



REPORT

Geological Assessment Findings and Recommendations for Repairs and Corrective Actions

Blanchard Springs Caverns - Geological Assessment and Design

Submitted to:

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Sylamore Ranger District

Submitted by:

Golder Associates Inc.

13515 Barrett Parkway Drive, Suite 260, Ballwin, Missouri, USA 63021

+1 314 984-8800

19129310

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Distribution List

Golder Associates Inc.

United States Forest Service

Robert Peccia & Associates, Inc.

Executive Summary

The United States Forest Service (Forest Service) contracted Golder Associates Inc. (Golder) through Robert Peccia & Associates, Inc. (RPA) in September 2019 to perform various tasks associated with the Blanchard Springs Caverns – Geological Assessment and Design Project (the Project) at Blanchard Springs Caverns, located near Fifty-Six, Arkansas (Project Site or Site).

This report of Geological Assessment Findings and Recommendations for Repairs and Corrective Actions (Report) presents the findings from Golder's geotechnical investigation and site assessment, presents the methodology and results of geotechnical analyses completed to determine recommendations for permanent repairs, presents recommendations for permanent ground support in the assessment areas, presents recommendations for instrumentation and monitoring, presents replacement options for airlock doors and security doors, and includes a preliminary construction cost estimate and schedule.

Golder visited the Site to complete the Site investigation/assessment on January 13-15, 2020. During the Site assessment, Golder gathered additional data and samples to aid in our geological assessment and design recommendations for five separate areas (assessment areas); the Dripstone Cave Entrance, Dripstone Cave Bypass Tunnel, Dripstone Cave Exit, Discovery Cave Exit, and Surface Sinkhole Area. For all areas, Golder visually observed rock and existing support conditions and used measuring devices to collect data. Samples of cavern roof rock were collected from loose rock bulk samples that were recently scaled from the cavern roof in the Dripstone Cave Entrance and were submitted for laboratory geotechnical testing. Photographs were also taken of the various assessment areas. In the Discovery Cave Exit, Golder drilled a series of probe holes in the shotcrete roof structure on either side of the inner airlock doors. Once drilled, a borescope camera was inserted into the drillhole to check shotcrete thickness, view rock conditions, and check for the presence of steel beams/reinforcement. Golder inspected the existing canopy structure in the Dripstone Cave Exit that is composed of steel I-beams and plate roofing with supporting masonry/steel column supports. The structure itself appeared in relatively poor condition due to deterioration/weathering of the steel. The void space between the steel plating and tunnel roof has been filled with masonry/cement. Rock conditions behind the structure were not visible but are assumed to be poor to necessitate the support structure.

In general, the rock mass quality in each formation appeared relatively uniform laterally between assessment areas. The rock quality in the roof of the assessment areas is generally fair while the quality in the limestone units in the floor and side walls is generally good. The Chattanooga Shale, which is present in thicknesses ranging from 2.5 to 4.0 feet in the side walls of the assessment areas, is generally poor quality. Most of the discontinuities encountered were bedding planes between bedrock units, with some near-vertical joints. Several rock ledges with potentially loose material were noted in the roof rock above the Dripstone Cave Entrance and Dripstone Cave Bypass tunnel.

Analysis of the unsupported span openings in the assessment areas using empirical relationships based on rock mass quality indicates that the unsupported spans are "potentially unstable" without the use of permanent ground (rock) support (rock bolts, mesh, shotcrete, etc.). The geotechnical analyses suggest the use of permanent ground support to improve stability in the Elevator Room and Dripstone Cave Entrance, Dripstone Cave Bypass Tunnel, and Dripstone Cave Exit. Due to the relatively long design life and use as a public facility, Golder recommends that permanent ground support be added to each of these areas.

The existing airlock and security doors were installed in the 1970s and have deteriorated considerably over approximately the last 50 years. Various construction material options and door options were reviewed by Golder as a part of this Report. Construction materials were considered for both new door and frame installations, as well as bulkhead installations that join the tunnel and cave walls to the structure of the door frame.

Golder's overall recommendations for each assessment area are detailed in the following paragraphs.

Elevator Room and Driestone Cave Entrance Recommendations: Recommended work includes replacement of the airlock door systems and installation of permanent ground support (rockbolts, mesh, and shotcrete) through the entry tunnel; scaling (removal) of loose rock, demolition and replacement of existing false ceilings and utilities/ducting, instrumentation installation near the interface with the natural cavern, and protection of existing features and the natural cave environment.

Driestone Cave Bypass Tunnel Recommendations: Recommended work includes replacement of the door between the tunnel and the surface shaft and installation of permanent ground support (rockbolts and mesh) through the tunnel; scaling of loose rock, instrumentation at both ends near the interface with the natural cavern, and protection of existing features and the natural cave environment.

Driestone Cave Exit Recommendations: Recommended work includes replacement of the airlock and security door systems and installation of permanent ground support (rockbolts, mesh, and shotcrete) through the exit tunnel; scaling of loose rock, demolition of existing canopy structure and replacement with structural shotcrete, instrumentation near the interface with the natural cavern, and protection of existing features and the natural cave environment.

Discovery Cave Exit Recommendations: Probe drilling of the existing shotcrete and steel beam ground support found the structure to be in good condition. Recommended work is limited to replacement of the airlock and security door systems and protection of existing features and the natural cave environment.

Surface Sinkhole Area Recommendations: Security of the cave is the primary concern. Golder recommends that the sinkhole be filled with crushed limestone and that a water diversion berm be constructed to divert surface water from the adjacent roadway and limit man-made water inflows.

For Forest Service budgeting purposes, estimated construction costs related to the recommended scope items outlined above are approximately **\$3,800,000** and total Project duration is estimated to be approximately **23 weeks**. We have estimated costs based on our prior experience on similar projects and conservatively assumed a contingency factor of 25%, based on the logistical factors involved. We have also included an estimate of costs related to engineering construction management during Project construction. The preliminary cost estimate should be considered order of magnitude and will continue to be refined as the design phase advances.

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1.0 INTRODUCTION

The United States Forest Service (Forest Service) contracted Golder Associates Inc. (Golder) through Robert Peccia & Associates, Inc. (RPA) in September 2019 to perform various tasks associated with the Blanchard Springs Caverns – Geological Assessment and Design Project (the Project) at Blanchard Springs Caverns, located near Fifty-Six, Arkansas (Project Site or Site). The Project scope includes various technical support services related to an assessment and design for stabilization and repairs at the Site. These technical support services include:

- On-site assessments and investigations
- Detailed findings and recommendations reporting
- Complete design packages for permanent repairs in identified areas

This report of Geological Assessment Findings and Recommendations for Repairs and Corrective Actions (Report) presents the findings from Golder's geotechnical investigation and site assessment, presents the methodology and results of geotechnical analyses completed to determine recommendations for permanent repairs, presents recommendations for ground support in the assessment areas, presents replacement options for air lock doors and security doors, and includes a preliminary construction cost estimate and schedule.

1.1 Background

Blanchard Springs Caverns and Visitor Center is located in North Central Arkansas in the Sylamore Ranger District of the Ozark-St. Francis National Forest. The Blanchard Springs Visitor Center opened to the public in 1973 and is the initial access point for the caverns, and the portal for the Driestone Cave. The Caverns are unique in that limited access has prevented cavern features from being damaged by man. It is an active "living" cave with large rooms "decorated" with crystalline formations that are still growing. The Site is on the Forest Service Regional Priority Investment list and plays a vital role in the local tourism economy in that part of the State.

During a March 2015 inspection, a Forest Service geologist identified potential hazards associated with horizontal tension fractures in the natural rock above the Driestone Cave Entrance tunnel. Temporary mitigation measures were installed in this area of the tunnel in 2015. The mitigation work was recommended and approved by the Roof Control Division, Mine Safety & Health Administration (MSHA) as a temporary solution, with the intention of following this work with a professional mining/tunneling assessment and design of a permanent solution.

Golder performed an initial Site visit and attended a preliminary assessment meeting with Forest Service personnel on October 8th and 9th, 2019 at the Project Site. During overall Project discussions at the conclusion of the meeting, Golder discussed conceptual recommendations for improving ground support and/or providing remedial measures at the following five separate areas (assessment areas):

- Driestone Cave Entrance
- Driestone Cave Bypass Tunnel
- Driestone Cave Exit
- Discovery Cave Exit
- Surface Sinkhole Area

Those areas and preliminary construction scope items were discussed in Golder's October 21, 2019 technical memorandum. All of the underground areas are manmade tunnels excavated to provide access to the caves and are only representative of natural cave conditions at the points where the tunnels transition into the cave areas. They were not located in critical bat hibernation areas. A plan view map of the cavern system that displays the relative location of the assessment areas is included in Figure 1.

Golder visited the Site to complete the Site investigation/assessment on January 13-15, 2020. During the Site assessment, Golder gathered additional data and samples from the assessment areas to aid in our geological assessment and design recommendations.

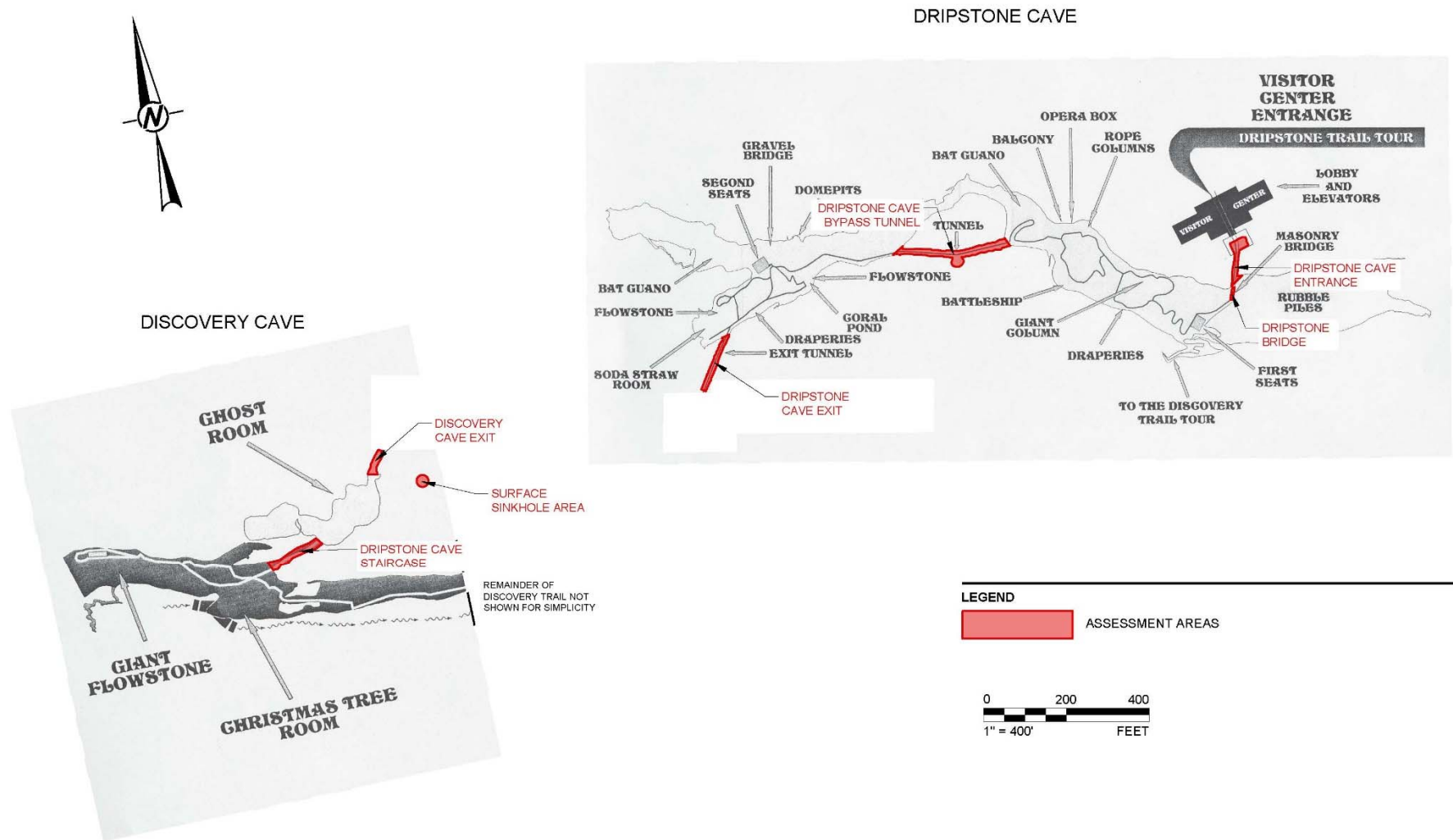


Figure 1: Cavern Map and Assessment Area Locations

2.0 GEOLOGIC SETTING

The Site area lies within the Ozarks Plateaus Physiographic Province (Ozark Province) in northern Arkansas, as shown in Drawing G-01. This Ozark Province is on the southern flank of an asymmetrical dome (or uplift) with a center located in the St. Francois Mountains in southeastern Missouri. Typically, units dip gently away from the center of the dome, which produces the slight southward to southwestward dip of bedrock strata in northern Arkansas. The Ozark Province is commonly divided into three different plateaus in Arkansas based on elevation and age of the rock units present at the surface. These three plateaus are (Arkansas Geological Survey (AGS), 2020):

- **Salem Plateau** – Oldest of the three plateaus and made up of Ordovician dolostones, sandstones, and limestones. The formations forming the Salem Plateau are present along the northern end of the Blanchard Cavern grounds and typically present in the Discovery Trail and the lower portions of the Dripstone Trail.
- **Springfield Plateau** – Mostly Mississippian limestone with chert that extends down to the Boone Formation. The formations forming the Springfield Plateau are present in the upper portions and roof of the Dripstone Trail.
- **Boston Mountains Plateau** – the youngest and southernmost of the three plateaus, typically Pennsylvanian sandstones and shales with minor amounts of limestone. The formations comprising the Boston Mountains Plateau are not present in the Blanchard Cavern trail system.

2.1 Geological Structures

No references that discuss the local geological structures in detail have been discovered, however, a geological map for the Fifty-six quadrangle (Braden et al., 2002) displays several structural features present in the area near the cave (See Drawing G-02). Approximately one mile north of the Site is the southeast trending North Sylamore Monocline. This monocline folds the sedimentary units and causes a steepening of the dip towards the southeast. Based on the cross section presented on the quadrangle map, the units flatten near North Sylamore Creek, north of the site. Mapping also displays a series of steeply dipping normal faults striking from northwest to southeast that are spaced approximately 1.5 to 2 miles apart. Geological mapping displays one of these features just south of Highway 14, 0.75 miles southeast of the site; and another ~0.75 miles to the northeast, near North Sylamore creek.

2.2 Stratigraphy

The stratigraphy of the Blanchard Caverns area consists of Ordovician, Silurian, Devonian, and Mississippian aged limestone and dolostone with lesser amounts of shale and sandstone. Table 1 presents the generalized stratigraphic sequence encountered at the cave, including general unit thicknesses and rock descriptions based on site specific observations and local/regional geological reports (McFarland, 1998, and Braden et al., 2002). Detailed descriptions of the units are provided in the following sub-sections. Blanchard caverns developed due to solution activity between the Boone and the St. Peters formations.

Table 1: Generalized Stratigraphic Sequence for Blanchard Caverns

System (Age)	Formation	Member	Thickness (Feet)	Brief Geological Description
Mississippian	Boone	Boone Limestone	250+	Light to medium gray, fine to coarse grained fossiliferous limestone with interbedded chert.
Mississippian	Boone	St. Joe Member	0-12	Dark gray, fine-grained crinoidal limestone with small round green spheres that are sometime flattened and appear to be composed of green clay at the top of the unit.
Devonian	Chattanooga	Chattanooga Shale	0-6	Black, fissile clay shale that may contain pyrite.
Devonian	Chattanooga	Sylamore Sandstone	0-1.5	Basal unit that is a white to dark gray quartz sandstone.
Silurian	Silurian Limestones	Lafferty Limestone	0-20	Sparsely fossiliferous, finely crystalline, medium gray
Silurian	Silurian Limestones	St. Clair Limestone	0-3	A coarse-grained, thickly bedded to massive, highly fossiliferous, light gray to pinkish gray
Silurian	Cason	Cason Shale	0-8	Clay shale with abundant black phosphate pebbles, dark gray, with reddish siltstone in upper portion.
Ordovician	Fernvale Limestone	Undifferentiated	0-30	Massive with occasional cross beds, coarsely crystalline, light gray to pink, clinoidal limestone
Ordovician	Kimmswick Limestone	Undifferentiated	0-15	Thin to massively bedded, light- to dark-gray, fine- to coarse-grained bioclastic limestone with a very sugary texture.
Ordovician	Plattin Limestone	Undifferentiated	20-180	Very fine grained, light to dark gray, thinly bedded, micritic limestone
Ordovician	Joachim Dolomite	Undifferentiated	0-90	Fine grained sandy dolostone or dolomitic limestone with thin shale beds throughout.
Ordovician	St. Peter Sandstone	Undifferentiated	20-300	Massively bedded, medium to very fine grained, friable, quartz sandstone

2.2.1 St. Peter Sandstone

The oldest and lowermost unit present in the Blanchard Caverns area is the St. Peter Sandstone. This formation is described as a massively bedded, very fine to medium grained, well sorted, friable, quartz sandstone with calcite cementation. Fresh exposures of the unit are typically white and the unit weathers to a buff to brownish color. The unit is also an important regional aquifer and is a frequent bluff-former. The St. Peter Sandstone was not encountered in the cave during this field investigation and forms the base of the lowest portions of the Discovery Trail. Outcroppings of the St. Peter Sandstone are present near Blanchard Springs.

2.2.2 Joachim Dolomite

The Joachim Dolomite lies conformably above the St. Peter Sandstone and is described as a fine grained to finely crystalline, sandy dolostone or dolomitic limestone with thin shale beds throughout. The unit is light to medium gray where fresh and weathers to dark gray or tan in color. The Joachim Dolomite was not encountered in the cave during this field investigation; however, it is typically present in the lower sections of the Discovery Trail. Outcroppings of the Joachim Dolomite are also present near Blanchard Springs.

2.2.3 Platin Limestone

The Platin Limestone lies unconformably above the Joachim Dolomite and is described as a very fine grained, thinly bedded, micritic limestone. While some fossils are present in the upper portions of the Platin Limestone, the unit is less fossiliferous than the overlying units. The unit is light to dark gray on fresh surfaces and weathers to dark gray. The Platin Limestone was encountered in the Discovery Trail; however, detailed descriptions of the unit were not established as it is not present in any of the areas of concern. The discharge of Blanchard Springs is formed in the Platin Limestone.

2.2.4 Kimmswick Limestone

The Kimmswick Limestone lies unconformably above the the Platin Limestone and is described as thin to massively bedded, medium crystalline, bioclastic limestone with a very sugary texture. Some beds of dolomite and sandstone have been noted, but they are not prevalent. The grains of the Kimmswick are typically a well-mixed accumulation of fossil fragments. The unit is light gray on fresh surfaces but weathers to a dark gray. The Kimmswick Formation was encountered in the Discovery Trail; however, detailed descriptions of the unit were not established as it is not present in any of the areas of concern.

2.2.5 Fernvale Limestone

The Fernvale Limestone lies conformably above Kimmswick Limestone and is described as massive with occasional cross beds, coarsely crystalline crinoidal limestone with occasional vugs and often contains traces of bluish to olive gray clays. The unit is white to light gray with a pink to reddish mottling on fresh surfaces and weathers to a dark gray color. The Fernvale was encountered in the Dripstone Trail and makes up the lowest portions of that trail.

2.2.6 Cason Formation

The Cason Formation is unconformable to the underlying Fernvale Limestone and is described as clay shale with abundant phosphate pebbles. The unit is dark gray on fresh surfaces and weathers to a buff or light brown color. Regionally, the unit has been described as also having flattened oncolites (algal buttons) and to be blue/green to dark gray/black in color. The unit was not specifically identified in the cave and is known to be missing in some parts of the region. However, in the main rooms of the cave, locations of walkways and large amounts of flowstone on the walls limit access to and observation of the geological units. Where present, the Cason

Formation would likely have weathered quickly after exposure, exposing the overlying limestone. If present in the cave, the Cason Formation would be at or below the floor of the Dripstone exit tunnel.

2.2.7 Silurian Limestones

In northern Arkansas there is a thin, typically 5 to 20-foot-thick series of Silurian limestones. In the area around Blanchard Cave in the Fifty-six Quadrangle, two of these units can exist, the Lafferty Limestone and the St. Clair Limestone.

2.2.7.1 St. Clair Limestone

The St. Clair Limestone is not laterally extensive throughout the area and is described as coarsely grained, thickly bedded to massive, and highly fossiliferous. The unit is typically light gray to white with small round spots on fresh surfaces but weathers to a medium gray. The St. Clair Limestone was not identified in the cave.

2.2.7.2 Lafferty Limestone

The Lafferty Limestone is unconformable to the underlying St. Clair Limestone, Cason Formation, or Fernvale Limestone, depending on which units are present. The unit is described as having few fossils, finely crystalline, thin to thickly bedded, and with frequent stylolites along bedding planes. The unit is fairly persistent throughout the area and is medium gray with small red spots on fresh surfaces and weathers to a light gray. The unit also often has pyrite cubes near its upper contact. In the Dripstone Cave, this unit was present in the lower sections of the entrance, exit, and bypass tunnels.

2.2.8 Chattanooga Formation

The Chattanooga Formation is typically broken up into two members, the upper Chattanooga Shale and the lower Sylamore Sandstone member. Both units are not laterally predominant in the Fifty-six quadrangle and are missing in many areas.

2.2.8.1 Sylamore Sandstone Member

The Sylamore Sandstone is unconformable with the Silurian limestones and is a medium grained, moderately sorted, sub-rounded to sub-angular, friable, iron-cemented sandstone. The unit has white to dark gray appearance were fresh but weathers to a light tan. The unit was not identified during the field investigation.

2.2.8.2 Chattanooga Shale

The Chattanooga Shale lies unconformably above the Silurian Limestones when the Sylamore is not present. The unit is described as a fissile clay shale, with small abundant pyrite, and is not laterally continuous. The unit is black on both fresh and weathered surfaces. In the Fifty-six quadrangle, the Chattanooga Shale often contains small lenticular sand bodies.

In the Dripstone Cave, the Chattanooga Shale is present in the side walls of the entrance, exit and bypass tunnels, where it is approximately 1.5 to 4.5 feet thick. In the cave, the unit is black to green with some large

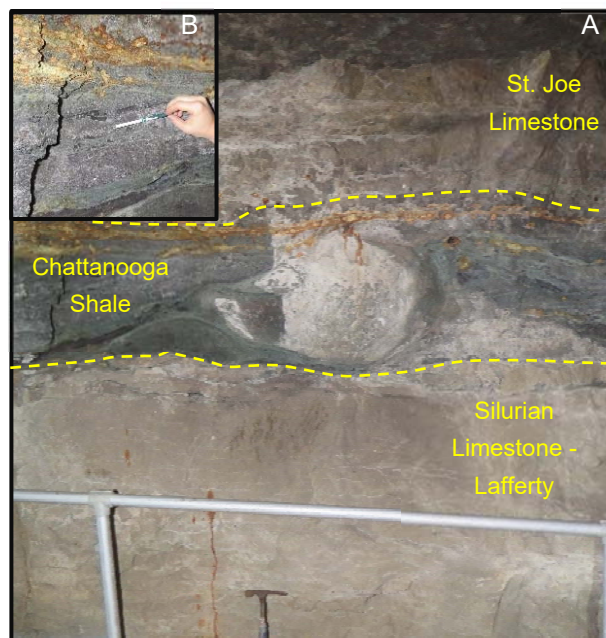


Figure 2: A: Sidewall of the Dripstone Trail exit displaying the St. Joe Limestone, Chattanooga Shale and Silurian Limestones. **B:** Fossils present in the Chattanooga Shale.

clasts of sandstone/limestone. The unit is soft and slightly to moderately weathered. Additionally, the unit is very iron rich near the top, with some pyrite present in fresh samples, and some fossils present throughout the unit.

2.2.9 Boone Formation

The Boone Formation has an unconformable contact with the underlying Chattanooga Formation and is described as a fine to coarse grained fossiliferous limestone with interbedded chert. This unit is typically light to medium gray on fresh surfaces and weathers to a dark gray. This unit is known throughout the region for having frequent springs and sinkholes. The Boone Formation is present in the natural roof portions of the Dripstone Cave. Additionally, this unit is present in unstained exposures just outside of the Dripstone Cave exit. In this area, the unit is a medium strong, slightly weathered limestone with very thin beds and frequent chert nodules.



Figure 3: Boone Formation outside of Dripstone Trail exit

2.2.9.1 St. Joe Limestone

At the bottom of the Boone Formation is the St. Joe Limestone member. This member, which is widespread throughout the Ozark region, is mostly a fine-grained, thin bedded, crinoidal limestone with occasional chert and thin shaley limestone beds. The unit is typically dark gray to reddish with some greenish mottling. The upper portion of the St. Joe in the Fifty-six Quadrangle is described as a prevalent and distinguishable unit containing small round green spheres that are sometime flattened and appear to be composed of green clay. Additionally, the lower portion of the St. Joe can contain a basal sandstone that is a fine to medium grained, moderately sorted, iron or quartz cemented sandstone.



Figure 4: Upper portion of the St. Joe Member in the roof of the bypass tunnel

In the Dripstone Trail, the St. Joe Formation is present at or within the roof in the entrance to the cave, the bypass tunnel and the exit from the cave. The Upper portion of the St. Joe Formation is a distinguishable bed in each of the areas due to the presence of the green spheres of clay like material. In some areas, this unit has undergone moderate weathering and is very weak to weak. There are also trace amounts of pyrite cubes. Below the upper clayey member is an approximately 2 to 5 foot-thick thinly bedded limestone with frequent fossils and calcite mineralization that was slightly weathered and was much stronger than the upper member, with a medium strong strength.

3.0 GEOTECHNICAL INVESTIGATION

Golder completed a geotechnical underground Site assessment on January 13-15, 2020. During the Site assessment, Golder gathered additional data and samples from the assessment areas to aid in geotechnical analyses and design recommendations and supplement data collected during the initial Site visit.

3.1 Underground Inspection

The assessment areas of the caverns consist of the Dripstone Cave Entrance, Dripstone Cave Bypass Tunnel, Dripstone Cave Exit, and Discovery Cave Exit. For all areas, Golder visually observed rock and existing support conditions (using A-frame ladders provided by the Forest Service, where necessary) and used measuring devices such as tape measures, laser distance meters, and handheld Brunton compass to collect data. Photographs were also taken of the various assessment areas.

In the Discovery Cave Exit, Golder used a battery powered handheld hammer drill to drill a series of 1-inch diameter probe holes in the shotcrete roof structure on either side of the inner airlock door. Once drilled, a borescope camera was inserted into the drillhole to check shotcrete thickness, view rock conditions, and check for the presence of steel beams/reinforcement. Probe holes were sealed with hydraulic cement following inspection.

3.1.1 Rock Quality

The rock quality as described by Rock Quality Designation (RQD) (Deere, 1988) data was estimated during the underground inspection. In general, the rock quality in each formation appeared fairly uniform laterally between assessment areas. The observed RQD was generally good (75 – 90%) to excellent (90 – 100%) except in the Chattanooga Shale, where it was observed to be poor (25 - 50%). Rock mass qualities as defined by the Norwegian Geotechnical Institute Rock Quality Index (NGI-Q index) system and Rock Mass Rating (RMR) system are further described in Section 4.1.

3.1.2 Discontinuities

Detailed description of structural discontinuities in the rock units in each assessment area were logged, including fracture type, strike/dip, shape, roughness, and infilling type and character. Most of the discontinuities encountered were bedding planes occurring between the bedrock units, with some near-vertical joints. These near-vertical discontinuities were primarily irregular surfaces with clean faces. Discontinuities observed in each assessment area are described in Table 2 below.

Table 2: Discontinuity Log

Assessment Area	Discontinuity Type	Dip	Strike	Persistence (ft)	Spacing (in)	Roughness	Shape	Weathering	Aperture (mm)	Infill	Water / Seepage
Elevator Room	Bedding	NM	NM	NM	4	Rough	Undulating	Slightly Weathered	<1	Shale, Iron Oxide	Damp
Dripstone Cave Entry - First Air Door to Second Air Door	Joint	84	145	8	12-60	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	86	351	4	8-60	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Bedding	9	65	40	6-24	Rough	Undulating	Moderately Weathered	0	Clay, Iron	Damp
	Bedding	4	91	40	4-18	Rough	Undulating	Moderately Weathered	0	Clay, Iron	Damp
Dripstone Cave Entry - Second Air Door to Cave	Bedding	9	45	40	2-8	Rough	Undulating	Moderately Weathered	0	Clean	Damp
	Bedding	4	104	40	2-8	Rough	Undulating	Moderately Weathered	0	Clean	Damp
	Joint	62	270	2	60-80	Rough	Undulating	Moderately Weathered	10	Calcite	Damp
	Joint	84	114	2	12-24	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	89	91	2	24	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Bedding	12	109	40	2-8	Rough	Undulating	Moderately Weathered	0	Clean	Damp
	Bedding	16	59	40	2-8	Rough	Undulating	Moderately Weathered	0	Clean	Damp
	Bedding	8	359	200	8-14	Rough	Undulating	Slightly Weathered	0	Clean	Damp
Dripstone Cave Bypass Tunnel	Joint	88	161	12	24-36	Rough	Undulating	Highly Weathered	300	Clay	Damp
	Joint	83	340	2	24-36	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	20	195	5	12-24	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Bedding	9	40	200	8-14	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	89	142	1-20	48-120	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	88	149	1-20	48-120	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Bedding	4	324	200	8-14	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	81	84	50	150	Rough	Undulating	Moderately Weathered	0	Clean	Damp
	Joint	89	170	3-10	24-60	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Bedding	9	194	200	8-11	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Bedding	8	326	200	8-11	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	81	270	7	24-48	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	82	262	6	24-48	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	89	89	6	24-48	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	88	270	2-8	36	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	85	275	2-8	36	Rough	Undulating	Moderately Weathered	0	Clean	Damp
Dripstone Cave Exit Tunnel	Bedding	15	190	60	6-18	Rough	Undulating	Moderately Weathered	0	Clean	Damp
	Bedding	9	157	60	6-18	Rough	Undulating	Moderately Weathered	0	Clean	Damp
	Joint	85	31	1-3	4-12	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	81	11	1-3	4-12	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	89	241	2-8	36	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	84	281	2-8	36	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Bedding	16	190	60	6-18	Rough	Undulating	Moderately Weathered	0	Clean	Damp
	Joint	86	350	1-3	4-12	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	89	265	2-8	36	Rough	Undulating	Slightly Weathered	0	Clean	Damp
	Joint	82	19	1-3	4-12	Rough	Undulating	Slightly Weathered	0	Clean	Damp

Notes:

1. "NM" = Not Measured
2. ft = feet
3. in = inches
4. mm = millimeters

3.2 Geotechnical Laboratory Testing

Five samples of cavern roof rock were collected from two loose rock bulk samples that were recently scaled from the cavern roof in the Dripstone Cave Entrance and were submitted to GeoTesting Express Inc. for laboratory geotechnical testing. The tests conducted included the following:

- Unconfined compressive strength (UCS) (ASTM D 7012 - Method D)
- Young's Modulus (ASTM D 7012 – Method D)
- Poisson's Ratio (ASTM D 7012 – Method D)

A total of six rock core samples were cored from the bulk samples at the laboratory for geotechnical testing, however, due to breakage during lab preparation, only five were tested. The complete results of the laboratory testing are presented in Appendix B at the end of this Report.

3.2.1 Testing Results

The roof of the Dripstone Cave Entrance is made up of rock from the Upper and Lower St. Joe Formation. Bulk samples from the other formations present at the Site were not available, so estimates of their geotechnical parameters were made based on typical values for the rock type. Table 3 presents a summary of the laboratory results. Copies of the laboratory reports, including photographs of the rock samples, are included in Appendix B.

Table 3: Laboratory Testing Results

Test	Sample ID	Rock Type / Formation	Broke Before Testing	UCS (psi)	Young's Modulus, E [ksi]	Poisson's Ratio, N	Bulk Density (pcf)	Bulk Specific Gravity
GeoTesting Express 2020 - ASTM D7012D Elastic Moduli of Rock in Uniaxial Compression	DS Roof LS 1	St. Joe (Lower)	No	21,081	27,800	0.46	150	2.40
	DS Roof LS 2	St. Joe (Lower)	No	19,010	37,900	N/A	151	2.42
	DS Roof LS 3	St. Joe (Lower)	No	10,732	11,000	0.28	146	2.34
	DS Roof Clayey 1	St. Joe (Upper)	No	18,047	N/A	N/A	170	2.72
	DS Roof Clayey 2	St. Joe (Upper)	No	16,398	9,840	N/A	150	2.40
	DS Roof Clayey 3	St. Joe (Upper)	Yes	N/A	N/A	N/A	N/A	N/A

Notes:

1. "N/A" Data not available
2. psi = pounds per square inch
3. ksi = thousand pounds per square inch
4. pcf = pounds per cubic foot

4.0 GEOTECHNICAL ANALYSES

The geotechnical analyses for the Site included the following:

- Rock mass classification and rating
- Material geotechnical properties
- Roof beam analysis
- Ground support analysis

- Joint kinematics analysis
- Finite element analysis

Geotechnical analyses and detailed calculations are presented in Appendix C and Appendix D.

4.1 Rock Mass Classification and Material Geotechnical Properties

Estimates of rock mass classifications using the NGI-Q index and the RMR system were carried out for the Boone Limestone, St. Joe (Upper), St. Joe (Lower), Chattanooga Shale, Lafferty Limestone, and Fernvale Limestone roof shale. Parameter values were determined based on the laboratory results and underground inspection performed as part of the geotechnical investigation.

4.1.1 NGI-Q System

The Q index incorporates six different rock parameters for the classification of the overall rock mass quality. The Q system consists of the following parameters (Barton et al., 1974):

$$Q = \left(\frac{RQD}{J_n} \right) \times \left(\frac{J_r}{J_a} \right) \times \left(\frac{J_w}{SRF} \right)$$

Where:

RQD = Rock Quality Designation

J_n = Joint Set number

J_r = Joint Roughness number

J_a = Joint Alteration number

J_w = Joint Water Reduction Factor

SRF = Stress Reduction Factor

For the rock mass characterization, the parameters were collected during the underground inspection. The stress reduction factors (SRF) were assumed to be 1 (medium stress) based on the rock strength, stress conditions, field observations, and professional judgement. Table 4 summarizes the Q rating for each unit based on the underground inspection.

Table 4: Summary of the Q Values by Formation

Formation	RQD	Jn	Jr	Ja	Jw	SRF	Q Rating	Class Description
Boone Limestone	79	9.0	3.0	1.8	0.66	1.0	10	Fair
St. Joe (Upper)	70	12.0	3.0	1.8	0.66	1.0	6	Fair
St. Joe (Lower)	90	9.0	3.0	1.2	0.66	1.0	17	Good
Chattanooga Shale	40	12.0	2.5	1.8	0.66	1.0	3	Poor
Lafferty Limestone	90	9.0	3.0	1.2	0.66	1.0	17	Good
Fernvale Limestone	90	9.0	3.0	1.2	0.66	1.0	17	Good

The analysis of rock mass quality, using the index developed by NGI, indicates the rock quality in the roof of the assessment areas is generally fair, while the limestone units in the floor and side walls are generally good quality. The Chattanooga Shale, which is present in thicknesses ranging from 2.5 to 4.0 feet in the side walls of the assessment areas, is generally poor quality. It should be noted that the NGI-Q system does not account for rock strength and is primarily a measure of the rock mass structure and condition of the discontinuities.

4.1.2 Rock Mass Rating

The RMR system assigns ratings based on the following five parameters (after Bieniawski, 1976 with subsequent updates in 1989):

- R1 = Rating based on uniaxial compressive strength of rock material
- R2 = Rating based RQD
- R3 = Rating based on Spacing of Discontinuities
- R4 = Rating based on Conditions of Discontinuities
- R5 = Rating based on Groundwater Conditions
- Rating Adjustment based on Discontinuity Orientations

Where:

$$RMR_{89} = R1 + R2 + R3 + R4 + R5 + \text{Rating Adjustment}$$

Since the various parameters are not equally important for the overall classification of a rock mass, importance ratings are allocated to the different value ranges of the parameters, with a higher rating indicating better rock mass conditions. The ratings for the five parameters are added to define the RMR values representing the rock mass condition of the formation under consideration. Five rock mass classes, based on the RMR values, classify the rock mass conditions from Very Good Rock ($RMR > 80$) to Very Poor Rock ($RMR \leq 20$). For the RMR classification, the first four parameters (R1-R4) were taken from the laboratory testing and field observations. The

groundwater parameter (R5) was assigned as 7 (wet) based on field observations. The Rating Adjustment was assigned based on field observations and the relative dip angles of the discontinuities.

Table 5 summarizes the RMR '89 rating for each formation using data from the field observations. Classification parameters and their ratings were evaluated for the given formation in each assessment area and overall classification parameters were calculated from these to give an overall RMR value for each formation. The analysis of RMR indicates the rock quality in the roof of the assessment areas is generally fair while the quality in the limestone units in the floor and side walls is generally good. The Chattanooga Shale, which is present in thicknesses ranging from 2.5 to 4.0 feet in the side walls of the assessment areas, is generally poor quality.

Table 5: Summary of RMR 89 Values by Formation

Formation	R1		R2		R3		R4	R5	Rating Adj.	RMR '89 Rating	Class Description
	Geomean UCS (psi)	Rating	Avg. RQD	Rating	Avg. Discontinuity Spacing (ft)	Rating					
Boone Limestone	14,000	9	79	16	0.3	8	22	7	-5	57	Fair
St. Joe (Upper)	17,203	12	70	14	0.7	9	18	7	-5	55	Fair
St. Joe (Lower)	16,262	12	90	19	1.2	10	22	7	-5	65	Good
Chattanooga Shale	2,600	4	40	8	0.7	9	16	7	-5	39	Poor
Lafferty Limestone	14,000	9	90	19	1.5	12	22	7	-5	64	Good
Fernvale Limestone	14,000	9	90	19	1.5	12	22	7	-5	64	Good

Notes:

1. psi = pounds per square inch
2. RQD = Rock Quality Designation
3. ft = feet

4.1.3 Material Geotechnical Properties

Hoek Brown classification and equivalent Mohr-Coulomb cohesion and friction angle were calculated for the formations using the computer program RocData™ from RocScience. Calculations were made using the geometric mean UCS and Young's Modulus laboratory result values for the Upper St. Joe and Lower St. Joe formations. Bulk samples from the other formations present at the Site were not available to be tested, so estimates of their geotechnical parameters were made based on typical values for the rock types. Geological Strength Index (GSI) values were estimated for each formation based on observed discontinuity condition and spacing. The rock mass modulus (E_{rm}) was calculated from the intact Young's modulus, GSI, and disturbance factor of the rock using a formula developed by Hoek and Dierderichs (2006). Material properties used in the geotechnical analyses are summarized in Table 6 below.

Table 6: Summary of Material Properties Used in Geotechnical Analyses

Rock Type	Unit Weight (pcf)	UCS (psi)	Young's Modulus, E (ksi)	Poisson's Ratio	Geological Strength Index (GSI)	Generalized Hoek-Brown Parameters				Young's Modulus of the Rock Mass, E _{rm} (ksi)	Mohr-Coulomb	
						m _i	m _b	s	a		Phi	C (psi)
Boone Limestone	165.0	14,000	9,800	0.26	73	10	3.813	0.050	0.501	7,615	57.0	438
St. Joe (Upper)	149.0	17,203	9,840	0.32	62	7	1.802	0.015	0.502	5,563	56.0	309
St. Joe (Lower)	160.0	16,262	11,000	0.36	73	10	3.803	0.050	0.501	8,638	58.0	505
Chattanooga Shale	145.0	2,600	520	0.30	44	6	0.812	0.002	0.509	109	48.0	40
Lafferty Limestone	165.0	14,000	9,800	0.26	73	10	3.813	0.050	0.501	7,696	58.0	435
Fernvale Limestone	165.0	14,000	9,800	0.26	73	10	3.813	0.050	0.501	7,696	58.0	435

Notes:

1. pcf = pounds per cubic foot
2. psi = pounds per square inch
3. ksi = thousand pounds per square inch

4.2 Roof Beam Analysis

The maximum design span was determined empirically using the following chart, developed by Pakalnis and Vongpaisal (1993) and Pakalnis and Brady (2004). The design span chart uses RMR '76 values, which were estimated using the RMR '89 values presented in Section 4.1.2 using the relationship $RMR\ '76 = RMR\ '89 - 5$ (Hoek and Kaiser, 1997). The two RMR methods differ in the weight they give to discontinuity conditions.

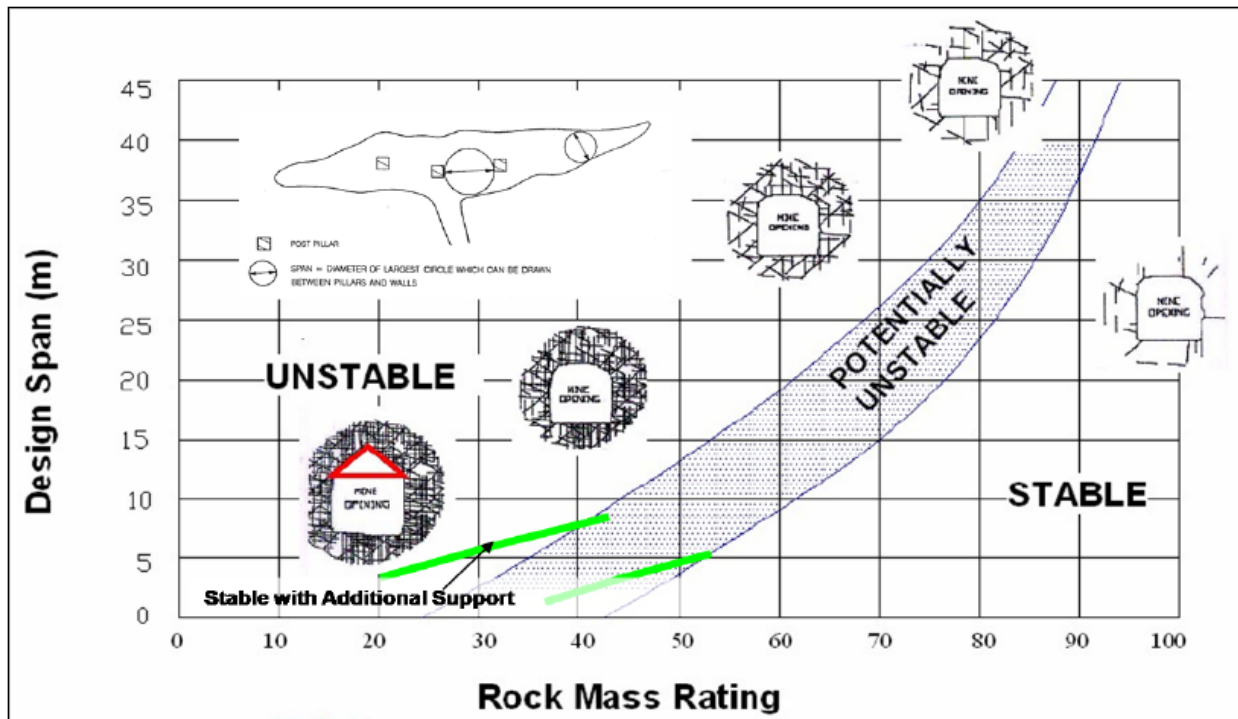


Chart Enlargement

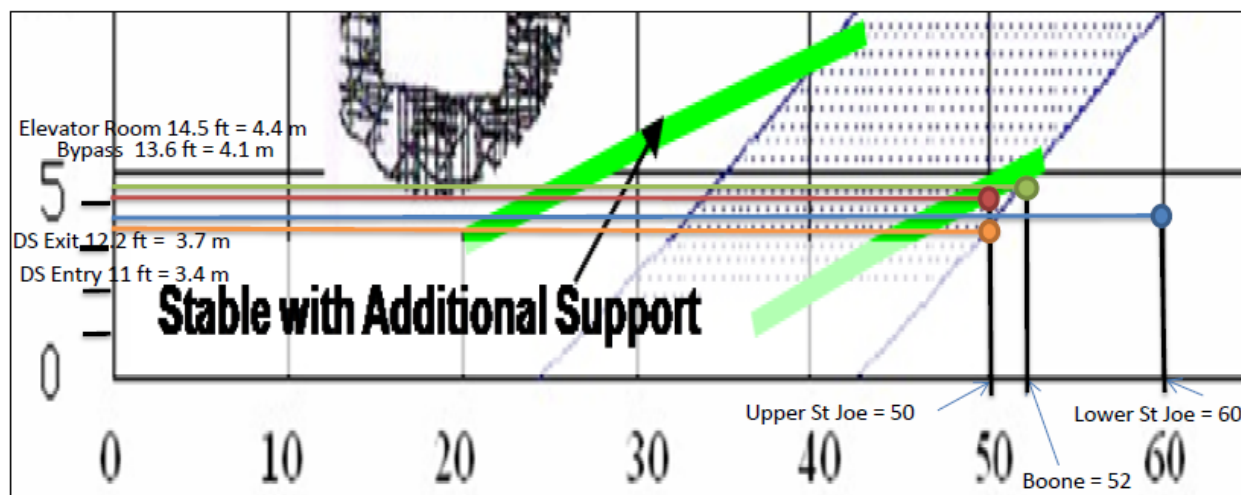


Figure 5: Empirical Design Span Chart

According to the empirical relationships in the above figure, the unsupported span openings in the Elevator Room, Dripstone Cave Bypass Tunnel, and Dripstone Cave Entrance are “potentially unstable”. The span in the Dripstone Cave Exit plots in the “stable” area of the chart. This design span chart was developed for mining applications from cut and fill stopes and defines a stable span as standing for 3 months. The design life of the Blanchard Springs Cavern tunnels is much greater than a typical mining application. Also, the chart does not factor in the effects of rock support and therefore represents conditions before supports are in place. It is

important to note that these charts provide estimated ranges for span stability. Localized conditions may result in more or less stability. Also, it is important to note that the life span “to date” for these rooms, since the 1970s, has also far exceeded this time span, generally with no visible instability except in the Dripstone Cave Entrance. This indicates conservatism in the material properties and analysis.

The stability of an unsupported roof beam was analyzed using Golder's Roof Beam Analysis spreadsheet, which calculates Factor of Safety (FS) values against crushing and buckling values based on an algorithm developed in Diederichs and Kaiser (1999). The maximum room span of each assessment area was analyzed. Each assessment area was analyzed to determine the minimum stable roof beam thickness at which the onset of potential buckling failure occurs. Discontinuity spacing present in the immediate roof less than these values will be in danger of buckling. Results of the analyses are summarized in Table 7 and presented in more detail in Appendix D

Table 7: Roof Beam Analysis FS Crushing and Buckling Limits

Result Parameter	Elevator Room (Boone Limestone)	Dripstone Cave Entry (Upper St. Joe)	Dripstone Cave Bypass Tunnel (Upper St. Joe)	Dripstone Cave Exit (Lower St. Joe)
Factor of Safety - Crushing	14.7	25.7	22.8	19.4
Factor of Safety - Sliding	62.8	65.4	59.7	74.2
Buckling Limit ⁽¹⁾	0.35	0.29	0.29	0.29
Minimum Stable Beam Thickness (feet)	0.20	0.16	0.21	0.16
Minimum Stable Beam Thickness (inches)	2.4	1.9	2.5	1.9

Notes:

1) Buckling Limits above 0.35 should be further examined due to potential failure. 0.02 is the lower limit of the buckling limit equation. A Buckling limit of 1.0 represents buckling failure.

The roof beam analysis suggests that the formations present in the roof of the assessment areas are capable of forming relatively thin stable beams. Due to the small span sizes, minimum stable beam thickness was calculated to be on the order of 1.9 to 2.5 inches. However, weathering over time and the effects of progressive-type failure could cause the roof conditions to degrade and for loose rock to occur if not supported, as evidenced by the current underground conditions.

It should be noted that these are two-dimensional analyses that do not take into account cases where the roof beam is open or unbound on one side, such as where the elevator shaft is present on one side or in the Dripstone Cave Entrance and Dripstone Cave Bypass Tunnel, where the tunnels enter into the large cavern area. The beam stability is therefore only being evaluated “across” sections that are constrained by the rock mass on both sides, and stability is decreased anywhere there is a “brow” that causes a discontinuous beam.

4.3 Ground Support Analysis

The permanent conditions of the maximum span were checked using the Empirical Support Design Chart shown in Figure 6, developed by Grimstad and Barton (1993) and revised by the Norwegian Geotechnical Institute (2015). The chart recommends support designs for underground excavations based on the relationship between the Equivalent Dimension (D_e) of the room and the NGI-Q value of the different formations that form the roof in the

assessment areas. D_e is defined by dividing the proposed span by a quantity called the Excavation Support Ratio (ESR). The value of ESR is related to the intended use of the excavation and to the degree of security which is demanded of the support system installed to maintain the stability of the excavation. An ESR of 0.8 was selected for this facility on the basis of the tunnels being categorized as a public facility. NGI-Q values for the Boone Limestone (10), Upper St. Joe (6), and Lower St. Joe (17) calculated earlier were used in the analysis. This resulted in all areas except for the Dripstone Cave Exit falling in the Number 3 (systematic bolting) category for the corresponding spans, as shown in Figure 6. The chart also suggests bolt lengths of 9.8 to 10.5 feet on spacings of 5.9 to 6.6 feet. In addition to bolts, 5-6 cm of fiber reinforced shotcrete and/or welded wire mesh may be applied.

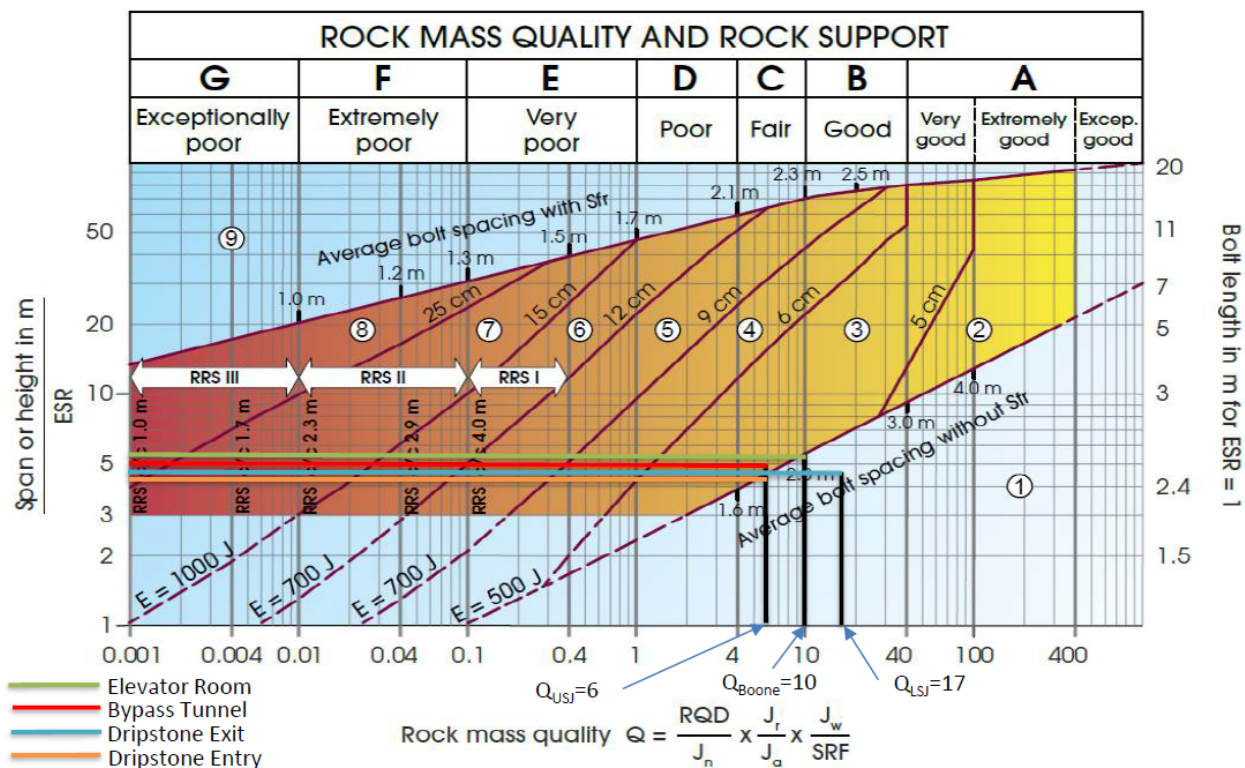


Figure 6: Empirical Support Design Chart (after NGI, 2015)

Barton (1974) suggests the following equation to evaluate the roof bolt length (L) based on design span and ESR, where L is the roof bolt length in meters, B is the design span in meters, and ESR is the Excavation Support Ratio as defined above.

$$L = 2 + 0.15 \left(\frac{B}{ESR} \right)$$

Using this equation results in the following suggested bolt lengths:

- Elevator Room – D_e of 5.5 resulted in a Bolt Length (L) of about 2.8 m (9.3 ft)

- Dripstone Entry – De of 4.3 resulted in a Bolt Length (L) of about 2.6 m (8.6 ft)
- Dripstone Cave Bypass Tunnel – De of 5.1 resulted in a Bolt Length (L) of about 2.8 m (9.1 ft)
- Dripstone Cave Exit – De of 4.6 resulted in a Bolt Length (L) of about 2.7 m (8.8 ft)

The US Army Corps of Engineers (USACE) (USACE, 1980) recommends that maximum bolt spacing be equal to the lesser of $\frac{1}{2}$ the bolt length or 6 ft. Bolt spacings greater than 6 feet make the attachment of surface treatments difficult. For the assessment areas, this results in spacings of 4.3 to 4.6 feet, per this recommendation.

The bolt lengths recommended by the empirical methods above are likely not feasible. Tunnel height limits the length of rockbolts that can be successfully installed, and the roof beam analysis and Golder's underground inspection suggest that only a relatively thin section of rock needs to be held together to form a self-supporting roof beam.

Therefore, maximum supportable rock thickness was also calculated for several bolt type and length configurations over a range of spacings. #5 (5/8-inch diameter) and #6 (3/4-inch diameter) 75 ksi steel threaded rebar rockbolts with lengths of 6 feet to 8 feet were used in the analysis. Square bolt patterns were analyzed with spacings ranging from 2-ft to 9-ft. A FS value of 2.0 and average specific gravity of rock in the back of 2.6 was used in the calculations. At 4-foot by 4-foot bolt pattern spacing, there is not much appreciable difference between the capacities of the #5 and #6 bolts. 6-foot long bolts were shown to be able to support a rock thickness of up to approximately 3 feet and 8-foot long bolts were shown to be able to support a thickness of up to approximately 4.8 feet. A weak grout bond strength (9,100 lb/ft) was assumed in the analysis.

In conditions such as those in the tunnels, with relatively flat, limestone roofs with generally low jointing/fracturing, Golder does not typically recommend placement of shotcrete as primary roof support. Shotcrete can be an effective measure for controlling and replacing deteriorated weak wall materials, as are present in some locations where the Chattanooga Shale is present in the tunnel walls.

Where small material may occasionally fall over time, especially from the roof, use of welded wire mesh is generally sufficient and preferable. Welded wire mesh can also be installed with relatively little effort required to avoid environmental impacts or excessive noise.

4.4 Finite Element Analyses

As part of the evaluation, a two-dimensional computer stress model of four of the critical assessment areas (Elevator Room, Dripstone Cave Entry, Dripstone Cave Bypass Tunnel, and Dripstone Cave Exit) was created using the finite element software RS2TM (version 2.012), developed by Rocscience. The model is used to evaluate stress conditions in the excavations and the capacities of ground support.

4.4.1 Model Inputs and Method

The following figures summarize the assessment area geometries analyzed in RS2. The geometry and material stratigraphy for each assessment area were determined based on measurements of the maximum span and excavation height during the geotechnical investigation. The model was run initially unexcavated to allow settling of the material under gravity loading. The current excavation conditions were then modeled in one stage, and a second stage was modeled with the ground support recommendations in place.

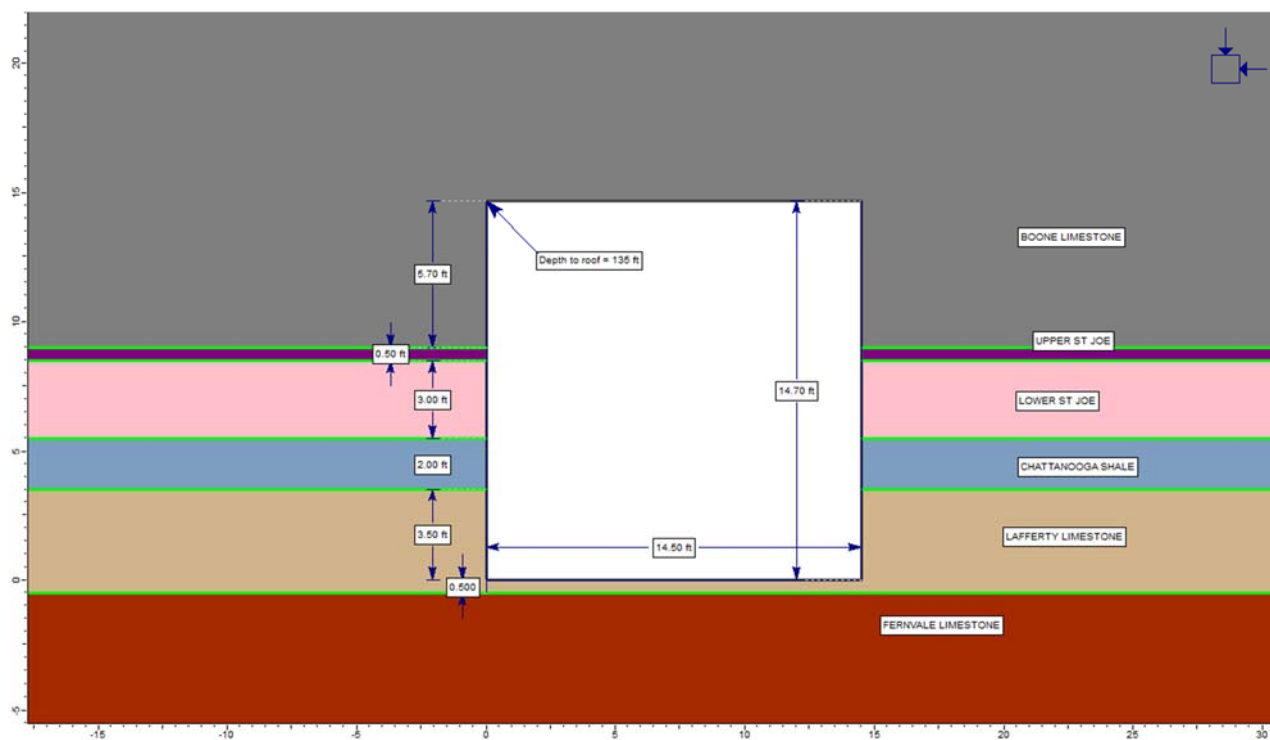


Figure 7: Elevator Room RS2 Model Geometry

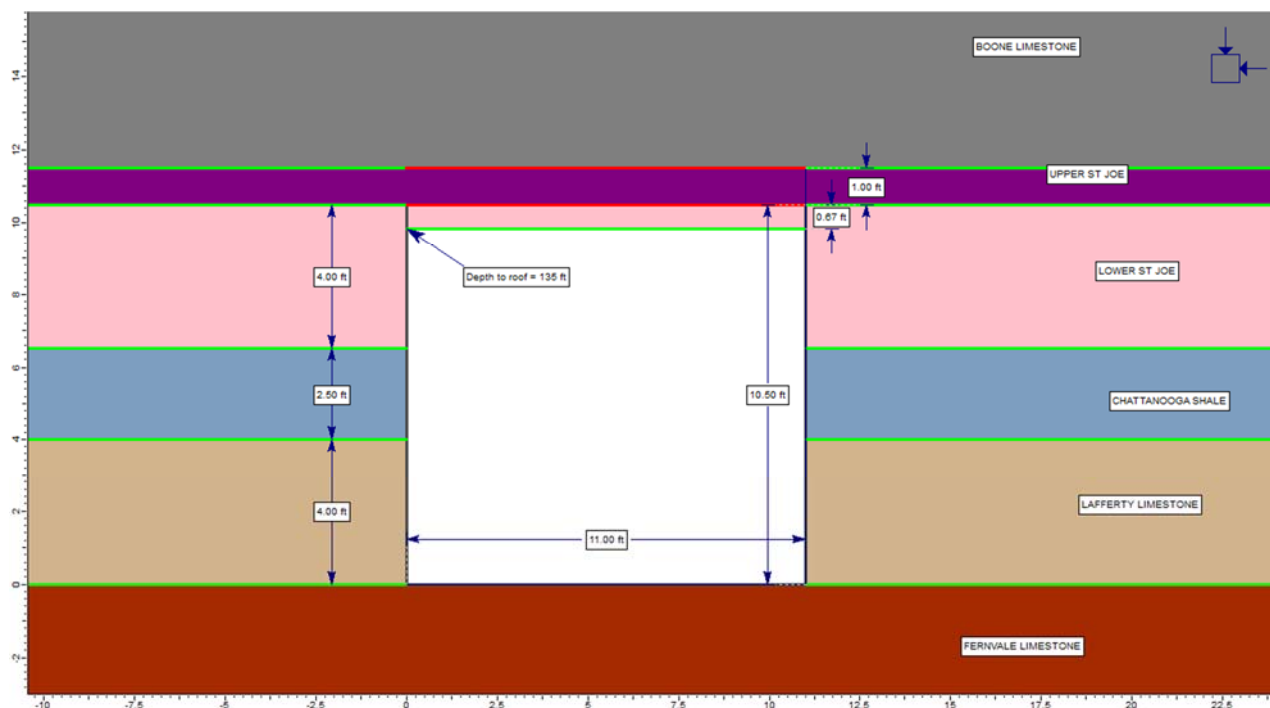


Figure 8: Dripstone Cave Entrance RS2 Model Geometry

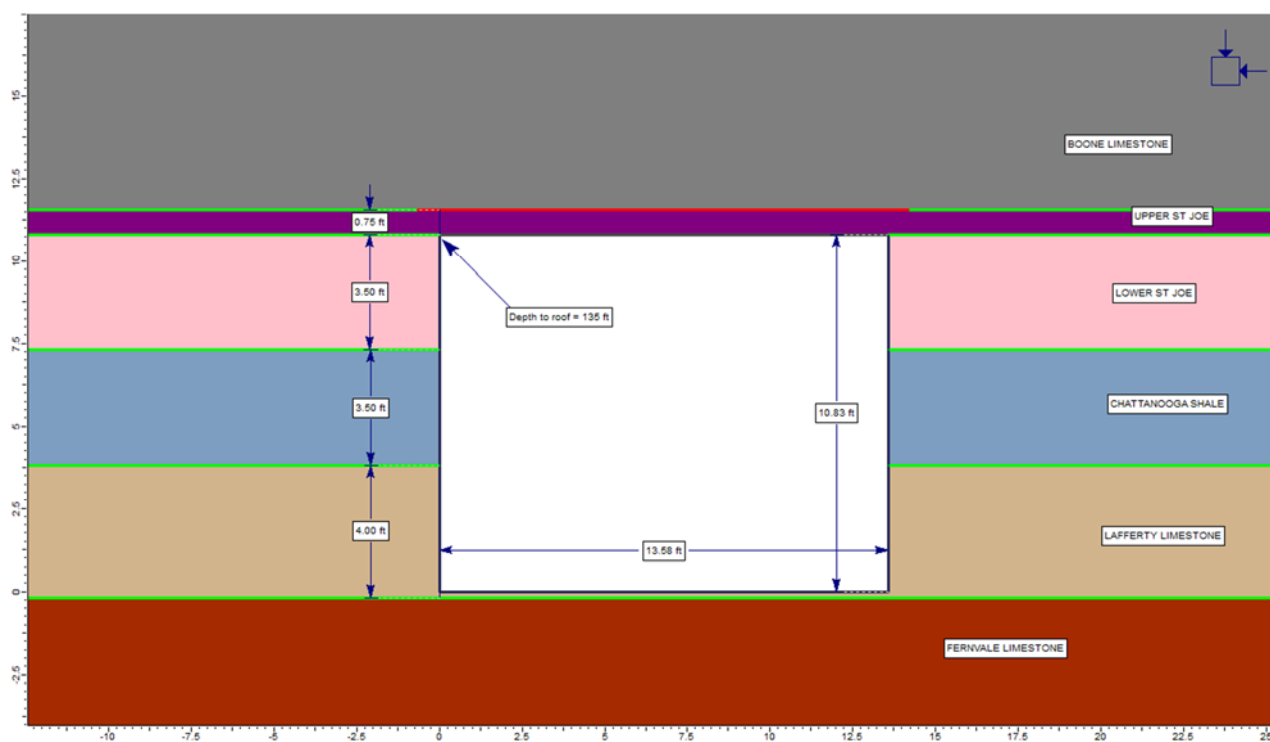


Figure 9: Dripstone Cave Bypass Tunnel RS2 Model Geometry

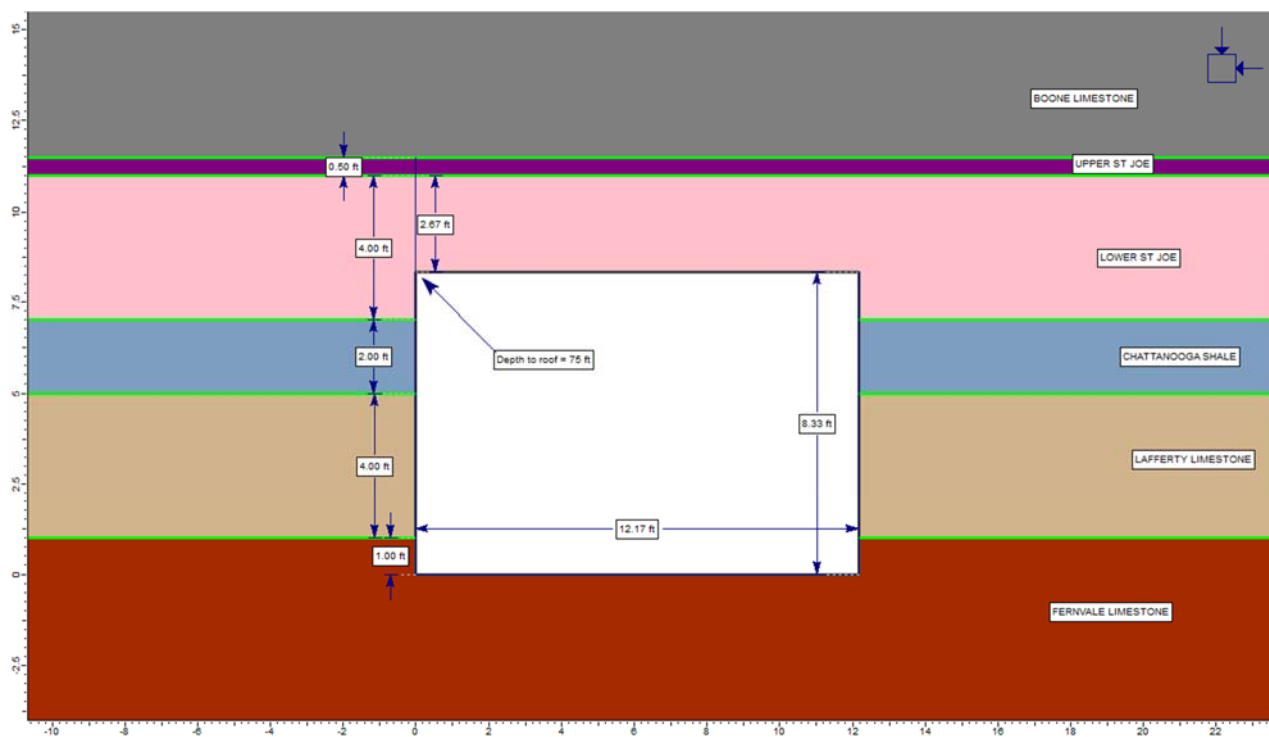


Figure 10: Dripstone Cave Exit RS2 Model Geometry

All materials were modeled using the Generalized Hoek-Brown failure criteria, assuming elastic-perfectly-plastic behavior. The input properties were calculated based on field data and Site observations in the assessment areas and are summarized in Table 6 in Section 4.1.3. The material stiffness for each unit was calculated using the Generalized Hoek-Diederichs (2006) method. The calculation of this value for each unit, as well as the theoretical background on this method, is summarized in Appendix C.

4.4.2 RS2 Model Results

Detailed plots showing the model setup, stress conditions, yielding, displacement, and strength factor for each case are included in Appendix E. Model results indicate that roof beam failure mechanisms are not dominant in any of the tested assessment areas. Complete sidewall failure is not observed in any of the models, but part of the sidewall in all cases has a strength factor of 1.0 to 1.5 in the Chattanooga Shale Formation. This fits with the weathered condition observed in the Chattanooga Shale during the geotechnical investigation. Strength factors less than 1.0 represent failure. Other key observations from the models are summarized below:

- Maximum total displacements were observed in the Chattanooga Shale Formation in each model, as the stresses in the surrounding rock and low relative strength and stiffness properties of the shale result in the formation squeezing out into the excavation. However, maximum displacements are still relatively small, and are as follows for each assessment area:
 - Elevator Room – 0.0037 ft (0.04 inches)
 - Dripstone Cave Entrance – 0.0032 ft (0.04 inches)
 - Dripstone Cave Bypass Tunnel – 0.0074 ft (0.09 inches)
 - Dripstone Cave Exit - 0.0011 ft (0.01 inches)
- Strength factors in the immediate roof of each assessment area maintain values greater than approximately 2.0 with the addition of the recommended ground support.

5.0 GEOTECHNICAL RECOMMENDATIONS

Based on the results of Golder's geotechnical Site investigation and analyses, the following subsections detail the geotechnical design criteria and ground support recommendations in each of the evaluated assessment areas. The geotechnical analyses discussed in Section 4.0 and detailed in Appendix D suggest the use of additional ground support in the Elevator Room, Dripstone Cave Entrance, Dripstone Cave Bypass Tunnel, and Dripstone Cave Exit. Due to the relatively long design life and use as a public facility, Golder recommends that ground support be added to each area.

5.1 Design Criteria

The follow section outlines design criteria related to geotechnical ground support recommendations.

- The Forest Service desires a 40- to 50-year life for the assessment areas. Appropriate construction materials should be considered for the ground support.
- Ground support systems shall be designed with a FS of 2.0

- Given the hours of operation, contractor work will need to be scheduled from approximately 6 pm to 8 am or 9 am. Contractor work will need to be scheduled and Site tour logistics will need to be considered in advance.
- To the extent possible, and within the constraints of the other design criteria, modifications to the cave and finish surface treatments of the ground support system should be aesthetically pleasing
- The Forest Service desires ground support solutions that require the least amount of maintenance over time.
- It is of paramount importance that the environment be protected during construction.
 - When work is conducted inside the airlock doors, it will be necessary to put up a temporary stopping/air curtain to prevent any mist, fumes, dust, etc. from entering the cave.
 - It will also be necessary/critical to ensure that no impacted water (dust, concrete, oils, etc.) enters the cave. In work areas that slope towards the cave, this will require berms and pumping of all water into a storage tank, which must be capable of being removed via the access for the respective work area, if they cannot be pumped from the cave.
 - It will also be necessary to control noise levels as much as possible. Noise reduction methods must be approved by the Forest Service and proven effective by on-site testing. Methods could include temporary bulkhead construction using noise insulating material, temporary air curtains, or other approved methods.
 - No gasoline equipment, and preferably no diesel equipment, to be located underground.
- The Forest Service desires practical instrumentation and monitoring options that are relatively easy to understand and implement.

5.2 Elevator Room and Dripstone Cave Entrance Support Recommendations

Work at the Elevator Room and Dripstone Cave Entrance is the highest priority work and will likely be conducted first and/or in the first mobilization. Work includes replacement of the airlock door systems (as outlined in Section 6.0) and installation of permanent ground support (rockbolts, welded wire mesh, and shotcrete) through the entry tunnel; scaling; demolition and replacement of existing false ceilings and utilities/ducting, and protection of existing features. Due to the complexity of this area, work is divided into three sections.

5.2.1 Elevator Room

This area includes the elevator doors to the first airlock door. Anticipated scope includes:

- Install water control at or past first airlock door, including all controls during operation (water pumping, etc.)
- Protect floor, elevator doors, and wing walls during scaling
- Demolish suspended ceiling and remove or protect overlying ducting/utilities, as needed
- Scale tunnel to remove loose rock from the ceiling and upper sidewalls
- Install 6-foot long, #5 fully resin grouted threaded rebar rockbolts on 4-foot centers

- Install 8-foot long, #5 fully resin grouted threaded rebar rockbolts on 4-foot centers in first two perimeter rows adjacent to elevator and stair shaft
- Pressure wash and clean all areas at close of work
- Install shoe-clean trough at inby end of work area at end of each day if returned to service, to prevent transport of any oil, dust, etc. into the cave
- Reinstall ductwork and utilities (if removed) and install new suspended ceiling. Ceiling panel design/type shall be approved by the Forest Service

5.2.2 Outer Airlock Door to Inner Airlock Door

Anticipated scope includes:

- Install water control at or past second airlock door, including all controls during operation (water pumping, etc.)
- Protect overlying electrical utilities, as needed
- Scale tunnel to remove loose rock from the ceiling and upper sidewalls
- Install 6-foot long, #5 fully resin grouted threaded rebar rockbolts on 4-foot centers
- Install welded wire mesh on the ceiling, supported by the rockbolt heads
- Demolish pipe and chain link cover
- Pressure wash and clean all areas at close of work
- Install shoe-clean trough at both ends of work area at end of each day, if to be returned to service, to prevent transport of any oil, dust, etc. into the cave
- Install utility tray for support of existing utility lines

5.2.3 Inner Airlock Door to Cave Interface

Anticipated scope includes:

- Install water control and air stop at the edge of the work area
- Protect floor wing walls, and utilities during scaling
- Scale tunnel to remove loose rock from the ceiling and upper sidewalls. Protection of underlying structures. Existing timbers and steel beams will be removed
- Install 6-foot long, #5 fully resin grouted threaded rebar rockbolts on 4-foot centers
- Install two rows of 8-foot long, #5 fully resin grouted threaded rebar rockbolts on 4-foot centers at the cavern interface end of this area
- Install a minimum of 4-inches of fiber-reinforced shotcrete with unreinforced finish coat; or, as an alternate, mesh-reinforced shotcrete on the left-hand sidewall (facing the cave)

- Install welded wire mesh on the ceiling, supported by the rockbolt heads
- Install crack gauge monitor devices across exposed bedding planes at cavern interface
- Install mechanical extensometer (telltale) warning device at interface with natural cavern
- Pressure wash and clean all areas at close of work
- Install shoe-clean trough at inby end of work area at end of each day, to prevent transport of any oil, dust, etc. into the cave

5.3 Dripstone Bridge Recommendations

During the underground inspection, Golder performed a visual inspection of conditions of the bridge near the cavern interface at Dripstone Cave Entrance that supports the tour pathway. The bridge abutments are constructed of limestone masonry over an approximately 18-foot diameter corrugated metal archway that has a surface coating to prevent corrosion. Conditions of the bridge appeared generally good during the visual inspection. No signs of fractures or stress cracks were observed in the masonry abutments and the coating on the metal archway appears sound. Some mortar loss was evident on the lower sides of the abutment on the side of the bridge towards the Dripstone Cave Entry. Golder recommends that tuckpointing of the masonry be performed.

5.4 Dripstone Cave Bypass Tunnel Support Recommendations

Work at the Dripstone Cave Bypass Tunnel includes installation of permanent ground support (rockbolts and welded wire mesh). Golder assumes that larger equipment and supplies can be manually brought in via paths from doors from outside and that air, water, and small supplies may be lowered down the shaft. Anticipated scope to include:

- Install stopping and water control at interface between tunnel and natural cave at both ends of the tunnel, including all controls during operation (water pumping, etc.)
- Scale tunnel to remove loose rock from the ceiling and sidewalls
- Install 6-foot long, #5 fully resin grouted threaded rebar rockbolts on 4-foot centers
- Install two rows of 8-foot long, #5 fully resin grouted threaded rebar rockbolts on 4-foot centers at the beginning (towards the dripstone cave entrance) of this area
- Install welded wire mesh on the ceiling, supported by the rockbolt heads
- Install crack gauge monitor devices across exposed bedding planes at cavern interface on both ends of the tunnel
- Install mechanical telltale warning device at both ends of the tunnel
- Pressure wash and clean all areas at close of work
- Install shoe-clean trough at both ends of work area at end of each day, to prevent transport of any oil, dust, etc. into the cave

5.5 Dripstone Cave Exit Support Recommendations

Work at the Dripstone Cave exit is anticipated to include replacement of the door systems (as outlined in Section 6.0) and installation of permanent ground support (rockbolts, welded wire mesh, and shotcrete) through the tunnel. Work areas will be returned to service in safe-to-access conditions each morning. During the geotechnical investigation, Golder inspected the existing canopy structure between the outer airlock door and security doors that is composed of steel I-beams and plate roofing with supporting masonry/steel column supports. The structure itself is in relatively poor condition due to deterioration/weathering of the steel. The void space between the steel plating and tunnel roof has been filled with masonry/cement. Rock conditions behind the structure were not visible but are assumed to be poor to necessitate the support structure. Therefore, it is recommended that the structure be demolished and replaced with structural shotcrete.

Due to the complexity of this area, work is divided into three sections.

5.5.1 Cave Interface to Inner Airlock Door

Anticipated scope to include:

- Install stopping and water control at interface between tunnel and natural cave, including all controls during operation (water pumping, etc.)
- Scale tunnel to remove loose rock from the ceiling and sidewalls
- Install 6-foot long, #5 fully resin grouted threaded rebar rockbolts on 4-foot centers
- Install two rows of 8-foot long, #5 fully resin grouted threaded rebar rockbolts on 4-foot centers at the cavern end of this area
- In locations where potential for raveling has been identified, install limited welded wire mesh (2-3 panels) on the ceiling, supported by the rockbolt heads
- Install crack gauge monitor devices across exposed bedding planes at cavern interface
- Install mechanical telltale warning device at interface with natural cavern
- Pressure wash and clean all areas at close of work
- Install shoe-clean trough at inby end of work area at end of each day, to prevent transport of any oil, dust, etc. into the cave

5.5.2 Inner Airlock Door to Outer Airlock Door

Anticipated scope to include:

- Install stopping and water control at or before the first airlock door, including all controls during operation (water pumping, etc.)
- Scale tunnel to remove loose rock from the ceiling and sidewalls
- Install 6-foot long, #5 fully resin grouted threaded rebar rockbolts on 4-foot centers
- Install welded wire mesh on the ceiling, supported by the rockbolt heads

- Pressure wash and clean all areas at close of work
- Install shoe-clean trough at inby end of work area at end of each day, to prevent transport of any oil, dust, etc. into the cave

5.5.3 Outer Airlock Door to Security Door

Anticipated scope to include:

- Install stopping and water control at or before the second airlock door, including all controls during operation (water pumping, etc.).
- Demolish steel beam and plate roofing with supporting masonry/steel column supports, with caution due to unknown conditions behind this structure
- Scale tunnel to remove loose rock from the ceiling and sidewalls
- Install 6-foot long, #5 fully resin grouted threaded rebar rockbolts on 4-foot centers
- Install welded wire mesh on the ceiling, supported by the rockbolt heads
- Install a minimum of 12 inches of fiber-reinforced structural shotcrete with non-fiber finish coat in this area
- Pressure wash and clean all areas at close of work
- Install shoe-clean trough at inby end of work area at end of each day, to prevent transport of any oil, dust, etc. into the cave

5.6 Discovery Cave Exit Recommendations

Work at the Discovery Cave is expected to be limited to replacement of the door systems as discussed in Section 6.0. During the geotechnical investigation, existing conditions in the Discovery Cave Exit appeared relatively good. Golder probe drilled the existing shotcrete and steel beam ground support during the underground inspection and found that shotcrete appears to be up to 12 inches thick and in good condition. Drainage strips are present above the shotcrete that drain most water to the sidewall and there are two rows of rockbolts on 5 to 6-foot centers installed through a metallic C-channel above the shotcrete. The installed support appears to be functioning adequately, and therefore no additional ground support is recommended at this time.

5.7 Surface Sinkhole Area Recommendations

Golder inspected the surface sinkhole area that is present on the hillside adjacent to the Discovery Cave Exit during the initial Site visit. The sinkhole appears to be approximately 12 feet in diameter and at least 15 feet deep. Security of the cave is the primary concern. Golder proposes that the sinkhole be filled with crushed limestone, which will allow natural water and air to flow into the cave and is the same material that makes up the cave environment. Golder also recommends that a water diversion berm be constructed to divert surface water from the adjacent roadway and limit man-made water inflows.

5.8 Recommendations for Instrumentation and Future Monitoring

As discussed in the above sections, Golder recommends the installation and routine monitoring of several ground instrumentation devices in the assessment areas.

It is recommended that crack gauge monitors be installed in several places across exposed bedding planes in the rock face at the interface between the tunnels and the natural cavern. These gauges would be monitored during future routine inspections by the Forest Service geologist, and initially more frequently by on-site Forest Service personnel until a pattern showing no movement is established. It is advisable to have additional crack gauges on-site. These instruments, such as the Humboldt Crack Gauge Plus shown in Figure 11, are economical and are simple to install and read. Should site personnel observe what appears to be a new crack in the roof rock, an additional crack gauge can quickly be installed across the crack and possible movement will be observed and quantifiable. Installation using epoxy to anchor the gauges is common.

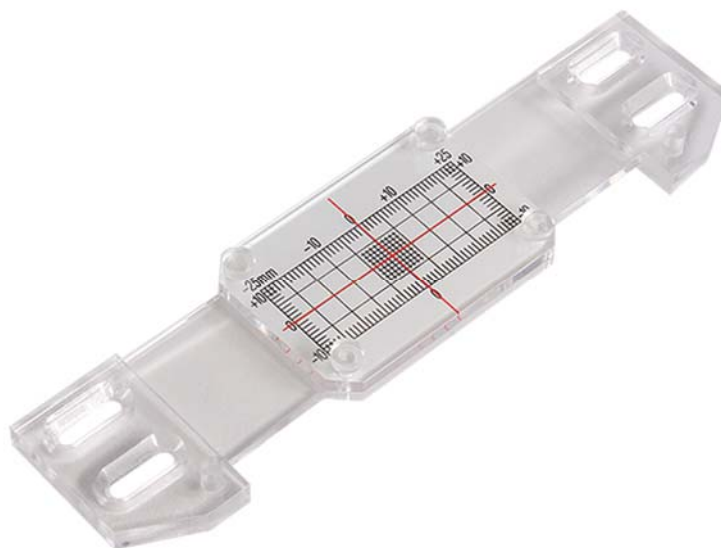


Figure 11: Example Crack Gauge

It is also recommended that mechanical telltale monitoring devices be installed in the roof rock in several areas near the interface between the tunnels and natural cavern. These devices are relatively low cost, visual tools for monitoring movement in a tunnel roof. They are installed in vertical boreholes in the tunnel roof and spring anchors attached to wires are connected to a visual indicator measurement mechanism. Any dilation or bed separation of the strata will appear to pull the indicators along their axis showing how much the anchor has moved relative to the roof. Several options exist, including the Trolex RockMonitor XM Telltale, which are low profile and can be configured with up to four measurement heights, or Trolex RMT Auto-Warning Telltale (AWTT), as shown in Figure 12, which have a single anchor point but include LED's for indication of movement above a set threshold.



Figure 12: Example Telltale Device

6.0 AIRLOCK DOORS AND SECURITY DOORS

The existing airlock and security doors were installed in the 1970s and have deteriorated considerably over approximately the last 50 years. The doors are generally constructed of aluminum and glass, both materials which have helped the doors withstand the cave's corrosive environment, while security doors are of steel and aluminum construction. The cave receives a high volume of visitors each year, ranging from small children to the elderly, and the doors must be safe and useable for pedestrian and wheelchair access. Besides safe access, the primary purpose of these doors is to seal the cave and protect its natural environment while also keeping wildlife and unauthorized persons out of the cave.

In total, 9 sets of doors were reviewed by Golder which are summarized below:

- Dripstone Cave Entrance airlock doors (2 sets)
- Dripstone Cave Exit airlock doors (2 sets)
- Dripstone Bypass Tunnel door (1 set)
- Dripstone Cave Exit security doors (1 set)
- Discovery Cave Exit security doors (1 set)
- Discovery Cave Exit airlock doors (2 sets)

Golder completed a Site visit and field investigation to better understand the purpose of the doors, specific design criteria for door selection and design, and to evaluate the current condition of each door set in order to prepare this report of findings and recommendations.

6.1 Design Criteria

The follow section outlines design criteria related to replacement of the door sets.

- The Forest Service desires a 40- to 50-year life for the doors. Appropriate construction materials should be considered for the doors.
- The airlock doors do not need to be full glass doors. However, glass doors can be transparent to allow the tour guides to see through and keep track of tour members. A door with a window may suffice.
- The airlock doors should eliminate the unnatural exchange of air due to broken or missing transom panels.
- The doors should eliminate unnatural access by wildlife.
- The airlock door system must be able to accommodate a tour of approximately 40 people.
- The doors need to be at least seven feet tall by three feet wide to accommodate most cave visitors.
- The airlock doors must be safe and useable for pedestrian and wheelchair access applications, for a wide range of visitors including children and the elderly.
- Handrails are needed for safety and to guide visitors on tour groups. Handrails should be replaced in all locations after door installation and adjacent construction is complete.
- Only the Dripline Cave Exit and Discovery Cave Exit Security Doors require a locking mechanism. All doors should provide a latching mechanism. These doors should use factory finished fiberglass reinforced plastic (FRP) and contain a removable mullion if double doors are installed.
- All doors should have closers.
- All doors should have latching hardware to keep the door in the closed position. This should be a rim style exit device, unless expected cave air pressures require multi-point latching, then a UL Listed Hurricane Resistant rim style exit device should be used.
- Both sets of side-by-side single doors at the Dripline Cave Entrance should be replaced with side-by-side single doors. These doors should be capable of opening in opposite directions to permit egress both ways.
- The single doors at the Dripline Cave Exit, Dripline Bypass Tunnel, and Discovery Cave Exit should be replaced with single doors.
- The Forest Service would prefer to use natural cave rock (limestone) for any masonry wall construction. A Forest Service Heritage Professional will identify potential rock sources inside the caverns. Once the large unstable entrance slab is removed, pieces may be suitable for masonry wall construction.

6.2 Door Replacement Options

Various construction material options and door options were reviewed by Golder as a part of this report of findings and recommendations. Construction materials were considered for both new door and frame installations, as well as bulkhead installations that join the tunnel and cave walls to the structure of the door frame.

New door and frame installations could use a wide variety of materials; however, only specific construction materials are recommended for long-term use in the cave's environment. Various material options are outlined in Table 8. Golder recommends the use of tempered glass, aluminum, stainless steel, or fiberglass for various components of new door and frame installations, with copper and bronze used only where necessary. Certain materials may be more suitable for certain applications. For instance, tempered glass is recommended for viewing

windows within doors to allow tour guides to monitor visitors. Aluminum, stainless steel, or fiberglass are recommended for door and frame materials, while copper, brass, bronze could be used for hardware components if another material such as aluminum or stainless steel is not available.

Construction materials for bulkhead installations are outlined in the lower portion of Table 8. Masonry stone, block, or brick walls are recommended when possible. Masonry stone could use the cave's natural limestone to maximize the natural appeal of the manmade structure relative to the surrounding environment. In some instances, concrete or shotcrete could be used and a textured finish applied in order to mimic the natural cave walls and rocks in both texture and color. Bulkhead installations may also require metal structural support to protect the doors and their frames from stress loads over time. Galvanized steel beams could be used and encased in concrete to provide a durable and lasting structural support.

Table 8: Door, Frame, and Bulkhead Material Options Reviewed

Construction Material	Durability	Appeal	Initial Cost	Maintenance	Unique Function	Overall
Door and Frame Installations						
Glass	Resistant to corrosive environments, fragile	Low	Low	Moderate	Allows guides to monitor visitors	Some potential, allows visual monitoring
Aluminum	Corrodes if scratched or damaged	Low to moderate	Low	Moderate	Lightweight	Suitable, potential option
Steel	Rusts in corrosive environments	Low	Moderate	High	n/a	Poor, unsuitable for environment
Galvanized steel	Rusts after depletion of zinc coating	Low	Low	Moderate	n/a	Moderate, long-term durability issues
304 stainless steel	Moderate resistance to rusting and corrosion	Low to moderate	Moderate	Moderate	n/a	Moderate, potential option
316 stainless steel	High resistance to rusting and corrosion	Low to moderate	High	Low	n/a	Suitable, potential option
Copper, brass, bronze	Corrosion resistant, may oxidize	Low to moderate	High	Moderate	n/a	Moderate, potential option (hardware)
Fiberglass	Will not rust or corrode	Low to moderate	High	Low	Lightweight	Suitable, potential option
Wood, composite, laminate	Unsuitable for wet conditions	Low to moderate	Low	High	n/a	Poor, non-durable
Bulkhead Installations						
Masonry stone, block, or brick	High	Moderate to high	High	Low	n/a	Preferred option
Concrete	High	Low to moderate	High	Low	Textured finishing options	Alternative option
Galvanized steel	Rusts after depletion of zinc coating	Low	Low	Moderate	n/a	Suitable for encased structural support

For cost comparison, a complete CR Lewis (CRL) door, frame, and glass pane package of materials is estimated to be approximately \$5,000 using aluminum, \$25,000 using Grade 304 stainless steel clad aluminum, and \$27,000 using Grade 316 stainless steel clad aluminum.

6.3 Reference Product Lines

A list of reference product lines is shown below followed by an image for one of their products:

- Commercial Door and Frame (CDF), Aluminum Storefront product line shown in Figure 13
- CRL, courtesy of Custom Glass, Tajima Prosteel storefront system shown in Figure 14

- CRL Aluminum Balancer storefront system shown in Figure 15
- Dortek, FRP Door product line shown in Figure 16
- Metropolitan Door, shown in Figure 17
- Trudor, SS304 product line shown in Figure 18
- Tubelite, E4500 storefront product line shown in Figure 19



Figure 13: Hollow Aluminum Doors with Brushed Aluminum and Bronze Finishes (Source: CDF)



Figure 14: Stainless Steel Storefront System (Source: CRL)



Figure 15: Aluminum Balancer Storefront System (Source: CRL)



Figure 16: FRP Door with Full Kick Plates, Push Bars, and Closers in RAL 5015 Blue (Source: DorteK)



Figure 17: Solid Fiberglass Door with Aluminum Frame and Glass/Fiberglass Panels (source: Metropolitan Door Industries)



Figure 18: Stainless Steel Door with Window Kit in #4 Stain Stainless Finish (source: Trudoor)



Figure 19: Tubelite E4500 Hollow Aluminum Storefront System with Wide Stile Doors in Clear Class Finish (source: Tubelite)

6.4 Door Information and Recommendations

The following sections outline the existing conditions at each door set location. A summary of proposed replacements is shown as Table 9.

Table 9: Proposed Replacements Summary

Location	Door and Frame	Handrails	Toe Drains	Bulkhead	Drop Ceiling
Dripstone Cave Entrance - Outer Airlock Doors	X	X	X	P	X
Dripstone Cave Entrance - Inner Airlock Doors	X	X	X	P	
Dripstone Bypass Tunnel Door	X		X		
Dripstone Cave Exit - Inner Airlock Door	X	X	X	P	
Dripstone Cave Exit - Outer Airlock Door	X	X	X	P	
Dripstone Cave Exit - Security Doors	X	X	X	P	
Discovery Cave Exit - Security Doors	X				
Discovery Cave Exit - Outer Airlock Door	X	X			
Discovery Cave Exit - Inner Airlock Door	X	X	X	P	

Note: "X" indicates selected item for replacement. "P" indicates potential item for replacement if weak structural condition is observed during door demolition.

6.4.1 Dripstone Cave Entrance – Outer Airlock Doors

The existing condition of these doors is shown as Figure 20. Overall, the masonry wall bulkhead appears to be in good structural condition as no major visible cracks were observed during the Site investigation. If the bulkhead is found to require replacement during demolition of the door and frame, a masonry stone bulkhead could be constructed as a replacement using natural cave material and internal structural beam for support around the door frame. If insufficient natural cave material is available for all applications, similar limestone material should be available in the area. Overhead utility ports are present and should be replaced with transom panel.



Figure 20: Dripstone Cave Entrance – Outer Airlock Doors (Existing Conditions). Existing stacked stone masonry bulkhead visible on left side of doors.

6.4.2 Dripstone Cave Entrance – Inner Airlock Doors

The existing condition of these doors is shown as Figure 21. Overall, the masonry wall bulkhead appears to be in good structural condition as no major visible cracks were observed during the Site investigation. If the bulkhead is found to require replacement during demolition of the door and frame, a masonry stone bulkhead could be constructed as a replacement using natural cave material and an internal structural beam for support around the door frame. Overhead utility ports are present and should be replaced with transom panel.



Figure 21: Dripstone Cave Entrance – Inner Airlock Doors (Existing Conditions)

6.4.3 Dripstone Cave Bypass Tunnel Door

The existing condition of this door is shown as Figure 22. Overall, the masonry wall appears to be in good structural condition as no major visible cracks were observed during the Site investigation. The masonry wall provides good aesthetic appeal and is recommended to remain in place without modification.



Figure 22: Dripstone Cave Bypass Tunnel Door (Existing Conditions)

6.4.4 Dripstone Cave Exit – Inner Airlock Door

The existing condition of this door is shown as Figure 23. Overall, the concrete wall bulkhead appears to be in good structural condition as no major visible cracks were observed during the Site investigation. If the bulkhead is found to require replacement during demolition of the door and frame, a masonry stone bulkhead could be constructed as a replacement using natural cave material and an internal structural beam for support around the door frame. Utility ports are present and should be replaced if bulkhead requires replacement.



Figure 23: Dripstone Cave Exit – Inner Airlock Door (Existing Conditions)

6.4.5 Dripstone Cave Exit – Outer Airlock Door

The existing condition of this door is shown as Figure 24. Overall, the concrete wall bulkhead appears to be in good structural condition as no major visible cracks were observed during the Site investigation. If the bulkhead is found to require replacement during demolition of the door and frame, a masonry stone bulkhead could be constructed as a replacement using natural cave material and an internal structural beam for support around the door frame. Utility ports are present and should be replaced if bulkhead requires replacement.



Figure 24: Dripstone Cave Exit – Outer Airlock Door (Existing Conditions)

6.4.6 Dripstone Cave Exit – Security Doors

The existing condition of these doors is shown as Figure 25. Overall, the concrete wall bulkhead appears to be in good structural condition as no major visible cracks were observed during the Site investigation. If the bulkhead is found to require replacement during demolition of the door and frame, a masonry stone bulkhead could be constructed as a replacement using natural cave material and an internal structural beam for support around the door frame. The bulkhead color is contrasting and refinishing is recommended with a color which more closely matches the surrounding cave rock and concrete floor. Utility ports are present and should be replaced if bulkhead requires replacement.



Figure 25: Dripstone Cave Exit - Security Doors (Existing Conditions)

6.4.7 Discovery Cave Exit – Security Doors

The existing condition of these doors is shown as Figure 26. Overall, the masonry wall appears to be in good structural condition as no major visible cracks were observed during the Site investigation. The masonry wall provides good aesthetic appeal and is recommended to remain in place without modification.



Figure 26: Discovery Cave Exit - Security Doors (Existing Conditions)

6.4.8 Discovery Cave Exit – Outer Airlock Door

The existing condition of this door is shown as Figure 27. Overall, the masonry wall appears to be in good structural condition as no major visible cracks were observed during the Site investigation. The masonry wall provides good aesthetic appeal and is recommended to remain in place without modification.



Figure 27: Discovery Cave Exit – Outer Airlock Door (Existing Conditions)

6.4.9 Discovery Cave Exit – Inner Airlock Door

The existing condition of this door is shown as Figure 28. Overall, the concrete wall bulkhead appears to be in good structural condition as no major visible cracks were observed during the Site investigation. If the bulkhead is found to require replacement during demolition of the door and frame, a masonry stone bulkhead could be constructed as a replacement using natural cave material and an internal structural beam for support around the door frame.



Figure 28: Discovery Cave Exit – Inner Airlock Door (Existing Conditions)

7.0 PRELIMINARY CONSTRUCTION COST ESTIMATE AND SCHEDULE

For Forest Service budgeting purposes, Golder has estimated construction costs related to the anticipated scope items listed above. Costs are summarized by assessment area, including mobilization and de-mobilizations costs assuming two separate work mobilizations.

We have estimated costs based on our prior experience on similar projects and conservatively assumed a contingency factor of 25%, based on the logistical factors involved. The preliminary cost estimate should be considered order of magnitude and will continue to be refined as the design phase advances.

Based on our discussions with the Forest Service at the conclusion of the meeting, we have also included an estimate of costs related to engineering construction management during Project construction. Golder's preliminary construction cost estimates are summarized by assessment area in Table 10.

Table 10: Preliminary Construction Cost Estimate

Category	Dripstone Cave Entry - Elevator Room	Dripstone Cave Entry - Between Air Doors	Dripstone Cave Entry - Cave Interface	Dripstone Cave Bypass Tunnel	Dripstone Cave Exit	Discovery Cave Exit	Surface Sinkhole Area	TOTALS
Labor	\$ 113,100	\$ 129,200	\$ 121,100	\$ 218,000	\$ 250,400	\$ 96,900	\$ 20,200	\$ 948,900
Equipment Costs	\$ 13,900	\$ 15,900	\$ 14,900	\$ 26,900	\$ 30,800	\$ 11,900	\$ 2,500	\$ 116,800
Consumables	\$ 7,100	\$ 7,800	\$ 7,300	\$ 14,100	\$ 15,200	\$ 5,700	\$ 800	\$ 58,000
Permanent Materials	\$ 2,100	\$ 105,800	\$ 2,400	\$ 40,100	\$ 140,300	\$ 132,300	\$ 4,000	\$ 427,000
Utilities, power propane, heating	\$ 600	\$ 700	\$ 600	\$ 1,100	\$ 1,300	\$ 500	\$ 100	\$ 4,900
Indirect Supplies & Services	\$ 6,700	\$ 7,700	\$ 7,200	\$ 12,900	\$ 14,900	\$ 5,800	\$ 1,200	\$ 56,400
Overhead & Expenses	\$ 90,400	\$ 103,400	\$ 96,900	\$ 174,400	\$ 200,300	\$ 77,500	\$ 16,200	\$ 759,100
Rounded Subtotal Rehabilitation Cost	\$ 234,000	\$ 371,000	\$ 250,000	\$ 488,000	\$ 653,000	\$ 331,000	\$ 45,000	\$ 2,372,000
Mobilization and Demobilization (10% of Subtotal per move/demove)	-	-	-	-	-	-	-	\$ 474,400
Engineering Construction Management (15% of Subtotal)	\$ 35,100	\$ 55,700	\$ 37,500	\$ 73,200	\$ 98,000	\$ 49,700	\$ 6,800	\$ 356,000
Contingency (25% of Subtotal)	\$ 58,500	\$ 92,800	\$ 62,500	\$ 122,000	\$ 163,300	\$ 82,800	\$ 11,300	\$ 593,000
ESTIMATED TOTAL COST (with 25% contingency)	\$ 328,000	\$ 520,000	\$ 350,000	\$ 683,000	\$ 914,000	\$ 464,000	\$ 63,000	\$ 3,795,000

Based on the anticipated scope of work and the conservative assumption that work will be completed linearly (no concurrent work in separate assessment areas) using one work shift per day, Golder estimates the total Project duration to be approximately 117 working days, or approximately 23.5 weeks assuming a five day work week. Golder's preliminary construction schedule and duration are summarized by assessment area in Table 11.

It may be possible to reduce the duration by working in several areas at the same time (such as the Driestone Cave Exit and Discovery Cave Exit, Discovery Cave Entrance and Bypass Tunnel, etc.) as Site conditions and tour access allows. It should be noted that the costs and schedule are Golder's current estimates based on the anticipated scope of work at this time and are presented to the Forest Service for budgeting and planning purposes. As such, we have attempted to be conservative in our assumptions and contingency factors applied.

Table 11: Preliminary Construction Schedule

[illegible][illegible][illegible]

Legend

Scheduled Work Period

Scheduled Days Off

8.0 CLOSING

Golder is grateful for the opportunity to be of continued service to the Forest Service in providing the Report. If there exists question, or comment, in regard to the contents of this Report, please do not hesitate to contact the undersigned.

Sincerely,

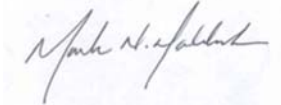
Golder Associates Inc.



Michael W. Dreyer, P.E.
Senior Project Engineer



Mark Sandfort, P.E.
Principal and Program Leader



Mark Haddock, P.E.
Principal and Practice Leader

MWD/MRS/MNH

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