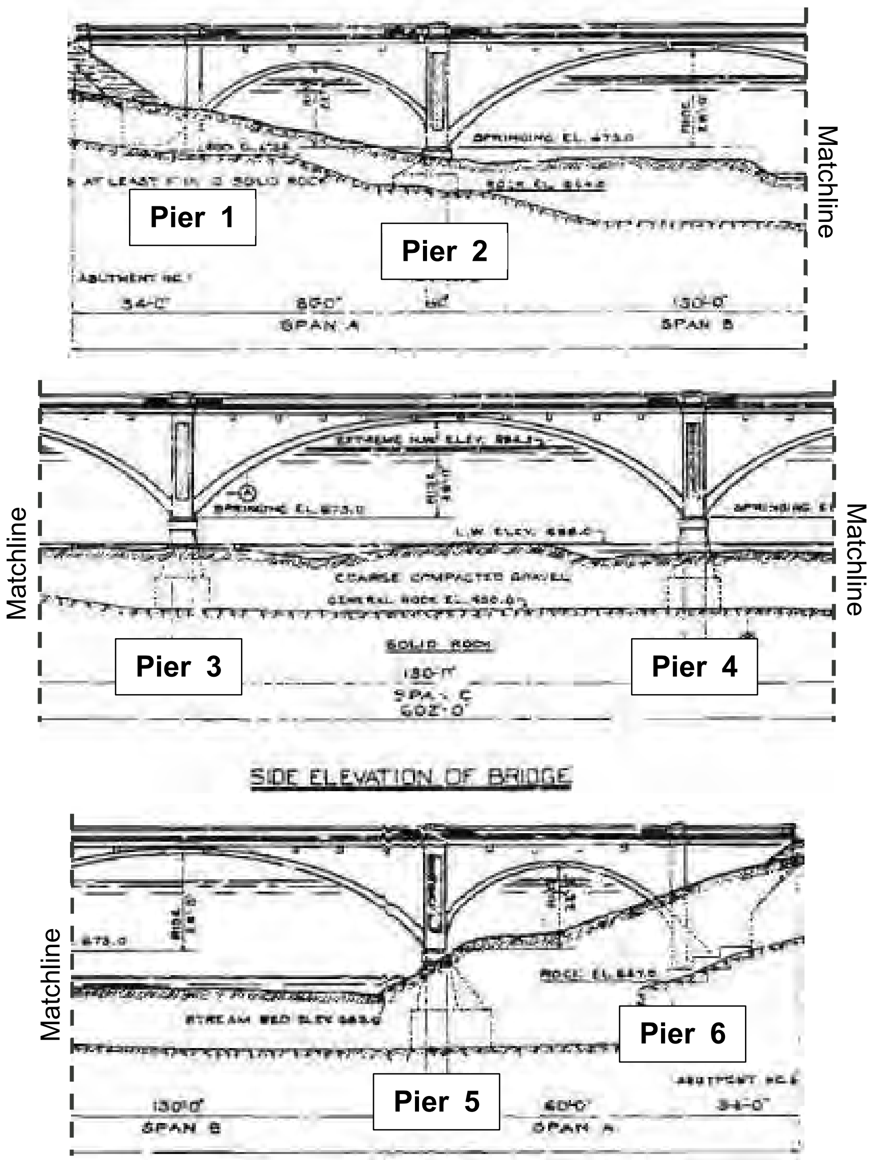


Our review of the bridge plans indicates that several 25-foot-deep (+/-) wooden piles were used beneath the east footing of Bridge J0420 pier number 9. While the lateral extent of the deeper layer could not be inferred from the project documents, this area will require further exploration.

Table 2: General Bedrock Elevation at Bridge G0804 Piers

Pier No.	1	2	3	4	5	6
Elevation (ft)	673	664	650	650	650	667

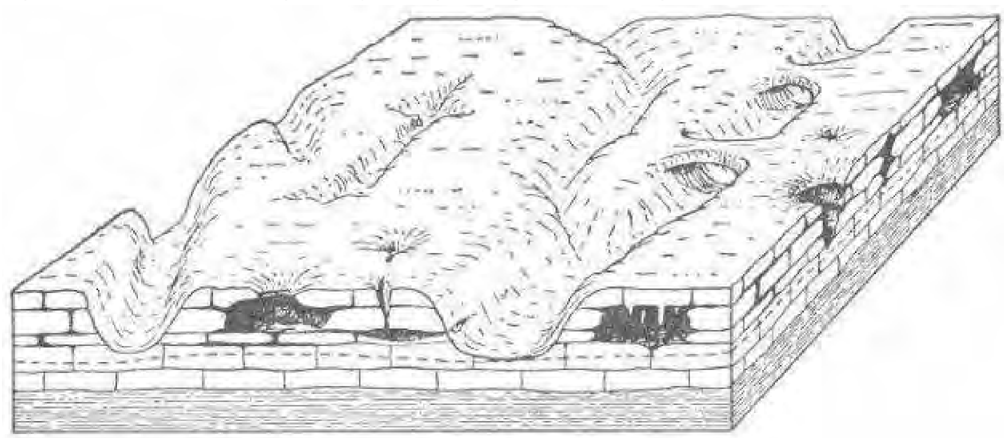
Figure 5: Configuration of Bridge G0804



B.2. KARST

The bedrock strata in the study area are soluble and prone to Karst. Karst is a landscape generally underlain by soluble bedrock which has been eroded by dissolution, producing solution valleys, natural bridges, columns, fissures, sinkholes, sinking streams, springs, caves, and other characteristic features. Karst in this ONSR generally occurs near aquitard horizons within the bedrock (e.g., Round Spring Cavern lies beneath the Gunter Sandstone Member), particularly where erosion has lowered the ground surface to near the top of locally confined parts of the Ozark Aquifer (Weary and Orndorff, 2016). A simplified diagram of karst topography is shown as Figure 6. Three karst features within the study area are identified by NPS and MoDNR: Round Spring, Spring Valley Creek, and Round Spring Cavern. Approximate locations of known karst features are presented on the Karst Features Map in Appendix B and discussed below. Unmapped karst features could also be present in the project study area.

Figure 6: Karst Topography Diagram (From Longwell, Knopf, & Flint 1934)



Round Spring and Spring Valley Creek

Round Spring is a circular primary sinkhole located approximately 450 feet northeast of Bridge J0420 (elev. 700 ft.). Eminence Dolomite outcrops over the north face of the spring. The basin has an explored well depth of 55 feet. The basin formed in the Eminence Dolomite strata during collapse of a cavern roof (Orndorff and Weary, 2009).

Spring Valley Creek passes beneath Route 19 at Bridge J0420. Missouri DNR defines the creek as a 40-mile-long losing stream, having solution-enlarged openings beneath the streambed that allow surface water to rapidly enter the subsurface resulting in significant loss of the stream flow into the groundwater system. These openings are likely covered by alluvial deposits.

Three recharge locations have been identified for Round Spring using die tracing techniques (Weary and Orndorff, 2016). Recharge for Round Spring includes George Hollow, located 4 miles upstream (i.e., west) of Bridge J0420, in the streambed of Spring Valley Creek (elev. 715 ft Other recharge locations include the Sunklands and Capps Hollow, located west and east of Round Spring, respectively. The paths of groundwater flow and locations of subsurface karst features were not available/clarified at the time that this report. Available flow paths, current during the writing of this report, were optimized (a straight line between die injection points and the spring) and likely do not accurately represent the actual locations of subsurface karstic features and groundwater flow paths at this site.

Round Spring Cavern

Round Spring Cavern is a 4250 +/- foot-long cave system occurring in the upper most parts of the Eminence Dolomite, just beneath the Gunter Sandstone Member. The cave is situated southwest of Bridge J0420 as shown on the cavern map in Appendix B. The Gunter Sandstone Member of the Gasconade Dolomite was observed in the ceiling of the largest room of Round Spring Cavern, approaching the approximate midway point of the traversable portion of the west to southwest corridor. The bedrock base of the cavern is buried by a floor of clay, gravel, flowstone, and fallen ceiling fragments. Delicate crystal and rock formations occur at points within the cave (e.g., calcium carbonate crystalline overgrowth, helictite growths, curtain type stalactite, and relatively slender columns). Large boulders have dislodged from the cave ceiling and rest on the red clay floor. (Bretz,1956)

B.3. MINERALS AND MINING OPERATIONS

According to MoDNR and the Hudson Institute of Mineralogy, there were no mining operations or mining prospects within the study area at the time of this report. The closest observed mine was located approximately 3 miles north of the study area (the retired Samuel Piatt Land Mine for iron ore, MoDNR). Additionally, there were no identified minerals or ores within the reviewed MoDNR and Minedata databases for this study area. However, limonite ($Fe_2O_3 \cdot nH_2O$) was encountered at the site in 1970 when a water well was drilled for the public use areas adjacent to the site (well No. 26637). Limonite was dominantly located within the Eminence Dolomite strata at approximate elevations of 675 feet through 585 feet +/-.

C. CLOSING

This report was prepared under the direction and supervision of a Professional Engineer registered in the State of Missouri with the firm of ***Olsson Inc***. This report has been prepared for the exclusive use of ***Missouri Department of Transportation*** and their authorized representatives for specific application to the proposed project.

D. REFERENCES

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Fenneman, N. M., 1938, Physiography of the eastern United States. New York: McGraw-Hill, 714 p.

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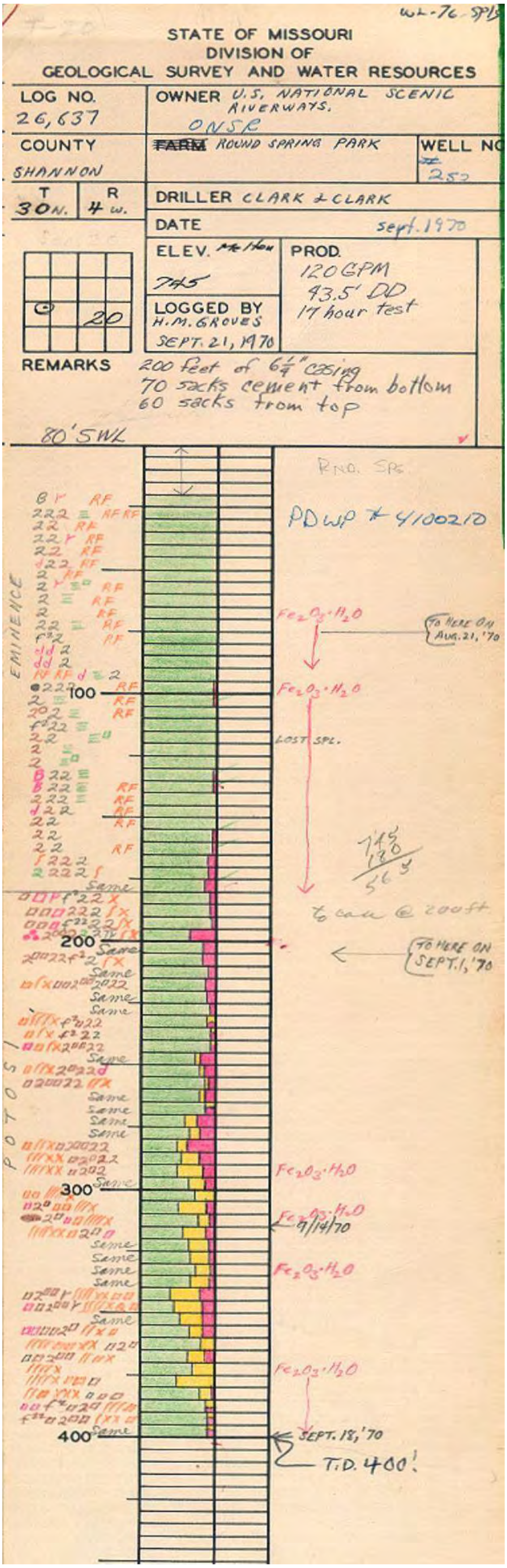
Longwell, C. R., Knopf, A., & Flint, R. F., 1934, Outlines of physical geology. New York: J. Wiley.

Orndorff R. C., & Weary, D. J., 2009, Geologic map of the Round Spring quadrangle, Shannon County, Missouri: U.S Geological Survey Scientific Investigations Map 3073, scale 1:24,000. http://pubs.usgs.gov/sim/3073.

Weary, D. J., & Orndorff, R. C., 2016, Geologic Context of Large Karst Springs and Caves in the Ozark National Scenic Riverways (ONSR), Southern Missouri. doi:10.1130/abs/2016am-282679.

APPENDIX A

Well Log Number 26637



Legend (Mo DNR 2007)	
Lithologic Description	
(pink)	Chert
(green)	Dolomite
(yellow)	Druse & Quartz xtls
Lithologic Sybmol (color of rock)	
xx	Chrystalline
d	dense
Residuum Symbols	
Y	Granite Pebbles
Quartz Symbols (always orange)	
ʃ	Druse
R	Rounded
F	Frosted
f	fine
X	Dogtooth Fragments
Shale & Its Modifiers	
≡	Shale
▱	Dolomoldic
Chert Texture & Modifier Symbols (color of rock)	
B	Beekite
ꝛ	Quartzose
o	Oolitic
∴	Ooids Cluster
▱	Dolomoldic
Other	
SWL	Static Water Level
RND.	Rounded
SPG	Sponge
SPL.	Sample
Minerals	
$Fe_2O_3 \cdot H_2O$	Lemonite

olsson

Source: MGS
Retrieved by: RRS
Date: 1/25/2021

Well Log Number 26637

Route 19 Bridges
Shannon County, MO

APPENDIX B

Topographic Map (USGS 2013)

Geologic Maps:

Karst Features (Mo DNR, ONSR NPS)

Mine Operation Locations (Mo DNR, MGS)

Surficial Texture by Soil Map Unit (NRCS 2019)

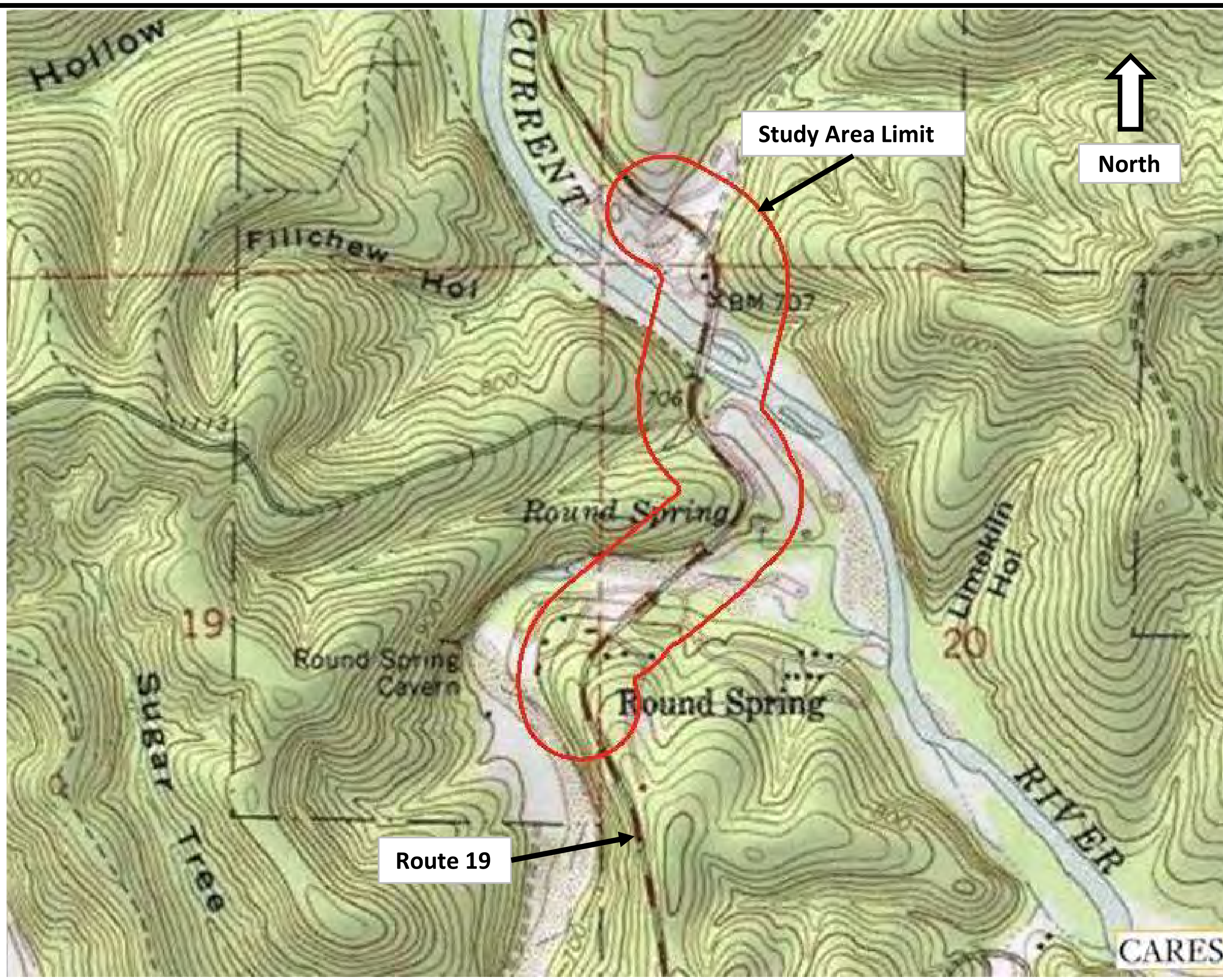
Surficial Geology by Region (Mo DNR 2013)

Quaternary Geology by Region (USGS 1996)

Bedrock, 1:500,000 Scale (Mo DNR 2016)

Alluvium Deposit Soils by Region (Mo DNR 2014)

Liquefaction Potential by Area (Mo DNR 2013)



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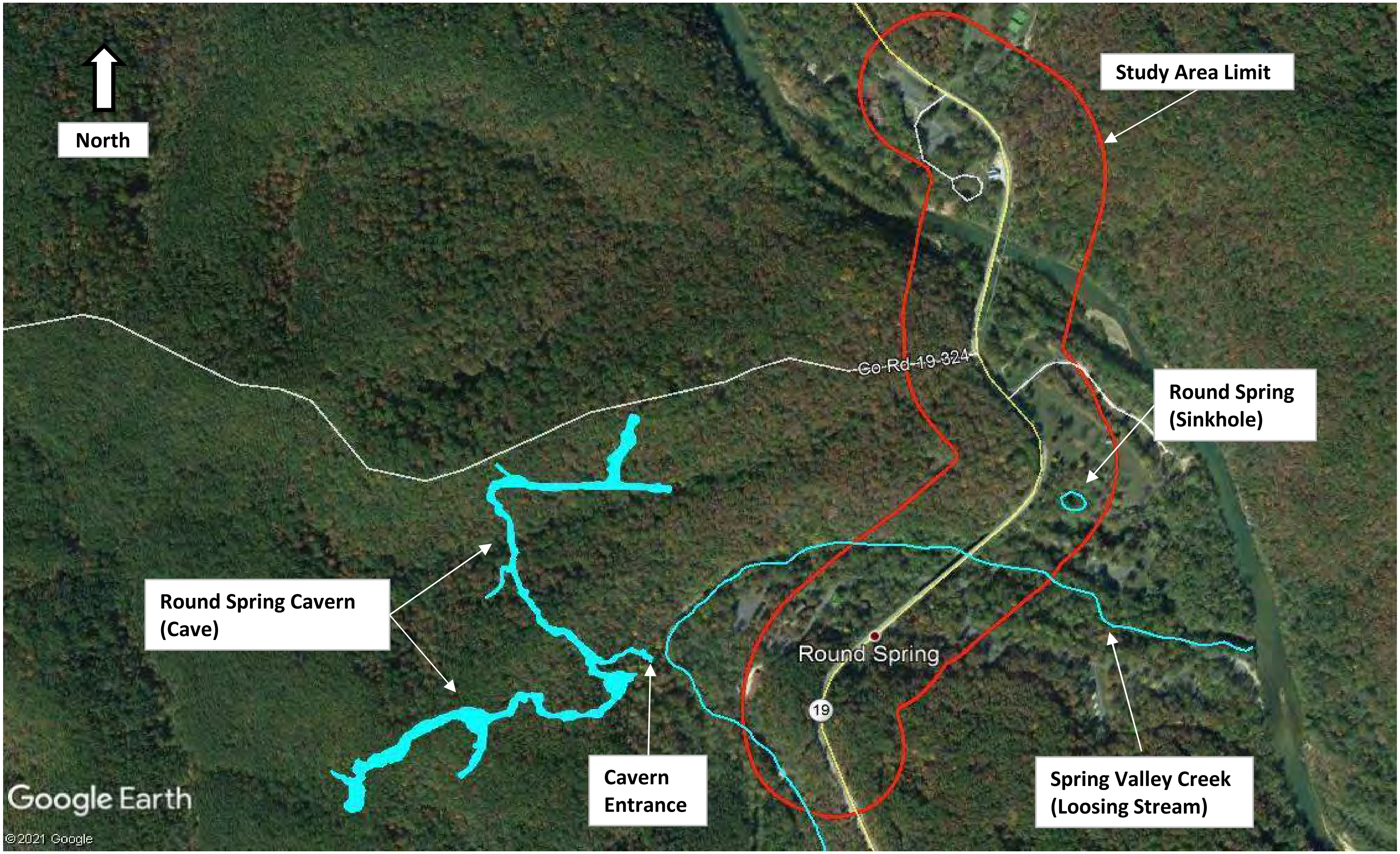
Scale: n.t.s.	**Topo Map**
Project No. 020-1986	**Route 19 Bridges Shannon County, Missouri**
Approved by: RRS	
Date: 2/23/2021	

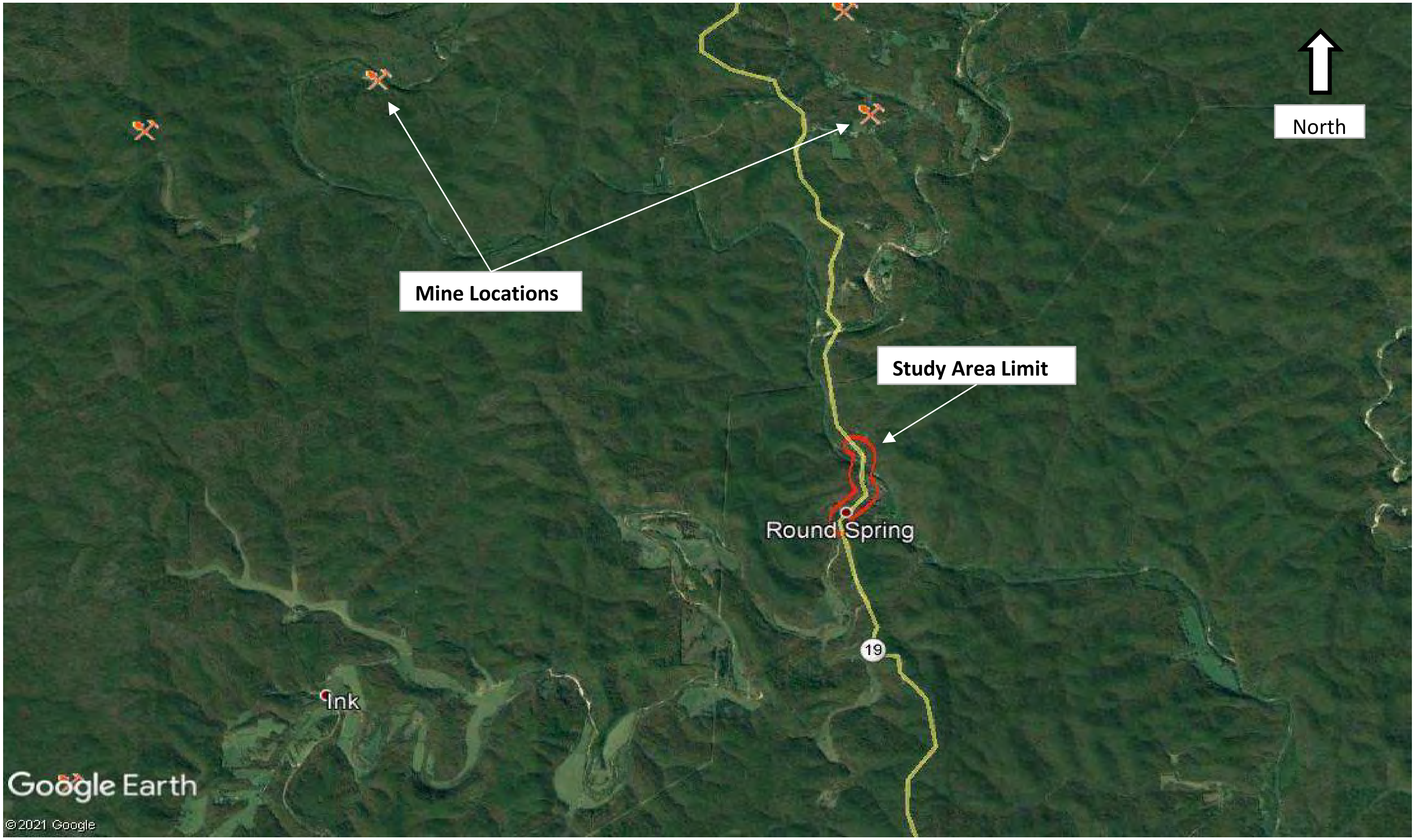


olsson

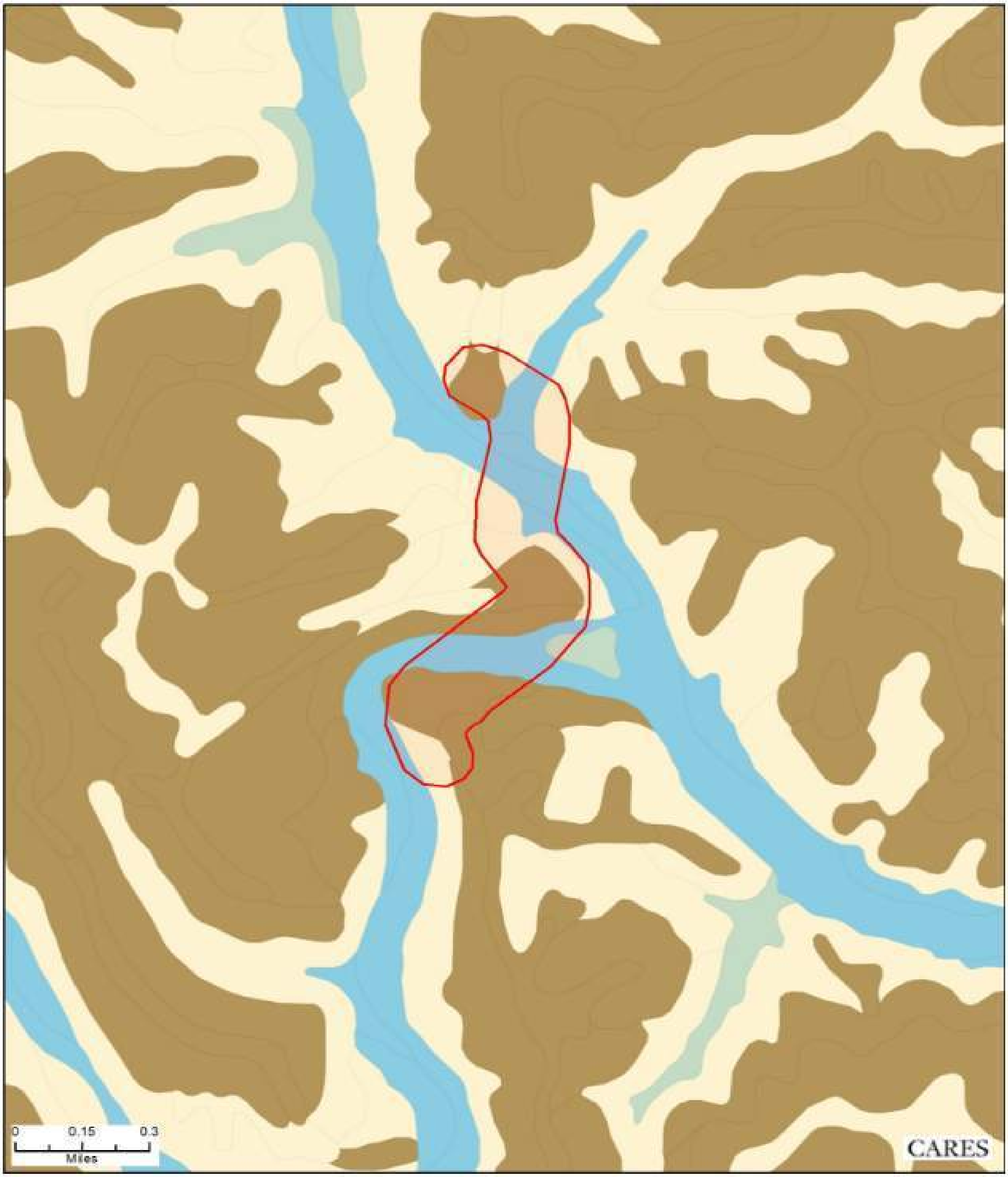
Scale: n.t.s.	
Project No. 020-1986	
Approved by: RRS	
Date: 2/23/2021	

Karst Features Map

Route 19 Bridges
Shannon County, Missouri



	Mine Operation Locations
Scale: n.t.s. Project No. 020-1986 Approved by: RRS Date: 2/23/2021	**Route 19 Bridges** **Shannon County, Missouri**



↑
NORTH

Surface Texture (Dominant Component) by Soil Map Unit, NRCS 2019

- Silt Loam
- Sandy Loam
- Loamy Sand
- Organic Materials

https://agintel.missouri.edu/map-room/, 1/25/2021

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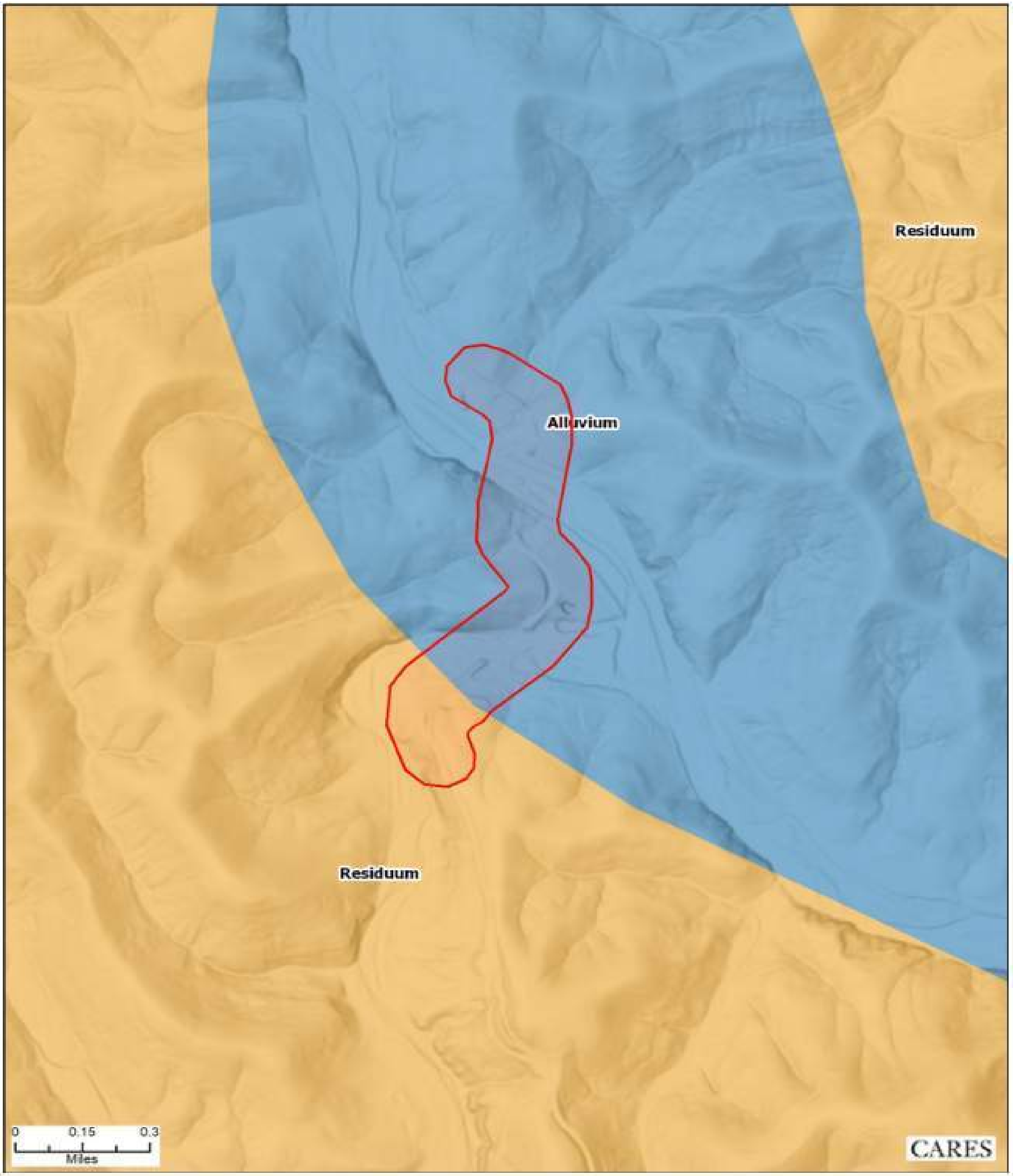
Surficial Texture by Soil Map Unit

Project No. 020-1986
Approved by: RRS
Date: 2/24/2021

Route 19 Bridges
Shannon County, Missouri



Surficial Geology by Region, MO DNR 2013

https://agintel.missouri.edu/map-room/, 1/25/2021

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Surficial Geology by Region

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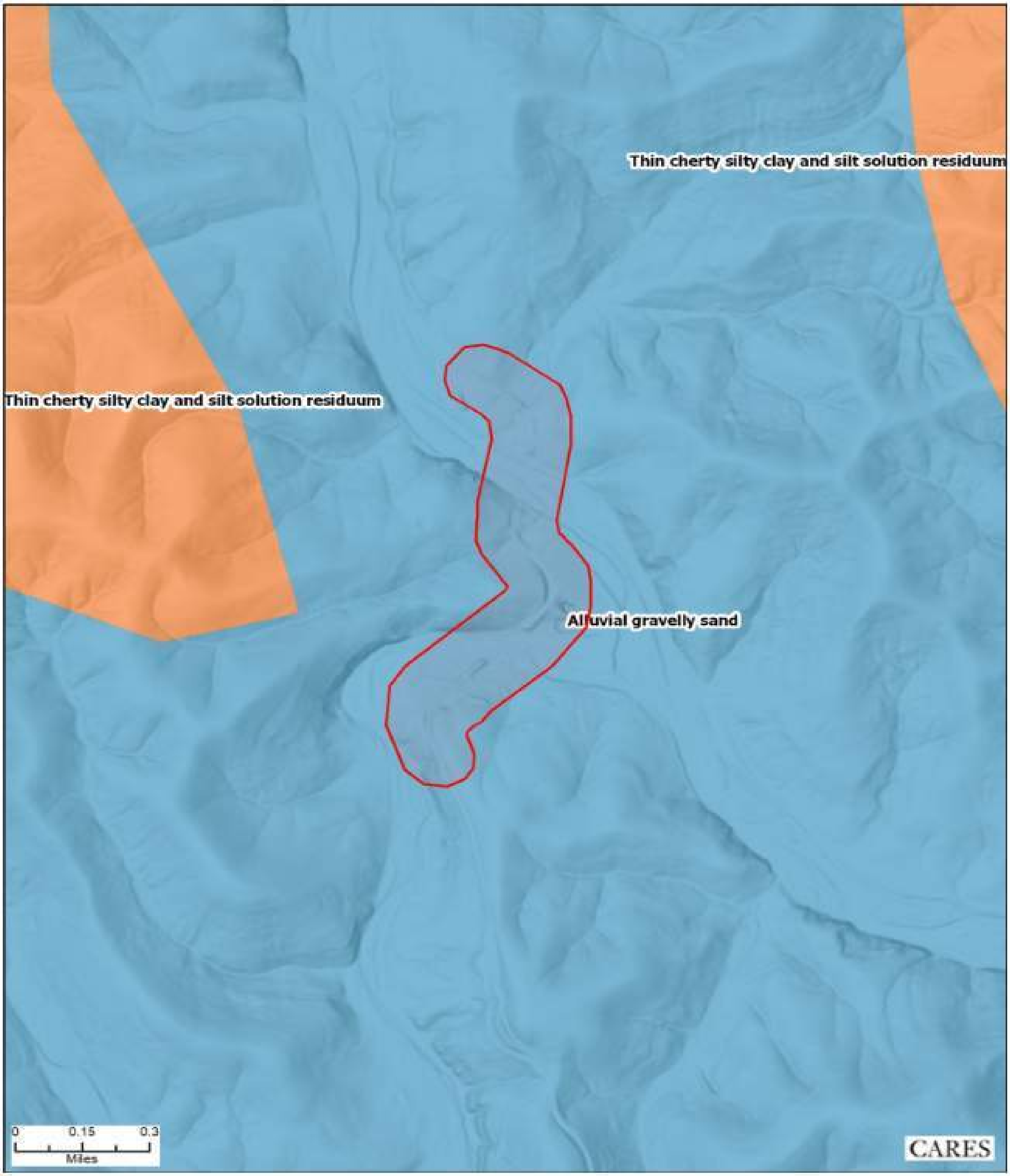
Project No. 020-1986	**Route 19 Bridges**
Approved by: RRS	**Shannon County, Missouri**
Date: 2/24/2021	



Quaternary Geology by Region, USGS 1996

https://agintel.missouri.edu/map-room/, 1/25/2021

↑ NORTH

Quaternary Geology by Region

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Project No. 020-1986	**Route 19 Bridges**
Approved by: RRS	**Shannon County, Missouri**
Date: 2/24/2021	

Bedrock, 1:500,000 Scale, MO DNR 2016

- Ordovician, Roubidoux
- Ordovician, Gasconade
- Ordovician System undifferentiated
- Cambrian, Eminence & Potosi

https://agintel.missouri.edu/map-room/, 1/25/2021

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Project No. 020-1986
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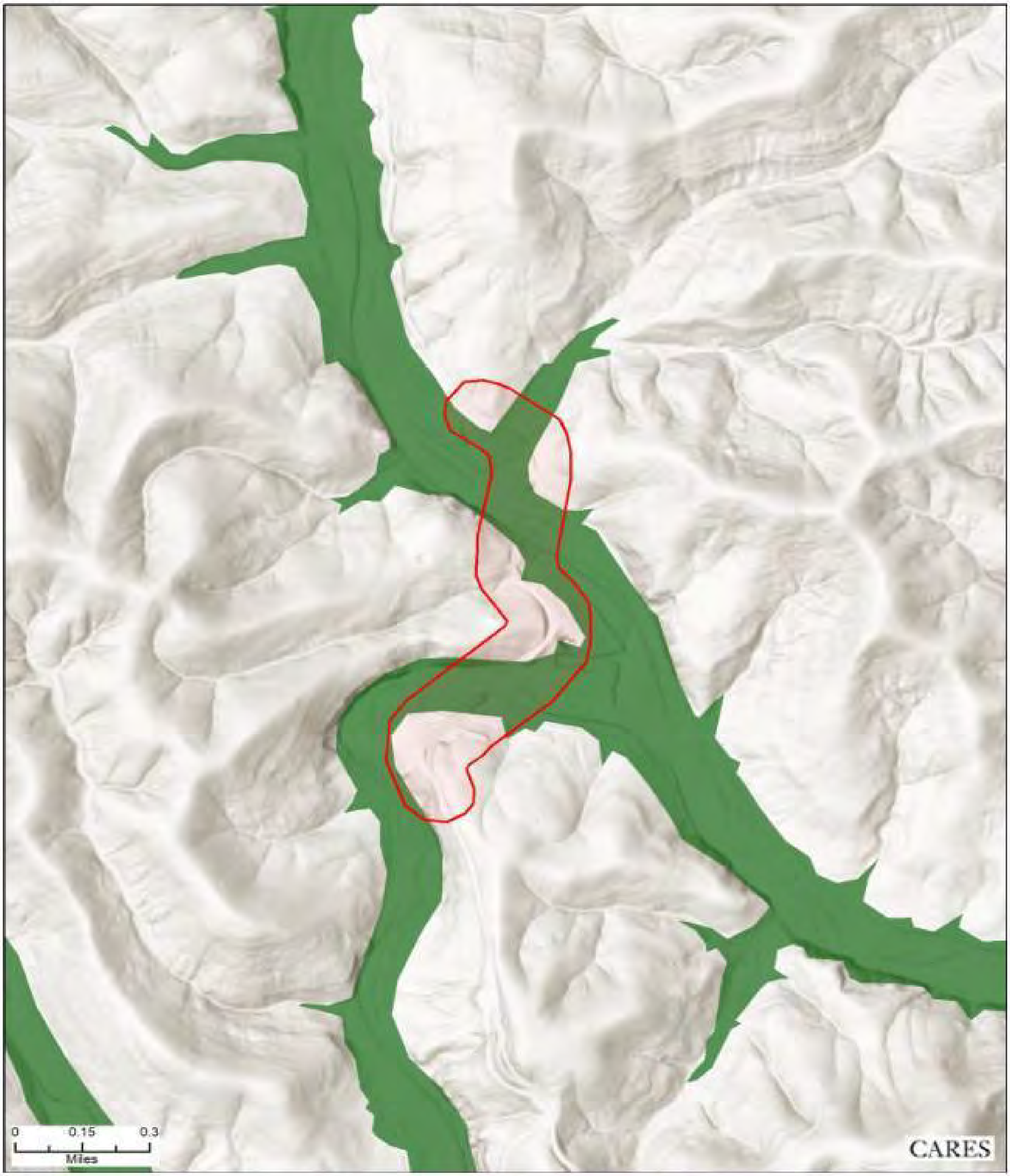
Date: 2/24/2021

Bedrock, 1:500,000 Scale

Route 19 Bridges
Shannon County, Missouri



Alluvium Deposit Soils by Region, MO DNR 2014

https://agintel.missouri.edu/map-room/, 1/25/2021

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Alluvium Deposit Soils by Region

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Project No. 020-1986
Approved by: RRS
Date: 2/24/2021

Route 19 Bridges
Shannon County, Missouri

Earthquake Liquefaction Potential by Area, MO DNR 2013

https://agintel.missouri.edu/map-room/, 1/25/2021

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Liquefaction Potential by Area

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Approved by: RRS	
Date: 2/24/2021	

Route 19 Bridges
Shannon County, Missouri

ATTACHMENT C

Preliminary Geotechnical Investigation for Route 19 Bridges at Round Spring (Prepared by GeoEngineers Inc., 2022)

Preliminary Geotechnical Investigation for Route 19 Bridges at Round Spring

J9P3305
Route 19 Bridges at Round Spring
Shannon County, Missouri

for
Missouri Department of Transportation

June 22, 2022

GeoEngineers
Earth Science + Technology

Preliminary Geotechnical Investigation for Route 19 Bridges at Round Spring

J9P3305
Route 19 Bridges at Round Spring
Shannon County, Missouri

for
Missouri Department of Transportation

June 22, 2022

GeoEngineers

2155-A Chesterfield Boulevard
Springfield, Missouri 65807
417.831.9700

Preliminary Geotechnical Investigation Report

J93305
Route 19 Bridges at Round Spring
Shannon County, Missouri

File No. 15273-022-01

June 22, 2022

Prepared for:

Missouri Department of Transportation
2675 N. Main Street
Sikeston, Missouri 63801

Attention: Pete Berry, P.E.

GeoEngineers, Inc.
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Principal

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LIST OF FIGURES

APPENDICES

1.0 INTRODUCTION AND PROJECT UNDERSTANDING

GeoEngineers, Inc. (GeoEngineers) has prepared this report for the Missouri Department of Transportation (MoDOT) documenting our preliminary geotechnical investigation for the Route 19 Bridges at Round Spring project. Work to complete this project was conducted in general accordance with MOU No. 2022-02-68210, executed on March 3, 2022. The site location is shown on the attached Vicinity Map, Figure 1.

We completed a preliminary geotechnical investigation for the subject project. The project is located at the Route 19, Spring Valley Bridge in Shannon County, Missouri, approximately 5.5 miles north of Route D on Highway 19. The purpose of the project was to investigate areas identified as anomalies by Collier Geophysics, LLC (a subcontractor to HG Consult) in the geophysical survey performed near the Spring Valley Creek and Round Spring in August, 2021 (Collier, 2021). The Collier geophysics report was included as part of a Karst Review by Olsson (Olsson, 2021), which recommended the geotechnical borings included in this report. We anticipate that additional geotechnical investigation work will be required for bridge foundation engineering and design. The location of the completed borings are shown on the attached Boring Location Map, Figure 2.

2.0 SCOPE OF SERVICES

The purpose of our services was to evaluate the existing subsurface soil, rock, and groundwater conditions by conducting a geotechnical investigation, performing downhole video investigation of the completed boreholes, and monitoring groundwater conditions at Round Spring during drilling operations for Borings B-2 and B-4. The specific scope of services provided by GeoEngineers included the following:

1. Completed site reconnaissance at the site to evaluate boring locations and site access.
2. Conducted a field exploration program by completing a total of 4 borings located at four anomalies identified in a geophysical survey and summarized in the Olsson Karst report (Olsson 2021). The four geotechnical borings were advanced from the ground surface using hollow stem augers and standard penetration testing (SPT) sampling methods using a calibrated automatic hammer on 5' intervals. Below the bedrock contact, rock was cored to depths of up to 75 feet below bedrock contact. (Drilling was completed by our subcontractor Anderson Engineering).
3. Logged the borings, recorded ground water levels at the time of our investigation and obtained samples of the soil and rock encountered during our exploration.
4. Performed SPT and split-barrel sampling in general accordance with ASTM D1586 using an automatic hammer. Gradation samples, moisture samples and pocket penetrometer readings were collected from the SPT samples, as applicable. Bedrock was cored with an NX size core barrel, photographed, and placed in labeled core boxes. Samples were taken from the rock core at approximately 5-foot intervals for unconfined compressive testing.
5. Attempted to obtain video imagery in the bedrock portion of each borehole using downhole video equipment.
6. Monitored water quality parameters (turbidity, pH, specific conductance, dissolved oxygen, oxygen-reduction potential and temperature) at Round Spring during drilling of Borings 2 and 4 which, based

upon the initial geophysical survey interpretation, could potentially have voids with the most direct hydraulic connection to Round Spring.

7. Backfilled the boreholes full-depth using bentonite chips upon completion.
8. Completed a laboratory testing program on samples obtained from the borings to evaluate pertinent engineering properties (testing completed by our subcontractor Anderson Engineering). The tests included the following:
    a. Standard Classification of Soils in general accordance with ASTM D2488.
    b. Standard Classification of Rock in general accordance with ASTM D5878.
    c. Gradation of soils in general accordance with ASTM D422.
    d. Moisture content in general accordance with ASTM D2216.
    e. Unconfined compressive strength for rock in general accordance with ASTM D7012.
9. Prepared gINT logs of the borings using MoDOT templates, to include the following:
    a. N value of blows per foot.
    b. N60 value of blows per foot (corrected for the energy efficiency of the auto- hammer).
    c. Energy efficiency of the auto hammer.
    d. Drilling equipment identification.
    e. Boring locations (Stations and/or Coordinates, and Elevations with datums).
    f. Rock quality designation (RQD), percent recovery.
    g. Index and classification properties of soil and rock.
10. Evaluated pertinent physical and engineering characteristics of the soil and rock based on the results of the field explorations, laboratory testing and our experience.
11. Analyzed data from drilling, laboratory testing, downhole video recording and water quality monitoring.
12. Submitted, by way of this report, the results of the geotechnical investigation and laboratory testing program along with the results of the downhole video analysis and water quality analysis.

3.0 SITE CONDITIONS

3.1. Bedrock Geology

Geologic mapping indicates that Upper Cambrian Age (499 to 488 million years ago) Eminence Dolomite is the predominant bedrock present at the Route 19 Bridges at Round Spring site. The Eminence Dolomite consists primarily of dolomite and chert. The Dolomite is light-gray, massive to thick-bedded, medium to coarse-grained, weathering to bluish gray or medium gray with a pitted surface. The Eminence Dolomite contains variable amounts of light gray and white stringers and nodules of chert throughout. The chert makes up less than 5 percent of the formation. The thickness of the Eminence Dolomite is typically about 150 feet (Orndorff and Weary, 2009).

3.2. Surficial and Site Geology

Surficial geologic mapping indicates Holocene Age (11,700 years ago to present) alluvium and Pleistocene Age (2.6 million to 11,700 year ago) terrace deposits are present at the Route 19 Bridges at Round Spring site, within the stream valley and floodplain of Spring Valley Creek. The alluvium typically consists of silt, sand, clay, and gravel derived from local bedrock. The gravel is angular to subrounded and consists mostly of chert and sandstone. The alluvium forms on floodplains and stream beds. The terrace deposits consist primarily of silt, sand, clay, and gravel. The gravel mostly consists of rounded cobbles of chert and sandstone. The terrace deposits occur within and along the sides of stream valley and typically lie above the alluvium. The thickness of the alluvium and terrace deposits is typically up to 30 feet, overlying the Eminence Dolomite as described above (Orndorff and Weary, 2009).

3.3. Subsurface Conditions

3.3.1. General

We explored the subsurface conditions at the site on April 25 through May 5, 2022 by drilling 4 geotechnical borings at locations previously identified as anomalies on the geophysical survey, and as requested by MoDOT. The borings were drilled to depths of up to approximately 95 feet bgs using a CME-550X ATV-mounted drill.

Our subcontract driller used 4-inch continuous flight augers to advance the boring in soil, and obtained soil samples from the borings using a 1.5-inch inside-diameter (I.D.) split-spoon sampler driven during SPT testing. Rock coring techniques were used to advance the boring through the bedrock and continuous rock core samples were obtained using NQ2 rock coring equipment. A GeoEngineers field geologist logged the borings on a full-time basis. Soil and rock samples collected were visually classified and other pertinent drilling information was documented, as applicable. Our subcontract laboratory completed testing, including moisture content determinations, sieve analyses, Atterberg limits determination, and unconfined compressive strength testing of the rock core for selected samples obtained from the borings. Logs of the borings, laboratory test data, the SPT automatic hammer calibration, and other pertinent information are presented in Appendix A.

While subsurface explorations aid in characterizing the subsurface formations in the areas previously identified as anomalies, subsurface formations can vary over time and between boring locations. Actual subsurface conditions may vary from those encountered within the borings. The types of field exploration methods used indicate subsurface conditions only at the specific locations of the borings where samples were obtained, only at the time they were obtained, and only to the drilled depths of each boring.

3.3.2. Existing Conditions

Native Soils (B-1, B-2, and B-3)

In general, we noted loose to dense (N_{60} blow counts from 5 to 37), native sand and gravelly soils in Borings B-1, B-2 from near the surface to auger refusal on dolomite bedrock at depths of 15 and 19 feet bgs, respectively. Brown silt with sand and gravel was encountered in the top 10 feet in Boring 3 underlain by gravel soils to a depth of 24 feet bgs where dolomite bedrock was noted.

Existing Embankment Fill (B-4)

Boring B-4 was located near the north end of the Spring Valley Bridge, where the highway embankment consists of approximately 40 feet of fill. The fill was generally stiff to hard in consistency (N_{60} blow counts from 8 to 32), lean and fat clay with gravel. A 7" sample of a cobble or boulder was recovered from a core sample taken from approximately 12 feet bgs. What may be native soil was encountered at 40 feet bgs, consisting of lean clay and sandy clay. Dolomite bedrock was encountered at approximately 51 feet bgs.

Dolomite Bedrock

We noted light gray, slightly weathered to fresh dolomite bedrock below the native soils described above in all of the borings. The bedrock was cored to depths of up to 95 feet bgs. Compressive strength testing was completed on 45 samples obtained from the rock core at approximately 5-foot intervals. The compressive strength testing indicates the strength of the bedrock varies from approximately 360 to 2,380 ksf., with an average compressive strength of approximately 1,190 ksf.

The rock-quality designation (RQD) of the rock core ranged from 25 to 100 (Poor to Excellent) with an average RQD of 79 (Good). Boring B-1 exhibited the lowest rock quality, ranging from 25 to 82 (Poor to Good), with an average RQD of 61 (Fair). The remainder of the borings averaged from 86 to 98 (Good to Excellent).

Three voids of approximately 1 foot each were logged in the upper 10 feet of the rock core from Boring B-1. A void of approximately 2 feet was logged in Boring B-2, and a void of approximately 1 foot was logged in Boring B-3. No other voids were noted during drilling.

The top of bedrock elevation varies from approximately 651.8 to 664.8 feet. The surface elevation is generally consistent at Boring B-2, B-3 and B-4, and on the order of 10 feet higher at Boring B-1, where voids were indicated in the top 10 feet.

The depths and elevations of the bedrock surface, groundwater, and voids are summarized in Table 1.

TABLE 1. GEOTECHNICAL BORING SUMMARY

GeoEngineers Boring No.	Depth to Bedrock (ft bgs)	Top of Bedrock Elevation (ft MSL)	Depth to Void (ft bgs)	Top of Void Elevation (ft MSL)	Vertical Extent of Void (ft)	Depth to Groundwater (ft bgs)	Groundwater Elevation (ft MSL)
B-1	15.5	664.8	17.5	662.8	1 foot	10.0	670.3
B-1 (Cont.)	"	"	21.5	658.8	1 foot	"	"
B-1 (Cont.)	"	"	23.5	656.8	1 foot	"	"
B-2	19.0	654.3	83.0	590.3	2 feet	7.0	666.3
B-3	24.0	651.8	37.0	638.8	1 foot	10.0	665.8
B-4	51.0	654.4	N/A			N/A	

3.3.3. Borehole Video

We attempted downhole camera videos after the completion of each boring. The boreholes were allowed to settle following drilling prior to introducing the downhole camera. However, due to excessive suspended sediment, meaningful video recordings were not obtained.

3.3.4. Groundwater Conditions

We encountered groundwater in Borings B-1, B-2 and B-3 during drilling at depths of 10, 7, and 10 feet, respectively. Groundwater was not encountered in Boring B-4. We anticipate the subsurface water level will likely vary with seasonal conditions.

3.3.5. Round Spring Water Quality Measurements

Based upon the geophysical survey report, we interpreted Borings B-2 and B-4 were more likely to encounter voids that could be directly connected to Round Spring. Therefore, we monitored the water quality in Round Spring during the drilling of Borings B-2 and B-4. We recorded temperature, turbidity, specific conductance, pH, oxidation-reduction potential (ORP), and dissolved oxygen with a YSI ProDSS multiparameter meter every five minutes from at least 30 minutes prior to the beginning of drilling each day until at least 30 minutes following the conclusion of drilling. Water quality data for the monitoring period is included in Appendix B and summarized below in Table 1.

Precipitation data is provided from the USGS Stream Gauge 7066000 Jacks Fork at Eminence station located approximately 10 miles south of Round Spring. The precipitation data at that station is recorded every 15 minutes and is included along with the water quality monitoring data in Appendix B.

Flow from Round Spring was generally consistent during the monitoring period, until Thursday, May 5, when we observed the flow to be steadily increasing. This increase in spring flow is likely due to heavy precipitation in the recharge area in the early morning hours.

TABLE 2. SUMMARY OF GROUNDWATER QUALITY MEASUREMENTS

Parameter	Low	High	Mean	Comment
Temperature (°F)	54.7	55.2	54.9	
Specific Conductance (µS/cm)	196.1	223.1	200.7	Higher values were often recorded at the beginning of the monitoring period each day and may reflect the probe still coming to equilibrium with ambient conditions.
pH	6.86	7.30	7.0	
ORP (mV)	108.4	161.2	141.7	
Dissolved Oxygen (DO) (mg/L)	7.36	7.94	7.60	
Turbidity (NTU)	0.16	5.09	0.8	Turbidity over 2 NTUs was recorded on 5/3/22 from 13:30 to 14:25 hours. This period of elevated turbidity was likely due to sediment or algae on the probe as it cleared upon shaking the probe.

Based upon the water quality data observed during drilling, we did not identify impacts to the water quality at Round Spring during the drilling of Borings B-2 and B-4.

4.0 DISCUSSION

The primary purpose of the geotechnical borings described herein was to investigate areas identified as anomalies by Collier Geophysics, LLC, in their geophysical survey performed near the Spring Valley Creek and Round Spring (Collier, 2021). The Collier Geophysics report was included as part of a Karst Review report by Olsson (Olsson, 2021). Olsson recommended four areas for further field investigation with geotechnical borings, representing both anomalies of high resistivity and low resistivity.

Table 3 summarizes how the geotechnical borings installed as part of this investigation relate to anomalies identified in the Collier report and recommended for further evaluation in the Olsson report.

TABLE 3. GEOTECHNICAL BORINGS CORRELATION TO GEOPHYSICAL ANOMALIES

Boring No.	Geophysics Line[1]	Geophysics Anomaly Identifier[1]	Type of Geophysics Anomaly[1]	Anomaly Top Depth (ft bgs)	Anomaly Depth Extent (ft)	Boring Description
B-1	Line 4	V	High resistivity	37	124	Soft to hard dolomite with some vugs and quartz druse
B-2	Line 4	W	Low resistivity	18	40	Medium hard to hard dolomite, slightly weathered with some vugs and clay lenses
B-2	Line 4	V	High resistivity	84	>50	Soft to hard dolomite, slightly weathered with some vugs and quartz druse; void identified 83 to 85 ft bgs.
B-3	Line 4	V	High resistivity	50	>75	Soft to hard dolomite, slightly weathered with some vugs and quartz druse
B-4	Line 3	Q	Low resistivity	13	35	Clay and clay with sand, moist and stiff (fill)

Note 1: From Collier (2021). See Appendix C.

We investigated the high resistivity anomaly identified as “V” by Collier (Collier, 2021) with Borings B-1, B-2, and B-3. All 3 borings identified this anomaly as slightly weathered, soft to hard dolomite with some vugs with quartz druse. The only void identified at or near the Anomaly V was a two-foot void from approximately 83 to 85 feet bgs in Boring B-2, which correlates roughly to the top of this anomaly at this location. In our opinion, it is unlikely that this relatively small void would have produced the large high resistivity anomaly identified as “V” in the Collier geophysics report. Therefore, we interpret this high resistivity anomaly to be attributed to dense bedrock with low moisture content.

We investigated the low resistivity anomaly identified as “W” in the Collier Geophysics report with Boring B-2. This boring was located adjacent to and south of the stream in Spring Valley. The top of bedrock in this boring was identified at 19 feet bgs, which approximately correlates to the top of this low resistivity geophysical anomaly. The geophysical survey Line 4 included in the Collier Geophysics report appears to indicate a depression in Anomaly V under the stream and above the low resistivity Anomaly W (See Appendix C). No distinct variation appears in the Boring B-2 boring log between the area identified as low resistivity (Anomaly W) and high resistivity (Anomaly V) in this boring.

We investigated the low resistivity anomaly identified as "Q" in the Collier Geophysics report with Boring B-4. The top of bedrock in this boring was identified at 51 feet below ground surface. The Boring B-2 boring log indicates the geology of this low resistivity anomaly to be moist clay and clay with sand fill along the edge of the bridge approach. No voids were encountered in Boring B-4.

5.0 SUMMARY AND CONCLUSIONS

5.1. Summary

We drilled four geotechnical borings in the MoDOT right-of-way along the Spring Valley Bridge on Highway 19 at Round Spring, Missouri between April 25 and May 5, 2022. These borings were drilled to investigate geophysical anomalies identified during a geophysical investigation of the area performed as part of the environmental assessment for bridge replacement.

We advanced the geotechnical borings from the ground surface using hollow stem augers and SPT sampling methods using a calibrated automatic hammer on 5' intervals. Below the bedrock contact, rock was cored to depths of up to 75 feet below bedrock contact. The borings were logged during drilling and samples of the soil and rock encountered during our exploration were sampled for laboratory testing. Upon completion of the borings, video recording of the borings was attempted with a downhole camera.

The geophysical investigation indicated the greatest likelihood of encountering significant voids with a hydrologic connection to Round Spring during Borings 2 and 4. Therefore, we monitored water quality in Round Spring during the drilling of these borings.

5.2. Conclusions

1. We encountered bedrock at depths ranging from 15.5 to 24 feet bgs in Borings B-1 through B-3, and 53 feet in Boring B-4 where approximately 40 feet of embankment fill was noted. Bedrock consisted of light gray, slightly weathered to fresh dolomite.
2. We noted the following five voids in the geotechnical borings:
    a. Boring B-1: Three voids of approximately 1 foot each in the upper 10 feet of the rock core.
    b. Boring B-2: One void of approximately 2 feet from 83 to 85 feet bgs.
    c. Boring B-3: A void of approximately 1 foot was logged at a depth of 37 feet bgs.

    No other voids were noted during geotechnical investigation summarized in this report.
3. Due to excessive suspended sediment in the borings, we were not able to record meaningful downhole video during the geotechnical investigation.
4. Based upon the water quality data observed during drilling, we did not observe impacts to the water quality at Round Spring during the drilling of Borings B-2 and B-4.

5. Based on the results of the borings, the areas identified as anomalies in the Collier report do not appear to represent significant risk for the further development of bridge foundation plans for this project.

6.0 LIMITATIONS

We have prepared this data report for use by MoDOT, their authorized agents, and other approved members of the design team involved with this project. This report is not intended for use by others, and the information contained herein is not applicable to other sites. The data and report may be provided to prospective contractors, but our report, conclusions, and interpretations should not be construed as a warranty of the subsurface conditions.

Variations in subsurface conditions are possible between the explorations. Subsurface conditions may also vary with time. A contingency for unanticipated conditions should be included in the project budget and schedule for such an occurrence. We recommend that sufficient monitoring, testing, and consultation be provided by GeoEngineers during construction to evaluate that the conditions encountered are consistent with those indicated by the explorations, to provide recommendations for design changes should the conditions revealed during the work differ from those anticipated, and to evaluate whether earthwork, bridge, and MSE wall construction comply with contract plans and specifications.

The scope of our services does not include services related to construction safety precautions. Our recommendations are not intended to direct the contractor's methods, techniques, sequences or procedures, except as specifically described in our report for consideration in design.

Within the limitations of scope, schedule, and budget, our services have been executed in accordance with generally accepted practices in this area at the time the report was prepared. The conclusions, recommendations, and opinions presented in this report are based on our professional knowledge, judgment, and experience. No warranty or other conditions, express, written, or implied, should be understood.

Any electronic form, facsimile, or hard copy of the original document (email, text, table, and/or figure), if provided, and any attachments are only a copy of the original document. The original document is stored by GeoEngineers and will serve as the official document of record.

Please refer to Appendix D, titled “Report Limitations and Guidelines for Use,” for additional information pertaining to use of this report.

7.0 REFERENCES

Collier, 2021. Geophysical Letter Report, Project #21-=145, Round Spring National Park, Eminence, MO. Collier Geophysics.LLC, December 14, 2021, 16 p. + appendices.

Olsson, 2021. Preliminary Geotechnical Study Route 19 Bridges Karst Review, December 30, 2021. 90 p.

Orndorff, R.C., and Weary, D.J., 2009, Geologic map of the Round Spring quadrangle, Shannon County, Missouri, U.S. Geological Survey, Scientific Investigations Map SIM-3073, Scale 1:24,000.

Regional Geology of North America, 2017, Ozark Plateau Province, gotbooks.miracosta.edu/geology/regions/Ozark_plateau.html, Accessed 4/21/2022.

FIGURES

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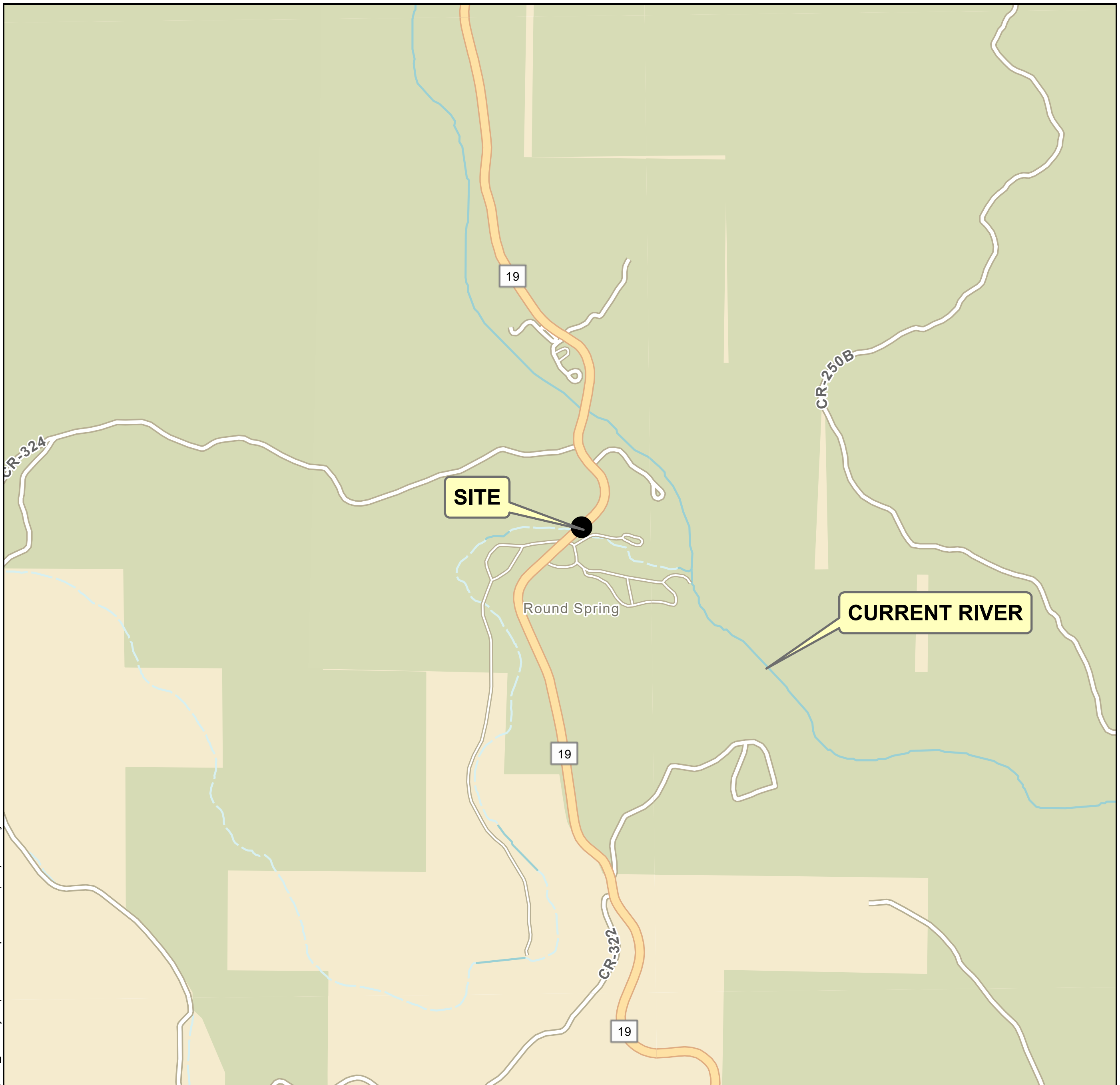

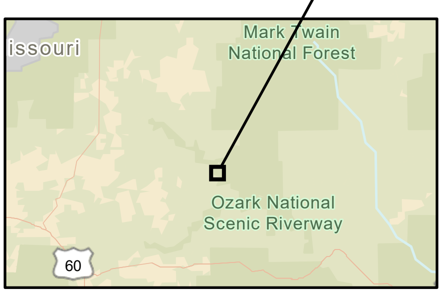

N
W E
S

2,000 0 2,000
Feet

Vicinity Map

MoDOT
Route 19 Bridges at Round Spring
Shannon County, Missouri

GEOENGINEERS

Figure 1

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: ESRI

Projection: NAD 1983 StatePlane Missouri Central FIPS 2402 Feet

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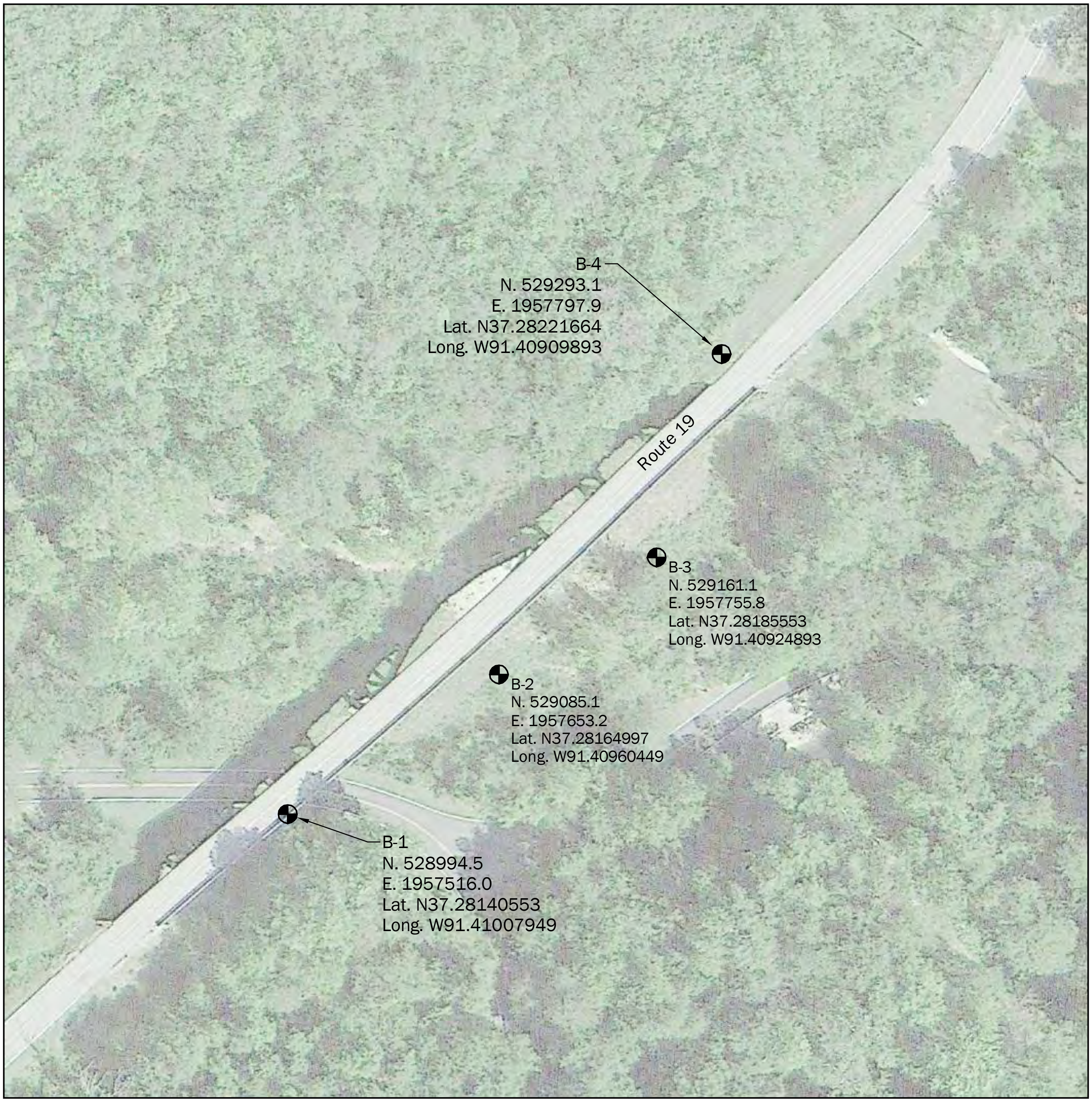

Legend

Boring Location

N W E S

100 0 100

Scale In Feet

Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

References: Aerial image taken from Google Earth Pro © 2022, licensed to GeoEngineers, Inc., image dated 09/10/12.

Boring Location Map

MoDOT
Route 19 Bridges at Round Spring
Shannon County, Missouri

GeoEngineers

Figure 2

MF : SWV

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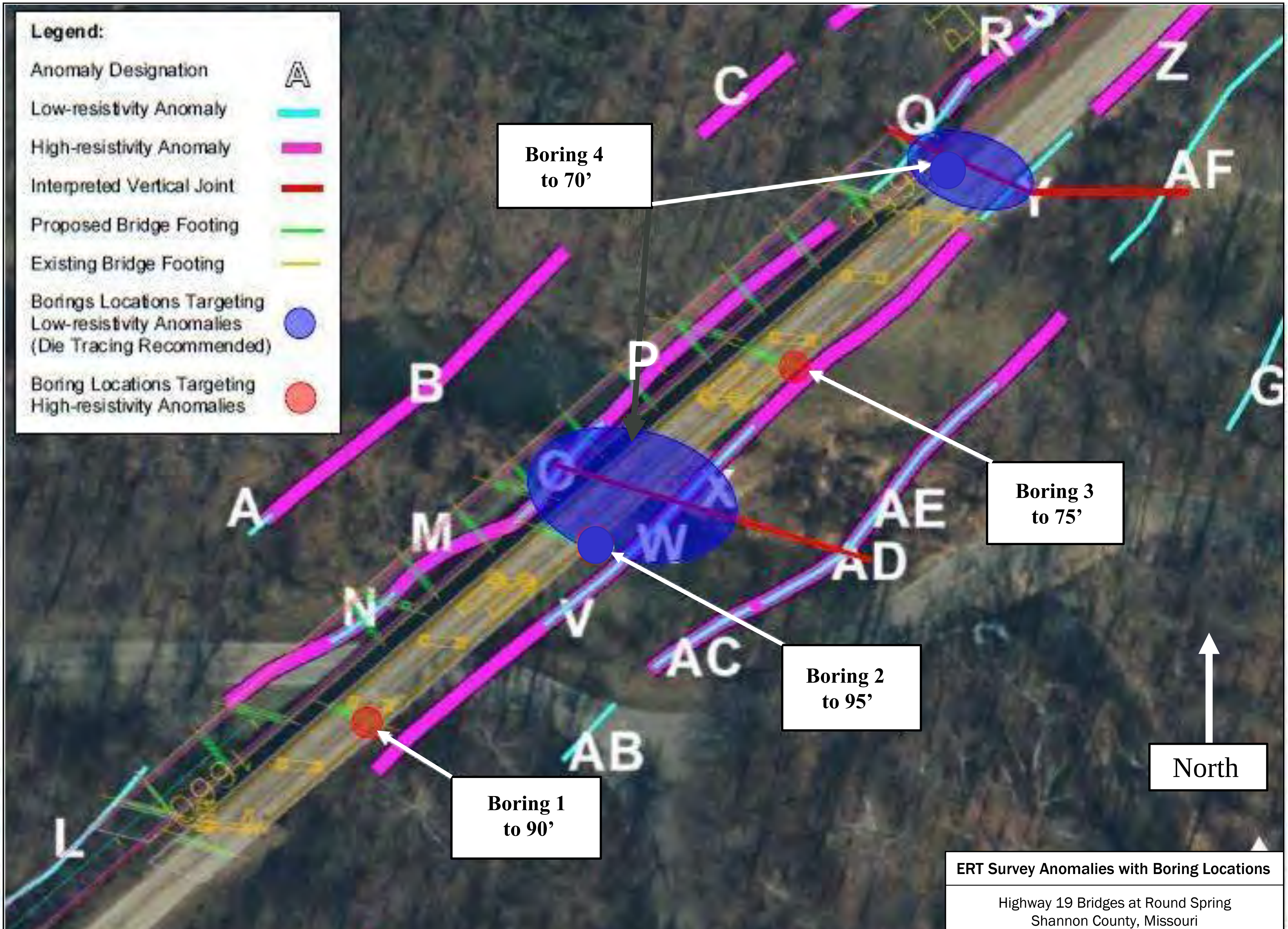

Reference: ERT Survey Image taken from Olsson Report, Preliminary Geotechnical Study Route 19 Bridges Karst Review, December 30, 2021

ERT Survey Anomalies with Boring Locations

Highway 19 Bridges at Round Spring
Shannon County, Missouri

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Figure 3

APPENDICES

APPENDIX A

Geotechnical Exploration Logs and Laboratory Test Results

APPENDIX A
FIELD EXPLORATIONS AND LABORATORY TESTING

Field Explorations

We explored subsurface conditions at the site on September 15 through September 29, 2020 by drilling four (4) geotechnical borings using a CME-550X ATV-Mounted Drill. The borings were drilled at or near the requested locations in order to characterize the subsurface conditions.

The drilling operations were monitored by GeoEngineers' geotechnical engineer who examined and classified the soil encountered, obtained representative samples, observed groundwater conditions where possible, and prepared a detailed log of each exploration. The soils encountered were classified visually in general accordance with American Society for Testing and Materials International (ASTM) D2488, which is described in Figure A-1. The rock core was classified in general accordance with the Unified Rock Classification System (URCS) in general accordance with ASTM D5878, which is described in Figure A-2. The approximate locations of the drilled explorations are shown on the attached Boring Location Map, Figure 2. The calibration of the drill rig hammer is attached.

In general, coarse-grained soil samples were obtained from the borings using a 1.5-inch inside-diameter (I.D.) split-spoon sampler used during SPT testing. The split-spoon sampler was driven 18 inches using a calibrated automatic hammer with a 140-pound hammer with a 30-inch drop. The number of hammer blows required to drive the sampler 12 inches after the initial 6-inch seating, or "N-value", was recorded on the field logs, and the values for N_{60} Were calculated and added the final logs. Bedrock core was obtained using 2-inch I.D. NQ2 rock coring tools. Upon completion, the borings were backfilled with soil cuttings.

We evaluated the relative density of the SPT samples based on correlations with lab and field observations in general accordance with the values outlined in Table A-1 below.

TABLE A-1 CORRELATION BETWEEN BLOW COUNTS AND RELATIVE DENSITY [1]

Cohesive Soils (Clay/Silt)						
Parameter	Very Soft	Soft	Medium Stiff	Stiff	Very Stiff	Hard
Blows, N	< 2	2 – 4	4 – 8	8 – 16	16 – 32	>32
Cohesionless Soils (Gravel/Sand/Silty Sand) [2]						
	Very Loose	Loose	Medium Dense	Dense	Very Dense	
Blows, N	0 – 4	4 – 10	10 – 30	30 – 50	> 50	

Notes:

[1] After Terzaghi, K and Peck, R.B., "Soil Mechanics in Engineering Practice," John Wiley & Sons, Inc., 1962.

[2] Classification applies to soils containing additional constituents; that is, organic clay, silty or clayey sand, etc.

The exploration logs are attached. The logs are based on our interpretation of the field data obtained from the subsurface explorations and indicate the various types of soil encountered, while indicating the approximate depths at which the subsurface conditions change. Unless noted on the exploration logs, the lines designating the layers between soil units represent approximate boundaries. The transition between materials may be gradual or may occur between recovered samples. Additionally, the logs represent conditions observed at the time of drilling and has been edited to incorporate results of the laboratory tests performed as appropriate.

Laboratory Testing

General

Representative soil and rock samples obtained from the explorations were tested by Anderson Engineering in their Springfield, Missouri office. Testing included moisture content determinations, sieve analyses, Atterberg limits determination, and unconfined compressive strength testing of the rock core samples. The laboratory testing procedures are discussed in more detail below.

Moisture Content Testing

Moisture content tests were completed for representative soil samples obtained from the explorations in general accordance with ASTM D2216. The results of these tests are presented on the exploration logs at the depths at which the samples were obtained.

Grain Size Distribution

Grain size distribution testing was performed on selected samples in general accordance with ASTM D422/D1140/D6913. The results of the grain size distribution tests were plotted and classified in general accordance with the Unified Soil Classification System (USCS) and are attached. The sieve analysis results are also shown on the boring logs at the respective sample depths.

Unconfined Compressive Strength Testing

Unconfined compressive strength (Q_u) tests were performed on selected rock samples obtained from the borings. The tests were used to evaluate shear strength characteristics of the rock and were completed in general accordance with ASTM D4543. The results of testing are presented on the boring logs at their respective sample depths and are attached in table form.

SOIL CLASSIFICATION CHART

MAJOR DIVISIONS			SYMBOLS GRAPH	SYMBOLS LETTER	TYPICAL DESCRIPTIONS
COARSE GRAINED SOILS MORE THAN 50% RETAINED ON NO. 200 SIEVE	GRAVEL AND GRAVELLY SOILS MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	CLEAN GRAVELS (LITTLE OR NO FINES)		GW	WELL-GRADED GRAVELS, GRAVEL - SAND MIXTURES
				GP	POORLY-GRADED GRAVELS, GRAVEL - SAND MIXTURES
		GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)		GM	SILTY GRAVELS, GRAVEL - SAND - SILT MIXTURES
				GC	CLAYEY GRAVELS, GRAVEL - SAND - CLAY MIXTURES
	SAND AND SANDY SOILS MORE THAN 50% OF COARSE FRACTION PASSING ON NO. 4 SIEVE	CLEAN SANDS (LITTLE OR NO FINES)		SW	WELL-GRADED SANDS, GRAVELLY SANDS
				SP	POORLY-GRADED SANDS, GRAVELLY SAND
		SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)		SM	SILTY SANDS, SAND - SILT MIXTURES
				SC	CLAYEY SANDS, SAND - CLAY MIXTURES
FINE GRAINED SOILS MORE THAN 50% PASSING NO. 200 SIEVE	SILTS AND CLAYS	LIQUID LIMIT LESS THAN 50		ML	INORGANIC SILTS, ROCK FLOUR, CLAYEY SILTS WITH SLIGHT PLASTICITY
				CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
				OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
	SILTS AND CLAYS	LIQUID LIMIT GREATER THAN 50		MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS SILTY SOILS
				CH	INORGANIC CLAYS OF HIGH PLASTICITY
				OH	ORGANIC CLAYS AND SILTS OF MEDIUM TO HIGH PLASTICITY
HIGHLY ORGANIC SOILS				PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENTS

NOTE: Multiple symbols are used to indicate borderline or dual soil classifications

Sampler Symbol Descriptions

- 2.4-inch I.D. split barrel / Dames & Moore (D&M)
- Standard Penetration Test (SPT)
- Shelby tube
- Piston
- Direct-Push
- Bulk or grab
- Continuous Coring

Blowcount is recorded for driven samplers as the number of blows required to advance sampler 12 inches (or distance noted). See exploration log for hammer weight and drop.

"P" indicates sampler pushed using the weight of the drill rig.

"WOH" indicates sampler pushed using the weight of the hammer.

ADDITIONAL MATERIAL SYMBOLS

SYMBOLS GRAPH	SYMBOLS LETTER	TYPICAL DESCRIPTIONS
	AC	Asphalt Concrete
	CC	Cement Concrete
	CR	Crushed Rock/ Quarry Spalls
	SOD	Sod/Forest Duff
	TS	Topsoil

Groundwater Contact

Measured groundwater level in exploration, well, or piezometer

Measured free product in well or piezometer

Graphic Log Contact

Distinct contact between soil strata

Approximate contact between soil strata

Material Description Contact

Contact between geologic units

Contact between soil of the same geologic unit

Laboratory / Field Tests

%F	Percent fines
%G	Percent gravel
AL	Atterberg limits
CA	Chemical analysis
CP	Laboratory compaction test
CS	Consolidation test
DD	Dry density
DS	Direct shear
HA	Hydrometer analysis
MC	Moisture content
MD	Moisture content and dry density
Mohs	Mohs hardness scale
OC	Organic content
PM	Permeability or hydraulic conductivity
PI	Plasticity index
PL	Point lead test
PP	Pocket penetrometer
SA	Sieve analysis
TX	Triaxial compression
UC	Unconfined compression
UU	Unconsolidated undrained triaxial compression
VS	Vane shear

Sheen Classification

NS	No Visible Sheen
SS	Slight Sheen
MS	Moderate Sheen
HS	Heavy Sheen

NOTE: The reader must refer to the discussion in the report text and the logs of explorations for a proper understanding of subsurface conditions. Descriptions on the logs apply only at the specific exploration locations and at the time the explorations were made; they are not warranted to be representative of subsurface conditions at other locations or times.

Key to Exploration Logs

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Figure A-1

Explanation of Bedrock Terms

Scale of Relative Rock Weathering[1]

Designation	Field Identification
Fresh	Crystals are bright. Discontinuities may show some minor surface staining. No discoloration in rock fabric.
Slightly Weathered	Rock mass is generally fresh. Discontinuities are stained and may contain clay. Some discoloration in rock fabric. Decomposition extends up to 1 inch into rock.
Moderately Weathered	Rock mass is decomposed 50% or less. Significant portions of rock show discoloration and weathering effects. Crystals are dull and show visible chemical alteration. Discontinuities are stained and may contain secondary mineral deposits.
Predominantly Decomposed	Rock mass is more than 50% decomposed. Rock can be excavated with geologist's pick. All discontinuities exhibit secondary mineralization. Complete discoloration of rock fabric. Surface of core is friable and usually pitted due to washing out of highly altered minerals by drilling water.
Decomposed	Rock mass is completely decomposed. Original rock "fabric" may be evident. May be reduced to soil with hand pressure.

Scale of Relative Rock Hardness[1]

Term	Hardness Designation	Field Identification	Approximate Unconfined Compressive Strength
Extremely Soft	R0	Can be indented with difficulty by thumbnail. May be moldable or friable with finger pressure.	< 100 psi
Very Soft	R1	Crumbles under firm blows with point of a geology pick. Can be peeled by a pocket knife. Scratched with fingernail.	100-1000 psi
Soft	R2	Can be peeled by a pocket knife with difficulty. Cannot be scratched with fingernail. Shallow indentation made by firm blow of geology pick.	1000-4000 psi
Medium Hard	R3	Can be scratched by knife or pick. Specimen can be fractured with a single firm blow of hammer/geology pick.	4000-8000 psi
Hard	R4	Can be scratched with knife or pick only with difficulty. Several hard hammer blows required to fracture specimen.	8000-16000 psi
Very Hard	R5	Cannot be scratched by knife or sharp pick. Specimen requires many blows of hammer to fracture or chip. Hammer rebounds after impact.	> 16000 psi

Discontinuity Spacing[1]

Description for Bedding, Foliation, or Flow Banding	Spacing	Description of Joints, Faults, or Other Fractures
Very Thick	>10 ft	Very Widely Spaced
Thick	3 ft – 10 ft	Widely Spaced
Medium	1 ft – 3 ft	Moderately Spaced
Thin	2 in – 1 ft	Closely Spaced
Very Thin	<2 in	Very Closely Spaced

Rock Quality Designation (RQD)[1, 2]

RQD (Percent)	Description of Rock Quality
0 – 25	Very Poor
25 – 50	Poor
50 – 75	Fair
75 – 90	Good
90 – 100	Excellent

Notes:

1. Based on ASCE Manual on Engineering Practice No. 56,1976.
2. RQD is a modified core recovery measurement which expresses the number of hard and sound rock pieces of 4" or more in size as a percentage of the total length of core run.

Explanation of Bedrock Terms

GeoEngineers

Figure A-2

Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5	**County:** Shannon	**Route:** Highway 19
Design:	**Skew:**	**Location:** 5.5 miles north of Route D
Bent:	**Logged By:** Seye Coker [GeoEngineers, Inc.]	**Operator:** Carmon Hunter [Anderson]
Station:	**Northing:** 528994.5	**Date of Work:** 04/25/22-04/26/22
Offset:	**Easting:** 1957516.01	**Depth to Water:** 10.0
Elevation: 680.3	**Requested Northing:**	**Depth Hole Open:** 90.5
Requested Station:	**Requested Easting:**	**Time Change:** At Time of Drilling
Requested Offset:	**Equipment:** CME 550X ,Split-Spoon Sampler	
Requested Elevation:	**Location Note:**	
Drill No.: 401073	**Hammer Efficiency:** 92.3%	**Drilling Method:** Continuous Flight Auger

Depth (ft)	Graphic	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
0		0.0-5.0' Brown silty SAND (loose, moist)	680	X	67	2-3-3 (9)			
5		5.0-10.0' Tan fine SAND with chert gravel (medium dense, moist)	675	X	22	2-6-9 (23)			Sieve Analysis Sieve # % Passing 3/4" 100.0 3/8" 83.1 #4 68.5 #10 58.9 #40 32.5 #100 4.9 #200 4.0
10	▽	10.0-15.5' Fine GRAVEL with sand (loose, wet)	670	X	39	2-3-3 (9)			
15		15.5-17.5' Gray DOLOMITE, fresh, hard, medium bedded, slightly vuggy, poor RQD	665						
		17.5-18.5' VOID							
20		18.5-21.5' Gray DOLOMITE, fresh, hard, thick bedded, slightly vuggy with quartz pockets	660	Core	71 (25)	(25)	Qu Test Results UCS = 1450 ksf		
		21.5-22.5' VOID							
		22.5-23.5' Gray DOLOMITE, fresh, hard, thin bedded							
		23.5-24.5' VOID							
25		24.5-26.0' Gray DOLOMITE, fresh, hard, medium bedded	655				Qu Test Results UCS = 1460 ksf		
30		26.0-30.0' Gray DOLOMITE, moderately weathered, hard, thick bedded, vuggy, sandy, fair RQD		Core					

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

Coordinate System: U.S. State Plane 1983	**Coordinate Zone:** Missouri Central	**Coordinate Proj. Factor:** 1.0000772
Coordinate Datum: NAD 83	**Coordinate Units:** U.S. Survey Feet	

Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5	**County:** Shannon	**Route:** Highway 19
Design:	**Skew:**	**Location:** 5.5 miles north of Route D
Bent:	**Logged By:** Seye Coker [GeoEngineers, Inc.]	**Operator:** Carmon Hunter [Anderson]
Station:	**Northing:** 528994.5	**Date of Work:** 04/25/22-04/26/22
Offset:	**Easting:** 1957516.01	**Depth to Water:** 10.0
Elevation: 680.3	**Requested Northing:**	**Depth Hole Open:** 90.5
Requested Station:	**Requested Easting:**	**Time Change:** At Time of Drilling
Requested Offset:	**Equipment:** CME 550X ,Split-Spoon Sampler	
Requested Elevation:	**Location Note:**	
Drill No.: 401073	**Hammer Efficiency:** 92.3%	**Drilling Method:** Continuous Flight Auger

Depth (ft)	Graphic	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
30		30.0-32.5' Gray DOLOMITE, moderately weathered, soft, thick bedded, vuggy, sandy	650		100 (50)		Qu Test Results UCS = 360 ksf		
		32.5-35.5' Gray DOLOMITE, slightly weathered, thick bedded, soft, vuggy, sandy							
35			645						
		35.5-39.5' Gray DOLOMITE, slightly weathered, soft, thick bedded, sandy with quartz pockets, poor RQD					Qu Test Results UCS = 360 ksf		
40		39.5-45.5' Gray DOLOMITE, slightly weathered, soft, thick bedded, vuggy, sandy	640		100 (42)		Qu Test Results UCS = 500 ksf		
45			635						
		45.5-49.5' Gray DOLOMITE, slightly weathered, soft, thick bedded, vuggy, good RQD					Qu Test Results UCS = 480 ksf		
50		49.5-50.5' Gray SANDSTONE, fresh, hard, thin bedded	630		100 (82)		Qu Test Results UCS = 1240 ksf		
		50.5-60.5' Gra DOLOMITE, fresh, hard, thick bedded, slightly vuggy with quartz pockets							
55			625						
		55.5' Fair RQD					Qu Test Results UCS = 2180 ksf		
60									

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

Coordinate System: U.S. State Plane 1983	**Coordinate Zone:** Missouri Central	**Coordinate Proj. Factor:** 1.0000772
Coordinate Datum: NAD 83	**Coordinate Units:** U.S. Survey Feet	

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Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5 **County:** Shannon **Route:** Highway 19
Design: **Skew:** **Location:** 5.5 miles north of Route D
Bent: **Logged By:** Seye Coker [GeoEngineers, Inc.] **Operator:** Carmon Hunter [Anderson]
Station: **Northing:** 528994.5 **Date of Work:** 04/25/22-04/26/22
Offset: **Easting:** 1957516.01 **Depth to Water:** 10.0
Elevation: 680.3 **Requested Northing:** **Depth Hole Open:** 90.5
Requested Station: **Requested Easting:** **Time Change:** At Time of Drilling
Requested Offset: **Equipment:** CME 550X ,Split-Spoon Sampler
Requested Elevation: **Location Note:**
Drill No.: 401073 **Hammer Efficiency:** 92.3% **Drilling Method:** Continuous Flight Auger

Depth (ft)	Graphic	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
60		60.5-65.5' Gray DOLOMITE, slightly weathered, hard, thick bedded, vuggy with green clay lenses	620		100 (69)		Qu Test Results UCS = 1090 ksf		
65		65.5-70.0' Gray DOLOMITE, slightly weathered, medium hard, thick bedded, vuggy with quartz pockets, fair RQD	615				Qu Test Results UCS = 960 ksf		
70		70.0-85.5' Gray DOLOMITE, slightly weathered, hard, very thick bedded, vuggy with quartz pockets	610		100 (63)		Qu Test Results UCS = 1240 ksf		
75		75.5' Good RQD	605				Qu Test Results UCS = 1620 ksf		
80			600		100 (79)		Qu Test Results UCS = 1420 ksf		
85		85.5-88.5' Gray DOLOMITE, slightly weathered, medium hard, medium bedded, vuggy, good RQD	595				Qu Test Results UCS = 1080 ksf		
		88.5-91.5' Gray DOLOMITE, slightly weathered, soft, medium bedded, vuggy			100 (75)		Qu Test Results UCS = 530 ksf		
90									

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

Coordinate System: U.S. State Plane 1983 **Coordinate Zone:** Missouri Central **Coordinate Proj. Factor:** 1.0000772
Coordinate Datum: NAD 83 **Coordinate Units:** U.S. Survey Feet

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Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5
County: Shannon
Route: Highway 19
Design:
Skew:
Location: 5.5 miles north of Route D
Bent:
Logged By: Seye Coker [GeoEngineers, Inc.]
Operator: Carmon Hunter [Anderson]
Station:
Northing: 528994.5
Date of Work: 04/25/22-04/26/22
Offset:
Easting: 1957516.01
Depth to Water: 10.0
Elevation: 680.3
Requested Northing:
Depth Hole Open: 90.5
Requested Station:
Requested Easting:
Time Change: At Time of Drilling
Requested Offset:
Equipment: CME 550X ,Split-Spoon Sampler
Requested Elevation:
Location Note:
Drill No.: 401073
Hammer Efficiency: 92.3%
Drilling Method: Continuous Flight Auger

Depth (ft)	Graphic	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
90		88.5-91.5' Gray DOLOMITE, slightly weathered, soft, medium bedded, vuggy *(continued)*	590						
		Bottom of borehole at 91.5 feet.							

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

Coordinate System: U.S. State Plane 1983
Coordinate Zone: Missouri Central
Coordinate Proj. Factor: 1.0000772
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Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5	**County:** Shannon	**Route:** Highway 19
Design:	**Skew:**	**Location:** 5.5 miles north of Route D
Bent:	**Logged By:** Seye Coker [GeoEngineers, Inc.]	**Operator:** Carmon Hunter (Anderson Engineering)
Station:	**Northing:** 529085.1	**Date of Work:** 05/02/22-05/03/22
Offset:	**Easting:** 1957653.19	**Depth to Water:** 7.0
Elevation: 673.3	**Requested Northing:**	**Depth Hole Open:** 96
Requested Station:	**Requested Easting:**	**Time Change:** At Time of Drilling
Requested Offset:	**Equipment:** CME 550X ,Split-Spoon Sampler	
Requested Elevation:	**Location Note:**	
Drill No.: 401073	**Hammer Efficiency:** 92.3%	**Drilling Method:** Continuous Flight Auger

Depth (ft)	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
0	0.0-5.0' Gray fine SAND with silt (loose, moist)		Split spoon	67	1-2-1 (5)			
		670						
5	5.0-19.0' Brown fine GRAVEL with sand (medium dense, moist)		Split spoon	50	5-8-11 (29)			
	(water level symbol ∇ at 7.0')	665						
10	10.0' Becomes wet		Split spoon	44	4-3-7 (15)			Sieve Analysis Sieve # % Passing 3/4" 100.0 3/8" 73.7 #4 49.2 #10 30.9 #40 17.2 #100 6.7 #200 5.9
		660						
15	15.0' Brown fine GRAVEL with sand (dense, wet)		Split spoon	39	2-8-16 (37)			
		655						
20	19.0-29.0' Gray DOLOMITE, slightly weathered, hard, thick bedded, fractured, vuggy with quartz pockets and clay lenses, good RQD	650	Core	100 (78)		Qu Test Results UCS = 1670 ksf		
25		645						
30			Core			Qu Test Results UCS = 820 ksf		

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

Coordinate System: U.S. State Plane 1983	**Coordinate Zone:** Missouri Central	**Coordinate Proj. Factor:** 1.0000772
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Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5	**County:** Shannon	**Route:** Highway 19
Design:	**Skew:**	**Location:** 5.5 miles north of Route D
Bent:	**Logged By:** Seye Coker [GeoEngineers, Inc.]	**Operator:** Carmon Hunter (Anderson Engineering)
Station:	**Northing:** 529085.1	**Date of Work:** 05/02/22-05/03/22
Offset:	**Easting:** 1957653.19	**Depth to Water:** 7.0
Elevation: 673.3	**Requested Northing:**	**Depth Hole Open:** 96
Requested Station:	**Requested Easting:**	**Time Change:** At Time of Drilling
Requested Offset:	**Equipment:** CME 550X ,Split-Spoon Sampler	
Requested Elevation:	**Location Note:**	
Drill No.: 401073	**Hammer Efficiency:** 92.3%	**Drilling Method:** Continuous Flight Auger

Depth (ft)	Graphic	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
30		29.0-33.5' Gray DOLOMITE, slightly weathered, medium hard, thick bedded, fractured, vuggy with quartz pockets, excellent RQD *(continued)*	640						
35		33.5-39.0' Gray DOLOMITE, slightly weathered, hard, thick bedded, fractured, vuggy	635		100 (90)		Qu Test Results UCS = 1270 ksf		
40		39.0-43.5' Gray DOLOMITE, slightly weathered, medium hard, thick bedded, fractured, vuggy, excellent RQD	630				Qu Test Results UCS = 870 ksf		
45		43.5-49.0' Gray DOLOMITE, slightly weathered, hard, thick bedded, slightly fractured, vuggy	625		100 (93)		Qu Test Results UCS = 1180 ksf		
50		49.0-53.5' Gray DOLOMITE, slightly weathered, soft, thick bedded, fractured, vuggy, good RQD	620				Qu Test Results UCS = 530 ksf		
55		53.5-69.0' Gray DOLOMITE, slightly weathered, hard, very thick bedded, vuggy	615		100 (88)		Qu Test Results UCS = 1350 ksf		
60		59.0' Excellent RQD					Qu Test Results UCS = 1250 ksf		

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

Coordinate System: U.S. State Plane 1983	**Coordinate Zone:** Missouri Central	**Coordinate Proj. Factor:** 1.0000772
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Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5
County: Shannon
Route: Highway 19
Design:
Skew:
Location: 5.5 miles north of Route D
Bent:
Logged By: Seye Coker [GeoEngineers, Inc.]
Operator: Carmon Hunter (Anderson Engineering)
Station:
Northing: 529085.1
Date of Work: 05/02/22-05/03/22
Offset:
Easting: 1957653.19
Depth to Water: 7.0
Elevation: 673.3
Requested Northing:
Depth Hole Open: 96
Requested Station:
Requested Easting:
Time Change: At Time of Drilling
Requested Offset:
Equipment: CME 550X ,Split-Spoon Sampler
Requested Elevation:
Location Note:
Drill No.: 401073
Hammer Efficiency: 92.3%
Drilling Method: Continuous Flight Auger

Depth (ft)	Graphic	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
60		53.5-69.0' Gray DOLOMITE, slightly weathered, hard, very thick bedded, vuggy *(continued)*	610		100 (100)		Qu Test Results UCS = 1270 ksf		
65			605						
70		69.0-73.5' Gray DOLOMITE, slightly weathered, medium hard, thick bedded, fractured, vuggy, good RQD	600				Qu Test Results UCS = 880 ksf		
75		73.5-79.0' Gray DOLOMITE, slightly weathered, hard, thick bedded, fractured, vuggy	595		100 (75)		Qu Test Results UCS = 2120 ksf		
80		79.0-82.0' Gray DOLOMITE, slightly weathered, medium hard, thick bedded, fractured, vuggy, good RQD					Qu Test Results UCS = 740 ksf		
		82.0-83.0' Gray DOLOMITE, slightly weathered, hard, thin bedded, fractured, vuggy	590		100 (88)		Qu Test Results UCS = 1630 ksf		
		83.0-85.0' VOID							
85		85.0-91.5' Gray DOLOMITE, slightly weathered, hard, thick bedded, vuggy with quartz pockets, sandy	585				Qu Test Results UCS = 1330 ksf		
90									

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

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Coordinate Zone: Missouri Central
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Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5	**County:** Shannon	**Route:** Highway 19
Design:	**Skew:**	**Location:** 5.5 miles north of Route D
Bent:	**Logged By:** Seye Coker [GeoEngineers, Inc.]	**Operator:** Carmon Hunter (Anderson Engineering)
Station:	**Northing:** 529085.1	**Date of Work:** 05/02/22-05/03/22
Offset:	**Easting:** 1957653.19	**Depth to Water:** 7.0
Elevation: 673.3	**Requested Northing:**	**Depth Hole Open:** 96
Requested Station:	**Requested Easting:**	**Time Change:** At Time of Drilling
Requested Offset:	**Equipment:** CME 550X ,Split-Spoon Sampler	
Requested Elevation:	**Location Note:**	
Drill No.: 401073	**Hammer Efficiency:** 92.3%	**Drilling Method:** Continuous Flight Auger

Depth (ft)	Graphic	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
90		89.5' Excellent RQD							
		91.5-94.0' Gray DOLOMITE, slightly weathered, soft, medium bedded, vuggy, sandy	580		93 (93)		Qu Test Results UCS = 560 ksf		
95		94.0-94.5' Clay filled VOID							
		94.5-96.0' Gray DOLOMITE, fresh, soft, medium bedded, sandy							
		Refusal at 19.0 feet. Bottom of borehole at 96.0 feet.							

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

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Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5
County: Shannon
Route: Highway 19
Design:
Skew:
Location: 5.5 miles north of Route D
Bent:
Logged By: Seye Coker [GeoEngineers, Inc.]
Operator: Carmon Hunter (Anderson Engineering)
Station:
Northing: 529161.14
Date of Work: 04/26/22-04/27/22
Offset:
Easting: 1957755.78
Depth to Water: 10.0
Elevation: 675.8
Requested Northing:
Depth Hole Open: 76.5
Requested Station:
Requested Easting:
Time Change: At Time of Drilling
Requested Offset:
Equipment: CME 550X ,Split-Spoon Sampler
Requested Elevation:
Location Note:
Drill No.: 401073
Hammer Efficiency: 92.3%
Drilling Method: Continuous Flight Auger

Depth (ft)	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
0	0.0-5.0' Brown SILT with sand and trace gravel (medium stiff, dry)	675	Split spoon	67	2-1-2 (5)			MC = 19.0%
5	5.0-10.0' Brown SILT with sand and gravel (stiff, moist)	670	Split spoon	22	3-5-4 (14)			MC = 16.6%
10	▽ 10.0-15.0' Brown GRAVEL with sand and silt (loose, wet)	665	Split spoon	39	0-1-3 (6)			
15	15.0-15.5' Coarse SAND (wet)	660	Split spoon	50	3-7-9 (25)			Sieve Analysis Sieve # % Passing 3/4" 100.0 3/8" 89.2 #4 74.3 #10 51.8 #40 13.4 #100 3.7 #200 3.0
	15.5-20.0' Fine GRAVEL with sand (medium dense, wet)							
20	20.0-23.0' Fine GRAVEL with sand (dense, wet)	655	Split spoon	44	5-12-10 (34)			
	23.0-24.0' Fine GRAVEL							
25	24.0-33.0' Gray DOLOMITE, slightly weathered, medium hard, thick bedded, vuggy, sandy, good RQD	650	Core	100 (84)		Qu Test Results UCS = 1040 ksf		
30								

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

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Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5	**County:** Shannon	**Route:** Highway 19
Design:	**Skew:**	**Location:** 5.5 miles north of Route D
Bent:	**Logged By:** Seye Coker [GeoEngineers, Inc.]	**Operator:** Carmon Hunter (Anderson Engineering)
Station:	**Northing:** 529161.14	**Date of Work:** 04/26/22-04/27/22
Offset:	**Easting:** 1957755.78	**Depth to Water:** 10.0
Elevation: 675.8	**Requested Northing:**	**Depth Hole Open:** 76.5
Requested Station:	**Requested Easting:**	**Time Change:** At Time of Drilling
Requested Offset:	**Equipment:** CME 550X ,Split-Spoon Sampler	
Requested Elevation:	**Location Note:**	
Drill No.: 401073	**Hammer Efficiency:** 92.3%	**Drilling Method:** Continuous Flight Auger

Depth (ft)	Graphic	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
30		24.0-33.0' Gray DOLOMITE, slightly weathered, medium hard, thick bedded, vuggy, sandy, good RQD *(continued)*	645						
35		33.0-37.0' Gray DOLOMITE, slightly weathered, hard, thick bedded, vuggy with quartz pockets, excellent RQD	640				Qu Test Results UCS = 1600 ksf		
		37.0-38.0' VOID							
40		38.0-44.0' Gray DOLOMITE, slightly weathered, hard, thick bedded, vuggy	635		98 (98)		Qu Test Results UCS = 1750 ksf		
		43.0' Good RQD					Qu Test Results UCS = 1190 ksf		
45, 50		44.0-53.0' Gray DOLOMITE, slightly weathered, hard, thick bedded, vuggy with quartz pockets	630, 625		100 (92)		Qu Test Results UCS = 1960 ksf		
55		53.0-57.0' Gray DOLOMITE, slightly weathered, soft, thick bedded, vuggy, fair RQD	620				Qu Test Results UCS = 440 ksf		
60		57.0-67.5' Gray DOLOMITE, slightly weathered, medium hard, thick bedded, vuggy			100 (64)		Qu Test Results UCS = 1140 ksf		

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

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Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5
County: Shannon
Route: Highway 19
Design:
Skew:
Location: 5.5 miles north of Route D
Bent:
Logged By: Seye Coker [GeoEngineers, Inc.]
Operator: Carmon Hunter (Anderson Engineering)
Station:
Northing: 529161.14
Date of Work: 04/26/22-04/27/22
Offset:
Easting: 1957755.78
Depth to Water: 10.0
Elevation: 675.8
Requested Northing:
Depth Hole Open: 76.5
Requested Station:
Requested Easting:
Time Change: At Time of Drilling
Requested Offset:
Equipment: CME 550X ,Split-Spoon Sampler
Requested Elevation:
Location Note:
Drill No.: 401073
Hammer Efficiency: 92.3%
Drilling Method: Continuous Flight Auger

Depth (ft)	Graphic	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
60		57.0-67.5' Gray DOLOMITE, slightly weathered, medium hard, thick bedded, vuggy *(continued)*	615						
		63.0' Good RQD					Qu Test Results UCS = 790 ksf		
65			610						
		67.5-76.5' Gray DOLOMITE, slightly weathered, hard, thick bedded, vuggy with quartz pockets			100 (80)		Qu Test Results UCS = 1550 ksf		
70			605						
							Qu Test Results UCS = 1510 ksf		
		73.0' Excellent RQD							
75			600		100 (100)		Qu Test Results UCS = 1440 ksf		
		Refusal at 23.0 feet. Bottom of borehole at 76.5 feet.							

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

Coordinate System: U.S. State Plane 1983
Coordinate Zone: Missouri Central
Coordinate Proj. Factor: 1.0000772
Coordinate Datum: NAD 83
Coordinate Units: U.S. Survey Feet

Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5
County: Shannon
Route: Highway 19
Design:
Skew:
Location: 5.5 miles north of Route D
Bent:
Logged By: Seye Coker [GeoEngineers, Inc.]
Operator: Carmon Hunter (Anderson Engineering)
Station:
Northing: 529293.12
Date of Work: 05/04/22-05/04/22
Offset:
Easting: 1957797.9
Depth to Water:
Elevation: 705.4
Requested Northing:
Depth Hole Open:
Requested Station:
Requested Easting:
Time Change:
Requested Offset:
Equipment: CME 550X ,Split-Spoon Sampler
Requested Elevation:
Location Note:
Drill No.: 401073
Hammer Efficiency: 92.3%
Drilling Method: Continuous Flight Auger

Depth (ft)	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
0	0.0-5.0' Red fat CLAY with gravel (stiff, moist) (fill)	705	Split spoon	67	2-3-2 (8)			
5	5.0-10.0' Red and gray CLAY with chert gravel and sand (stiff, moist) (fill)	700	Split spoon	67	2-2-4 (9)			
10	10.0-12.0' Red and gray clayey SAND with gravel (hard, moist) (fill)	695	Split spoon	44	3-3-18 (32)			Sieve Analysis Sieve # % Passing 1" 100.0 3/4" 89.6 3/8" 80.8 #4 67.5 #10 59.4 #40 50.1 #100 37.0 #200 34.2
12	12.0-30.0' Red CLAY with 7" dolomite boulder (fill)		Tube	12				
15		690						
18.5	18.5' Red CLAY with sand, gravel and chert (stiff, moist) (fill)		Split spoon	67	3-6-4 (15)			
20		685						
25	25.0' Red and gray CLAY with wood and trace gravel (stiff, moist) (fill)	680	Split spoon	67	4-4-6 (15)			
30								

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

Coordinate System: U.S. State Plane 1983
Coordinate Zone: Missouri Central
Coordinate Proj. Factor: 1.0000772
Coordinate Datum: NAD 83
Coordinate Units: U.S. Survey Feet

Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5
Design:
Bent:
Station:
Offset:
Elevation: 705.4
Requested Station:
Requested Offset:
Requested Elevation:
Drill No.: 401073

County: Shannon
Skew:
Logged By: Seye Coker [GeoEngineers, Inc.]
Northing: 529293.12
Easting: 1957797.9
Requested Northing:
Requested Easting:
Equipment: CME 550X ,Split-Spoon Sampler
Location Note:
Hammer Efficiency: 92.3%

Route: Highway 19
Location: 5.5 miles north of Route D
Operator: Carmon Hunter (Anderson Engineering)
Date of Work: 05/04/22-05/04/22
Depth to Water:
Depth Hole Open:
Time Change:
Drilling Method: Continuous Flight Auger

Depth (ft)	Graphic	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
30		30.0-40.0' Tan and red fat CLAY with trace gravel (stiff, moist) (fill)	675		67	3-5-6 (17)			
35		35.0' Tan and red fat CLAY with sand (stiff, moist) (fill)	670		67	6-5-5 (15)			
40		40.0-51.0' Tan and red sandy CLAY (stiff, wet)	665		67	3-2-2 (6)			
45		45.0' Tan and red fat CLAY (medium stiff, wet)	660		67	3-3-3 (9)			
50		50.0' Tan and red CLAY with bedrock at tip (very soft, wet)	655		56	1-1-50 (78)			
		51.0-63.0' Gray DOLOMITE, slightly weathered, medium hard, thick bedded, vuggy with clay lenses 53.0' Excellent RQD							
55			650		100 (100)		Qu Test Results UCS = 1140 ksf		
60									

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

Coordinate System: U.S. State Plane 1983
Coordinate Zone: Missouri Central
Coordinate Proj. Factor: 1.0000772
Coordinate Datum: NAD 83
Coordinate Units: U.S. Survey Feet

* Persons using this information are cautioned that the materials shown are determined by the equipment noted and accuracy of the "log of materials" is limited thereby and by judgement of the operator. THIS INFORMATION IS FOR DESIGN PURPOSES ONLY.

Missouri Department of Transportation
Construction and Materials

Job No.: J9P33.5	**County:** Shannon	**Route:** Highway 19
Design:	**Skew:**	**Location:** 5.5 miles north of Route D
Bent:	**Logged By:** Seye Coker [GeoEngineers, Inc.]	**Operator:** Carmon Hunter (Anderson Engineering)
Station:	**Northing:** 529293.12	**Date of Work:** 05/04/22-05/04/22
Offset:	**Easting:** 1957797.9	**Depth to Water:**
Elevation: 705.4	**Requested Northing:**	**Depth Hole Open:**
Requested Station:	**Requested Easting:**	**Time Change:**
Requested Offset:	**Equipment:** CME 550X ,Split-Spoon Sampler	
Requested Elevation:	**Location Note:**	
Drill No.: 401073	**Hammer Efficiency:** 92.3%	**Drilling Method:** Continuous Flight Auger

Depth (ft)	Graphic	Description	Elevation (ft)	Sample Type	REC % (RQD %)	Blow Counts (N_{60})	Shear Data	Field Tests	Index Tests
60		51.0-63.0' Gray DOLOMITE, slightly weathered, medium hard, thick bedded, vuggy with clay lenses *(continued)* 60.5' Excellent RQD	645				Qu Test Results UCS = 990 ksf		
65		63.0-66.0' Bluish gray DOLOMITE, slightly weathered, hard, thick bedded, vuggy with clay pockets and fractures	640		100 (96)		Qu Test Results UCS = 2380 ksf		
70		66.0-70.0' Light gray DOLOMITE, slightly weathered, very hard, thick bedded, slightly vuggy with fractures					Qu Test Results UCS = 1050 ksf		
		Refusal at 53.0 feet. Bottom of borehole at 70.0 feet.							

N_{60} = (Em/60)Nm N_{60} - Corrected N value for standard 60% SPT efficiency; Em - Measured hammer efficiency in percent; Nm - Observed N-value
(1) = Assumed, (2) = Actual

Coordinate System: U.S. State Plane 1983 **Coordinate Zone:** Missouri Central **Coordinate Proj. Factor:** 1.0000772
Coordinate Datum: NAD 83 **Coordinate Units:** U.S. Survey Feet

* Persons using this information are cautioned that the materials shown are determined by the equipment noted and accuracy of the "log of materials" is limited thereby and by judgement of the operator. THIS INFORMATION IS FOR DESIGN PURPOSES ONLY.

Anderson Engineering Laboratory Test Results and Summaries

ROCK CORE COMPRESSION REPORT (ASTM D 4543-19)

Client: GeoEngineers / MoDot - GEO # 15273-022-01 Project #: 22SP30077

Project: Highway 19 Bridge

Boring	Depth, ft	Core Diameter (in.)	Weight (LBS)	Sawed Length (in.)	Length w/ Cap (in.)	L/D Ratio	Date Tested	Max Load (LBS)	Area of Cores (in.2)	L/D Correction	Compressive strength (PSI)	Type Break
B-1	18.75	1.97	1.38	4.54	4.81	2.4	05/03/22	30,730	3.05	1.00	10,082	5
B-1	20.66	1.97	1.20	4.05	4.15	2.1	05/03/22	30,980	3.05	1.00	10,164	2
B-1	27.75	1.96	0.84	3.82	3.93	2.0	05/03/22	7,460	3.02	1.00	2,473	3
B-1	32.25	1.97	0.86	3.66	3.87	2.0	05/03/22	7,700	3.05	1.00	2,526	3
B-1	36.25	1.97	1.02	3.43	3.62	1.8	05/03/22	10,670	3.05	1.00	3,501	3
B-1	43.00	1.97	0.84	2.84	3.12	1.4	05/03/22	10,150	3.05	1.00	3,330	3
B-1	46.50	1.98	1.38	4.74	4.91	2.4	05/03/22	26,580	3.08	1.00	8,632	3
B-1	52.25	1.96	1.54	5.10	5.31	2.6	05/03/22	45,790	3.02	1.00	15,176	5
B-1	58.25	1.98	1.36	4.51	4.67	2.3	05/03/22	23,230	3.08	1.00	7,544	3
B-1	64.50	1.97	1.44	4.81	4.94	2.4	05/03/22	20,300	3.05	1.00	6,660	2
B-1	70.20	1.97	1.24	4.06	4.27	2.1	05/03/22	3,774	3.05	1.00	1,238	2
B-1	73.75	1.97	1.48	4.86	5.03	2.5	05/03/22	34,300	3.05	1.00	11,253	2
B-1	76.50	1.95	1.50	4.95	5.16	2.5	05/03/22	29,360	2.99	1.00	9,831	2

Report Date: 5/3/2022

Signed: [signature], P.E.

with Anderson Engineering

2 - Columnar, cone break
3 - Columnar break
5 - Side fracture, top or bottom

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ROCK CORE COMPRESSION REPORT (ASTM D 4543-19)

Client: GeoEngineers / MoDot - GEO # 15273-022-01 Project #: 22SP30077

Project: Highway 19 Bridge

	Boring	Depth, ft	Core Diameter (in.)	Weight (LBS)	Sawed Length (in.)	Length w/ Cap (in.)	L/D Ratio	Date Tested	Max Load (LBS)	Area of Cores (in.2)	L/D Correction	Compressive strength (PSI)	Type Break
A	B-2	21.66	1.97	1.20	3.95	4.15	2.0	05/06/22	35,370	3.05	1.00	11,604	3
B	B-2	28.20	1.97	1.40	4.04	4.19	2.1	05/06/22	17,310	3.05	1.00	5,679	3
C	B-2	33.20	1.96	1.28	4.25	4.48	2.2	05/06/22	26,640	3.02	1.00	8,829	3
D	B-2	38.33	1.98	1.24	4.08	4.37	2.1	05/06/22	18,660	3.08	1.00	6,060	3
E	B-2	43.00	1.97	1.26	4.12	4.30	2.1	05/06/22	25,020	3.05	1.00	8,209	3
F	B-2	45.20	1.97	1.22	4.11	4.36	2.1	05/06/22	11,290	3.05	1.00	3,704	3
G	B-2	50.25	1.98	1.20	3.94	4.14	2.0	05/06/22	28,890	3.08	1.00	9,383	4
H	B-2	58.66	1.98	1.24	4.03	4.23	2.0	05/06/22	26,750	3.08	1.00	8,688	3
I	B-2	65.00	1.97	1.26	4.04	4.25	2.1	05/06/22	26,800	3.05	1.00	8,793	3
J	B-2	68.50	1.97	1.18	3.98	4.19	2.0	05/06/22	18,580	3.05	1.00	6,096	3
K	B-2	69.33	1.97	1.24	4.02	4.26	2.0	05/06/22	44,780	3.05	1.00	14,691	3
L	B-2	78.60	1.97	1.24	4.07	4.29	2.1	05/06/22	15,760	3.05	1.00	5,171	4
M	B-2	80.25	1.98	1.22	4.13	4.27	2.1	05/06/22	34,950	3.08	1.00	11,351	3
N	B-2	88.33	1.97	1.22	4.05	4.28	2.1	05/06/22	28,090	3.05	1.00	9,216	3
O	B-2	93.80	1.98	1.16	3.95	4.09	2.0	05/06/22	11,920	3.08	1.00	3,871	3

Report Date: 5/6/2022

Signed: [signature], P.E.

3 - Columnar break
4 - Diagonal fracture

with Anderson Engineering

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ROCK CORE COMPRESSION REPORT (ASTM D 4543-19)

Client: GeoEngineers / MoDot - GEO # 15273-022-01 Project #: 22SP30077

Project: Highway 19 Bridge

Boring	Depth, ft	Core Diameter (in.)	Weight (LBS)	Sawed Length (in.)	Length w/ Cap (in.)	L/D Ratio	Date Tested	Max Load (LBS)	Area of Cores (in.2)	L/D Correction	Compressive strength (PSI)	Type Break
B-3	25.33	1.97	1.46	5.10	5.10	2.6	05/03/22	22,090	3.05	1.00	7,247	3
B-3	30.33	1.97	1.30	4.30	4.30	2.2	05/03/22	33,930	3.05	1.00	11,132	3
B-3	38.00	1.97	1.20	3.88	3.88	2.0	05/03/22	36,970	3.05	1.00	12,129	3
B-3	40.20	1.97	1.62	5.24	5.24	2.7	05/03/22	25,260	3.05	1.00	8,287	2
B-3	47.75	1.97	1.68	5.52	5.52	2.8	05/03/22	41,550	3.05	1.00	13,632	3
B-3	49.66	1.97	1.44	4.84	4.84	2.5	05/03/22	9,330	3.05	1.00	3,061	3
B-3	56.00	1.97	1.26	4.31	4.31	2.2	05/03/22	24,190	3.05	1.00	7,936	3
B-3	61.75	1.98	1.58	5.31	5.31	2.7	05/03/22	16,950	3.08	1.00	5,505	2
B-3	63.66	1.97	1.42	4.61	4.61	2.3	05/03/22	32,890	3.05	1.00	10,790	3
B-3	72.50	1.98	1.18	3.96	3.96	2.0	05/03/22	32,270	3.08	1.00	10,480	3
B-3	75.50	1.97	1.44	4.63	4.63	2.4	05/03/22	30,510	3.05	1.00	10,010	3
B-1	82.50	1.97	0.98	3.30	3.30	1.7	05/03/22	22,780	3.05	1.00	7,474	2
B-1	86.00	1.94	1.06	3.86	3.86	2.0	05/03/22	10,880	2.96	1.00	3,681	2

Report Date: 5/3/2022

Signed: John T. Snider P.E.

with Anderson Engineering

2 - Columnar, cone break
3 - Columnar break
5 - Side fracture, top or bottom

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ROCK CORE COMPRESSION REPORT (ASTM D 4543-19)

Client: GeoEngineers / MoDot - GEO # 15273-022-01 Project #: 22SP30077

Project: Highway 19 Bridge

	Boring	Depth, ft	Core Diameter (in.)	Weight (LBS)	Sawed Length (in.)	Length w/ Cap (in.)	L/D Ratio	Date Tested	Max Load (LBS)	Area of Cores (in.2)	L/D Correction	Compressive strength (PSI)	Type Break
A	B-4	54.75	1.85	1.08	4.40	4.18	2.4	05/10/22	21,210	2.69	1.00	7,891	3
B	B-4	61.50	1.85	1.06	3.97	4.10	2.1	05/10/22	18,550	2.69	1.00	6,901	3
C	B-4	65.42	1.85	1.06	3.90	4.07	2.1	05/10/22	44,410	2.69	1.00	16,521	3
D	B-4	68.25	1.85	1.08	3.95	4.10	2.1	05/10/22	19,570	2.69	1.00	7,280	3
E													
F													
G													
H													
I													
J													
K													
L													
M													
N													
O													

Report Date: 5/10/2022 Signed: John T. Smiler, PE

3 - Columnar break

with Anderson Engineering

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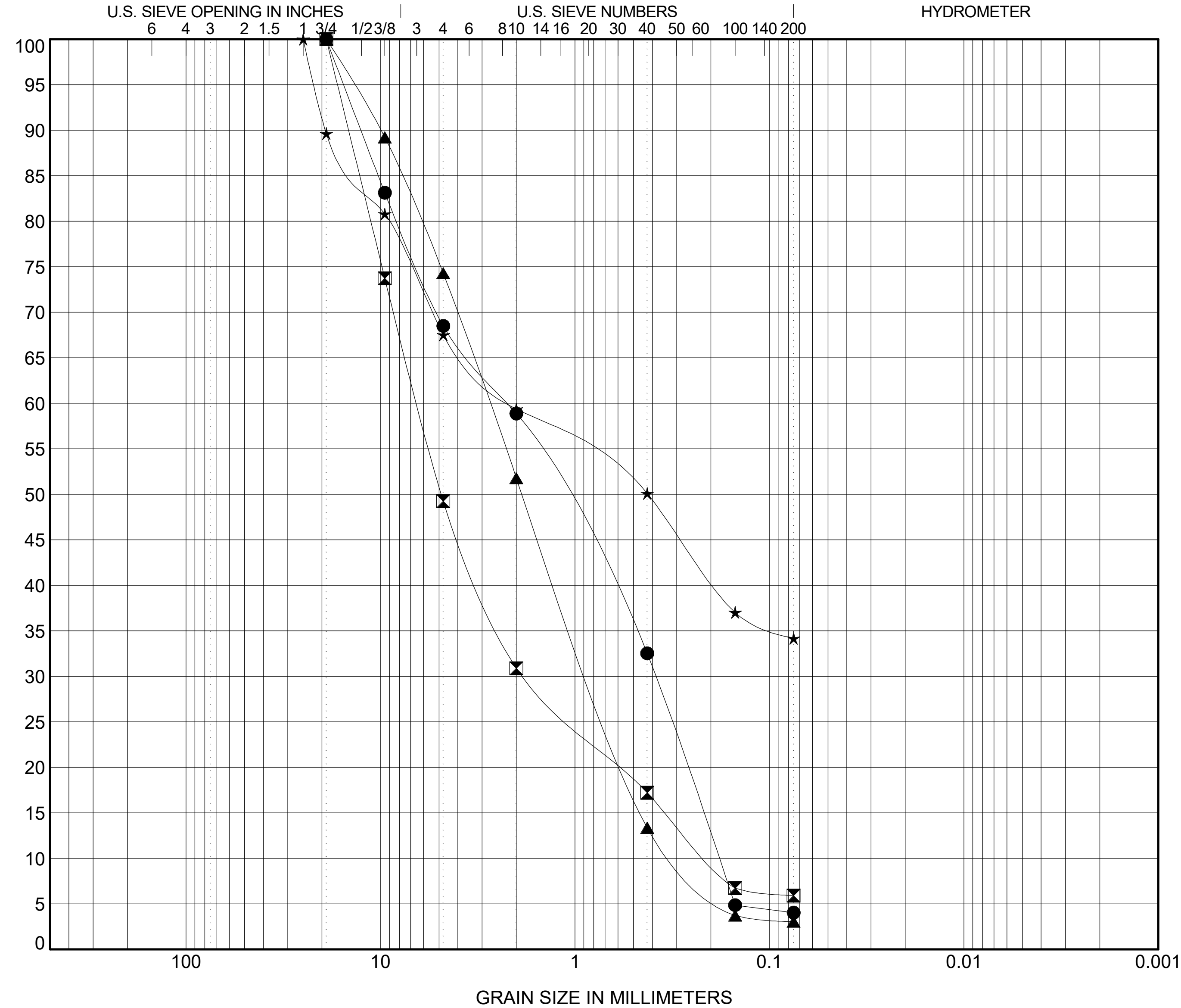
Anderson Engineering Inc
3213 S. West Bypass
Springfield, MO 65807
Telephone: 417-866-2741
Fax: 417-866-2778

GRAIN SIZE DISTRIBUTION

CLIENT GEOENGINEERS - GEO # 15273-022-01 **PROJECT NAME** HIGHWAY 19 BRIDGE

PROJECT NUMBER 22SP30077 **PROJECT LOCATION** SHANNON COUNTY, MO



	BOREHOLE	DEPTH	Classification	LL	PL	PI	Cc	Cu
●	B-1	5.0	POORLY GRADED SAND with GRAVEL(SP)				0.37	12.16
⧗	B-2	10.0					2.44	31.02
▲	B-3	15.0	POORLY GRADED SAND with GRAVEL(SP)				0.85	9.28
★	B-4	10.0						

	BOREHOLE	DEPTH	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	B-1	5.0	19	2.213	0.386	0.182	31.5	64.5	4.0	
⧗	B-2	10.0	19	6.441	1.808	0.208	50.8	43.3	5.9	
▲	B-3	15.0	19	2.743	0.831	0.296	25.7	71.3	3.0	
★	B-4	10.0	25	2.141			32.5	33.3	34.2	

Anderson Engineering Drill Calibration

FOUNDATION TESTING
& CONSULTING, LLC
Knowledge To Build On®

16500 Lucille St. Overland Park, KS 66221
phone 913-626-8499
fax 913-439-1703

September 16, 2020

Mr. Gary White
Anderson Engineering, Inc.
3213 S. West Bypass
Springfield, Missouri 65807

Subject: SPT Hammer Calibration for Drill Rigs
FTC Project Number 075-2020

Dear Mr. White,

Foundation Testing and Consulting, LLC (FTC) is pleased to submit the results of our SPT hammer calibration to you. The field work associated with the hammer calibrations was performed September 10, 2020 at your drill yard in Springfield, Missouri. The energy efficiency rating for the hammers on 3 of your drill rigs was determined by us.

Hammer blow rates, average maximum compressive forces, average maximum velocities, average energy transfer and average transfer ratio were computed for each sample interval from data collected using a PAX 8 model pile driving analyzer (PDA) unit manufactured by Pile Dynamics Incorporated with upgraded software to comply with ASTM D4633. The PDA unit was connected to an instrumented AWJ rod. The primary objective of the calibration testing was to determine the average energy transfer efficiency for each hammer system. The testing procedure and detailed test results are presented below.

Procedure

SPT sample depths ranged from surface to 16.5 feet below ground surface.

Energy measurements were taken over the full 18 inches of sample drive for each sample interval. The drill rig was equipped with an auto-hammer. A total of 3 or more data sets were collected for each rig and we elected to use selected representative intervals in our analysis for each rig.

Rig Type	Serial Number	Average Efficiency (%)	Energy Correction Factor
CME 75	249037	80.5	1.34
CME 550X	295993	86.3	1.44
CME 550X	401073	92.3	1.54

These calibration results are presented graphically in the attached plots for the SPT data sets collected in the borings.

Please note that per ASTM D4633, hammer energy measurements (calibrations) should be performed at least annually and following major repair or refurbishment of the hammer system components.

It was our pleasure to provide these calibration services to you. Please contact me with any questions or future needs.

Sincerely,

William C. Jones, P.E*, P.G.** – Technical Director, FTC

*Professional Engineer in Kansas, Missouri, Iowa, Illinois, Tennessee, Arkansas, Texas, Nevada and Oklahoma
**Professional Geologist in Kansas and Missouri

Enclosure: Tables and Data Plots

Table 1

Anderson Engineering, Inc., CME75 Rig, (Serial Number 249037) Auto Hammer
Hammer Calibration Performed September 10, 2020

Rod Length (feet)	Beginning Depth (feet)	Final Depth (feet)	Blows per 6-inch interval	**N**	**N_{60}**	BPM	Avg. Max. Compressive Force (kips)	Avg. Max. Velocity (ft/sec)	Avg. Transferred Energy (lb-ft)	**Average Transfer Ratio (%)**
13.5	10.0	11.5	7-9-11	**20**	**27**	54	24	15	284	**81**
18.6	15.0	16.5	3-2-50+	**50+**	**50+**	59	34	18	280	**80**

Overall Average	56.5	29.0	16.5	282.0	80.5
Standard Deviation	2.5	5.0	1.5	2.0	0.5

Overall Calibration Factor for N_{60} = 80.5.0/60 = 1.34
To compute N_{60} values for this rig multiply recorded N-value by 1.34*

* Calibration factor should be recomputed annually or sooner if changes are made to rig and/or hammer

Table 2

Anderson Engineering, Inc. CME550X Rig, (Serial Number 295993) Auto Hammer
Hammer Calibration Performed September 10, 2020

Rod Length (feet)	Beginning Depth (feet)	Final Depth (ft)	Blows per 6-inch interval	**N**	N_{60}	BPM	Avg. Max. Compressive Force (kips)	Avg. Max. Velocity (ft/sec)	Avg. Transferred Energy (lb-ft)	**Average Transfer Ratio (%)**
3.3	0	1.5	12-19-13	**32**	**46**	58	30	18	326	**93**
8.7	5.0	6.5	4-9-9	**18**	**26**	58	27	17	294	**84**
13.5	10.0	11.5	5-6-5	**11**	**16**	57	27	17	287	**82**
Overall Average						57.7	28.0	17.3	302.3	86.3
Standard Deviation						0.5	1.4	0.5	17.0	4.8

Overall Calibration Factor for N_{60} = 86.3/60 = 1.44
To compute N_{60} values for this rig multiply recorded N-value by 1.44*

* Calibration factor should be recomputed annually or sooner if changes are made to rig and/or hammer

Table 3

Anderson Engineering, Inc., CME 550X Rig (Serial Number 295993) Auto Hammer
Hammer Calibration Performed September 10, 2020

Rod Length (feet)	Beginning Depth (feet)	Final Depth (ft)	Blows per 6-inch interval	**N**	**N_{60}**	BPM	Avg. Max. Compressive Force (kips)	Avg. Max. Velocity (ft/sec)	Avg. Transferred Energy (lb-ft)	**Average Transfer Ratio (%)**
3.3	5.0	6.5	7-14-8	**22**	**34**	56	32	21	322	**92**
8.7	10.0	11.5	2-4-9	**13**	**20**	55	31	22	319	**91**
13.5	15.0	16.5	7-50+	**50+**	**50+**	55	34	21	329	**94**

	BPM	Avg. Max. Compressive Force (kips)	Avg. Max. Velocity (ft/sec)	Avg. Transferred Energy (lb-ft)	Average Transfer Ratio (%)
Overall Average	55.3	32.3	21.3	323.3	92.3
Standard Deviation	0.5	1.2	0.5	4.2	1.2

Overall Calibration Factor for N_{60} = 92.3/60 = 1.54
To compute N_{60} values for this rig multiply recorded N-value by 1.54*

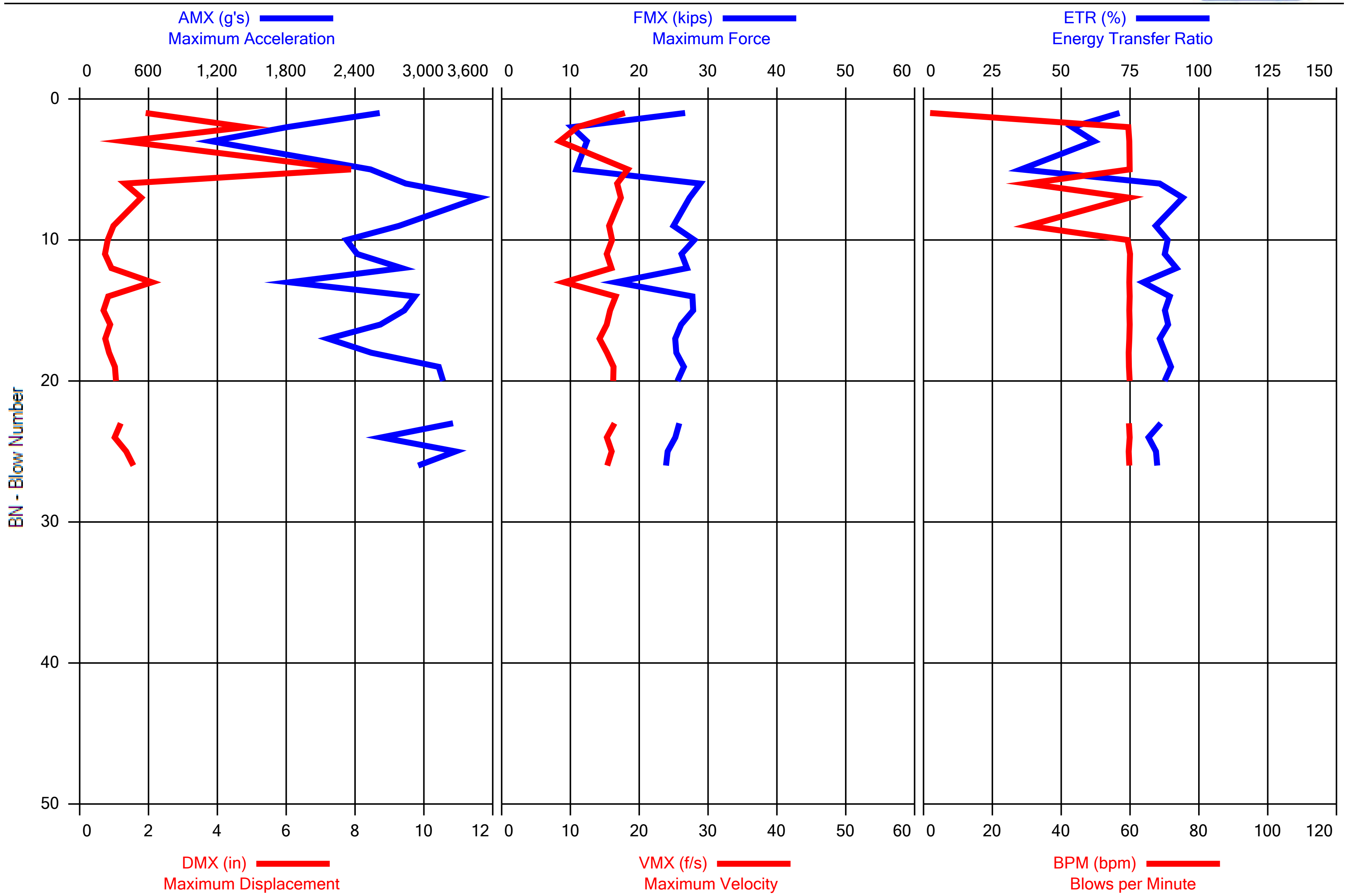
* Calibration factor should be recomputed annually or sooner if changes are made to rig and/or hammer

Foundation Testing & Consulting LLC - PDIPLOT2 Ver 2017.2.58.3 - Case Method & iCAP® Results

Printed: 15-September-2020

Test started: 10-September-2020

ANDERSON ENG, INC. - 249037.3



ANDERSON ENG, INC. - 249037.3 CME
OP: CMH Date: 10-September-2020

AR: 1.19 in² SP: 0.492 k/ft³
LE: 13.54 ft EM: 30,000 ksi
WS: 16,807.9 f/s JC: 0.00

AMX: Maximum Acceleration
DMX: Maximum Displacement
FMX: Maximum Force
VMX: Maximum Velocity
ETR: Energy Transfer Ratio
BPM: Blows per Minute
CSX: Max Measured Compr. Stress
EMX: Max Transferred Energy
CSI: Max F1 or F2 Compr. Stress

BL#	Depth	BLC	AMX	DMX	FMX	VMX	ETR	BPM	CSX	EMX	CSI
	ft	**	g's	in	kips	f/s	(%)	bpm	ksi	k-ft	ksi
1	10.00	0	2,615	2	27	18	71	2	22.4	0.2	22.8
2	10.00	0	1,808	5	10	11	54	60	8.6	0.2	8.6
3	10.00	0	1,150	1	12	8	62	60	10.4	0.2	10.6
5	10.00	0	2,535	8	11	18	35	60	9.1	0.1	9.2
6	10.00	0	2,842	1	29	17	86	30	24.3	0.3	24.4
7	10.00	0	3,483	2	27	17	94	60	22.9	0.3	23.3
9	10.00	0	2,784	1	25	16	84	30	21.0	0.3	21.1
10	10.00	0	2,325	1	28	16	89	59	23.5	0.3	23.7
11	10.00	0	2,418	1	26	15	88	60	22.0	0.3	22.0
12	10.00	0	2,809	1	27	16	92	60	22.6	0.3	23.2
13	10.00	0	1,827	2	17	9	80	60	14.0	0.3	14.0
14	10.00	0	2,922	1	28	17	89	60	23.3	0.3	23.8
15	10.00	0	2,830	1	28	16	88	60	23.4	0.3	23.8
16	10.00	0	2,621	1	26	15	89	60	21.9	0.3	22.3
17	10.00	0	2,165	1	25	14	86	60	21.2	0.3	21.4
18	10.00	0	2,541	1	25	15	88	60	21.3	0.3	21.3
19	10.00	0	3,130	1	26	16	90	60	22.3	0.3	22.5
20	10.00	0	3,168	1	26	16	88	60	21.5	0.3	21.7
23	10.00	0	3,255	1	26	16	86	60	21.7	0.3	22.2
24	10.00	0	2,629	1	25	15	82	60	21.2	0.3	21.3
25	10.00	0	3,277	1	24	16	84	60	20.3	0.3	20.3
26	10.00	0	2,951	2	24	15	85	60	20.1	0.3	20.1
		Average	2,640	2	24	15	81	54	19.9	0.3	20.2

Total number of blows analyzed: 22

BL# Sensors

1-26 F3: [AWJ-1-2015] 214.3 (1.00); F4: [AWJ-2-2015] 213.7 (1.00); A3: [K10511] 360.0 (1.00); A4: [K10514] 354.0 (1.00)

Time Summary

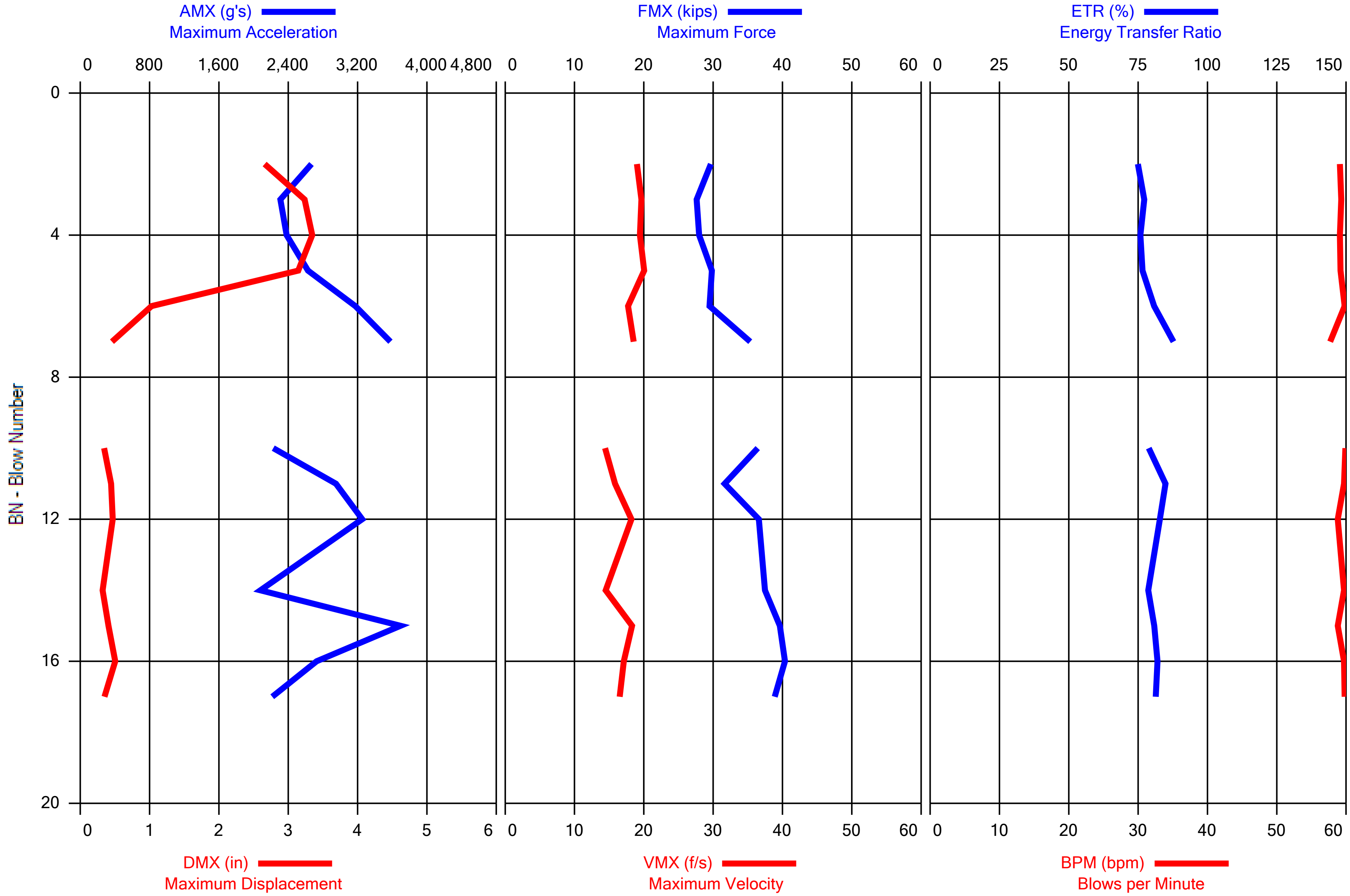
Drive 27 seconds 1:04 PM - 1:04 PM BN 1 - 26

Foundation Testing & Consulting LLC - PDIPLOT2 Ver 2017.2.58.3 - Case Method & iCAP® Results

Printed: 15-September-2020

Test started: 10-September-2020

ANDERSON ENG, INC. - 249037.4



ANDERSON ENG, INC. - 249037.4 CME
OP: CMH Date: 10-September-2020

AR:	1.19 in^2	SP:	0.492 k/ft^3
LE:	18.67 ft	EM:	30,000 ksi
WS:	16,807.9 f/s	JC:	0.00

AMX: Maximum Acceleration
DMX: Maximum Displacement
FMX: Maximum Force
VMX: Maximum Velocity
ETR: Energy Transfer Ratio
BPM: Blows per Minute
CSX: Max Measured Compr. Stress
EMX: Max Transferred Energy
CSI: Max F1 or F2 Compr. Stress

BL#	Depth	BLC	AMX	DMX	FMX	VMX	ETR	BPM	CSX	EMX	CSI
	ft	**	g's	in	kips	f/s	(%)	bpm	ksi	k-ft	ksi
2	15.00	0	2,668	3	30	19	75	59	24.9	0.3	25.1
3	15.00	0	2,309	3	28	20	77	59	23.2	0.3	23.2
4	15.00	0	2,382	3	28	19	76	59	23.5	0.3	23.6
5	15.00	0	2,629	3	30	20	77	59	25.1	0.3	25.1
6	15.00	0	3,174	1	29	18	81	60	24.8	0.3	24.8
7	15.00	0	3,580	0	35	19	88	58	29.7	0.3	29.7
10	15.00	0	2,227	0	36	14	79	60	30.6	0.3	30.7
11	15.00	0	2,950	0	32	16	85	60	26.6	0.3	26.7
12	15.00	0	3,254	0	37	18	83	59	30.7	0.3	30.8
14	15.00	0	2,079	0	37	15	79	60	31.5	0.3	31.5
15	15.00	0	3,697	0	40	18	81	59	33.3	0.3	33.4
16	15.00	0	2,727	1	40	17	82	60	33.9	0.3	33.9
17	15.00	0	2,215	0	39	17	81	60	32.7	0.3	32.7
		Average	2,761	1	34	18	80	59	28.5	0.3	28.6

Total number of blows analyzed: 13

BL# Sensors

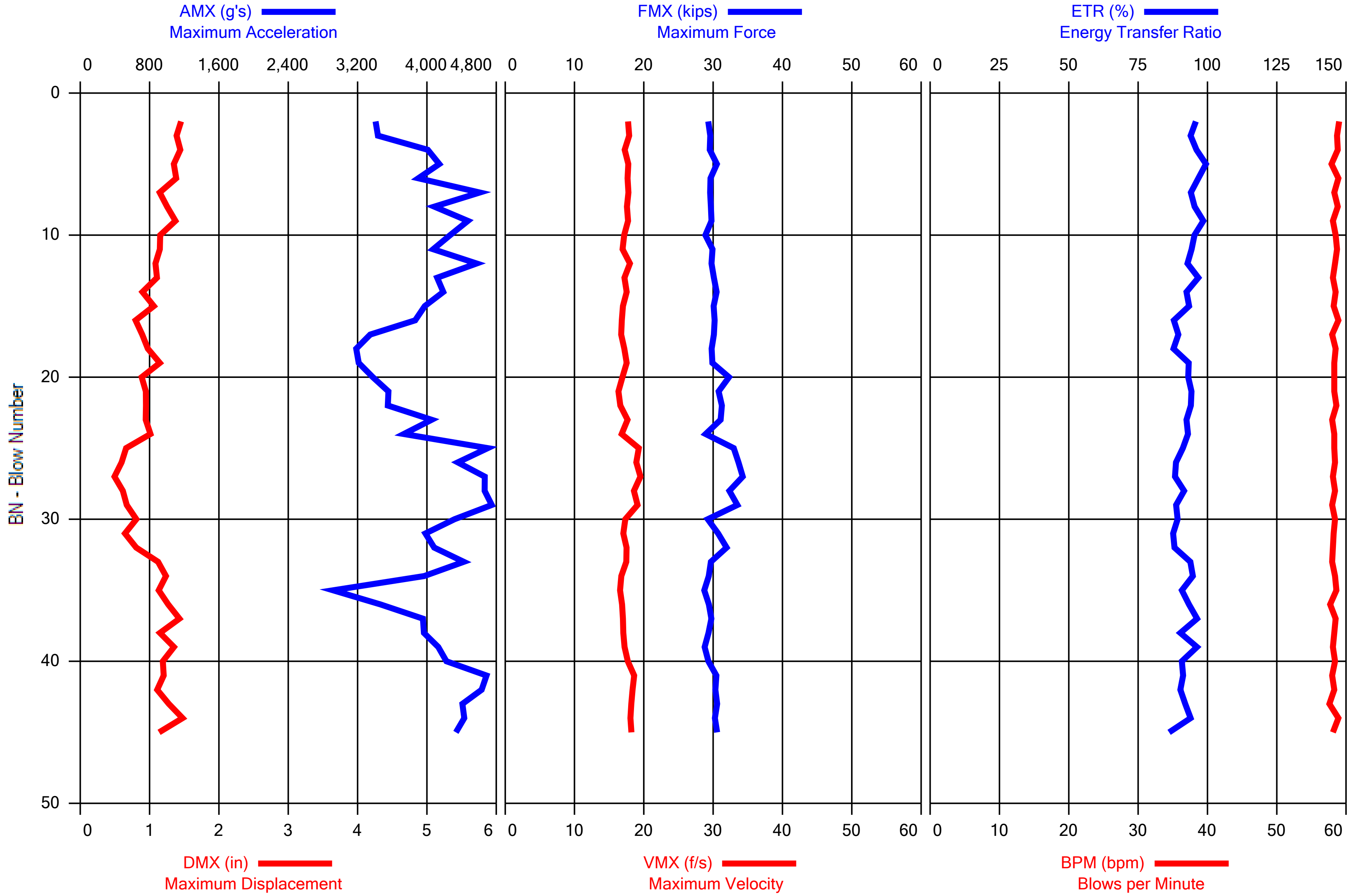
2-17 F3: [AWJ-1-2015] 214.3 (1.00); F4: [AWJ-2-2015] 213.7 (1.00); A3: [K10511] 360.0 (1.00); A4: [K10514] 354.0 (1.00)

Time Summary

Drive 19 seconds 1:15 PM - 1:15 PM BN 1 - 17

Foundation Testing & Consulting LLC - PDIPLOT2 Ver 2017.2.58.3 - Case Method & iCAP® Results
Printed: 15-September-2020
Test started: 10-September-2020

ANDERSON ENG, INC. - 295993



ANDERSON ENG, INC. - 295993 CME
OP: CMH Date: 10-September-2020

AR: 1.19 in² SP: 0.492 k/ft³
LE: 3.33 ft EM: 30,000 ksi
WS: 16,807.9 f/s JC: 0.00

AMX: Maximum Acceleration
DMX: Maximum Displacement
FMX: Maximum Force
VMX: Maximum Velocity
ETR: Energy Transfer Ratio
BPM: Blows per Minute
CSX: Max Measured Compr. Stress
EMX: Max Transferred Energy
CSI: Max F1 or F2 Compr. Stress

BL#	Depth	BLC	AMX	DMX	FMX	VMX	ETR	BPM	CSX	EMX	CSI
	ft	**	g's	in	kips	f/s	(%)	bpm	ksi	k-ft	ksi
2	0.00	0	3,407	1	29	18	96	59	24.6	0.3	24.7
3	0.00	0	3,436	1	30	18	94	59	24.9	0.3	25.0
4	0.00	0	4,010	1	30	17	96	59	24.8	0.3	24.9
5	0.00	0	4,143	1	31	18	99	58	25.7	0.3	25.8
6	0.00	0	3,900	1	30	18	97	59	24.9	0.3	25.1
7	0.00	0	4,610	1	30	18	94	58	24.8	0.3	25.2
8	0.00	0	4,085	1	30	18	95	59	24.9	0.3	25.2
9	0.00	0	4,474	1	30	18	99	58	25.0	0.3	25.4
10	0.00	0	4,269	1	29	17	95	59	24.3	0.3	24.4
11	0.00	0	4,073	1	30	17	94	59	25.1	0.3	25.3
12	0.00	0	4,575	1	30	18	93	58	25.0	0.3	25.3
13	0.00	0	4,119	1	30	17	97	58	25.3	0.3	25.6
14	0.00	0	4,190	1	31	18	92	59	25.6	0.3	25.9
15	0.00	0	3,976	1	30	17	93	58	25.3	0.3	25.5
16	0.00	0	3,865	1	30	17	88	59	25.4	0.3	25.5
17	0.00	0	3,346	1	30	17	90	58	25.3	0.3	25.4
18	0.00	0	3,184	1	30	17	88	59	25.0	0.3	25.2
19	0.00	0	3,213	1	30	18	93	58	25.1	0.3	25.2
20	0.00	0	3,376	1	32	17	93	58	27.1	0.3	27.1
21	0.00	0	3,556	1	31	16	94	58	25.9	0.3	26.1
22	0.00	0	3,549	1	31	17	94	59	26.3	0.3	26.5
23	0.00	0	4,055	1	31	18	92	58	26.1	0.3	26.2
24	0.00	0	3,734	1	29	17	93	58	24.3	0.3	24.4
25	0.00	0	4,702	1	33	19	91	58	27.7	0.3	27.8
26	0.00	0	4,357	1	34	19	89	58	28.3	0.3	28.4
27	0.00	0	4,668	0	34	20	88	58	28.8	0.3	28.9
28	0.00	0	4,667	1	32	19	92	58	27.2	0.3	27.5
29	0.00	0	4,749	1	33	19	89	58	28.1	0.3	28.3
30	0.00	0	4,319	1	29	17	89	58	24.6	0.3	24.7
31	0.00	0	3,983	1	31	17	88	58	25.8	0.3	25.9
32	0.00	0	4,085	1	32	18	88	58	26.8	0.3	27.0
33	0.00	0	4,426	1	30	17	94	58	24.9	0.3	25.0
34	0.00	0	3,969	1	29	17	95	58	24.7	0.3	24.8
35	0.00	0	2,918	1	29	17	91	59	24.1	0.3	24.3
36	0.00	0	3,464	1	29	17	93	58	24.7	0.3	24.8
37	0.00	0	3,955	1	30	17	96	59	25.0	0.3	25.1
38	0.00	0	3,965	1	29	17	90	58	24.6	0.3	24.9
39	0.00	0	4,132	1	29	17	96	58	24.2	0.3	24.3
40	0.00	0	4,225	1	29	18	91	58	24.6	0.3	24.7
41	0.00	0	4,689	1	30	19	91	58	25.6	0.3	25.8
42	0.00	0	4,632	1	30	18	90	58	25.5	0.3	25.7
43	0.00	0	4,410	1	31	18	92	58	25.7	0.3	25.8
44	0.00	0	4,432	1	30	18	94	59	25.4	0.3	25.5
45	0.00	0	4,336	1	31	18	86	58	25.7	0.3	25.9
		Average	4,051	1	30	18	93	58	25.5	0.3	25.7

ANDERSON ENG, INC. - 295993
OP: CMH

CME
Date: 10-September-2020

BL#	Depth	BLC	AMX	DMX	FMX	VMX	ETR	BPM	CSX	EMX	CSI
	ft	**	g's	in	kips	f/s	(%)	bpm	ksi	k-ft	ksi

Total number of blows analyzed: 44

BL# Sensors

2-45 F3: [AWJ-1-2015] 214.3 (1.00); F4: [AWJ-2-2015] 213.7 (1.00); A3: [K10511] 360.0 (1.00);
A4: [K10514] 354.0 (1.00)

Time Summary

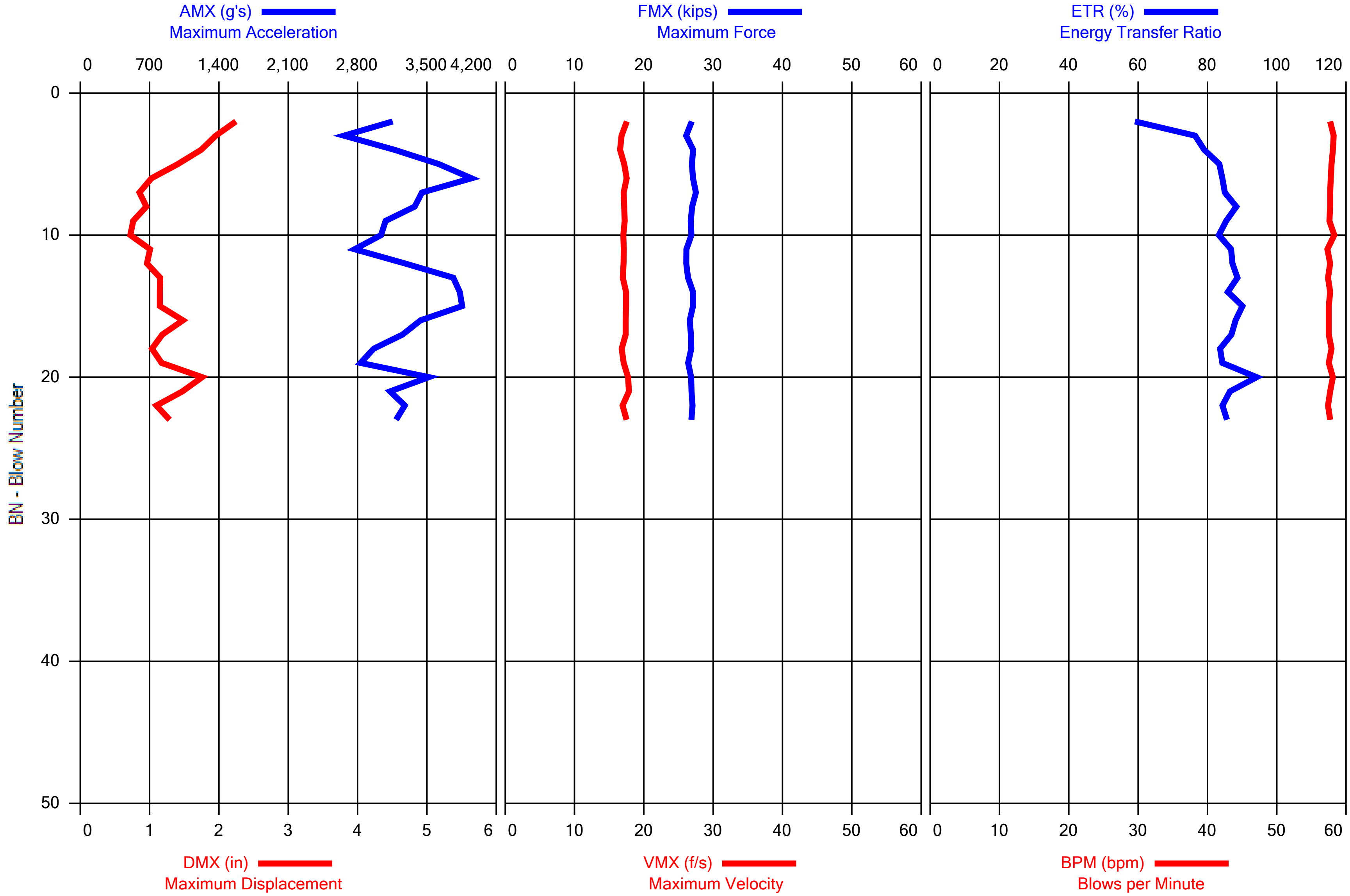
Drive 45 seconds 1:37 PM - 1:38 PM BN 1 - 45

Foundation Testing & Consulting LLC - PDIPLOT2 Ver 2017.2.58.3 - Case Method & iCAP® Results

Printed: 15-September-2020

Test started: 10-September-2020

ANDERSON ENG, INC. - 295993-2



ANDERSON ENG, INC. - 295993-2 CME
OP: CMH Date: 10-September-2020

AR: 1.19 in² SP: 0.492 k/ft³
LE: 8.67 ft EM: 30,000 ksi
WS: 16,807.9 f/s JC: 0.00

AMX: Maximum Acceleration
DMX: Maximum Displacement
FMX: Maximum Force
VMX: Maximum Velocity
ETR: Energy Transfer Ratio
BPM: Blows per Minute
CSX: Max Measured Compr. Stress
EMX: Max Transferred Energy
CSI: Max F1 or F2 Compr. Stress

BL#	Depth	BLC	AMX	DMX	FMX	VMX	ETR	BPM	CSX	EMX	CSI
	ft	**	g's	in	kips	f/s	(%)	bpm	ksi	k-ft	ksi
2	5.00	0	3,155	2	27	18	59	58	22.6	0.2	22.6
3	5.00	0	2,663	2	26	17	76	58	21.9	0.3	22.1
4	5.00	0	3,173	2	27	17	79	58	22.8	0.3	22.8
5	5.00	0	3,619	1	27	17	83	58	22.6	0.3	22.7
6	5.00	0	3,951	1	27	18	84	58	22.8	0.3	22.9
7	5.00	0	3,450	1	28	17	85	58	23.1	0.3	23.2
8	5.00	0	3,377	1	27	17	88	58	22.7	0.3	22.7
9	5.00	0	3,083	1	27	17	85	58	22.5	0.3	22.6
10	5.00	0	3,038	1	27	17	83	58	22.6	0.3	22.7
11	5.00	0	2,770	1	26	17	87	57	22.0	0.3	22.3
12	5.00	0	3,279	1	26	17	87	58	22.0	0.3	22.1
13	5.00	0	3,766	1	26	17	89	57	22.2	0.3	22.2
14	5.00	0	3,832	1	27	17	86	58	22.8	0.3	22.8
15	5.00	0	3,856	1	27	17	90	58	22.8	0.3	22.9
16	5.00	0	3,436	1	27	17	88	58	22.4	0.3	22.5
17	5.00	0	3,255	1	27	17	87	58	22.5	0.3	22.6
18	5.00	0	2,963	1	27	17	84	58	22.6	0.3	22.7
19	5.00	0	2,831	1	26	17	84	58	22.2	0.3	22.2
20	5.00	0	3,521	2	27	18	94	58	22.5	0.3	22.7
21	5.00	0	3,129	1	27	18	87	58	22.6	0.3	22.7
22	5.00	0	3,277	1	27	17	84	57	22.7	0.3	22.9
23	5.00	0	3,189	1	27	18	86	58	22.6	0.3	22.7
		Average	3,301	1	27	17	84	58	22.5	0.3	22.6

Total number of blows analyzed: 22

BL# Sensors

2-23 F3: [AWJ-1-2015] 214.3 (1.00); F4: [AWJ-2-2015] 213.7 (1.00); A3: [K10511] 360.0 (1.00);
A4: [K10514] 354.0 (1.00)

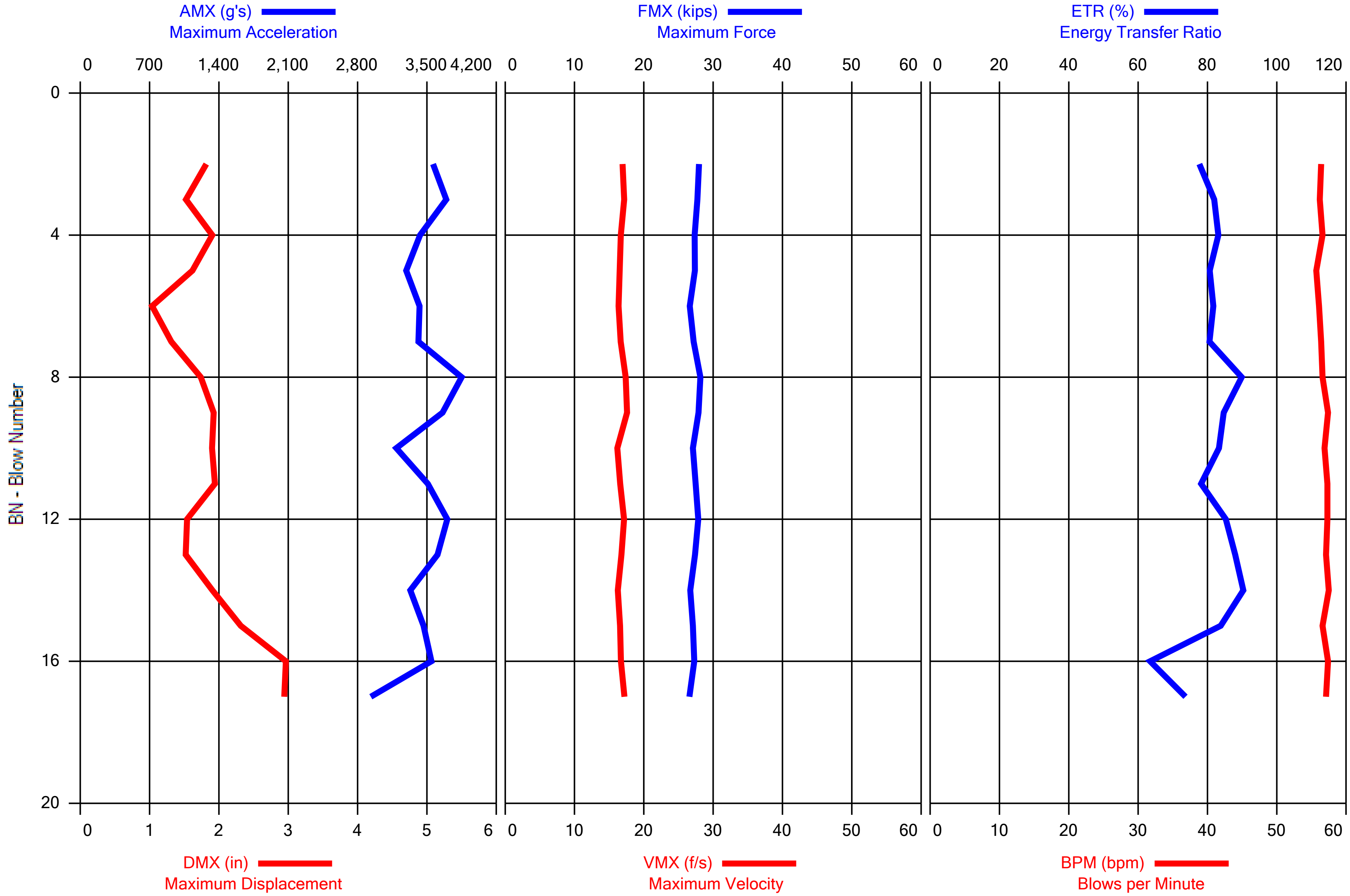
Time Summary

Drive 22 seconds 1:45 PM - 1:45 PM BN 1 - 23

Foundation Testing & Consulting LLC - PDIPLOT2 Ver 2017.2.58.3 - Case Method & iCAP® Results

Printed: 15-September-2020 Test started: 10-September-2020

ANDERSON ENG, INC. - 295993-3



ANDERSON ENG, INC. - 295993-3 | CME
OP: CMH | Date: 10-September-2020

AR: 1.19 in² | SP: 0.492 k/ft³
LE: 13.46 ft | EM: 30,000 ksi
WS: 16,807.9 f/s | JC: 0.00

AMX: Maximum Acceleration
DMX: Maximum Displacement
FMX: Maximum Force
VMX: Maximum Velocity
ETR: Energy Transfer Ratio
BPM: Blows per Minute
CSX: Max Measured Compr. Stress
EMX: Max Transferred Energy
CSI: Max F1 or F2 Compr. Stress

BL#	Depth	BLC	AMX	DMX	FMX	VMX	ETR	BPM	CSX	EMX	CSI
	ft	**	g's	in	kips	f/s	(%)	bpm	ksi	k-ft	ksi
2	10.00	0	3,563	2	28	17	78	56	23.5	0.3	23.7
3	10.00	0	3,696	2	28	17	82	56	23.3	0.3	23.5
4	10.00	0	3,431	2	27	17	83	57	23.0	0.3	23.1
5	10.00	0	3,292	2	27	17	81	56	23.0	0.3	23.1
6	10.00	0	3,426	1	27	16	82	56	22.4	0.3	22.7
7	10.00	0	3,415	1	27	17	81	56	22.8	0.3	23.0
8	10.00	0	3,852	2	28	17	90	57	23.7	0.3	23.9
9	10.00	0	3,658	2	28	18	85	57	23.4	0.3	23.6
10	10.00	0	3,191	2	27	16	83	57	22.8	0.3	22.8
11	10.00	0	3,510	2	27	17	78	57	23.1	0.3	23.2
12	10.00	0	3,705	2	28	17	85	57	23.4	0.3	23.6
13	10.00	0	3,608	2	27	17	88	57	23.0	0.3	23.1
14	10.00	0	3,333	2	27	16	90	58	22.4	0.3	22.5
15	10.00	0	3,467	2	27	17	84	57	22.8	0.3	23.0
16	10.00	0	3,546	3	27	17	63	57	22.9	0.2	23.2
17	10.00	0	2,934	3	27	17	74	57	22.3	0.3	22.5
		Average	3,477	2	27	17	82	57	23.0	0.3	23.2

Total number of blows analyzed: 16

BL# Sensors

2-17 F3: [AWJ-1-2015] 214.3 (1.00); F4: [AWJ-2-2015] 213.7 (1.00); A3: [K10511] 360.0 (1.00); A4: [K10514] 354.0 (1.00)

Time Summary

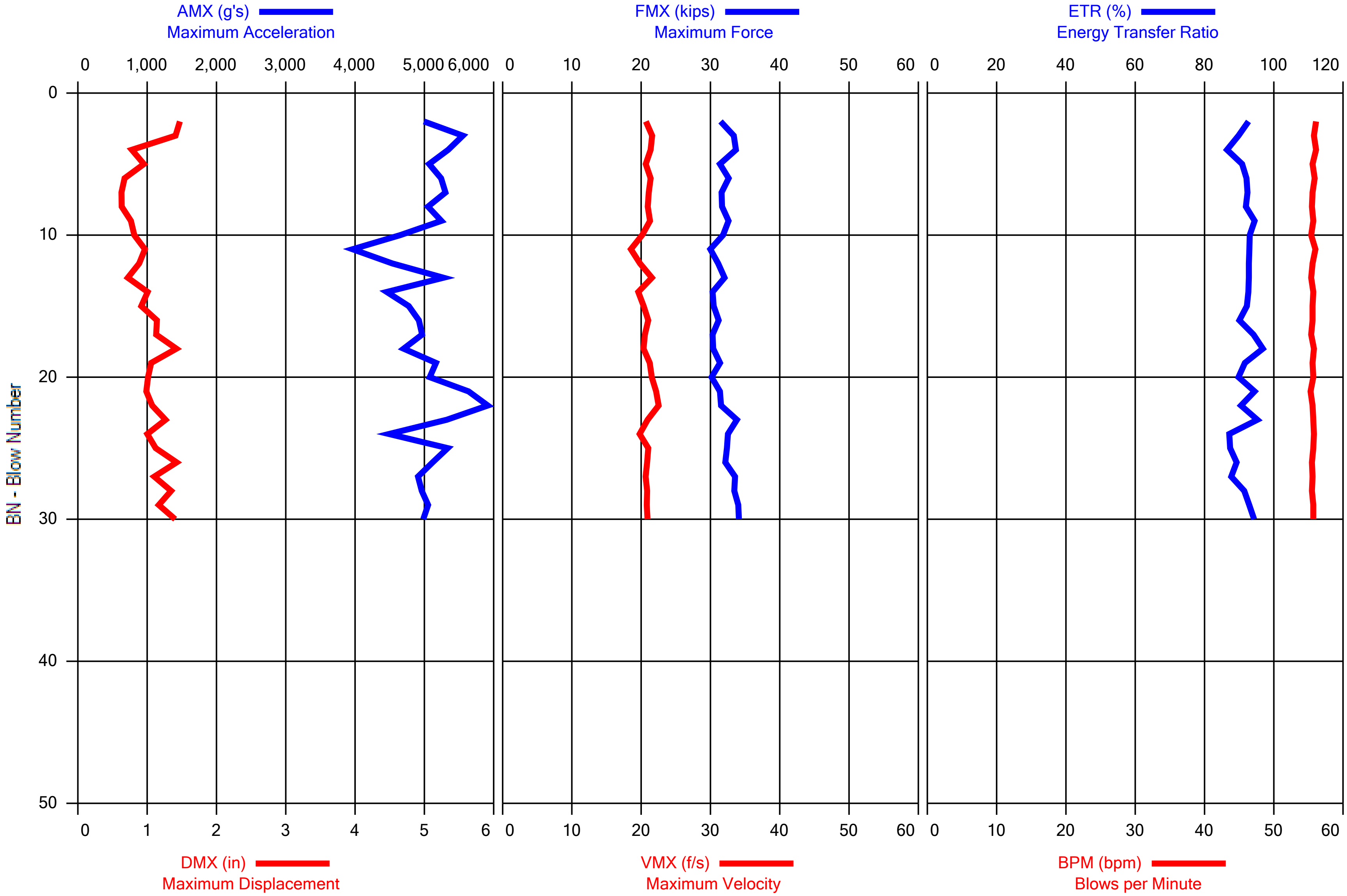
Drive 16 seconds 1:54 PM - 1:55 PM BN 1 - 17

Foundation Testing & Consulting LLC - PDIPLOT2 Ver 2017.2.58.3 - Case Method & iCAP® Results

Printed: 15-September-2020

Test started: 10-September-2020

ANDERSON ENG, INC. - 401073-2



ANDERSON ENG, INC. - 401073-2 GEOPROBE
OP: CMH Date: 10-September-2020

AR: 1.19 in² SP: 0.492 k/ft³
LE: 8.71 ft EM: 30,000 ksi
WS: 16,807.9 f/s JC: 0.00

AMX: Maximum Acceleration
DMX: Maximum Displacement
FMX: Maximum Force
VMX: Maximum Velocity
ETR: Energy Transfer Ratio
BPM: Blows per Minute
CSX: Max Measured Compr. Stress
EMX: Max Transferred Energy
CSI: Max F1 or F2 Compr. Stress

BL#	Depth	BLC	AMX	DMX	FMX	VMX	ETR	BPM	CSX	EMX	CSI
	ft	**	g's	in	kips	f/s	(%)	bpm	ksi	k-ft	ksi
2	5.00	0	4,993	1	31	21	93	56	26.4	0.3	26.9
3	5.00	0	5,555	1	33	22	90	56	28.0	0.3	28.2
4	5.00	0	5,346	1	34	21	87	56	28.3	0.3	28.4
5	5.00	0	5,069	1	31	21	91	56	26.4	0.3	26.6
6	5.00	0	5,242	1	33	21	92	56	27.4	0.3	27.6
7	5.00	0	5,306	1	32	21	92	56	26.6	0.3	26.9
8	5.00	0	5,053	1	32	21	92	56	26.6	0.3	26.8
9	5.00	0	5,247	1	33	21	94	56	27.4	0.3	27.6
10	5.00	0	4,652	1	32	20	93	55	26.7	0.3	26.9
11	5.00	0	3,964	1	30	19	93	56	25.2	0.3	25.3
12	5.00	0	4,539	1	31	20	93	56	26.2	0.3	26.4
13	5.00	0	5,277	1	32	22	93	55	26.9	0.3	27.0
14	5.00	0	4,458	1	30	20	93	56	25.5	0.3	25.8
15	5.00	0	4,775	1	30	20	92	56	25.6	0.3	26.0
16	5.00	0	4,921	1	31	21	90	56	26.2	0.3	26.3
17	5.00	0	4,967	1	30	21	94	55	25.5	0.3	25.6
18	5.00	0	4,702	1	30	20	97	56	25.5	0.3	25.7
19	5.00	0	5,168	1	31	21	92	56	26.4	0.3	26.6
20	5.00	0	5,078	1	30	22	90	56	25.3	0.3	25.5
21	5.00	0	5,639	1	31	22	94	55	26.4	0.3	26.5
22	5.00	0	5,917	1	32	23	91	56	26.5	0.3	26.6
23	5.00	0	5,324	1	34	21	95	56	28.4	0.3	28.6
24	5.00	0	4,491	1	33	20	87	56	27.3	0.3	27.3
25	5.00	0	5,337	1	32	21	87	56	27.2	0.3	27.3
26	5.00	0	5,121	1	32	21	89	56	27.0	0.3	27.3
27	5.00	0	4,908	1	34	21	88	56	28.2	0.3	28.4
28	5.00	0	4,963	1	33	21	91	56	28.1	0.3	28.2
29	5.00	0	5,055	1	34	21	93	56	28.6	0.3	28.6
30	5.00	0	4,984	1	34	21	94	56	28.7	0.3	28.7
		Average	5,036	1	32	21	92	56	26.8	0.3	27.0

Total number of blows analyzed: 29

BL# Sensors

2-30 F3: [AWJ-1-2015] 214.3 (1.00); F4: [AWJ-2-2015] 213.7 (1.00); A3: [K10511] 360.0 (1.00); A4: [K10514] 354.0 (1.00)

Time Summary

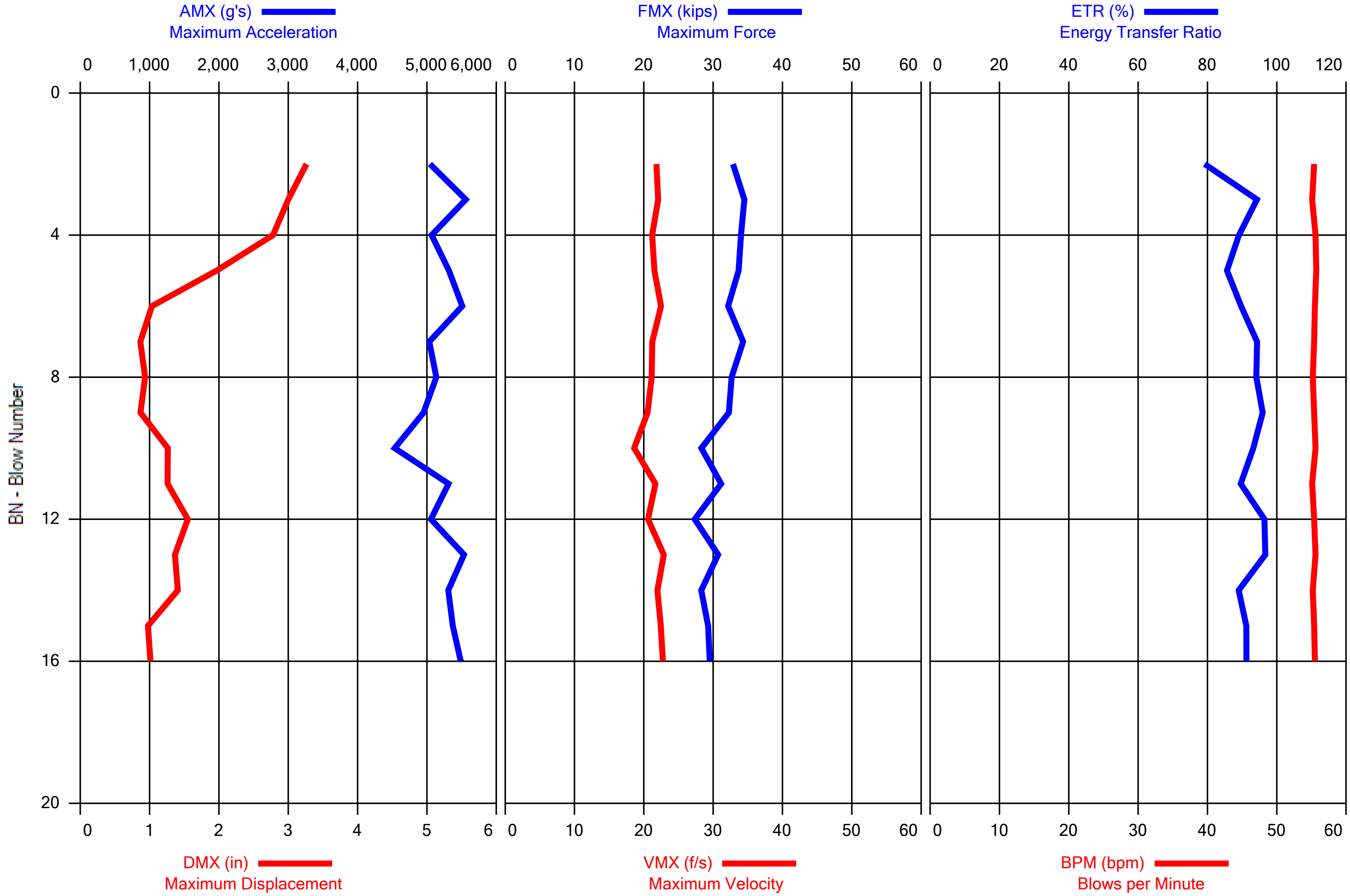
Drive 31 seconds 11:04 AM - 11:04 AM BN 1 - 30

Foundation Testing & Consulting LLC - PDIPLOT2 Ver 2017.2.58.3 - Case Method & iCAP® Results

Printed: 15-September-2020

Test started: 10-September-2020

ANDERSON ENG, INC. - 401073-3



ANDERSON ENG, INC. - 401073-3 GEOPROBE
OP: CMH Date: 10-September-2020

AR: 1.19 in² SP: 0.492 k/ft³
LE: 13.46 ft EM: 30,000 ksi
WS: 16,807.9 f/s JC: 0.00

AMX: Maximum Acceleration
DMX: Maximum Displacement
FMX: Maximum Force
VMX: Maximum Velocity
ETR: Energy Transfer Ratio
BPM: Blows per Minute
CSX: Max Measured Compr. Stress
EMX: Max Transferred Energy
CSI: Max F1 or F2 Compr. Stress

BL#	Depth	BLC	AMX	DMX	FMX	VMX	ETR	BPM	CSX	EMX	CSI
	ft	**	g's	in	kips	f/s	(%)	bpm	ksi	k-ft	ksi
2	10.00	0	5,045	3	33	22	79	55	27.6	0.3	27.7
3	10.00	0	5,561	3	34	22	94	55	29.0	0.3	29.3
4	10.00	0	5,069	3	34	21	89	56	28.6	0.3	28.7
5	10.00	0	5,319	2	34	22	86	56	28.3	0.3	28.6
6	10.00	0	5,511	1	32	22	90	56	27.0	0.3	27.1
7	10.00	0	5,036	1	34	21	94	55	28.8	0.3	29.1
8	10.00	0	5,136	1	33	21	94	55	27.4	0.3	27.7
9	10.00	0	4,951	1	32	21	96	55	27.1	0.3	27.4
10	10.00	0	4,536	1	28	19	93	56	23.8	0.3	24.2
11	10.00	0	5,313	1	31	22	90	55	26.2	0.3	26.2
12	10.00	0	5,059	2	27	21	96	55	23.0	0.3	23.2
13	10.00	0	5,537	1	31	23	97	56	25.8	0.3	26.0
14	10.00	0	5,309	1	28	22	89	55	23.8	0.3	24.1
15	10.00	0	5,374	1	29	22	91	55	24.6	0.3	25.1
16	10.00	0	5,489	1	30	23	91	56	24.8	0.3	25.1
		Average	5,216	2	31	22	91	55	26.4	0.3	26.6

Total number of blows analyzed: 15

BL# Sensors

2-16 F3: [AWJ-1-2015] 214.3 (1.00); F4: [AWJ-2-2015] 213.7 (1.00); A3: [K10511] 360.0 (1.00); A4: [K10514] 354.0 (1.00)

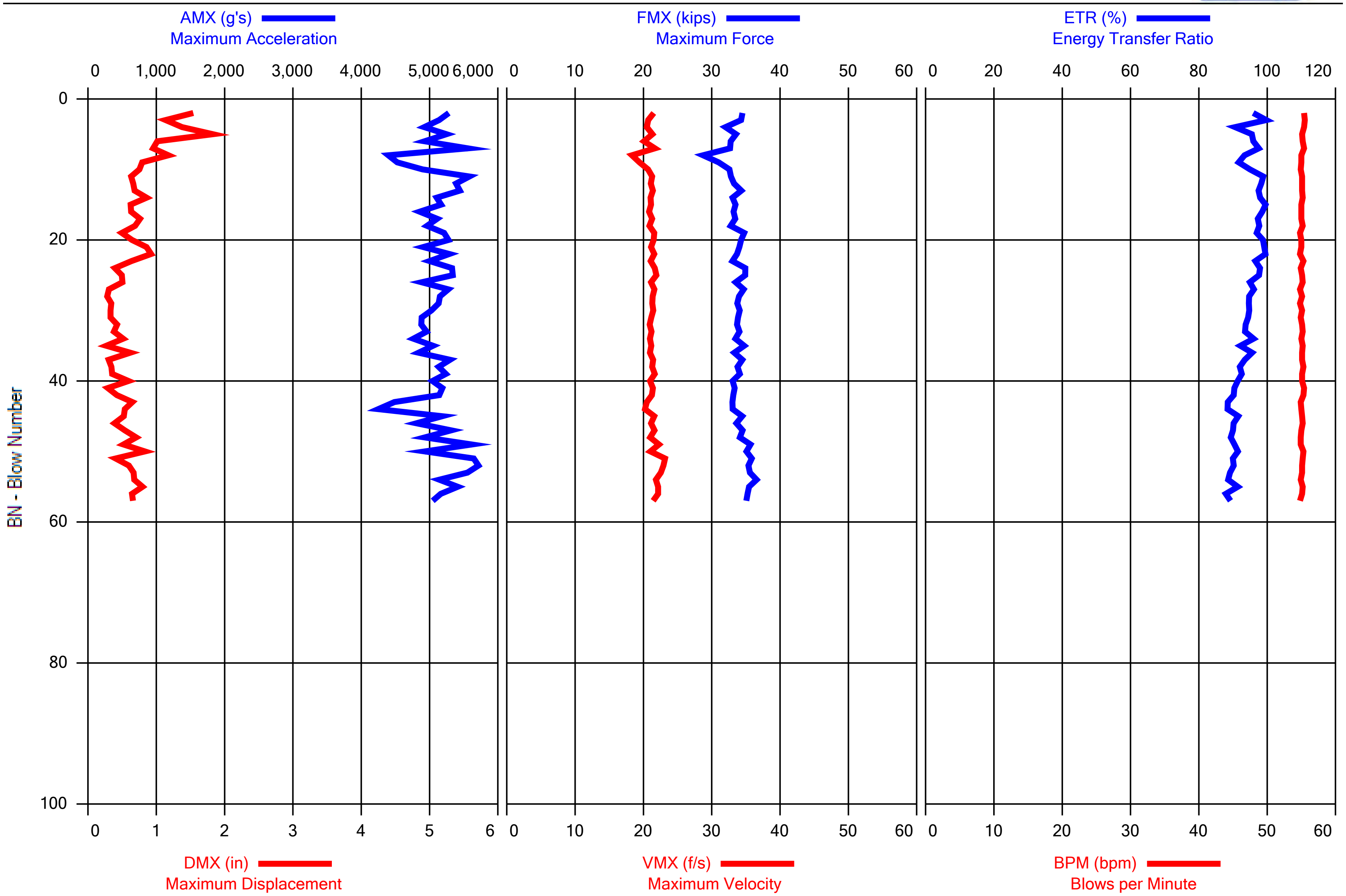
Time Summary

Drive 16 seconds 11:11 AM - 11:11 AM BN 1 - 16

Foundation Testing & Consulting LLC - PDIPLOT2 Ver 2017.2.58.3 - Case Method & iCAP® Results

Printed: 15-September-2020 | Test started: 10-September-2020

ANDERSON ENG, INC. - 401073-4



ANDERSON ENG, INC. - 401073-4 GEOPROBE
OP: CMH Date: 10-September-2020

AR: 1.19 in² SP: 0.492 k/ft³
LE: 18.42 ft EM: 30,000 ksi
WS: 16,807.9 f/s JC: 0.00

AMX: Maximum Acceleration
DMX: Maximum Displacement
FMX: Maximum Force
VMX: Maximum Velocity
ETR: Energy Transfer Ratio
BPM: Blows per Minute
CSX: Max Measured Compr. Stress
EMX: Max Transferred Energy
CSI: Max F1 or F2 Compr. Stress

BL#	Depth	BLC	AMX	DMX	FMX	VMX	ETR	BPM	CSX	EMX	CSI
	ft	**	g's	in	kips	f/s	(%)	bpm	ksi	k-ft	ksi
2	15.00	0	5,283	2	34	22	96	55	29.0	0.3	29.2
3	15.00	0	5,140	1	34	21	100	56	28.8	0.3	29.0
4	15.00	0	4,922	1	32	20	91	55	26.9	0.3	27.1
5	15.00	0	5,248	2	34	21	96	55	28.2	0.3	28.4
6	15.00	0	4,927	1	33	20	96	55	27.5	0.3	27.7
7	15.00	0	5,560	1	33	22	98	55	27.5	0.3	27.6
8	15.00	0	4,395	1	29	18	93	55	24.1	0.3	24.3
9	15.00	0	4,526	1	31	19	92	55	26.1	0.3	26.3
10	15.00	0	4,899	1	33	21	95	55	27.4	0.3	27.7
11	15.00	0	5,584	1	33	21	99	55	27.6	0.3	27.7
12	15.00	0	5,388	1	33	21	98	55	27.9	0.3	28.1
13	15.00	0	5,443	1	34	21	97	55	28.8	0.3	29.1
14	15.00	0	5,103	1	33	21	98	55	27.8	0.3	27.9
15	15.00	0	5,169	1	33	21	100	55	28.1	0.3	28.4
16	15.00	0	4,854	1	33	21	99	55	27.9	0.3	27.9
17	15.00	0	5,111	1	33	21	97	55	28.1	0.3	28.3
18	15.00	0	4,962	1	33	21	98	55	27.5	0.3	27.6
19	15.00	0	5,213	0	35	22	97	55	29.2	0.3	29.4
20	15.00	0	5,277	1	34	21	99	55	28.8	0.3	29.1
21	15.00	0	4,909	1	34	21	99	55	28.6	0.3	28.8
22	15.00	0	5,289	1	34	22	99	55	28.3	0.3	28.6
23	15.00	0	5,000	1	33	21	97	55	27.7	0.3	28.0
24	15.00	0	5,329	0	35	22	98	55	29.3	0.3	29.7
25	15.00	0	5,340	0	35	22	98	55	29.3	0.3	29.7
26	15.00	0	4,885	1	33	21	95	55	28.1	0.3	28.3
27	15.00	0	5,275	0	35	22	96	55	29.1	0.3	29.5
28	15.00	0	5,150	0	34	21	95	55	28.6	0.3	28.8
29	15.00	0	5,132	0	34	21	95	55	28.3	0.3	28.6
30	15.00	0	5,028	0	34	21	95	55	28.7	0.3	29.0
31	15.00	0	4,884	0	34	21	94	55	28.4	0.3	28.8
32	15.00	0	4,878	0	34	21	94	55	28.3	0.3	28.4
33	15.00	0	4,957	0	34	21	93	55	28.6	0.3	28.7
34	15.00	0	4,762	1	33	21	96	55	28.1	0.3	28.2
35	15.00	0	5,052	0	35	21	92	55	29.2	0.3	29.4
36	15.00	0	4,838	1	33	21	96	55	28.0	0.3	28.1
37	15.00	0	5,301	0	34	21	93	55	29.0	0.3	29.3
38	15.00	0	5,133	0	34	21	92	55	28.4	0.3	28.6
39	15.00	0	5,239	0	34	22	93	55	28.7	0.3	29.0
40	15.00	0	5,043	1	33	21	91	55	27.8	0.3	28.1
41	15.00	0	5,187	0	33	21	90	55	28.0	0.3	28.4
42	15.00	0	5,142	0	33	21	90	55	27.9	0.3	28.1
43	15.00	0	4,484	1	33	21	88	55	27.8	0.3	28.0
44	15.00	0	4,249	1	33	20	88	55	27.8	0.3	27.9
45	15.00	0	5,186	1	34	22	92	55	29.0	0.3	29.3
46	15.00	0	4,809	0	34	21	90	55	28.2	0.3	28.5

ANDERSON ENG, INC. - 401073-4
OP: CMH
GEOPROBE
Date: 10-September-2020

BL#	Depth	BLC	AMX	DMX	FMX	VMX	ETR	BPM	CSX	EMX	CSI
	ft	**	g's	in	kips	f/s	(%)	bpm	ksi	k-ft	ksi
47	15.00	0	5,316	1	35	22	90	55	29.0	0.3	29.1
48	15.00	0	4,929	1	34	21	89	55	28.7	0.3	28.8
49	15.00	0	5,618	1	36	22	90	55	30.0	0.3	30.2
50	15.00	0	4,932	1	35	21	91	55	29.5	0.3	29.5
51	15.00	0	5,646	0	36	23	90	55	30.1	0.3	30.3
52	15.00	0	5,717	1	35	23	90	55	29.7	0.3	29.9
53	15.00	0	5,555	1	36	23	89	55	29.9	0.3	29.9
54	15.00	0	5,143	1	37	22	89	55	30.7	0.3	30.8
55	15.00	0	5,413	1	35	22	91	55	29.8	0.3	29.9
56	15.00	0	5,164	1	35	22	88	55	29.6	0.3	29.8
57	15.00	0	5,046	1	35	21	89	55	29.5	0.3	29.5
		Average	5,107	1	34	21	94	55	28.4	0.3	28.6

Total number of blows analyzed: 56

BL# Sensors

2-57 F3: [AWJ-1-2015] 214.3 (1.00); F4: [AWJ-2-2015] 213.7 (1.00); A3: [K10511] 360.0 (1.00); A4: [K10514] 354.0 (1.00)

Time Summary

Drive 1 minute 0 second 11:20 AM - 11:21 AM BN 1 - 57

APPENDIX B
Round Spring Water Quality Monitoring Data

Round Spring Water Quality Data
Spring Valley GeoTechnical Investigation

DATE	TIME	Temp (°F)	Sp Cond (µS/cm)	pH	ORP (mV)	ODO (mg/L)	Turbidity (NTU)	Precipitation (in) NOTE 1
5/2/2022	7:00:26 AM	54.7	213.2	7.16	134.8	7.64	0.23	0.00
5/2/2022	7:05:26 AM	54.7	211.3	7.11	145.3	7.46	0.82	
5/2/2022	7:10:26 AM	54.7	210.1	7.07	148.9	7.44	0.35	
5/2/2022	7:15:26 AM	54.7	209.2	7.06	150.1	7.45	0.30	0.00
5/2/2022	7:20:26 AM	54.7	208.5	7.05	150.4	7.45	0.27	
5/2/2022	7:25:26 AM	54.7	207.8	7.02	150.9	7.46	0.30	
5/2/2022	7:30:26 AM	54.7	207.2	7.01	151.0	7.46	0.27	0.00
5/2/2022	7:35:26 AM	54.7	206.7	6.98	151.2	7.47	0.32	
5/2/2022	7:40:26 AM	54.7	206.4	6.97	150.8	7.47	0.27	
5/2/2022	7:45:26 AM	54.7	205.8	6.96	150.5	7.47	0.20	0.00
5/2/2022	7:50:25 AM	54.7	205.4	6.94	150.1	7.47	0.23	
5/2/2022	7:55:25 AM	54.7	205.1	6.93	149.5	7.48	0.24	
5/2/2022	8:00:25 AM	54.8	204.8	6.92	149.0	7.48	0.25	0.00
5/2/2022	8:05:25 AM	54.8	204.4	6.91	148.5	7.48	0.30	
5/2/2022	8:10:25 AM	54.8	204.0	6.91	147.8	7.48	0.25	
5/2/2022	8:15:25 AM	54.8	203.8	6.90	146.9	7.49	0.27	0.00
5/2/2022	**8:15:00 AM**	**Boring B-2: Begin drilling.**						
5/2/2022	8:20:25 AM	54.8	203.5	6.90	145.6	7.51	0.25	
5/2/2022	8:25:25 AM	54.8	203.3	6.90	144.1	7.53	0.22	
5/2/2022	8:30:25 AM	54.8	203.0	6.90	142.3	7.56	0.24	0.00
5/2/2022	8:35:25 AM	54.8	202.9	6.90	140.5	7.58	0.26	
5/2/2022	8:40:25 AM	54.8	202.6	6.91	138.6	7.60	0.22	
5/2/2022	8:45:25 AM	54.8	202.4	6.91	136.7	7.61	0.20	0.00
5/2/2022	8:50:25 AM	54.8	202.2	6.91	134.8	7.63	0.32	
5/2/2022	8:55:25 AM	54.8	202.0	6.92	133.0	7.64	0.24	
5/2/2022	9:00:25 AM	54.8	201.8	6.92	131.2	7.65	0.24	0.00
5/2/2022	**9:00:00 AM**	**Boring B-2: Encountered bedrock at 19 feet below ground surface (bgs).**						
5/2/2022	9:05:25 AM	54.8	201.7	6.93	129.3	7.67	0.26	
5/2/2022	9:10:25 AM	54.8	201.6	6.94	127.4	7.71	0.24	
5/2/2022	9:15:25 AM	54.8	201.4	6.94	125.4	7.74	0.27	0.00
5/2/2022	9:20:25 AM	54.8	201.2	6.95	123.8	7.74	0.29	
5/2/2022	9:25:25 AM	54.8	201.1	6.96	122.6	7.75	0.25	
5/2/2022	9:30:25 AM	54.8	200.9	6.96	121.9	7.72	0.32	0.00
5/2/2022	9:35:25 AM	54.8	200.8	6.97	121.6	7.70	0.26	
5/2/2022	9:40:25 AM	54.8	200.7	6.97	121.1	7.68	0.31	
5/2/2022	9:45:25 AM	54.8	200.6	6.98	120.5	7.69	0.28	0.00
5/2/2022	9:50:25 AM	54.8	200.6	6.98	119.6	7.70	0.29	
5/2/2022	9:55:25 AM	54.8	200.3	6.99	118.6	7.71	0.30	
5/2/2022	10:00:25 AM	54.9	200.3	7.00	117.3	7.74	0.31	0.00
5/2/2022	10:05:25 AM	54.9	200.2	7.00	116.2	7.78	0.25	
5/2/2022	10:10:25 AM	54.9	200.1	7.01	115.7	7.77	0.23	
5/2/2022	10:15:25 AM	54.9	199.9	7.01	115.7	7.75	0.28	0.00
5/2/2022	10:20:25 AM	54.8	199.8	7.02	115.9	7.74	0.21	
5/2/2022	10:25:25 AM	54.8	199.6	7.02	116.2	7.72	0.81	
5/2/2022	10:30:25 AM	54.8	199.6	7.02	116.4	7.70	0.31	0.00
5/2/2022	10:35:25 AM	54.8	199.5	7.02	116.9	7.69	0.23	

Round Spring Water Quality Data
Spring Valley GeoTechnical Investigation

DATE	TIME	Temp (°F)	Sp Cond (µS/cm)	pH	ORP (mV)	ODO (mg/L)	Turbidity (NTU)	Precipitation (in) [NOTE 1]
5/2/2022	10:40:25 AM	54.8	199.4	7.03	117.8	7.66	0.28	
5/2/2022	10:45:25 AM	54.8	199.4	7.03	119.0	7.63	0.26	0.00
5/2/2022	10:50:25 AM	54.8	199.2	7.03	120.3	7.59	0.27	
5/2/2022	10:55:25 AM	54.8	199.1	7.03	121.5	7.58	0.16	
5/2/2022	11:00:25 AM	54.8	199.2	7.03	122.7	7.56	0.26	0.00
5/2/2022	11:05:25 AM	54.8	199.1	7.03	124.0	7.54	0.26	
5/2/2022	11:10:25 AM	54.8	199.0	7.04	125.0	7.52	0.23	
5/2/2022	11:15:25 AM	54.8	199.0	7.04	126.2	7.51	0.22	0.00
5/2/2022	11:20:25 AM	54.8	198.7	7.05	127.4	7.48	0.25	
5/2/2022	11:25:25 AM	54.8	198.7	7.05	128.3	7.48	0.20	
5/2/2022	11:30:25 AM	54.8	198.6	7.05	129.2	7.48	0.33	0.00
5/2/2022	11:35:25 AM	54.8	198.6	7.05	130.0	7.48	0.31	
5/2/2022	11:40:25 AM	54.8	198.4	7.05	130.7	7.47	0.30	
5/2/2022	11:45:24 AM	54.8	198.4	7.05	131.3	7.47	0.28	0.03
5/2/2022	11:50:24 AM	54.8	198.3	7.06	131.5	7.47	0.26	
5/2/2022	11:55:24 AM	54.8	198.2	7.06	131.8	7.47	0.25	
5/2/2022	12:00:24 PM	54.8	198.1	7.06	131.8	7.49	0.21	0.04
5/2/2022	12:05:24 PM	54.8	198.1	7.06	131.1	7.52	0.25	
5/2/2022	12:10:24 PM	54.8	198.1	7.06	130.4	7.54	0.18	
5/2/2022	12:15:24 PM	54.8	198.1	7.07	129.6	7.55	0.23	0.02
5/2/2022	12:20:24 PM	54.8	198.0	7.07	128.9	7.56	0.28	
5/2/2022	12:25:24 PM	54.8	197.9	7.07	128.3	7.57	0.22	
5/2/2022	12:30:24 PM	54.8	197.8	7.07	127.6	7.58	0.33	0.01
5/2/2022	12:35:24 PM	54.8	197.8	7.07	127.4	7.57	0.16	
5/2/2022	12:40:24 PM	54.8	197.8	7.07	127.2	7.56	0.19	
5/2/2022	12:45:24 PM	54.8	197.7	7.07	127.2	7.56	0.23	0.01
5/2/2022	12:50:24 PM	54.8	197.7	7.07	126.7	7.56	0.25	
5/2/2022	12:55:24 PM	54.8	197.7	7.07	126.5	7.58	0.19	
5/2/2022	1:00:24 PM	54.8	197.6	7.07	126.4	7.57	0.21	0.00
5/2/2022	1:05:24 PM	54.8	197.6	7.07	126.7	7.57	0.21	
5/2/2022	1:10:24 PM	54.8	197.5	7.07	126.9	7.55	0.22	
5/2/2022	1:15:24 PM	54.8	197.4	7.07	126.9	7.56	0.23	0.00
5/2/2022	1:20:24 PM	54.8	197.4	7.07	127.2	7.56	0.22	
5/2/2022	1:25:24 PM	54.8	197.3	7.07	127.9	7.53	0.24	
5/2/2022	1:30:24 PM	54.8	197.3	7.07	128.5	7.52	0.22	0.01
5/2/2022	1:35:24 PM	54.8	197.2	7.07	129.0	7.51	0.30	
5/2/2022	1:40:24 PM	54.8	197.1	7.07	129.5	7.51	0.25	
5/2/2022	1:45:24 PM	54.8	197.0	7.07	129.9	7.51	0.25	0.03
5/2/2022	1:50:24 PM	54.8	197.1	7.07	129.8	7.53	0.24	
5/2/2022	1:55:24 PM	54.8	197.1	7.08	129.6	7.54	0.24	
5/2/2022	2:00:24 PM	54.8	196.9	7.07	129.5	7.55	0.28	0.02
5/2/2022	2:05:24 PM	54.8	197.0	7.07	128.6	7.57	0.29	
5/2/2022	2:10:24 PM	54.8	197.1	7.08	127.6	7.60	0.28	
5/2/2022	2:15:24 PM	54.8	197.0	7.08	126.6	7.63	0.22	0.01
5/2/2022	2:20:24 PM	54.8	197.0	7.08	126.2	7.61	0.23	
5/2/2022	2:25:24 PM	54.8	196.9	7.08	125.7	7.62	0.39	

Round Spring Water Quality Data
Spring Valley GeoTechnical Investigation

DATE	TIME	Temp (°F)	Sp Cond (µS/cm)	pH	ORP (mV)	ODO (mg/L)	Turbidity (NTU)	Precipitation (in) NOTE 1
5/2/2022	2:30:24 PM	54.8	196.9	7.08	125.4	7.62	0.37	0.01
5/2/2022	2:35:24 PM	54.8	196.8	7.08	124.9	7.63	0.39	
5/2/2022	2:40:24 PM	54.8	197.0	7.08	123.3	7.67	0.34	
5/2/2022	2:45:24 PM	54.8	196.9	7.09	121.4	7.70	0.41	0.00
5/2/2022	2:50:24 PM	54.8	197.0	7.08	122.2	7.64	0.32	
5/2/2022	2:55:24 PM	54.8	196.8	7.08	122.7	7.60	0.33	
5/2/2022	3:00:24 PM	54.8	196.8	7.08	123.0	7.61	0.33	0.00
5/2/2022	3:05:24 PM	54.8	196.7	7.08	123.1	7.62	0.36	
5/2/2022	3:10:24 PM	54.8	196.7	7.08	123.6	7.59	0.42	
5/2/2022	3:15:24 PM	54.8	196.6	7.08	124.5	7.57	0.30	0.00
5/2/2022	3:20:24 PM	54.8	196.7	7.08	125.2	7.56	0.36	
5/2/2022	3:25:24 PM	54.8	196.6	7.08	125.0	7.58	0.35	
5/2/2022	3:30:24 PM	54.8	196.6	7.08	125.4	7.59	0.42	0.00
5/2/2022	3:35:24 PM	54.8	196.6	7.08	125.2	7.60	0.30	
5/2/2022	3:40:24 PM	54.8	196.5	7.08	125.1	7.62	0.36	
5/2/2022	3:45:24 PM	54.8	196.5	7.08	125.0	7.62	0.33	0.00
5/2/2022	3:50:23 PM	54.8	196.5	7.08	124.8	7.63	0.30	
5/2/2022	3:55:23 PM	54.8	196.6	7.09	124.0	7.66	0.32	
5/2/2022	4:00:23 PM	54.8	196.4	7.09	124.2	7.65	0.31	0.01
5/2/2022	4:05:23 PM	54.8	196.4	7.08	125.0	7.61	0.40	
5/2/2022	4:10:23 PM	54.8	196.4	7.08	125.3	7.60	0.39	
5/2/2022	4:15:23 PM	54.8	196.4	7.08	125.5	7.61	0.34	0.01
5/2/2022	**4:20:00 PM**	**Boring B-2: End drilling for the day at 79 feet bgs.**						
5/2/2022	4:20:23 PM	54.8	196.3	7.08	125.9	7.59	0.36	
5/2/2022	4:25:23 PM	54.8	196.2	7.08	126.5	7.57	0.28	
5/2/2022	4:30:23 PM	54.8	196.3	7.08	126.9	7.56	0.26	0.00
5/2/2022	4:35:23 PM	54.8	196.3	7.08	127.6	7.53	0.34	
5/2/2022	4:40:23 PM	54.8	196.2	7.07	129.0	7.50	0.37	
5/2/2022	4:45:23 PM	54.8	196.2	7.07	130.4	7.46	0.33	0.00
5/2/2022	4:50:23 PM	54.8	196.2	7.07	131.4	7.46	0.38	
5/2/2022	4:55:23 PM	54.8	196.2	7.07	132.3	7.45	0.38	
5/2/2022	5:00:23 PM	54.8	196.1	7.07	133.6	7.43	0.37	0.00
5/2/2022: Precipitation through midnight: 0.08 inches. 5/3/2022: Precipitation midnight through 07:15 AM: 0.10 inches.								
5/3/2022	7:25:03 AM	54.8	219.7	7.15	144.3	7.43	0.98	
5/3/2022	7:30:03 AM	54.8	215.9	7.05	152.6	7.41	0.99	0.00
5/3/2022	7:35:03 AM	54.8	213.0	6.99	156.7	7.41	1.03	
5/3/2022	7:40:03 AM	54.8	211.6	6.94	158.8	7.40	0.92	
5/3/2022	7:45:03 AM	54.8	209.9	6.92	159.7	7.39	0.96	0.00
5/3/2022	7:50:03 AM	54.8	208.5	6.90	160.0	7.40	1.01	
5/3/2022	7:55:03 AM	54.8	207.0	6.88	160.3	7.40	0.95	
5/3/2022	8:00:03 AM	54.8	205.5	6.87	160.5	7.38	0.96	0.00
5/3/2022	**8:00:00 AM**	**Boring B-2: Begin drilling at 79 feet bgs.**						
5/3/2022	8:05:03 AM	54.8	204.7	6.87	160.4	7.38	0.98	
5/3/2022	8:10:03 AM	54.8	204.0	6.86	159.9	7.39	0.94	
5/3/2022	8:15:03 AM	54.8	203.3	6.86	159.4	7.41	1.03	0.00

Round Spring Water Quality Data
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DATE	TIME	Temp (°F)	Sp Cond (µS/cm)	pH	ORP (mV)	ODO (mg/L)	Turbidity (NTU)	Precipitation (in) NOTE 1
5/3/2022	8:20:03 AM	54.8	202.8	6.86	158.8	7.42	0.96	
5/3/2022	8:25:03 AM	54.8	202.3	6.86	158.6	7.41	1.00	
5/3/2022	8:30:03 AM	54.8	201.9	6.86	158.4	7.40	1.05	0.00
5/3/2022	8:35:03 AM	54.8	201.5	6.86	157.6	7.42	0.99	
5/3/2022	8:40:03 AM	54.8	201.2	6.87	156.7	7.44	1.00	
5/3/2022	8:45:03 AM	54.8	200.9	6.87	155.9	7.44	0.97	0.00
5/3/2022	8:50:02 AM	54.8	200.6	6.88	155.5	7.43	0.99	
5/3/2022	8:55:02 AM	54.8	200.3	6.88	155.0	7.42	1.01	
5/3/2022	9:00:02 AM	54.8	200.1	6.88	154.5	7.43	1.07	0.00
5/3/2022	9:05:02 AM	54.8	199.9	6.89	153.6	7.45	1.01	
5/3/2022	9:10:02 AM	54.8	199.7	6.89	152.6	7.48	1.01	
5/3/2022	9:15:02 AM	54.8	199.5	6.90	151.1	7.50	0.96	0.00
5/3/2022	9:20:02 AM	54.9	199.4	6.90	148.8	7.56	1.00	
5/3/2022	9:25:02 AM	54.9	199.3	6.91	147.0	7.58	1.10	
5/3/2022	9:30:02 AM	54.9	199.2	6.92	144.7	7.61	0.99	0.00
5/3/2022	9:35:02 AM	54.9	199.1	6.92	142.1	7.65	0.92	
5/3/2022	9:40:02 AM	54.9	199.0	6.93	139.9	7.67	0.96	
5/3/2022	9:45:02 AM	54.9	198.9	6.94	139.0	7.66	0.93	0.00
5/3/2022	9:50:02 AM	54.9	198.7	6.94	139.8	7.58	1.02	
5/3/2022	9:55:02 AM	54.9	198.7	6.94	139.6	7.53	0.96	
5/3/2022	10:00:02 AM	54.9	198.6	6.95	137.4	7.61	1.06	0.00
5/3/2022	10:05:02 AM	55.0	198.5	6.96	134.6	7.71	1.15	
5/3/2022	10:10:02 AM	54.9	198.5	6.96	133.2	7.73	0.98	
5/3/2022	10:15:02 AM	54.9	198.3	6.97	131.9	7.72	0.97	0.00
5/3/2022	10:20:02 AM	54.9	198.3	6.97	130.9	7.71	0.97	
5/3/2022	10:25:02 AM	55.0	198.2	6.97	129.2	7.74	1.03	
5/3/2022	10:30:02 AM	55.0	198.2	6.98	127.4	7.77	1.04	0.00
5/3/2022	10:35:02 AM	55.0	198.1	6.99	125.7	7.81	0.98	
5/3/2022	10:40:02 AM	55.0	198.1	6.99	125.9	7.77	0.95	
5/3/2022	10:45:02 AM	55.0	198.0	6.99	125.5	7.75	1.20	0.00
5/3/2022	10:50:02 AM	55.0	197.9	7.00	125.3	7.78	0.96	
5/3/2022	10:55:02 AM	54.9	197.9	6.99	127.1	7.66	1.00	
5/3/2022	11:00:02 AM	54.9	197.8	6.99	128.3	7.64	1.02	0.00
5/3/2022	11:05:02 AM	54.9	197.7	6.99	129.2	7.61	0.98	
5/3/2022	**11:10:00 AM**	**Boring B-2: Drilling ended at total depth of 95 feet bgs.**						
5/3/2022	11:10:02 AM	54.9	197.7	7.00	130.4	7.58	1.05	
5/3/2022	11:15:02 AM	54.9	197.7	7.00	131.7	7.55	1.03	0.00
5/3/2022	11:20:02 AM	54.9	197.6	7.00	132.5	7.56	0.97	
5/3/2022	11:25:02 AM	54.9	197.6	7.00	132.9	7.56	0.92	
5/3/2022	11:30:02 AM	54.9	197.5	7.00	132.2	7.60	0.97	0.00
5/3/2022	11:35:02 AM	54.9	197.5	7.01	130.3	7.68	1.07	
5/3/2022	11:40:02 AM	54.9	197.4	7.01	130.1	7.66	1.02	
5/3/2022	11:45:02 AM	55.0	197.5	7.01	127.7	7.73	0.94	0.00
5/3/2022	11:50:02 AM	54.9	197.4	7.02	126.5	7.75	0.95	
5/3/2022	11:55:02 AM	54.9	197.4	7.02	126.4	7.72	1.02	
5/3/2022	12:00:02 PM	54.9	197.3	7.02	126.8	7.69	1.01	0.00

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DATE	TIME	Temp (°F)	Sp Cond (µS/cm)	pH	ORP (mV)	ODO (mg/L)	Turbidity (NTU)	Precipitation (in) NOTE 1
5/3/2022	12:05:02 PM	54.9	197.3	7.02	126.9	7.67	1.05	
5/3/2022	12:10:02 PM	55.0	197.3	7.02	124.1	7.77	1.00	
5/3/2022	12:15:02 PM	55.0	197.3	7.03	121.7	7.82	0.97	0.00
5/3/2022	12:20:02 PM	55.0	197.2	7.03	121.4	7.80	0.99	
5/3/2022	12:25:02 PM	55.0	197.2	7.03	120.9	7.79	1.03	
5/3/2022	12:30:02 PM	55.0	197.2	7.03	120.8	7.77	0.99	0.00
5/3/2022	12:35:02 PM	55.0	197.2	7.03	120.5	7.78	1.73	
5/3/2022	12:40:02 PM	55.0	197.2	7.03	118.4	7.80	0.96	
5/3/2022	12:45:02 PM	55.0	197.2	7.03	118.0	7.77	2.32	0.00
5/3/2022	12:50:02 PM	55.0	197.1	7.03	116.5	7.83	1.71	
5/3/2022	12:55:02 PM	55.0	197.1	7.04	116.2	7.83	1.70	
5/3/2022	1:00:02 PM	55.0	197.1	7.03	115.7	7.82	1.75	0.00
5/3/2022	1:05:01 PM	55.0	197.1	7.03	115.4	7.80	0.95	
5/3/2022	1:10:01 PM	55.0	197.1	7.04	114.2	7.84	0.99	
5/3/2022	1:15:01 PM	55.0	197.0	7.04	115.2	7.78	0.96	0.00
5/3/2022	1:20:01 PM	55.0	197.0	7.04	116.2	7.75	0.98	
5/3/2022	1:25:01 PM	55.0	197.0	7.04	116.8	7.74	1.03	
5/3/2022	1:30:01 PM	55.0	197.0	7.03	115.5	7.79	3.34	0.00
5/3/2022	1:35:01 PM	55.1	197.1	7.04	113.5	7.89	4.97	
5/3/2022	1:40:01 PM	55.1	197.1	7.04	112.0	7.93	2.64	
5/3/2022	1:45:01 PM	55.1	197.1	7.05	111.2	7.94	4.11	0.00
5/3/2022	1:50:01 PM	55.1	197.1	7.05	110.8	7.94	3.60	
5/3/2022	1:55:01 PM	55.1	197.0	7.05	110.3	7.93	4.05	
5/3/2022	2:00:01 PM	55.2	197.0	7.05	110.0	7.94	3.88	0.00
5/3/2022	2:05:01 PM	55.1	197.0	7.04	110.0	7.90	4.21	
5/3/2022	2:10:01 PM	55.2	197.0	7.05	109.3	7.93	4.22	
5/3/2022	2:15:01 PM	55.1	197.0	7.05	108.9	7.92	5.09	0.00
5/3/2022	2:20:01 PM	55.1	197.0	7.05	108.4	7.91	4.27	
5/3/2022	2:25:01 PM	55.1	197.0	7.04	108.6	7.87	4.51	
5/3/2022	2:30:01 PM	55.0	197.1	7.04	110.1	7.81	1.08	0.00
5/3/2022: Precipitation through midnight: 0.00 inches. 5/4/2022: Precipitation midnight through 07:15 AM: 0.00 inches.								
5/4/2022	7:25:02 AM	54.8	223.1	7.30	130.4	7.45	1.44	
5/4/2022	7:30:02 AM	54.8	220.1	7.13	144.6	7.41	0.49	0.00
5/4/2022	7:35:02 AM	54.8	217.6	7.08	149.4	7.42	0.54	
5/4/2022	7:40:02 AM	54.8	215.4	7.05	151.7	7.42	0.57	
5/4/2022	7:45:02 AM	54.8	213.5	7.04	152.9	7.42	0.49	0.00
5/4/2022	7:50:02 AM	54.8	211.8	7.02	154.0	7.43	0.45	
5/4/2022	7:55:02 AM	54.8	210.3	7.01	154.7	7.44	0.39	
5/4/2022	8:00:02 AM	54.8	209.1	6.99	155.3	7.44	0.41	0.00
5/4/2022	8:05:02 AM	54.8	207.9	6.98	155.7	7.44	0.38	
5/4/2022	8:10:02 AM	54.8	206.9	6.97	156.1	7.46	0.39	
5/4/2022	8:15:02 AM	54.8	206.1	6.96	156.5	7.46	0.48	0.00
5/4/2022	8:20:02 AM	54.8	205.4	6.96	156.8	7.46	0.39	
5/4/2022	8:25:02 AM	54.8	204.7	6.95	156.9	7.48	0.38	
5/4/2022	8:30:02 AM	54.8	204.2	6.95	157.0	7.50	0.41	0.00

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DATE	TIME	Temp (°F)	Sp Cond (µS/cm)	pH	ORP (mV)	ODO (mg/L)	Turbidity (NTU)	Precipitation (in) NOTE 1
5/4/2022	8:35:02 AM	54.8	203.7	6.94	157.2	7.51	0.40	
5/4/2022	**8:40:00 AM**	**Boring B-4: Begin drilling.**						
5/4/2022	8:40:02 AM	54.8	203.3	6.94	157.3	7.51	0.39	
5/4/2022	8:45:02 AM	54.8	202.9	6.93	157.5	7.52	0.34	0.00
5/4/2022	8:50:02 AM	54.8	202.5	6.93	157.5	7.52	0.45	
5/4/2022	8:55:02 AM	54.8	202.2	6.93	157.5	7.53	0.36	
5/4/2022	9:00:02 AM	54.8	201.9	6.93	157.4	7.55	0.36	0.00
5/4/2022	9:05:02 AM	54.9	201.7	6.93	157.3	7.56	0.33	
5/4/2022	9:10:02 AM	54.9	201.5	6.93	157.0	7.60	0.33	
5/4/2022	9:15:02 AM	54.9	201.3	6.93	156.9	7.60	0.39	0.00
5/4/2022	9:20:02 AM	54.9	201.1	6.93	156.6	7.61	0.43	
5/4/2022	9:25:02 AM	54.9	200.9	6.93	156.4	7.61	0.39	
5/4/2022	9:30:02 AM	54.9	200.7	6.93	156.2	7.62	0.31	0.00
5/4/2022	9:35:02 AM	54.9	200.6	6.94	155.8	7.64	0.40	
5/4/2022	9:40:02 AM	54.9	200.5	6.94	155.6	7.65	0.35	
5/4/2022	9:45:02 AM	54.9	200.3	6.94	155.2	7.65	0.41	0.00
5/4/2022	9:50:02 AM	54.9	200.2	6.95	154.8	7.66	0.37	
5/4/2022	9:55:02 AM	54.9	200.1	6.95	154.6	7.66	0.35	
5/4/2022	10:00:02 AM	54.9	200.0	6.95	154.3	7.67	0.38	0.00
5/4/2022	10:05:02 AM	54.9	199.9	6.96	153.9	7.70	0.35	
5/4/2022	10:10:02 AM	54.9	199.8	6.96	153.4	7.72	0.37	
5/4/2022	10:15:02 AM	54.9	199.7	6.96	153.2	7.70	0.34	0.00
5/4/2022	10:20:02 AM	54.9	199.6	6.97	153.1	7.70	0.33	
5/4/2022	10:25:02 AM	54.9	199.5	6.97	152.9	7.72	0.35	
5/4/2022	10:30:02 AM	54.9	199.5	6.98	152.6	7.72	0.33	0.00
5/4/2022	10:35:01 AM	54.9	199.4	6.98	152.3	7.75	0.32	
5/4/2022	10:40:01 AM	55.0	199.4	6.99	151.9	7.79	0.39	
5/4/2022	10:45:01 AM	55.0	199.3	6.99	151.5	7.79	0.33	0.00
5/4/2022	10:50:01 AM	55.0	199.3	7.00	151.0	7.81	0.35	
5/4/2022	10:55:01 AM	55.0	199.2	7.00	150.3	7.85	0.35	
5/4/2022	11:00:01 AM	55.0	199.2	7.00	149.8	7.86	0.32	0.00
5/4/2022	11:05:01 AM	55.0	199.2	7.01	149.2	7.88	0.29	
5/4/2022	11:10:01 AM	55.0	199.1	7.01	148.7	7.87	0.38	
5/4/2022	11:15:01 AM	55.0	199.0	7.01	148.5	7.86	0.32	0.00
5/4/2022	11:20:01 AM	55.0	199.0	7.02	148.2	7.86	0.35	
5/4/2022	11:25:01 AM	55.0	198.9	7.02	148.2	7.84	0.38	
5/4/2022	11:30:01 AM	55.0	198.9	7.02	148.0	7.84	0.33	0.00
5/4/2022	11:35:01 AM	55.0	198.9	7.02	147.8	7.85	0.32	
5/4/2022	11:40:01 AM	55.0	198.8	7.03	147.6	7.85	0.37	
5/4/2022	11:45:01 AM	55.0	198.7	7.03	147.6	7.82	0.30	0.00
5/4/2022	11:50:01 AM	55.0	198.7	7.03	147.6	7.82	0.32	
5/4/2022	11:55:01 AM	55.0	198.7	7.03	147.7	7.82	0.31	
5/4/2022	12:00:01 PM	55.0	198.6	7.04	147.6	7.81	0.35	0.00
5/4/2022	12:05:01 PM	55.0	198.6	7.04	147.6	7.82	0.30	
5/4/2022	12:10:01 PM	55.0	198.6	7.04	147.9	7.82	0.33	
5/4/2022	12:15:01 PM	55.0	198.5	7.04	148.1	7.79	0.33	0.00

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DATE	TIME	Temp (°F)	Sp Cond (µS/cm)	pH	ORP (mV)	ODO (mg/L)	Turbidity (NTU)	Precipitation (in) NOTE 1
5/4/2022	12:20:01 PM	55.0	198.5	7.04	148.3	7.78	0.33	
5/4/2022	12:25:01 PM	55.0	198.4	7.04	148.3	7.77	0.37	
5/4/2022	12:30:01 PM	54.9	198.4	7.04	148.6	7.75	0.33	0.00
5/4/2022	12:35:01 PM	54.9	198.3	7.04	148.9	7.74	0.44	
5/4/2022	12:40:01 PM	54.9	198.3	7.04	149.3	7.71	0.36	
5/4/2022	12:45:01 PM	54.9	198.3	7.04	149.8	7.67	0.35	0.00
5/4/2022	12:50:01 PM	54.9	198.3	7.04	150.3	7.62	0.41	
5/4/2022	12:55:01 PM	54.9	198.3	7.04	150.8	7.59	0.35	
5/4/2022	1:00:01 PM	54.9	198.2	7.04	151.1	7.58	0.32	0.00
5/4/2022	1:05:01 PM	54.9	198.2	7.04	151.6	7.58	0.27	
5/4/2022	1:10:01 PM	54.9	198.2	7.04	151.8	7.59	0.39	
5/4/2022	1:15:01 PM	54.9	198.1	7.05	151.9	7.62	0.36	0.00
5/4/2022	**1:15:00 PM**	**Boring B-4: End drilling for the day at top of bedrock (53 feet bgs).**						
5/4/2022	1:20:01 PM	54.9	198.1	7.05	152.1	7.62	0.36	
5/4/2022	1:25:01 PM	54.9	198.1	7.05	152.5	7.59	0.32	
5/4/2022	1:30:01 PM	54.9	198.1	7.05	152.7	7.60	0.33	0.00
5/4/2022	1:35:01 PM	54.9	198.1	7.05	153.0	7.57	0.30	
5/4/2022	1:40:01 PM	54.9	198.1	7.05	153.3	7.56	0.34	
5/4/2022	1:45:01 PM	54.9	198.0	7.05	153.2	7.60	0.37	0.00
5/4/2022	1:50:01 PM	54.9	198.0	7.05	153.1	7.64	0.30	
5/4/2022	1:55:01 PM	54.9	198.0	7.05	153.4	7.62	0.29	
5/4/2022	2:00:01 PM	54.9	198.0	7.05	153.8	7.58	0.36	0.00
5/4/2022	2:05:01 PM	54.9	198.0	7.05	154.1	7.54	0.42	
5/4/2022	2:10:01 PM	54.9	198.0	7.05	154.4	7.53	0.32	
5/4/2022	2:15:01 PM	54.9	198.0	7.05	154.6	7.53	0.37	0.00
5/4/2022	2:20:01 PM	54.9	198.0	7.06	154.3	7.57	0.35	
5/4/2022	2:25:01 PM	54.9	197.9	7.06	154.3	7.57	0.34	
5/4/2022	2:30:01 PM	54.9	197.9	7.06	154.6	7.55	0.41	0.00
5/4/2022	2:35:01 PM	54.9	197.9	7.06	154.8	7.54	0.37	
5/4/2022	2:40:01 PM	54.9	197.9	7.06	155.1	7.52	0.36	
5/4/2022	2:45:00 PM	54.9	197.9	7.06	155.5	7.50	0.30	0.00
5/4/2022	2:50:00 PM	54.9	197.9	7.06	155.5	7.49	0.38	
5/4/2022	2:55:00 PM	54.9	197.9	7.06	156.0	7.47	0.32	
5/4/2022	3:00:00 PM	54.8	197.9	7.05	156.6	7.40	0.42	0.00
5/4/2022	3:05:00 PM	54.8	197.9	7.05	157.1	7.39	0.38	
5/4/2022	3:10:00 PM	54.8	197.9	7.05	157.5	7.38	0.43	
5/4/2022	3:15:00 PM	54.8	197.8	7.05	157.8	7.37	0.47	0.00
5/4/2022	3:20:00 PM	54.8	197.5	7.05	158.1	7.38	0.67	
5/4/2022	3:25:00 PM	54.8	197.5	7.06	158.5	7.39	0.55	
5/4/2022	3:30:00 PM	54.8	197.6	7.06	158.9	7.38	0.48	0.11
5/4/2022	3:35:00 PM	54.8	197.7	7.05	159.2	7.39	0.47	
5/4/2022	3:40:00 PM	54.8	197.7	7.05	159.5	7.38	0.32	
5/4/2022	3:45:00 PM	54.8	197.7	7.06	159.7	7.37	0.38	0.09
5/4/2022	3:50:00 PM	54.8	197.7	7.06	160.0	7.36	0.35	
5/4/2022	3:55:00 PM	54.8	197.6	7.06	160.3	7.36	0.35	
5/4/2022	4:00:00 PM	54.8	197.6	7.06	160.4	7.36	0.37	0.06

Round Spring Water Quality Data
Spring Valley GeoTechnical Investigation

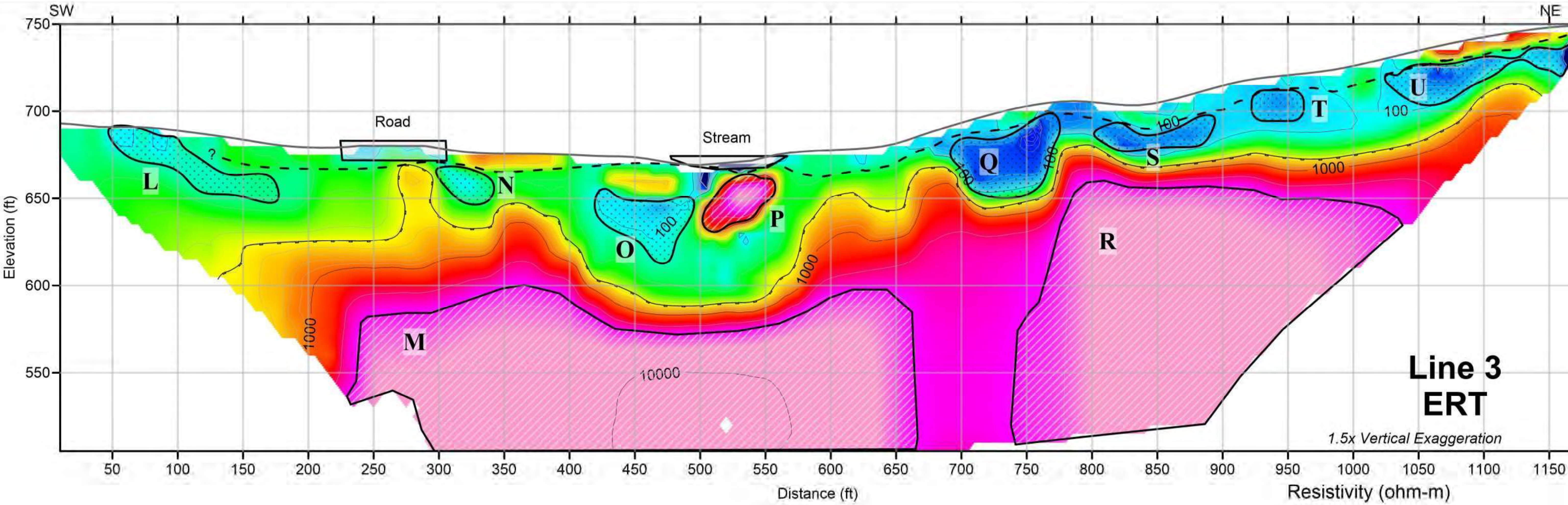
DATE	TIME	Temp (°F)	Sp Cond (µS/cm)	pH	ORP (mV)	ODO (mg/L)	Turbidity (NTU)	Precipitation (in) NOTE 1
5/4/2022: Precipitation through midnight: 0.02 inches.								
5/5/2022: Precipitation from midnight through 09:45 AM: 2.3 inches.								
5/5/2022	9:55:03 AM	54.9	218.2	7.28	138.8	7.60	1.37	
5/5/2022	10:00:03 AM	54.9	213.4	7.09	150.8	7.55	1.26	0.00
5/5/2022	10:05:03 AM	54.9	211.1	7.06	153.6	7.55	1.27	
5/5/2022	10:10:03 AM	54.9	209.6	7.04	155.1	7.57	1.44	
5/5/2022	10:15:03 AM	54.9	208.5	7.01	155.9	7.56	1.35	0.00
5/5/2022	10:20:03 AM	54.9	207.8	6.99	156.3	7.56	1.34	
5/5/2022	10:25:03 AM	54.9	207.2	6.98	156.8	7.54	1.42	
5/5/2022	10:30:03 AM	54.9	206.8	6.96	157.4	7.51	1.36	0.00
5/5/2022	10:35:03 AM	54.9	206.4	6.94	157.9	7.51	1.34	
5/5/2022	10:40:03 AM	54.9	206.1	6.93	158.5	7.49	1.41	
5/5/2022	10:45:03 AM	54.9	205.8	6.92	158.9	7.48	1.47	0.00
5/5/2022	10:50:03 AM	54.9	205.6	6.91	159.1	7.47	1.39	
5/5/2022	10:55:03 AM	54.9	205.3	6.90	159.6	7.46	1.34	
5/5/2022	11:00:03 AM	54.9	205.1	6.89	159.9	7.46	1.45	0.00
5/5/2022	11:05:03 AM	54.9	205.0	6.89	160.2	7.45	1.37	
5/5/2022	11:10:03 AM	54.9	204.8	6.89	160.2	7.46	1.39	
5/5/2022	11:15:03 AM	54.9	204.6	6.88	160.4	7.48	1.37	0.00
5/5/2022	11:20:03 AM	54.9	204.5	6.88	160.2	7.49	1.43	
5/5/2022	11:25:03 AM	54.9	204.4	6.88	160.3	7.48	1.47	
5/5/2022	11:30:03 AM	54.9	204.3	6.88	160.5	7.46	1.48	0.00
5/5/2022	11:35:03 AM	54.9	204.1	6.88	160.7	7.45	1.54	
5/5/2022	11:40:03 AM	54.9	204.0	6.87	161.0	7.44	1.51	
5/5/2022	11:45:03 AM	54.9	203.9	6.88	161.1	7.44	1.43	0.00
5/5/2022	11:50:03 AM	54.9	203.8	6.88	161.2	7.44	1.47	
5/5/2022	11:55:03 AM	54.9	203.7	6.88	161.1	7.46	1.40	
5/5/2022	12:00:03 PM	54.9	203.6	6.88	160.9	7.46	1.51	0.00
5/5/2022	12:05:03 PM	54.9	203.5	6.88	160.8	7.47	1.46	
5/5/2022	12:10:03 PM	54.9	203.5	6.88	160.7	7.47	1.56	
5/5/2022	12:15:03 PM	54.9	203.3	6.89	160.5	7.48	1.41	0.00
5/5/2022	12:20:03 PM	54.9	203.2	6.89	160.4	7.48	1.61	
5/5/2022	12:25:03 PM	54.9	203.1	6.90	160.2	7.47	1.50	
5/5/2022	12:30:03 PM	54.9	203.1	6.90	160.0	7.47	1.57	0.00
5/5/2022	12:35:03 PM	54.9	203.0	6.90	159.9	7.46	1.52	
5/5/2022	**12:40:00 PM**	**Boring B-4: Begin drilling at 53 feet bgs.**						
5/5/2022	12:40:03 PM	54.9	202.9	6.91	159.7	7.47	1.54	
5/5/2022	12:45:03 PM	54.9	202.8	6.91	159.4	7.47	1.56	0.00
5/5/2022	12:50:03 PM	54.9	202.8	6.92	159.1	7.49	1.58	
5/5/2022	12:55:03 PM	54.9	202.7	6.92	158.6	7.50	1.58	
5/5/2022	1:00:03 PM	54.9	202.7	6.93	158.1	7.51	1.58	0.00
5/5/2022	1:05:03 PM	54.9	202.6	6.93	157.5	7.53	1.54	
5/5/2022	1:10:03 PM	54.9	202.6	6.94	157.1	7.53	1.58	
5/5/2022	1:15:02 PM	54.9	202.6	6.94	156.9	7.52	1.65	0.00
5/5/2022	1:20:02 PM	54.9	202.5	6.94	156.5	7.52	1.63	
5/5/2022	1:25:02 PM	54.9	202.5	6.95	156.0	7.54	1.55	

Round Spring Water Quality Data
Spring Valley GeoTechnical Investigation

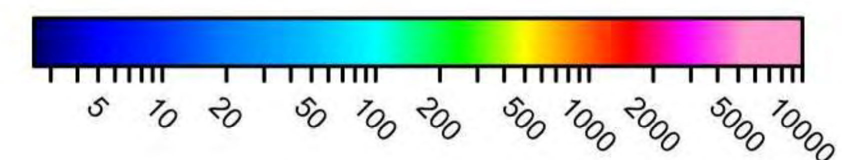
DATE	TIME	Temp (°F)	Sp Cond (µS/cm)	pH	ORP (mV)	ODO (mg/L)	Turbidity (NTU)	Precipitation (in) NOTE 1
5/5/2022	1:30:02 PM	54.9	202.4	6.95	155.9	7.54	1.61	0.00
5/5/2022	1:35:02 PM	54.9	202.4	6.96	155.4	7.54	1.62	
5/5/2022	1:40:02 PM	54.9	202.3	6.96	155.2	7.54	1.82	
5/5/2022	1:45:02 PM	54.9	202.3	6.96	154.9	7.53	1.68	0.00
5/5/2022	1:50:02 PM	54.9	202.3	6.97	154.6	7.53	1.76	
5/5/2022	1:55:02 PM	55.0	202.2	6.97	154.2	7.56	1.72	
5/5/2022	2:00:02 PM	55.0	202.2	6.98	153.5	7.57	1.82	0.00
5/5/2022	**2:00:00 PM**	**Boring B-4: Drilling ended at total depth of 70 feet bgs.**						
5/5/2022	2:05:02 PM	55.0	202.2	6.98	152.4	7.59	1.72	
5/5/2022	2:10:02 PM	55.0	202.2	6.98	152.2	7.57	1.67	
5/5/2022	2:15:02 PM	54.9	202.1	6.99	152.5	7.54	1.73	0.00
5/5/2022	2:20:02 PM	54.9	202.1	6.99	152.6	7.53	1.75	
5/5/2022	2:25:02 PM	55.0	202.1	6.99	152.1	7.55	1.78	
5/5/2022	2:30:02 PM	55.0	202.0	6.99	152.1	7.55	1.76	0.00
5/5/2022	2:35:02 PM	54.9	202.0	7.00	152.1	7.54	1.71	
5/5/2022	2:40:02 PM	54.9	202.0	7.00	152.4	7.53	1.74	
5/5/2022	2:45:02 PM	54.9	201.9	7.00	152.5	7.52	1.84	0.00
5/5/2022	2:50:02 PM	54.9	201.9	7.00	152.5	7.53	1.95	
5/5/2022	2:55:02 PM	54.9	201.9	7.00	152.3	7.53	1.82	
5/5/2022	3:00:02 PM	55.0	201.9	7.01	152.1	7.54	1.85	0.00
5/5/2022	3:05:02 PM	54.9	201.8	7.01	152.3	7.53	1.85	
5/5/2022	3:10:02 PM	54.9	201.8	7.01	152.4	7.52	1.81	
5/5/2022	3:15:02 PM	54.9	201.8	7.01	152.7	7.52	1.85	0.00
5/5/2022	3:20:02 PM	54.9	201.8	7.01	152.6	7.52	1.71	
5/5/2022	3:25:02 PM	54.9	201.7	7.02	152.7	7.52	1.85	
5/5/2022	3:30:02 PM	55.0	201.7	7.02	152.4	7.53	1.88	0.00
5/5/2022	3:35:02 PM	54.9	201.7	7.02	153.0	7.51	1.84	0.00

Note: 1. Precipitation from USGS stream gauge 7066000 Jacks Fork at Eminence, located approximately 10 miles south of Round Sprin

APPENDIX C
Collier Geophysics Survey Lines 3 and 4
From: Collier (2021)



Resistivity (ohm-m)



Legend

A Anomaly Designation

High resistivity anomaly in bedrock
Potential air-filled void

Low resistivity anomaly in bedrock
Potential dissolution feature or residuum

Interpreted Bedrock
Top of Wx (Dashed)
Competent (Ticked)

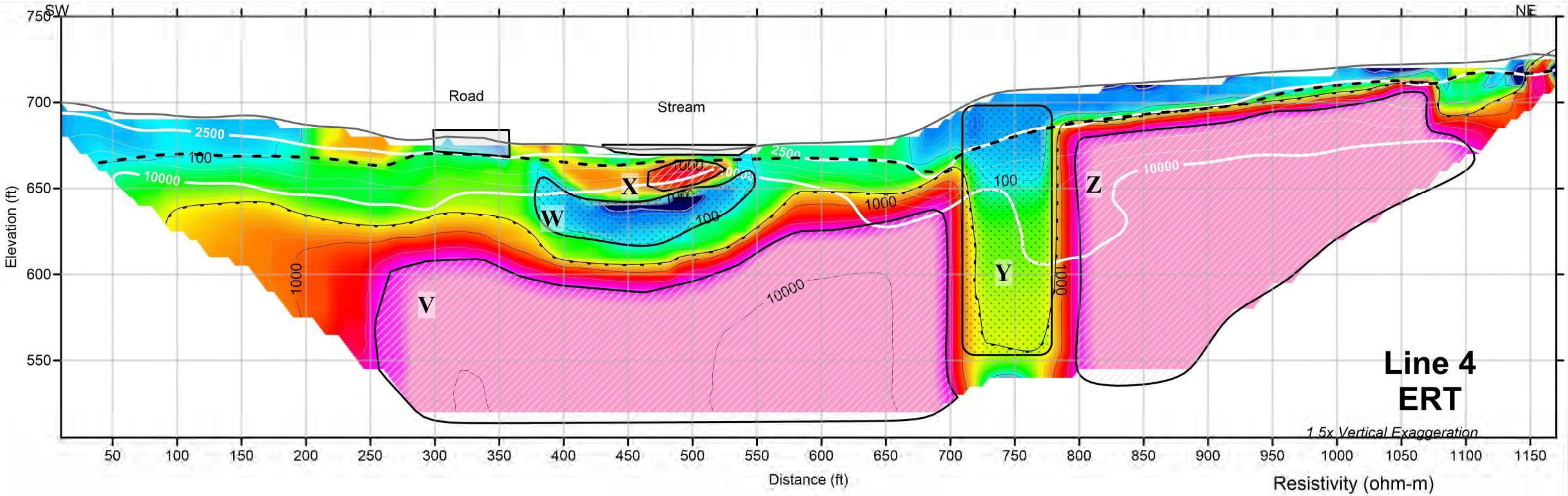
Resistivity Results - Line 3
Round Spring Nat'l Park
Eminence, MO

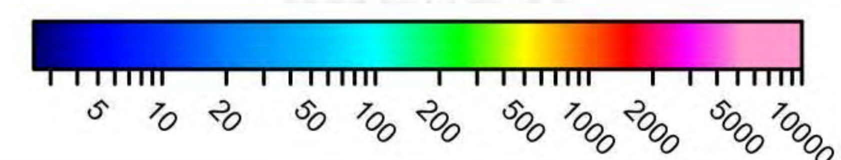
COLLIER GEOPHYSICS

HG Consult Inc.

Project #: 21-146 | **Figure A-3**

Drafted by: T. Ensele | Checked by: N. Pendrigh | December 2021





Legend

A Anomaly Designation

Seismic P-wave Velocity (ft/s) From SRT

High resistivity anomaly in bedrock *Potential air-filled void*

Low resistivity anomaly in bedrock *Potential dissolution feature or residuum*

Interpreted Bedrock
Top of Wx (Dashed)
Competent (Ticked)

Resistivity Results - Line 4
Round Spring Nat'l Park
Eminence, MO

COLLIER GEOPHYSICS

HG Consult Inc.

Project #: 21-146	**Figure A-4**

Drafted by: T. Ensele | Checked by: N. Pendrigh | December 2021

APPENDIX D
Report Limitations and Guidelines for Use

APPENDIX D
REPORT LIMITATIONS AND GUIDELINES FOR USE[1]

This appendix provides information to help you manage your risks with respect to the use of this report.

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

This report has been prepared for the exclusive use of MoDOT, and their authorized agents. This report is not intended for use by others, and the information contained herein is not applicable to other sites.

GeoEngineers structures our services to meet the specific needs of our clients. For example, a geotechnical or geologic study conducted for a civil engineer or architect may not fulfill the needs of a construction contractor or even another civil engineer or architect that are involved in the same project. Similarly, an environmental assessment study conducted for a property owner may not fulfill the needs of a prospective purchaser of the same property. Because each study is unique, each report is unique, prepared solely for the specific client and project site. Our report is prepared for the exclusive use of our Client. No other party may rely on the product of our services unless we agree in advance to such reliance in writing. This is to provide our firm with reasonable protection against open-ended liability claims by third parties with whom there would otherwise be no contractual limits to their actions. Within the limitations of scope, schedule and budget, our services have been executed in accordance with our Agreement with the Client and generally accepted geotechnical practices in this area at the time this report was prepared. This report should not be applied for any purpose or project except the one originally contemplated.

A Geotechnical Engineering or Environmental Report Is Based on a Unique Set of Project-Specific Factors

This report has been prepared for the Missouri Department of Transportation Route 19 Bridges at Round Spring Project, located in Shannon County, Missouri. GeoEngineers considered a number of unique, project-specific factors when establishing the scope of services for this project and report. Unless GeoEngineers specifically indicates otherwise, do not rely on this report if it was:

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

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[1] Developed based on material provided by ASFE/The Best People on Earth, Professional Firms Practicing in the Geosciences; www.asfe.org.

For example, changes that can affect the applicability of this report include those that affect:

- the function of the proposed structures;
- elevation, configuration, location, orientation or weight of the proposed structures;
- composition of the design team; or
- project ownership.

If important changes are made after the date of this report, GeoEngineers should be given the opportunity to review our interpretations and recommendations and provide written modifications or confirmation, as appropriate.

Subsurface Conditions Can Change

This report is based on conditions that existed at the time the study was performed. The findings and conclusions of this report may be affected by the passage of time, by manmade events such as construction on or adjacent to the site, by new releases of hazardous substances, or by natural events such as floods, earthquakes, slope instability or groundwater fluctuations. Always contact GeoEngineers before applying a report to determine if it remains applicable.

Top Soil

For the purposes of this report, we consider topsoil to consist of generally fine-grained soil with an appreciable amount of organic matter, based on visual examination, and to be unsuitable for direct support of the proposed improvements. However, the organic content and other mineralogical and gradational characteristics used to evaluate the suitability of soil for use in landscaping and agricultural purposes were not determined, nor were they considered in our analyses. Therefore, the information and recommendations in this report, and our logs and descriptions, should not be used as a basis for estimating the volume of topsoil available for such purposes.

Most Geotechnical and Environmental Findings Are Professional Opinions

Our interpretations of subsurface conditions are based on field observations and laboratory test results from widely spaced sampling locations at the site. Site exploration identifies subsurface conditions only at those points where subsurface tests are conducted or samples are taken. GeoEngineers reviewed field and laboratory data and then applied our professional judgment to render an opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ, sometimes significantly, from those indicated in this report. Our report, conclusions and interpretations should not be construed as a warranty of the subsurface conditions.

Geotechnical Engineering Report Recommendations Are Not Final

Do not over-rely on the preliminary construction recommendations included in this report. These recommendations are not final, because they were developed principally from GeoEngineers' professional judgment and opinion. GeoEngineers' recommendations can be finalized only by observing actual subsurface conditions revealed during construction. GeoEngineers cannot assume responsibility or liability for this report's recommendations if we do not perform construction observation.

Sufficient monitoring and consultation by GeoEngineers should be provided during construction to confirm that the conditions encountered are consistent with those indicated by the explorations, to provide recommendations for design changes should the conditions revealed during the work differ from those anticipated, and to evaluate whether or not construction activities are completed in accordance with our recommendations. Retaining GeoEngineers for construction observation for this project is the most effective method of managing the risks associated with unanticipated conditions.

A Geotechnical Engineering or Geologic Report Could Be Subject to Misinterpretation

Misinterpretation of this report by other design team members can result in costly problems. You could lower that risk by having GeoEngineers confer with appropriate members of the design team after submitting the report. Also, retain GeoEngineers to review pertinent elements of the design team's plans and specifications. If important changes are made after the date of this report, GeoEngineers should be given the opportunity to review our interpretations and recommendations and provide written modifications or confirmation, as appropriate. Contractors can also misinterpret a geotechnical engineering or geologic report. Reduce that risk by having GeoEngineers participate in pre-bid and preconstruction conferences, and by providing construction observation.

Do Not Redraw the Exploration Logs

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

Give Contractors a Complete Report and Guidance

Some owners and design professionals believe they can make contractors liable for unanticipated subsurface conditions by limiting what they provide for bid preparation. To help prevent costly problems, give contractors the complete geotechnical engineering or geologic report, but preface it with a clearly written letter of transmittal. In that letter, advise contractors that the report was not prepared for purposes of bid development and that the report’s accuracy is limited; encourage them to confer with GeoEngineers and/or to conduct additional study to obtain the specific types of information they need or prefer. A pre-bid conference can also be valuable. Be sure contractors have sufficient time to perform additional study. Only then might an owner be in a position to give contractors the best information available, while requiring them to at least share the financial responsibilities stemming from unanticipated conditions. Further, a contingency for unanticipated conditions should be included in your project budget and schedule.

Contractors Are Responsible for Site Safety on Their Own Construction Projects

Our geotechnical recommendations are not intended to direct the contractor’s procedures, methods, schedule or management of the work site. The contractor is solely responsible for job site safety and for managing construction operations to minimize risks to on-site personnel and to adjacent properties.

Read These Provisions Closely

Some clients, design professionals and contractors may not recognize that the geoscience practices (geotechnical engineering or geology) are far less exact than other engineering and natural science disciplines. This lack of understanding can create unrealistic expectations that could lead to disappointments, claims and disputes. GeoEngineers includes these explanatory “limitations” provisions in our reports to help reduce such risks. Please confer with GeoEngineers if you are unclear how these “Report Limitations and Guidelines for Use” apply to your project or site.

Geotechnical, Geologic and Environmental Reports Should Not Be Interchanged

The equipment, techniques and personnel used to perform an environmental study differ significantly from those used to perform a geotechnical or geologic study and vice versa. For that reason, a geotechnical engineering or geologic report does not usually relate any environmental findings, conclusions or recommendations; e.g., about the likelihood of encountering underground storage tanks or regulated contaminants. Similarly, environmental reports are not used to address geotechnical or geologic concerns regarding a specific project.

ATTACHMENT D

Route 19 Bridges Geophysics Investigation Karst Review Report (Prepared by GeoEngineers Inc., 2021)

Route 19 Bridges Geophysical Investigation
Karst Review

Round Spring Area
Ozark National Scenic Riverways
Shannon County, Missouri

for
HG Consultants

December 21, 2021

GeoEngineers
Earth Science + Technology

Route 19 Bridges Geophysical Investigation
Karst Review

Round Spring Area
Ozark National Scenic Riverways
Shannon County, Missouri

For

HG Consultants
18963 W. 117th Street
Olathe, Kansas 66061

December 21, 2021

GeoEngineers
2155-A Chesterfield Boulevard
Springfield, Missouri 65807
417.831.9700

Route 19 Bridges Geophysical Investigation
Karst Review
Round Spring Area
Ozark National Scenic Riverways
Shannon County, Missouri

File No. 15273-022-00

December 21, 2021

Prepared for:

HG Consult, Inc.
18963 W. 117th Street
Olathe, Kansas 66061

Attention: David Kocour

Prepared by:

GeoEngineers, Inc.
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Shiloh Beeman
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Associate

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GeoEngineers

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LIST OF FIGURES

APPENDICES

1.0 INTRODUCTION

GeoEngineers, Inc. (GeoEngineers) was retained by Hg Consult Inc. (Hg) to assist with karst interpretation of the Round Spring area in support of Hg's environmental assessment activities associated with the Route 19 Bridges Evaluation in the Ozark National Scenic Riverways (ONSR) in Shannon County, Missouri (project site), as shown in the project Vicinity Map (Figure 1). GeoEngineers has conducted background research on the karst and hydrogeologic characteristics of the project site, performed site reconnaissance to inventory potential karst features during the geophysics field work, and has also reviewed the geophysical investigation report completed by Collier Geophysics, Inc (Collier) (Collier 2021). The results of these karst project review activities are included in this report.

2.0 PHYSICAL SETTING

The project area is located north of Eminence in rural Shannon County, Missouri, and within the ONSR, a federal recreation unit managed by the National Park Service (Figure 1). The overall project site extends from approximately 0.25 miles north of the Current River bridge along Route 19 to approximately 0.25 miles south of the Spring Valley Creek bridge and includes 300 feet on either side of Route 19.

2.1. Geology and Hydrogeology

The project site is located within the Salem Plateau sub-province of the Ozark Plateaus physiographic province. The Salem Plateau is underlain by Cambrian and Ordovician Rocks with well-developed karst, numerous caves, and several high-flow springs. The project site is located along Highway 19 north of Eminence, Missouri near a crossing of the Current River, which occupies an entrenched valley underlain by the Upper Cambrian Eminence Dolomite. The topography of the site and prominent karst features are shown in the Site Diagram (Figure 2). The Eminence Dolomite consists of massive to thick bedded light gray dolomite with stringers and nodules of chert throughout (Orndorff and Weary 2009). Uplands and ridge tops are capped by the Gasconade Dolomite, which consists of dolomite, chert, sandstone and orthoquartize, with the Gunter Sandstone found at the base of the formation unconformably overlying the Eminence Dolomite.

Round Spring has an average flow of approximately 26 million gallons per day discharging to the Current River. Round Spring is named for the circular basin in the Eminence Dolomite from which it discharges. Cave formation is common at the base of the Gasconade formation where the Gunter Sandstone contacts the Eminence Dolomite. Round Spring was initially an example of this type of cave formation. The spring, as seen today, formed when the roof of a cave located at the end of the stream valley and within the Gasconade/Eminence contact failed, exposing a roughly circular spring discharge.

As with Round Spring, the main passage of Round Spring Cavern, located approximately 2,500 feet southwest of Round Spring along the Spring Valley Creek, is located below the Gunter Sandstone in the upper Eminence Dolomite. The eastern end of the cave passage crosses the Gunter Sandstone and continues for approximately 300 feet into the lower Gasconade Dolomite.

The Salem Plateau is immediately underlain by the Ozark Aquifer, which is subdivided into Upper and Lower Ozark aquifers by the Everton Formation, which acts as an aquitard. The Ozark Aquifer is 800 to 1,000 feet thick in the northern part of the Salem Plateau and can reach 3,000 feet thick at the Arkansas border. At the project site, the Upper Ozark Aquifer has been weathered away, leaving the Ordovician-aged Lower Gasconade Formation, including the Gunter Sandstone, and the Cambrian-aged Eminence and Potosi Dolomites below to form the Ozark Aquifer. Below the Ozark Aquifer, the Cambrian-aged Derby-Doe Run and Davis Formations form the St. Francis Confining Unit and are underlain by the St. Francois Aquifer consisting of the Cambrian-aged Bonneterre Formation and Lamotte Sandstone.

2.2. Round Spring Recharge Area

The hydrology of the ONSR river system includes a large number of springs, of various sizes and flows, with complex groundwater/surface water interactions. The spring systems on the ONSR have been researched in many historical studies, including groundwater traces that have been used to identify recharge areas for multiple major springs and spring complexes along the Current River.

The Current River Springs Complex is the name given to an undetermined number of springs that discharge in or near the channel of the Current River between the mouth of Sinking Creek located approximately 1.7miles upstream of Round Spring to the mouth of Root Hollow, located approximately 2.7 miles downstream of Round Spring. Historical water tracing data suggest these springs have common or overlapping recharge areas and have not been able to be specifically separated either due to a lack of detailed study, remote locations preventing inaccessibility, location within the Current River channel, or overlapping recharge areas. Round Spring is not considered part of the Current River Springs Complex, although it does share at least some of its recharge area with the Current River Springs Complex.

A recharge area has been identified for Round Spring by Aley and Aley (1987) and modified with additional data in Mugel et al (2009). This recharge area delineation is based upon a limited number of groundwater traces performed as part of larger groundwater investigations on the ONSR going back to the 1970s as well as limited historical flow data. Round Spring and the Current River Springs Complex share at least some their recharge areas. The Round Spring recharge area primarily consists of the lower half of the Spring Valley Creek watershed. The upper half of the Spring Valley Creek watershed is part of the recharge area for Alley Spring, located south of Round Spring on the Jacks Fork tributary to the Current River. A lesser portion of the Round Spring recharge area is shared with Pulltite Spring, located along the Current River upstream of Round Spring. It is noteworthy that although Round Spring is located on the southwest side of the Current River, an additional portion of the recharge area for Round Spring is located north of Round Spring on the northeast side of the Current River. The full extent of Round Spring's recharge area north of the Current River has not been identified.

2.3 Site Reconnaissance

At the request of HG Consult, GeoEngineers performed a field reconnaissance at the project site on August 19, 2021, for the purpose of investigating the area for surface expressions of karst that have the potential to impact, or be impacted by, future bridge construction. Collier was performing the Line 4 ERT survey during GeoEngineers site visit. The project site was viewed by both a walking and driving reconnaissance of the area.

Round Spring is located on the southwest side of the Current River, just upstream of the Spring Valley Creek confluence. The spring discharges from the valley floor at the end of a steep ridge that divides the Spring Valley Creek from the Current River. The spring branch flows approximately 1,200 feet to the southeast and discharges into the Spring Valley Creek immediately upstream of the confluence with the Current River.

The Current River generally flows to the southeast and is fed by a number of Magnitude 1 and Magnitude 2 springs, including Round Spring (Magnitude 2). Spring flow is classified by the following magnitude definitions:

SPRING MAGNITUDES

Magnitude	Flow Range
1	>100 cfs
2	≥ 10 to100 cfs
3	≥ 1 to 10 cfs
4	≥ 100 gpm to 1 cfs
5	≥ 10 to 100 gpm
6	≥ 1 to 10 gpm

Notes: cfs = cubic feet per second
gpm = gallons per minute

In addition to the Magnitude 1 and 2 springs that contribute flow to the Current River, there are an undetermined number of smaller springs (Magnitude 3 and smaller) that discharge along its bank and directly into the river. No additional springs were observed in the project site area during the field reconnaissance.

Spring Valley Creek is a tributary stream to the Current River. Spring Valley Creek flows within a well-developed channel that is relatively deeply incised in a losing stream valley. During the site reconnaissance, small pools of water were observed in some locations within the Spring Valley Creek channel with actual surface flow estimated at 10 gallons per minute or less. In other areas, the Spring Valley Creek channel was dry.

In general, the side slopes and ridgetops appeared to be covered in a mantle of residuum that appeared to vary in thickness across the area. Valley bottoms appeared to have thicker alluvial deposits. Vegetation in much of the study area, including in both the Current River and Spring Valley Creek valley bottoms, was very dense at the time of the site visit.

During the field reconnaissance, the project site was walked to identify potential karst features such as sinkholes, piping holes, springs, seeps, or caves in the project site that had not been previously identified. No sinkholes, piping holes, or cave entrances were identified in the project site that is centered along the highway. No additional springs, seeps, or karst windows were identified along the valleys or base of the ridges. In addition to Spring Valley Creek, two other losing stream valleys cross the project site. Kelly Hollow enters the Current River from the northeast (near the general store/canoe rental business). One other losing stream valley enters the Current River from the southwest between Spring Valley Creek and the Current River. No surface flow was observed in either of these tributary valleys during the field reconnaissance.

3.0 GEOPHYSICAL INVESTIGATION

The area adjacent to Round Spring along the bridge alignment was investigated by Collier using five (5) electrical resistivity tomography (ERT) traverse lines and a seismic refraction tomography (SRT) traverse line (Collier 2021). ERT and SRT have proven to be the useful geophysical methods for subsurface investigations in karst terrain. ERT may be used to define bedrock joints and fractures and the moisture content of earth materials, and SRT determines depth to bedrock and engineering properties of earth materials. A total of 5,310 linear feet of ERT data were acquired along 5 separate lines at Round Spring. Parallel ERT lines were spaced at 50- to 100-foot intervals, and tests were set up to provide good resolution of subsurface features to a depth of 100 feet. The data from each ERT line were processed and interpreted to yield a vertical profile of the subsurface along the traverse. SRT data were acquired along ERT Line 4 primarily to provide top-of-bedrock control.

3.1. Geophysical Investigation Objectives

The geophysical investigation was conducted by Collier to provide additional information regarding subsurface groundwater flow pathways in the vicinity of Highway 19 at Round Spring in order to better understand how to prevent or mitigate potential impacts to the spring during future construction projects. This information can be used to interpret what areas may require special care during construction activities to minimize contamination or impacts to the quality or quantity of water discharging from the spring.

3.2. Interpretations of the Geophysical Data

In general, two types of geophysical resistivity anomalies were identified in Collier's geophysical report (Collier 2021):

- **Low Resistivity Anomalies:** Anomalies designated as A, C, F, G, H, J, L, N, O, Q, S, T, U, W, Y, AA, AB, AC, AE, AF, and AH; and
- **High Resistivity Anomalies:** Anomalies designated as B, D, E, I, K, M, P, R, V, X, Z, AD, AG, and AI.

The following sections provide a more detailed discussion of potential karst features that may be represented by these identified anomalies.

3.2.1. Low Resistivity Anomalies

Figure 2 in this report presents the ERT profiles completed by Collier along with lineaments attributed to solution widened bedrock joints that have potential to carry water into the subsurface. Anomalies designated by Collier as follows may be indicative of solution widened vertical joints that carry water through the unsaturated zone of bedrock into the subsurface to the formational boundary where karst is anticipated to be more developed at this site:

- Line 1: Anomaly C,
- Line 2: Anomalies H and I/J,
- Line 3: Anomalies O/P and Q,
- Line 4: Anomalies W/X and Y, and
- Line 5: Anomalies AE, AF, and AH.

Solution widened joints, when encountered by excavations or drilling, are likely to carry water as well as dissolved and suspended solids into the subsurface and, thus, ultimately to the karst system that feed Round Spring. As such, avoiding intersections with potential vertical pathways when planning excavations and drilling may be one effective strategy for reducing any adverse effects to Round Spring, whether it be water quality or quantity.

Figure 3 illustrates the more common joint trends in the area, as presented in Orndorf and Weary (2009). The more common joint trends have been observed from 0 to 10 degrees west of north to 0 to 10 degrees east of south and from 10 to 20 degrees south of west to 10 to 20 degrees north of east.

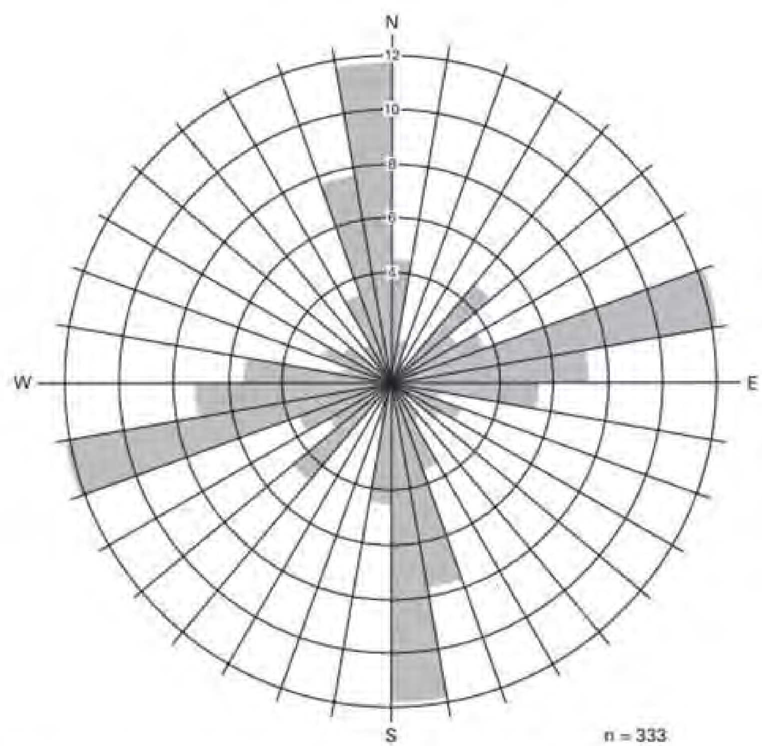

Figure 3. Weighted Joint Orientations of Paleozoic Rocks of the Round Spring Quadrangle from Orndorff and Weary, 2009.

The more dominant joint orientations observed within Round Spring Cave were from 0 to 40 degrees north of east to 0 to 40 degrees south of west, as shown in the Rose Diagram in Figure 4 (Weary and Grant 2014).

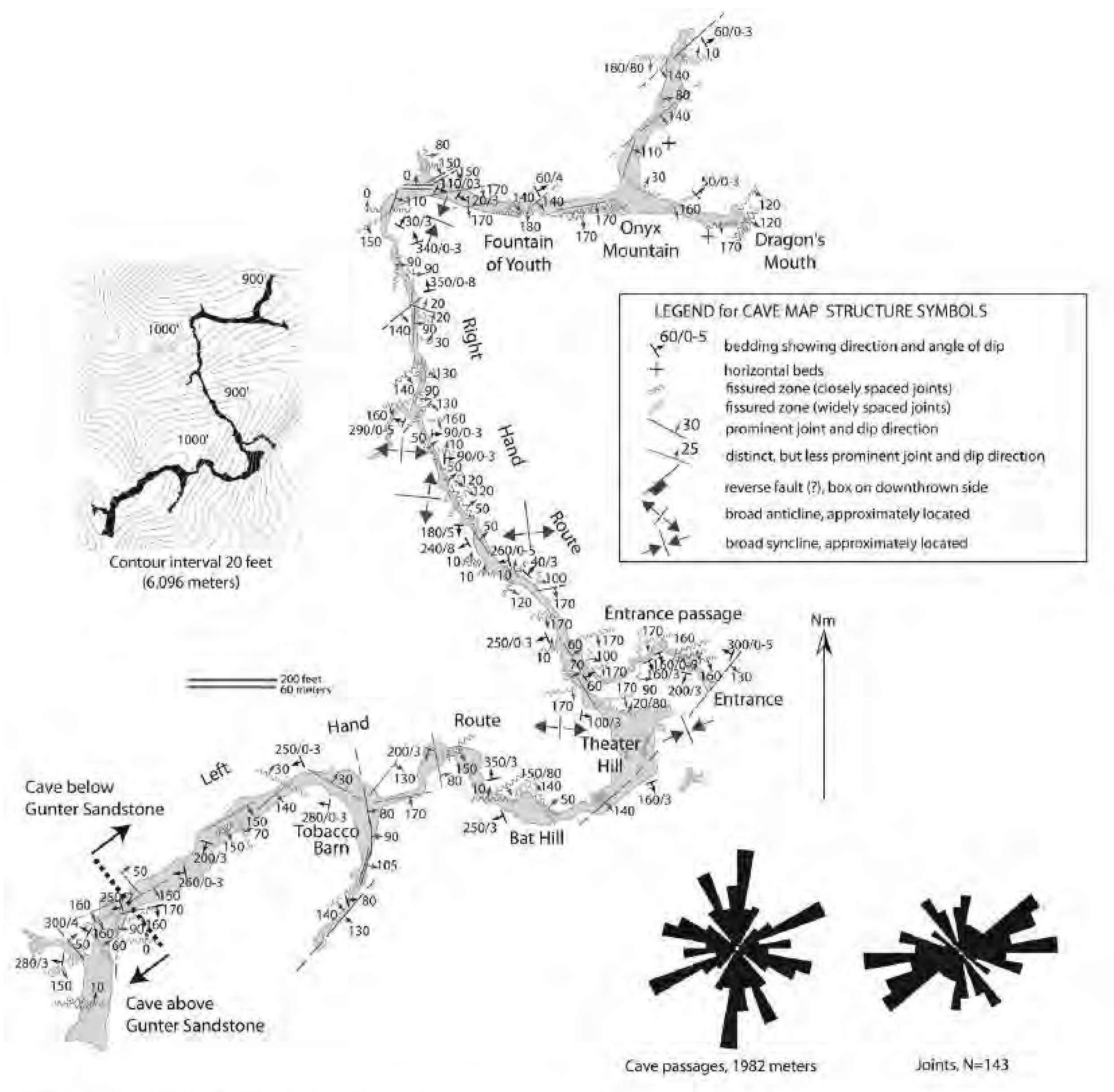

Figure 4. Round Spring Cave Map showing dominant joint orientations from Weary and Grant, 2014.

Based on the Collier geophysical data and illustrated in Figure 2, major joints interpreted crossing Highway 19 in the study area appear to be oriented from 10 degrees north of west to 10 degrees south of east, closely matching the stream valley and topography. In addition, joints interpreted from Collier's geophysical data near Round Spring are oriented approximately 10 degrees south of west to 10 degrees north of east. The ERT data suggests a major joint intersection in the vicinity of Highway 19 southwest of Round Spring. Since the geophysical survey line orientation along the existing highway is oblique to joints oriented roughly north-south (N-S), there may be joints parallel to the geophysical alignments that are less apparent or were not detected.

In addition to the interpreted location of solution widened joints, Anomaly J on Line 2 is potentially indicative of a water-filled void that extends to the west toward Highway 19 from Round Spring.

3.2.2. High Resistivity Anomalies

ERT Lines 3 and 4 display highly resistive features immediately below where the profile crosses the losing stream reach (Anomalies P and X). These anomalies may be indicative of shallow voids but are also a possible indication of gravel and detached boulders in the center of the valley and a groundwater level that is close to the elevation of Round Spring (approximately 670 feet above mean sea level (AMSL)).

Based on geologic and cave mapping, contact between the Gunter Sandstone and Eminence Dolomite is expected at or below elevation 800 feet AMSL in the vicinity of Round Spring. Prominent cave and void features are anticipated near the elevation where solution widening along existing bedrock joints occurred along the major bedding plane represented by the unconformity between the Gunter Sandstone and the Eminence Dolomite. Any well-developed voids within the geophysical survey area are, therefore, anticipated to be near the ground surface where the study resolution is the greatest.

The following anomalies were identified by Collier (2021) as being large in size (200 feet or greater in lateral extent and greater than 50 feet in vertical extent) and exhibiting high resistivity in comparison with the surrounding subsurface:

- Line 1: Anomaly B
- Line 3: Anomalies M and R,
- Line 4: Anomalies V and Z, and
- Line 5: Anomaly AD.

As indicated by Collier (2021), extremely high resistivity signatures can result from air filled voids as well as cohesive, competent rock with near-zero porosity and low saturation. The two possible interpretations of these large anomalies with very high resistivity are drastically different. Considering the well-developed karst associated with nearby Round Spring at an elevation of approximately 670 feet AMSL, it would be unlikely to have a large air-filled void possibly extending across Lines 1, 3, 4, and 5 located at an elevation of 650 feet AMSL and below. However, it is possible that voids that terminate at the spring may extend along the bedding plane at the Gasconade/Eminence formational contact for some distance away from the spring.

Anomaly I on ERT Line 2 is another area of high resistivity. Similar to the anomalies discussed on Lines 1, 3, 4, and 5 above, this area could be a competent bedrock cap over low resistivity Anomaly J, which has been identified as a potentially water-filled conduit extending to the west from Round Spring (Section 3.2.1.). This interpretation is consistent with the competent rock layer visible in the hillside immediately above the Round Spring discharge located to the east of ERT Line 2.

3.2.3. SRT Data

Based on data from the SRT, survey soil thickness ranges from less than 10 to 30 feet below ground surface (bgs). As anticipated, the soil is thickest where bedrock is structurally lowest (natural surface drainage pathways). Solution-widening of joints occurs where moisture has been preferentially migrating into the subsurface over extended periods of time (i.e., beneath natural drainage pathways and along major bedding planes). Top-of-bedrock appears to correlate well between the SRT and ERT survey along Line 4, suggesting that the data is likely of good quality and the ERT iterations chosen by Collier are a good representation of subsurface moisture.

3.3 Limitations of Geophysical Interpretations in Karst

The geophysical techniques employed in this study by Collier are remote sensing techniques and are, therefore, limited by the terrain, complexity of the subsurface geology, data resolution, and ground moisture at the time the study was completed. As such, it should not be used as conclusive evidence that a major karst feature does or does not exist in the vicinity of Round Spring. Given the data provided, it appears unlikely that a major karst void exists in the immediate vicinity of the southernmost bridge adjacent to Round Spring; however, it is possible that the cave system that terminates at the spring may extend along the bedding plane at the Gasconade/Eminence formational contact for some distance away from the spring. Additionally, multiple solution widened joints are potentially interconnected throughout the spring valley and could carry turbidity or contamination if encountered while drilling or excavating to both Round Spring and directly to the Current River.

4.0 RECOMMENDATIONS

Previous research in the study area indicates that karst voids, cave systems, and springs have developed along the horizontal and relatively flat-lying unconformity between the Gunter Sandstone and Eminence Dolomite, with the sandstone forming the roofs of subsurface voids and the voids extending downward into the Eminence Dolomite. In the vicinity of the project site, this unconformity is located at or below 800 feet AMSL and, thus, karst structures related to Round Spring are anticipated to be located at or below that elevation. The discharge pool elevation of Round Spring is located at approximately 670 feet AMSL. Collier's analysis of the geophysical investigation indicates an irregular bedrock surface ranging from 650 to 700 feet AMSL. Based on these data, karst is likely to be more developed in the shallow bedrock near the ground surface in the vicinity of Round Spring.

Vertical karst conduits often develop along solution widened joints that intersect the horizontal plane where karst is more developed, carrying surface water vertically to these horizontal pathways. As such, the locations of several possible vertical joint locations are represented by anomalies in the geophysical investigation (Collier 2021). Excavations or extensive drilling of the shallow subsurface may encounter solution widened vertical joints that could carry turbidity, contaminants, or water down to the horizontal conduits that feed Round Spring.

Although the results of the geophysical survey generated data appears to be of sufficient quality and correlates well between the two methods employed along geophysical survey Line 4, geophysical surveys generate data that is interpretive and not definitive. Additional exploration (ground-truthing) of potential key karst features, such as major solution widened joints that have the potential to impact construction, is warranted. The following recommendations are made related to a subsequent drilling investigation:

- Drilling investigation of future bridge footing locations is warranted to examine the likelihood of intersecting these potential vertical conduits created by karst processes.
- Additional drilling investigation of potential vertical joint locations as highlighted in Figure 2 may also be desirable in order to attempt to quantify to what extent encountering one of these vertical conduits during construction may affect water quality or quantity in Round Spring.
- Extending one or more geotechnical borings at, or near, possible bridge footing locations into one or more of the high resistivity anomalies is recommended to field verify the high resistivity signature in those areas.

The geotechnical study should also attempt to closely constrain the range of elevations at which the transition between the Gunter Sandstone (where present) and Eminence Dolomite are encountered since the plane defined by these elevations represents the anticipated upper surface of major horizontal karst development across the project area. Furthermore, although the geophysical survey conducted by Collier has identified major joint sets in the study area near Round Spring that are interpreted to be solution widened by karst processes, it is highly likely that not all potential groundwater flow pathways to Round Spring in the project site have been identified during this geophysical investigation. To more definitively identify groundwater flow paths to the spring, groundwater tracing can be performed from test borings. The geotechnical design consultant should consider siting at least some boring locations such that they can also be used to investigate the rock quality in the immediate vicinity of areas likely to contain major joints, and these locations could also serve to investigate the hydrologic connectivity of the joints to the Round Spring. Dye tracing could be used during the design phase to estimate travel time and degree of dilution to provide better insight into what protections should be implemented during construction to protect the spring and other karst features found on-site.

Although Round Spring is the significant karst feature in the immediate study area, it also shares a recharge area with other springs in the Current River Spring Complex. This complex of smaller springs also has the potential to discharge sediment disturbed during construction activities and other potential contaminants directly to the Current River. As such, karst buffer zones should be established onsite prior to initiation of construction activities that are likely to disturb soil or discharge water.

The Missouri Department of Natural Resources (MDNR) recommends maintaining a vegetated 100-foot buffer zone surrounding the karst features such as caves, sinkholes and springs with best management practices (BMPs) appropriate for the removal of sediment at that 100-foot buffer distance. The following practices are recommended for karst buffer zones during construction:

- Buffer zones located down slope of construction areas should be physically screened with sediment controls and should be monitored after rain and maintained for the duration of the project. The sediment controls should be removed at the end of the active construction period.
- General application of pesticides, herbicides or fertilizers within the buffer zone should be prohibited to avoid contamination due to over-spray or runoff.
- All buffer zones disturbed by the project should be revegetated immediately following or concurrent with project implementation. Native trees, shrubs, and grasses should be planted to ensure long-term stability in areas where the soil erosion threat is not critical. Annual non-native species should only be planted in conjunction with native species to provide short-term erosion control. Areas judged to be subject to immediate soil loss due to steep slopes or other factors causing critical erosion conditions may be planted with non-native mixtures or covered with erosion control materials or hydroseeded.
- MDNR recommends that post-construction evaluation of vegetation establishment should be conducted at one-month intervals for at least three months after completion of the project. Any recommended sediment controls should be inspected at these times. Proper clean-up of the temporary erosion controls will be necessary.
- Construction debris and waste materials should be stored away from karst areas and outside karst buffer zones.

- Sediment erosion controls appropriate to soil type, water flows, exposure, and other site-specific factors should be implemented during all phases of construction.
- All temporary sediment erosion controls should be removed (unless removal would cause further disturbance) and disposed of within 30 days after final site stabilization is achieved or after temporary practices are no longer needed.
- All debris and excess materials should be removed and properly disposed of upon completion of project.
- Staging areas for sanitation, crew parking, equipment parking, hazardous materials, chemicals, fuels, and lubricating oils should be located sufficiently far from stream banks, sinkholes, springs, caves, or other known karst features to prevent impact to those features in the event of a spill.
- Spills must be cleaned up sufficiently quickly and to a sufficient degree that they are not allowed to impact karst buffer zones.
- Springs should be monitored on an hourly basis during drilling or excavation activities. Furthermore, all activities should be discontinued if an increase in turbidity is detected. Subsequent construction activities should not recommence until the source of the turbidity has been investigated and sufficient measures put in place to prevent further discharge of suspended solids or other impacts to water quality.

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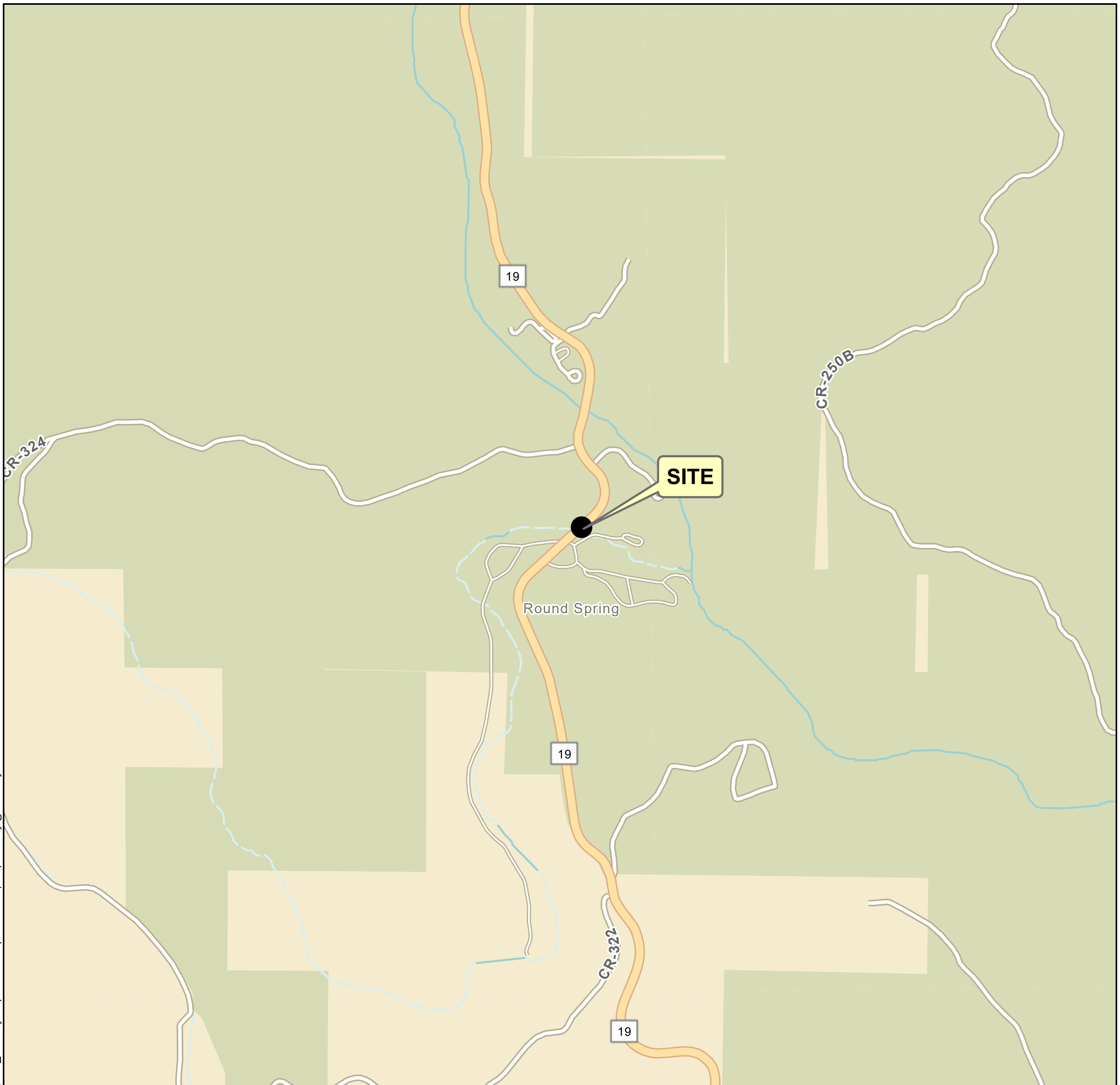
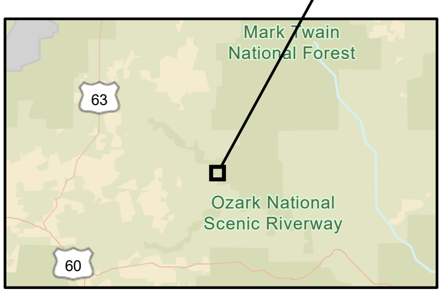
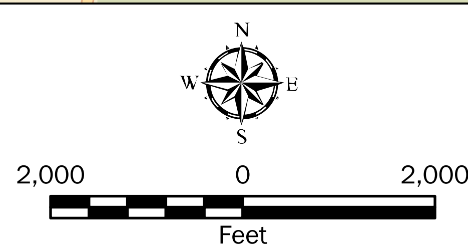
FIGURES







Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: ESRI

Projection: NAD 1983 StatePlane Missouri Central FIPS 2402 Feet

Vicinity Map

Round Spring Geophysical Investigation
Eminence, Missouri

GEOENGINEERS

Figure 1

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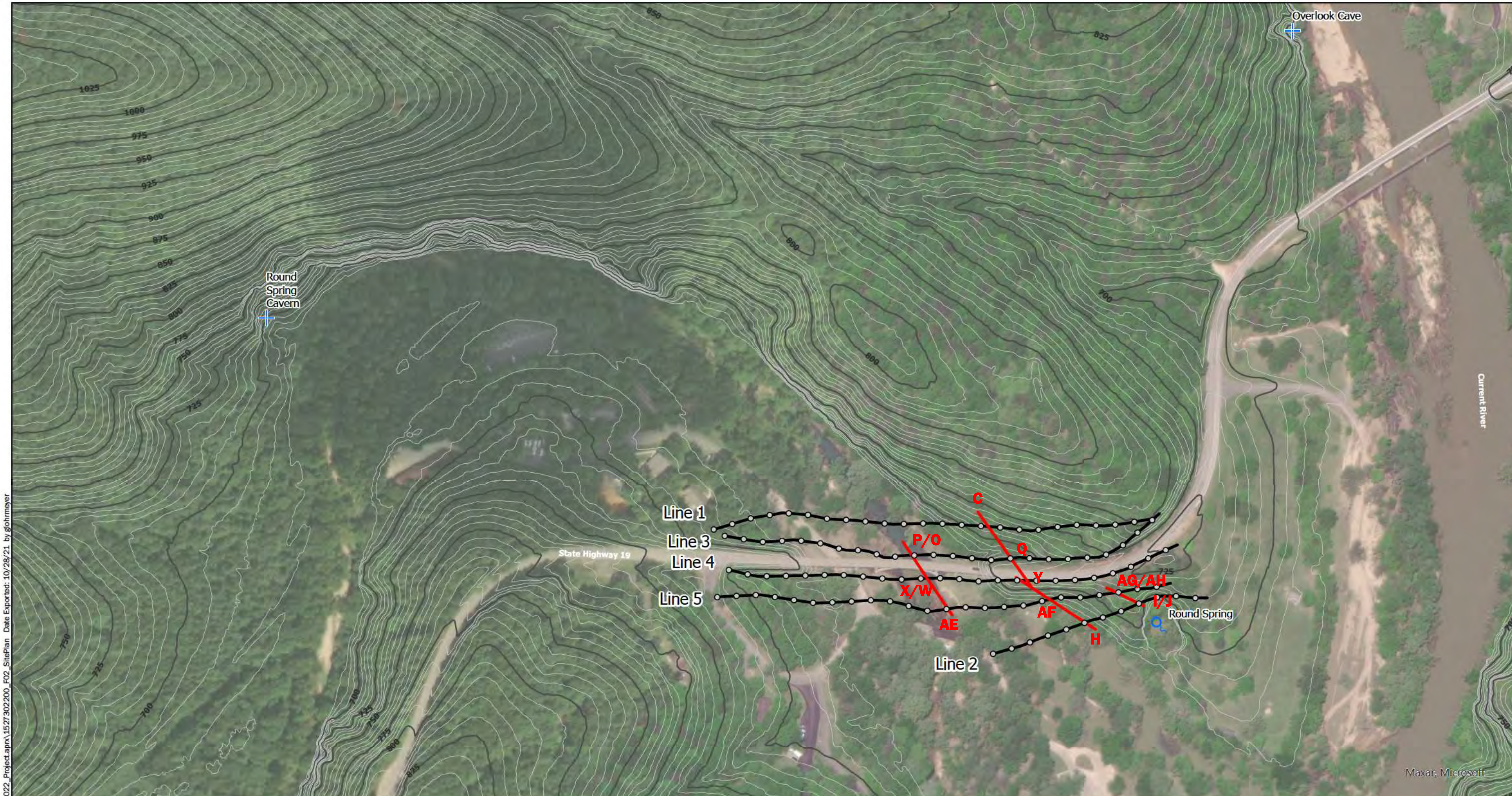

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: Aerial from ESRI. LiDAR from MSDIS 2014.

Projection: NAD 1983 StatePlane Missouri Central FIPS 2402 Feet

Legend

- Cave
- Spring
- Stationing - 50 feet
- Resistivity Line Location
- Interpreted Vertical Join Locations
- 5-Foot Contour
- 25-Foot Contour
- A Anomaly Designation From Collier Report

250 0 250
Feet

Site Plan

Round Spring Geophysical Investigation
Eminence, Missouri

GeoEngineers

Figure 2

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APPENDICES

APPENDIX A
Report Limitations and Guidelines For Use

APPENDIX A
REPORT LIMITATIONS AND GUIDELINES FOR USE[1]

This appendix provides information to help you manage your risks with respect to the use of this report.

Read These Provisions Closely

It is important to recognize that the geoscience practices (geotechnical engineering, geology and environmental science) rely on professional judgment and opinion to a greater extent than other engineering and natural science disciplines, where more precise and/or readily observable data may exist. To help clients better understand how this difference pertains to our services, GeoEngineers includes the following explanatory "limitations" provisions in its reports. Please confer with GeoEngineers if you need to know more how these "Report Limitations and Guidelines for Use" apply to your project or site.

Report Use and Reliance

This report has been prepared for HG Consultants and the Missouri Department of Transportation (MODOT). The report is not intended for use by others, and the information contained herein is not applicable to other projects or properties. No party or parties other than those named above may rely on the product of our services unless we agree to such reliance in advance and in writing. The purpose of this limitation is to provide our firm with reasonable protection against open-ended liability claims by third parties with whom there would otherwise be no contractual limits to their actions.

This report is intended to be used only for the specific purpose or project originally contemplated for our services and use of this report is not recommended for any other purpose or project. The data was developed and compiled for this project only, and no representation or warranty is made, either express or implied. GeoEngineers shall not be responsible for any alterations, modifications or additions to the data herein or the consequences of any interpretations of the data. Any use of the data, including any conclusion or information obtained or derived from the use of the data, other than by HG Consultants and MODOT, their authorized agents and regulatory agencies for the specific purpose or project originally contemplated for our services will be at the user's sole risk.

If changes are made to the project or property after the date of the report, we recommend that GeoEngineers be given the opportunity to review the data, and then we can provide written modifications or confirmation, as appropriate.

Information Provided by Others

GeoEngineers makes no warranties or guarantees regarding the accuracy or completeness of data provided or compiled by others and shall not be responsible for user's interpretation of such data.

1 Developed based on material provided by GBA, GeoProfessional Business Association; www.geoprofessional.org.

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ATTACHMENT E

Geophysics Letter Report (Prepared by Collier Geophysics, LLC, 2021)

COLLIER
GEOPHYSICS
Surface • Marine • Borehole

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December 14, 2021

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RE: Geophysical Letter Report | Project # 21-146
Round Spring National Park, Eminence, MO

Collier Geophysics, LLC (Collier) conducted a geophysical survey beneath the Missouri State Route 19 bridge over Spring Valley within Round Spring National Park located in Shannon County in southeast Missouri. The investigation was performed for Hg Consult, Inc. (HG) in support of a future replacement bridge design and construction project. The bridge is located approximately 11 miles north of Eminence, Missouri along Route 19 (**Figure 1**). The objective of the geophysical survey is to evaluate the area around the existing bridge and Round Spring to provide a more complete understanding of the geologic and hydrological setting as it relates to the flow of groundwater at the Round Spring. Specific geophysical objectives include: 1) to identify the top of bedrock; and 2) to interpret voids or dissolution widened joints in the karstic limestone underlying the bridge foundation. In order to meet the survey objects, the geophysical survey included electrical resistivity tomography (ERT) and seismic refraction tomography (SRT).

Field data acquisition was performed over five days from August 16th through 20th, 2021, led by Collier senior geophysicist Trever Ensele. The following report summarizes the site conditions, field methods, data acquisition, and interpretation procedures.

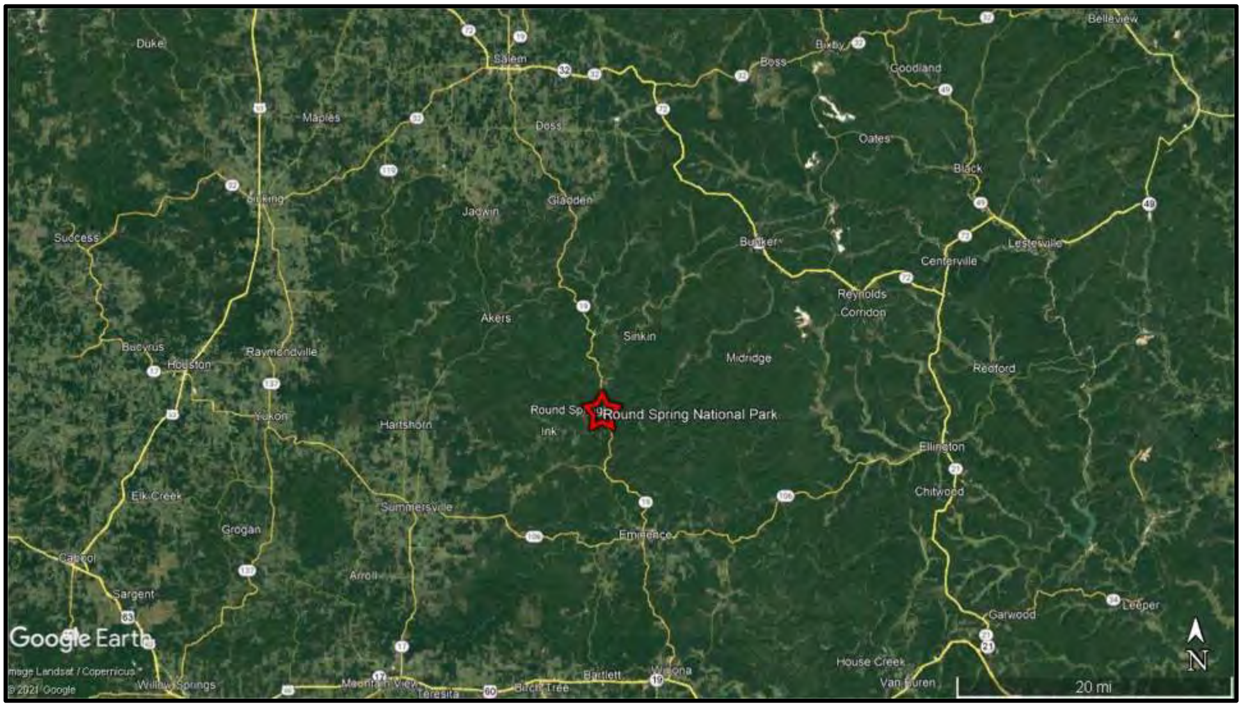


Figure 1: Site location shown by red star (*Imagery source: Google Maps 2021)*

Site Description

The investigation site covered approximately 7 acres parallel to and beneath the Spring Valley bridge. The site is a steep-sided, heavily forested valley with a stream at the bottom. Site access was provided from the paved Round Spring National Park service road, which runs beneath the Spring Valley bridge. Vegetation was extremely heavy, requiring path clearing with hand tools to obtain access along the proposed profile lines. Five of the six geophysical lines acquired at the site crossed the stream. The water in the stream was stagnant, but clear, with depths from zero (dry) to twenty-four inches. Some infrastructure elements from the park were noted in the field, including culverts, water pipelines, and electrical service but impact on the geophysical data was minimal. Visitors to the park were very few and did not impact geophysical surveying activities. The dense broadleaf forest has multiple dense canopies and impacted GPS surveying techniques used to position the geophysical sensors and lines. Weather was warm and muggy with occasional thunderstorms and heavy rain.

Site geology consists of horizontally bedded karstic limestone with thin soil cover. On steeper slopes some bedrock outcrops at the surface.

Figure 2: Photos showing site conditions encountered during the survey.

Data Acquisition

Five (5) ERT and one (1) SRT lines were collected parallel to and beneath the Spring Creek bridge within the area of interest (**Figure 3**). The geophysical lines locations were determined by HG in collaboration with Collier and the Missouri Department of Transportation (MODOT). The orientation and position of some lines were adjusted in the field to fit within the physical limitations of the site. The geophysical lines were numbered sequentially in the order they were acquired. The one SRT line was acquired coincident with ERT Line 4.

Figure 3: Overview of project area with geophysical (ERT) lines (orange) and approximate area of interest for the investigation (shaded red). The SRT line was collected along the Line 4 profile.

Electrical Resistivity Tomography (ERT)

The electrical resistivity tomography (ERT) method is used to characterize subsurface lithology and/or materials in terms of electrical resistance. The electrical resistivity method incorporates the injection of an electrical current into the ground through a pair of electrodes (current electrodes) while simultaneously measuring the potential, or voltage, between an offset electrode pair (potential electrodes) in contact with the ground. The subsurface resistance, or apparent resistivity, is then calculated from the measured voltages and electrode geometry.

The apparent resistivity (**ρ**) represents the bulk resistance of earth materials where the majority of injected current flows. The geometry between two current electrodes and two potential electrodes define an array. The distance between the potential electrodes is directly related to resistivity measurements with depth. The amount of current injected and distance between the current electrodes determines the depth potential, i.e., larger spacing forces more available current to flow at larger depth values.

IRIS Syscal Pro-96 10-channel resistivity meter.

The ERT survey was performed using an IRIS Instruments Syscal Pro-96 10-channel multiple electrode resistivity imaging system (the Syscal, *inset photo, right*). The survey equipment consists of a transmitter/receiver, an internal switch and cables capable of utilizing up to 96-takeouts for electrodes. Electroes were spaced every 10 feet for a static array length of 950 feet. Longer lines were acquired by "rolling-along" 48 electrodes, or half of the array, to the end of the first static array for a continuous subsurface measurement. The electrode positions were measured with a Trimble Geo7x, a handheld differential grade global positioning system (GPS) unit capable of sub-meter accuracy. Due to poor satellite coverage and poor position precisions in the heavy canopy cover, LIDAR point data provided by HG and USGS Digital Elevation Model (DEM) data were used to correct topographic heights, and lateral positions were filtered and interpolated to reduce the positioning errors.

Optimum array geometry was determined by satisfying four requirements: time efficiency, data quality, vertical/horizontal resolution capacities, and desired investigative depth. The ERT survey utilized the dipole-dipole array (see inset image below), which is most sensitive to lateral changes in resistivity and can achieve a maximum depth of investigation of about one-fifth of the total electrode array length The electrode spread geometry was controlled by the transmitter switching system of the resistivity meter. Multiple measurements were made along the line to sample the lateral and vertical changes in subsurface resistivity. Electrodes were placed every 10 feet on all ERT Lines. ERT line lengths varied including:

ERT Line 1: 1,150 feet

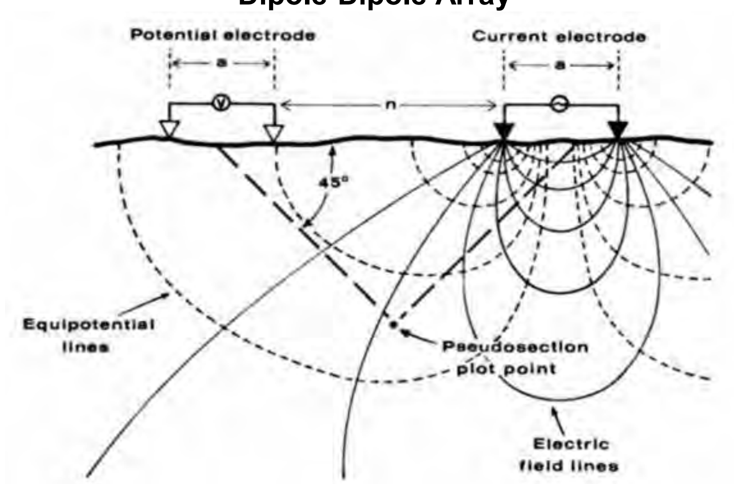
ERT Line 2: 590 feet

ERT Line 3: 1,190 feet

ERT Line 4: 1,190 feet

ERT Line 5: 1,190 feet

Dipole-Dipole Array



The total line length collected for ERT was 5,310 feet.

ERT lines were marked out using a tape measure to locate each electrode position. A small shallow hole was dug at each electrode location, a stainless steel electrode was driven in the ground in the hole and the hole was filled with salt water to reduce electrode contact resistance with the surface soils. Contact resistance was checked prior to data collection for each line and any electrode with high contact resistance were checked and re-watered, then contact resistance was re-checked. Measured contact resistance on most electrodes on each line was less than 1 kOhm.

ERT data acquisition parameters included a pre-built acquisition sequence uploaded to the Syscal Pro meter using a dipole-dipole array with varying “a” and “n” spacings to take full advantage the 10 recording channels and the automated switching capability of the instrument.

Seismic Refraction Tomography

The Seismic Refraction Tomography Method (SRT) is used to measure the P-wave velocity (Vp) distribution of the subsurface to evaluate the thickness of overburden soils and the competency of the bedrock. Seismic energy traveling within the ground as body waves will refract (**Figure 4**) at velocity boundaries and seek a higher velocity path if velocities increase with depth. These interfaces and pathways where seismic waves refract correlate with real physical / geologic boundaries in the ground, such as geo-mechanical boundaries, and velocity gradients are often observed in soils due to overburden loading and compaction effects. Velocity gradients are also observed at weathered bedrock to competent bedrock transitions. The SRT method records the arrival times of refracted waves returning to the ground surface at geophones as they travel away from a seismic source. These refracted-wave arrival times are then used to computationally determine, using the process of geophysical inversion, both lateral and vertical changes in compressional-wave velocity field beneath a survey area.

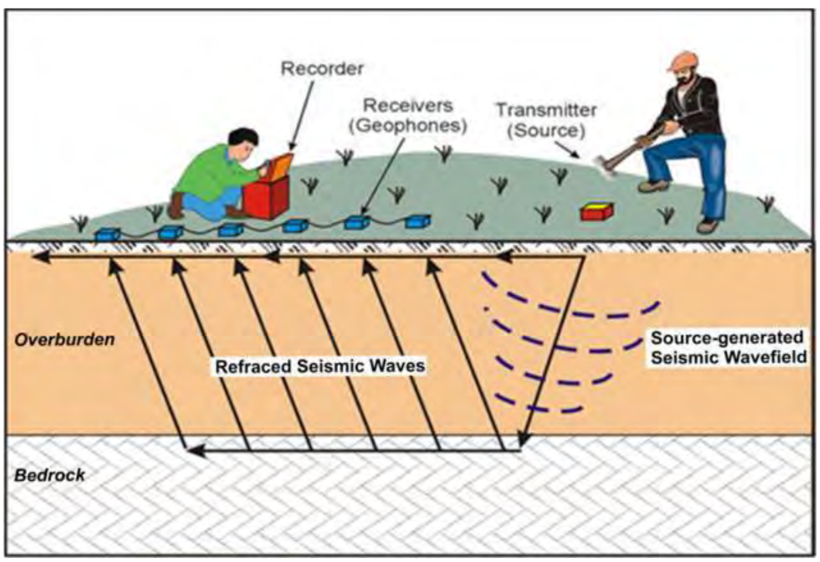


Figure 4: Schematic illustration of typical SRT field instrumentation, setup, and data recording.

Seismic data were acquired using two Geometrics Geode 24-channel digital seismographs. This system utilizes a 24 bit A/D seismograph connected to a field laptop via an ethernet cable. Analog data from the geophones are collected in the seismograph where the data are digitized, transmitted to the laptop computer, and recorded on the internal hard drive *(inset photo, below)*. Acquisition parameters of the seismic system for the SRT survey comprised of stacked 2-second records at a 0.125 millisecond (ms) sample rate.

The SRT data were acquired using an active seismic source which consisted of a 16-lb sledgehammer and strike plate. Forty-eight active channels spaced 10 feet apart were set up, for a total static array length of 470 feet. At each source point, hammer blows were repeated and records were stacked to improve signal-to-noise ratio. Source points were located every 30 feet along the line, with additional off-end source locations 30 ft and 10 ft from the beginning and end of the line, respectively. The geophone positions were measured with a Trimble Geo7x, a handheld differential grade global positioning system (GPS) unit capable of sub-meter accuracy. As with the ERT lines, positions were corrected for topography using LIDAR point data provided by HG and USGS DEM data, and filtered and interpolated to reduce position error along the profile. To achieve the total line-length of 1,190 feet, half of the geophone array was "rolled-along" to the end of the initial array to acquire continuous subsurface data along the profile.

Geometrics Geode 24-Channel Digital Seismograph

Data Processing

Electrical Resistivity Tomography (ERT)

Resistivity data were downloaded from the Syscal and processed and filtered for analysis using Prosys III, version 1.05.02, by IRIS Instruments. Data are filtered by removing negative and erroneously high apparent resistivity values from each dataset. Moving average filters are then applied to remove spikes and smooth noisy data. The processed data were then imported to Res2DInvx64, version 4.05, for geophysical inversion modeling.

The inversion starts with a static depth versus resistivity model based on the average apparent resistivity of the measured data. Then a calculated apparent resistivity 'pseudo–section' is generated using the parameters of the survey and the apparent resistivity values recorded. This section is compared to the measured section, creating a difference matrix which is used to perturb the initial model toward a better fit with the measured data. This process repeats until the best fit is achieved, defined by the minimum difference between measured and calculated apparent resistivity values. **Figure 5** shows an example of the three components of the inverse modeling process: from top to bottom; the measured data, the calculated data, and the inverted subsurface model. Multiple models are generated subject to different parametric smoothing constraints to achieve the best fit model to the measured data, ground truth, and known geologic conditions.

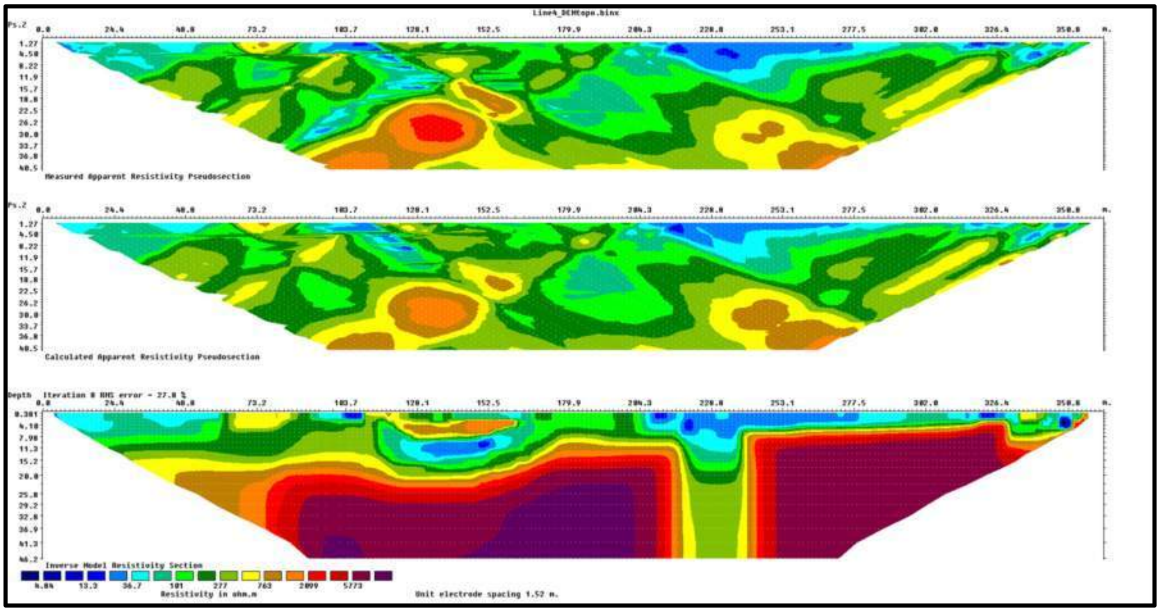


Figure 5: From top to bottom: measured apparent resistivity (i.e., pseudo-section), calculated (i.e., forward model) apparent resistivity, and inverse modeled (i.e., earth model) resistivity section, from data obtained for Line 3 from this investigation.

An important measure of data quality is the Root Mean Square (RMS) between the calculated and measured apparent resistivity sections. A lower RMS error, for example below 10%, is usually considered a stable 2D resistivity model result with good convergence. The RMS error characterizes the fit of all modeled data points, with a perfect fit represented by 0% RMS error. The histogram in **Figure 6** illustrates distribution of percent error between calculated and measured apparent resistivity values from the inverted model on Line 4. 78% of calculated apparent resistivity values fall within 10% error after inversion. This model for 2D ERT results has good convergence, but a relatively high overall RMS error of 27%. Due to the very high apparent resistivity values presented by some of the subsurface targets (such as the potential for air-filled voids) resulting in anomalously high resistivity values and runaway model conditions, models were constrained during inversion by limiting high resistivity values and utilizing high damping factors to produce smooth subsurface models, which resulted in higher RMS error than normal. Multiple iterations of inversion modeling parameters were performed and compared to decide which parameters produced models with the best fit to the measured data, minimized noise, and conformed to a representative expected geologic model for the site under investigation.

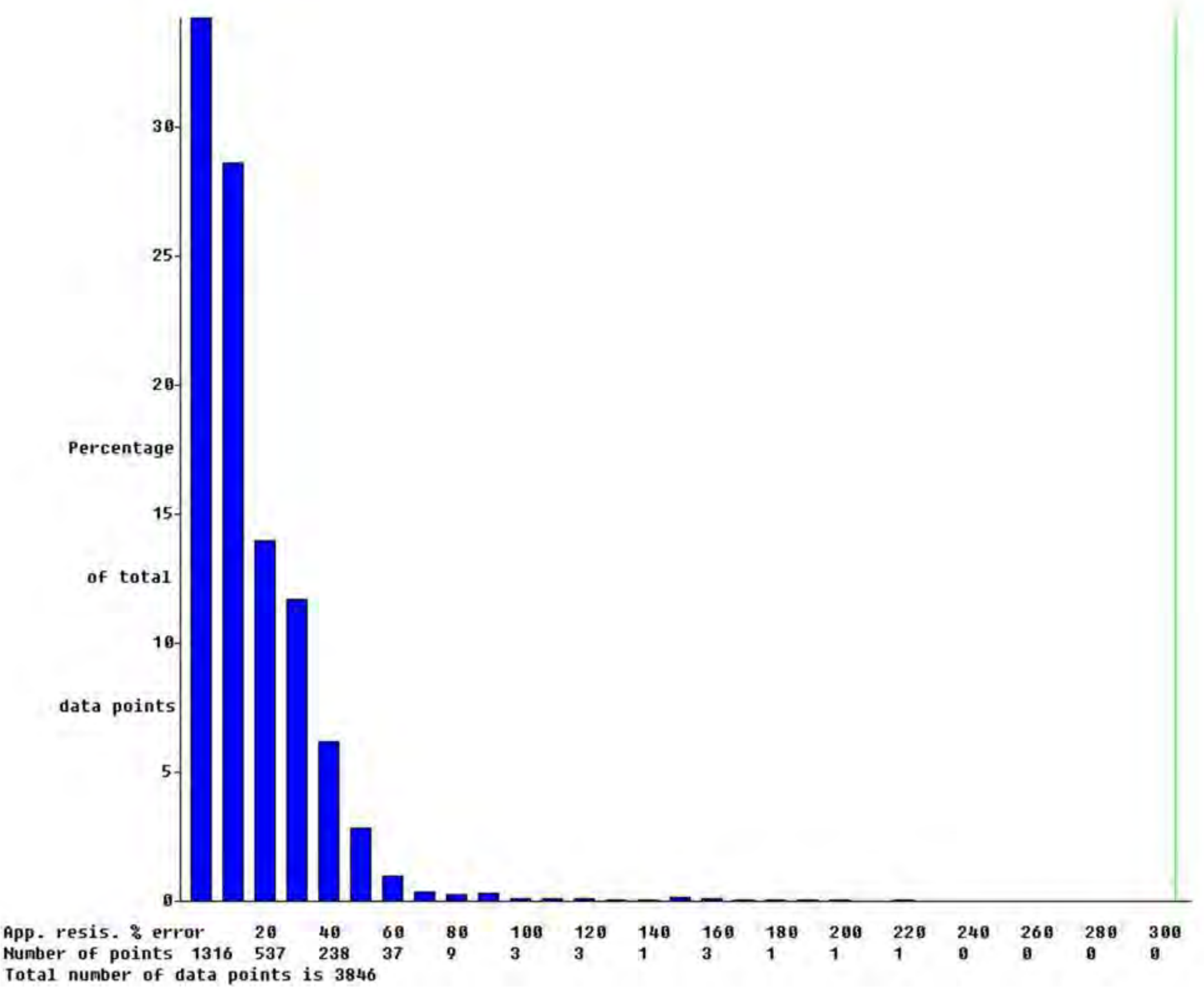


Figure 6: Histogram of percent difference between calculated and measured apparent resistivity values from the inversion process for Line 4. 78% of all calculated data fall within 10% difference with the

Seismic Refraction Tomography (SRT)

Refraction data from this investigation were processed using Rayfract®, version 4.01, by Intelligent Resources, Inc. The two main processing steps involved with SRT processing are first arrival picking and tomographic inversion. The first arrival picking step consists of picking the time for each signal trace where the onset of the first-arrival energy is observed at each geophone position for each shot record. **Figure 7** illustrates the picking approach used, with an example from this survey. After picking is completed, data inversion is performed by generating a 2D P-wave velocity (Vp) model that best fits the arrival picks by iteratively modifying an initial velocity grid model until the misfit between the modeled and measured travel-time values is minimized, subject to smoothing constraints.

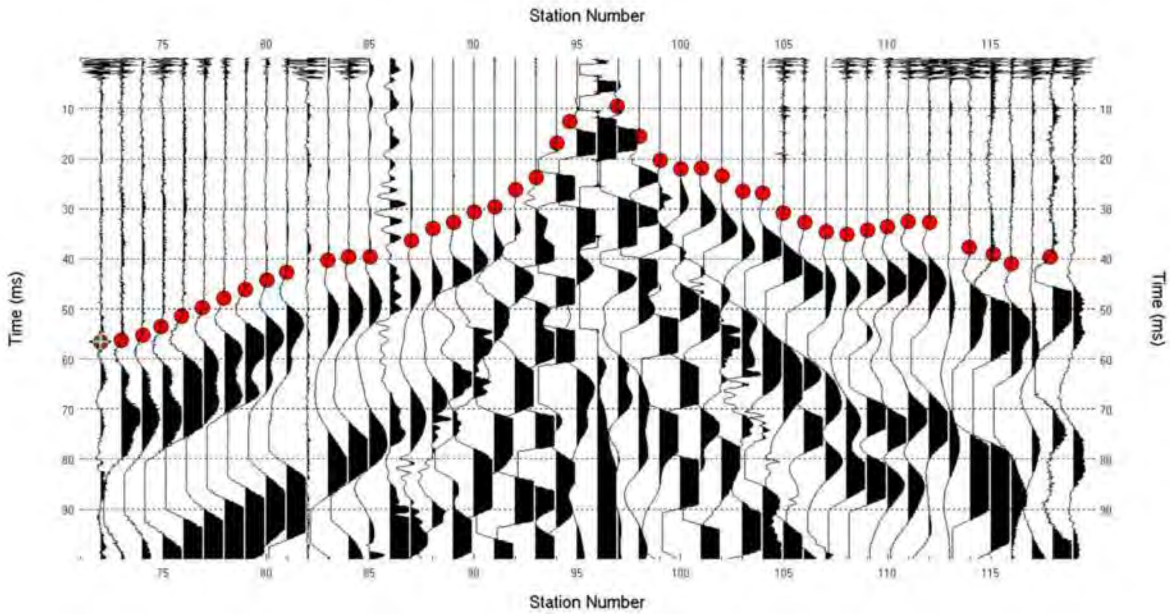


Figure 7: Example of first arrival picks (red circles) on a sample seismic record from this survey.

Results and Discussion

Results of the ERT and Seismic investigation are appended to this report and presented in 11 by 17 inch landscape format. **Figures A-1 through A-5** present the results of the ERT Lines 1 through 5. **Figure A-6** presents the results of the SRT survey along Line 4. The figures include an aerial overview of each line section with station distances. The results are presented as 2-dimensional color-mapped resistivity versus depth profiles (ERT result); and, p-wave velocity (Vp) versus depth model (SRT result), with hot colors (reds) representing high resistivity and velocity values, and cool colors (blues) representing low resistivity and velocity and values.

Review of Objectives

The objectives of the investigation are: 1) to identify the top of bedrock; and 2) to interpret potential voids or dissolution widened joints in the karstic limestone underlying the bridge foundation.

The generalized site geology consists of a thin overburden soil overlying karstic limestone bedrock. Both Vp and resistivity values are expected to increase in the bedrock materials. Two anomalous resistivity conditions are expected to exist within the limestone: air-filled dissolution voids which are expected to exhibit extremely high anomalous resistivity values (>> 1000 ohm-m); and clay mineralization, or dissolution residuum, which may be present in fractures and other fluid flow-paths within the limestone where hydrologic conditions are promoting active dissolution of the bedrock, which are expected to be represented by reduced resistivity value anomalies within the bedrock.

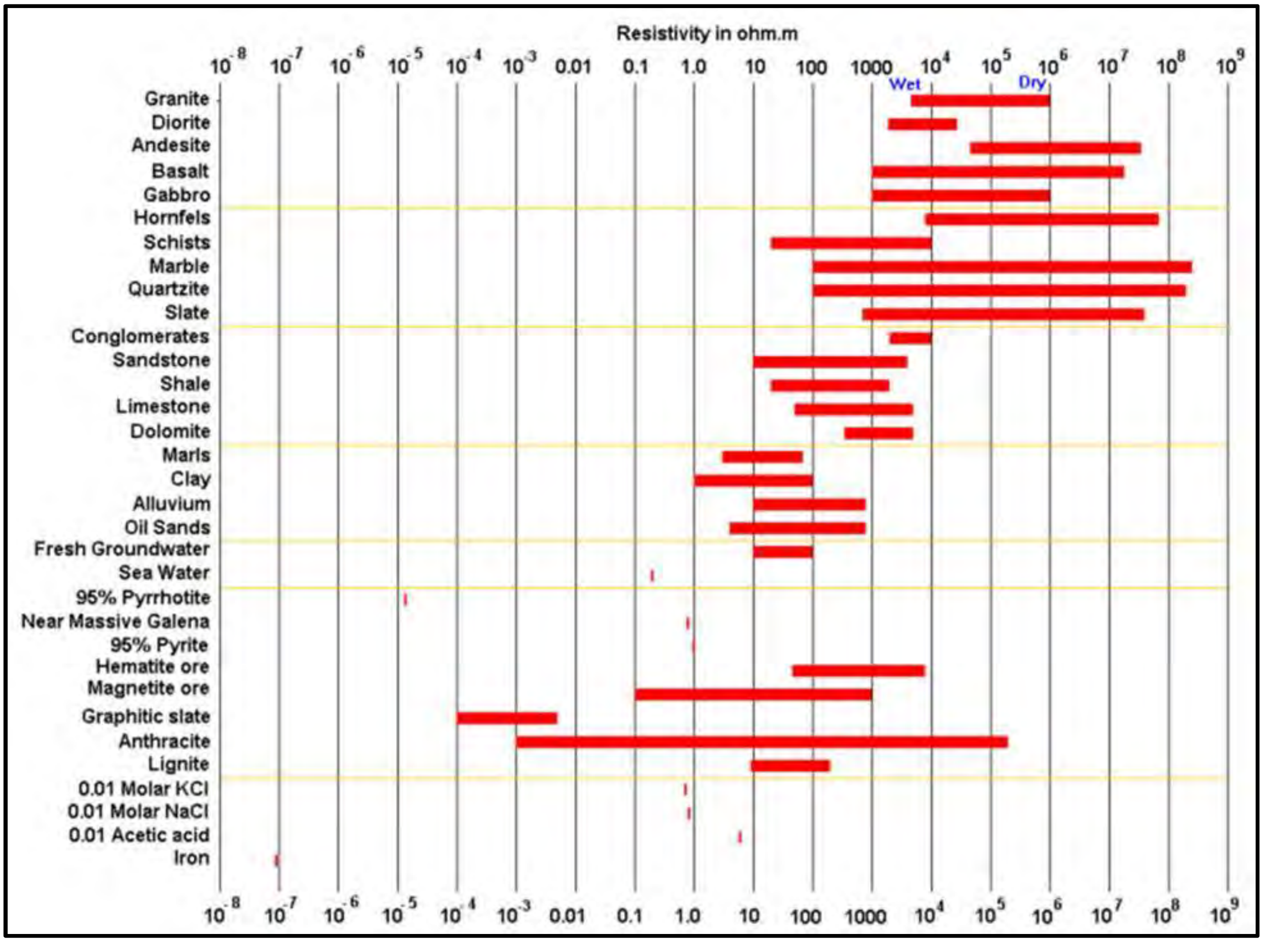
Bedrock Interpretation

A general overview of the ERT earth models is interpreted to show a thin (< 10 ft) overburden layer with resistivity values ranging from 5 to 300 ohm-m, an upper weathered bedrock layer ranging from 100 to 500 ohm-m, and a consolidated or competent bedrock layer with resistivity values greater than 500 ohm-m. The modeled resistivity values across the site range from about 1 Ohm-m to 10,000 Ohm-m. Due to the apparent overlap in resistivity values between the overburden and bedrock materials, resistivity values alone were not sufficient to constrain a bedrock contact interpretation.

Seismic velocity values from the SRT profile for Line 4 on **Figure A-6** were used to interpret the transition from unconsolidated to competent material at the bedrock interface and correlate with the ERT results. A contour representing **2,500** ft/s Vp overlain on the ERT results on **Figure A-4** loosely correlates with a transition in the ERT results from vertical contour lines (primarily lateral variations in resistivity) to horizontal contour lines (primarily vertical variation in contour lines). There is not a clear transition in resistivity **values** at the interpreted contact, but rather a transition in **character**. This is used to interpret the upper bedrock contact on all the ERT profiles. Due to the low Vp value, it is interpreted as a contact with weathered bedrock, and displayed as a dashed black line on the ERT results. The Vp values from Line 4 show a very high gradient, increasing to 10,000 ft/s within about 25 feet depth of the 2,500 ft/s contour. This strongly supports a bedrock condition within this velocity value interval (from 2,500 to 10,000 ft/s), and variations in the actual bedrock contact versus the interpreted contact are expected to fall within this range.

Karstic conditions in the bedrock, specifically the potential for air filled voids, present difficulties using the SRT results to evaluate conditions below the bedrock contact. For example, SRT is not sensitive to velocity inversion, such as competent bedrock bridging over an air filled void, and instead would model such condition as the highest velocity material transited by the refracted wave, such as through the bedrock located above a void. **Table 1** gives expected resistivity values for a variety of rock and ore types. Competent limestone is expected to have resistivity values from 100 to 1000 ohm-m, depending on degrees of saturation, permeability, and cohesion. A steep gradient in resistivity values around the 500 ohm-m contour on all ERT sections is interpreted to represent a transition from weathered bedrock to competent bedrock, and are shown on the figures with a ticked solid line. This is subjective and is intended to represent the clear change in character of the resistivity model at this transition and not necessarily rock competency. In fact, the correlation of resistivity to rock competency is fairly weak, so we consider the two interpreted “contacts” to be the upper and lower bounds for probable bedrock transition. This geo-electrical transition will be influenced by other factors than rock competency, such as degree of saturation, fracturing, or weathering. The interpretation given is based on expected subsurface conditions, but ground truth provided by boring or other in situ testing method is strongly suggested to constrain the geophysical interpretation.

Table 1. Resistivity of Rocks, Soils and Minerals (Loke, 2015).



Interpretation of Anomalies

Two anomalous conditions are expected, extremely high resistivity values due to potentially air-filled voids or caves in the karstic bedrock, and low resistivity values within the bedrock due to some groundwater condition with elevated hydraulic conductivity or elevated solutes which may reduce electrical resistivity. The exact characteristic of the subsurface materials which influences each anomaly identified in the ERT sections is unknown, as such the interpretation is constrained to two conditions. Anomalies are assigned an alphabetical designation from A to AI, notated on the resistivity figures, and detailed in **Table 2**, in **Appendix A**. Each resistivity anomaly is defined by its extent in station distance and depths, and by which anomaly condition is indicated (low or high resistivity). **Figure 8** depicts a plan map of the surface extents of each low-resistivity anomaly, and **Figure 9** depicts the same for each high-resistivity anomaly.

Figure 8: Plan view map of low resistivity anomaly surface extents.
NAD83 State Plane Missouri East US Survey Foot

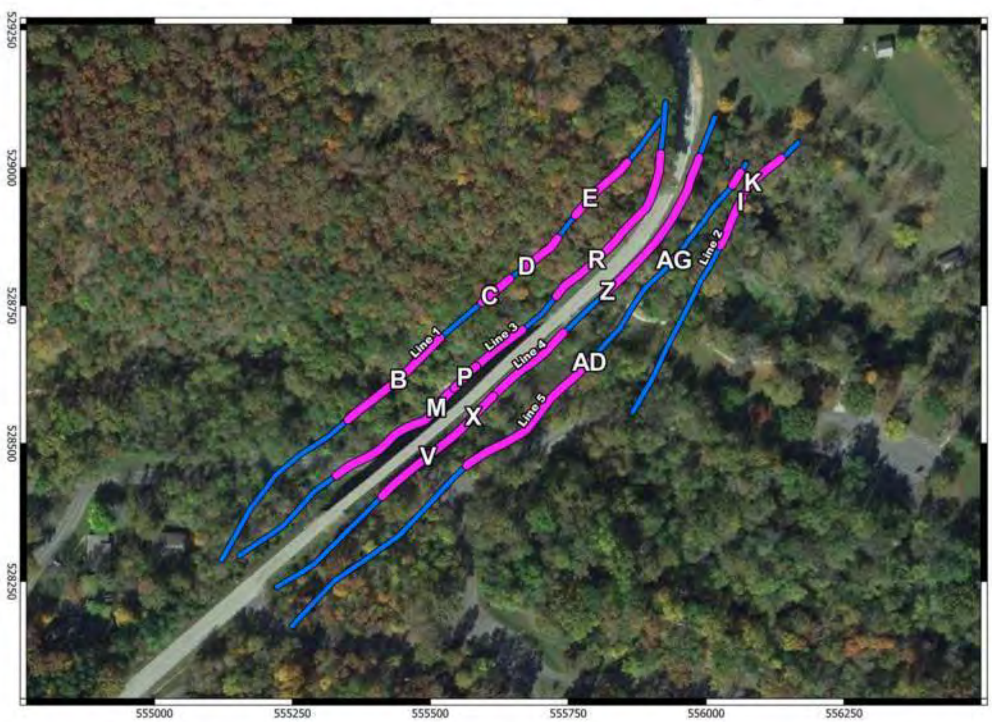


Figure 9: Plan view map of high-resistivity anomaly surface extents.
NAD83 State Plane Missouri East US Survey Foot

The high resistivity value condition encompasses areas on the sections with resistivity values above **3000** ohm-m, which is generally 10x greater than the average resistivity of the bedrock within the upper and lower boundary conditions identified in the previous section (300 ohm-m). As geophysical targets for electrical resistivity, air-filled voids are functionally infinite resistors, and in previous case histories resistivity inversion modeling is found to trend toward extremely high resistivity values. Previous iterations of geophysical inversions using the same data but with lower damping factors and lower constraints produced models with resistivity values greater than 40,000 ohm-m over some of the anomalous features identified on the ERT sections. These anomalies are strong signals of potentially air-filled voids or cavities. Alternatively, extremely cohesive, competent limestone with near-zero porosity and low saturation could reproduce a similar resistivity anomaly. Our interpretation is that these high resistivity anomalies have a high probability to represent air-filled voids or caves due to the characteristics of the inversion models and the expected subsurface conditions, with the caveat that other scenarios exist which could produce a similar result. The exact geometry of the high resistivity anomalies is unconstrained at depth due to the rapid decrease in sensitivity of the method at depth, so the size of any potential air-filled voids is unconstrained. Therefore confirmation with exploratory borings is highly recommended.

Low-resistivity value anomalies were identified generally in the weathered bedrock interval and encompass areas on the sections with resistivity values less than 150 ohm-m. A number of conditions could produce the same anomalies, including but not limited to, a high degree of weathering, fluid filled fractures, deposition of residuum, or a groundwater condition with elevated hydraulic conductivity or dissolved solids. The low-resistivity value anomalies generally fall into two categories, those with an extension in the vertical dimension, and those with extension in the horizontal dimension. These may represent different conditions and warrant investigation in order to classify them geologically. Line 4, on **Figure A-4** , shows a correlation between a low-Vp value anomaly and a low-resistivity value anomaly with vertical extension around 750 feet line distance. The decreased velocity may indicate this target as a weakened zone in the rock, such as a fracture zone, and the decreased resistivity may be influenced by fluid saturation, alteration, or clay deposition. This vertically extended anomaly appears to extend to the northwest through Lines 3 and 1 as well. As before, these geophysical anomalies represent targets for exploration to further constrain the subsurface interpretation.

One more unexpected anomalous condition is present which deserves discussion. On Line 2, **Figure A-2**, from approximately 340 to 440 feet line distance, and again on Line 4, **Figure A-4**, from 390 to 530 feet line distance, there is high resistivity value anomaly immediately overlying a low resistivity value anomaly. It is not well understood what each of these anomalies represent. The inversion modeling process sometimes produces these coupled highs and lows as an artifact when attempting to resolve extremely high resistivity contrasts. An example of this is along Line 5, **Figure A-5**, at around 280 feet line distance, where the resistivity array crossed over what appears to be a conductive buried utility (in this case what may be a steel waterline). This characteristic anomaly may be an artifact of the inversion process. Another potential subsurface condition may be an air- and water-filled void or cavity with air above and water below. If subsurface water is pooled in an air-filled cavity, and actively dissolving or flowing through the rock, it may explain the large resistivity contrast suggested by this type of anomaly. The target at Line 2 appears to be located directly uphill from an open sinkhole, and the target on Line 4 appears immediately below the stream in Spring Valley.

Closure

The overall quality of the seismic and ERT data acquired during this investigation was very good. ERT inversion modeling results are of good quality with moderate RMS due to high damping factors used to stabilize the inversion over large resistivity contrasts. The SRT inversion model had very low RMS of 5.3% but is understood to poorly represent conditions where there may be open voids or velocity inversions at depth. The distribution of resistivity values is representative of the current geological and hydrogeological understanding of the site. Geophysical anomalies classified by this interpretation are indicative of karstic conditions expected in the subsurface. However they are not definitive and exploration of the geophysical targets interpreted in this investigation is strongly recommended.

The geophysical methods and field procedures defined in this report were applicable to the project objectives and have been successfully applied by Collier geophysicists to investigations of similar size and nature. However, sometimes field or subsurface conditions are different from those anticipated and the resultant data may not achieve the investigation objectives. Collier warrants that our services were performed within the limits prescribed for this project, with the usual thoroughness and competence of the geophysical profession. Collier conducted this project using the current standards of the geophysical industry and utilized in house quality control standards to produce a precise geophysical survey.

If you have any questions regarding the field procedures, data analyses, or the interpretive results presented herein, please do not hesitate to contact us. We appreciate working with you and look forward to providing Hg Consult, Inc. with geophysical services in the future.

Respectfully Submitted,

Collier Geophysics, LLC

Trever Ensele
Senior Geophysicist

Jacob Sheehan, PGp.
Senior Geophysicist

(1 copy e-mailed PDF format)

References:

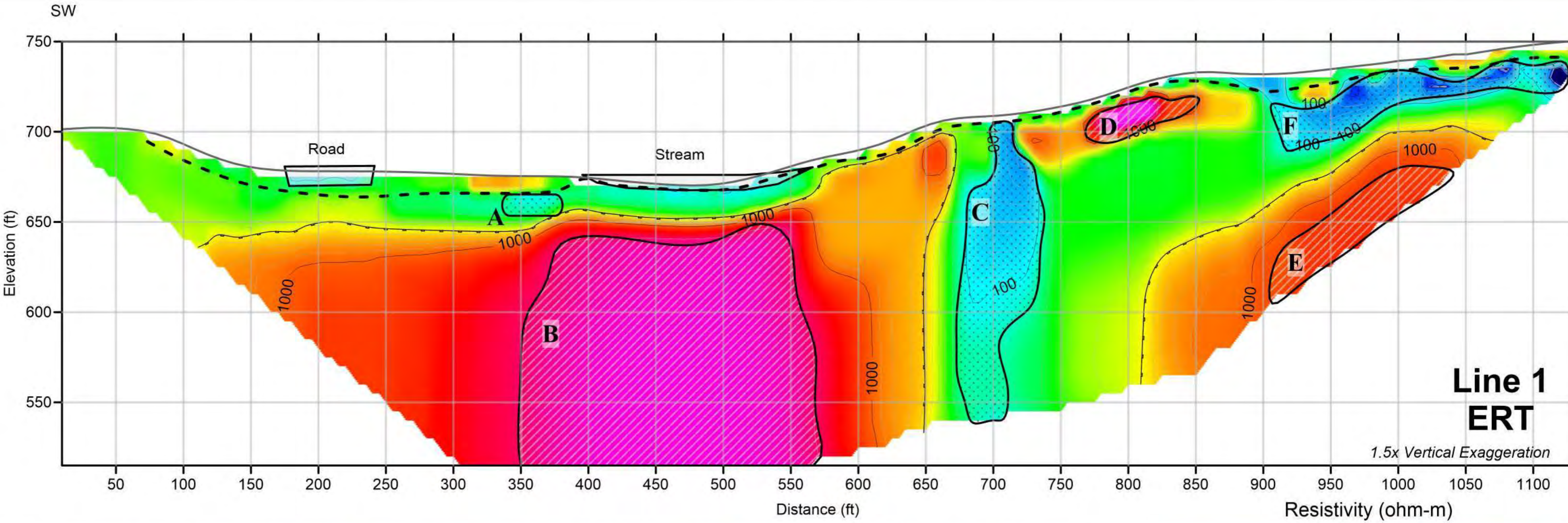
Loke, M.H., 2015, Tutorial: 2-D and 3-D electrical imaging surveys, 187 p.

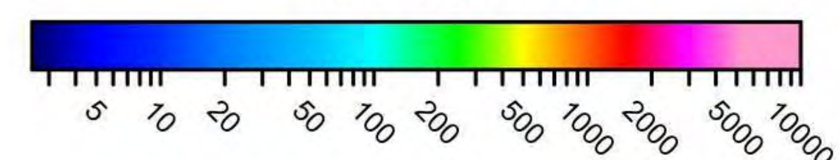
APPENDIX AND FIGURES

Appendix A

Table 2: Table of resistivity anomalies identified on resistivity sections on Figures A-1 through A-5.

Anomaly	Resistivity	Surface Elevation (ft)	Top Elevation (ft)	Bottom Elevation (ft)	Start Station (ft)	End Station (ft)	Top Depth (ft)	Depth Extent (ft)	Station Width (ft)	Figure	Note
A	**LOW (< 150 ohm-m)**	675	666	653	336	353	9	13	17	**A-1**	
B	**HIGH (> 3000 ohm-m)**	675	641	573	348	573	34	68	225	**A-1**	Unkown maximum depth.
C	**HIGH (> 3000 ohm-m)**	705	705	540	672	738	0	165	66	**A-1**	Unkown maximum depth. Vertical characteristic
D	**HIGH (> 3000 ohm-m)**	723	715	700	767	852	8	15	85	**A-1**	
E	**HIGH (> 3000 ohm-m)**	735	681	605	905	1040	54	76	135	**A-1**	
F	**LOW (< 150 ohm-m)**	739	734	689	904	1126	5	45	222	**A-1**	
G	**LOW (< 150 ohm-m)**	679	661	616	42	111	18	45	69	**A-2**	
H	**LOW (< 150 ohm-m)**	692	692	656	196	269	0	36	73	**A-2**	
I	**HIGH (> 3000 ohm-m)**	710	706	688	341	439	4	18	98	**A-2**	High/Low anomaly, associated with J
J	**LOW (< 150 ohm-m)**	710	685	650	337	439	25	35	102	**A-2**	High/Low anomaly, associated with I
K	**HIGH (> 3000 ohm-m)**	721	691	636	452	539	30	55	87	**A-2**	Limited extent, poor resolution
L	**LOW (< 150 ohm-m)**	691	691	647	46	177	0	44	131	**A-3**	
M	**HIGH (> 3000 ohm-m)**	676	600	505	230	664	76	95	434	**A-3**	Very large, deep, high resistivity anomaly, max depth unknown
N	**LOW (< 150 ohm-m)**	677	668	647	297	342	9	21	45	**A-3**	
O	**LOW (< 150 ohm-m)**	673	648	613	418	495	25	35	77	**A-3**	
P	**HIGH (> 3000 ohm-m)**	671	663	631	501	557	8	32	56	**A-3**	Below stream
Q	**LOW (< 150 ohm-m)**	698	685	650	691	775	13	35	84	**A-3**	Q, S, T, U likely related
R	**HIGH (> 3000 ohm-m)**	711	656	508	740	1083	55	148	343	**A-3**	Very large high resistivity anomaly, maximum depth unknown
S	**LOW (< 150 ohm-m)**	704	691	677	801	893	13	14	92	**A-3**	Q, S, T, U likely related
T	**LOW (< 150 ohm-m)**	720	712	694	922	962	8	18	40	**A-3**	Q, S, T, U likely related
U	**LOW (< 150 ohm-m)**	743	732	703	1024	1169	11	29	145	**A-3**	Q, S, T, U likely related
V	**HIGH (> 3000 ohm-m)**	674	637	513	253	697	37	124	444	**A-4**	Very large, high resistivity anomaly, maximum depth unkown
W	**LOW (< 150 ohm-m)**	674	656	616	377	547	18	40	170	**A-4**	W & X likely related high/low anomalies, located below stream
X	**HIGH (> 3000 ohm-m)**	673	667	648	465	525	6	19	60	**A-4**	W & X likely related high/low anomalies, located below stream
Y	**LOW (< 150 ohm-m)**	706	698	552	709	779	8	146	70	**A-4**	Vertical low-resistivity anomaly separating V and Z
Z	**HIGH (> 3000 ohm-m)**	716	705	535	796	1105	11	170	309	**A-4**	Very large high resistivity anomaly, maximum depth unknown
AA	**LOW (< 150 ohm-m)**	690	677	646	84	218	13	31	134	**A-5**	
AB	**LOW (< 150 ohm-m)**	681	668	631	363	405	13	37	42	**A-5**	Beneath Road
AC	**LOW (< 150 ohm-m)**	675	667	653	435	498	8	14	63	**A-5**	
AD	**HIGH (> 3000 ohm-m)**	676	660	515	433	739	16	145	306	**A-5**	Large high resistivity anomaly, maximum depth unknown
AE	**LOW (< 150 ohm-m)**	674	665	641	505	710	9	24	205	**A-5**	AC/AE likely related, below stream bed
AF	**LOW (< 150 ohm-m)**	690	679	594	779	1042	11	85	263	**A-5**	Anomalous shape, peak anomaly at station 816 ft, elevation 637 ft
AG	**HIGH (> 3000 ohm-m)**	700	694	682	963	992	6	12	29	**A-5**	Very small extent, near surface anomaly
AH	**LOW (< 150 ohm-m)**	715	710	682	1098	1150	5	28	52	**A-5**	
AI	**HIGH (> 3000 ohm-m)**	715	709	687	1142	1169	6	22	27	**A-5**	





Legend

A Anomaly Designation

High resistivity anomaly in bedrock
Potential air-filled void

Low resistivity anomaly in bedrock
Potential dissolution feature or residuum

Interpreted Bedrock
Top of Wx (Dashed)
Competent (Ticked)

Resistivity Results - Line 1
Round Spring Nat'l Park
Eminence, MO

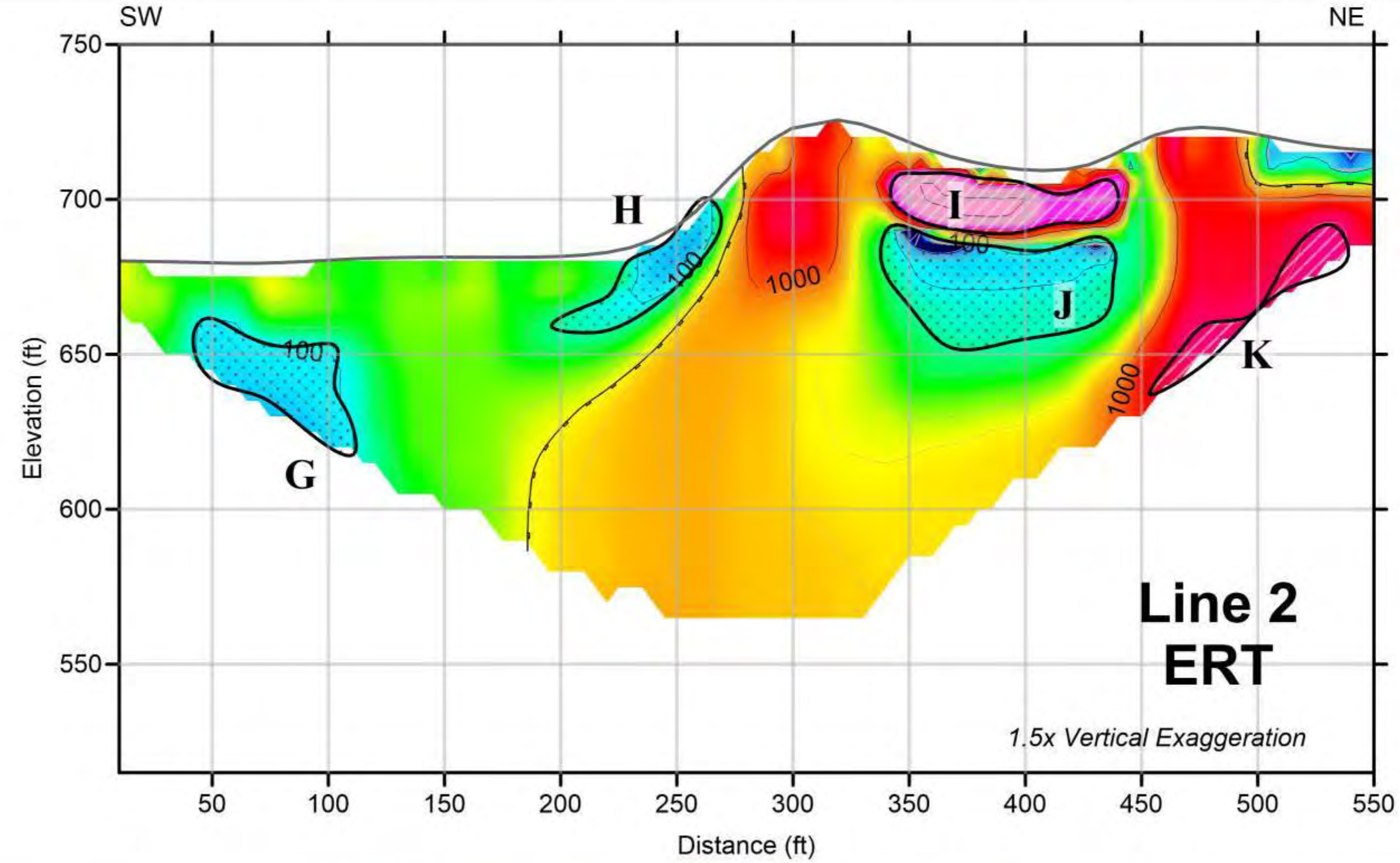
COLLIER GEOPHYSICS

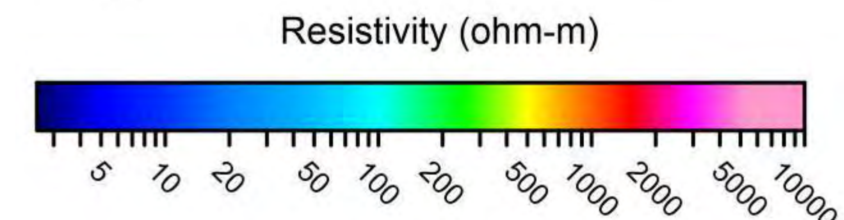
HG Consult Inc.

Project #: 21-146

Figure A-1

Drafted by: T. Ensele | Checked by: N. Pendrigh | December 2021





Legend

A Anomaly Designation

High resistivity anomaly in bedrock
Potential air-filled void

Low resistivity anomaly in bedrock
Potential dissolution feature or residuum

Interpreted Bedrock
Top of Wx (Dashed)
Competent (Ticked)

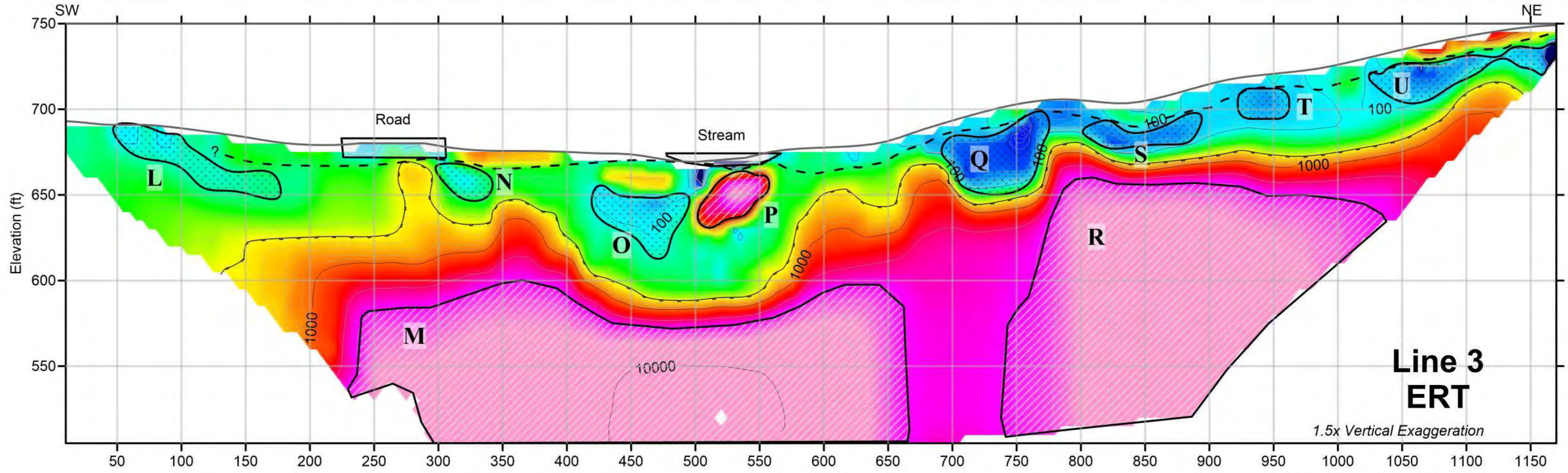
Resistivity Results - Line 2
Round Spring Nat'l Park
Eminence, MO

COLLIER GEOPHYSICS

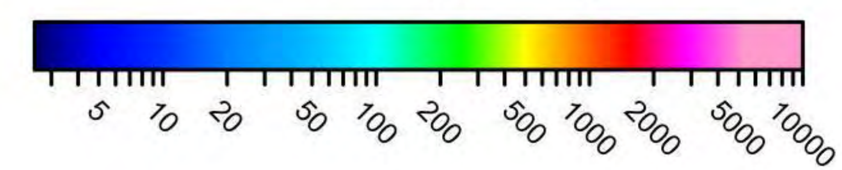
HG Consult Inc.

Project #: 21-146 | **Figure A-2**

Drafted by: T. Ensele | Checked by: N. Pendrigh | **December 2021**



Resistivity (ohm-m)



Legend

A Anomaly Designation

High resistivity anomaly in bedrock
Potential air-filled void

Low resistivity anomaly in bedrock
Potential dissolution feature or residuum

Interpreted Bedrock
Top of Wx (Dashed)
Competent (Ticked)

Resistivity Results - Line 3
Round Spring Nat'l Park
Eminence, MO

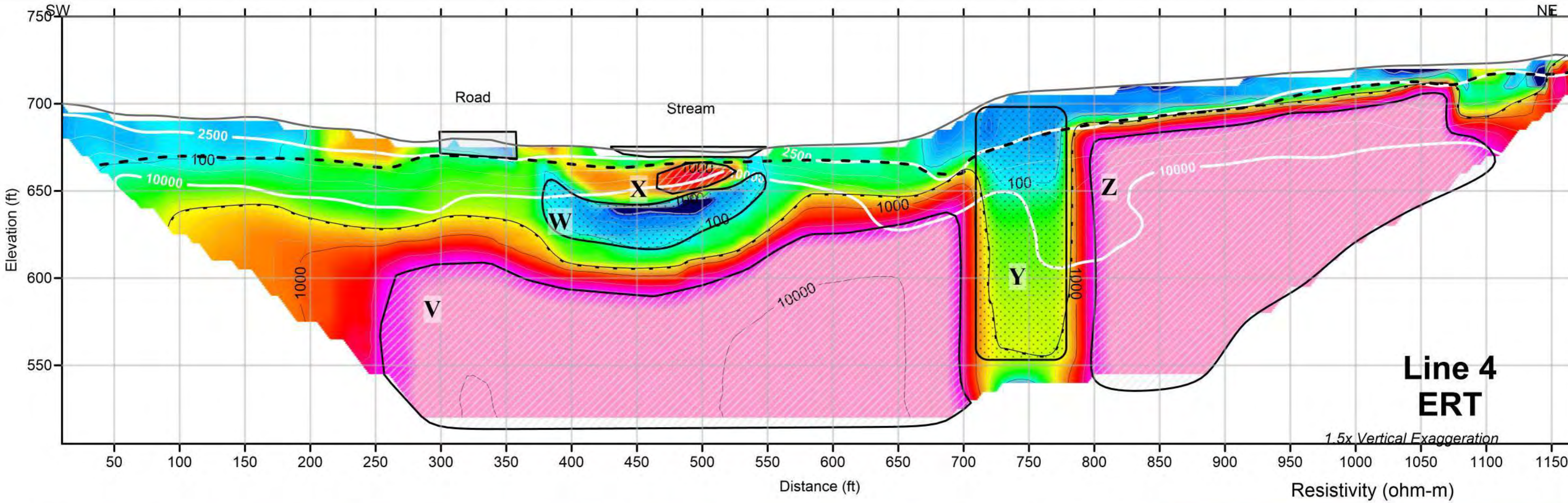
COLLIER GEOPHYSICS

HG Consult Inc.

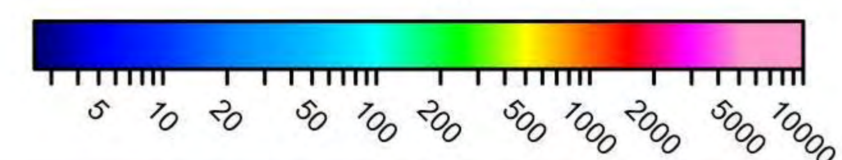
Project #: 21-146

Figure A-3

Drafted by: T. Ensele | Checked by: N. Pendrigh | December 2021



Resistivity (ohm-m)



Legend

A Anomaly Designation

Seismic P-wave Velocity (ft/s) From SRT

High resistivity anomaly in bedrock *Potential air-filled void*

Low resistivity anomaly in bedrock *Potential dissolution feature or residuum*

Interpreted Bedrock
Top of Wx (Dashed)
Competent (Ticked)

Resistivity Results - Line 4
Round Spring Nat'l Park
Eminence, MO

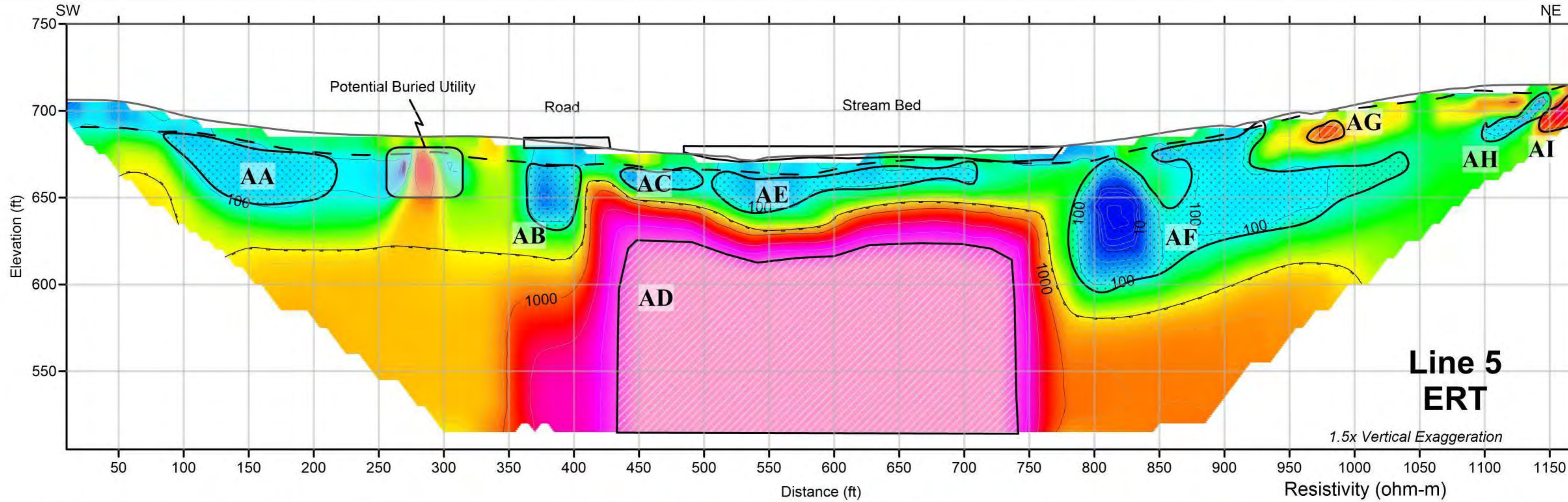
COLLIER GEOPHYSICS

HG Consult Inc.

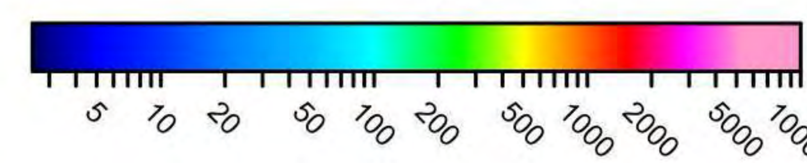
Project #: 21-146

Figure A-4

Drafted by: T. Ensele | Checked by: N. Pendrigh | December 2021



Resistivity (ohm-m)



Legend

A Anomaly Designation

High resistivity anomaly in bedrock
Potential air-filled void

Low resistivity anomaly in bedrock
Potential dissolution feature or residuum

Interpreted Bedrock
Top of Wx (Dashed)
Competent (Ticked)

Resistivity Results - Line 5
Round Spring Nat'l Park
Eminence, MO

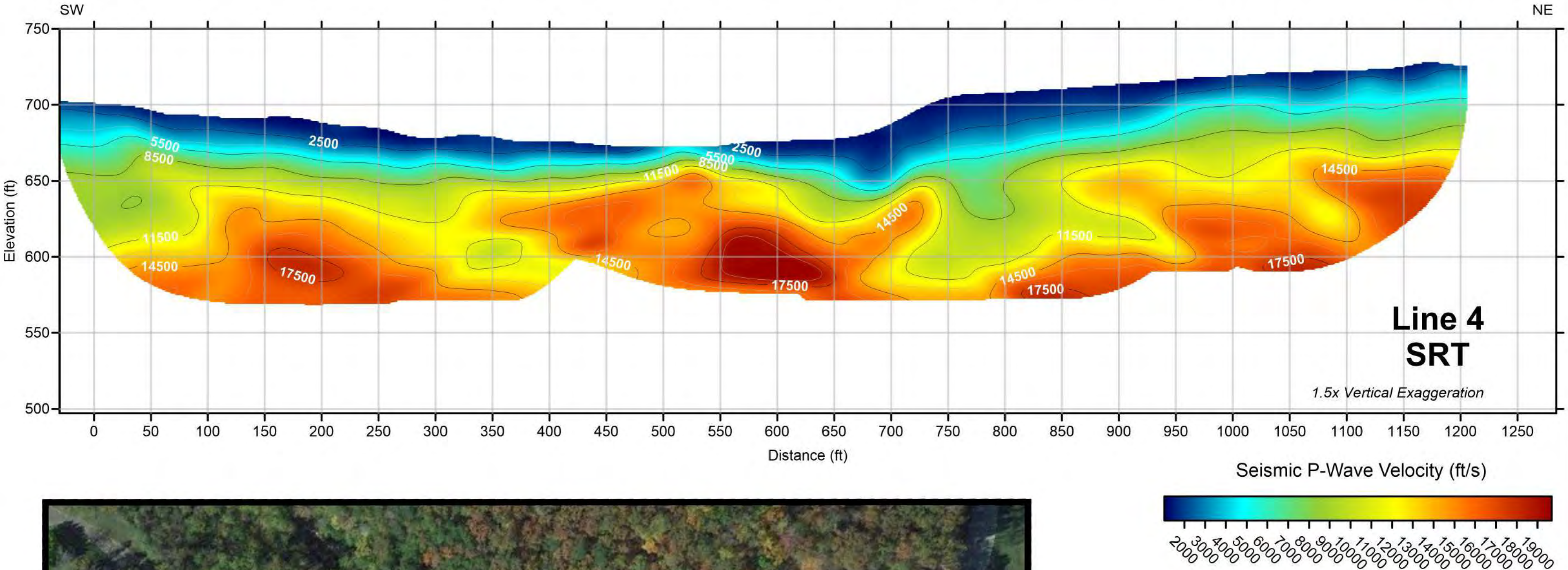
COLLIER GEOPHYSICS

HG Consult Inc.

Project #: 21-146

Figure A-5

Drafted by: T. Ensele | Checked by: N. Pendrigh | December 2021



Seismic SRT - Line 4
Round Spring Nat'l Park
Eminence, MO

COLLIER GEOPHYSICS

HG Consult Inc.

Project #: 21-146

Figure A-6

Drafted by: T. Ensele | Checked by: J. Sheehan | **October 2021**

ROUTE 19 BRIDGES KARST REVIEW

Shannon County, Missouri - 2022

August 19, 2022

Olsson Project No. 020-1986