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ATTACHMENT L

HDD Reports

STL Pipeline
24-inch Spanish Lake Crossing
by Horizontal Directional Drilling

HDD Design Report

August 6, 2018

Prepared for

spire

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Prepared by

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August 6, 2018

Spire STL Pipeline LLC
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St. Louis, MO 63101

Attention: Mr. Russell English

SUBJECT: HDD Design Report
STL Pipeline - Spanish Lake Crossing

Dear Mr. English:

J. D. Hair & Associates, Inc. (JDH&A) is pleased to submit the following report titled *HDD Design Report, Spire STL Pipeline, 24-inch Spanish Lake Crossing by Horizontal Directional Drilling*." The report specifically discusses design considerations, subsurface conditions, feasibility, construction duration, and presents the results of a comprehensive engineering evaluation of the proposed HDD installation.

We appreciate your confidence in JDH&A. If you have any questions or need additional information, please do not hesitate to contact us.

Sincerely,

J. D. HAIR & ASSOCIATES, INC.

Jeffrey M. Scholl

Jeffrey M. Scholl, P.E.
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Executive Summary

The following report presents a summary of design considerations and engineering calculations associated with the proposed 24-inch Spanish Lake pipeline crossing which involves passing beneath Sunfish Lake using horizontal directional drilling (HDD). The proposed HDD crossing is located in the northern suburbs of St. Louis, Missouri, near the community of Spanish Lake. This report specifically discusses design considerations, subsurface conditions, feasibility and risks, construction duration, and presents the results of a comprehensive engineering evaluation of the proposed HDD installation.

The design of the Spanish Lake crossing utilizes a 14-degree entry angle, an 8-degree exit angle, and radii of curvature equal to 2,400 feet. The crossing achieves 80 feet of cover beneath the principle obstacle, Sunfish Lake, and nearly 100 feet of cover beneath the secondary obstacle, Spanish Pond Road. The horizontal length of the crossing is 2,226 feet while the true drilled length is 2,247 feet.

Mott MacDonald (Mott) and Terracon administered subsurface investigations at the proposed crossing site. The results of these investigations revealed that overburden consisted of interbedded silts, sands, and clays. Overburden N-values were generally measured as soft to very stiff for cohesive soils and loose to medium dense for non-cohesive soils. Limestone was found to be the primary bedrock material. The limestone exhibited a vuggy texture with minor dissolution. Based on available mapping, the general area surrounding the crossing is shown to contain Karst features. In order to better quantify the risk of encountering large solution cavities, Mott Macdonald engaged THG Geophysics, LTD (THG) to conduct a geophysical survey at the crossing location. THG conducted electrical imaging (EI) surveys slightly to the south of the proposed HDD alignment. The two EI surveys closest to the proposed HDD segment did not indicate the presence of karst features. THG also conducted a microgravity survey (MG) on the west side of Sunfish Lake east of Spanish Pond Road. The MG survey showed gentle declines in gravity as the profile approached the lake but did not show depressions that could be interpreted as significant solution cavities.

Although the site-specific borings and geophysical data did not indicate karst features on the land-based portion of the crossing, there is the potential that the HDD segment will encounter a large solution cavity/sinkhole while drilling under Sunfish Lake. It is the opinion of JDH&A that, although subsurface conditions present higher than average risk of encountering solution features given the karst mapping, the feasibility of the crossing cannot be ruled out.

A hydrofracture evaluation was conducted in order to quantify the risk of inadvertent returns due to hydrofracture. The calculations indicate under normal drilling operations, there is low risk of inadvertent drilling fluid returns due to hydrofracture within the lake boundaries while passing through the limestone bedrock. The low potential for inadvertent drilling fluid returns due to hydrofracture is largely due to the fact that the crossing will be installed through sedimentary bedrock. However, given the local Karst topography, there is an increased risk of loss of drilling fluid circulation loss into the formation, which may, in some cases make its way to the ground surface. Due to the depth of the HDD design, however, it is our opinion, the risk of drilling fluid surfacing within the lake is low. As is the case with most HDD installations, the risk of inadvertent drilling fluid returns due to hydrofracture is high near the entry and exit points where the depth of cover is shallow and the drilled segment is passing through overburden soils.

HDD installation and operational stresses were analyzed under multiple loading scenarios. The results indicate pipe stresses associated with installation will be within acceptable limits provided the actual pullback geometry does not vary significantly from that used in the installation loading models, that the HDD contractor will not employ any improper construction procedures, and that unanticipated problematic subsurface conditions are not encountered. Combined stress associated with operational loading also fall within acceptable limits provided the operational parameters do not exceed those discussed in the report and that the radius of curvature does not fall below the recommended 1,600 feet.

An estimate for the duration of HDD construction was also completed as part of JDH&A's evaluation. Based on subsurface conditions described previously, the estimated duration is 50 days. The estimate assumes single 10-hour shifts with a 6-day work week during pilot hole, reaming, and pullback operations, and does not include contingency.

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1 INTRODUCTION

This purpose of this report is to provide a summary of design considerations and engineering calculations associated with a proposed 24-inch crossing beneath Sunfish Lake in St. Louis County, Missouri, which is proposed for installation by horizontal directional drilling (HDD). The proposed crossing is part of the Spire STL Pipeline Project. J. D. Hair & Associates, Inc. (JDH&A) has undertaken this report in accordance with the Spire Pipeline LLC Statement of Work dated May 21, 2018.

2 BASE DATA

The HDD design and engineering calculations presented in this report are based on the following base data.

- Topographic survey data provided by Spire STL Pipeline LLC.
- Pipe specification: 24-inch O.D., 0.508-inch Wall Thickness, API-5L X70 steel pipe specification provided by Spire STL Pipeline LLC
- Geotechnical Memorandum prepared by Mott Macdonald titled “Spire STL Pipeline – Spanish Lake Park Crossing” dated October 3, 2017.
- Draft Geotechnical boring logs prepared by Terracon Consultants, Inc., dated May 18, 2018.

3 HDD DESIGN CONSIDERATIONS

3.1 General Site Description

The proposed crossing site is located in northeast St. Louis County, Missouri, northeast of the community of Spanish Lake. The site is roughly four miles west of the convergence of the Missouri and Mississippi Rivers in northeast St. Louis County. Refer to Figure 1 for a vicinity map showing the project location.

The primary obstacles to be crossed by the proposed 24-inch diameter HDD installation is Spanish Pond Road and Sunfish Lake. Sunfish lake is a relatively small (29 acres) public fishing lake located within Spanish Lake Park. Based on available mapping, the lake is approximately 530 feet wide at the proposed crossing location. Spanish Pond Road is a narrow two-lane paved road with relatively light traffic. The topography in the vicinity is variable, best characterized as gently rolling.

The proposed entry point for the HDD crossing is located on the grounds of the Emerald Greens Golf Course, which is adjacent to the southeast property line of Spanish Lake Park. The HDD alignment trends to the northwest over a distance of approximately 2,082 feet, passing beneath Sunfish Lake and Spanish Pond Road prior to exiting within a cultivated farm field northwest of Spanish Pond Road. Refer to Figure 2 for a detail view of the proposed HDD alignment.

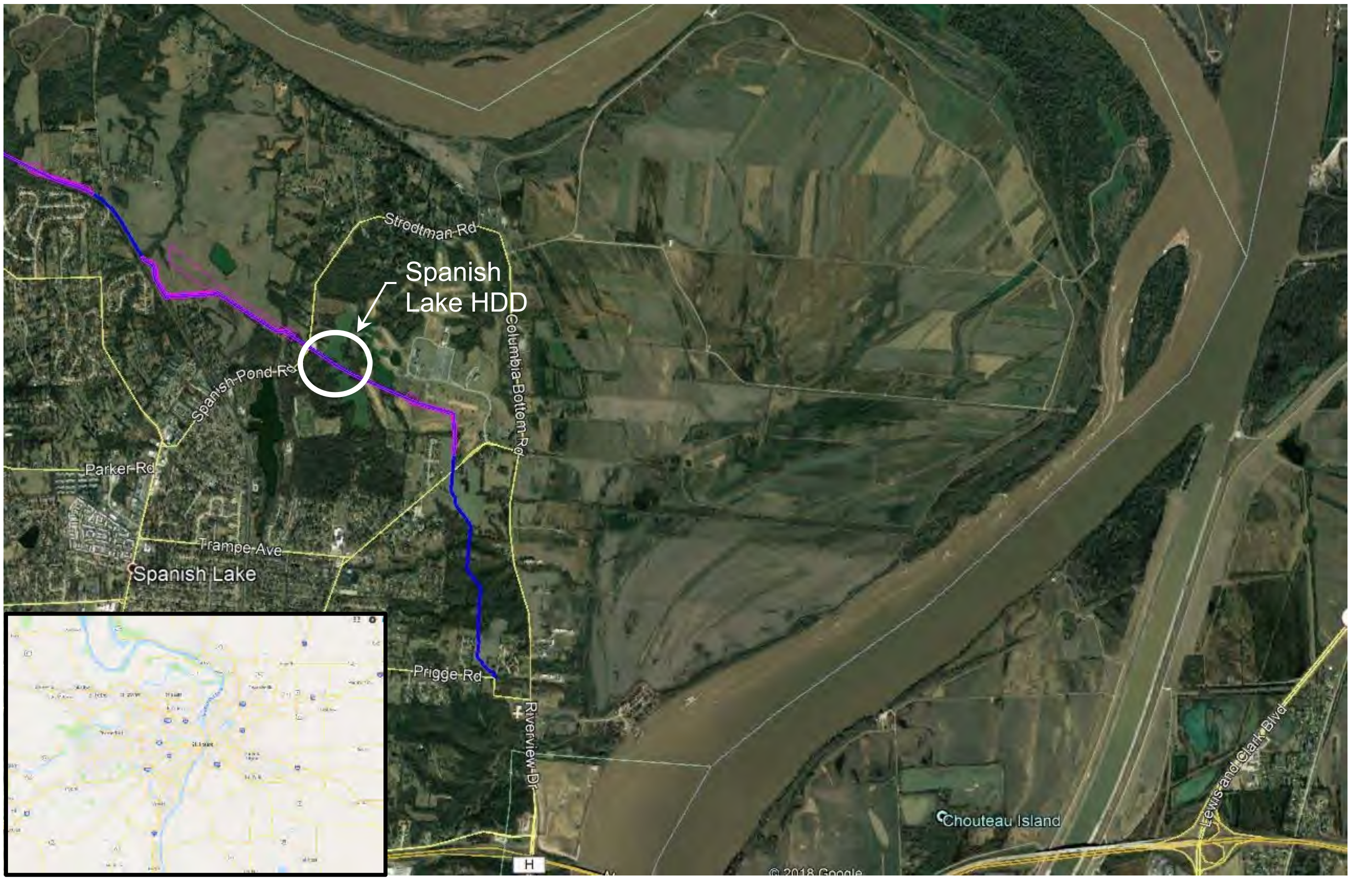

Figure 1: Vicinity map

Figure 2: Detail view of the proposed HDD crossing

3.2 HDD Design Geometry

The plan and profile design for the proposed Spanish Lake HDD crossing is provided in Appendix 1. The crossing has been designed in general accordance with standard HDD industry practices. The HDD entry point is located on the southeast side of the crossing, approximately 600 feet from of the edge of Sunfish Pond. The design utilizes a 14-degrees entry angle, which allows the HDD installation to achieve a minimum of 10 feet of cover beneath an existing Buckeye pipeline located approximately 64 feet west of the entry point. In order to reduce the risk of inadvertent drilling fluid returns surfacing within Sunfish Lake, as well as to reduce the risk of encountering karst features that may be located in the upper reaches of the bedrock, the design depth has been set to pass deep beneath the lake at elevation 378, which provides approximately 80 feet of cover. It should be noted that the lake bottom has been assumed since survey data (bathymetric or other) has not been gathered at the time of this writing. The PC, or point of curvature, of the first sag bend on the entry side, is located such that temporary steel surface casing can be installed to the top of bedrock if necessary. Installation of temporary surface casing during pilot hole drilling is beneficial in two ways. First, it stabilizes loose overburden soils and creates an open conduit for drilling fluid returns. This in turn promotes drilling fluid circulation and reduces the risk of inadvertent drilling fluid returns. Second, if casing is set all the way to bedrock, it can restrain the drill bit allowing it to penetrate the rock, rather than deflecting and sliding along the bedrock surface.

The HDD exit point is located on the northwest side of the crossing within a cultivated farm field. The exit point is approximately 100 feet northwest of two existing pipelines that cross the proposed alignment at an approximate angle of 147-degrees. The design uses an 8-degree exit angle. The benefit of the shallow exit angle is that it helps to facilitate breakover of product line during pullback by reducing the required lifting height. The HDD design employs a radius of curvature of 2,400 feet, which is in line with HDD industry practice for a 24-inch steel pipeline. The designed horizontal length of the crossing is 2,082 feet, and the true length is 2,247 feet.

As mentioned previously, the HDD design radius for the crossing is 2,400 feet. However, since the pilot hole generally deviates from the exact design centerline during construction, a minimum allowable radius of 1,600 feet has been specified as part of the pilot hole tolerances called out on the drawing. A minimum allowable radius, which is typically analyzed over three joints of drill pipe, or roughly 93 feet, provides the contractor the flexibility to make steering corrections that may be necessary due to subsurface conditions without violating the radius requirements. Adding this sort of flexibility during pilot hole construction helps to avoid delays associated with unnecessarily re-drilling portions of the hole that from a technical standpoint are acceptable. This is particularly important with HDD installations through rock, since “kicking out” of a previously drilled pilot hole can be extremely difficult. Calculations that confirm the acceptability of the specified minimum radius are summarized in Sections 4.1 and 4.2.

3.3 Temporary Workspace

Proposed workspace limits available for HDD operations are shown on the plan and profile drawing in Appendix 1. Additional information is provided below.

3.3.1 Entry Site

Temporary workspace for HDD rig side operations is located on the southeast side of the crossing on the grounds of Emerald Greens Golf Course. The workspace limits are roughly 360 feet long by 195 feet wide and will provide suitable workspace for the contractor's HDD rig and ancillary equipment, as well as for personal and work vehicles (vac trucks, fuel trucks, semi-trucks) visiting the site.

3.3.2 Exit Site

Temporary workspace for HDD pipe side operations and pullsection fabrication is located on the northwest side of the crossing in cultivated fields. In addition to the existing permanent ROW, there is a block of temporary workspace immediately surrounding the exit point that is approximately 250 feet wide by 219 feet long, which is sufficient to accommodate typical pipe side operations during pilot hole drilling, reaming, and pullback operations. In addition, the pipe side workspace provides ample room to accommodate a second HDD equipment spread should one be needed during the pilot hole (pilot hole intersect) or reaming operations. For the purposes of pullsection fabrication and layout, there is a stretch of additional temporary workspace that trends in a linear fashion to the northwest. The additional temporary workspace is in line with the proposed HDD segment and extends a distance of approximately 3,550 feet, which allows the pull section to be staged in one continuous segment. Staging the pullsection in one section will allow the contractor to continuously pull the product pipe into the reamed hole without the need to interrupt operations for a tie-in weld.

3.4 Subsurface Conditions

Mott Macdonald and Terracon, in coordination with Spire STL Pipeline LLC, conducted geotechnical investigations for the proposed crossing. Mott's borings, B-STL-09, B-STL-10, and B-STL-11, were all taken north of the alignment at distances of 35 feet, 224 feet, and 326 feet, respectively. Each boring was drilled to a depth of 150 feet below the ground surface. Each of the borings primarily encountered medium stiff silts, medium stiff to stiff clays, and medium dense silty sands overlying limestone bedrock. Depth to bedrock ranged from 60 feet in B-STL-10 to 70 feet in B-STL-11, which are the two borings closest to the HDD alignment. Copies of the geotechnical reports are included in Appendix 6.

Terracon drilled two exploratory borings in the general vicinity of the proposed crossing. Only one of the borings (B-17B), however, was taken sufficiently close to the current alignment as to provide information that is considered reliable for characterization purposes. Boring B-17B encountered subsurface materials consistent with those encountered in the Mott Macdonald borings. It encountered primarily clay and some sand overlying limestone bedrock. Top of limestone bedrock was encountered at an approximate elevation of 438 feet, which is generally consistent with the Mott Macdonald borings.

Based on the exploratory borings, the proposed HDD segment will pass through limestone bedrock over the majority of its length. Rock Quality Designation (RQD) of rock samples in the Mott Macdonald borings ranged from 0% to 100%, with the majority falling at 75% or better, indicating good quality bedrock overall. Unconfined compressive strength (UCS) of the samples ranged from 4,104 psi to 30,865 psi, with an average value of 20,600 psi. Chert nodules were encountered in all three borings at various depths.

Overall, based specifically on the results of the site-specific geotechnical borings, subsurface conditions are conducive to the HDD process. There are, however, a few features associated with the limestone bedrock that may impact HDD operations. Chert, often called flint, is a very hard quartz material, that when encountered in high percentages can be very abrasive to downhole tooling. This can result in reduced production rates and subsequent delays to the project schedule. Chert nodules were encountered in three of the borings at varying depths, with an approximate 4-foot chert seam encountered in Boring B-STL-10. Another feature of the limestone worth noting is that clay-filled solution cavities/voids were encountered in boring B-STL-10 from a depth of 63.2 feet to 65.8 feet and from 92.7 feet to 95 feet. Solution cavities are common in carbonate rock such as limestone. Large cavities, or caves, have been known to pose significant challenges for installation by HDD. While the wall of a competent rock hole serves to limit the deflection of the drill string, penetration of a large void may leave the drill string unconstrained potentially allowing it to deflect laterally. Continued rotation of a drill string subjected to such a deflection can result in failure of the drill pipe due to low-cycle fatigue. Although very large solution cavities were not encountered in the site-specific borings, their presence cannot be entirely ruled out. The desktop study conducted by Mott Macdonald indicated that area of the proposed crossing is within a region characterized by karst topography. According to the report, "sinkhole areas" have been mapped adjacent to the proposed crossing.

In order to better quantify the risk of encountering large voids, Mott Macdonald engaged THG Geophysics, LTD to conduct a geophysical survey at the crossing location. THG conducted three electrical imaging surveys (EI), with two of them, EI Profile 1 and EI Profile 2, mostly parallel and slightly south of the project alignment. EI Profile 1 was taken on the northwest side of the crossing between the exit point and Spanish Pond Road and EI Profile 2 was taken on the southeast side of the crossing extending from the edge of the Lake across the fairway. According to the summary report prepared by THG, neither showed evidence of significant voids along the alignment. It is interesting to note that the EI surveys indicated a very deep bedrock surface below elevation 360. Borings B-STL-09 and B-STL-10 encountered bedrock near elevation 460. Therefore, the EI surveys did not correlate well with the site-specific borings. Therefore, the reliability of the EI results is questionable. THG also conducted a microgravity survey (MG) near the alignment extending from Spanish Pond Road to the northeast edge of Sunfish Lake. The results indicate "the profiles collected along the alignment show a gentle decline in gravity as the profile approaches the lakes in this area" which presumably indicates voids were not detected since stark depressions or anomalies in the data were not evident.

3.5 Assessment of Feasibility

With a horizontal length of 2,104 feet and a product line diameter of 24-inches, the proposed Spanish Lake installation is within current HDD industry capabilities. Based on the site-specific geotechnical investigation, as well as local geological mapping, subsurface conditions are conducive to the HDD with the exception that there is the possibility of encountering a very large solution cavity. Although there is risk of encountering Karst features, particularly large, near surface sinkholes, we do not believe the feasibility of the proposed crossing can be ruled out.

4 RISK IDENTIFICATION AND ASSESSMENT

4.1 Geotechnical Considerations

As noted previously, encountering a significant solution cavity within the limestone, particularly a large cavity that does not contain unconsolidated in-fill material, can cause HDD operational problems. Without material to restrain the drill pipe, severe deflection in the drill pipe can result, leading to low-cycle fatigue failure. Approximately twenty years ago, JDH&A was involved with a failed HDD crossing that resulted due to drilling into large cavity/open cave during the pilot hole. Multiple pilot holes were attempted but all resulted in drill pipe failures. More recently, JDH&A was involved with a successful HDD crossing that involved passing through significant Karst features. We believe one reason for the success of the recent crossing is that the predominant dissolution features were near-surface in the form of sinkholes. The sinkholes were filed with unconsolidated sediment which helped restrain the drill pipe and reduced the risk of failure due to low cycle fatigue. That, combined with the fact that HDD contractors have moved away from the 5.0-inch O.D. drill pipe that was common in the late 1990's, to larger 6.625-inch diameter drill pipe (and greater). The larger drill pipe has higher strength and resistance to deflection, which reduces the risk of drill pipe failure.

Based on site-specific data, should a dissolution feature be encountered, it will likely be beneath the lake and will take the form of a filled sinkhole. Although the desktop study completed by Mott MacDonald did not indicate it, Sunfish Lake may itself have originally formed due to ground collapse associated with dissolution. With this in mind, the crossing was designed to pass deeply beneath the lake so as drill below potential sinkhole features. In the event that the HDD segment drills through a near surface sinkhole, we believe the unconsolidated soil within it will likely provide enough support to prevent severe deflection and drill pipe failure. Because of this, we believe the feasibility of installation by HDD cannot be ruled out at this location. That is not to say that drilling from bedrock, into a softer sediment, and then back into bedrock will be easy. Just that it would involve operational risk typical of partial rock crossings, such as tools hanging up on the rock ledge. These would not be expected to prevent a successful installation, however.

Since the crossing will be installed primarily through relatively hard limestone bedrock as evidenced by UCS values 20,600 psi, the crossing will involve risk of operational problems consistent with typical hard rock crossings. Operational problems associated with hard rock crossings include failure of large diameter rock reaming tools downhole (losing cones), hole misalignment at the soil/rock interface which can result in downhole tools binding or hanging up on the rock ledge, or with the pullsection getting lodged as it transitions from overburden and into rock. In addition, excessive bit wear and reduced penetration rates can sometimes occur, particularly when seams containing high percentages of quartz minerals are encountered. It is rare that operational problems such as these will prevent a successful installation. Rather, they result in construction delays, which negatively impact the in-service date.

4.2 Drilling Fluid Impact

As is the case with all pipeline crossings to be installed by HDD, there is a chance that inadvertent drilling fluid returns, also known as "frac-outs" will occur. Although these can generally be contained and controlled with sand bags, silt fences, and hay bales, and do not typically prevent a successful installation, they can be problematic from an environmental perspective if they surface within a sensitive environmental resource such as Sunfish Lake. In addition to impacting the environment, there is also a possibility that drilling fluid will surface beneath Spanish Lake Road, resulting in heaving of the asphalt, which can be a threat to public health and safety.

Overall, based on the depth of the crossing, and the fact that it most likely will remain within bedrock over its duration, the risk of inadvertent drilling fluid returns due to hydrofracture is low over the majority of the crossings length. It is only near the entry and exit points where the drilled segment is passing through the overburden soils and where cover is shallow that the risk of inadvertent drilling fluid returns due to hydrofracture is high. Hydrofracture risk near the entry point can be mitigated by setting temporary surface casing, which stabilizes loose overburden soils and creates an open conduit for drilling fluid returns. This in turn promotes drilling fluid circulation and decreases annular pressure, which reduces the risk of inadvertent drilling fluid returns due to hydrofracture.

As mentioned earlier in this report, inadvertent drilling fluid returns can result due to other mechanisms unrelated to hydrofracture. With rock crossings, it is more likely that drilling fluid will flow through existing fractures or voids. Considering that solution cavities were encountered in one of the borings, as well as areas of bedrock with existing fractures as indicated by low RQD, the crossing has a higher than average risk of drilling fluid loss into the formation through these existing features. Given the depth of the proposed HDD design beneath Sunfish Lake and Spanish Pond Road, however, drilling fluid impact to the ground surface is not expected.

5 PIPE STRESS ANALYSIS

5.1 Installation Stress

Loads and stresses associated with installation by HDD were analyzed using methods developed by JDH&A for the Pipeline Research Committee International (PRCI) of the American Gas Association. Details with respect to the "PRCI Method" can be found in Section 5 of *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide.*[1]

Two HDD installation scenarios were evaluated. The first scenario assumed the pull section would be installed along a reamed hole that follows the exact design centerline shown on the plan and profile drawing included in Appendix 1. The second scenario assumed a worse-case model in which the pull section is installed along a reamed hole that is drilled 25 feet deeper and 50 feet longer than the design profile with a radius of curvature reduced to 50% of the design radius (1,200 feet). A summary of the assumptions used in each loading scenario is provided in Table 1.

Table 1: Loading Scenarios

Loading Scenario	Path Geometry	Drilling Fluid Weight	Buoyancy Condition	Above Ground Load
Number 1 As-Designed	Length: As designed Depth: As designed Radius: 2,400’	9 ppg 12 ppg	Empty	Assumed Negligible
Number 2 Worse-Case	Length: 50’ Longer Depth: 25’ deeper design Radius: 1,200’	9 ppg 12 ppg	Empty	Assumed Negligible

In summary, for each of the loading scenarios investigated, tensile, bending, external hoop, and combined stresses are within acceptable limits as defined by the PRCI Method. The results are based on three assumptions: 1.) that the geometry of the pullsection segment will not vary significantly from the models described above, 2.) that the HDD contractor will not employ any improper construction procedures, 3.) and that unanticipated problematic subsurface conditions will not be encountered. A summary of the estimated pulling loads for each installation scenario is provided in Table 2. Please refer to Appendix 2 for detailed installation stress calculations.

It is important to keep in mind that the PRCI method considers pulling tension, pipe bending, and external pressure. It does not consider point loads that may result from subsurface conditions such as a

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

rock ledge or boulder, which under certain circumstances, could cause mechanical damage to the pullsection.

Table 2: Summary of Results –Installation Stress Analysis

Loading Scenario	Path Geometry	Drilling Fluid Weight (ppg)	Pulling Load (lbs.)	PRCI Stress Checks
Number 1	As-Designed	9 ppg 12 ppg	117,165 167,899	Pass
Number 2	Worse-Case	9 ppg 12 ppg	130,136 181,025	Pass

5.2 Operational and Testing Stress Analysis

A pipeline installed by HDD involves elastic bending that result as the product pipeline is pulled through the reamed hole. Flexural stresses associated with bending were analyzed in combination with longitudinal and hoop stresses that develop during hydrostatic testing and subsequent operation of the pipeline to verify that applicable limits specified in ASME B31.8 (2010) are maintained. Four scenarios for pipeline operation and testing were investigated. Details relative to the variables used in each scenario are provided in Table 3.

Table 3: Operational & Testing Parameters

Scenario	Radius (ft.)	Max. Pressure (psig)	Installation Temperature (ºF)	Max Operating Temperature (ºF)
Number 1 (Operation)	Design (2,400 feet)	1,440	60	80
Number 2 (Operation)	2/3 of Design (1,600 feet)	1,440	60	80
Number 3 (Hydrostatic Testing)	2/3 of Design (1,600 feet)	2,200	60	60

In summary, pipe stress resulting from operational loading scenarios 1 and 2, which involve the same pipeline operating parameters but different radii of curvature, are within acceptable limits as governed by ASME B31.8 (2010). Scenario 3 involves pipe stress associated with the minimum radius under hydrostatic testing. It to shows combined stress within reasonable limits. Refer to Appendix 3 for detailed results.

6 HYDROFRACTURE ANALYSIS

Hydrofracture, also known as hydraulic fracture, is a phenomenon that occurs when drilling fluid pressure in the annular space of the drilled hole exceeds the strength of the surrounding soil mass, resulting in deformation, cracking, and fracturing. The fractures may then serve as flow conduits for drilling fluid allowing the fluid to escape into the formation and possibly up to the ground surface. Drilling fluid that makes its way to the ground surface is known as an inadvertent drilling fluid return or, more commonly, a “frac-out.”

Although hydrofracture may be one mechanism by which frac-outs occur, it is not the only one. In fact, it is thought that inadvertent returns due to true hydrofracture occur in only a small percentage of cases.[2] Drilling fluid flows in the path of least resistance. Ideally, the path of least resistance is through the annulus of the drilled hole and back to the fluid containment pits at the entry or exit points. However, the path of least resistance may also be through naturally occurring subsurface features such as fissures in the soil, shrinkage cracks, or porous deposits of gravel. Drilling fluid may also flow to the surface alongside piers, piles, utility poles, or other structures.

The risk of hydrofracture can be determined by comparing the soil confining capacity (formation limit pressure) of the subsurface to the estimated annular pressure necessary to conduct HDD operations. If the anticipated drilling fluid pressure in the annulus exceeds the confining capacity of the subsurface, there is risk that inadvertent drilling fluid returns due to hydrofracture will occur.

6.1 Soil Confining Capacity

The soil confining capacity for the proposed crossings was calculated using the “Delft Method”. The Delft Method is described in Appendix B of the Technical Report CPAR-GL-98-1 titled *Recommended Guidelines for Installation of Pipelines beneath Levees using Horizontal Directional Drilling*[3] prepared for the U.S. Army Corps of Engineers. The Delft Method is applicable to unconsolidated formations only and requires engineering judgment with respect to the selection of geotechnical parameters that are used the analysis. Although the Delft Method is widely accepted for estimating the potential for hydrofracture on HDD installations through unconsolidated sediments, the method is not applicable to crossings installed through bedrock. A widely recognized method for calculating confining pressure of HDD operations through bedrock has yet to been adopted. This is partially due to the fact that annular pressures with respect to HDD operations are very low relative to pressures typically necessary to initiate bedrock fracturing; therefore, true hydrofracture in rock due to HDD installations can generally be classified as a low risk occurrence. For the purposes of this analysis, only the overburden soil, where the risk of inadvertent drilling fluid returns due to hydrofracture are potentially the highest, has been considered.

6.2 Estimated Annular Pressure

The estimated annular pressure is a function of the hydrostatic pressure associated with the column of drilling fluid in the annulus and the frictional pressure (pressure loss) that must be overcome for the drilling fluid to continue flowing. Frictional pressure losses for HDD pilot hole operations are calculated using the conservative Bingham Plastic Model, which is described in Chapter 4 of the Society of Petroleum Engineers’ *Applied Drilling Engineering*.[4] The Bingham Plastic Model is a conservative approach and generally overestimates the friction loss component of the annular pressure in our view. However, JDH&A believes a conservative approach is valid for hydrofracture evaluations since

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[2] *Step by Step Evaluation of Hydrofracture Risks for HDD Projects*, North American Society for Trenchless Technology, NoDig Conference, Grapevine, TX., Bennett, R.D., Wallin, K., (2008)

[3] *Recommended Guidelines for Installation of Pipelines beneath Levees using Horizontal Directional Drilling*, prepared for U.S. Army Corps of Engineers, Kimberlie Staheli [et al], April 1998

[4] *Applied Drilling Engineering,* Society of Petroleum Engineers, Richardson, Texas, A. T. Bourgoyne, Jr. [et al], 1991

conditions downhole that can increase annular pressure, such as partial blockage of annular flow due to excess cuttings, cannot be predicted or accounted for.

Variables with respect to drilling fluid rheology and tooling used in these annular pressure calculations are provided in Table 4.

Table 4: Drilling Fluid Parameters

Drilling Fluid Parameter	Value
Effective Pilot Hole Diameter	14 inches
Drill Pipe Diameter	6.625 inches
Drilling Fluid Weight	10 pounds per gallon
Pump Flow Rate	500 gallons per minute
Yield Point	29 pounds per 100 ft^2
Plastic Viscosity	15 cP
Frictional Pressure Gradient	0.020 psi/ft

6.3 Hydrofracture Risk Assessment

The results of the hydrofracture calculations are presented as a plot of the formation limit pressure of overburden soil versus the estimated annular pressure associated with HDD pilot hole operations. Subsurface limiting pressures and annular pressures were calculated at 50-foot increments along the proposed drilled segment depicted on the design drawing. Because the highest annular pressures are observed during pilot hole drilling, the potential for hydrofracture during reaming operations was not calculated. As mentioned previously, the confining capacity of the limestone has not been considered as part of this analysis since hydrofracture of competent bedrock is not typically a risk when subjected to the annular pressures experienced during normal HDD operations. Refer to Appendix 4 for the graphical results of the hydrofracture evaluation.

The limiting pressure (P_{max}) is plotted as a solid red line, with the x-axis indicating the distance from the entry point in feet and the y-axis indicating pressure in psi. P_{max} indicates the theoretical pressure along the HDD segment at which plastic deformation/shear failure will reach the ground surface. The estimated annular pressure associated with drilling fluid is plotted in blue. Any location where the annular pressure curve meets or exceeds the limiting pressure curve, a theoretical inadvertent drilling fluid return could occur.

The calculations indicate that on the entry side of the crossing, the estimated annular pressure will remain below the confining capacity of the overburden soil. Although the annular pressure does not exceed the limiting pressure, there is not a large factor of safety. Therefore, as with most HDD crossings, there is a high risk of inadvertent returns for approximately the first 150 feet of the crossing. The high risk is a function of the relatively shallow depth of the HDD segment as well as subsurface material that consists of cohesive soil that is subject to plastic deformation under relatively low pressure. HDD operational measures such as using temporary surface casing can help mitigate the risk of hydrofracture.

On the exit side of the crossing, the calculations indicate that the the annular pressure will exceed the strength of the overburden soils over the last approximate 100 feet of the crossing. Inadvertent drilling fluid returns over the last few hundred feet of a pilot hole are common in the HDD industry and result from the fact that cover is shallow. In many cases, inadvertent drilling fluid returns near the exit point are not a problem though since they often surface within temporary workspace as opposed to an environmental resource, and can easily be contained. Prudent contractors will have workers stationed on the exit side as the bit approaches the ground surface so that the driller can be notified in the event that drilling fluid surfaces, and he can turn off the mud system to reduce the total area of impact.

It is important to keep in mind that inadvertent drilling fluid returns may occur due to mechanisms unrelated to hydrofracture. As discussed previously, it remains possible that inadvertent drilling fluid returns will occur by flowing to the ground surface through preexisting fractures in the soil. It is not possible to predict the occurrence or non-occurrence of inadvertent drilling fluid returns due to mechanisms unrelated to hydrofracture. It is also important to note that the estimated annular pressure is based on the annulus being "open" with drilling fluid freely flowing back to the entry point. If the annulus becomes partially blocked, or blocked completely, significantly higher annular pressures may result.

7 CONSTRUCTION DURATION

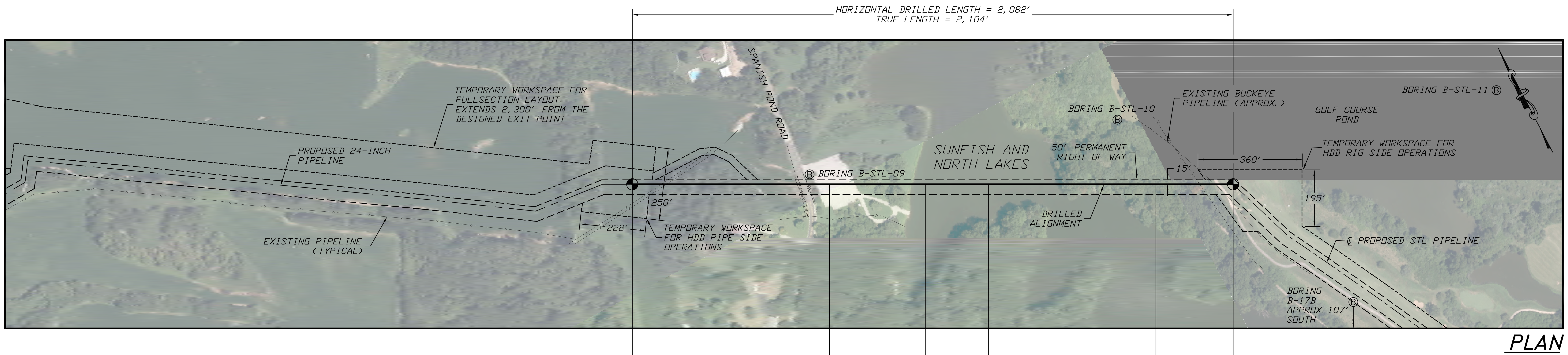
The estimated duration of construction for the Spanish Lake Crossing is 50 days. The estimate assumes a 6-day work week with single 10-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speeds were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[5], as well as past experience in similar subsurface conditions. Refer to Appendix 6 for details relative to the estimate.

Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

[5] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, prepared under the sponsorship of the Pipeline Research Committee at the American Gas Association, April 15, 1995, Revised under the sponsorship of the Pipeline Research Council International, Inc., 2008.

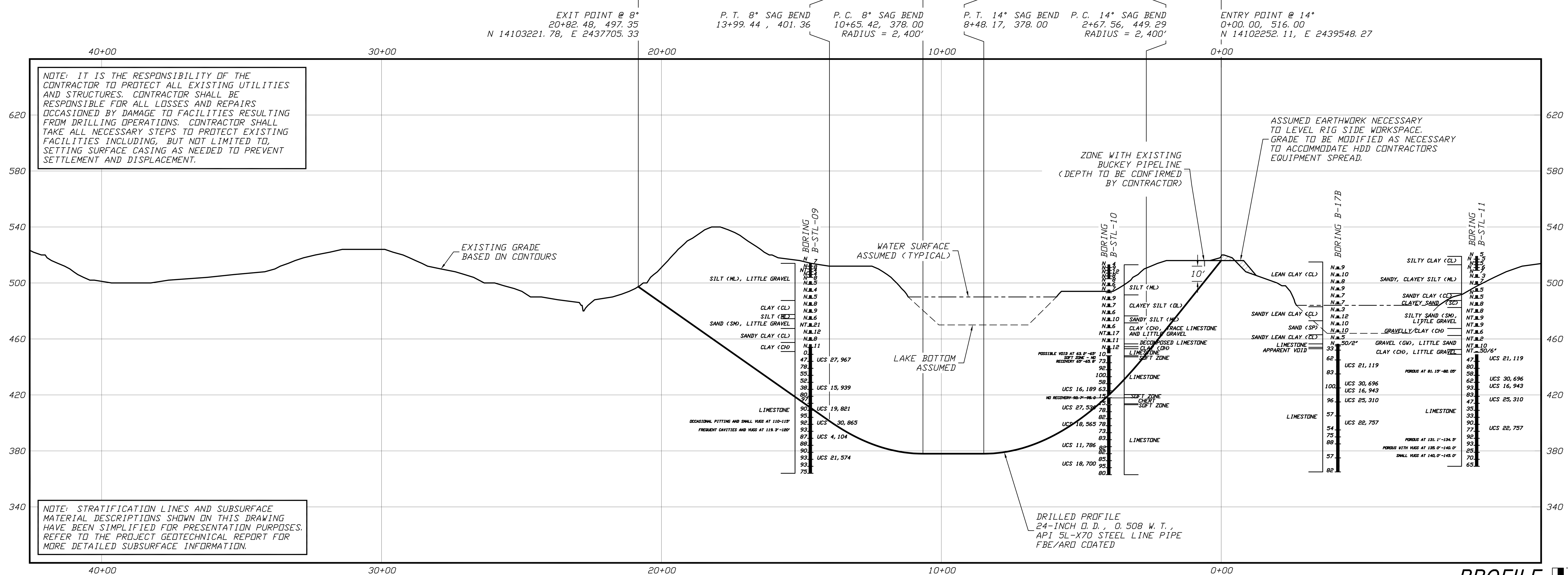
APPENDIX 1

HDD Plan and Profile Drawing



PLAN

SCALE: 1"=200'



PROFILE

SCALE: 1"=200' HORIZONTAL
1"= 40' VERTICAL

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES — PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
53 6 — MOHS HARDNESS — ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY TERRACON CONSULTANTS, OLATHE, KS, AND MOTT MACDONALD, ISELIN, NJ. REFER TO DRAFT GEOTECHNICAL BORING LOGS AND GEOTECHNICAL MEMORANDUM FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGEMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC AND SURVEY DATA PROVIDED BY SPIRE STL PIPELINE LLC, ST. LOUIS, MO.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM ZONE 15, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 5 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 5 FEET SHORT OR 15 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 1,600 FEET BASED ON A 3-JOINT AVERAGE

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED SUCH THAT THERE IS 3 FEET OF CLEARANCE ON ALL SIDES.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

PRELIMINARY

PLAN AND PROFILE
24-INCH SPANISH LAKE CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: ST. LOUIS COUNTY, MISSOURI

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
ACM	06/26/18	KWW	JMS	SHOWN FOR D-SIZED PLOT	SPANISH LAKE	P2

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.
P2	07/26/18	REVISE ENTRY POINT LOCATION	JMS	JMS	JMS
P1	07/26/18	UPDATE DESIGN AND ADD COORDINATES	ACM	LKB	JMS

J.D.Hair&Associates,Inc.
Consulting Engineers
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO. SP/1816

SHEET NO. 2

APPENDIX 2

Installation Loading and Stress Analysis

HDD Pulling Load and Pipe Stress Analysis

Project Description			
Project: STL Pipeline	User :	KWW	
Crossing: Spanish Lake	Date :	17-Jul-18	
Installation model based based on As-Designed model. Assumes 9 ppg drilling fluid, No buoyancy control measures			
Line Pipe Properties			
Pipe Outside Diameter =	24.000	in	
Wall Thickness =	0.508	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	2586.33	in^4	
Pipe Face Surface Area =	37.49	in^2	
Diameter to Wall Thickness Ratio, D/t =	47		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	127.45	lb/ft	
Pipe Interior Volume =	2.88	ft^3/ft	
Pipe Exterior Volume =	3.14	ft^3/ft	
HDD Installation Properties			
Drilling Mud Density =	9.0	ppg	
=	67.3	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	179.79	lb/ft	
Displaced Mud Weight =	211.49	lb/ft	
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,910	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,770	psi	Yes
Allowable Bending Stress, F_b =	45,770	psi	
Elastic Hoop Buckling Stress, F_{he} =	11,434	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	11,434	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,558	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,610	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	11,434	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,622	psi	

Point	Station (ft)	Offset (ft)	Elevation (ft)	Length (ft)	Heading (˚)	Inclination (˚)	Azimuth (˚)	Submerged	Ballasted	Assumed Tension (lbs)	Average Tension (lbs)	Total Pull (lbs)
Entry Point	0.00	0.00	516.00		0.00	76.00	0.00					117,165
				275.75				yes	no	1,000	Straight	
PC Vertical	267.56	0.00	449.29		0.00	76.00	0.00					109,788
				586.43				yes	no	92,973	92,973	
PT Vertical	848.17	0.00	378.00		0.00	90.00	0.00				0	76,158
				217.25				yes	no	68,840	Straight	
PC Vertical	1065.42	0.00	378.00		0.00	90.00	0.00					65,767
				335.10				yes	no	53,328	53,328	
PT Vertical	1399.43	0.00	401.36		0.00	98.00	0.00				0	40,889
				689.74				yes	no	64,101	Straight	
Exit Point	2082.46	0.00	497.35		0.00	98.00	0.00					0
											Above Ground Load	
True Length (ft)				2,104.3								
Drilling Mud (ft)			497.0									
Ballast (ft)												

Point	Fluidic Drag (lbs)	Weight & Weight Friction (lbs)	Bending Friction (lbs)	Total Pull (lbs)	Tensile Stress (psi)		Bending Stress (psi)		External Hoop Stress (psi)		Tensile & Bending Stress (unity check)		Tensile, Bending & Ext. Hoop Stress (unity check)	
Entry Point	47,597	27,862	41,705	117,165	3,125	ok	0	ok	0	ok	0.05	ok	0.00	ok
					2,928	ok	0	ok	527	ok	0.05	ok	0.01	ok
PC Vertical	41,360	26,723	41,705	109,788										
					2,928	ok	12,083	ok	527	ok	0.31	ok	0.09	ok
					2,031	ok	12,083	ok	1314	ok	0.30	ok	0.11	ok
PT Vertical	28,095	32,729	15,334	76,158										
					2,031	ok	0	ok	1314	ok	0.03	ok	0.03	ok
					1,754	ok	0	ok	1314	ok	0.03	ok	0.03	ok
PC Vertical	23,181	27,251	15,334	65,767										
					1,754	ok	12,083	ok	1314	ok	0.29	ok	0.11	ok
					1,091	ok	12,083	ok	1056	ok	0.28	ok	0.09	ok
PT Vertical	15,602	25,287	0	40,889										
					1,091	ok	0	ok	1056	ok	0.02	ok	0.02	ok
Exit Point		0		0										

J.D.Hair&Associates,Inc.
Consulting Engineers

HDD Pulling Load and Pipe Stress Analysis

Project Description			
Project: STL Pipeline	User :	KWW	
Crossing: Spanish Lake	Date :	17-Jul-18	
Installation model based based on As-Designed model. Assumes 12 ppg drilling fluid, No buoyancy control measures			
Line Pipe Properties			
Pipe Outside Diameter =	24.000	in	
Wall Thickness =	0.508	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	2586.33	in^4	
Pipe Face Surface Area =	37.49	in^2	
Diameter to Wall Thickness Ratio, D/t =	47		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	127.45	lb/ft	
Pipe Interior Volume =	2.88	ft^3/ft	
Pipe Exterior Volume =	3.14	ft^3/ft	
HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	179.79	lb/ft	
Displaced Mud Weight =	281.99	lb/ft	
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,910	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,770	psi	Yes
Allowable Bending Stress, F_b =	45,770	psi	
Elastic Hoop Buckling Stress, F_{he} =	11,434	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	11,434	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,558	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,610	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	11,434	psi	
Allowable Hoop Buckling Stress, F_{hc}/1.5 =	7,622	psi	

Point	Station (ft)	Offset (ft)	Elevation (ft)	Length (ft)	Heading (˚)	Inclination (˚)	Azimuth (˚)	Submerged	Ballasted	Assumed Tension (lbs)	Average Tension (lbs)	Total Pull (lbs)
Entry Point	0.00	0.00	516.00		0.00	76.00	0.00					167,899
				275.75				yes	no	1,000	Straight	
PC Vertical	267.56	0.00	449.29		0.00	76.00	0.00					159,566
				586.43				yes	no	136,523	136,523	
PT Vertical	848.17	0.00	378.00		0.00	90.00	0.00				0	113,480
				217.25				yes	no	68,840	Straight	
PC Vertical	1065.42	0.00	378.00		0.00	90.00	0.00					98,494
				335.10				yes	no	80,298	80,298	
PT Vertical	1399.43	0.00	401.36		0.00	98.00	0.00				0	62,101
				689.74				yes	no	64,101	Straight	
Exit Point	2082.46	0.00	497.35		0.00	98.00	0.00					0
											Above Ground Load	
True Length (ft)				2,104.3								
Drilling Mud (ft)			497.0									
Ballast (ft)												

Point	Fluidic Drag (lbs)	Weight & Weight Friction (lbs)	Bending Friction (lbs)	Total Pull (lbs)	Tensile Stress (psi)		Bending Stress (psi)		External Hoop Stress (psi)		Tensile & Bending Stress (unity check)		Tensile, Bending & Ext. Hoop Stress (unity check)	
Entry Point	47,597	51,235	69,067	167,899	4,478	ok	0	ok	0	ok	0.07	ok	0.01	ok
					4,256	ok	0	ok	703	ok	0.07	ok	0.02	ok
PC Vertical	41,360	49,140	69,067	159,566										
					4,256	ok	12,083	ok	703	ok	0.33	ok	0.11	ok
					3,027	ok	12,083	ok	1752	ok	0.31	ok	0.15	ok
PT Vertical	28,095	60,184	25,201	113,480										
					3,027	ok	0	ok	1752	ok	0.05	ok	0.06	ok
					2,627	ok	0	ok	1752	ok	0.04	ok	0.06	ok
PC Vertical	23,181	50,112	25,201	98,494										
					2,627	ok	12,083	ok	1752	ok	0.31	ok	0.15	ok
					1,656	ok	12,083	ok	1408	ok	0.29	ok	0.11	ok
PT Vertical	15,602	46,500	0	62,101										
					1,656	ok	0	ok	1408	ok	0.03	ok	0.04	ok
Exit Point		0		0										

J.D.Hair&Associates,Inc.
Consulting Engineers

HDD Pulling Load and Pipe Stress Analysis

Project Description			
Project: STL Pipeline	User :	KWW	
Crossing: Spanish Lake	Date :	17-Jul-18	
Installation model based based on Worse Case model with design 50 feet longer, 25 feet deeper, and with radii dropping to 50% of design. Assumes 9 ppg drilling fluid, No buoyancy control measures			
Line Pipe Properties			
Pipe Outside Diameter =	24.000	in	
Wall Thickness =	0.508	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	2586.33	in^4	
Pipe Face Surface Area =	37.49	in^2	
Diameter to Wall Thickness Ratio, D/t =	47		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	127.45	lb/ft	
Pipe Interior Volume =	2.88	ft^3/ft	
Pipe Exterior Volume =	3.14	ft^3/ft	
HDD Installation Properties			
Drilling Mud Density =	9.0	ppg	
=	67.3	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	179.79	lb/ft	
Displaced Mud Weight =	211.49	lb/ft	
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,910	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,770	psi	Yes
Allowable Bending Stress, F_b =	45,770	psi	
Elastic Hoop Buckling Stress, F_{he} =	11,434	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	11,434	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,558	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,610	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	11,434	psi	
Allowable Hoop Buckling Stress, F_{hc}/1.5 =	7,622	psi	

Point	Station (ft)	Offset (ft)	Elevation (ft)	Length (ft)	Heading (˚)	Inclination (˚)	Azimuth (˚)	Submerged	Ballasted	Assumed Tension (lbs)	Average Tension (lbs)	Total Pull (lbs)
Entry Point	0.00	0.00	516.00		0.00	76.00	0.00					130,136
				526.43				yes	no	1,000	Straight	
PC Vertical	510.79	0.00	388.65		0.00	76.00	0.00					116,054
				293.22				yes	no	102,667	102,667	
PT Vertical	801.10	0.00	353.00		0.00	90.00	0.00				0	89,281
				253.42				yes	no	68,840	Straight	
PC Vertical	1054.52	0.00	353.00		0.00	90.00	0.00					77,159
				167.55				yes	no	65,846	65,846	
PT Vertical	1221.53	0.00	364.68		0.00	98.00	0.00				0	54,533
				919.90				yes	no	64,101	Straight	
Exit Point	2132.47	0.00	492.70		0.00	98.00	0.00					0
										Above Ground Load		
True Length (ft)				2,160.5								
Drilling Mud (ft)			492.0									
Ballast (ft)												

HDD Design Geometry

Point	Fluidic Drag (lbs)	Weight & Weight Friction (lbs)	Bending Friction (lbs)	Total Pull (lbs)	Tensile Stress (psi)		Bending Stress (psi)		External Hoop Stress (psi)		Tensile & Bending Stress (unity check)		Tensile, Bending & Ext. Hoop Stress (unity check)	
Entry Point	48,870	40,268	40,998	130,136	3,471	ok	0	ok	0	ok	0.06	ok	0.00	ok
					3,095	ok	0	ok	1141	ok	0.05	ok	0.03	ok
PC Vertical	36,962	38,093	40,998	116,054										
					3,095	ok	24,167	ok	1141	ok	0.58	ok	0.29	ok
					2,381	ok	24,167	ok	1535	ok	0.57	ok	0.31	ok
PT Vertical	30,330	41,096	17,855	89,281										
					2,381	ok	0	ok	1535	ok	0.04	ok	0.04	ok
					2,058	ok	0	ok	1535	ok	0.03	ok	0.04	ok
PC Vertical	24,598	34,707	17,855	77,159										
					2,058	ok	24,167	ok	1535	ok	0.56	ok	0.30	ok
					1,455	ok	24,167	ok	1406	ok	0.55	ok	0.28	ok
PT Vertical	20,808	33,725	0	54,533										
					1,455	ok	0	ok	1406	ok	0.02	ok	0.04	ok
Exit Point		0		0										

HDD Pulling Load and Pipe Stress Analysis

Project Description			
Project: STL Pipeline	User :	KWW	
Crossing: Spanish Lake	Date :	17-Jul-18	
Installation model based based on Worse Case model with design 50 feet longer, 25 feet deeper, and with radii dropping to 50% of design. Assumes 12 ppg drilling fluid, No buoyancy control measures			
Line Pipe Properties			
Pipe Outside Diameter =	24.000	in	
Wall Thickness =	0.508	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	2586.33	in^4	
Pipe Face Surface Area =	37.49	in^2	
Diameter to Wall Thickness Ratio, D/t =	47		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	127.45	lb/ft	
Pipe Interior Volume =	2.88	ft^3/ft	
Pipe Exterior Volume =	3.14	ft^3/ft	
HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	179.79	lb/ft	
Displaced Mud Weight =	281.99	lb/ft	
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,910	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,770	psi	Yes
Allowable Bending Stress, F_b =	45,770	psi	
Elastic Hoop Buckling Stress, F_{he} =	11,434	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	11,434	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,558	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,610	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	11,434	psi	
Allowable Hoop Buckling Stress, F_{hc}/1.5 =	7,622	psi	

Point	Station (ft)	Offset (ft)	Elevation (ft)	Length (ft)	Heading (˚)	Inclination (˚)	Azimuth (˚)	Submerged	Ballasted	Assumed Tension (lbs)	Average Tension (lbs)	Total Pull (lbs)
Entry Point	0.00	0.00	516.00		0.00	76.00	0.00					181,025
				526.43				yes	no	1,000	Straight	
PC Vertical	510.79	0.00	388.65		0.00	76.00	0.00					165,118
				293.22				yes	no	147,409	147,409	
PT Vertical	801.10	0.00	353.00		0.00	90.00	0.00				0	129,700
				253.42				yes	no	68,840	Straight	
PC Vertical	1054.52	0.00	353.00		0.00	90.00	0.00					112,219
				167.55				yes	no	97,522	97,522	
PT Vertical	1221.53	0.00	364.68		0.00	98.00	0.00				0	82,824
				919.90				yes	no	64,101	Straight	
Exit Point	2132.47	0.00	492.70		0.00	98.00	0.00					0
											Above Ground Load	
True Length (ft)				2,160.5								
Drilling Mud (ft)			492.0									
Ballast (ft)												

Point	Fluidic Drag (lbs)	Weight & Weight Friction (lbs)	Bending Friction (lbs)	Total Pull (lbs)	Tensile Stress (psi)		Bending Stress (psi)		External Hoop Stress (psi)		Tensile & Bending Stress (unity check)		Tensile, Bending & Ext. Hoop Stress (unity check)	
Entry Point	48,870	74,049	58,106	181,025	4,828	ok	0	ok	0	ok	0.08	ok	0.01	ok
					4,404	ok	0	ok	1522	ok	0.07	ok	0.05	ok
PC Vertical	36,962	70,049	58,106	165,118										
					4,404	ok	24,167	ok	1522	ok	0.60	ok	0.35	ok
					3,459	ok	24,167	ok	2047	ok	0.58	ok	0.37	ok
PT Vertical	30,330	75,571	23,799	129,700										
					3,459	ok	0	ok	2047	ok	0.05	ok	0.08	ok
					2,993	ok	0	ok	2047	ok	0.05	ok	0.08	ok
PC Vertical	24,598	63,823	23,799	112,219										
					2,993	ok	24,167	ok	2047	ok	0.58	ok	0.37	ok
					2,209	ok	24,167	ok	1875	ok	0.56	ok	0.33	ok
PT Vertical	20,808	62,016	0	82,824										
					2,209	ok	0	ok	1875	ok	0.04	ok	0.06	ok
Exit Point		0		0										

APPENDIX 3

Operational & Testing Stress Calculatoins

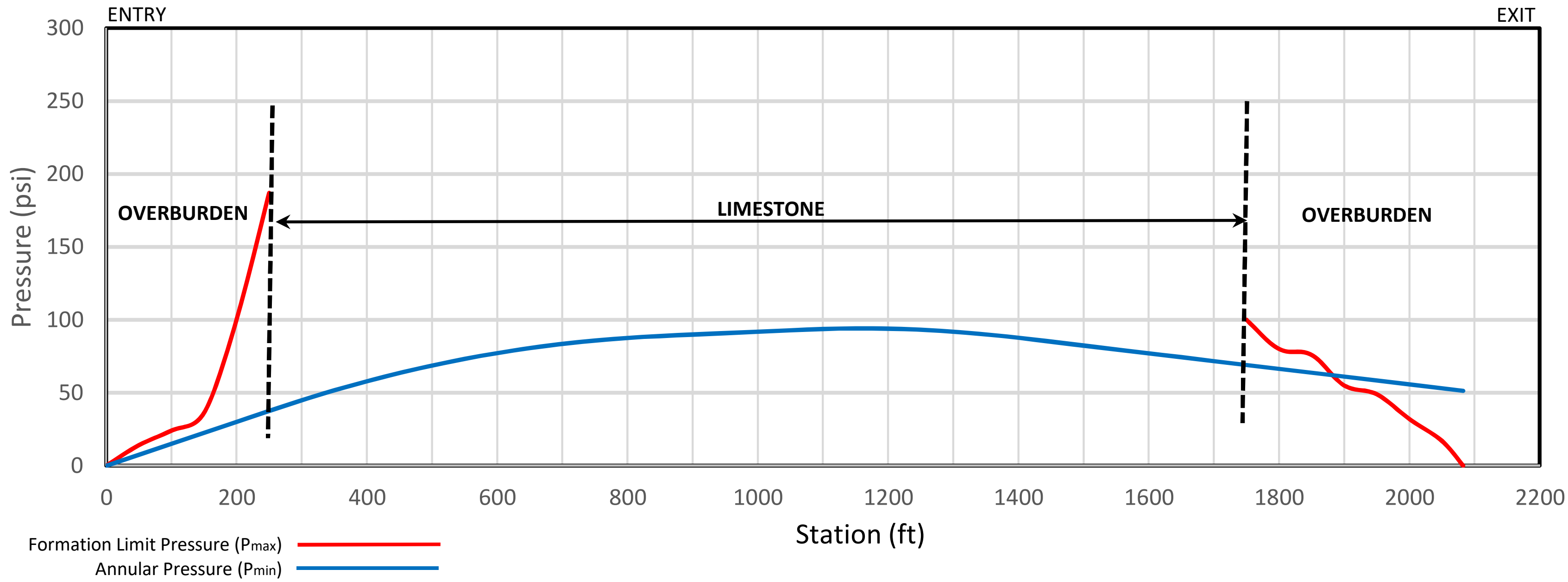
Operating Stress Analysis

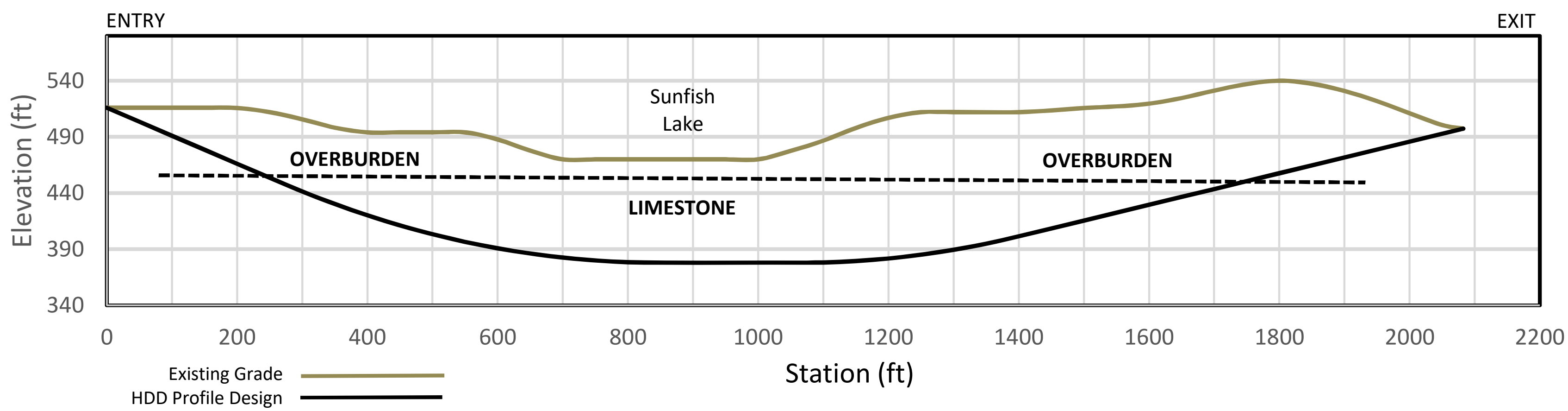
PROJECT: Spire STI Pipeline Project - 24-inch Spanish Lake Crossing
Operating Stress

Pipe Properties	Operation: Design Radius Check		Operation: Minimum Radius Check		Hydrostatic Testing: Minimum Radius Check	
	Scenario 1		Scenario 2		Scenario 3	
Pipe Outside Diameter =	24.000	in	24.000	in	24.000	in
Wall Thickness =	0.508	in	0.508	in	0.508	in
Specified Minimum Yield Strength =	70,000	psi	70,000	psi	70,000	psi
Young's Modulus =	2.9E+07	psi	2.9E+07	psi	2.9E+07	psi
Moment of Inertia =	2586.33	in^4	2586.33	in^4	2586.33	in^4
Pipe Face Surface Area =	37.49	in^2	37.49	in^2	37.49	in^2
Diameter to Wall Thickness Ratio, D/t =	47		47		47	
Poisson's Ratio =	0.3		0.3		0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	6.5E-06	in/in/°F	6.5E-06	in/in/°F
Pipe Weight in Air =	127.45	lb/ft	127.45	lb/ft	127.45	lb/ft
Pipe Interior Volume =	2.88	ft^3/ft	2.88	ft^3/ft	2.88	ft^3/ft
Pipe Exterior Volume =	3.14	ft^3/ft	3.14	ft^3/ft	3.14	ft^3/ft
Operating Parameters						
Maximum Allowable Operating Pressure =	1,440	psig	1,440	psig	2,200	psig
Radius of Curvature =	2,400	ft	1,600	ft	1,600	ft
Installation Temperature =	60	°F	60	°F	60	°F
Operating Temperature =	80	°F	80	°F	60	°F
Groundwater Table Head =		ft		ft		ft
Operating Stress Check						
Hoop Stress =	34,016	psi	34,016	psi	51,969	psi
% SMYS =	49%		49%		74%	
Longitudinal Stress from Internal Pressure =	10,205	psi	10,205	psi	15,591	psi
% SMYS =	15%		15%		22%	
Longitudinal Stress from Temperature Change =	-3,770	psi	-3,770	psi	0	psi
% SMYS =	5%		5%		0%	
Longitudinal Stress from Bending =	12,083	psi	18,125	psi	18,125	psi
% SMYS =	17%		26%		26%	
Net Longitudinal Stress (taking bending in tension) =	18,518	psi	24,560	psi	33,716	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	26%	ok	35%	ok	48%	
Net Longitudinal Stress (taking bending in compression) =	-5,649	psi	-11,690	psi	-2,534	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	8%	ok	17%	ok	4%	
Combined Stress (NLS w/bending in tension) - Max. Shear Stress Theory =	15,498	psi	9,456	psi	18,253	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	22%	ok	14%	ok	26%	
Combined Stress (NLS w/bending in compression) - Max. Shear Stress Theory =	39,664	psi	45,706	psi	54,503	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	57%	ok	65%	ok	78%	
Combined Stress (NLS w/bending in tension) - Max. Distortion Energy Theory =	29,497	psi	30,411	psi	45,665	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	42%	ok	43%	ok	65%	
Combined Stress (NLS w/bending in compression) - Max. Distortion Energy Theory =	37,163	psi	41,126	psi	53,281	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	53%	ok	59%	ok	76%	

APPENDIX 4

Hydrofracture Evaluation





J.D.Hair&Associates,Inc.
Consulting Engineers

HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
24" SPANISH LAKE CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 8/2/2018 Revision: 0

APPENDIX 5

HDD Construction Duration

Construction Duration - HDD Operations

General Data		Comments
Work Schedule, hours/shift =	10.0	24-inch Spanish Lake Crossing
days/week =	6.0	
Drilled Length, feet =	2,104	
Pilot Hole		
Production Rate, feet/hour =	20	
shifts/day =	1	
Drilling Duration, hours =	105.2	
shifts =	10.5	
Trips to change tools, shifts =	1.0	
Pilot Hole Duration, days =	11.5	

Ream and Pull Back

Pass Description =	24-inch	36-inch				Swab	Pull Back	Total
Travel Speed, feet/minute =	0.3	0.3				8.0	8.0	
shifts/day =	1	1				1	1	
Reaming Duration, hours =	142.5	142.5				6.6	6.6	298.3
shifts =	14.3	14.3				0.7	0.7	29.8
Rig up, shifts =	0.5	0.5				0.5	1.0	2.5
Trips to change tools, shifts =	1.0	1.0				0.0	0.0	2.0
Pass Duration, days =	15.8	15.8				1.2	1.7	34.3

Summary	
HDD Duration at Site, days =	49.9

Site Establishment	Move in	Rig Up	Rig Down	Move Out
shifts/day =	1	1	1	1
shifts =	0.0	2.0	2.0	0.0
days =		2.0	2.0	

APPENDIX 6

Geotechnical Data

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spire

Spire STL Pipeline – Spanish Lake Park Crossing
Geotechnical Memorandum
Mott MacDonald Project #372453

October 3, 2017

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1.0 Introduction

Mott MacDonald has been retained by Spire STL Pipeline LLC (Spire) to conduct a subsurface investigation in support of the proposed 24-inch diameter, Federal Energy Regulatory Commission (FERC) regulated pipeline at the proposed Spanish Lake Park Crossing location in St. Louis County, Missouri. Mott MacDonald understands that the proposed pipeline will be installed beneath Spanish Lake Park and adjacent golf course using Horizontal Directional Drill (HDD) methods. A Site Vicinity Map depicting the approximate crossing location has been provided as Figure 1. Mott MacDonald's subsurface investigation program consisted of exploratory soil borings to gather geotechnical information specific to the proposed crossing, as well as material testing to determine index properties for engineering evaluation. A supplemental phase consisting of geophysical surveying was conducted in May and July of 2017 to evaluate potential karst features beneath the proposed crossing alignment.

A total of three (3) soil borings have been proposed and advanced at this crossing location. Locations of the advanced borings are represented in the Boring Location Plan, included as Attachment A. Mott MacDonald has prepared this geotechnical memorandum to present the observed subsurface conditions at the proposed crossing location.

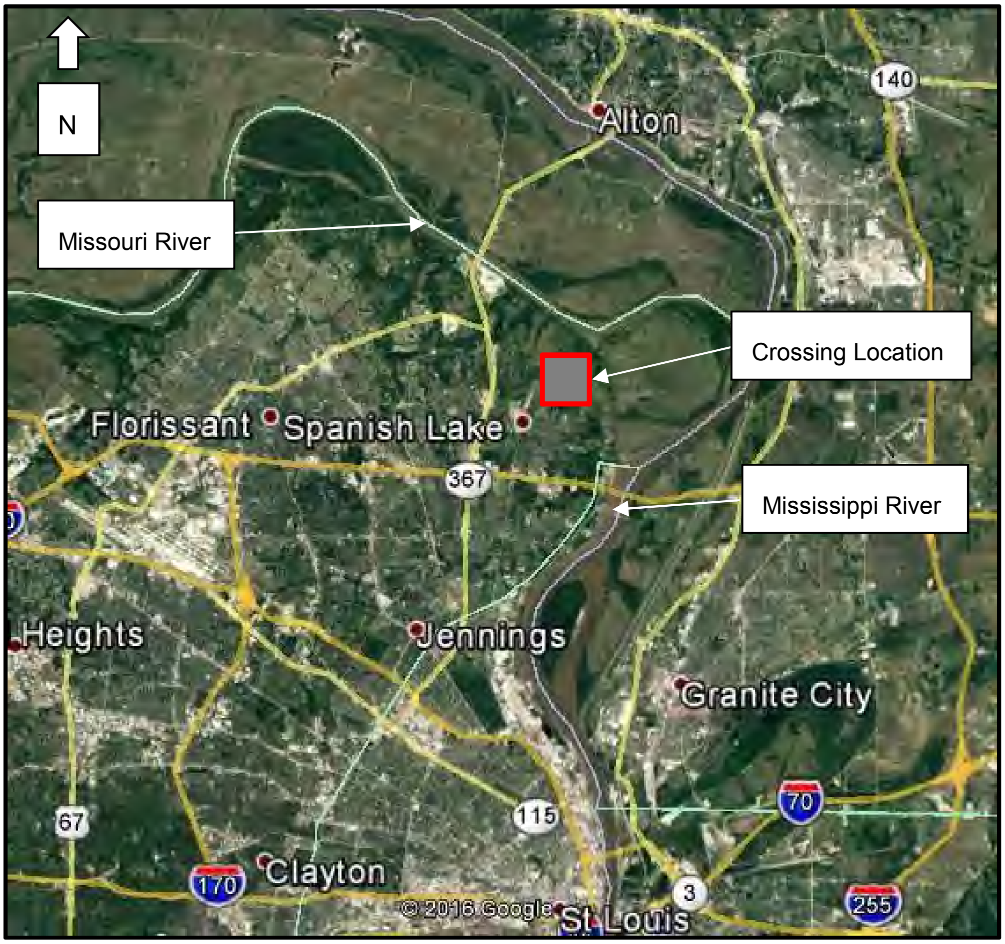

Figure 1: Site Vicinity Map

2.0 Methodology

Drilling and sampling activities were conducted by TSI Geotechnical, Inc. of St. Louis, Missouri and were overseen and logged by a qualified Mott MacDonald geotechnical representative under the direction of a Professional Engineer licensed in the State of Missouri. Soil and rock samples were collected in accordance with the American Society for Testing and Materials (ASTM) standards D1586-11 and D2113-14, respectively. Soil samples were recovered within a 2-inch outer-diameter split spoon sampler, driven continuously for the top 10 feet of each boring, then in 5-foot intervals thereafter. The Standard Penetration Test was performed to advance the split spoons and to obtain an N-Value[1] for the material. Mott MacDonald maintained detailed boring logs during drilling activities and field-classified samples in accordance with ASTM D2488 classifications.

Upon split spoon or auger refusal, rock coring was performed in the soil borings to their proposed termination depths. Rock cores were retrieved with a double-barrel NQ2 series wireline setup. Recovered cores were measured for recovery and RQD[2], logged for discontinuities, and described based on type, color, hardness, weathering, bedding thickness, dip angle, and discontinuity spacing. Soil boring termination depths and approximate ground surface elevations are presented in Table 1.

[1] N-Value is the sum of the blows from the second and third 6 inches of penetration.

[2] RQD is Rock Quality Designation and is the percentage of rock core that is in pieces of larger than 4 inches.

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Table 1: Boring Elevations and Depths

Boring Number	Approximate Ground Surface Elevation[a], in feet	Boring Termination Depth *(Elevation)*, in feet	Approximate Bedrock Depth *(Elevation)*, in feet
B-STL-09	514	150’ *(364)*	63’ *(451)*
B-STL-10	513	150’ *(363)*	60’ *(453)*
B-STL-11	518	150’ *(368)*	70’ *(448)*

[a] Based on WGS84 Vertical Datum (Google Earth)

Upon completion, all boreholes were backfilled with cement and bentonite grout. All work areas that may have been disturbed by the drill rig, vehicles, and other equipment were levelled to its previous grade following the investigation.

3.0 Local Geology

3.1 Bedrock Geology

Prior to commencing the subsurface investigation, Mott MacDonald performed a desktop study of the local geology within the project area. Based on United States Geological Survey (USGS) mapping, the Spanish Lake Crossing exists within the St. Louis Limestone Unit, which is mapped to consist of dark gray, finely crystalline to lithographic limestone with occasional dolomite, chert, and fossiliferous components. The thickness of this unit ranges from 100 to 250 feet.

Major Structural Features mapping from the Missouri Department of Natural Resources indicate that the Dupo Anticline exists within the immediate vicinity of the project area. Mott MacDonald notes that it is possible that other formations or rock types may exist along the alignment due to the approximate nature of USGS maps. Geologic references used as part of our desktop study have been provided as Attachment B.

3.2 Surficial Geology

Surficial mapping from the Natural Resources Conservation Service’s (NRCS) Web Soil Survey, also provided in Attachment B, indicates that the proposed crossing extends through the Menfro Silt Loam Unit and Urban Land-Harvester Complex. These regions are mapped as generally well drained silty and clayey materials with a low to moderate risk rating for the corrosion of steel. It is understood, however, that this risk for corrosion will be minimized by the implementation of the planned cathodic protection system along the proposed pipeline. It should also be noted that a portion of the Menfro Silt Loam Unit is mapped to contain potential karst features.

3.3 Karst Conditions

As mapped carbonate formations were identified in the project area, Mott MacDonald performed a review of available mapping for documented areas of sinkhole and karst regions. The project area is found to exist within the immediate vicinity of regions depicted as known karst areas. Mott MacDonald consulted Missouri Department of Natural Resources’s (DNR) GeoSTRAT application, and observed the crossing location to exist adjacent to mapped “sinkhole areas” as shown in Figure 2. Resources reviewed by Mott MacDonald have been compiled and provided within Attachment B.

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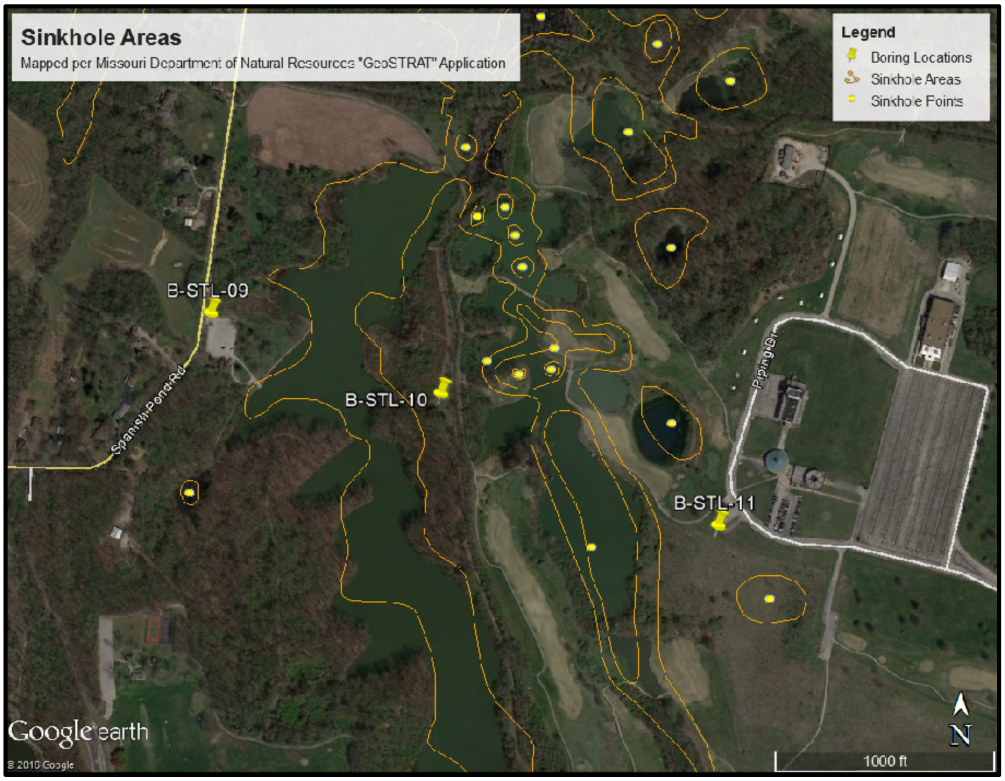

Figure 2: Missouri DNR Sinkhole Area Map

4.0 Subsurface Description

Mott MacDonald has summarized the findings and observations recorded from the subsurface investigation program below. Material descriptions of the soils and rock encountered within the investigations have been summarized and are presented in approximate order encountered from shallow to deep. It is noted that the descriptions listed in this section are simplified representations of observed materials, and individual soil boring logs, provided as Attachment C, should be consulted for detailed information specific to each boring location.

4.1 Subsurface Profile

- **TOPSOIL:** was encountered within the top 3 to 8 inches of grade within borings B-STL-09 and 10.
- **SILT (ML):** was encountered underlying the topsoil layer. This stratum was identified as primarily silt material with a clay layer observed at grade in boring B-STL-11. This material can be generally described as medium stiff in consistency with average N-values around 6 blows per foot (bpf). This stratum consisted of predominately low plasticity material and extended down to 21.5 to 26.5 feet below ground surface (bgs).
- **CLAY (CL/OL):** was identified underlying the silt layer. This material was observed to be slightly organic within B-STL-10, and varied in thickness from 5 to 15 feet between the three bores. This low to medium-plasticity material rendered N-values of 5 to 9 bpf, indicative of medium stiff to stiff soil.
- **SILTY SAND (SM):** was observed to be the next significant stratum beneath the clay material. Silty sand was encountered within borings B-STL-09 and B-STL-11 and extended down to 46.5 to 51.5 feet bgs. The silty sand was classified as medium dense material with average N-values around 11 bpf.

Mott MacDonald notes that this material was also identified within B-STL-10, but with a larger silt component; and was therefore classified as sandy silt material.

> **CLAY (CL/CH):** a second clay layer was encountered beneath the silty sand material. This material was observed to be similar to the clay layer observed at a shallower depth, but with a generally higher plasticity and greater stiffness. The clays were observed to demonstrate medium to high plasticity properties, and recorded N-values between 6 and 17 blows per foot. It should be noted that a 10-foot gravel layer was embedded within this stratum in boring B-STL-11. This layer extended down to the top of bedrock.

> **LIMESTONE:** was observed to be the primary bedrock material, encountered between 60 and 70 feet below grade within the three borings. Rock coring activities rendered recovery and RQD values ranging from 32 to 100 and 0 to 100 and percent, respectively. Mott MacDonald notes that voids up to 2 feet in size were encountered within B-STL-10 around approximately 64 and 94 feet bgs, which may be indicative of karst conditions. Recovered limestone material was generally observed to be moderately weathered with medium strong properties. It should also be noted that small components of chert material was identified at various depths within all three borings.

Upon comparison, the materials encountered during Mott MacDonald's field investigation were in general conformance with the mapped local geology.

4.2 Observed Karst Conditions

Mott MacDonald notes that observations recorded during drilling activities within boring B-STL-10 indicate the existence of karst-like features as documented within our desktop review of local geology. Field observations of sudden rod drops and rapid drilling rates confirmed the presence of clay-filled voids beneath this borehole at depths of 63.2 to 65.8 feet and 92.7 to 97 feet below grade. It is noted that a single borehole may not be representative of general subsurface conditions, therefore geophysical testing by THG was conducted to provide additional information regarding this geologic feature. Results of THG's geophysical investigations have been provided as Attachment D.

5.0 Laboratory Testing

Select rock samples collected from the subsurface investigation were submitted to TSI Geotechnical, Inc., an accredited geotechnical laboratory, for testing of engineering properties and strength. The laboratory testing program prepared by Mott MacDonald is outlined below.

5.1 Rock Testing Program

The following tests were submitted to TSI Geotechnical, Inc. for testing in accordance with the applicable ASTM standards:

> **ASTM D7012 – Unconfined Compressive Strength of Rock**

- B-STL-09: R-2 (68'-70'), R-7 (90'-92'), R-9 (102'-104'), R-11 (113'-115'), R-13 (120'-122'), R-16 (137'-140')
- B-STL-10: R-7 (90'-92'), R-10 (106'-108'), R-12 (116'-119'), R-24 (128'-130'), R-17 (140'-142')
- B-STL-11: R-1 (73'-75'), R-4 (86'-88'), R-5 (92'-95'), R-7 (100'-103'), R-10 (115'-120')

- **ASTM D5731 – Point Load Strength**
  - B-STL-09: R-2 (68'-70'), R-7 (90'-92'), R-9 (102'-104'), R-11 (113'-115'), R-13 (120'-122'), R-16 (137'-140')
  - B-STL-10: R-7 (90'-92'), R-10 (106'-108'), R-12 (116'-119'), R-24 (128'-130'), R-17 (140'-142')
  - B-STL-11: R-1 (73'-75'), R-4 (86'-88'), R-5 (92'-95'), R-7 (100'-103'), R-10 (115'-120')

5.2 Rock Testing Results

A summary of laboratory testing results performed on select rock specimens has been provided in Table 2. As-received testing results have been provided within Attachment E.

Table 2: Rock Testing Results

Boring No.	Run	Depth	Maximum Axial Point Load (psi)	Unconfined Compressive Stress (psi)
B-STL-09	R-2	68'-70'	1,000	27,967
	R-7	90'-92'	400	15,939
	R-9	102'-104'	1,230	19,821
	R-11	113'-115'	600	30,865
	R-13	120'-122'	300	4,104
	R-16	137'-140'	1,000	21,574
B-STL-10	R-7	90'-92'	1,000	16,189
	R-10	106'-108'	1,120	27,536
	R-12	116'-119'	1,200	18,565
	R-14	128'-130'	510	11,786
	R-17	140'-142'	800	18,700
B-STL-11	R-1	73'-75'	1,180	21,119
	R-4	86'-88'	1,000	30.696
	R-5	92'-95'	1,320	16,943
	R-7	100'-103'	1,250	25,310
	R-10	117'-119'	1,200	22,757

6.0 Limitations

The information presented in this geotechnical memorandum are based on the results of laboratory testing supplemented by observations recorded during Mott MacDonald's and THG's subsurface investigations advanced between March and July of 2017. Should additional investigations or laboratory testing be conducted, Mott MacDonald should be given the opportunity to review and modify our memo.

Attachments

A. Boring Location Plan

NOTES
1. SCALE IS APPROXIMATE
2. GOOGLE EARTH AERIAL IMAGERY DATED 04/02/2016

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F +1 973-912-2400
www.mottmacamericas.com
Certificate No. 24GA28016600

Client
SPIRE STL PIPELINE LLC
700 MARKET STREET
ST. LOUIS, MO 63101

Rev	Date	Drawn	Description	Ch'k'd	App'd

0 250 500
SCALE: 1" = 250'

Designed	EWP	Eng check		
Drawn	EWP	Coordination		
Dwg check	VAS	Approved		
Scale at 11" x 17" AS SHOWN	Status	Rev	Security	

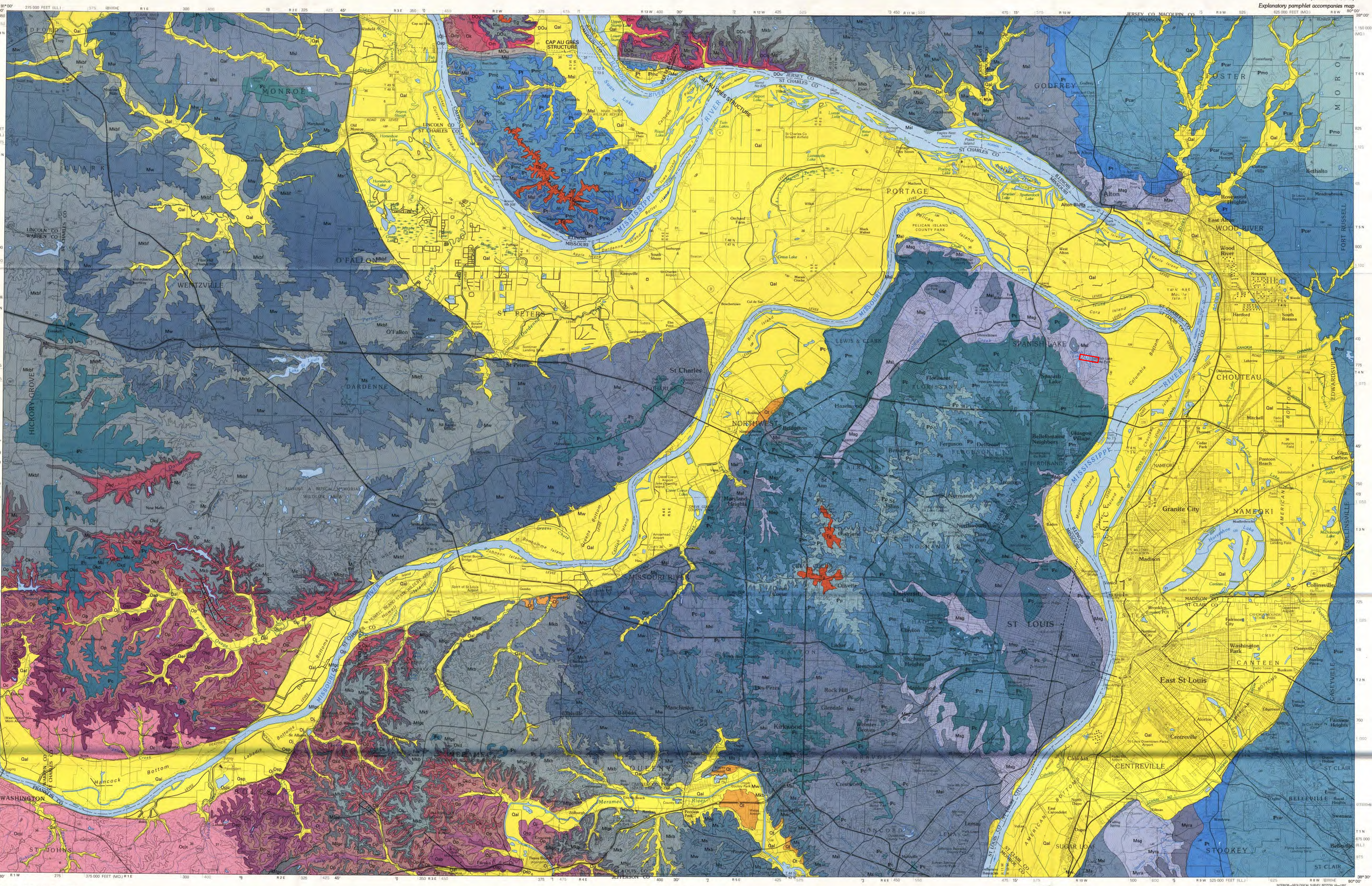
Project Number	B/O	Total	Drawing Number
372453	1	1	BLP-SL-1

Title
SPIRE STL PIPELINE
SPANISH LAKE CROSSING
BORING LOCATION PLAN

B. Geologic References

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

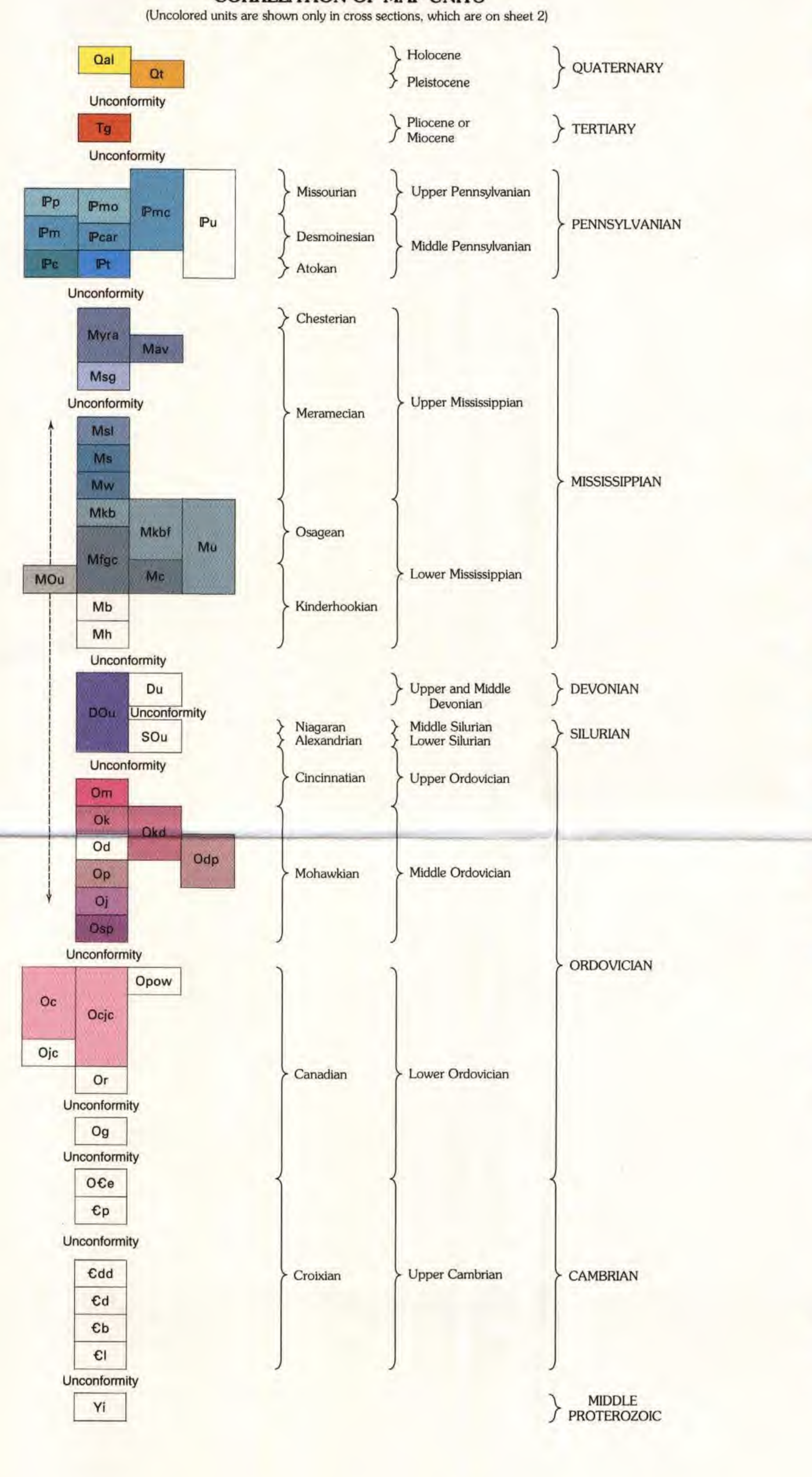
MISCELLANEOUS INVESTIGATIONS SERIES
MAP I-2533 (SHEET 1 OF 2)
Explanatory pamphlet accompanies map



Geology compiled in 1992

QUADRANGLE LOCATION

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qal — **Alluvium (Holocene)**—Gravel, sand, and silt, on flood plains of major rivers and smaller streams. Thickness ranges from 10 to 215 ft

Qt — **Terrace deposits (Holocene and Pleistocene)**—Sand, gravel, and silt

Tg — **Grover Gravel (Pliocene or Miocene)**—High-level deposits of gravel, sand, and clay. Consists dominantly of rounded, polished, light-brown chert pebbles, and lesser quantities of red (hematitic) chert, purple quartzite, and white to pink quartz pebbles. Oolitic chert or silicified oolite pebbles are also common. Matrix is largely red to tan sand and clay that contains sparse amounts of zircon and tourmaline. Leighton and Willman (1949) described rare pebbles of igneous and metamorphic rocks weathered to clay and coarse mica. The deposits are poorly sorted and clasts are typically matrix supported. Well-rounded boulders of red to purple quartzite also occur within finer matrix of the Grover Gravel, as well as in isolated patches. These boulders are as much as 2 ft in diameter. Some show distinct schistose lamination that Rubey (1952) interpreted as being of metamorphic origin. This unit was named by Rubey (1952) for exposures in the St. Louis quadrangle near the town of Grover, Mo., in secs. 1 and 3, T. 44 N., R. 3 E. However, because of small outcrop areas there, these occurrences have been omitted on the source maps used for compilation. Thickness ranges from 3 to 30 ft

IPu — **Pennsylvanian rocks, undivided**—Shown on cross sections only. Units as low in the stratigraphic section as the Joachim Dolomite are overlain by Pennsylvanian rocks

IPp — **Pleasanton Group, undivided (Upper Pennsylvanian, Missourian)**—Shale and sandstone. Mapped only in Missouri. As much as 100 ft thick

IPmc — **McLeansboro Group and Carbondale Formation, undivided (Upper and Middle Pennsylvanian, lower Missourian and upper Desmoinesian)**—Limestone, shale, sandstone, and coal. Mapped only in Illinois between the Illinois and Mississippi Rivers. Approximately 100 ft thick

IPmo — **Modesto Formation of the McLeansboro Group (Upper and Middle Pennsylvanian, lower Missourian and upper Desmoinesian)**—Limestone, shale, sandstone, and thin coal. Mapped only in Illinois. Includes all Pennsylvanian strata above the Danville (No. 7) Coal Member of the Carbondale Formation. As much as 75 ft thick

IPm — **Marmaton Group, undivided (Middle Pennsylvanian, Desmoinesian)**—Intercalated shale, limestone, clay, and coal. Mapped only in Missouri. Approximately 80 ft thick

IPcar — **Carbondale Formation (Middle Pennsylvanian, Desmoinesian)**—Sandstone, gray shale, fissile black shale, limestone, and coal. Mapped only in Illinois. Contains the principal economic coal deposits of Illinois (Willman and others, 1975). From 30 to 80 ft thick; thickens toward the south

IPc — **Cherokee Group, undivided (Middle Pennsylvanian, Desmoinesian and Atokan)**—Cycles of sandstone, siltstone, shale, clay, and coal. Mapped only in Missouri. As much as 100 ft thick

IPt — **Tradewater Formation (Middle Pennsylvanian, Desmoinesian and Atokan)**—Sandstone, siltstone, dark shale, white-gray "fire" clay, coal, and limestone. Sandstone occurs in channels, as sheet-like bodies, and in a basal bed that is locally conglomeratic and crossbedded. Mapped by Rubey (1952) as the Pottsville Formation, and by Baxter (1965), Odom (1971), and Jacobs (1971) as the Spoon Formation. Mapped only in Illinois. From 30 to 80 ft thick

Myra — **Yankeetown Sandstone, Renault Limestone, and Aux Vases Sandstone, undivided (Upper Mississippian, Chesterian and Meramecian)**

Yankeetown Sandstone (Chesterian)—Calcareous sandstone, variegated shale, and chert. Less than 45 ft thick

Renault Limestone (Chesterian and Meramecian)—Dominantly limestone and lesser variegated shale, fine-grained sandstone, sandy limestone, and conglomerate near the base (Spreng, 1961). Sandstone beds commonly contain worm borings. In Ilinois, it contains a relatively pure limestone (Levias Member) that is Meramecian and Chesterian in age and is not found in Missouri (Spreng, 1961). From 30 to 100 ft thick

Aux Vases Sandstone (Meramecian)—See Mav below for description

Mav — **Aux Vases Sandstone (Upper Mississippian, Meramecian)**—Sandstone, siltstone, minor shale, and local lens of dolomite and limestone. Sandstone is gray, calcareous, hematitic in places, and very fine to fine grained. Interfingers with various facies of the underlying Ste. Genevieve Limestone (Atherton and others, 1975). As much as 60 ft thick

argillaceous limestone in irregular beds less than 1 ft thick. Bedding planes are typically wavy and have shale partings. Most beds are fossiliferous and crinoids are dominant. Locally, the Bushberg Sandstone is included in this map unit. From 3 to 70 ft thick. Similar to the Fern Glen Formation, it thickens westward out of the Illinois basin

Mb — **Bushberg Sandstone (Lower Mississippian, Kinderhookian)**—Yellow to yellowish-brown, fine- to coarse-grained, friable quartz sandstone. Consists of a discontinuous, single massive bed. On the map it is included with the Chouteau Limestone, but on cross sections it is shown as a separate unit. From 0 to 25 ft thick

Mh — **Hannibal Shale (Lower Mississippian, Kinderhookian)**—Fissile siltstone and shale; uppermost part is commonly a very fine-grained, argillaceous sandstone. From 0 to 60 ft thick. Shown only on cross sections

DOu — **Devonian, Silurian, and Ordovician rocks, undivided (Upper and Middle Devonian, Middle and Lower Silurian, and Upper Ordovician)**—See Du and SOu units for descriptions

Du — **Upper and Middle Devonian rocks, undivided**—Limestone, sandstone, calcareous siltstone, and hard, fissile, carbonaceous shale. Uppermost beds are non-calcareous, friable (case hardened) sandstone or very sandy limestone. Near Meppen, Ill., sandstone beds contain angular pebbles of chert as much as 1.6 in. in diameter (Rubey, 1952). Lower beds are massive, well-indurated, very fossiliferous, crystalline limestone and fine-grained, poorly indurated, cherty, moderately fossiliferous, sandy limestone. According to Rubey (1952), clastic dikes of Devonian sandstone as much as 1.5 ft wide and 17 ft deep occur within Silurian rocks north of the Mississippi River in the north-central part of the St. Louis quadrangle. Shown only on cross sections

SOu — **Middle Silurian to Upper Ordovician rocks, undivided (Middle and Lower Silurian, Niagaran to Cincinnatian)**—Dolomite containing sparse fossils and oolitic limestone. Includes the Noix Limestone (Cincinnatian) at the base of the unit, which was thought to be Silurian by Rubey (1952), subsequently redefined as Ordovician by Thompson and Satterfield (1971, 1975) and Amsden (1974, 1983, 1986). Shown only on cross sections

Om — **Maquoketa Shale (Upper Ordovician, Cincinnatian)**—Massive platy mudstone to fissile claystone or shale that has basal argillaceous dolomite and calcareous mudstone. A few thin layers (depauperate zones) in the lowermost beds contain small phosphatic grains and microscopic fossils (Rubey, 1952). This unit occurs in all but the southwestern third of the St. Louis quadrangle, where it was cut out along a regional unconformity at the base of Upper Devonian rocks. Outcrops are restricted to the area just north of the Cap au Grès structure in Illinois. As much as 150 ft thick

Ok — **Kimmswick Limestone (Middle Ordovician, Mohawkian)**—Coarsely crystalline, light-colored, medium-bedded to massive fossiliferous limestone. Weathered outcrops are distinctively pitted or honeycombed. Locally, beds of fine- to medium-grained calcarenite occur; chert is minor and usually occurs only in the lower part of the formation. *Receptaculites* (sunflower coral) is a Kimmswick index fossil. Approximately 3 ft above the base is a prominent altered volcanic ash bed, the House Springs Bentonite Bed (Kolata and others, 1986). From 60 to 120 ft thick

Okd — **Kimmswick Limestone and Decorah Group, undivided (Middle Ordovician, Mohawkian)**—See Ok and Od units for descriptions

Od — **Decorah Group, undivided (Middle Ordovician, Mohawkian)**—Shown only on cross sections. Consists of three formations, in descending order: Guttenburg Limestone, Kings Lake Limestone, and Spechts Ferry Formation

Guttenburg Limestone—Light-gray, thick-bedded, sublithographic limestone and intercalated red to reddish-brown shale

Kings Lake Limestone—Thinly bedded, silty and dolomitic, fossiliferous, finely crystalline to coquinoidal limestone that has thin shale partings. A thin, unnamed bentonite bed occurring near its base is correlated with the K-5 bentonite in Tennessee by Templeton and Willman (1963)

Spechts Ferry Formation—Upper part is green to brown shale and minor calcarenite, argillaceous limestone, and limestone (Glencoe Shale Member); lower part is a massive bed of fine-grained, slightly argillaceous limestone that has a 3-inch-thick basal dark-brown shale (Castlewood Limestone Member). A thin (< 1 in.) bentonite bed called the Deicke K-bentonite by Willman and Kolata (1978) occurs near the base of the Castlewood Limestone Member. The Millbrig K-bentonite Bed of Willman and Kolata (1978) is interbedded with the Glencoe Shale Member, and is the thickest (1.8–8.0 ft) and most persistent of the Ordovician bentonite beds in the Midcontinent (Kolata and others, 1987). Published isotopic ages for the Millbrig K-bentonite Bed are 453.7 ± 1.8 Ma (Tucker and others, 1990) and 454.1 ± 2.1 Ma (Kunk and others, 1985). The Glencoe and Castlewood share the same type-section in the St. Louis quadrangle, on the southeast bank of the Meramec River in the SE1/4 SE1/4, sec. 21, T. 44 N., R. 4 E., Manchester 7.5-minute quadrangle, St. Louis County, Mo. Total thickness of the Decorah Group is 30–60 ft

Odp — **Decorah and Plattin Groups, undivided (Middle Ordovician, Mohawkian)**—See Od and Op units for descriptions

Op — **Plattin Group, undivided (Middle Ordovician, Mohawkian)**—Gray mudstone interbedded with thin, laminated to cross-laminated grainstone. Upper part contains thin shale beds; shale forms partings in the middle and lower parts. Generally chert poor. Fucoid, or burrow markings, are a distinctive feature. In Missouri, its base is placed at a prominent, oolitic limestone-conglomerate bed (Grohskopf, 1948). Recognized formations within the Plattin Group differ between Missouri and Illinois. There is no acknowledged correlation. Thickness increases from approximately 80 ft in the west to more than 300 ft in the east

Oj — **Joachim Dolomite (Middle Ordovician, Mohawkian)**—Unit consists of five members in the St. Louis area, recognized in both Missouri and Illinois (Thompson, 1991; Willman and others, 1975). They are, in descending order: the Metz, Matson, Defiance, Boles, and Augusta Members. All but the Metz Member have type-section locality in the St. Louis area, in a cut along the Chicago, Rock Island and Pacific Railroad on the southeast side of the Missouri River in SW1/4 NE1/4 SW1/4, sec. 10, T. 44 N., R. 2E., Labadie 7.5-minute quadrangle, Franklin County, Mo.

Metz Member—Yellow-brown, laminated, shaly dolomite. Algal stromatolites, mud cracks, scour surfaces, and clots of crystalline calcite (birdseye structures) are common

Matson Member—Dense, dark-brown, fetid, algal dolomite; most beds are 3–4 ft thick. Algal stromatolite domes 2 ft high are common. It is the most resistant member of the Joachim Dolomite and weathers to a distinctive pitted surface

Defiance Member—Silty, shaly dolomite

Boles Member—Silty, shaly dolomite containing seven discontinuous layers of white to black chert (Templeton and Willman, 1963)

Augusta Member—Alternating layers of shale, siltstone, and dolomitic sandstone. Distinctive upper beds consist of brown, algal dolomite and limestone that is locally conglomeratic. A nodular chert bed occurs about 1 ft below the top of this member. Thickness of the Joachim Dolomite ranges from 60 to 160 ft

Osp — **St. Peter Sandstone (Middle Ordovician, Mohawkian)**—Well-sorted, medium- to fine-grained quartzose sandstone and orthoquartzite. Grains are rounded, spherical, and characteristically frosted. The unit varies from friable to well indurated. Basal 3–5 ft consists of strongly weathered and reworked green shale, sandstone, and chert detritus; this zone was named the Kress Member by Buschbach (1964) and Templeton and Willman (1963). The base of the St. Peter Sandstone also marks one of the most pronounced regional unconformities in the Midcontinent. Composed of nearly pure (98-99 percent) silica, this unit is extensively quarried in the St. Louis quadrangle. It is also a major regional aquifer. Thickness increases toward the northeast and ranges from about 60 to 165 ft

Opow — **Powell Dolomite (Lower Ordovician, Canadian)**—Medium to finely crystalline dolomite containing thin beds of green shale and fine-grained sandstone. Contact with the underlying Cotter Dolomite is defined as unconformable in eastern Missouri and thus represents a pre-Powell erosional surface (Weller and St. Clair, 1928). Shown on cross sections only; on the map, this unit is included with either the Cotter Dolomite (Oc) or the Cotter and Jefferson City Dolomites (Ocjc). Ranges in thickness from 30 to 150 ft

Oc — **Cotter Dolomite (Lower Ordovician, Canadian)**—Brown to gray, medium to finely crystalline dolomite containing localized thin beds of green shale and sandstone. Chert content is highly variable, ranging from abundant to absent. In a Missouri-wide characterization, Martin and others (1961) describe the lower part as relatively devoid of chert, the middle part as containing oolitic chert and large siliceous ooliths, and the upper part as containing quartz masses and brown oolitic chert. Present across the entire St. Louis quadrangle, it has a thickness range of 180 to 330 ft. In Missouri, the Powell Dolomite is mapped with the Cotter Dolomite

Ocjc — **Cotter and Jefferson City Dolomites, undivided (Lower Ordovician, Canadian)**—See Oc and Ojc units for descriptions

Ojc — **Jefferson City Dolomite (Lower Ordovician, Canadian)**—Brown, medium to finely crystalline dolomite and argillaceous dolomite. Lenses of orthoquartzite, conglomerate, and shale occur locally. Chert is not abundant and where present is typically oolitic, layered, mottled, or sandy. It is noted for its complex succession of lithologies, such that "one locality is rarely duplicated in another locality" (Martin and others, 1961). Shown only on cross sections. Thickness ranges from 140 to 275 ft

Or — **Roubidoux Formation (Lower Ordovician, Canadian)**—Interbedded sandstone, sandy dolomite, chert, sandy chert, and cherty dolomite. Shown only on cross sections. Thickness ranges from 110 to 170 ft

Og — **Gasconade Dolomite (Lower Ordovician, Canadian)**—Thin- to medium bedded, medium to finely crystalline dolomite. Contains varying amounts of chert and minor sandstone lenses. Its basal unit is the Gunter Sandstone Member. It consists of 25–30 ft of medium-grained quartzose sandstone and sandy dolomite. Shown only on cross sections. Total thickness range of 230–290 ft

O€e — **Eminence Formation (Lower Ordovician and Upper Cambrian, Canadian and Croixian)**—Sandy, fine- to medium-grained, dolomitized, oolitic to coquinoidal calcarenite. It also contains oolitic chert, stromatolites, and thin beds of sandstone. The Cambrian-Ordovician boundary probably occurs in the upper part of this formation (Kurtz, 1981). Shown only on cross sections. Thickness range of 110–285 ft

€p — **Potosi Formation (Upper Cambrian, Croixian)**—Slightly argillaceous, medium to finely crystalline dolomite. Druse-lined cavities are characteristic. Shown only on cross sections. From 100 to 550 ft thick

€dd — **Derby and Doe Run Formations, undivided (Upper Cambrian, Croixian)**—Dense, medium to finely crystalline dolomite in upper part; thinly to irregularly bedded, shaly to silty, glauconitic dolomitized calcarenite in lower part. Shown only on cross sections. From 120 to 155 ft thick

€d — **Davis Formation (Upper Cambrian, Croixian)**—Repetitive sequences of shale, siltstone, and silty dolomite or limestone. "Flat pebble" and "edgewise-conglomerate" (mud-chip breccia) are characteristic (Hayes and Knight, 1961; Howe and others, 1972). Shown on cross sections only. From 30 to 240 ft thick; greatly thinned over Precambrian knob on cross section A–A′

€b — **Bonneterre Formation (Upper Cambrian, Croixian)**—Coarse to finely crystalline, dolomitized calcarenite. Glauconitic and thin shaly beds occur locally. Shown only on cross sections. From 190 to 550 ft thick; greatly thinned over Precambrian knob on cross section A–A′

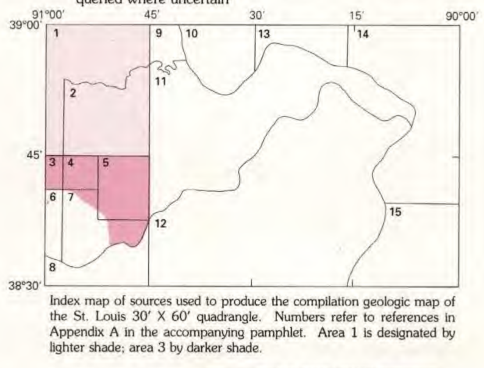
€l — **Lamotte Formation (Upper Cambrian, Croixian)**—Fine- to coarse-grained quartzose sandstone and conglomerate. Grains are typically well rounded. Conglomerate contains pebbles and boulders of Precambrian lithologies. Shown only on cross sections. From 0 to 520 ft thick; absent over Precambrian knob on cross section A–A′

Yi — **Igneous crystalline basement (Middle Proterozoic)**—Gabbro, norite, and diorite intruded by granitic dikes and leucogranite. Shown only on cross sections. Two deep holes drilled in the St. Louis quadrangle penetrated Precambrian basement, No. 19247 in the northwestern corner and No. 12525 in the east-central region (cross section A–A′). The first hole encountered Precambrian rocks at an elevation of 2563 ft below sea level. Rock types recovered were gabbro, norite, and diorite intruded by granitic dikes (Kisvarsanyi, 1975). A sample of diorite from this hole has yielded a K-Ar age from biotite of 1410 ± 70 Ma (Muehlberger and others, 1966). The second well was drilled on the crest of the Florissant dome on the Cap au Grès-Waterloo-Dupo structure and encountered a Precambrian knob at an elevation of 2641 ft below sea level. The rock recovered was leucogranite (alaskite) (Kisvarsanyi, 1975) that has a whole-rock Rb-Sr age of 1380 ± 70 Ma (Muehlberger and others, 1966)

EXPLANATION OF MAP SYMBOLS

Contact—Dashed where concealed

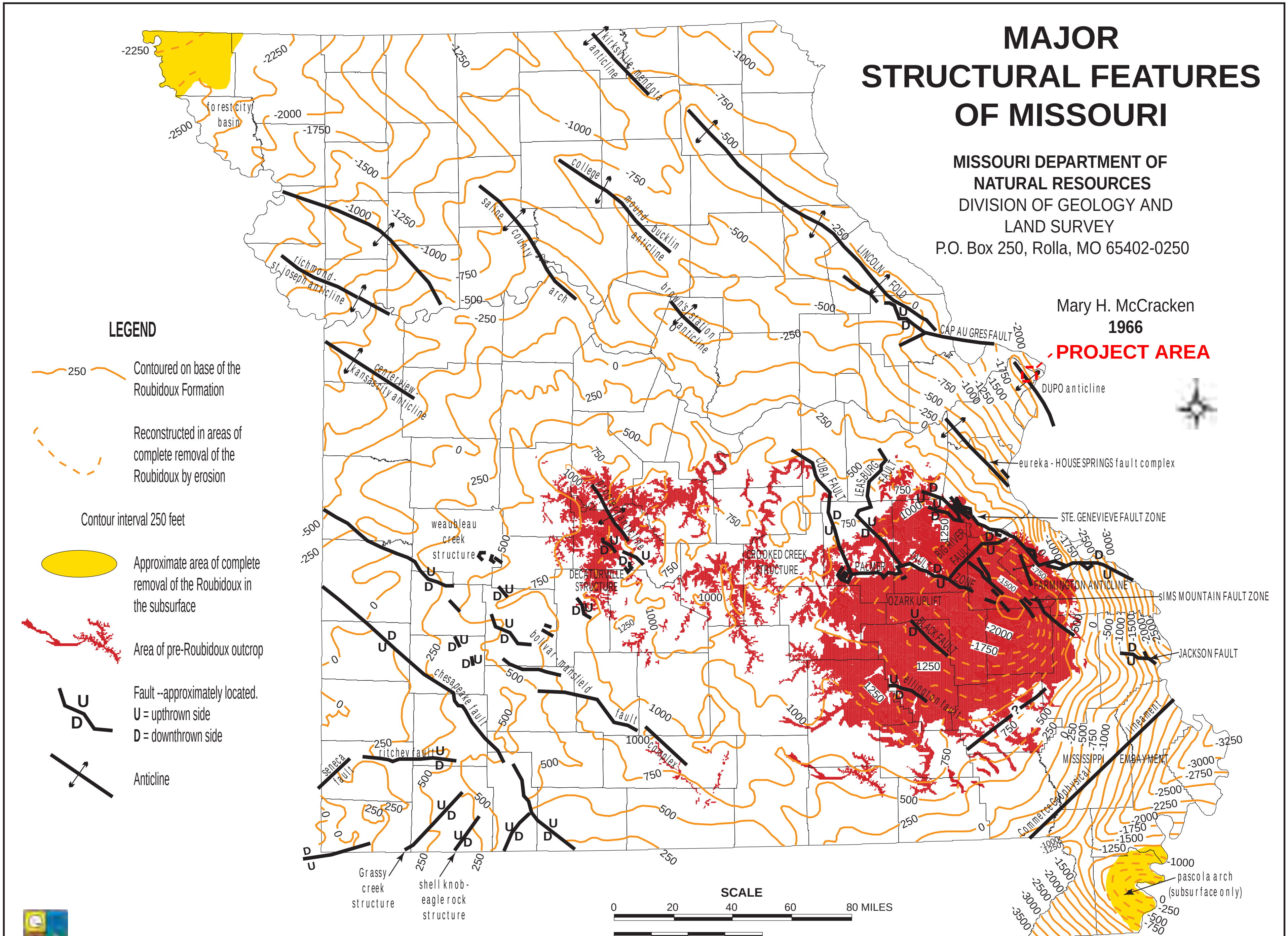
Fault—Dashed where inferred, dotted where projected. Bar and ball on downthrown side. Arrows show relative horizontal movement; queried where uncertain



Index map of sources used to produce the compilation geologic map of the St. Louis 30′ X 60′ quadrangle. Numbers refer to references in

BEDROCK GEOLOGIC MAP OF THE ST. LOUIS 30′ × 60′ QUADRANGLE, MISSOURI AND ILLINOIS

Compiled by
Richard W. Harrison
1997



DNR/DGLS Fact Sheet No. 6

Soil Map—St. Louis County and St. Louis City, Missouri
(Spire STL Pipeline - Spanish Lake Crossing)

Map Scale: 1:8,630 if printed on A landscape (11" x 8.5") sheet.

N

Meters: 0, 100, 200, 400, 600

Feet: 0, 400, 800, 1600, 2400

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 15N WGS84

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Map Unit Polygons

Soil Map Unit Lines

Soil Map Unit Points

Special Point Features

Blowout

Borrow Pit

Clay Spot

Closed Depression

Gravel Pit

Gravelly Spot

Landfill

Lava Flow

Marsh or swamp

Mine or Quarry

Miscellaneous Water

Perennial Water

Rock Outcrop

Saline Spot

Sandy Spot

Severely Eroded Spot

Sinkhole

Slide or Slip

Sodic Spot

Spoil Area

Stony Spot

Very Stony Spot

Wet Spot

Other

Special Line Features

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: St. Louis County and St. Louis City, Missouri
Survey Area Data: Version 16, Sep 28, 2016

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Feb 2, 2012—Jun 25, 2014

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

St. Louis County and St. Louis City, Missouri (MO189)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
60001	Menfro silt loam, 5 to 9 percent slopes, eroded	12.5	7.5%
60003	Menfro silt loam, 9 to 14 percent slopes, eroded	15.2	9.2%
60004	Menfro silt loam, 14 to 20 percent slopes, eroded	15.6	9.4%
60025	Urban land-Harvester complex, 2 to 9 percent slopes	30.0	18.1%
60171	Menfro silt loam, karst, 2 to 14 percent slopes, eroded	11.2	6.7%
60176	Menfro silt loam, karst, 9 to 35 percent slopes	55.4	33.4%
99001	Water	26.1	15.7%
Totals for Area of Interest		**165.9**	**100.0%**

St. Louis County and St. Louis City, Missouri

60176—Menfro silt loam, karst, 9 to 35 percent slopes

Map Unit Setting

National map unit symbol: 2qp6d
Elevation: 400 to 900 feet
Mean annual precipitation: 31 to 40 inches
Mean annual air temperature: 54 to 57 degrees F
Frost-free period: 160 to 190 days
Farmland classification: Not prime farmland

Map Unit Composition

Menfro, karst, and similar soils: 85 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Menfro, Karst

Setting

Landform: Hillslopes, sinkholes, ridges
Landform position (two-dimensional): Backslope, summit
Landform position (three-dimensional): Side slope, crest
Down-slope shape: Convex, linear
Across-slope shape: Convex, linear
Parent material: Loess

Typical profile

Ap - 0 to 7 inches: silt loam
Bt1 - 7 to 33 inches: silty clay loam
Bt2 - 33 to 60 inches: silty clay loam

Properties and qualities

Slope: 9 to 35 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: High (about 11.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6e
Hydrologic Soil Group: C

Ecological site: Deep Loess Protected Backslope Forest (F115BY003MO), Deep Loess Exposed Backslope Woodland (F115BY043MO)
Other vegetative classification: Trees/Timber (Woody Vegetation)
Hydric soil rating: No

Data Source Information

Soil Survey Area: St. Louis County and St. Louis City, Missouri
Survey Area Data: Version 16, Sep 28, 2016

St. Louis County and St. Louis City, Missouri

60025—Urban land-Harvester complex, 2 to 9 percent slopes

Map Unit Setting

National map unit symbol: 2qp0t
Mean annual precipitation: 37 to 47 inches
Mean annual air temperature: 52 to 57 degrees F
Frost-free period: 184 to 228 days
Farmland classification: Not prime farmland

Map Unit Composition

Urban land: 50 percent
Harvester and similar soils: 40 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Urban Land

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8
Hydric soil rating: No

Description of Harvester

Setting

Landform: Interfluves, hillslopes
Landform position (two-dimensional): Summit, shoulder
Landform position (three-dimensional): Interfluve, side slope
Down-slope shape: Linear, convex
Across-slope shape: Linear, convex
Parent material: Loess

Typical profile

C1 - 0 to 7 inches: silt loam
C2 - 7 to 31 inches: silty clay loam
C3 - 31 to 80 inches: clay loam

Properties and qualities

Slope: 2 to 9 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Moderately well drained
Runoff class: High
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: About 30 to 36 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Moderate (about 8.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3e
Hydrologic Soil Group: C
Ecological site: Deep Loess Upland Woodland (F115BY001MO)
Other vegetative classification: Trees/Timber (Woody Vegetation)
Hydric soil rating: No

Data Source Information

Soil Survey Area: St. Louis County and St. Louis City, Missouri
Survey Area Data: Version 16, Sep 28, 2016

St. Louis County and St. Louis City, Missouri

60004—Menfro silt loam, 14 to 20 percent slopes, eroded

Map Unit Setting

National map unit symbol: 2r0f2
Elevation: 400 to 900 feet
Mean annual precipitation: 37 to 49 inches
Mean annual air temperature: 52 to 59 degrees F
Frost-free period: 184 to 228 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Menfro and similar soils: 90 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Menfro

Setting

Landform: Hillslopes
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Loess

Typical profile

Ap - 0 to 3 inches: silt loam
Bt1 - 3 to 45 inches: silty clay loam
Bt2 - 45 to 79 inches: silt loam

Properties and qualities

Slope: 14 to 20 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: High (about 11.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6e
Hydrologic Soil Group: C

Ecological site: Deep Loess Protected Backslope Forest (F115BY003MO), Deep Loess Exposed Backslope Woodland (F115BY043MO)
Other vegetative classification: Trees/Timber (Woody Vegetation)
Hydric soil rating: No

Minor Components

Goss

Percent of map unit: 10 percent
Landform: Ridges
Landform position (two-dimensional): Summit, shoulder
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Ecological site: Chert Upland Woodland (F116AY011MO)
Other vegetative classification: Trees/Timber (Woody Vegetation)
Hydric soil rating: No

Data Source Information

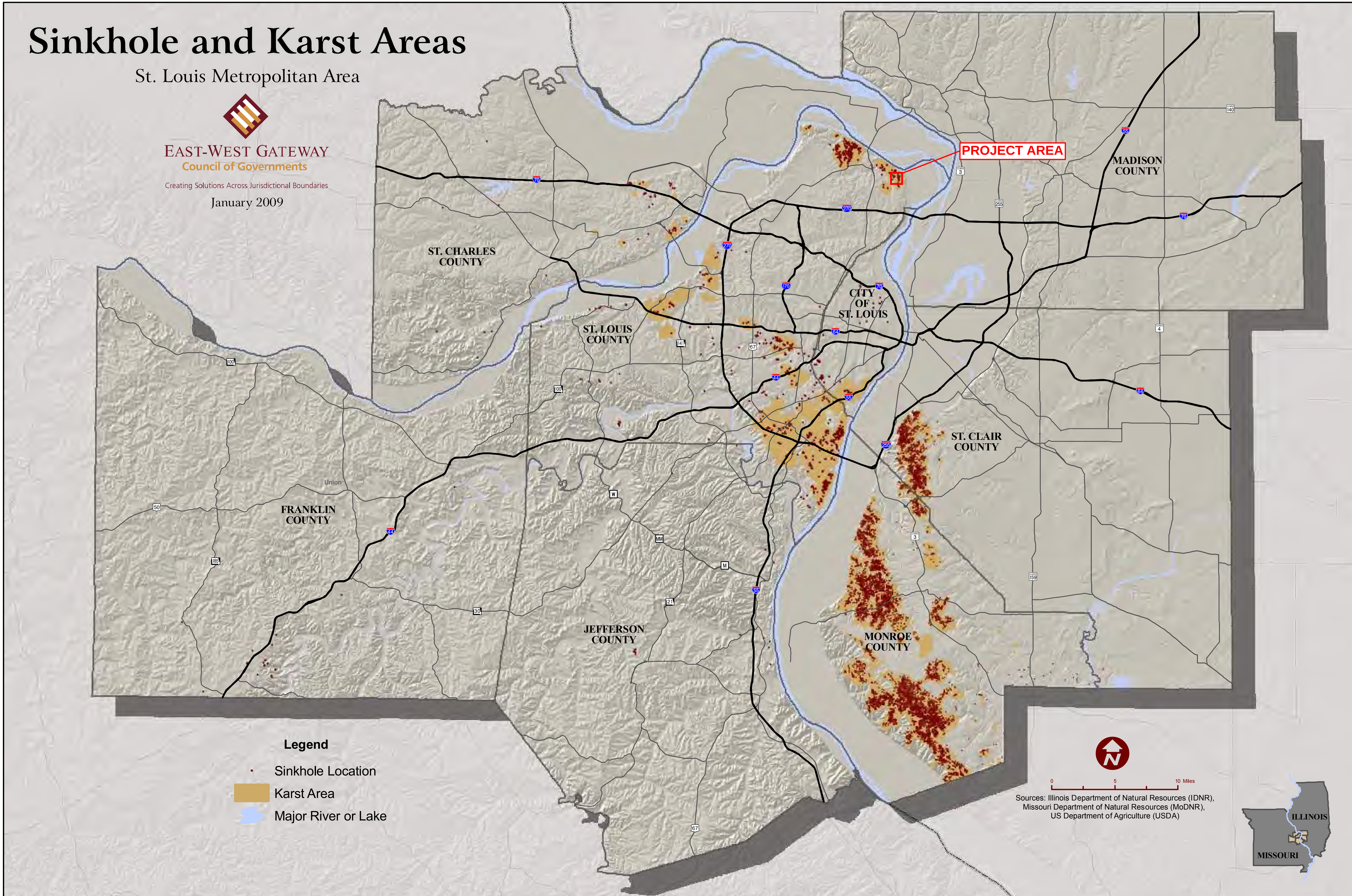
Soil Survey Area: St. Louis County and St. Louis City, Missouri
Survey Area Data: Version 16, Sep 28, 2016

Sinkhole and Karst Areas

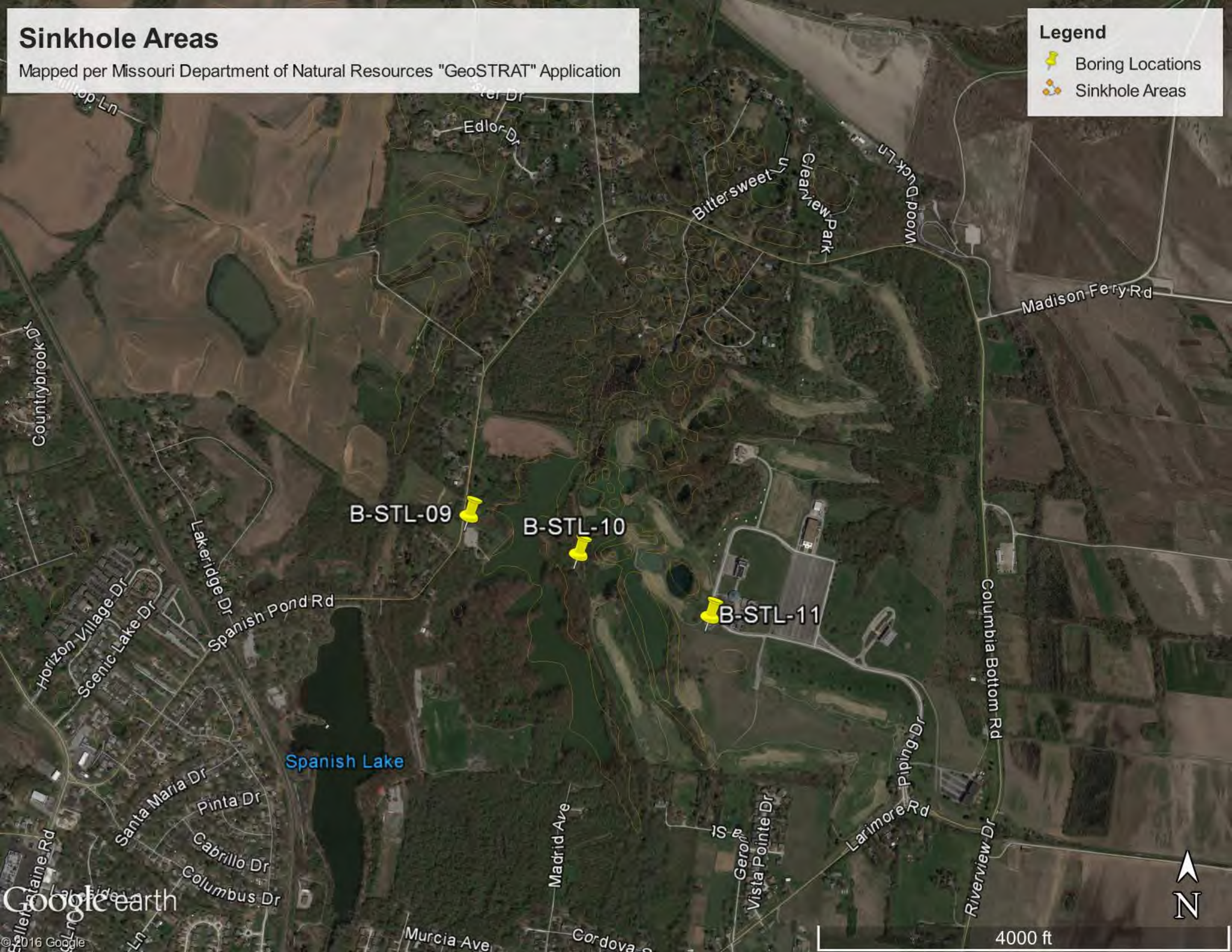
St. Louis Metropolitan Area

East-West Gateway
Council of Governments
Creating Solutions Across Jurisdictional Boundaries

January 2009



Sources: Illinois Department of Natural Resources (IDNR), Missouri Department of Natural Resources (MoDNR), US Department of Agriculture (USDA)


Sinkhole Areas
Mapped per Missouri Department of Natural Resources "GeoSTRAT" Application
Legend
Boring Locations
Sinkhole Areas
B-STL-09
B-STL-10
B-STL-11
Edlor Dr
Bittersweet Ln
Clearview Park
Wood Duck Ln
Madison Fery Rd
Countrybrook Dr
Lakeridge Dr
Spanish Pond Rd
Horizon Village Dr
Scenic Lake Dr
Columbia Bottom Rd
Spanish Lake
Santa Maria Dr
Pinta Dr
Cabrillo Dr
Columbus Dr
Madrid Ave
Vista Pointe Dr
Larimore Rd
Piping Dr
Riverview Dr
Murcia Ave
N
4000 ft
Google earth
© 2016 Google

C. Soil Boring and Rock Core Logs

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-STL-09**

Project:	Spire STL Pipeline	**Project No.:**	372453
Location:	Missouri/Illinois	**Project Mgr:**	Vatsal Shah
Client:	Spire STL Pipeline LLC	**Field Eng. Staff:**	Jonathan Nelson
Drilling Co.:	TSi Geotechnical, Inc.	**Date/Time Started:**	March 24, 2017 at 3:30 pm
Driller/Helper:	Randy Kelly /Lance Leonard	**Date/Time Finished:**	March 28, 2017 at 10:35 am

Elevation: 514 ft. **Vertical Datum:** WGS84 **Boring Location:** 22 feet east of pavement on the edge of Spanish Pond Road **Coord.:** **N:** 38.802561 **E:** -90.199603 **Horizontal Datum:** WGS84

Item	Casing	Sampler	Core Barrel
Type	HSA	S	NQ
Length (ft)	5	2	10
Inside Dia. (in.)	4.25	1.375	1.875
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-550X

☐ Truck ☐ Tripod ☐ Cat-Head
☑ ATV ☐ Geoprobe ☐ Winch
☐ Track ☐ Air Track ☐ Roller Bit
☐ Skid ☐ ______ ☑ Cutting Head

Hammer Type: ☐ Safety ☐ Doughnut ☑ Automatic ☐ ______

Drilling Fluid: ☑ Bentonite ☑ Polymer ☑ Water ☑ None

Drill Rod Size:

Casing Advance: Hollow Stem Auger/Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-1 0.0'- 2.0'	17	2 3 4 4			8" - TOPSOIL	-	L	M	L	P.P. = 1.25 tsf
						0.8					
					ML	Medium stiff, yellowish red SILT, moist (ML)					
	S-2 2.0'- 4.0'	16	1 3 5 5		ML	Medium stiff, yellowish red SILT, moist (ML)	-	L	NP	L	P.P. = 2.60 tsf
510 / 5	S-3 4.0'- 6.0'	8	2 1 3 2		ML	Soft, yellowish red SILT, little coarse to fine Gravel, trace coarse to fine Sand, moist (ML)	-	L	NP	L	P.P. = 1.6 tsf
	S-4 6.0'- 8.0'	16	1 2 2 2		ML	Soft, yellowish red to brownish yellow Clayey SILT, moist (ML)	-	M	L	M	P.P. = 1.0 tsf
	S-5 8.0'- 10.0'	24	1 4 4 4		ML	Medium stiff, yellowish red Clayey SILT, moist (ML)	-	M	L	M	P.P. = 2.6 tsf T.V. = 0.50 tsf
10											
500	S-6 13.0'- 15.0'	24	2 2 3 1		ML	Medium stiff, yellowish red Clayey SILT, moist (ML)	-	M	L	M	P.P. = 0.90 tsf T.V. = 0.13 tsf
15											
	S-7 18.0'- 20.0'	24	2 2 2 3		ML	Soft, reddish brown Clayey SILT, moist (ML)	-	M	L	M	P.P. = 1.6 tsf T.V. = 0.31 tsf

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Geoprobe

Notes:
P.P. = Pocket Penetrometer.
T.V. = Torvane.

Boring No.: **B-STL-09**

Field Test Legend: Dilatancy: N - None S - Slow R - Rapid; Toughness: L - Low M - Medium H - High; Plasticity: NP - Non-Plastic L - Low M - Medium H - High; Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading. 3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
490	S-8 23.0'-25.0'	24	2 2 3 4		ML	Medium stiff, yellowish red to reddish brown Clayey SILT, moist (ML)	-	M	L	M	P.P. = 2.5 tsf T.V. = 0.30 tsf
25											
						26.5					
	S-9 28.0'-30.0'	24	2 3 5 4		CL	Medium stiff, brown to light brown Silty CLAY, trace fine Sand, moist (CL)	-	M	M	M	P.P. = 2.5 tsf T.V. = 0.37 tsf Mottling includes 1/4" brownish yellow lenses.
30											
480	S-10 33.0'-35.0'	18	3 4 5 4		CL	Stiff, brown to brownish yellow Silty CLAY, fine Sand, moist (CL)	N	M	M	VH	P.P. = 2.7 tsf T.V. = 0.64 tsf Mottling contains 1/4" lenses.
35											
						36.5					
	S-11 38.0'-40.0'	21	2 2 4 3		ML	Yellowish red Sandy SILT, little Clay, wet (ML)	-	L	L	M	Groundwater encountered at 38 feet BGS while drilling.
						39.5					
					SM	Yellowish red Silty coarse to fine SAND, trace Clay, wet (SM)					
40											
470	S-12 43.0'-45.0'	20	6 9 12 13		SM	Medium dense, brownish yellow to brown Silty coarse to fine SAND, little coarse to fine Gravel, wet (SM)	-	L	-	L	
45											
						46.5					

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
	S-13 48.0'-50.0'	2	8 7 5 7		CL	Stiff, dark brown Sandy CLAY, little Silt, wet (CL)	-	H	M	H	
50											
	S-14 53.0'-55.0'	24	2 3 5 6		CL	Stiff, dark brown Sandy SILT, little Clay, wet (CL)	-	M	M	M	P.P. = 4.3 tsf
460											
55											
						56.5					
	S-15 58.0'-60.0'		3 5 6 6		CH	Stiff, dark brown CLAY, trace Silt, trace fine Sand, wet (CH)	-	H	H	VH	P.P. = 2.3 tsf
60											
						63.0					
	63.0'-'					Top of Rock at 63 feet BGS. See Rock Coring Log.	-	-	-	-	Encountered refusal at 63 feet BGS.
450											
65											
70											
440											
75											

NOTES:

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

CORE BORING LOG

MOTT MACDONALD

BORING NO.: **B-STL-09**

Project:	Spire STL Pipeline	**Project No.:**	372453
Location:	Missouri/Illinois	**Project Mgr:**	Vatsal Shah
Client:	Spire STL Pipeline LLC	**Field Eng. Staff:**	Jonathan Nelson
Drilling Co.:	TSi Geotechnical, Inc.	**Date/Time Started:**	March 24, 2017 at 3:30 pm
Driller/Helper:	Randy Kelly /Lance Leonard	**Date/Time Finished:**	March 28, 2017 at 10:35 am

Elevation: 514 ft.		**Vertical Datum:** WGS84	
Item	**Casing**	**Core Barrel**	**Core Bit**
Type	HSA	NQ	Imp. Diamond
Length (ft)	5	10	6
Inside Dia. (in.)	4.25	1.875	1.875

Boring Location: 22 feet east of pavement on the edge of Spanish Pond Road

Horizontal Datum: WGS84

Rig Make & Model: CME-550X

Coord.: N: 38.802561 **E:** -90.199603

Drilling Method: Wireline

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations) SEE TEST BORING LOG FOR OVERBURDEN DETAILS	Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	3.20	63.0							LIMESTONE, light gray, fine grained, medium strong, highly weathered, extremely close to close spaced discontinuities 63' - 65' Highly Fractured zone								Rod dropped from 64.3 to 64.4 feet BGS.
450	2.00	65.0	R-1	21 88%	0 0%	R3	H			63.90 64.54	J J	14 61	U,R U,R	DG DS	W W	N N	
65	2.90	65.0							LIMESTONE, light gray, fine grained, medium strong, moderately weathered, very close to moderately spaced discontinuities Frequent stylolites 65' - 66.6' Highly Fractured zone	65.00 65.80	B J	6 40	U,Sm U,Sm	FR DS	W W	N N	
	2.80									66.10 66.30	J Sty	0 0	U,Sm U,R	FR DS	W O	N N	
	2.10		R-2	49 82%	28 47%	R3	M		67.2' - 67.5' Highly Fractured zone	67.50	Sty	13	U,R	FR	W	N	Soft zone.
	2.30								68.8' - 69' Highly Fractured zone								Soft zone.
	2.70	70.0															
70	2.20	70.0							LIMESTONE with interbedded Marlstone, gray to light gray, fine grained, moderately weathered, medium strong, extremely close to moderately spaced discontinuities 70' - 72.2' Marlstone 71.2' - 72' Highly Fractured zone	70.60	B	7	U,R	DG	PO	CL	
	1.10									71.20 71.80	F B	15 11	U,R U,R	DS DE	PO MW	N CL	
	2.00		R-3	60 100%	47 78%	R3	M			73.00	Sty	10	U,R	DS	PO	N	
	2.00																
440	1.50	75.0															
75	1.90	75.0							LIMESTONE, light gray, fine grained, highly weathered, extremely close to moderately spaced discontinuities	74.90	F	7	U,Sm	FR	MW	N	
	1.60								76.5' - 76.7' Highly Fractured zone	76.70	Sty	3	U,Sm	DG	W	N	
	1.70		R-4	59 98%	33 55%	R3	M			77.30 77.80	B B	4 10	P,R U,Sm	DS DG	O O	N CL	
	2.10									78.30	B	12	U,Sm	DE	MW	CL	
	1.70	80.0							79.2' - 80' Highly Fractured zone	79.40	B	32	U,R	DE	W	CL	
80	2.50	80.0							LIMESTONE, light gray, fine grained, moderately weathered, medium strong, very close to moderately spaced discontinuities	80.40 80.70	Sty B	10 0	U,R U,R	DG DG	MW O	CL CL	
	1.60									81.70	J	16	U,Sm	FR	MW	N	
	1.70		R-5	60 100%	31 52%	R3	M			82.60	Sty	0	U,Sm	DS	MW	N	

Discontinuities (See Legend for Rock Description System)

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
		-			

Notes:

Elevation marks (ft): 430, 420, 410. Depth marks (ft): 85, 90, 95, 100, 105.

Depth (ft)	Avg Core Rate (min/ft)	Run/(Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath
– 85.0	1.90, 1.60					
85.0 – 90.0	1.90, 2.10, 2.30, 2.10, 2.00	R-6	60 / 100%	23 / 38%	R4	M
90.0 – 95.0	5.60, 7.80, 11.1, 8.30, 8.70	R-7	60 / 100%	48 / 80%	R5	SL
95.0 – 100.0	3.50, 6.10, 6.70, 5.90, 5.50	R-8	60 / 100%	58 / 97%	R5	FR
100.0 – 105.0	5.30, 4.30, 4.50, 4.20, 5.10	R-9	60 / 100%	54 / 90%	R3	FR
105.0 –	3.90, 4.50, 3.40, 4.30	R-10	60 / 100%	57 / 95%	R3	SL

Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)

84.2' - 84.7' Highly Fractured zone

LIMESTONE, light gray, fine grained, moderately weathered, strong, extremely close to moderately spaced discontinuities
85' - 87.6' Highly Fractured zone

Argillitic LIMESTONE, light gray to white, fine grained, slightly weathered, very strong, very close to moderately spaced discontinuities
90' - 92.3' Frequent dark gray Chert nodules 2" to 3" thick

Argillitic LIMESTONE, light gray, fine grained, fresh, (un) weathered, very strong, extremely close to moderately spaced discontinuities

Argelaceous LIMESTONE, light gray to white, fine grained, fresh, (un) weathered, strong, close to moderately spaced discontinuities
Laminating layers of light gray to white with light gray being dominant and thicker
100' - 103.2' Frequent stylolites

LIMESTONE, light gray, fine grained, slightly weathered, medium strong, close to moderately spaced discontinuities

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
83.00	Sty	0	U,Sm	DE	MW	CL
83.80	J	0	U,Sm	DS	O	N
84.70	F	5	U,Sm	DG	PO	CL
85.40	J	3	U,Sm	DS	PO	N
86.30	Sty	9	U,R	DG	O	N
86.70	Sty	8	U,Sm	FR	MW	N
87.20	J	5	U,Sm	DS	MW	N
87.60	Sty	0	U,R	DG	MW	CL
88.20	Sty	0	U,R	DG	MW	CL
88.80	Sty	10	U,R	DS	MW	N
89.40	Sty	0	U,R	DG	O	CL
91.00	Sty	0	P,R	DS	O	N
91.80	B	0	U,R	DS	O	QZ
92.50	B	20	U,R	DS	O	QZ
92.90	Sty	10	U,R	DS	O	N
93.70	Sty	10	U,R	DS	T	N
94.80	J	0	P,Sm	DS	PO	N
95.35	B	3	P,Sm	DS	O	N
96.00	J	5	U,Sm	DS	O	N
97.70	Sty	12	U,R	DS	T	Li
98.20	Sty	14	U,R	DS	T	Li
98.70	J	3	U,R	DS	O	N
99.50	Sty	10	U,R	DS	O	N
100.50	J	0	U,Sm	DS	O	N
100.70	Sty	7	U,Sm	DS	O	N
101.50	J	2	P,R	DG	MW	CL
102.20	J	2	U,Sm	DG	O	CL
103.20	Sty	5	U,R	DS	PO	N
105.10	J	4	U,Sm	DG	O	CL
105.70	J	6	U,Sm	DE	PO	CL
106.70	Sty	8	U,R	DG	O	N
107.90	J	8	U,R	DG	O	N

Remarks

NOTES:

Depth (ft)	Run/(Box) No.	Avg Core Rate (min/ft)	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Remarks
– 110.0		4.30, 4.00						
110.0 – 115.0	R-11	2.10, 5.30, 5.00, 4.90, 4.20	60 100%	55 92%	R4	SL	LIMESTONE, light gray to dark gray, fine grained, slightly weathered, strong, close to wide spaced discontinuities Occasional pitting and small vugs 110' - 112.7' Light gray stylolites 112.7' - 115' Dark gray very strong Marlstone	Used approximatetly 450 gallons of water from 63 to 110 feet BGS.
115.0 – 120.0	R-12	2.20, 2.10, 2.10, 1.60, 1.60	60 100%	56 93%	R3	M	MARLSTONE, light brown to light gray, fine grained, moderately weathered, medium strong, moderately spaced discontinuities 116.2' - 116.3' Quartz infilled cavity 119.3' - 120' Frequent cavities and vugs	Rock is weathered but reacts with HCL when scratched.
120.0 – 125.0	R-13	1.90, 1.70, 1.80, 2.10, 1.50	60 100%	52 87%	R2	H	LIMESTONE with interbedded Marlstone, brown to gray, fine grained, highly weathered, weak, close to wide spaced discontinuities 120' - 122' Porous calcerous Mudstone 122' - 125' Gray to dark gray Marlstone, porous	
125.0 – 130.0	R-14	2.00, 1.70, 2.00, 1.70, 1.50	60 100%	53 88%	R2	H	LIMESTONE, brown to gray, fine grained, highly weathered, weak, extremely close to wide spaced discontinuities 125' - 125.6' Porous Marlstone 125.6' - 129.3' Calcarous brown Mudstone 129.3' - 130' Very strong, highly fractured, micro cystalline limestone	
130.0 –	R-15	2.00, 2.00, 2.10, 2.30	60 100%	54 90%	R2	H	LIMESTONE with interbedded Mudstone, brown to light gray, fine grained, highly weathered, weak, close to wide spaced discontinuities 130' - 132.9' Brown Marlstone 131.5' - 132.9' Slightly porous with many 1/32" and finer fissures 132.9' - 135' Light gray Limestone	

Depth/Elev. (ft): 110, 400, 115, 120, 390, 125, 130

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
108.30	Sty	3	U,R	DG	O	N
109.10	J	8	U,R	DG	O	N
109.60	J	3	U,R	DG	O	N
110.45	B	10	U,Sm	DS	MW	N
110.70	Sty	8	U,Sm	DS	MW	N
111.70	Sty	12	U,R	DG	O	CL
112.70	B	3	U,R	DE	MW	CL
114.10	J	0	U,Wa	DS	PO	N
115.70	J	3	U,Sm	DS	T	N
116.40	Sty	4	U,Sm	DS	T	N
117.40	B	13	U,Wa	DE	MW	CL
118.20	J	5	U,Wa	FR	PO	N
119.20	J	16	U,Sm	DG	MW	CL
120.50	J	25	U,Sm	DG	O	CL
120.70	J	2	U,Sm	DG	O	CL
122.60	B	10	U,Sm	DE	MW	CL
125.60	B	0	U,Sm	DS	O	N
127.50	Sty	11	U,R	DS	PO	N
129.60	B	10	U,Sm	DE	MW	CL
129.80	B	7	P,Sm	DG	PO	CL
130.15	J	8	U,Sm	DS	MW	ML
130.80	J	2	U,Sm	DG	PO	ML
132.90	B	5	U,Sm	DG	O	CL

NOTES:

Depth/ Elev. (ft)	Avg Core Rate (min/ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)
	2.60	135.0						
135	2.80	135.0						LIMESTONE with interbedded Marlstone, gray to white, fine grained, moderately weathered, weak, extremely close to moderately spaced discontinuities
	2.80							
	2.00		R-16	60 100%	56 93%	R2	M	
	2.40							
	3.00	140.0						
140	2.70	140.0						Argellaceous LIMESTONE, light gray to white, fine grained, moderately weathered, weak, close to moderately spaced discontinuities
	2.10							
	2.40		R-17	60 100%	56 93%	R2	M	
	2.70							
370	2.80	145.0						
145	3.00	145.0						LIMESTONE with interbedded Marlstone, olive gray to light gray, fine grained, moderately weathered, weak, close to moderately spaced discontinuities 147.9' - 150' White Limestone
	3.00							
	2.40		R-18	60 100%	45 75%	R2	M	
	1.70							
	2.90	150.0						150.0
150								End of Boring at 150 feet BGS. Borehole grouted with cement and bentonite hole plug.
360								
155								

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
133.90	J	0	P,Sm	DS	MW	N	
134.70	Sty	12	U,R	DS		ML	
137.40	Sty	5	U,R	DG	O	ML	
138.70	Sty	8	U,R	DS	O	N	
139.20	B	0	U,R	DS	MW	CL	
139.70	B	3	P,Sm	DS	T	CL	
140.20	Sty	0	P,R	DG	O	CL	
140.90	Sty	2	U,R	DS	T	N	
141.50	Sty	2	U,R	DG	O	CL	
143.45	B	4	U,R	DG	O	CL	
144.50	B	8	U,Sm	DG	T	CL	
145.65	J	0	P,Sm	DS	T	N	
146.10	J	5	U,Sm	FR	PO	N	
147.10	Sty	8	U,R	DS	O	N	
147.35	Sty	13	U,R	DG	MW	N	
147.90	J	28	U,Sm	DS	MW	N	
	J	28	U,Sm	DS	MW	N	
149.10	Sty	8	U,R	DG	MW	N	

NOTES:

Figure B-STL-09.1
B-STL-09 Box 1 Runs 1-2 Dry

Figure B-STL-09.2
B-STL-09 Box 1 Runs 1-2 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-09

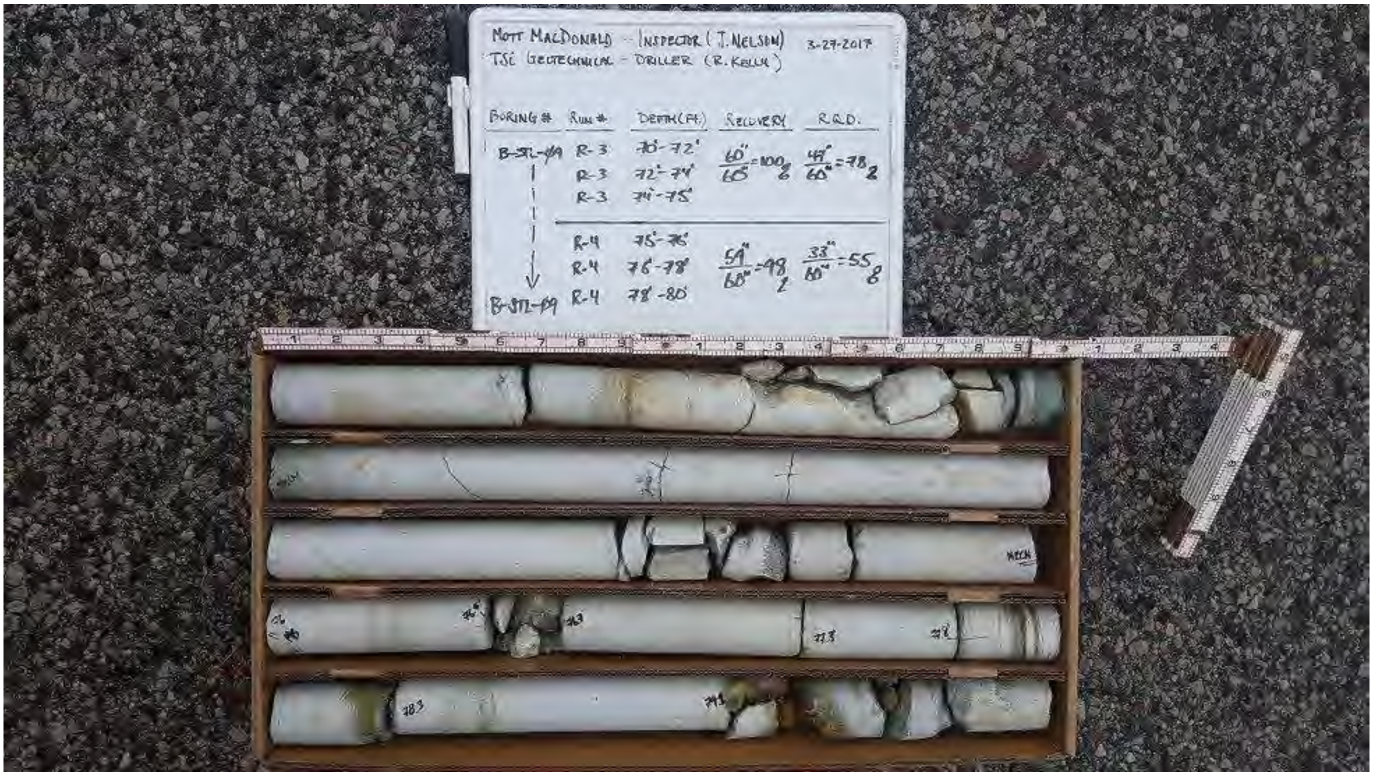


Figure B-STL-09.3
B-STL-09 Box 2 Runs 3-4 Dry

Figure B-STL-09.4
B-STL-09 Box 2 Runs 3-4 Wet

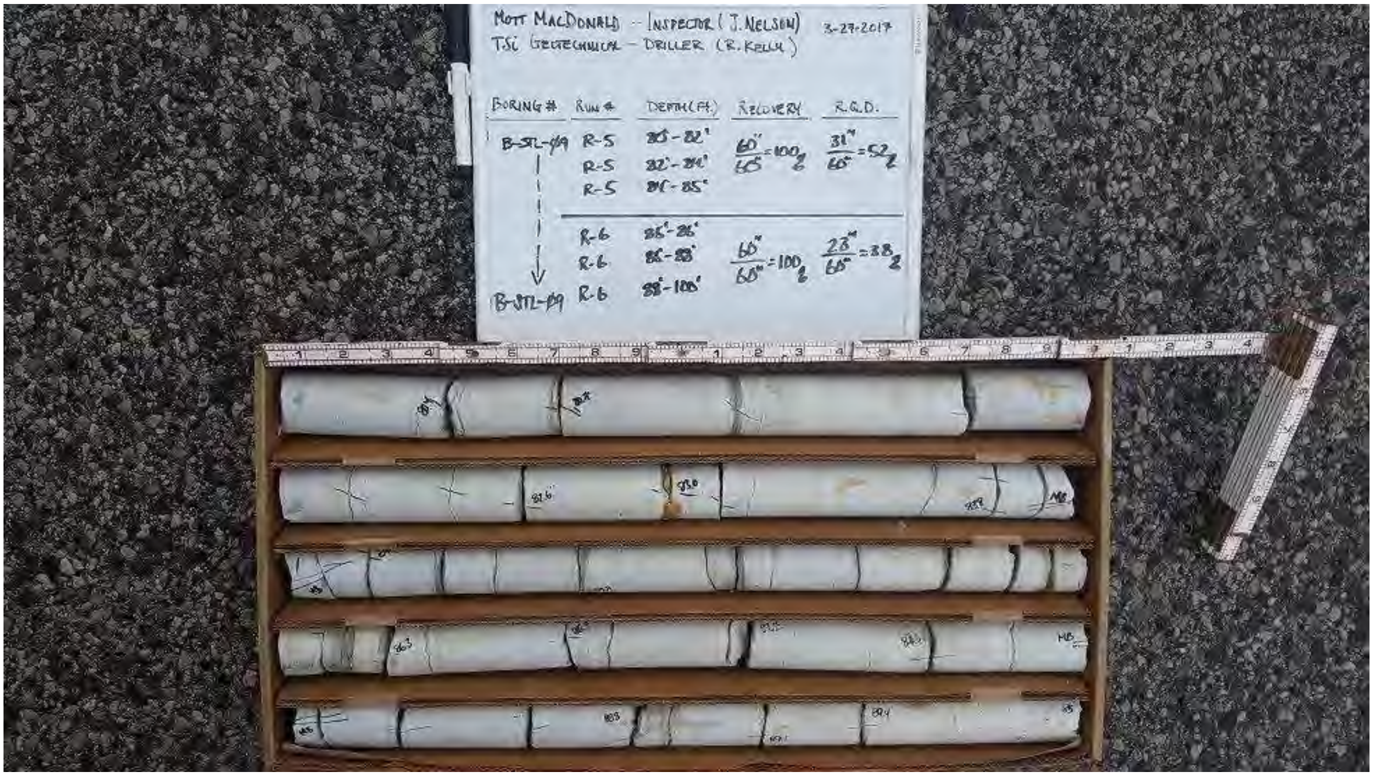


Figure B-STL-09.5
B-STL-09 Box 3 Runs 5-6 Dry

Figure B-STL-09.6
B-STL-09 Box 3 Runs 5-6 Wet

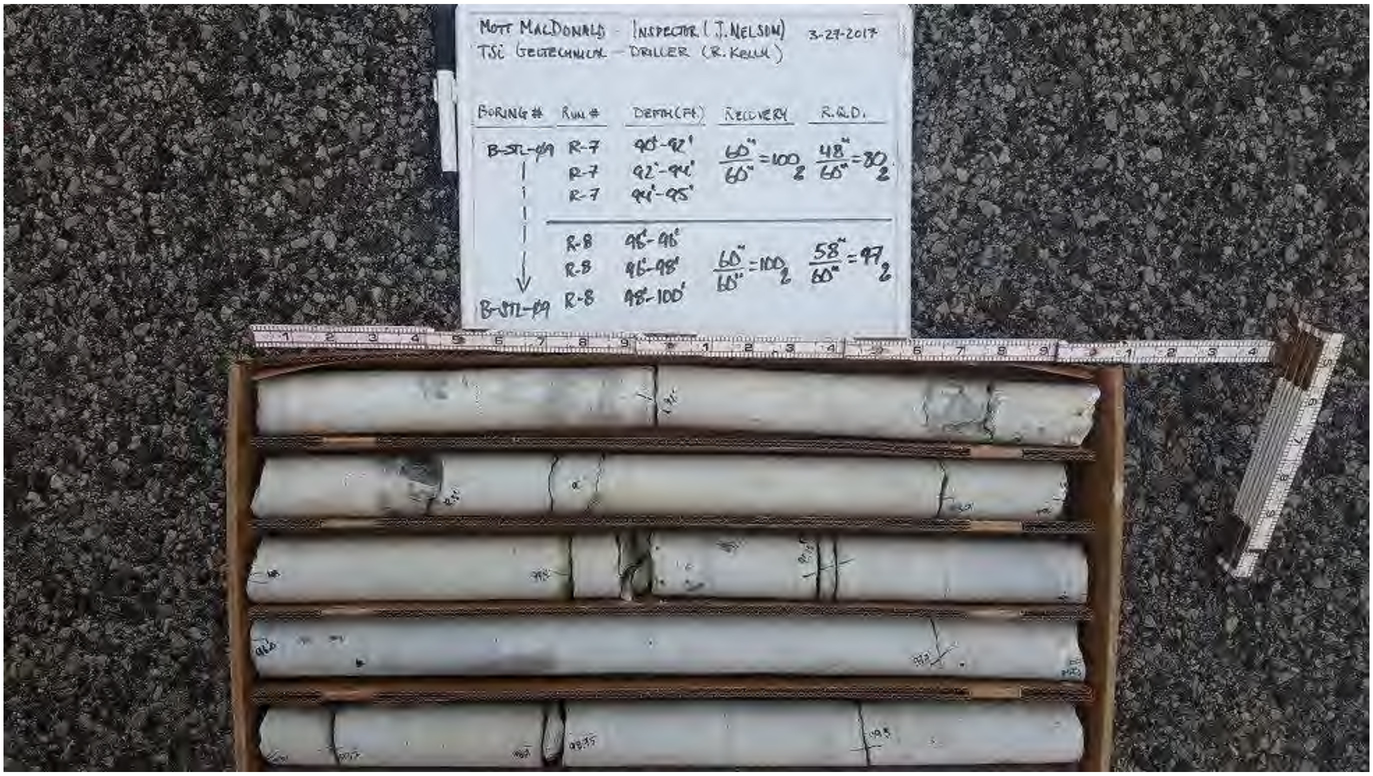


Figure B-STL-09.7
B-STL-09 Box 4 Runs 7-8 Dry

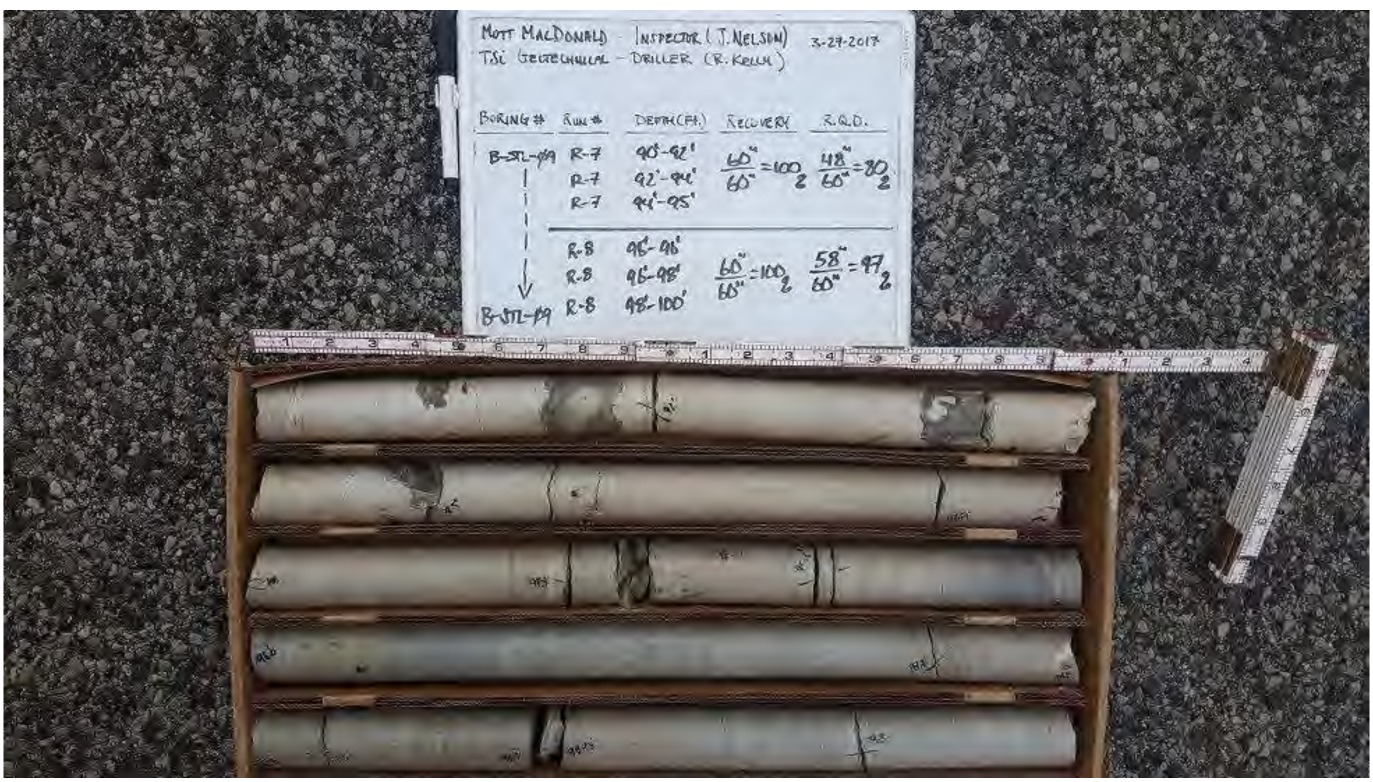


Figure B-STL-09.8
B-STL-09 Box 4 Runs 7-8 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-09

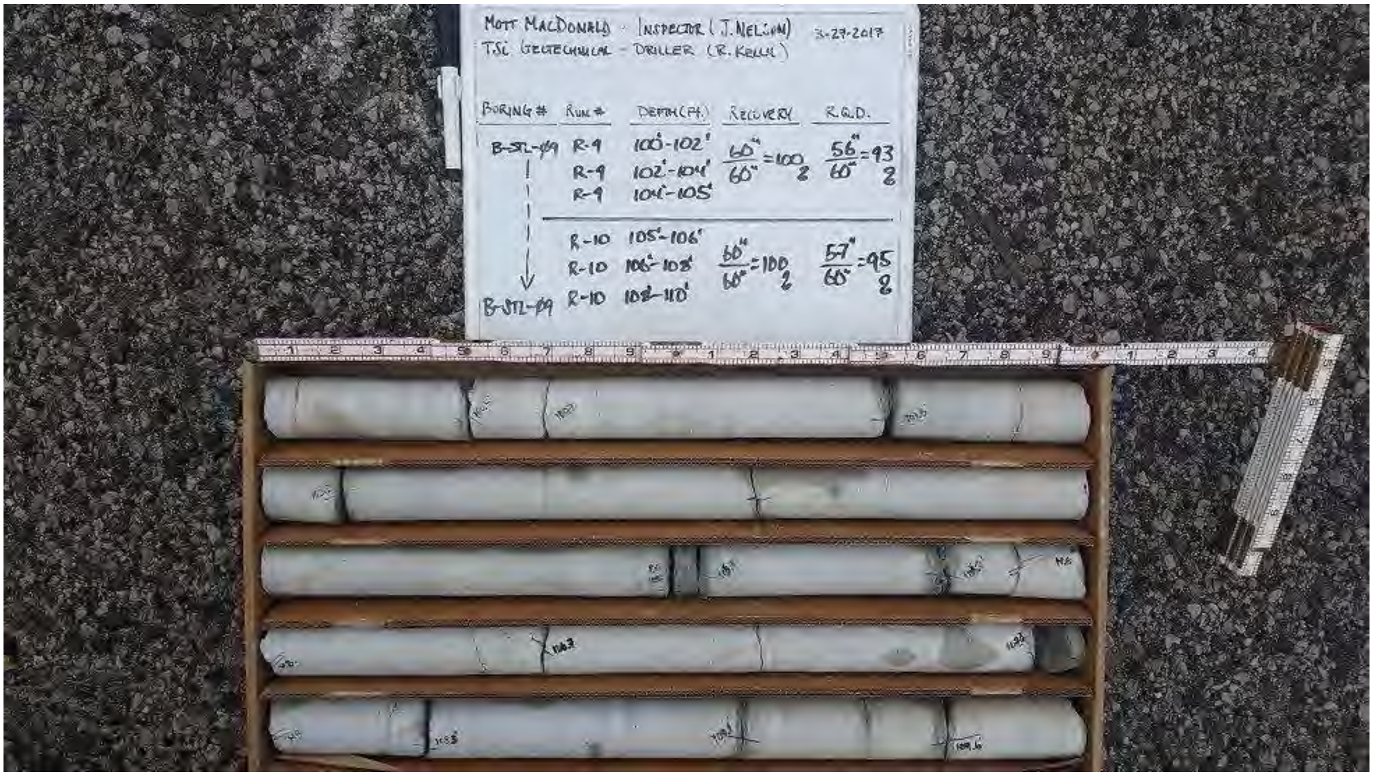


Figure B-STL-09.9
B-STL-09 Box 5 Runs 9-10 Dry

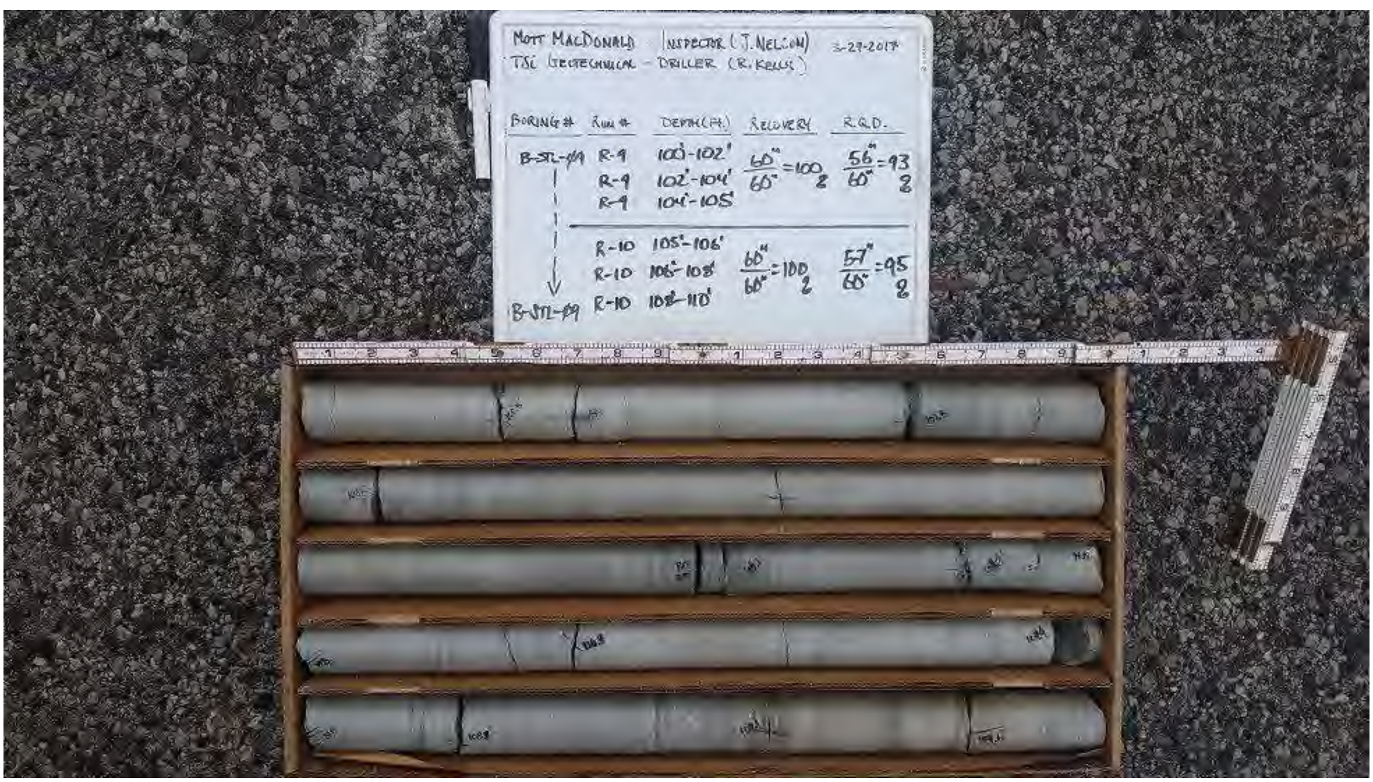


Figure B-STL-09.10
B-STL-09 Box 5 Runs 9-10 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-09

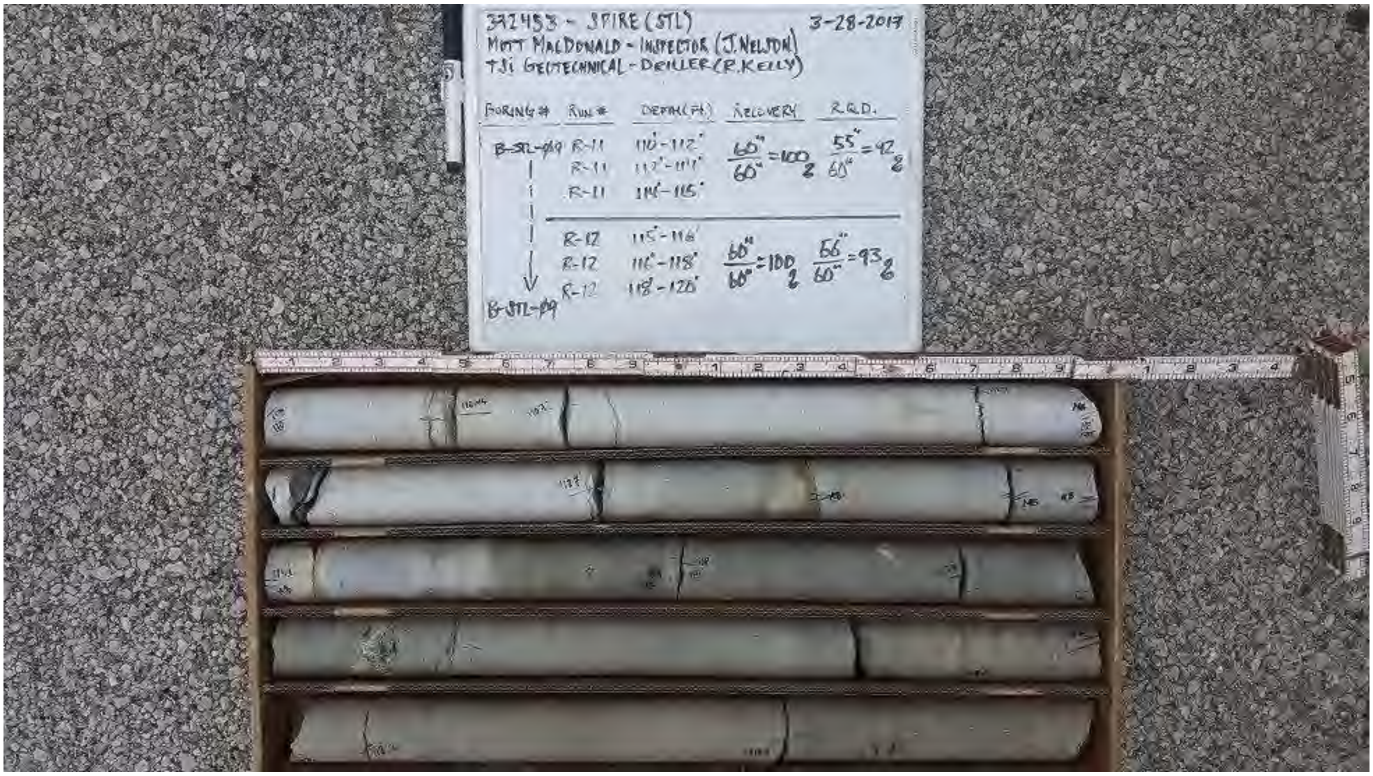


Figure B-STL-09.11
B-STL-09 Box 6 Runs 11-12 Dry

Figure B-STL-09.12
B-STL-09 Box 6 Runs 11-12 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-09

Figure B-STL-09.13
B-STL-09 Box 7 Runs 13-14 Dry

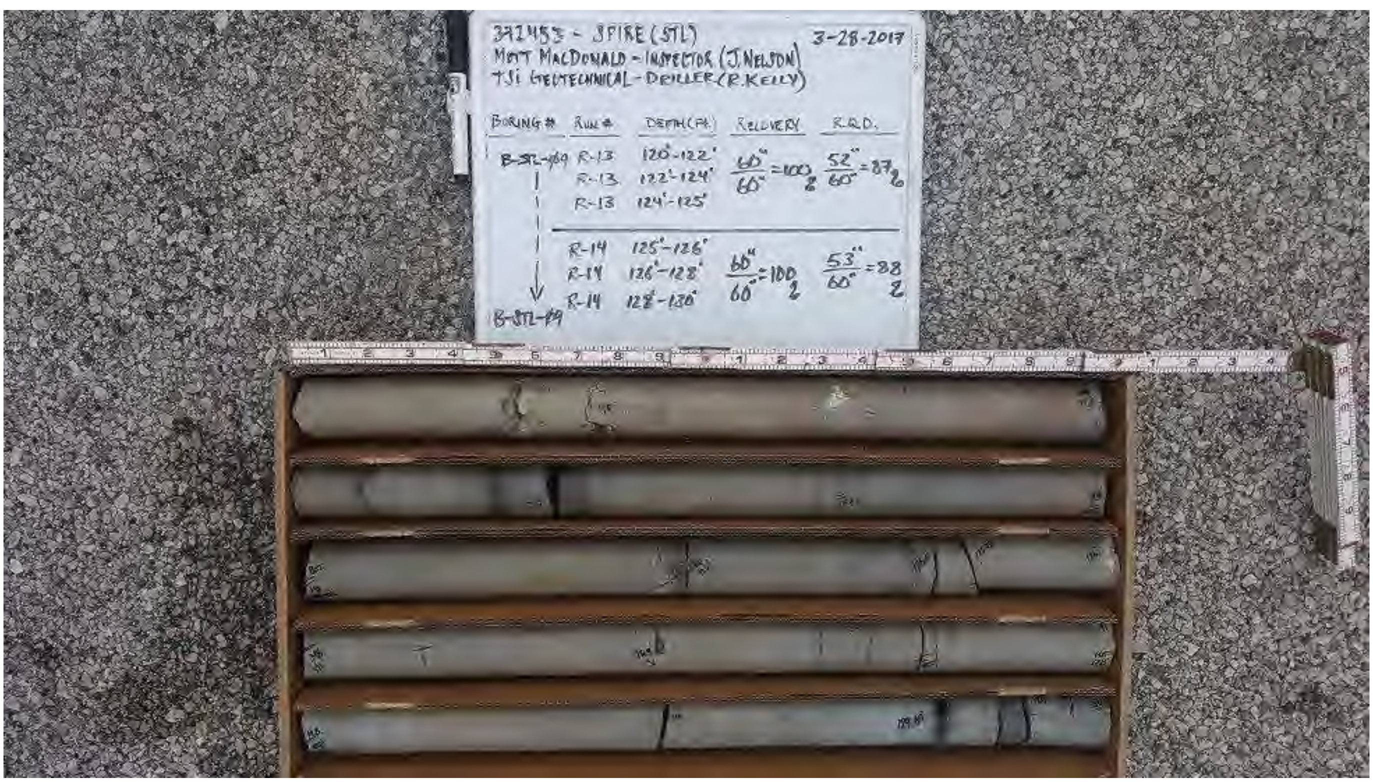


Figure B-STL-09.14
B-STL-09 Box 7 Runs 13-14 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-09

Figure B-STL-09.15
B-STL-09 Box 8 Runs 15-16 Dry

Figure B-STL-09.16
B-STL-09 Box 8 Runs 15-16 Wet

Figure B-STL-09.17
B-STL-09 Box 9 Runs 17-18 Dry

Figure B-STL-09.18
B-STL-09 Box 9 Runs 17-18 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-09

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-STL-10**

Project:	Spire STL Pipeline	**Project No.:**	372453
Location:	Missouri/Illinois	**Project Mgr:**	Vatsal Shah
Client:	Spire STL Pipeline LLC	**Field Eng. Staff:**	Jonathan Nelson
Drilling Co.:	TSi Geotechnical, Inc.	**Date/Time Started:**	March 29, 2017 at 8:30 am
Driller/Helper:	Randy Kelly /Lance Leonard	**Date/Time Finished:**	March 30, 2017 at 3:40 pm

Elevation: 513 ft. **Vertical Datum:** WGS84 **Boring Location:** 77 feet west of the access path running between Sunfish and North Lakes **Coord.:** **N:** 38.801571 **E:** -90.19602 **Horizontal Datum:** WGS84

Item	Casing	Sampler	Core Barrel
Type	HSA	S	NQ
Length (ft)	5	2	10
Inside Dia. (in.)	4.25	1.375	1.875
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-550X

☐ Truck ☐ Tripod ☐ Cat-Head
☑ ATV ☐ Geoprobe ☑ Winch
☐ Track ☐ Air Track ☐ Roller Bit
☐ Skid ☐ ______ ☑ Cutting Head

Hammer Type: ☐ Safety ☐ Doughnut ☑ Automatic ☐ ______

Drilling Fluid: ☑ Bentonite ☑ Polymer ☑ Water ☑ None

Drill Rod Size:

Casing Advance: Hollow Stem Auger/Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-1 0.0'- 2.0'	10	1 2 2 4			0.3 3" - TOPSOIL with Roots	-	L	NP	L	PP = 0.75 tsf
					ML	Medium stiff, dark brown SILT, moist (ML)					
510	S-2 2.0'- 4.0'	19	2 4 5 5		ML	Stiff, dark brown SILT, moist (ML)	-	L	NP	L	PP = 3.6 tsf
5	S-3 4.0'- 6.0'	18	3 6 6 7		ML	Stiff, yellowish red SILT, moist (ML)	-	L	NP	L	PP = 2.0 tsf
	S-4 6.0'- 8.0'	23	2 4 4 5		ML	Stiff, yellowish red to brown SILT, trace fine Sand, moist (ML)	-	L	NP	L	PP = 3.4 tsf
	S-5 8.0'- 10.0'	24	4 3 5 4		ML	Stiff, brown to brownish yellow Clayey SILT, trace fine Sand, moist (ML)	-	L	L	L	PP = 2.3 tsf
10											
500	S-6 13.0'- 15.0'	24	2 3 3 4		ML	Medium stiff, brown to brownish yellow Clayey SILT, moist (ML)	-	L	L	M	PP = 1.7 tsf Mottling present.
15											
	S-7 18.0'- 20.0'	24	3 3 4 3		ML	Stiff, brown Clayey SILT, little fine Sand, moist (ML)	-	L	L	M	PP = 1.3 tsf Brownish yellow mottling present.

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water

Sample Type

- **O** Open End Rod
- **T** Thin-Wall Tube
- **U** Undisturbed Sample
- **S** Split Spoon Sample
- **G** Geoprobe

Notes:
P.P. = Pocket Penetrometer.
T.V. = Torvane.

Boring No.: **B-STL-10**

Field Test Legend: Dilatancy: N - None S - Slow R - Rapid; Toughness: L - Low M - Medium H - High; Plasticity: NP - Non-Plastic L - Low M - Medium H - High; Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
						21.5					
490	S-8 23.0'-25.0'	23	3 4 5 3		OL	Stiff, dark brown organic Clayey SILT, trace fine Sand, moist (OL)	-	L	L	M	PP = 2.3 tsf
25											
	S-9 28.0'-30.0'	21	2 3 4 2		OL	Medium stiff, dark brown organic Clayey SILT, trace fine Sand, moist (OL)	-	L	L	M	PP = 2.6 tsf
30											
480	S-10 33.0'-35.0'	24	3 2 4 4		OL	Medium stiff, dark brown organic Clayey SILT, trace fine Sand, wet (OL)	-	L	L	M	PP = 2.66 tsf Groundwater encountered while drilling at 34 feet BGS.
35											
						36.5					
	S-11 38.0'-40.0'	24	3 3 7 5		ML	Stiff, greenish gray Sandy SILT, trace Clay, wet (ML)	-	L	L	L	PP = 2.7 tsf Slightly organic.
40											
						41.5					
470	S-12 43.0'-45.0'	24	2 3 3 3		CH	Medium stiff, olive gray CLAY, moist (CH)	-	M	H	VH	PP = 1.2 tsf Slightly organic.
45											

NOTES:

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
	S-13 48.0'-50.0'	24	7 9 8 7		CH	Very stiff, brownish yellow to yellowish brown Sandy CLAY, little fine Gravel, moist (CH)	-	H	H	VH	PP = 4.5 tsf
50											
						51.5					
460	S-14 53.0'-55.0'	23	4 5 6 7		CL	Stiff, greenish gray to yellowish red Sandy CLAY, little Silt, trace coarse to fine Limestone fragments, moist (CL)	-	H	M	H	PP = 4.0 tsf
55											
						56.5					
	S-15 58.0'-60.0'	24	14 4 8 5			58.5 Medium dense, light brown DECOMPOSED LIMESTONE, some Clay, wet	-	H	H	VH	Moderate Auger refusal at 57.5 feet BGS. Was able to auger to 60 feet BGS.
					OH	Stiff, greenish gray organic CLAY, trace Decomposed Limestone fragments, wet (OH)					
60						60.0 Top of Rock at 60 feet BGS. See Rock Coring Log.					
450											
65											
70											
440											
75											

NOTES:

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading. 3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD

CORE BORING LOG

Project:	Spire STL Pipeline	**Project No.:**	372453
Location:	Missouri/Illinois	**Project Mgr:**	Vatsal Shah
Client:	Spire STL Pipeline LLC	**Field Eng. Staff:**	Jonathan Nelson
Drilling Co.:	TSi Geotechnical, Inc.	**Date/Time Started:**	March 29, 2017 at 8:30 am
Driller/Helper:	Randy Kelly /Lance Leonard	**Date/Time Finished:**	March 30, 2017 at 3:40 pm

Elevation: 513 ft.		**Vertical Datum:** WGS84	
Item	**Casing**	**Core Barrel**	**Core Bit**
Type	HSA	NQ	Imp. Diamond
Length (ft)	5	10	6
Inside Dia. (in.)	4.25	1.875	1.875

Boring Location: 77 feet west of the access path running between Sunfish and North Lakes

Horizontal Datum: WGS84

Rig Make & Model: CME-550X

Coord.: N: 38.801571 **E:** -90.19602

Drilling Method: Wireline

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations) SEE TEST BORING LOG FOR OVERBURDEN DETAILS	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	3.90	60.0							LIMESTONE, white to light brown, fine grained, moderately weathered, medium strong, extremely close to close spaced discontinuities 60' - 60.8' Vertical Fracture with Calcite infilling	60.40	J	8	U,Sm	DS	W	N	Rig chatter from 61.8 to 63.2 feet BGS. Rod dropped from 63.2 to 65 feet BGS.
	1.90								61.65' - 63.2' Very soft zone	61.00 61.65	Sty J	13 0	U,R U,Sm	DG DS	O EW	N N	
	1.00		R-1	19 32%	6 10%	R3	M										
450	0.30								63.2' - 65' Possible Void								
	0.30	65.0						65.0									
65	1.50	65.0						65.8	65' - 65.8' Soft zone - No Recovery LIMESTONE, light brown, fine grained, moderately weathered, medium strong, extremely close to moderately spaced discontinuities 65.8' - 66.1' Calcerous Decomposed Mudstone	66.10	B	3	U,Sm	DS	O	N	Rig chatter from 69.2 to 69.6 feet BGS.
	2.70																
	2.40		R-2	50 83%	44 73%	R3	M			67.30 67.60	J Sty	7 4	U,Sm U,R	FR DG	PO MW	N CL	
	2.70									68.00 68.70	J Sty	0 23	U,Sm U,R	FR FR	O O	N N	
	2.70	70.0								69.60	J	10	P,Sm	DS	O	N	
70	2.10	70.0							LIMESTONE, light gray to light brown, fine grained, slightly weathered, medium strong, extremely close to wide spaced discontinuities	70.00 70.70	Sty J	10 10	U,R P,Sm	DG DS	O W	SD N	
	2.50									71.30 71.80	J J	18 12	U,R U,R	DS DS	MW MW	N N	
	2.90		R-3	60 100%	55 92%	R3	SL			72.70	Sty	11	U,R	DS	T	N	
440	2.30																
	2.70	75.0															
75	3.10	75.0							Argillaceous LIMESTONE, light gray to greenish gray, fine grained, slightly weathered, medium strong, close to moderately spaced discontinuities								
	2.60									76.00 76.60	Sty Sty	9 5	U,R U,R	DG DE	O MW	N CL	
	7.50		R-4	60 100%	60 100%	R3	SL			77.00	B	0		DG	PO	CL	
	2.00									78.40	B	20	U,R	DS	W	N	
	2.20	80.0								78.90	J	6	U,Sm	DS	T	N	

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
		-			

Notes:

Depth/ Elev. (ft)	Avg Core Rate (min/ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.00	80.0							LIMESTONE, brown to light gray, fine grained, moderately weathered, medium strong, extremely close to moderately spaced discontinuities 80' - 82' Frequent Chert nodules	80.30 80.50	Sty J	8 3	U,R S,R	DG DS	MW MW	CL N	
	2.30									81.40	J	3	P,Sm	DS	O	N	
	2.00		R-5	57 95%	35 58%	R3	M			82.20	J	13	U,Sm	DS	O	N	
430	2.10								83.1' - 83.4' Highly Fractured zone	82.90 83.10 83.40	J J B	14 0 19	X,R U,Sm U,Sm	DG DG DE	MW VW VW	N CL CL	
	2.10	85.0							84.2' - 84.7' Highly Fractured zone	84.20 84.70	J J	0 5	U,Wa U,Sm	DS DS	VW VW	N N	
85	3.30	85.0							LIMESTONE, white, fine grained, medium strong, moderately weathered, extremely close to moderately spaced discontinuities								
	2.30									86.50	Sty	4	U,Sm	DS	MW	N	
	1.90		R-6	60 100%	38 63%	R3	M		87.5' - 90' Frequent stylolites 87.6' - 90' Highly Fractured zone	87.60 87.80	Sty Sty	12 11	U,R U,Sm	DS DG	PO MW	N CL	
	2.20																
	2.10	90.0								89.00 89.30 89.80	Sty Sty Sty	6 0 8	U,Sm U,R U,R	DG DG DG	O O O	CL CL CL	
90	3.10	90.0							LIMESTONE, light gray to gray, fine grained, moderately weathered, medium strong, extremely close to close spaced discontinuities	90.30 90.60	J Sty	3 4	U,Sm U,R	DG DG	MW MW	N CL	Rod dropped from 93 to 95 feet BGS. Most likely Clay Decomposed rock infill.
	2.20									91.20 91.70	Sty Sty	0 0	U,Sm U,Sm	DG DG	MW MW	CL CL	
	2.00		R-7	34 57%	9 15%	R3	M	92.7	No Recovery	92.20	Sty	4	U,R	DG	MW	CL	
420	0.00																
	0.00	95.0						95.0									
95	0.20	95.0							CHERT with highly weathered Limestone, gray to brownish yellow, fine grained, completely weathered, strong, extremely close to moderately spaced discontinuities 95' - 97.6' Little to no recovery								
	0.20																
	4.90		R-8	25 42%	9 15%	R4	C		97.6' - 98.3' Highly Fractured zone	97.60 97.80	J J	32 45	U,Sm U,R	DS DS	VW O	CL N	
	2.70									98.30	B	45	U,R	DE	W	N	
	2.30	100.0						99.3 100.0	99.3' - 100' No Recovery	99.30	B	10	U,Wa	DS	VW	N	Soft zone from 99.5 to 100 feet BGS.
100	3.50	100.0							LIMESTONE with interbedded Chert, brownish yellow to light gray, fine grained, completely weathered, strong, extremely close to moderately spaced discontinuities 100' - 100.3' Chert nodule 100' - 103.7' Chert infilling 100.8' - 101.6' Chert nodule 101.65' - 102.35' No Recovery	100.00	B	10	U,R	DG	MW	CL	Rig chatter from 101.6 to 102.4 feet BGS.
	7.90									101.65	J	13	U,R	DG	VW	CL	
	2.70		R-9	47 78%	47 78%	R4				102.35	J	18	U,R	DG	VW	CL	
410	4.80								103.7' - 105' Slightly weathered Limestone	103.70	B	9	U,Sm	DG	PO	CL	
	5.90	105.0								104.35	J	5	U,R	DS	PO	CL	
105		105.0							Argillaceous LIMESTONE, light gray, fine grained, slightly weathered, medium strong, extremely close to	105.00	J	23	U,R	DS	O	N	

(See Legend for Rock Description System)

NOTES:

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)
	5.70							slightly weathered, medium strong, extremely close to moderately spaced discontinuities
	5.90							
	5.40		R-10	59 98%	49 82%	R3	SL	
	5.40							
	5.70	110.0						
110	4.80	110.0						LIMESTONE, light gray to light brown, fine grained, moderately weathered, weak, extremely close to moderately spaced discontinuities
	4.30							
	4.20		R-11	60 100%	47 78%	R2	M	
400	4.30							
	4.40	115.0						114.2' - 114.6' Vertical Fracture
115	4.70	115.0						Argillaceous LIMESTONE, light gray, fine grained, moderately weathered, weak, very close to moderately spaced discontinuities
	4.30							
	3.50		R-12	60 100%	44 73%	R2	M	
	4.20							
	6.10	120.0						
120	3.50	120.0						Argillaceous LIMESTONE with interbedded Marlstone, light gray to brown, fine grained, moderately weathered, medium strong, close to moderately spaced discontinuities Frequent zones of higher siliceous accumulation
	3.00							
	3.00		R-13	60 100%	50 83%	R3	M	
390	4.80							123.85' - 125' Very strong Marlstone
	3.20	125.0						
125	3.60	125.0						LIMESTONE with interbedded Marlstone, light gray to brown, fine grained, moderately weathered, strong, extremely close to moderately spaced discontinuities 125' - 128' Argillaceous Limestone
	3.30							
	3.80		R-14	60 100%	49 82%	R4	M	
	3.40							128' - 130' Marlstone, some Chert nodules
	3.40	130.0						
130	3.50	130.0						Argillaceous LIMESTONE, light gray, fine grained, slightly weathered, strong, extremely close to moderately spaced discontinuities

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
105.80	J	13	U,Sm	DG	O	ML	
106.70	J	11	U,Sm	DG		CL	
107.35	Sty	10	U,R	DS	T	N	
107.75	Sty	10	U,R	DS	T	N	
108.10	Sty	11	U,R	DS	MW	N	
109.10	J	17	U,R	DG	W	CL	
110.70	Sty	3	U,R	DS	PO	N	
111.30	Sty	14	U,R	DS	T	N	
112.60	J	5	U,Sm	DE	MW	CL	
113.25	J	35	U,Sm	DS	W	N	
114.60	Sty	10	U,Sm	DS	MW	N	
115.00	Sty	8	U,R	DS	O	ML	Used approximately 360 gallons of water from 107 to 118 feet BGS. Drill chatter at 118 feet BGS.
115.60	Sty	6	U,Sm	DS	MW	N	
116.20	Sty	6	U,Sm	DS	MW	N	
116.55	J	6	U,Wa	DS	MW	N	
117.50	J	6	U,R	DS	T	N	
118.40	Sty	7	U,Sm	DS	T	N	
119.00	Sty	6	U,Sm	DS	T	N	
119.80	Sty	8	U,Wa	DS	T	ML	
120.95	Sty	8	U,Wa	DS	O	N	
121.85	J	6	U,Sm	DS	O	N	
122.35	J	6	U,Sm	DE	MW	CL	
122.60	J	4	U,Wa	DE	MW	CL	
123.50	B	5	U,Sm	DS	T	N	
123.85	Sty	4	U,Sm	DG	MW	CL	
124.40	J	12	U,Wa	DS	MW	N	
125.30	J	14	U,Sm	DS	O	N	
126.00	J	4	U,Sm	DS	PO	N	
127.00	B	16	U,Sm	DG	PO	CL	
127.60	B	30	U,Sm	DS	MW	N	
128.00	B	10	U,Sm	DS	O	N	
129.30	J	8	U,Sm	DE	O	CL	
129.60	J	7	U,Sm	DE	O	CL	
130.25	B	13	S,Sm	DS	W	N	Increased pull down PSI to 200 PSI at 132 feet
130.50	J	12	U,Sm	DS	W	N	

NOTES:

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)
	3.10							130' - 130.5' Marlstone/Chert - Porous
	2.50		R-15	60 100%	49 82%	R4	SL	
380	2.50							
	2.80	135.0						134' - 135' Chert nodules 1/4" to 1/2" thick
135	3.00	135.0						Argillaceous LIMESTONE, light gray to gray, fine grained, moderately weathered, medium strong, extremely close to moderately spaced discontinuities
	2.50							
	2.20		R-16	60 100%	51 85%	R3	M	
	2.30							138.2' - 138.3' Chert nodule
	2.00	140.0						
140	1.20	140.0						Argillaceous LIMESTONE with interbedded Marlstone, gray to light gray, fine grained, moderately weathered, weak, close to moderately spaced discontinuities 140' - 142' Marlstone
	1.80							
	2.20		R-17	60 100%	57 95%	R2	M	142' - 145' Argillaceous Limestone with frequent stylolites
370	2.20							
	2.30	145.0						
145	2.50	145.0						Argillaceous LIMESTONE, light gray, fine grained, moderately weathered, weak, extremely close to moderately spaced discontinuities 145' - 146' Highly Fractured zone
	2.30							
	2.60		R-18	60 100%	48 80%	R2	M	
	2.50							148.6' - 148.9' Fossils
	2.00	150.0						150.0
150								End of Boring at 150 feet BGS. Borehole grouted with cement and bentonite hole plug.
360								
155								

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
							BGS.
130.90	Sty	10	U,R	DS	PO	N	
131.20	Sty	4	U,R	FR	O	N	
132.20	Sty	15	U,R	DS	MW	N	
133.75	Sty	13	U,R	DS	O	N	
135.20	Sty	6	U,R	DS	PO	N	
136.35	Sty	11	U,R	DS	T	N	
138.30	B	40	U,R	DE	MW	CL	/Qz
140.00	B	10	U,Sm	DS	W	CL	
141.20	J	10	P,Sm	DS	PO	N	
141.85	J	15	U,Sm	DS	MW	N	
143.10	Sty	5	U,Sm	DS	MW	N	
144.80	Sty	8	U,R	DG	MW	ML	
146.60	B	12	U,Sm	DS	MW	N	
147.10	Sty	10	U,Sm	DS	T	N	
147.70	Sty	7	U,Wa	DS	MW	N	
148.90	Sty	10	U,Sm	DS	MW	N	

NOTES:

Figure B-STL-10.1
B-STL-10_Box 1 Runs 1-2 Dry

Figure B-STL-10.2
B-STL-10_Box 1 Runs 1-2 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-10

Figure B-STL-10.3
B-STL-10_Box 2 Runs 3-4 Dry

Figure B-STL-10.4
B-STL-10_Box 2 Runs 3-4 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-10

Figure B-STL-10.5
B-STL-10_Box 3 Runs 5-6 Dry

Figure B-STL-10.6
B-STL-10_Box 3 Runs 5-6 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-10

Figure B-STL-10.7
B-STL-10_Box 4 Runs 7-8 Dry

Figure B-STL-10.8
B-STL-10_Box 4 Runs 7-8 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-10

Figure B-STL-10.9
B-STL-10_Box 5 Runs 9-10 Dry

Figure B-STL-10.10
B-STL-10_Box 5 Runs 9-10 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-10

Figure B-STL-10.11
B-STL-10_Box 6 Runs 11-12 Dry

Figure B-STL-10.12
B-STL-10_Box 6 Runs 11-12 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-10

Figure B-STL-10.13
B-STL-10_Box 7 Runs 13-14 Dry

Figure B-STL-10.14
B-STL-10_Box 7 Runs 13-14 Wet

MOTT MACDONALD	Spire STL Pipeline **Rock Core Photographs**	**BORING NO.:** B-STL-10

Figure B-STL-10.15
B-STL-10_Box 8 Runs 15-16 Dry

Figure B-STL-10.16
B-STL-10_Box 8 Runs 15-16 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-10

MOTT MACDONALD

SOIL BORING LOG

Project:	Spire STL Pipeline	**Project No.:**	372453
Location:	Missouri/Illinois	**Project Mgr:**	Vatsal Shah
Client:	Spire STL Pipeline LLC	**Field Eng. Staff:**	Jonathan Nelson
Drilling Co.:	TSi Geotechnical, Inc.	**Date/Time Started:**	April 5, 2017 at 12:00 pm
Driller/Helper:	Randy Kelly /Lance Leonard	**Date/Time Finished:**	April 6, 2017 at 8:45 am

Elevation: 519 ft. **Vertical Datum:** WGS84
Boring Location: 48.5 feet from closest Southern edge of side parking lot and 83 feet from the Northern edge
Coord.: **N:** 38.799909 **E:** -90.19154
Horizontal Datum: WGS84

Item	**Casing**	**Sampler**	**Core Barrel**
Type	HSA	S	NQ
Length (ft)	5	2	10
Inside Dia. (in.)	4.25	1.375	1.875
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-550X

			Hammer Type	**Drilling Fluid**
☐ Truck	☐ Tripod	☐ Cat-Head	☑ Safety	☐ Bentonite
☑ ATV	☐ Geoprobe	☑ Winch	☐ Doughnut	☐ Polymer
☐ Track	☐ Air Track	☐ Roller Bit	☐ Automatic	☑ Water
☐ Skid	☑ Rubber	☑ Cutting Head	☐ ______	☐ None

Drill Rod Size:
Casing Advance: Hollow Stem Auger/Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-1 0.0'- 2.0'	18	2 2 3 3		CL	Medium stiff, yellowish red Silty CLAY, moist (CL)	N	M	M	H	PP = 1.3 tsf Some roots present within sample.
	S-2 2.0'- 4.0'	24	1 3 2 3		CL	Medium stiff, yellowish red Silty CLAY, moist (CL)	N	M	M	M	PP = 2.1 tsf
5	S-3 4.0'- 6.0'	24	1 2 3 3		CL	Medium stiff, yellowish red Silty CLAY, moist (CL) 6.0	N	M	M	M	PP = 1.3 tsf
	S-4 6.0'- 8.0'	24	2 3 3 5		ML	Medium stiff, yellowish red to light brown Sandy SILT, little Clay, moist (ML)	S	L	L	L	PP = 1.2 tsf
510 10	S-5 8.0'- 10.0'	24	2 3 4 5		ML	Medium stiff, yellowish red to light brown Sandy SILT, little Clay, moist (ML)	S	L	L	L	PP = 1.2 tsf
15	S-6 13.0'- 15.0'	24	1 1 2 3		ML	Soft, yellowish red Clayey SILT, trace fine Sand, moist (ML)	S	L	L	L	PP = 0.5 tsf
500	S-7 18.0'- 20.0'	18	2 3 4 4		ML	Medium stiff, yellowish red Sandy SILT, little Clay, moist (ML)	S	L	L	L	PP = 2.0 tsf

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Geoprobe

Notes:
P.P. = Pocket Penetrometer.
T.V. = Torvane.

Boring No.: **B-STL-11**

Field Test Legend: Dilatancy: N - None S - Slow R - Rapid; Toughness: L - Low M - Medium H - High; Plasticity: NP - Non-Plastic L - Low M - Medium H - High; Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
	S-8 23.0'-25.0'	24	2 2 3 3		ML	Medium stiff, yellowish red Sandy SILT, little Clay, moist (ML)	S	L	L	L	PP = 2.1 tsf
25											
26.5											
	S-9 28.0'-30.0'	24	2 2 3 4		CL	Medium stiff, yellowish red to light brown Sandy CLAY, little Silt, moist (CL)	N	H	M	H	PP = 2.3 tsf
490											
30											
31.5											
	S-10 33.0'-35.0'	18	3 3 5 6		SC	Loose, brownish yellow to light brown Clayey fine SAND, moist (SC)	S	M	M	M	
35											
36.5											
	S-11 38.0'-40.0'	20	5 4 4 4		SM	Loose, brown Silty fine SAND, moist (SM)	S	-	NP	L	
480											
40											
	S-12 43.0'-45.0'	18	3 3 6 4		SM	Loose, light brown to yellowish red Silty fine SAND, trace Clay, wet (SM)	S	L	L	L	Groundwater encountered at approximately 43 feet BGS.
45											

NOTES:

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
470	S-13 48.0'-50.0'	18	3 4 5 6		SM	Loose, yellowish red Silty coarse to fine SAND, little coarse to fine Gravel, wet (SM)	-	-	NP	-	
50						51.5					
	S-14 53.0'-55.0'	21	2 2 4 15		CH	Medium stiff, yellowish red to gray Gravelly CLAY, trace Silt, moist (CH)	N	H	H	VH	PP = 1.9 tsf Hollow Stem Auger to 53 feet BGS, added water and used split spoon rod to advance beyond casing to 58 feet BGS.
55						56.5					
460	S-15 58.0'-60.0'	10	4 1 1 2		GW	Very loose, brown to brownish yellow coarse to fine GRAVEL, little coarse to fine Sand, trace Silt, wet (GW)	-	-	NP	N	
60											
	S-16 63.0'-65.0'	24	2 5 5 8		GW	Medium dense, brown to brownish yellow coarse to fine GRAVEL, little coarse to fine Sand, trace Silt, wet (GW)	-	-	NP	N	
65						66.5					
450	S-17 68.0'-70.0'	6	50/6"		CH	Hard, brownish yellow to yellowish red CLAY, little coarse to fine Gravel, wet (CH)	N	H	H	VH	Limestone fragments in tip of split spoon.
70						70.0 Top of Rock at 70 feet BGS. See Rock Coring Log.					
75											

NOTES:

PROJECT NO.: **372453**

BORING NO.: **B-STL-11**

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD	CORE BORING LOG	BORING NO.: **B-STL-11**

Project:	Spire STL Pipeline	**Project No.:**	372453
Location:	Missouri/Illinois	**Project Mgr:**	Vatsal Shah
Client:	Spire STL Pipeline LLC	**Field Eng. Staff:**	Jonathan Nelson
Drilling Co.:	TSi Geotechnical, Inc.	**Date/Time Started:**	April 5, 2017 at 12:00 pm
Driller/Helper:	Randy Kelly /Lance Leonard	**Date/Time Finished:**	April 6, 2017 at 8:45 am

Elevation: 519 ft.		**Vertical Datum:** WGS84		**Boring Location:** 48.5 feet from closest Southern edge of side parking lot and 83 feet from the Northern edge	**Coord.: N:** 38.799909 **E:** -90.19154
Item	**Casing**	**Core Barrel**	**Core Bit**		
Type	HSA	NQ	Imp. Diamond	**Horizontal Datum:** WGS84	**Drilling Method:** Wireline
Length (ft)	5	10	6	**Rig Make & Model:** CME-550X	
Inside Dia. (in.)	4.25	1.875	1.875		

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations) SEE TEST BORING LOG FOR OVERBURDEN DETAILS	Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.20	70.0							Crystalline LIMESTONE, white, fine grained, moderately weathered, strong, very close to moderately spaced discontinuities 70' - 70.3' Highly Fractured zone	70.10	Sty	19	U,Sm	DS	O	N	
	1.90								71.05' - 73.1' Highly Fractured zone 71.05' - 71.4' Yellowish red to olive green Silty Clay infilling, still soil not hardened	71.05 71.40	J J	25 42	U,Sm U,R	DS DS	VW VW	CL CL	
	1.30		R-1	60 100%	28 47%	R4	M			72.30	J	13	U,R	DS	VW	CL	
	2.10								73.6' - 74' Highly Fractured zone	73.10 73.60	J Sty	7 8	U,R U,R	DS DS	VW O	CL Ca	
	2.20	75.0							74.9' - 75.8' Highly Fractured zone with Clay infilling								
75	1.80	75.0							LIMESTONE, white, fine grained, slightly weathered, strong, extremely close to wide spaced discontinuities	74.90 75.80	F J	52 10	U,R U,Sm	DS DS	VW VW	Ca N	Rig chatter from 75.5 to 75.6 feet BGS. Frequent stylolites.
	1.60									76.10	Sty	15	U,R	DG	O	CL	
	1.40		R-2	58 97%	48 80%	R4	SL			77.90	F	60	U,Sm	DS	MW	Fe	
	4.10																
440	3.20	80.0															
80	3.20	80.0							LIMESTONE, light gray to brownish yellow, fine grained, moderately weathered, strong, extremely close to wide spaced discontinuities								Rig chatter at 83 feet BGS.
	1.80								81.15' - 82.05' Completely weathered to thin brownish yellow color slightly porous								
	1.70		R-3	56 93%	35 58%	R4	M		82.05' - 83' Highly Fractured zone	82.05 82.60 82.90	J J F	13 6 51	U,R U,R S,R	DG DG DG	VW VW W	N N Fe	/Qz
	2.10																
	2.30	85.0							84' - 85' Vertical Fracture	84.10	Sty	16	U,R	DG	MW	Fe	
85	3.40	85.0							LIMESTONE, light gray, fine grained, slightly weathered, strong, very close to wide spaced discontinuities Frequent stylolites 85' - 85.7' Vertical Fracture	85.60 85.90	F Sty	85 5	U,R U,R	DS DG	MW O	Fe Fe	Used approximately 1300 gallons of water from 70 to 90 feet BGS.
	2.70																
	2.60		R-4	57 95%	37 62%	R4	SL										
	2.30								88.5' - 90' Quartz mixed into cementation	88.50	Sty	9	U,R	DG	PO	QZ	
430	2.40	90.0								89.00 89.30 89.70	Sty Sty Sty	15 10 5	U,R U,Sm U,Sm	DG DG DG	O PO PO	Fe Fe Fe	/Qz

(Discontinuities: See Legend for Rock Description System)

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
		-			

Notes:

Depth (ft)	Run/(Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)
90.0 – 95.0	R-5	60 / 100%	56 / 93%	R3	SL	LIMESTONE, light gray, fine grained, slightly weathered, medium strong, close to wide spaced discontinuities Siliceous type nodules Calcite filled pores 93' - 93.4' Highly Weathered zone
95.0 – 100.0	R-6	60 / 100%	50 / 83%	R3	SL	Argillaceous LIMESTONE, light gray to gray, fine grained, slightly weathered, medium strong, extremely close to moderately spaced discontinuities Frequent Clay infilled stylolites 95' - 96.7' Chert/Siliceous and Calcite infilling
100.0 – 105.0	R-7	60 / 100%	28 / 47%	R3	SL	Argillaceous LIMESTONE, light gray, slightly weathered, medium strong, extremely close to close space discontinuities Very frequent stylolites Layers of high Calcite core and Siliceous infilling
105.0 – 110.0	R-8	60 / 100%	21 / 35%	R3	SL	Crystalline LIMESTONE, light gray, slightly weathered, medium strong, extremely close to moderately spaced discontinuities Very frequent stylolites Fossils present with core
110.0 – 115.0	R-9	60 / 100%	20 / 33%	R3	SL	Argillaceous LIMESTONE, light gray to gray, fine grained, slightly weathered, strong, moderately spaced discontinuities Very frequent stylolites
115.0						

Depth/Elev. (ft): 95, 100, 105, 110, 115; Elev. 420 (approx. 99.6 ft), 410 (approx. 109.6 ft)

Depth interval (ft)	Avg Core Rate (min/ft)
90–91	2.70
91–92	2.80
92–93	1.70
93–94	2.00
94–95	2.50
95–96	2.40
96–97	2.30
97–98	2.00
98–99	1.90
99–100	2.10
100–101	2.00
101–102	2.00
102–103	2.10
103–104	2.30
104–105	2.70
105–106	2.70
106–107	1.90
107–108	1.90
108–109	2.00
109–110	2.00
110–111	2.50
111–112	2.00
112–113	1.70
113–114	3.00
114–115	6.90

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
92.30	J	0	U,Sm	DS	PO	Fe
93.40	J	10	U,R	DG	MW	N
93.90	J	5	U,Sm	DS	T	Fe
95.50	B	3	U,Sm	DG	MW	CL
96.20	Sty	6	U,Sm	DS	O	N
96.70	B	0	U,R	DS	O	Fe
97.40	Sty	3	U,R	DS	MW	CL
98.30	Sty	12	U,R	DG	MW	CL
99.00	Sty	2	U,R	DG	MW	CL
99.70	Sty	2	U,R	DG	MW	CL
	Sty	2	U,R	DG	MW	CL
100.10	Sty	3	U,R	DS	MW	CL
100.50	Sty	0	U,R	DS	MW	QZ
101.10	Sty	9	U,R	DS	MW	N
102.45	Sty	0	U,R	DG	MW	CL
103.70	Sty	6	U,R	DG	MW	N
104.80	Sty	6	U,R	DG	MW	CL
105.25	Sty	4	U,R	DG	O	CL
105.50	Sty	3	U,R	DS	MW	N
106.40	Sty	10	U,R	DG	MW	N
107.20	Sty	6	U,Sm	DG	MW	CL
107.70	Sty	0	U,Sm	DG	MW	CL
108.10	Sty	0	U,Sm	DG	MW	CL
109.30	Sty	0	U,Sm	DS	MW	N
110.25	Sty	0	U,R	DS	PO	N
110.50	Sty	6	U,R	DS	MW	CL
111.10	B	12	U,Sm	DS	PO	QZ
112.00	Sty	3	U,R	DS	PO	N
113.00	Sty	0	U,Sm	DS	MW	N
113.90	Sty	4	U,R	DS	MW	N
115.00	B	5	U,Sm	DS	MW	Ca

Remarks:

- (90 ft) Used approximately 300 gallons of water from 90 to 94 feet BGS.
- (100 ft) Stylolites decrease overall core strength but cementation is still medium strong to strong.
- (110 ft) Chert nodules and thin Chert infilling increases overall rock structure.

NOTES:

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Remarks
	6.00								
	5.90							Argillaceous LIMESTONE, light gray to gray, fine grained, slightly weathered, strong, extremely close to moderately spaced discontinuities Very frequent stylolites Chert and Argillaceous infilling less than 1/4" to Chert nodules up to 2" thick	Used approximately 1300 gallons of water from 90 to 115 feet BGS.
	5.10		R-10	60 100%	54 90%	R4	SL		
	4.90								
400	4.70	120.0							
120	3.20	120.0						LIMESTONE, gray to light gray, fine grained, slightly weathered, very strong, close to moderately spaced discontinuities 120' - 121' Slightly porous with Argillaceous/Calcite layers and occasional Quartz infilling	
	3.90								
	4.70		R-11	60 100%	46 77%	R5	SL		
	4.00								
	4.00	125.0							
125	4.20	125.0						LIMESTONE, light gray to gray, fine grained, slightly weathered, strong, close to moderately spaced discontinuities Visible Calcite/Argillite cementation layers	Used approximately 300 gallons of water from 126 to 130 feet BGS.
	3.50								
	3.30		R-12	60 100%	55 92%	R4	SL		
	3.40							128.2' - 129' - 2 to 1/8" thick quartz veins running vertical along core	
390	3.00	130.0							
130	3.40	130.0						LIMESTONE, light gray to gray, fine grained, moderately weathered, medium strong, close to wide spaced discontinuities 130' - 131.1' Limestone, frequent stylolites 131.1' - 134.5' Porous, gray anhydrous	
	3.60								
	3.50		R-13	60 100%	56 93%	R3	M		
	3.50								
	3.60	135.0						134.5' - 134.85' 1/4" to 1" Calcite laminations	
135	2.50	135.0						LIMESTONE, light gray to gray, fine grained, moderately weathered, weak, extremely close to moderately spaced discontinuities Rock is slightly anhydrous silaceous, and porous with Vugs 135.25' - 137' Vertical Fracture	Used approximately 800 gallons of water from 130 to 140 feet BGS.
	2.10								
	1.30		R-14	60 100%	15 25%	R2	M	137.4' - 138.4' Vertical Fracture	
	1.90							138.6' - 139' Many thin stylolites	
380	1.70	140.0							
140	1.50	140.0						Argillaceous Silty LIMESTONE, light brown to light gray, fine grained, moderately weathered, weak, extremely close to moderately spaced discontinuities	Used approximately 200 gallons of

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
116.55	B	18	P,Sm	DS	W	Ca
118.30	Sty	9	U,R	DS	MW	N
119.20	Sty	0	U,Sm	DS	O	N
121.00	Sty	22	U,R	DG	MW	CL
121.70	Sty	5	U,Sm	DS	MW	N
123.60	Sty	11	U,R	DS	T	N
124.10	Sty	2	U,R	DS	O	N
125.10	J	12	U,Sm	DS	MW	N
125.75	J	3	U,R	DG	MW	N
127.00	Sty	5	U,Sm	DS	PO	N
127.60	F	71	U,Wa	DS	PO	N
127.70	Sty	10	U,Wa	DE	MW	CL
129.00	J	10	U,Sm	DS	MW	N
129.50	Sty	10	U,R	DS	O	N
130.00	Sty	16	U,Sm	DG	O	CL
131.10	B	5	P,R	DG	MW	CL
134.50	Sty	8	U,R	DG	MW	CL
134.85	Sty	4	U,R	DS	T	N
135.30	B	39	U,Sm	DG	W	CL
135.80	F	83	U,Sm	DS	O	Ca
137.00	J	9	U,R	FR	PO	N
137.30	B	14	U,Sm	DS	PO	N
137.70	F	85	U,R	FR		N
139.40	F	11	U,R	DG	W	Rx
139.80	J	7	U,Sm	DS	O	N
140.30	J	8	U,Sm	DS	MW	N

NOTES:

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Remarks
									Porous irregular small vugs tunnelling Calcite mineralization is frequent	water from 140 to 145 feet BGS.
	1.70		R-15	60 100%	42 70%	R2	M			
	1.60									
	1.40									
	1.90	145.0								
145	1.90	145.0	R-16	60 100%	39 65%	R3	M		LIMESTONE, brown to light gray, fine grained, moderately weathered, medium strong, extremely close to moderately spaced discontinuities 145' - 146.45' Silty/porous/anhydrous brown Limestone	Used approximately 300 gallons of water from 145 to 150 feet BGS.
	2.60								146.45' - 147.3' Highly Fractured zone	
	2.70								147.3' - 150' Argillaceous Limestone, light gray	
	3.40									
370	3.10	150.0							149.2' - 150' Vertical Fracture	
150								150.0	End of Boring at 150 feet BGS. Borehole grouted with cement and bentonite hole plug.	
155										
360										
160										
165										

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
140.80	J	5	U,Sm	FR	O	N
141.20	B	8	U,Sm	DG	T	ML
141.60	Sty	3	S,Sm	DS	MW	N
143.30	J	0	U,Sm	DG	O	SD
144.60	J	13	U,Sm	DS	O	N
146.45	B	12	S,Sm	DS	W	N
147.30	J	10	U,Sm	DS	VW	N
148.70	Sty	4	U,R	DS	O	N
149.60	F	85	U,R	DS	O	Fe

NOTES:

Figure B-STL-11.1
B-STL-11 Box 1 Runs 1-2 Dry

Figure B-STL-11.2
B-STL-11 Box 1 Runs 1-2 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-11

Figure B-STL-11.3
B-STL-11 Box 2 Runs 3-4 Dry

Figure B-STL-11.4
B-STL-11 Box 2 Runs 3-4 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-11

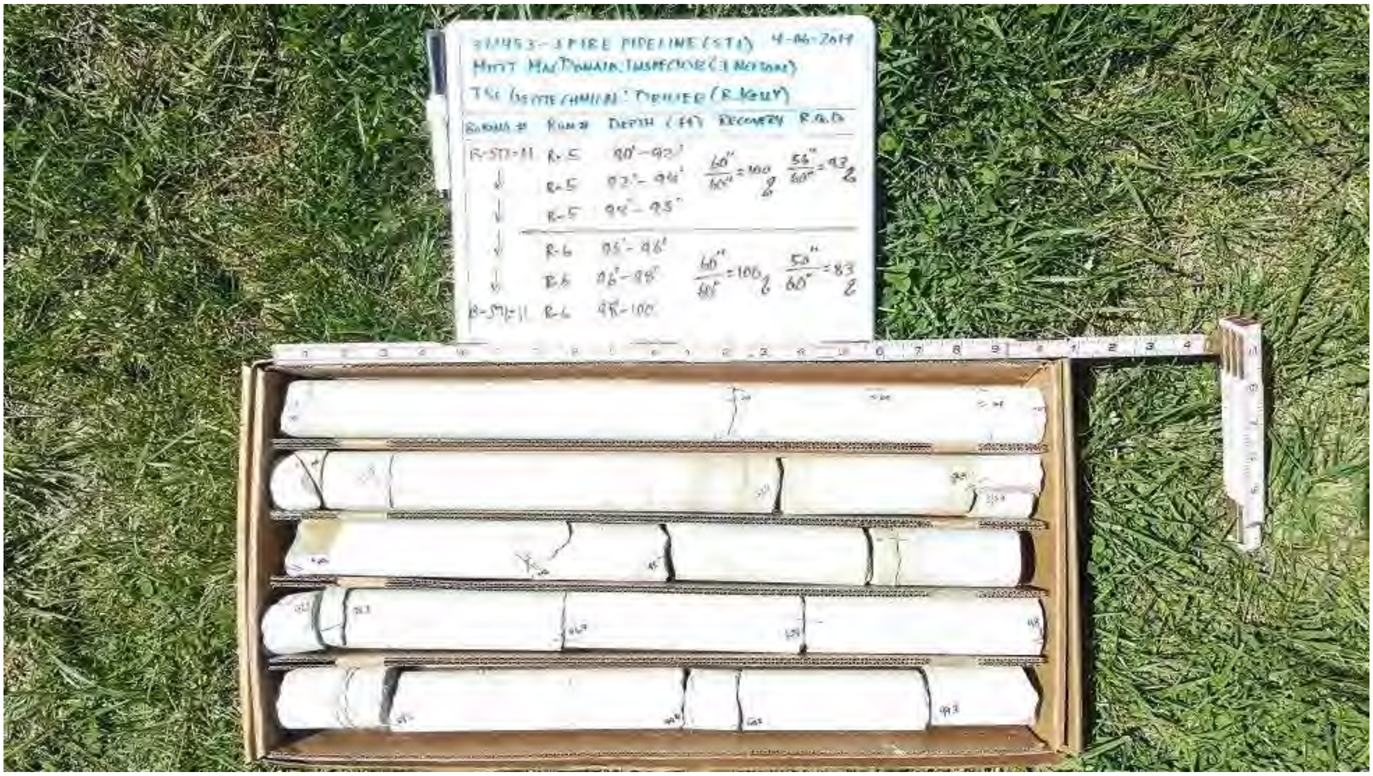


Figure B-STL-11.5
B-STL-11 Box 3 Runs 5-6 Dry

Figure B-STL-11.6
B-STL-11 Box 3 Runs 5-6 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-11

Figure B-STL-11.7
B-STL-11 Box 4 Runs 7-8 Dry

Figure B-STL-11.8
B-STL-11 Box 4 Runs 7-8 Wet

MOTT MACDONALD

Spire STL Pipeline

Rock Core Photographs

BORING NO.:

B-STL-11

Figure B-STL-11.9
B-STL-11 Box 5 Runs 9-10 Dry

Figure B-STL-11.10
B-STL-11 Box 5 Runs 9-10 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-11

Figure B-STL-11.11
B-STL-11 Box 6 Runs 11-12 Dry

Figure B-STL-11.12
B-STL-11 Box 6 Runs 11-12 Wet

Figure B-STL-11.13
B-STL-11 Box 7 Runs 13-14 Dry

Figure B-STL-11.14
B-STL-11 Box 7 Runs 13-14 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-11

Figure B-STL-11.15
B-STL-11 Box 8 Runs 15-16 Dry

Figure B-STL-11.16
B-STL-11 Box 8 Runs 15-16 Wet

D. THG Geophysical Survey Report

July 31, 2017

Eric Pauli, EIT
Engineer III
Mott MacDonald
111 Wood Avenue South
Iselin, NJ 08830-4112
(973) 379-8602

Re: Geophysical Karst Investigation
Spire Alignment, St. Louis, Missouri
THG Project No. 639-6549

Dear Mr. Pauli:

THG Geophysics, Ltd. (THG) performed a geophysical survey along the proposed alignment to the Spire pipeline in St. Louis, Missouri, May 15-16, 2017 (Figure 1). The objective of this investigation was to locate subsurface Karst features within the Cambrian-aged Eminence Dolomite. THG deployed electrical imaging (EI) and microgravity (MG) methods to image the subsurface. The alignment consisted of 2 portions; Coldwater Creek (Items 1-5) and Spanish Lake (Items 6-10):

Line	Method	Profile	Distance (ft)	Figure #
		Coldwater Creek Alignment		
1	EI	Coldwater Creek HDD Entry to south Spur to 367	410	2
1	MG	Spur to Road	300	3
2	MG	North Spur to rail crossing	510	4
3	MG	Lindbergh Blvd to north Coldwater Creek	170	5
2	EI	South side Coldwater Creek to CWC HDD – beyond Exit	1,900	2
3	EI	Line 2 sinkhole	230	2
		Spanish Lake Align**ment**		
1	EI	Spanish Lake HDD Entry to Spanish Pond Rd	700	3
1	MG	Spanish Pond Rd to north Spanish Lake	310	7
		Spanish Lake peninsula (not completed)	130	3
2	EI	Spanish Lake Island north to south	820	3
3	EI	South Spanish Lake to Spanish Lake HDD Exit	620	3

Electrical Imaging

Electrical resistance is based upon Ohm's Law, where resistance is equal to the difference between the current flow and voltage differential. However, resistivity depends upon the bulk property and geometry of the material. Consequently, resistivity is measured in Ohm-meters.

Currents are carried through earth materials by motion of the ions in connate water. Ions in connate water come from the dissociation of salts and provide for the flow of electric current. Further, resistivity decreases in water-bearing rocks and earth materials with increasing:

a. Fractional volume of the rock occupied by groundwater;
b. Total dissolved solid and chloride content of the groundwater;
c. Permeability of the pore spaces; and,
d. Temperature.

Materials with minimal primary pore space (i.e., limestone) or that lack groundwater in the pore spaces will exhibit high resistivity values (Mooney, 1980). Highly porous, moist or saturated soil, such as fat clays, will exhibit very low resistivity values. Most earthen materials show medium to low resistivity.

In homogeneous ground, the apparent resistivity is the true ground resistivity; however, in heterogeneous ground, the apparent resistivity represents a weighted average of all formations through which the current passes. A forward modeling subroutine was used to calculate the apparent resistivity values using the EarthImager program (AGI, 2002). This program is based upon the smoothness-constrained least-squares method (deGroot-Hedlin and Constable, 1990; Loke and Barker, 1996). The EarthImager program divides the subsurface 2D space into a number of rectangular blocks. Resistivities of each block are then calculated to produce an apparent resistivity pseudosection. The pseudosection is compared to the actual measurements for consistency. A measure of the difference is given by the root-mean-squared error.

Six EI profiles were collected using a GF Instruments ARES continuous vertical electric sounder (Figures 2 and 6). The profiles were collected using a 4-meter Schlumberger array merged with a dipole-dipole array.

Coldwater Creek EI Profiles 1, 2, and are, respectively 410 ft, 1,900 ft, and 230 ft (Figure 2). Profile 1 imaged to 95 feet below grade (ft bg); whereas, EI Profile 2 as deep as 120 ft bg. Line 3 imaged to only 50 ft below grade.

Spanish Lake EI Profile 1, 2, and 3 are, respectively, 700 ft, 850 ft, and 620 ft long (Figure 6). All 3 profiles image to at least 150 ft bg. Profile EI 2 imaged to 170 ft bg. Spanish Lake Profile 2 (Item 10) is 620 feet long and imaged to 130 ft bg (Figure 2).

EI data quality for this survey was very high. Locational data were recorded using a Trimble Geo7x global positioning system.

Microgravity Survey

Four microgravity profiles were collected 3 for Coldwater Creek in and around Louis and Clark Blvd and 1 at the boat dock in the northern portion of the Spanish Lake alignment. A total of approximately 128 differential microgravity measurements for the 3 surveys were collected using a Scintrex CG-5 microgravimeter (Figures 3, 4, and 5).

Microgravity measurements are not readily impacted by cultural noise; consequently, microgravity measurements can be collected in urban areas (i.e. on paved lots and near utilities). Microgravity has been used for many geologic purposes; however, in near surface geophysics, microgravity is used to determine the presence of subsurface voids, to image subsurface bedrock topography, and to find the depth of waste (Carmichael and George, 1977; Kick, 1985; Stewart, 1980).

Small changes in rock density produce small changes in the gravity field that can be measured by the microgravimeter. A microgravimeter measures the acceleration due to the earth's gravitational field (in mgal = 0.001 cm/sec^2) using an astatic spring mechanism (Carmichael and George, 1977). The Earth's gravitational field is roughly equivalent to a sphere with variations for sea level and elevation (Milsom, 1989).

The 1930 International Gravity Formula (Nettleton, 1971) for calculating absolute gravity is:

$$g_\phi = g_o\left(1 + \alpha \sin^2\phi - \beta \sin^2 2\phi\right)$$

Where, (g_ϕ) is the theoretical acceleration due to gravity at a given latitude (ϕ) ,and α and β are constants that depend on the amount of flattening of the spheroid and upon the speed of rotation of the Earth (Reynolds, 1997). Gravity is calculated in g.u. (10 g.u. (10-6 m/sec^2) = 1 mgal, a c.g.s. unit).

Processing raw gravity data includes corrections for latitude, elevation, Bouguer gravity, tidal, and terrain corrections.

Latitude corrections were automatically corrected automatically by subtracting the International Gravity Formula normal datum from the observed gravity:

$$G_l = \frac{8.12 \sin 2L g.u.}{km}$$

Where, g_l is the theoretical local gradient and L is the latitude.

The elevation or free-air correction normalizes the gravity data to a given datum that does not have to be sea level. Free-air correction is based upon the free-air correction of 0.3086 mgals/meter (0.0941 mgals/ft).

Where, the free-air corrected value is the sum of the elevation difference between the actual elevation and the normal elevation times the free-air correction, and the measured gravity in mgals.

Bouguer corrections were applied to the dataset. Bouguer corrections account for the rock mass between the measuring station and sea level. Bouguer (b) corrections are based upon:

$$b = 2\pi\rho g_s h$$

Where, Bouguer gravity is related to density (ρ = 2.54 Mg/m3) and known thickness (h) above sea level.

The Scintrex CG-5 microgravimeter applied an automatic gravitational tidal correction to all data based upon the diurnal variation in the Earth's position to the moon and Sun.

Conclusions

Coldwater EI Profile 1 shows that this portion of the alignment is probably not impacted by Karst features (Figure 2). Top of rock occurs at a depth of 60 ft bg and deeper. The depth to the top of rock between points 100 ft and 150 ft along the profile (approximately 90 feet) suggests that dissolution and/or deep erosion may have occurred at some point in geologic time.

Coldwater EI profiles 2 and 3 display obvious Karst features. A sinkhole exists at the tie of EI Profiles 2 and 3. This void appears saturated, yielding low apparent resistivity readings. Two additional areas are possibly characterized by Karst features (i.e., voids or vuggy porosity); between 450 and 550 ft and 800 to 900 ft along EI Profile 2 (Figure 2). Further, EI Profile 2 shows subsurface pinnacles and other dissolution remnant features.

Three EI profiles collected in the Spanish Lake portion of the Spire Pipeline indicate that top of rock occurs very deep along all 3 profiles. EI Profile 3 shows that top of rock shallows to the south and indicates that a probable void or very vuggy rock exists between points 400 ft and 450 ft along the profile (Figure 6).

Microgravity data is a useful tool for mapping Karst features in areas where there was limited access to the EI methods. The measured anomaly is relative to the depth and size of the target measured. The profiles collected along the alignment show a gentle decline in gravity as the profile approaches the lakes in this area.

Coldwater Creek Gravity profile indicates depressions in the gravity between 70 and 120 ft; and between 210 ft and 250 ft along the profile. These anomalies are interpreted to be urban phenomena. The area on either side of US Hwy 67 has been built up with dense material except in those areas indicated, with all of the readings above a base level observed in the other gravity profiles.

If you have any questions or comments regarding this interpretation, please contact us to discuss in further detail.

Respectfully,
THG Geophysics, Ltd.
Peter J. Hutchinson

Peter J. Hutchinson, PhD, PG
Senior Geophysicist

References

AGI, 2002. EarthImager Program. American Geosciences Inc., Austin Texas.

Carmichael, R.S. and H. George, Jr., 1977, Gravity exploration for groundwater and bedrock topography in glaciated areas; Geophysics, Vol. 42, pp. 850.

deGroot-Hedlin, C. and Constable, S., 1990, Occam's inversion to generate smooth, two-dimensional models from magnetotelluric data. Geophysics, V. 55, 1613-1624.

Kick, J.F. (1985). Depth to bedrock using gravimetry; The Leading Edge, V. 4 (4), p. 38-42.

Milsom J., (1989). Field Geophysics. Open University Press and Halstead Press, New York, NY, 182 p

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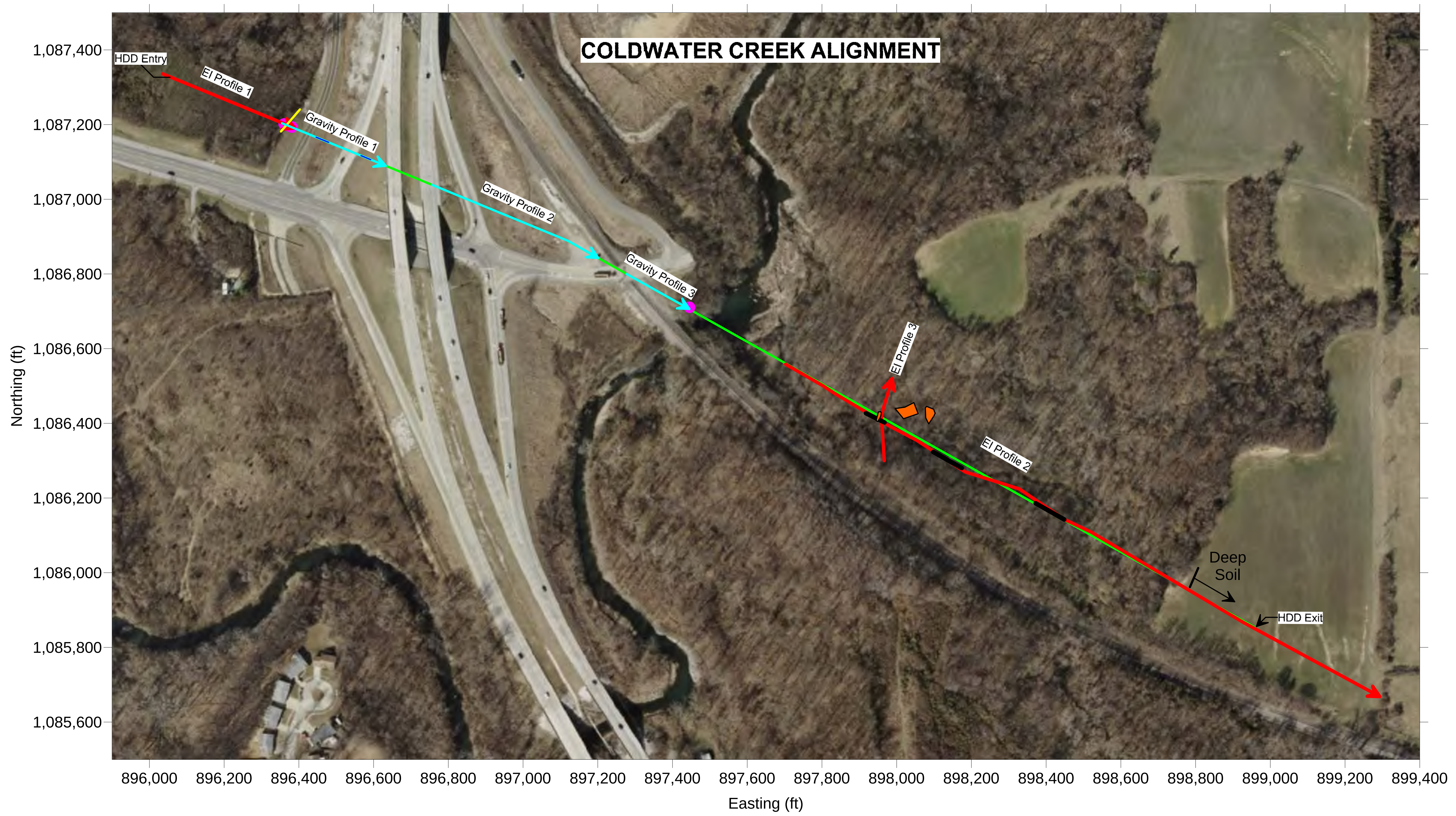

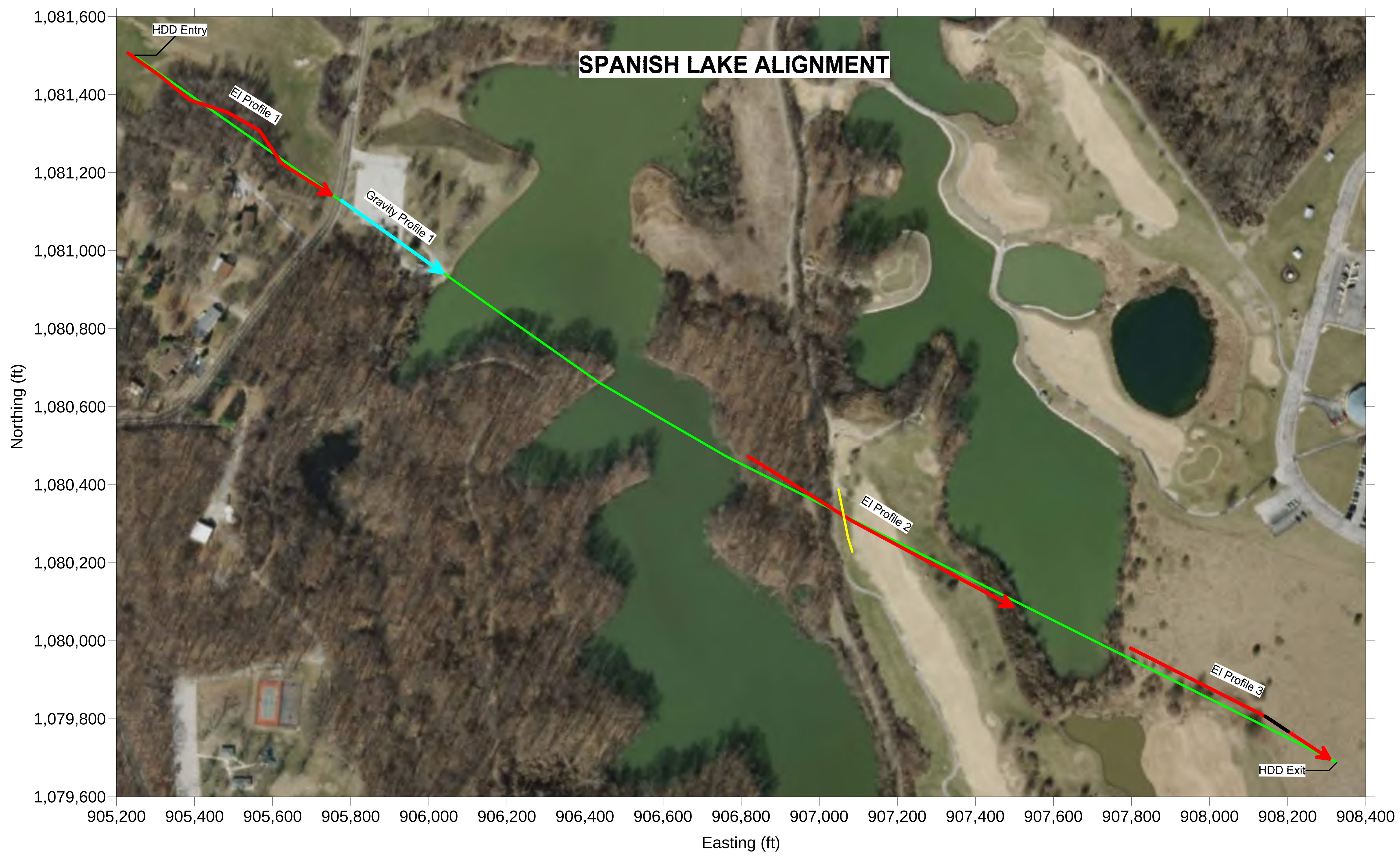

0 ft 300 ft 600 ft 900 ft 1200 ft 1500 ft 1800 ft

True North Approximate

Legend

- Gravity Anomaly
- EI Anomaly
- Gravity Profile
  Arrow is collection direction
- EI Profile
  Arrow is collection direction
- Proposed Alignment
- Underground gas line
- Urban induced gravity low
- Sinkhole Surface Expression

Notes

Geophysical survey conducted May 15-16 and July 25-26, 2017 using GF Instruments ARES continuous vertical electrical sounder and Scintrex CG-5 Microgravimeter.

Real-time positioning of data using fully integrated Trimble Geo7x global positioning system set to NAD 1983 Missouri State Plane coordinate system in US Survey Feet.

Locations are approximate.

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DRN	PJH	5/18/17
DES	PJH	5/18/17
CHK	PJH	8/1/17
REV	AXB	7/27/17
PROJ. MGR.	PJH	8/1/17

PROJECT: Geophysical Investigation
Spire Pipeline
St. Louis, Missouri

SCALE: 1" = 300'

SOURCE: USGS 2012

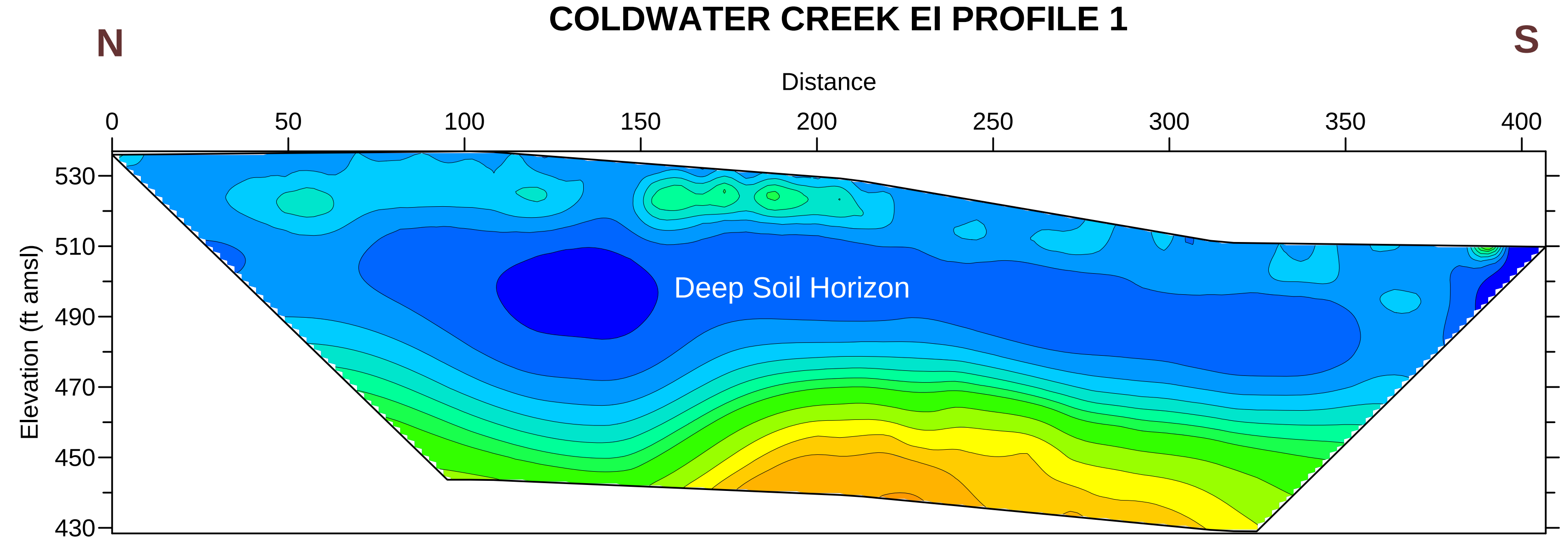
DRAWING NO.: **Figure 1**
Location Map

PREPARED FOR: M M MOTT MACDONALD

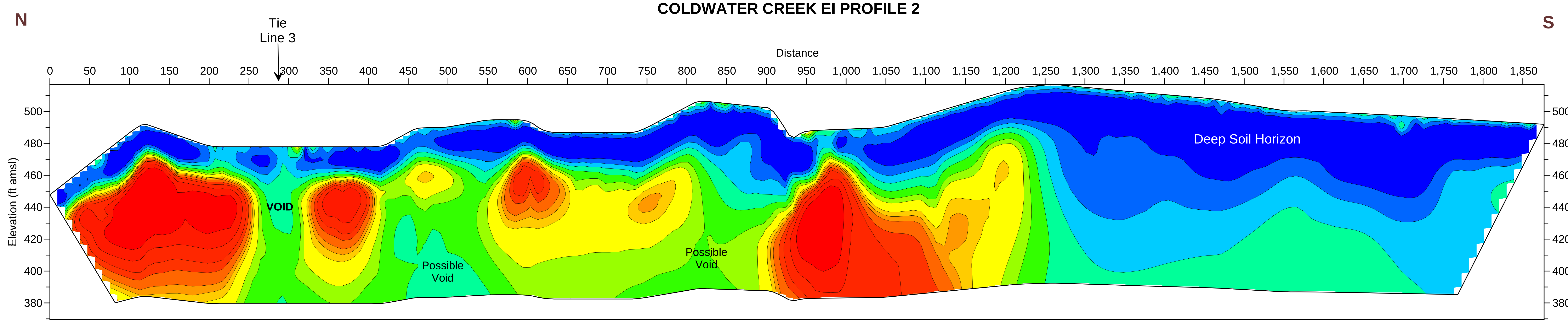
PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F1

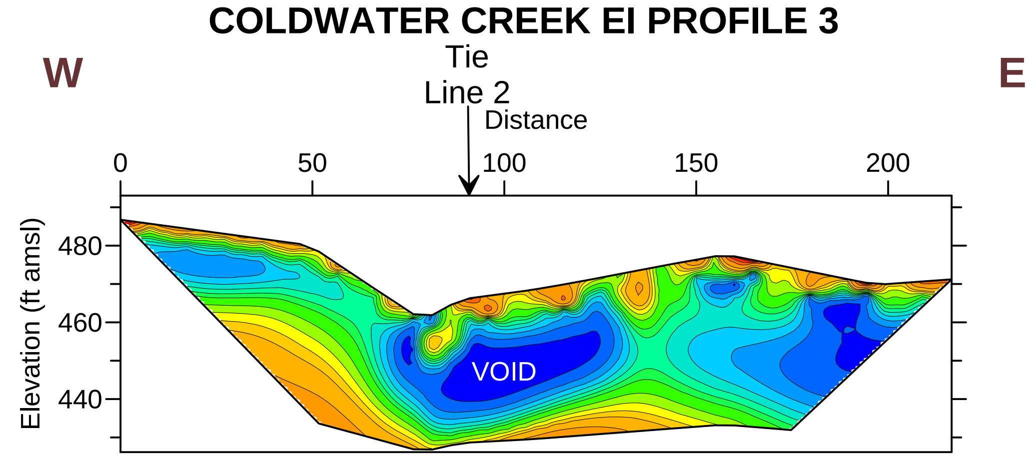
COLDWATER CREEK EI PROFILE 1



COLDWATER CREEK EI PROFILE 2



COLDWATER CREEK EI PROFILE 3



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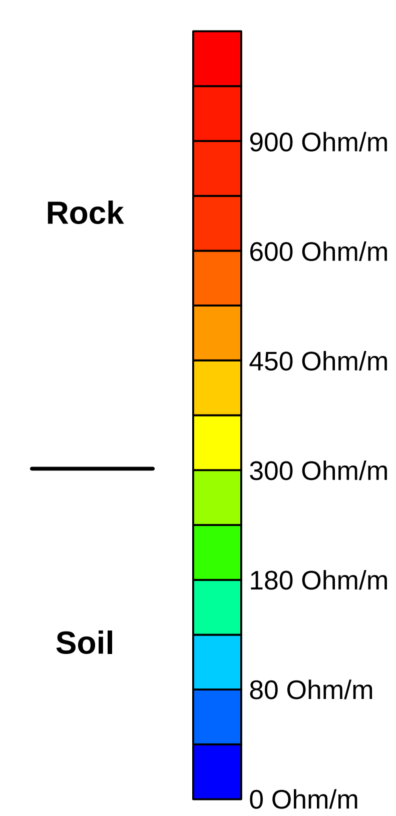

Notes

Geophysical survey conducted May 15-16, and July 24-26, 2017 using GF Instruments ARES continuous vertical electrical sounder with 4-m spacing.

Real-time positioning of data using fully integrated Trimble ProXRS global positioning system set to NAD 1983 Missouri State Plane coordinate system in feet.

No vertical exaggeration
Vertical 1" = 50'
Horizontal 1" = 50'

Vertical Exaggeration Coldwater Profile 2 Times 2
Vertical 1" = 100'
Horizontal 1" = 50'

Locations are approximate.

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DRN	PJH	5/18/17
DES	PJH	5/18/17
CHK	PJH	7/21/17
REV		
PROJ. MGR.	PJH	7/21/17

SCALE: As noted

SOURCE:

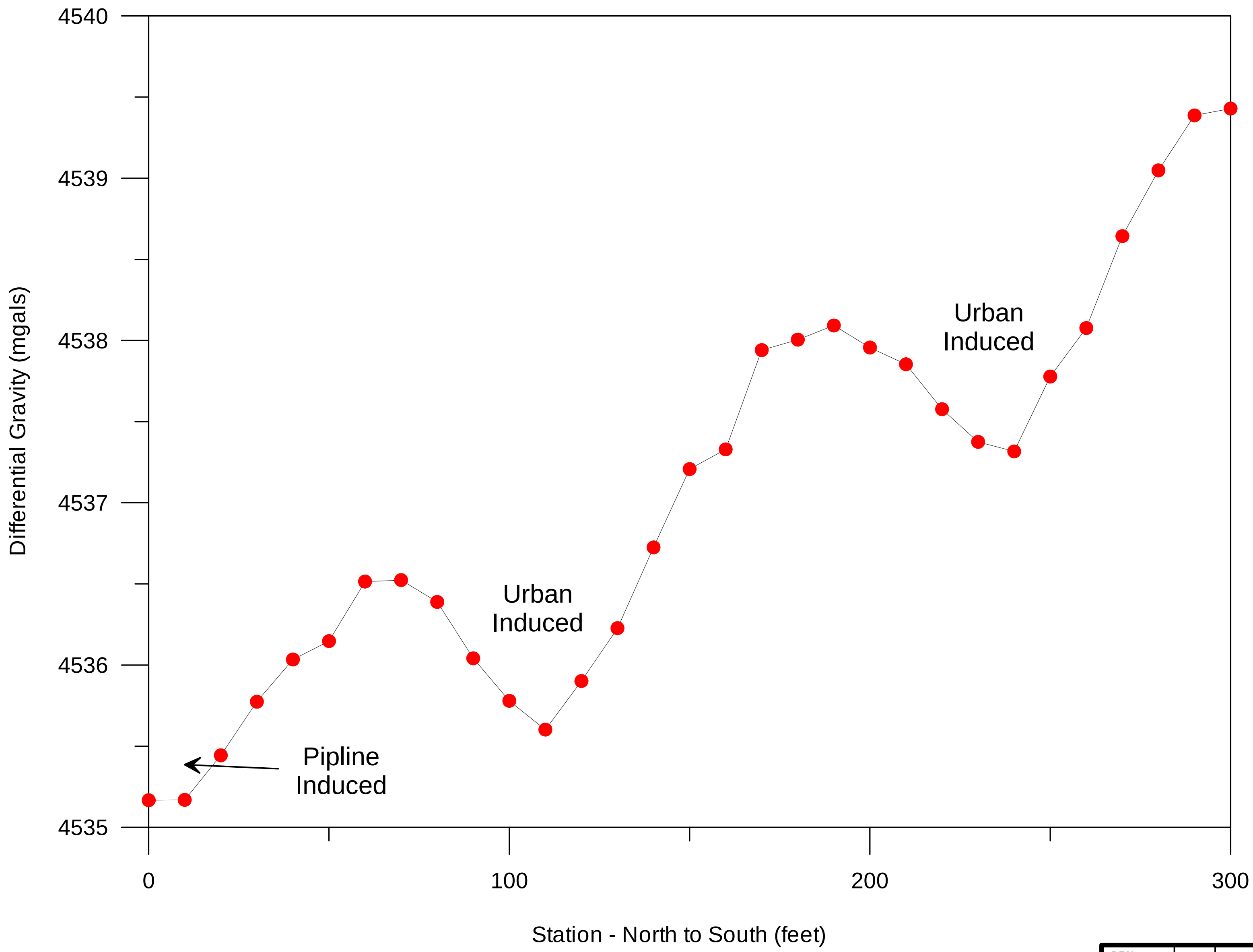
PROJECT: Geophysical Investigation
Spire Pipeline
St. Louis, Missouri

DRAWING NO.: **Figure 2**
Coldwater Creek EI Profiles

PREPARED FOR: MOTT MACDONALD

PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F2



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DRN	PJH	5/18/17
DES	PJH	5/18/17
CHK	PJH	5/18/17
REV		
PROJ. MGR.	PJH	5/18/17

SCALE: As noted

SOURCE:

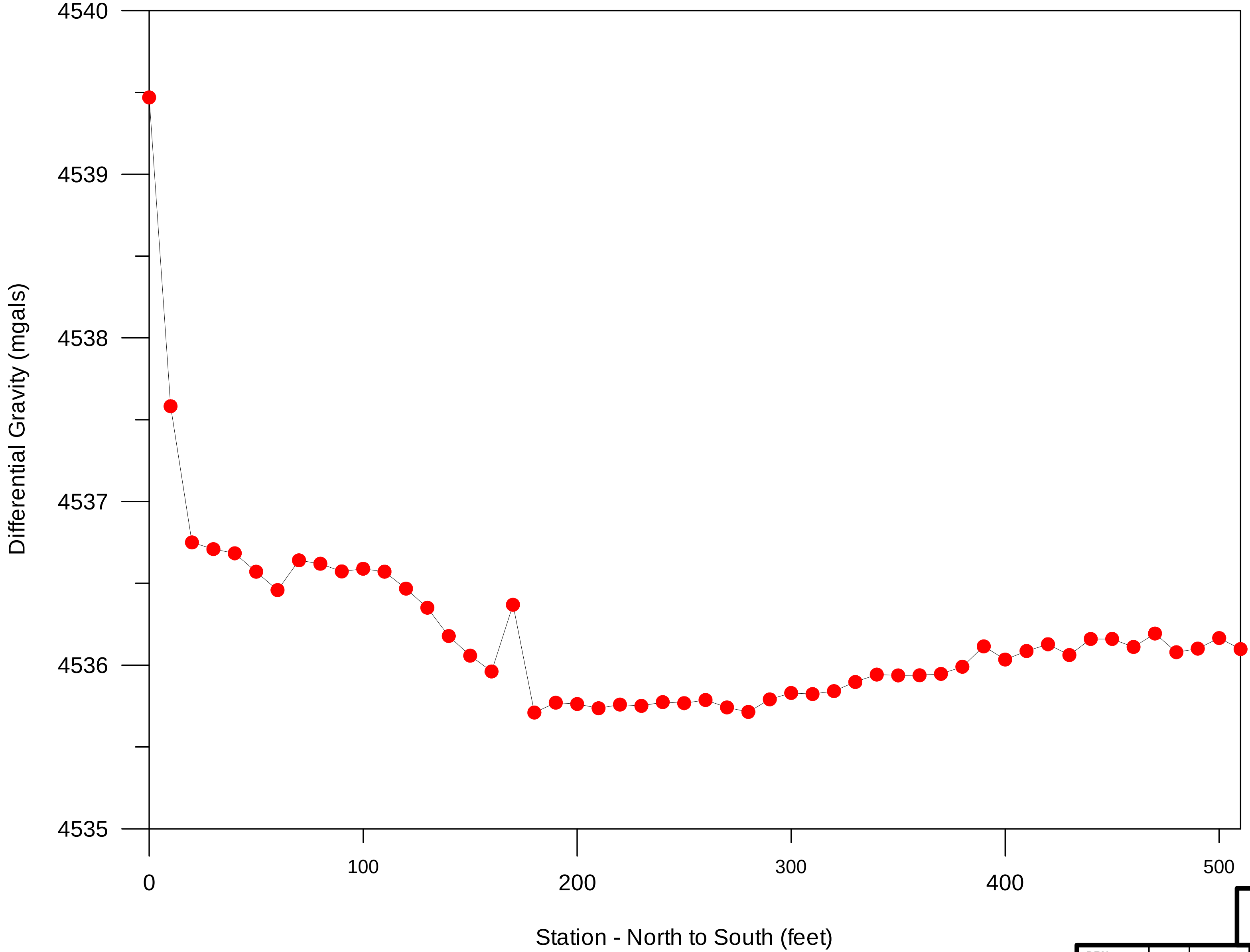
PROJECT:
Geophysical Investigation
Spire Pipeline
St. Louis, Missouri

DRAWING NO.:
Figure 3
Coldwater Creek
Gravity Profile 1

PREPARED FOR: M M MOTT MACDONALD

PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F3



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DRN	PJH	5/18/17
DES	PJH	5/18/17
CHK	PJH	5/18/17
REV		
PROJ. MGR.	PJH	5/18/17

SCALE: As noted

SOURCE:

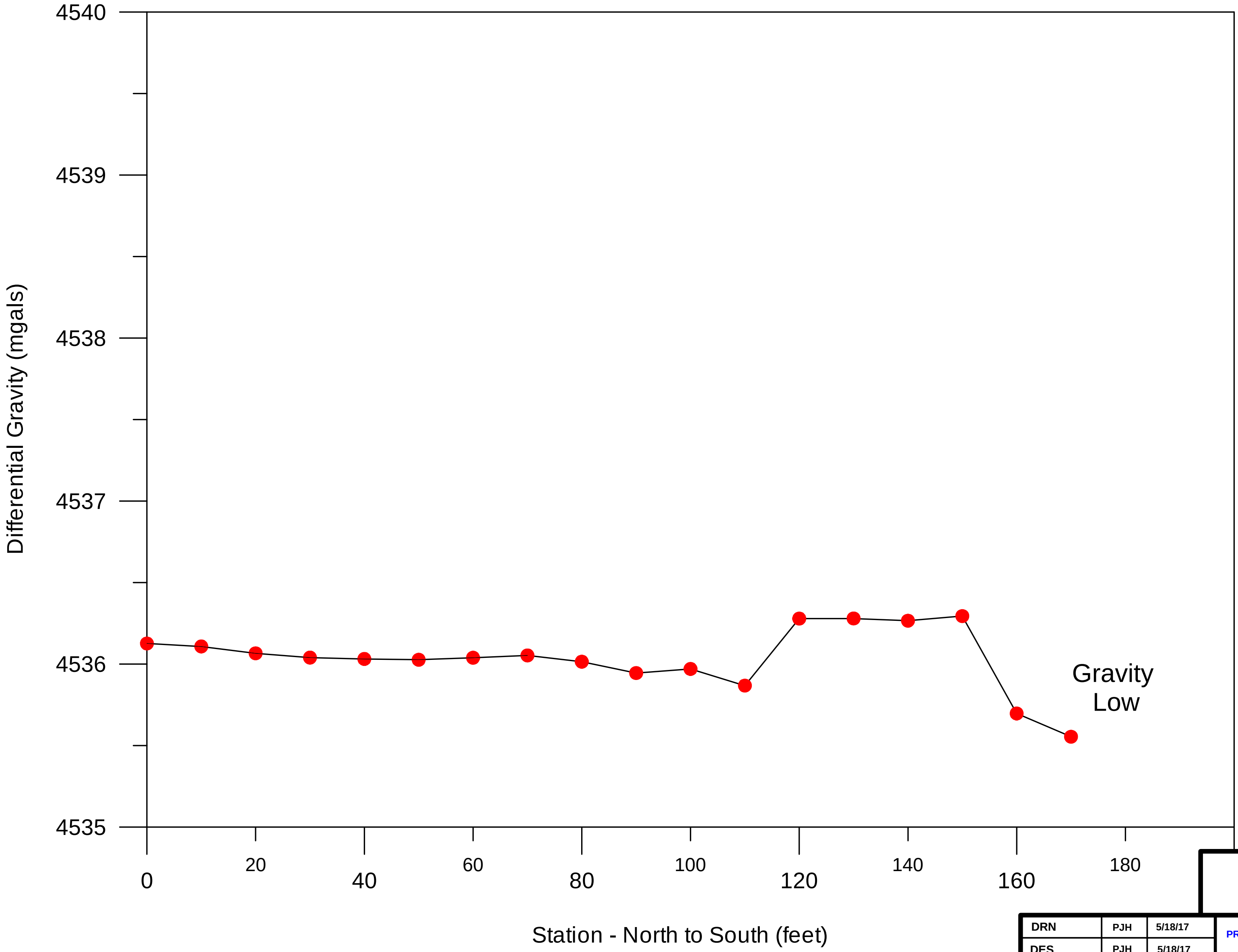
PROJECT:
Geophysical Investigation
Spire Pipeline
St. Louis, Missouri

DRAWING NO.:
Figure 4
Coldwater Creek
Gravity Profile 2

PREPARED FOR: MOTT MACDONALD

PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F4



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DRN	PJH	5/18/17
DES	PJH	5/18/17
CHK	PJH	5/18/17
REV		
PROJ. MGR.	PJH	5/18/17

PROJECT: Geophysical Investigation
Spire Pipeline
St. Louis, Missouri

SCALE: As noted

SOURCE:

DRAWING NO.: **Figure 5**
Coldwater Creek
Gravity Profile 3

PREPARED FOR: M M MOTT MACDONALD

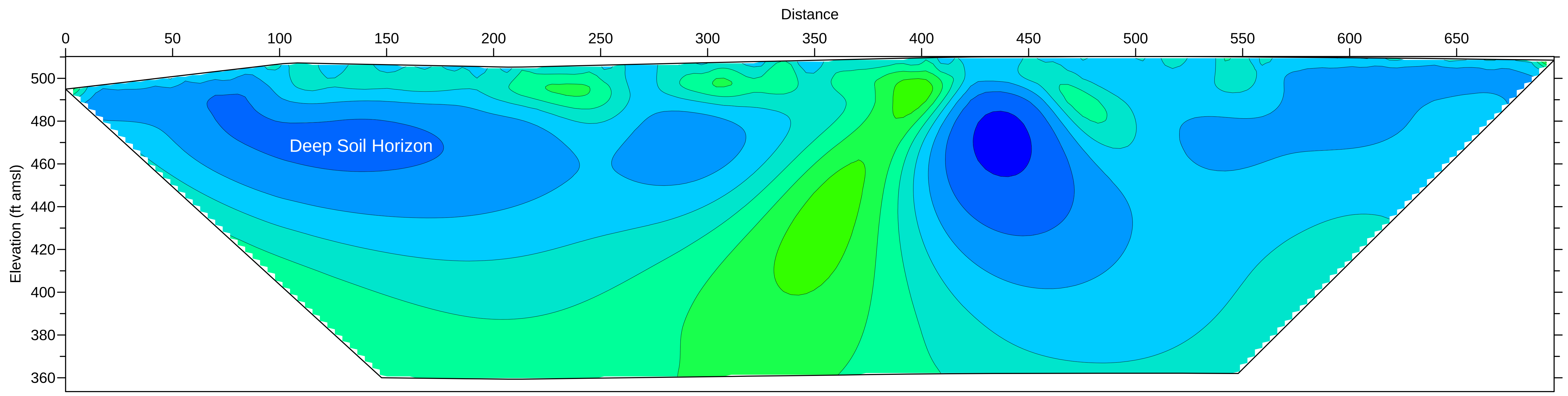
PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F5

N

SPANISH LAKE EI PROFILE 1

S



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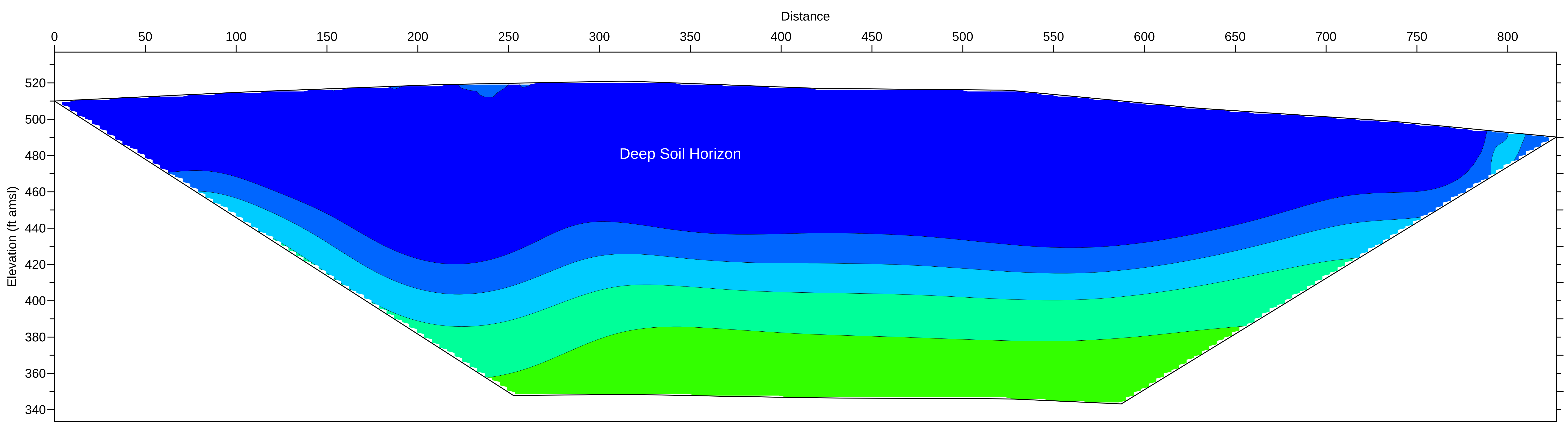
SPANISH LAKE EI PROFILE 2

S



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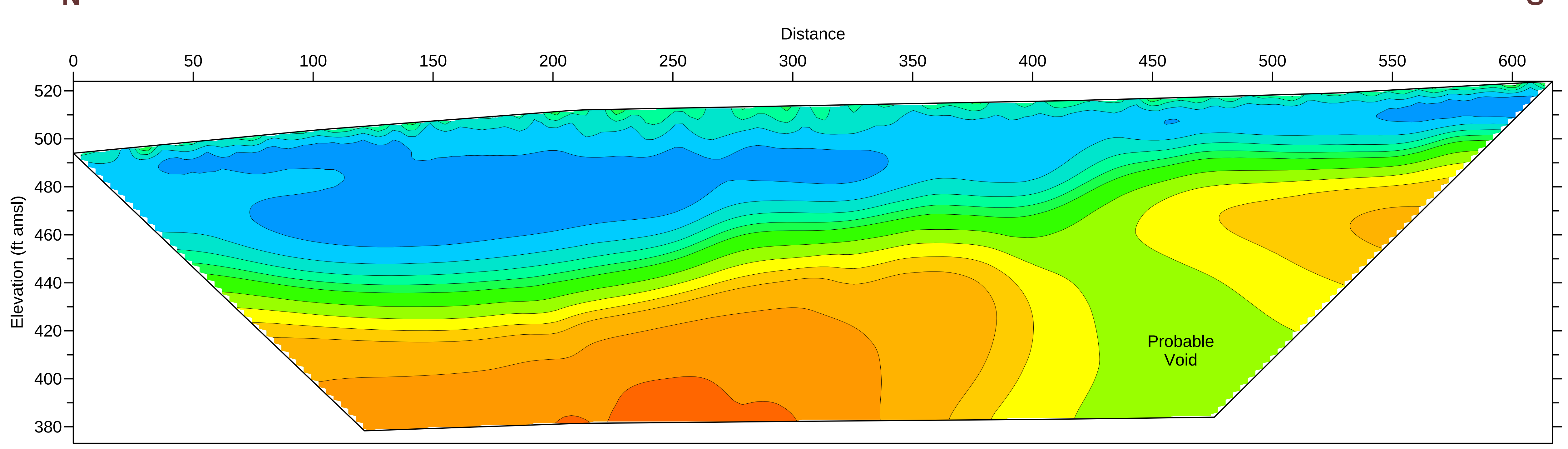
SPANISH LAKE EI PROFILE 3

S



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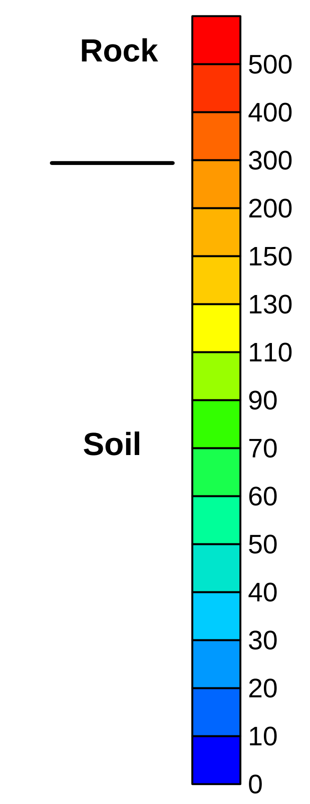

Notes

Geophysical survey conducted May 15-16, 2017 using GF Instruments ARES continuous vertical electrical sounder with 4-m spacing.

Real-time positioning of data using fully integrated Trimble ProXRS global positioning system set to NAD 1983 Missouri State Plane coordinate system in feet.

No vertical exaggeration
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Horizontal 1" = 50'

Locations are approximate.

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DRN	PJH	5/18/17
DES	PJH	5/18/17
CHK	PJH	7/21/17
REV		
PROJ. MGR.	PJH	7/21/17

PROJECT:
Geophysical Investigation
Spire Pipeline
St. Louis, Missouri

SCALE: As noted

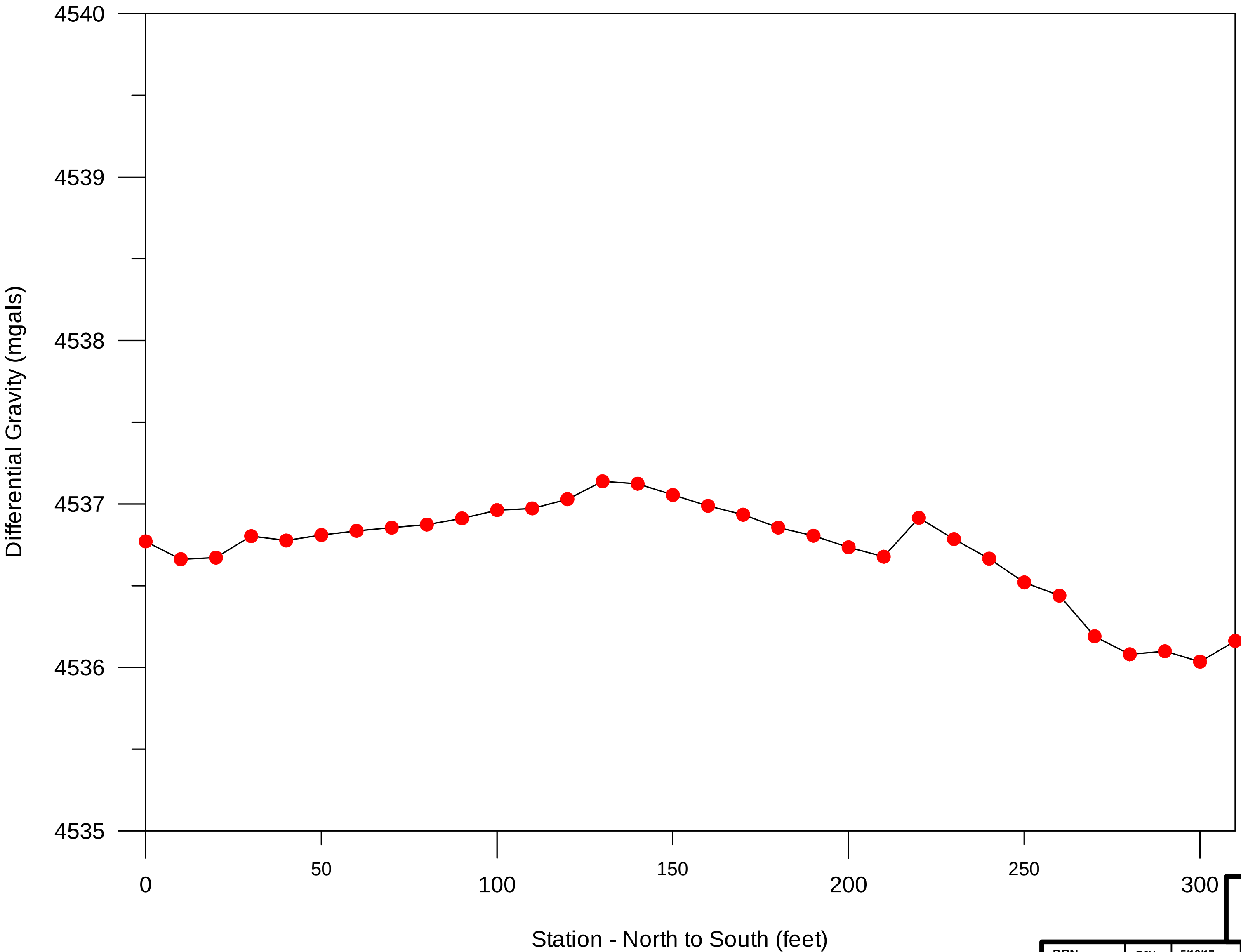
SOURCE:

DRAWING NO.:
Figure 6
Spanish Lake EI Profiles

PREPARED FOR:
MOTT MACDONALD

PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F6



DRN	PJH	5/18/17
DES	PJH	5/18/17
CHK	PJH	5/18/17
REV		
PROJ. MGR.	PJH	5/18/17

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PROJECT: Geophysical Investigation
Spire Pipeline
St. Louis, Missouri

SCALE: As noted

SOURCE:

DRAWING NO.: **Figure 7**
Spanish Lake
Gravity Profile 1

PREPARED FOR: M M MOTT MACDONALD

PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F7

E. Laboratory Testing Results

Point Load Testing - Lab Worksheet
For Axial Tests

Project	Spire Pipeline		Tested By / Date:	JAS	4/6/17
Location	St. Louis, Missouri		Calculated By / Date:	CMB	4/6/17
Job No.	41-1-37762-003		Checked By / Date:	CMB	4/6/17
File	41-1-37762-003 D5731		Procedure	ASTM D5731	

Boring Number	Run Number	Depth (feet)	Test Type	Width, W, in.	Penetration Data, mm		Failure Load, psi	Picture Number
					Starting	Ending		
B-STL-09	R-7	91.0 - 91.5	a ⊥	1.863	24	23	400	7079
B-STL-09	R-9	102.2 - 102.7	a ⊥	1.863	24	21	1230	7080
B-STL-09	R-11	114.1 - 114.6	a ⊥	1.855	24	22	600	7081
B-STL-09	R-13	120.0 - 120.5	a ⊥	1.850	24	22	300	7082
B-STL-09	R-16	139.2 - 139.7	a ⊥	1.866	24	20	1000	7083
B-STL-10	R-7	91.3 - 91.7	a ⊥	1.863	24	22	1000	7084
B-STL-10	R-10	106.8 - 107.3	a ⊥	1.862	24	22	1120	7085
B-STL-10	R-12	118.5 - 119.0	a ⊥	1.863	24	21	1200	7086
B-STL-10	R-14	128.15 - 128.65	a ⊥	1.867	24	21	510	7087
B-STL-10	R-17	140.5 - 141.0	a ⊥	1.870	24	21	800	7088

a = axial
⊥ = perdendicular to rock core

Point Load Test Results Summary - SI Units
For Axial Tests

Project	Spire Pipeline
Location	St. Louis, Missouri
Job No.	41-1-37762-003
File	41-1-37762-003 D5731

Tested By / Date:	JAS	4/6/17
Calculated By / Date:	CMB	4/6/17
Checked By / Date:	CMB	4/6/17
Procedure	ASTM D5731	

Boring Number	Run Number	Depth (feet)	Test Type	Penetration Data, mm Starting	Ending	Total	Corrected D', mm	Width, mm	D_e^2, mm^2	Load (P), kN	I_s, MPa	F	$I_{s(50)}$, MPa	S_c, MPa*
B-STL-09	R-7	91.0 - 91.5	a ⊥	24	23	1	23	47	1386	3.98	2.87	0.88	2.51	52
B-STL-09	R-9	102.2 - 102.7	a ⊥	24	21	3	21	47	1265	12.23	9.67	0.86	8.30	170
B-STL-09	R-11	114.1 - 114.6	a ⊥	24	22	2	22	47	1320	5.97	4.52	0.87	3.92	80
B-STL-09	R-13	120.0 - 120.5	a ⊥	24	22	2	22	47	1316	2.98	2.27	0.87	1.96	40
B-STL-09	R-16	139.2 - 139.7	a ⊥	24	20	4	20	47	1207	9.95	8.24	0.85	7.00	144
B-STL-10	R-7	91.3 - 91.7	a ⊥	24	22	2	22	47	1325	9.95	7.50	0.87	6.51	134
B-STL-10	R-10	106.8 - 107.3	a ⊥	24	22	2	22	47	1325	11.14	8.41	0.87	7.29	150
B-STL-10	R-12	118.5 - 119.0	a ⊥	24	21	3	21	47	1265	11.9	9.4	0.86	8.1	166
B-STL-10	R-14	128.15 - 128.6	a ⊥	24	21	3	21	47	1268	5.1	4.0	0.86	3.4	70
B-STL-10	R-17	140.5 - 141.0	a ⊥	24	21	3	21	47	1270	8.0	6.3	0.86	5.4	110

a = axial

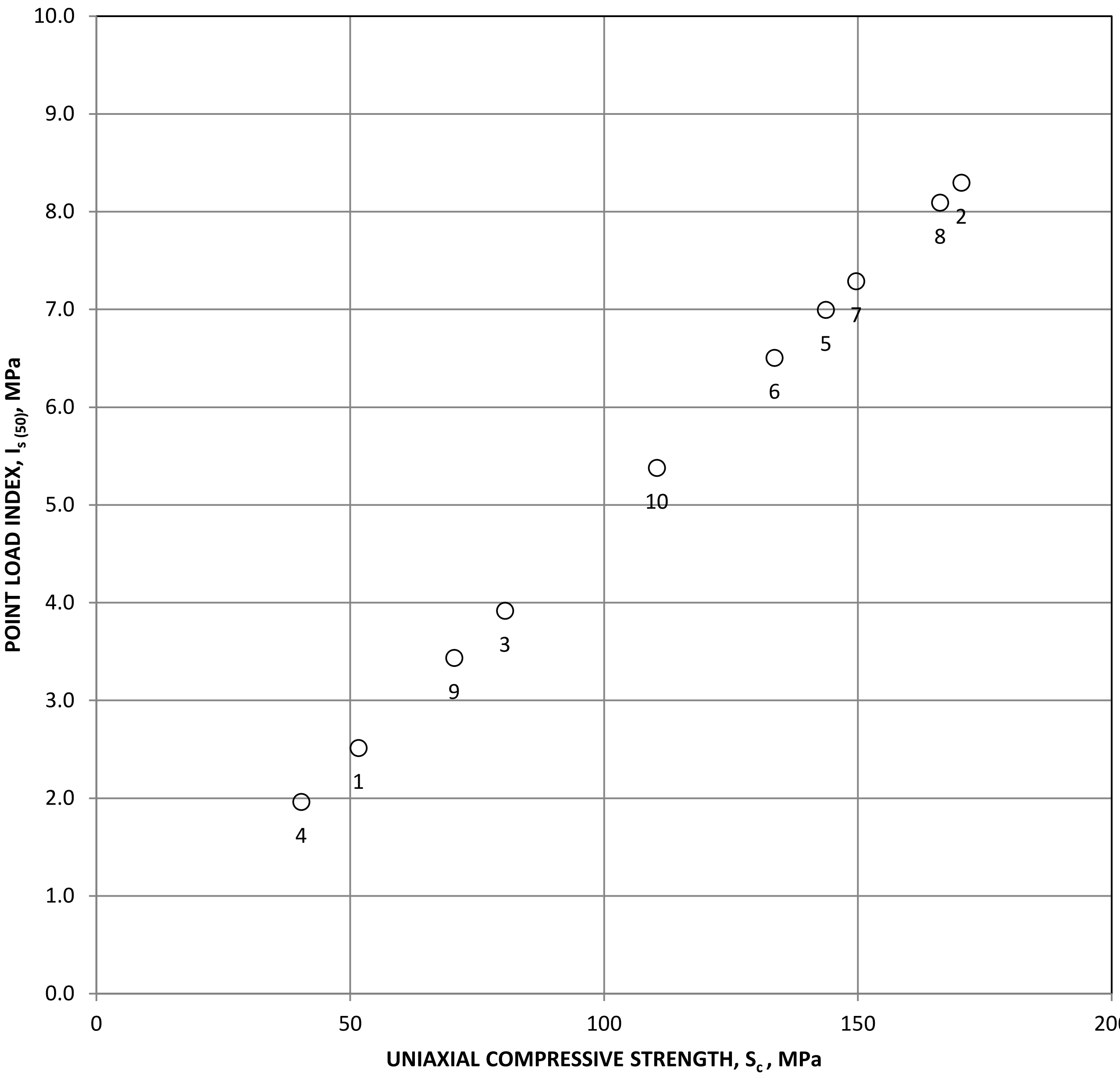
⊥ = perdendicular to rock core

* = Uniaxial Compressive Strength calculated using an extrapolated K value from TABLE 1 in test method.

Moisture Content Of Samples At Testing = Laboratory Air Dry

Statistics	
Mean $I_{s(50)\,//}$	5.44
$Ia_{(50)}$	4.23

Point Load Index vs. Uniaxial Strength



Test	Run	S_c, MPa	$I_{s(50)}$, MPa	Test	Run	S_c, MPa	$I_{s(50)}$, MPa
1	R-7	52	2.51	10	R-17	110	5.38
2	R-9	170	8.30				
3	R-11	80	3.92				
4	R-13	40	1.96				
5	R-16	144	7.00				
6	R-7	134	6.51				
7	R-10	150	7.29				
8	R-12	166	8.09				
9	R-14	70	3.43				

Spire Pipeline
St. Louis, Missouri

Point Load Test Results
Borings B-STL-09,10

April 2017 41-1-37762-003

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG.

Point Load Test Results Summary - US Units
For Axial, Block and Lump Tests

Project	Spire Pipeline
Location	St. Louis, Missouri
Job No.	41-1-37762-003
File	41-1-37762-003 D5731

Tested By / Date:	JAS	4/6/17
Calculated By / Date:	CMB	4/6/17
Checked By / Date:	CMB	4/6/17
Procedure	ASTM D5731	

Boring Number	Run Number	Depth (feet)	Test Type	Penetration Data, in: Starting	Penetration Data, in: Ending	Penetration Data, in: Total	Corrected D', in	Width, in	D_e^2, in^2	Load (P), lbs	I_s, psi	$I_{s(50)}$, psi	S_c, psi*
B-STL-09	R-7	91.0 - 91.5	a ⊥	0.94	0.91	0.04	0.91	1.86	2.15	894	416	365	7488
B-STL-09	R-9	102.2 - 102.7	a ⊥	0.94	0.83	0.12	0.83	1.86	1.96	2750	1402	1203	24711
B-STL-09	R-11	114.1 - 114.6	a ⊥	0.94	0.87	0.08	0.87	1.86	2.05	1342	656	568	11675
B-STL-09	R-13	120.0 - 120.5	a ⊥	0.94	0.87	0.08	0.87	1.85	2.04	671	329	285	5853
B-STL-09	R-16	139.2 - 139.7	a ⊥	0.94	0.79	0.16	0.79	1.87	1.87	2236	1195	1015	20845
B-STL-10	R-7	91.3 - 91.7	a ⊥	0.94	0.87	0.08	0.87	1.86	2.05	2236	1088	944	19374
B-STL-10	R-10	106.8 - 107.3	a ⊥	0.94	0.87	0.08	0.87	1.86	2.05	2504	1220	1057	21710
B-STL-10	R-12	118.5 - 119.0	a ⊥	0.94	0.83	0.12	0.83	1.86	1.96	2683	1368	1174	24108
B-STL-10	R-14	128.15 - 128.65	a ⊥	0.94	0.83	0.12	0.83	1.87	1.97	1140	580	498	10224
B-STL-10	R-17	140.5 - 141.0	a ⊥	0.94	0.83	0.12	0.83	1.87	1.97	1789	909	780	16012

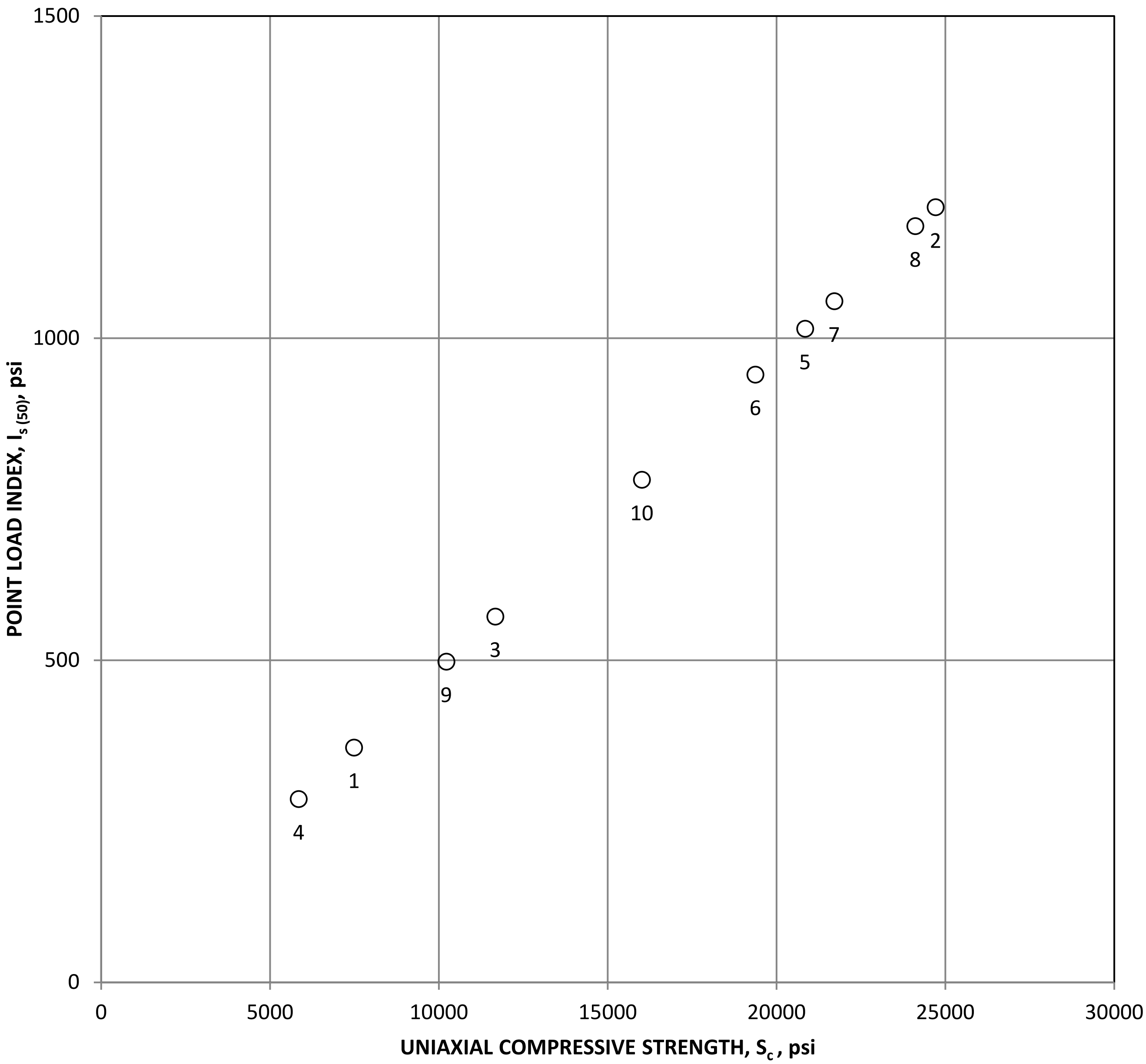
a = axial

⊥ = perdendicular to rock core

Moisture Content During Testing = Laboratory Air Dry

Statistics	
Mean $I_{s(2)\,//}$	789
$I_{a(2)}$	4

Point Load Index vs. Uniaxial Strength



Test	Run	S_c, psi	$I_{s(50)}$, psi	Test	Run	S_c, psi	$I_{s(50)}$, psi
1	R-7	7488	365	10	R-17	16012	780
2	R-9	24711	1203				
3	R-11	11675	568				
4	R-13	5853	285				
5	R-16	20845	1015				
6	R-7	19374	944				
7	R-10	21710	1057				
8	R-12	24108	1174				
9	R-14	10224	498				

Spire Pipeline
St. Louis, Missouri

Point Load Test Results
Borings B-STL-09,10

April 2017 41-1-37762-003

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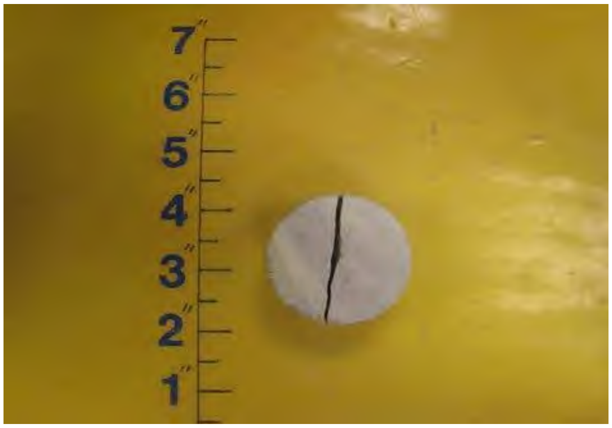
FIG.

Point Load Test Photographs

Project Spire Pipeline
Location St. Louis, Missouri
Job No. 41-1-37762-003



Boring Number B-STL-09
Run Number R-7
Depth (ft.) 91.0 - 91.5

Boring Number B-STL-09
Run Number R-9
Depth (ft.) 102.2 - 102.7

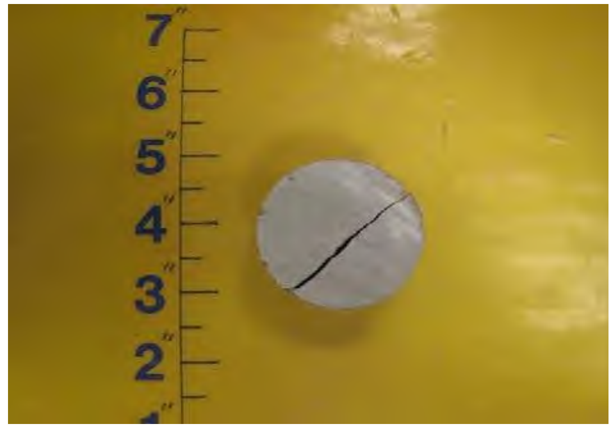
Boring Number B-STL-09
Run Number R-11
Depth (ft.) 114.1 - 114.6

Boring Number B-STL-09
Run Number R-13
Depth (ft.) 120.0 - 120.5

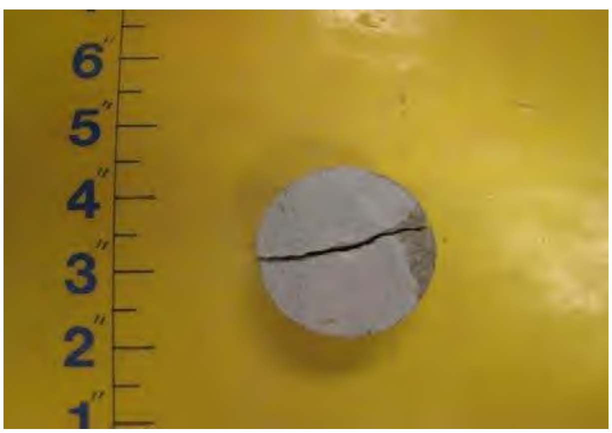
Point Load Test Photographs

Project Spire Pipeline
Location St. Louis, Missouri
Job No. 41-1-37762-003

Boring Number B-STL-09
Run Number R-16
Depth (ft.) 139.2 - 139.7



Boring Number B-STL-10
Run Number R-7
Depth (ft.) 91.3 - 91.7



Boring Number B-STL-10
Run Number R-10
Depth (ft.) 106.8 - 107.3

Boring Number B-STL-10
Run Number R-12
Depth (ft.) 118.5 - 119.0

Point Load Test Photographs

Project	Spire Pipeline
Location	St. Louis, Missouri
Job No.	41-1-37762-003

Boring Number	B-STL-10
Run Number	R-14
Depth (ft.)	128.15 - 128.65

Boring Number	B-STL-10
Run Number	R-17
Depth (ft.)	140.5 - 141.0

Point Load Testing - Lab Worksheet
For Axial Tests

Project	Spire Pipeline		Tested By / Date:	JAS	4/14/17
Location	St. Louis, Missouri		Calculated By / Date:	CMB	4/14/17
Job No.	41-1-37762-003		Checked By / Date:	CMB	4/14/17
File	41-1-37762-003 D5731		Procedure	ASTM D5731	

Boring Number	Run Number	Depth (feet)	Test Type	Width, W, in.	Penetration Data, mm		Failure Load, psi	Picture Number
					Starting	Ending		
B-STL-09	R-2	68.0 - 68.5	a ⊥	1.860	24	22	1000	7093
B-STL-11	R-1	73.1 - 73.6	a ⊥	1.862	24	22	1180	7094
B-STL-11	R-4	86.65 - 87.15	a ⊥	1.860	24	23	1000	7095
B-STL-11	R-5	92.45 - 92.95	a ⊥	1.861	24	22	1320	7096
B-STL-11	R-7	102.3 - 102.8	a ⊥	1.860	24	22	1250	7097
B-STL-11	R-10	118.4 - 118.9	a ⊥	1.860	24	22	1200	7098

a = axial
⊥ = perdendicular to rock core

Point Load Test Results Summary - SI Units
For Axial Tests

Project	Spire Pipeline
Location	St. Louis, Missouri
Job No.	41-1-37762-003
File	41-1-37762-003 D5731

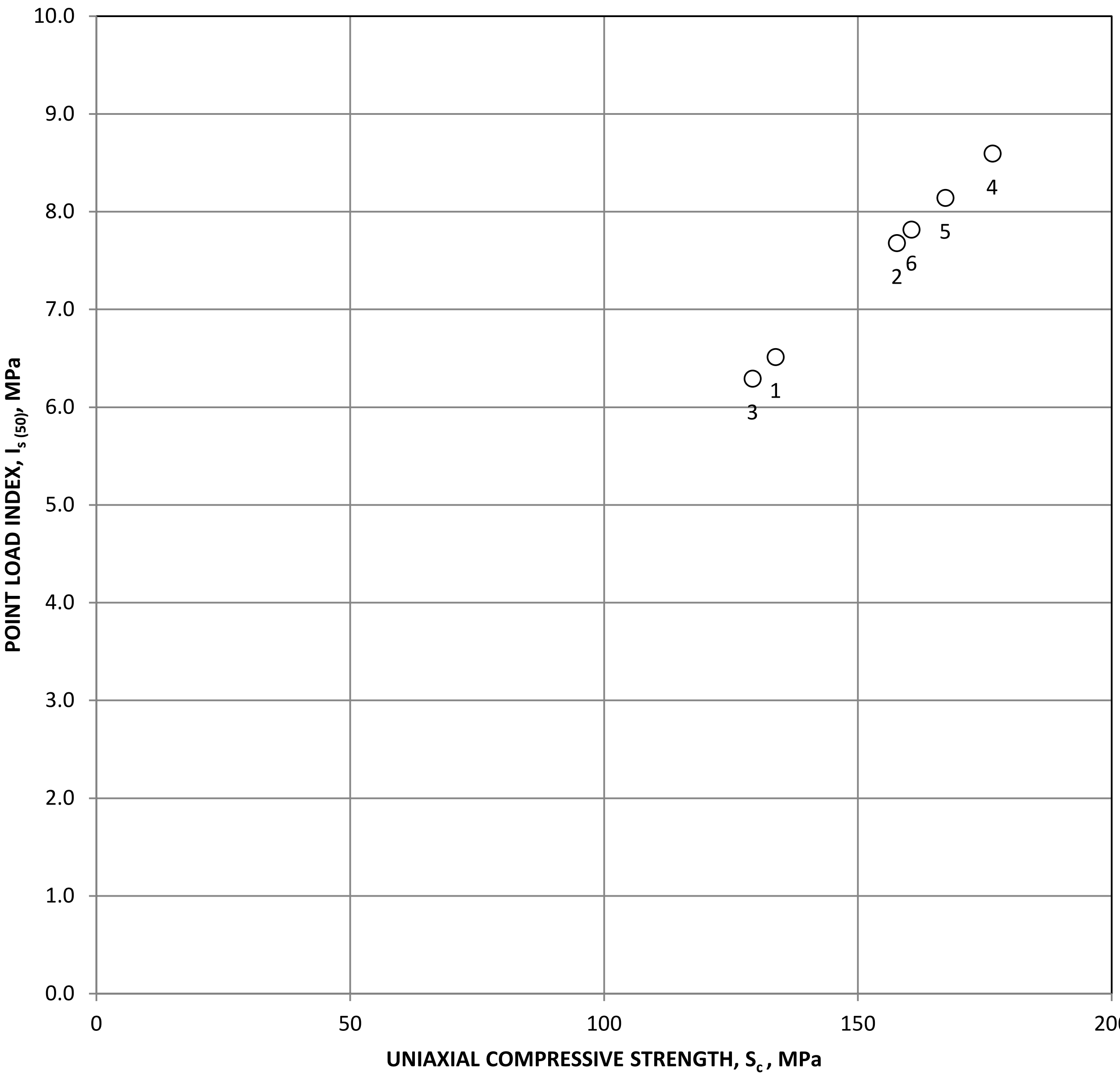
Tested By / Date:	JAS	4/14/17
Calculated By / Date:	CMB	4/14/17
Checked By / Date:	CMB	4/14/17
Procedure	ASTM D5731	

Boring Number	Run Number	Depth (feet)	Test Type	Penetration Data, mm Starting	Penetration Data, mm Ending	Penetration Data, mm Total	Corrected D', mm	Width, mm	D_e^2, mm^2	Load (P), kN	I_s, MPa	F	$I_{s(50)}$, MPa	S_c, MPa*
B-STL-09	R-2	68.0 - 68.5	a ⊥	24	22	2	22	47	1323	9.95	7.52	0.87	6.51	134
B-STL-11	R-1	73.1 - 73.6	a ⊥	24	22	2	22	47	1325	11.74	8.86	0.87	7.68	158
B-STL-11	R-4	86.65 - 87.15	a ⊥	24	23	1	23	47	1384	9.95	7.19	0.88	6.29	129
B-STL-11	R-5	92.45 - 92.95	a ⊥	24	22	2	22	47	1324	13.13	9.92	0.87	8.59	177
B-STL-11	R-7	102.3 - 102.8	a ⊥	24	22	2	22	47	1323	12.43	9.39	0.87	8.14	167
B-STL-11	R-10	118.4 - 118.9	a ⊥	24	22	2	22	47	1323	11.94	9.02	0.87	7.82	161

a = axial
⊥ = perdendicular to rock core
* = Uniaxial Compressive Strength calculated using an extrapolated K value from TABLE 1 in test method.
Moisture Content Of Samples At Testing = Laboratory Air Dry

Statistics	
Mean $I_{s(50)\ //}$	7.51
$Ia_{(50)}$	1.37

Point Load Index vs. Uniaxial Strength



Test	Run	S_c, MPa	$I_{s(50)}$, MPa	Test	Run	S_c, MPa	$I_{s(50)}$, MPa
1	R-2	134	6.51				
2	R-1	158	7.68				
3	R-4	129	6.29				
4	R-5	177	8.59				
5	R-7	167	8.14				
6	R-10	161	7.82				

Spire Pipeline
St. Louis, Missouri

Point Load Test Results
Borings B-STL-09,11

April 2017 41-1-37762-003

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG.

Point Load Test Results Summary - US Units
For Axial, Block and Lump Tests

Project	Spire Pipeline
Location	St. Louis, Missouri
Job No.	41-1-37762-003
File	41-1-37762-003 D5731

Tested By / Date:	JAS	4/14/17
Calculated By / Date:	CMB	4/14/17
Checked By / Date:	CMB	4/14/17
Procedure	ASTM D5731	

Boring Number	Run Number	Depth (feet)	Test Type	Penetration Data, in: Starting	Penetration Data, in: Ending	Penetration Data, in: Total	Corrected D', in	Width, in	D_e^2, in^2	Load (P), lbs	I_s, psi	$I_{s(50)}$, psi	S_c, psi*
B-STL-09	R-2	68.0 - 68.5	a ⊥	0.94	0.87	0.08	0.87	1.86	2.05	2236	1090	945	19405
B-STL-11	R-1	73.1 - 73.6	a ⊥	0.94	0.87	0.08	0.87	1.86	2.05	2638	1285	1114	22874
B-STL-11	R-4	86.65 - 87.15	a ⊥	0.94	0.91	0.04	0.91	1.86	2.14	2236	1043	913	18750
B-STL-11	R-5	92.45 - 92.95	a ⊥	0.94	0.87	0.08	0.87	1.86	2.05	2952	1438	1247	25601
B-STL-11	R-7	102.3 - 102.8	a ⊥	0.94	0.87	0.08	0.87	1.86	2.05	2795	1363	1181	24257
B-STL-11	R-10	118.4 - 118.9	a ⊥	0.94	0.87	0.08	0.87	1.86	2.05	2683	1308	1134	23286

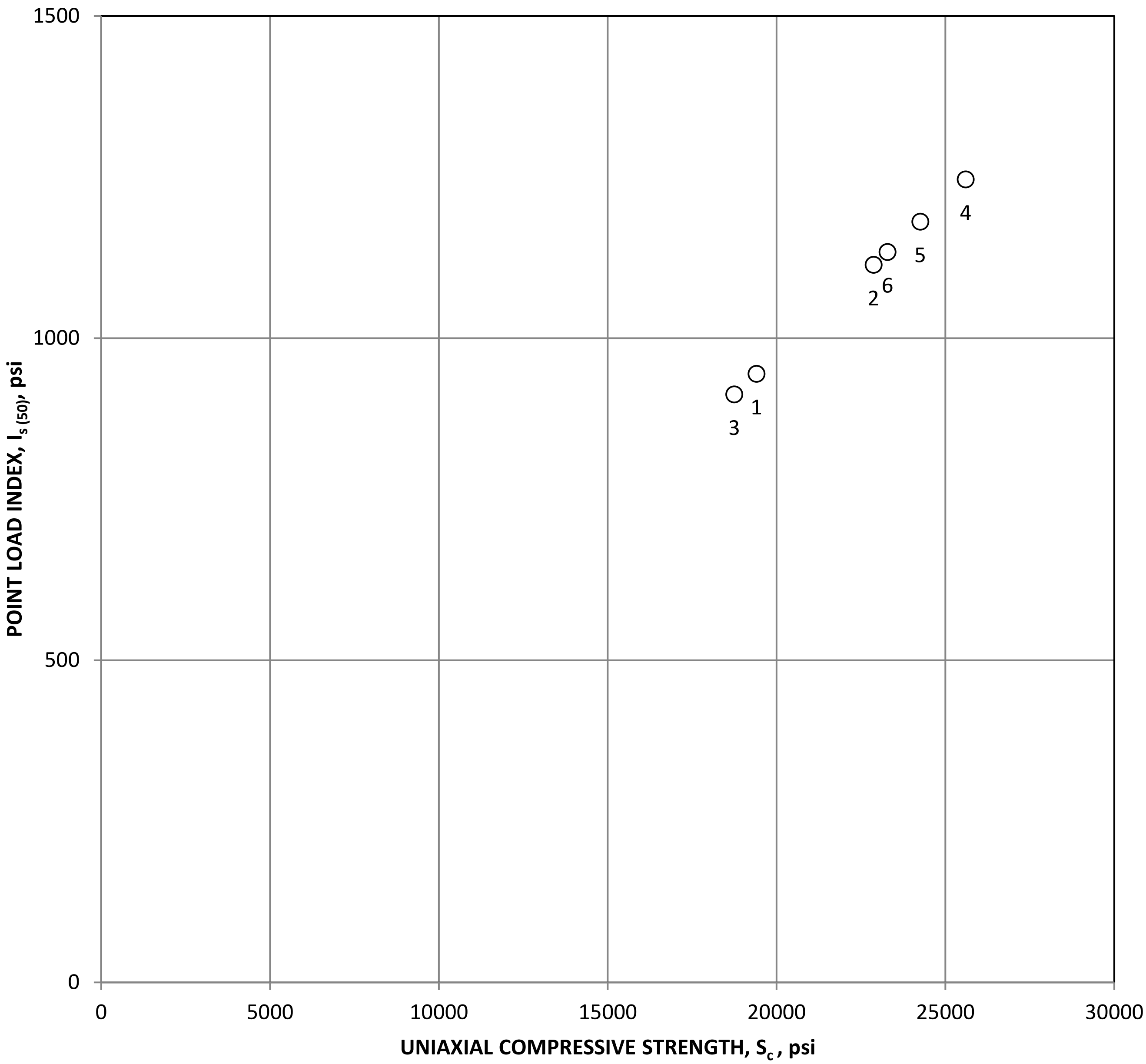
a = axial

⊥ = perdendicular to rock core

Moisture Content During Testing = Laboratory Air Dry

Statistics	
Mean $I_{s(2)\,//}$	1089
$I_{a(2)}$	1

Point Load Index vs. Uniaxial Strength



Test	Run	S_c, psi	$I_{s(50)}$, psi	Test	Run	S_c, psi	$I_{s(50)}$, psi
1	R-2	19405	945				
2	R-1	22874	1114				
3	R-4	18750	913				
4	R-5	25601	1247				
5	R-7	24257	1181				
6	R-10	23286	1134				

Spire Pipeline
St. Louis, Missouri

Point Load Test Results
Borings B-STL-09,11

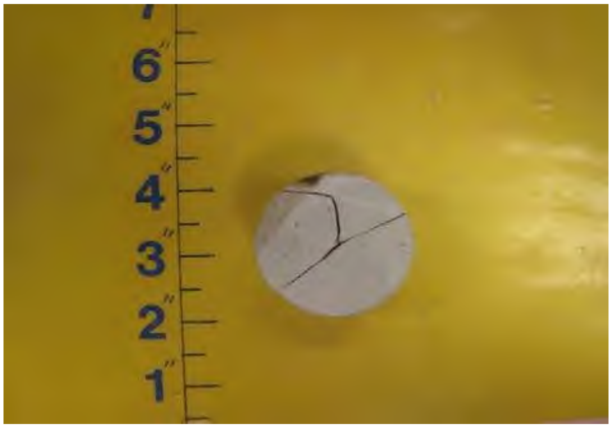
April 2017 41-1-37762-003

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

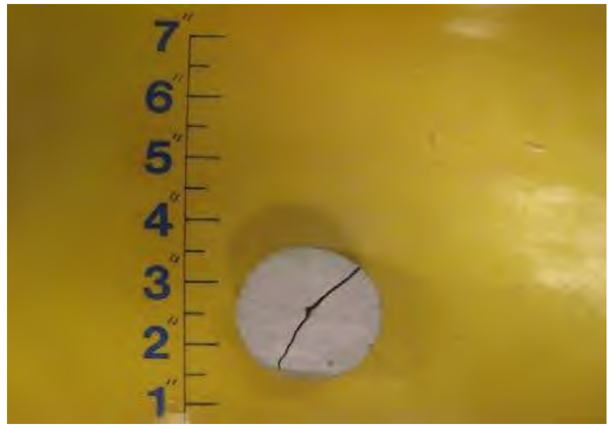
FIG.

Point Load Test Photographs

Project Spire Pipeline
Location St. Louis, Missouri
Job No. 41-1-37762-003

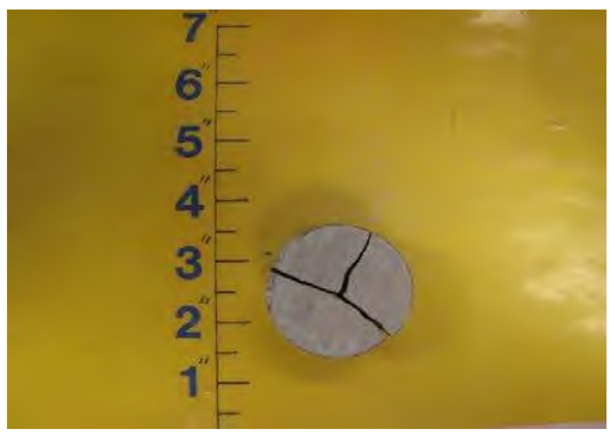


Boring Number B-STL-09
Run Number R-2
Depth (ft.) 68.0 - 68.5



Boring Number B-STL-11
Run Number R-1
Depth (ft.) 73.1 - 73.6

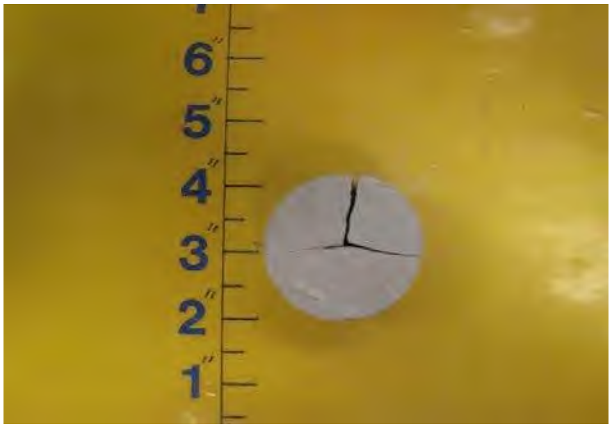
Boring Number B-STL-11
Run Number R-4
Depth (ft.) 86.65 - 87.15



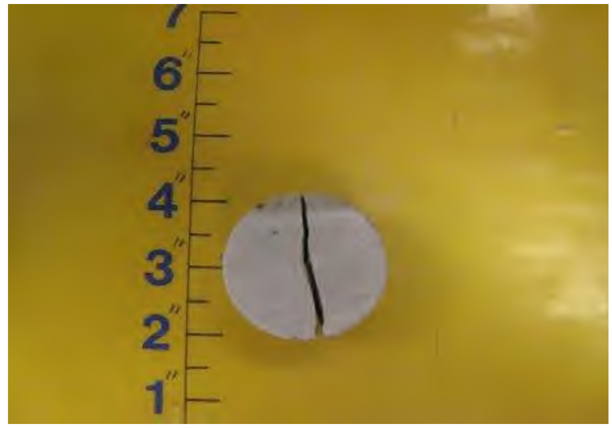
Boring Number B-STL-11
Run Number R-5
Depth (ft.) 92.45 - 92.95

Point Load Test Photographs

Project Spire Pipeline
Location St. Louis, Missouri
Job No. 41-1-37762-003



Boring Number B-STL-11
Run Number R-7
Depth (ft.) 102.3 - 102.8

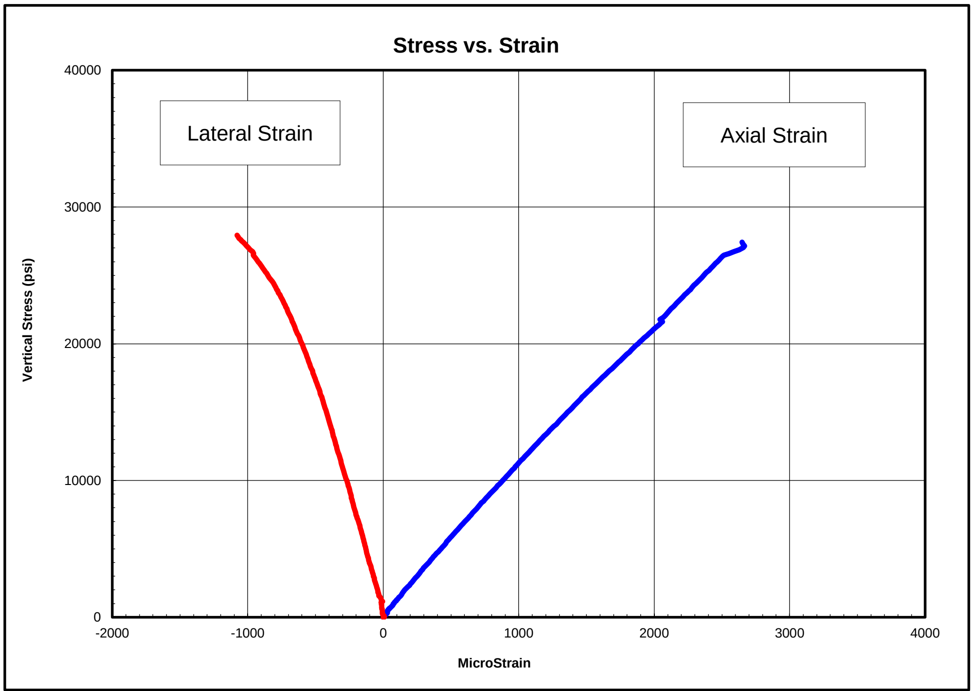


Boring Number B-STL-11
Run Number R-10
Depth (ft.) 118.4 - 118.9

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-2
Depth, ft:	69.10-69.45
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 27,967 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
2800-10200	11,100,000	0.31
10200-17700	10,200,000	0.31
17700-25100	10,100,000	0.46

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

GeoTesting EXPRESS

Client:	TSI Geotechnical	Test Date:	4/13/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-09		
Sample ID:	R-2		
Depth:	69.10-69.45 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average
Specimen Length, in:	3.97	3.97	3.97
Specimen Diameter, in:	1.86	1.86	1.86
Specimen Mass, g:	468.43		
Bulk Density, lb/ft^3	165	**Minimum Diameter Tolerence Met?**	**NO**
Length to Diameter Ratio:	2.1	**Length to Diameter Ratio Tolerance Met?**	**YES**

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap ≤ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00010	-0.00010	-0.00010	0.00030	0.00030	0.00030	0.00010	0.00000	0.00000	0.00000	-0.00010	0.00000	0.00030	0.00030	0.00010
Diameter 2, in (rotated 90°)	0.00030	0.00030	0.00030	0.00030	0.00030	0.00020	0.00000	0.00000	0.00000	0.00000	0.00010	0.00020	0.00030	0.00030	0.00030

Difference between max and min readings, in:

0° = 0.00040 90° = 0.00030

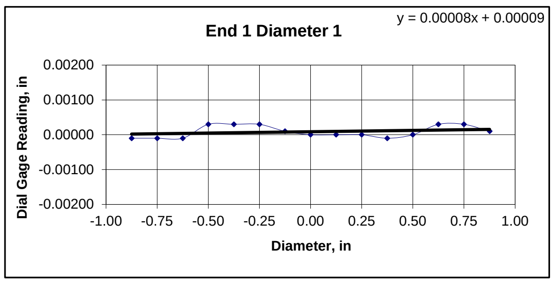
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00000	0.00000	0.00010	0.00020	0.00020	0.00030	0.00020	0.00000	0.00000	0.00000	0.00010	0.00020	0.00030	0.00030	0.00040
Diameter 2, in (rotated 90°)	0.00010	0.00010	0.00020	0.00030	0.00030	0.00030	0.00020	0.00000	0.00000	0.00000	0.00000	0.00010	0.00010	0.00020	0.00020

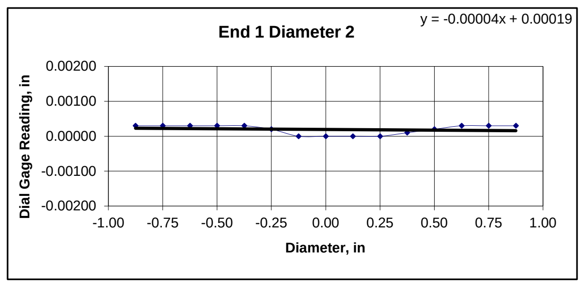
Difference between max and min readings, in:

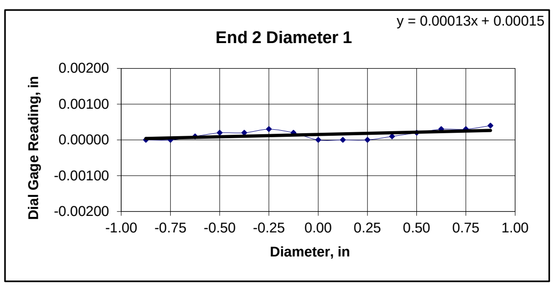
0° = 0.0004 90° = 0.0003

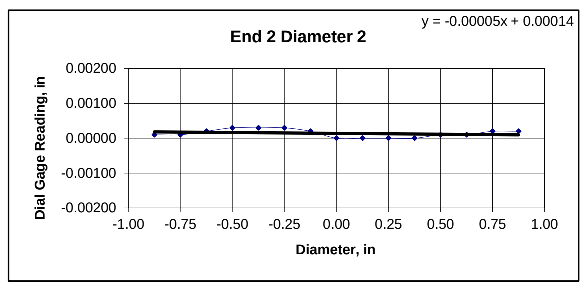
Maximum difference must be < 0.0020 in. Difference = ± 0.00020

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:	Slope of Best Fit Line	0.00008
	Angle of Best Fit Line:	0.00458
End 2:	Slope of Best Fit Line	0.00013
	Angle of Best Fit Line:	0.00745
Maximum Angular Difference:		0.00286

Parallelism Tolerance Met? **YES**
Spherically Seated

DIAMETER 2

End 1:	Slope of Best Fit Line	-0.00004
	Angle of Best Fit Line:	-0.00229
End 2:	Slope of Best Fit Line	-0.00005
	Angle of Best Fit Line:	-0.00286
Maximum Angular Difference:		0.00057

Parallelism Tolerance Met? **YES**
Spherically Seated

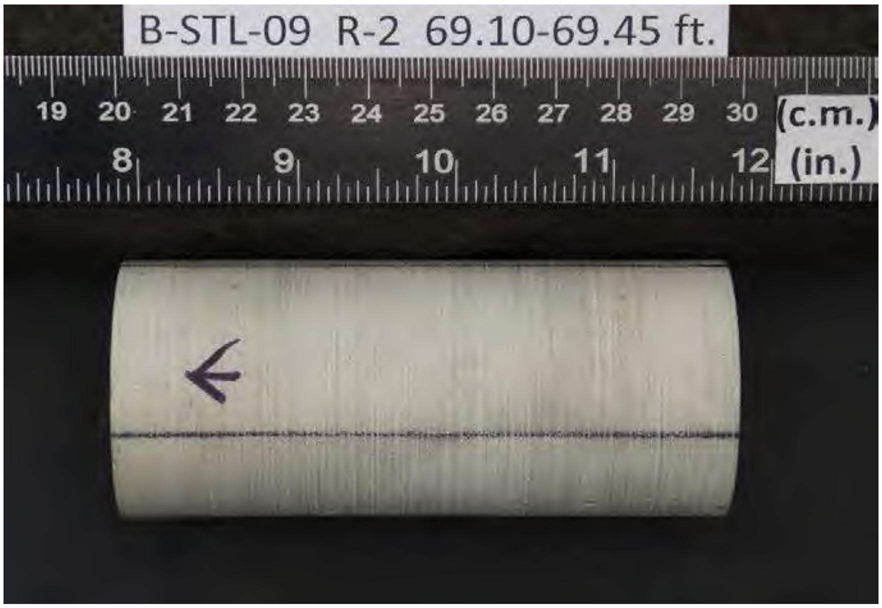
PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00040	1.860	0.00022	0.012	YES
Diameter 2, in (rotated 90°)	0.00030	1.860	0.00016	0.009	YES
END 2					
Diameter 1, in	0.00040	1.860	0.00022	0.012	YES
Diameter 2, in (rotated 90°)	0.00030	1.860	0.00016	0.009	YES

Maximum angle of departure must be ≤ 0.25°

Perpendicularity Tolerance Met? **YES**

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-2
Depth, ft:	69.10-69.45

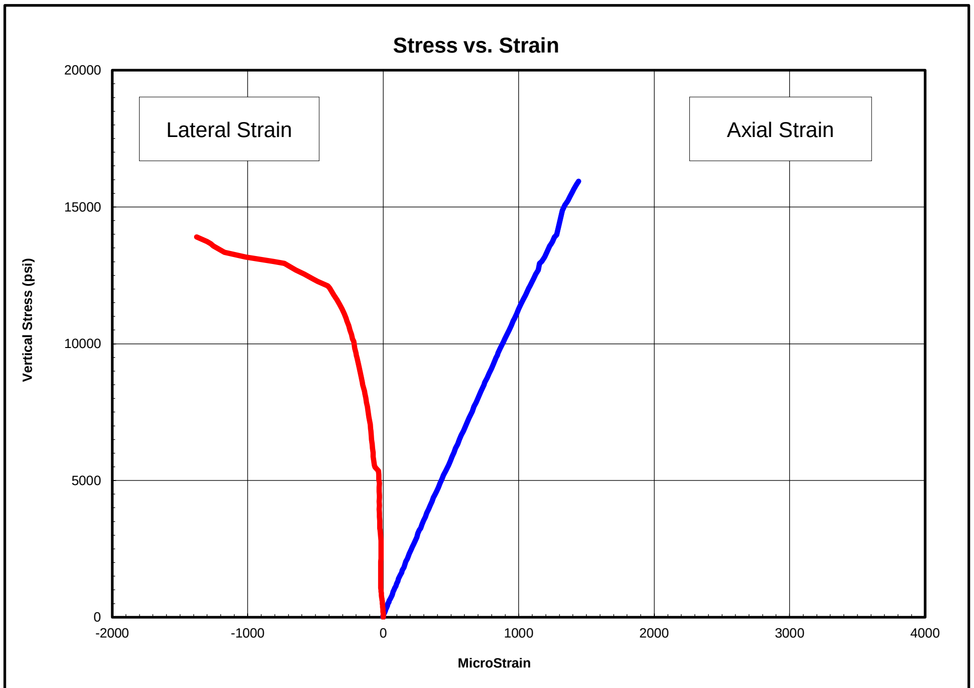


After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-7
Depth, ft:	90.57-90.92
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 15,939 psi

The graph above does not include values up to the peak stress value. The lateral strain gauges failed before the peak value was attained.

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
1600-5800	11,300,000	0.15
5800-10100	11,100,000	0.40
10100-14300	9,900,000	---

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-09		
Sample ID:	R-7		
Depth:	90.57-90.92 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average		
Specimen Length, in:	4.03	4.03	4.03		
Specimen Diameter, in:	1.87	1.87	1.87		
Specimen Mass, g:	472.12				
Bulk Density, lb/ft^3	162			**Minimum Diameter Tolerence Met?**	**NO**
Length to Diameter Ratio:	2.2			**Length to Diameter Ratio Tolerance Met?**	**YES**

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap ≤ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00020	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Diameter 2, in (rotated 90^o)	0.00000	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010

Difference between max and min readings, in:

0° = 0.00020 90° = 0.00010

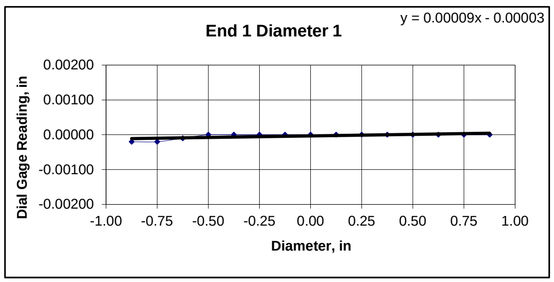
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00010	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020	-0.00030	-0.00030	-0.00030
Diameter 2, in (rotated 90^o)	-0.00010	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

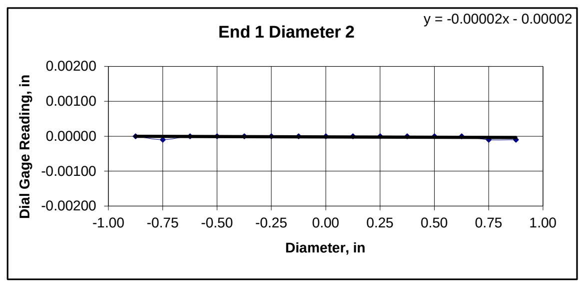
Difference between max and min readings, in:

0° = 0.0003 90° = 0.0002

Maximum difference must be < 0.0020 in. Difference = ± 0.00015

Flatness Tolerance Met? **YES**





DIAMETER 1

End 1:

Slope of Best Fit Line	0.00007
Angle of Best Fit Line:	0.00401

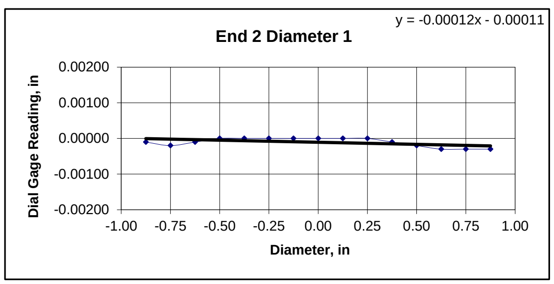
End 2:

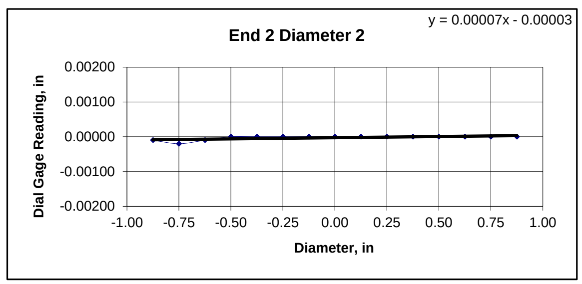
Slope of Best Fit Line	0.00007
Angle of Best Fit Line:	0.00401

Maximum Angular Difference: 0.00000

Parallelism Tolerance Met? **YES**

Spherically Seated





DIAMETER 2

End 1:

Slope of Best Fit Line	0.00002
Angle of Best Fit Line:	0.00115

End 2:

Slope of Best Fit Line	0.00001
Angle of Best Fit Line:	0.00057

Maximum Angular Difference: 0.00057

Parallelism Tolerance Met? **YES**

Spherically Seated

PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00020	1.870	0.00011	0.006	YES
Diameter 2, in (rotated 90^o)	0.00010	1.870	0.00005	0.003	YES
END 2					
Diameter 1, in	0.00030	1.870	0.00016	0.009	YES
Diameter 2, in (rotated 90^o)	0.00020	1.870	0.00011	0.006	YES

Maximum angle of departure must be ≤ 0.25°

Perpendicularity Tolerance Met? **YES**

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-7
Depth, ft:	90.57-90.92

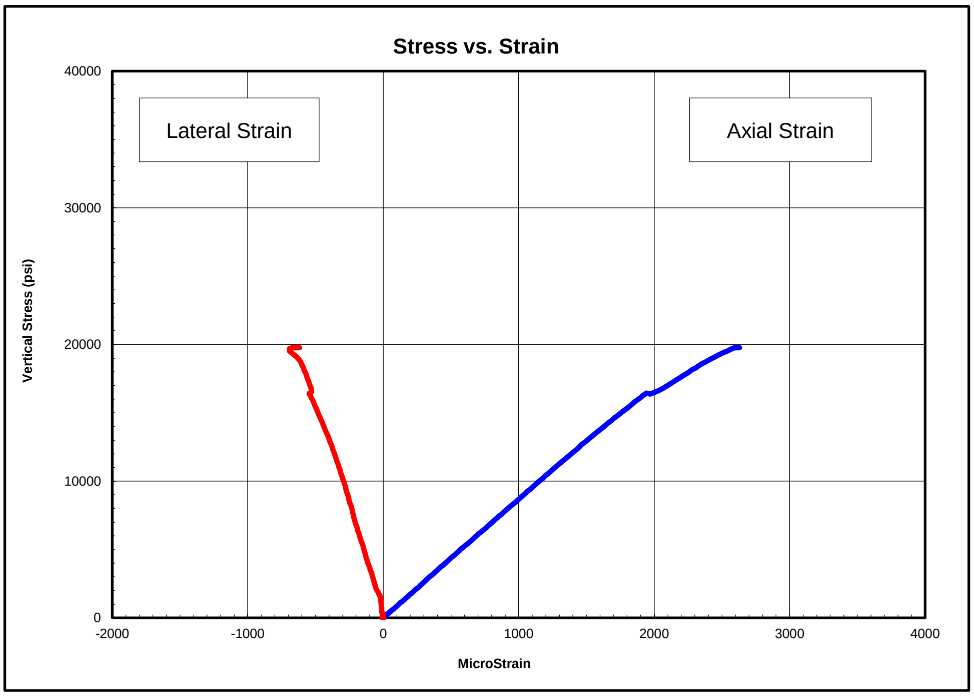
After cutting and grinding

After break

GeoTesting EXPRESS

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-9
Depth, ft:	102.73-103.02
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 19,821 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
2000-7200	8,700,000	0.28
7200-12500	8,580,000	0.27
12500-17800	6,700,000	0.25

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

GeoTesting EXPRESS

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-09		
Sample ID:	R-9		
Depth:	102.73-103.02 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average		
Specimen Length, in:	4.12	4.12	4.12		
Specimen Diameter, in:	1.86	1.86	1.86		
Specimen Mass, g:	497.51				
Bulk Density, lb/ft^3	169	**Minimum Diameter Tolerence Met?**		**NO**	
Length to Diameter Ratio:	2.2	**Length to Diameter Ratio Tolerance Met?**		**YES**	

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:
Is the maximum gap $\leq$ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00020	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00020
Diameter 2, in (rotated 90^o)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

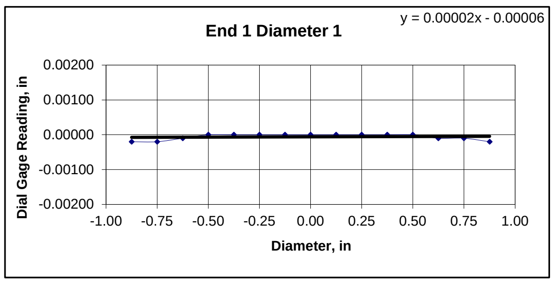
Difference between max and min readings, in:
0° = 0.00020 90° = 0.00000

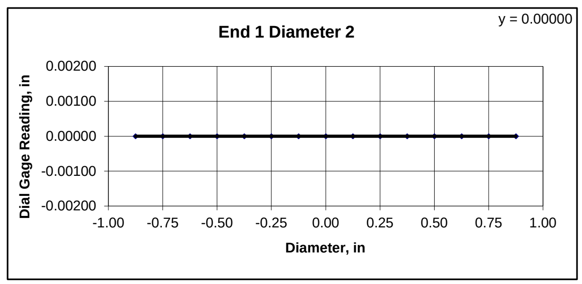
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00020	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00000	0.00000	0.00000
Diameter 2, in (rotated 90^o)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

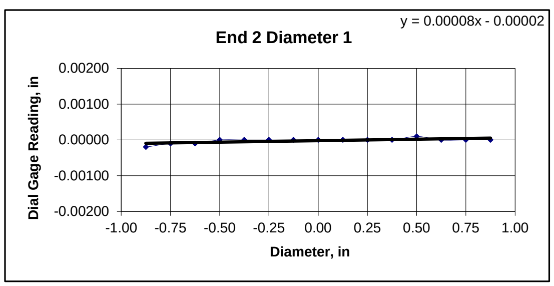
Difference between max and min readings, in:
0° = 0.0003 90° = 0

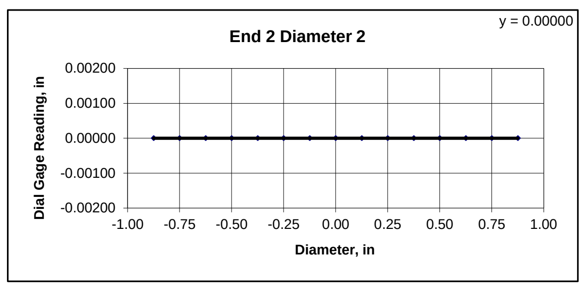
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00015

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:
Slope of Best Fit Line 0.00002
Angle of Best Fit Line: 0.00115

End 2:
Slope of Best Fit Line 0.00008
Angle of Best Fit Line: 0.00458

Maximum Angular Difference: 0.00344

Parallelism Tolerance Met? **YES**
Spherically Seated

DIAMETER 2

End 1:
Slope of Best Fit Line 0.00000
Angle of Best Fit Line: 0.00000

End 2:
Slope of Best Fit Line 0.00000
Angle of Best Fit Line: 0.00000

Maximum Angular Difference: 0.00000

Parallelism Tolerance Met? **YES**
Spherically Seated

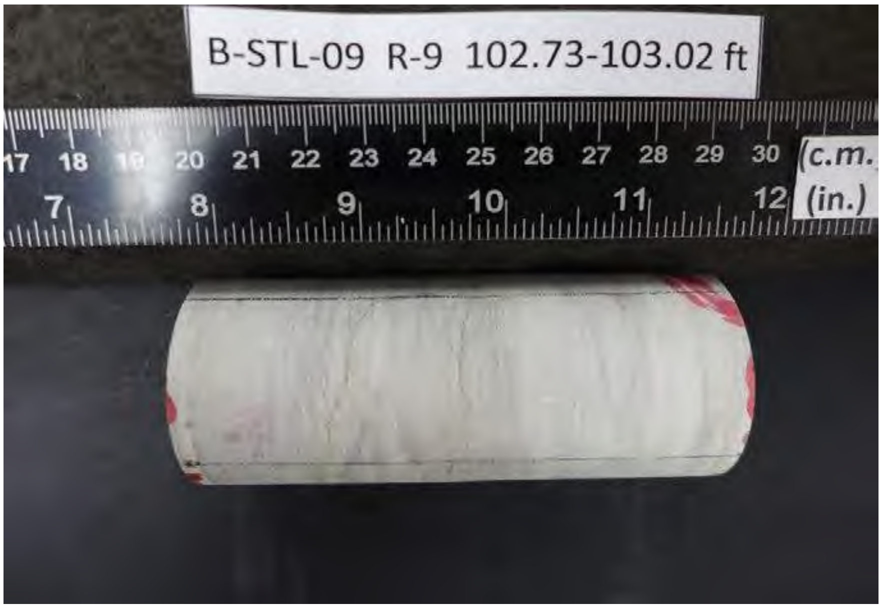
PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00020	1.860	0.00011	0.006	YES
Diameter 2, in (rotated 90^o)	0.00000	1.860	0.00000	0.000	YES
END 2					
Diameter 1, in	0.00030	1.860	0.00016	0.009	YES
Diameter 2, in (rotated 90^o)	0.00000	1.860	0.00000	0.000	YES

Maximum angle of departure must be $\leq$ 0.25°

Perpendicularity Tolerance Met? **YES**

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-9
Depth, ft:	102.73-103.02

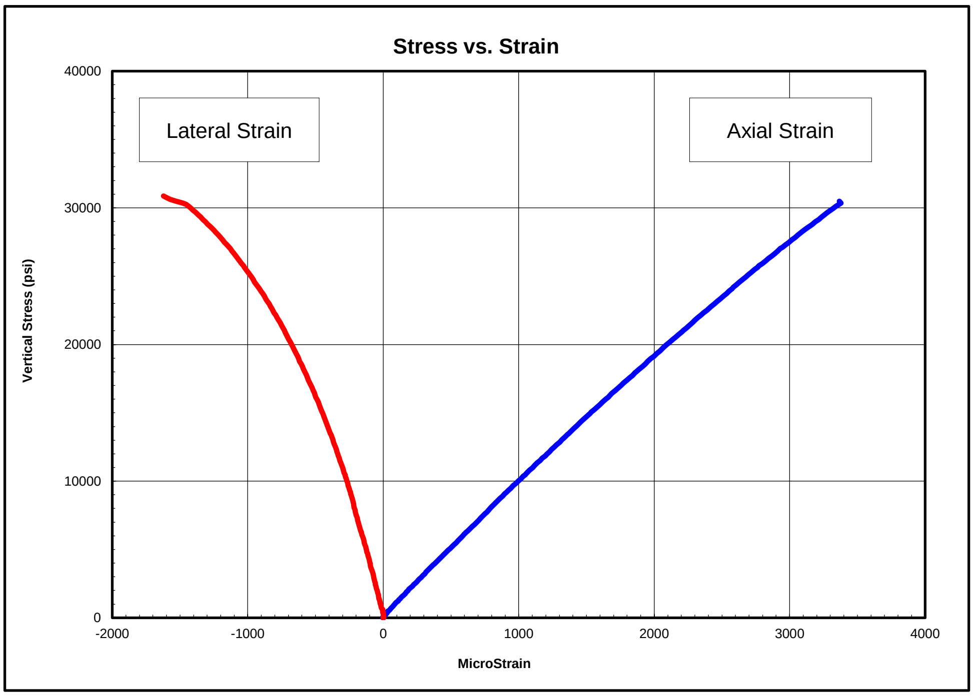


After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-11
Depth, ft:	112.7-113.08
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 30,865 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
3100-11300	9,780,000	0.28
11300-19500	9,090,000	0.37
19500-27800	8,370,000	---

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-09		
Sample ID:	R-11		
Depth:	112.7-113.08 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average		
Specimen Length, in:	4.14	4.14	4.14		
Specimen Diameter, in:	1.86	1.87	1.87		
Specimen Mass, g:	494.95				
Bulk Density, lb/ft^3	166	**Minimum Diameter Tolerence Met?**		**NO**	
Length to Diameter Ratio:	2.2	**Length to Diameter Ratio Tolerance Met?**		**YES**	

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:
Is the maximum gap $\leq$ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00010	-0.00020	-0.00020
Diameter 2, in (rotated 90^o)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

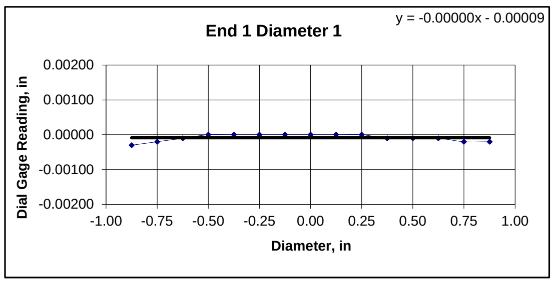
Difference between max and min readings, in:
0° = 0.00030 90° = 0.00000

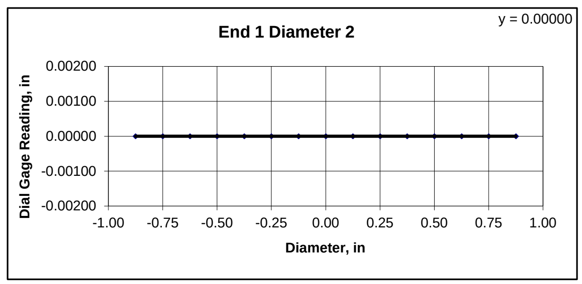
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00020	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010
Diameter 2, in (rotated 90^o)	-0.00010	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

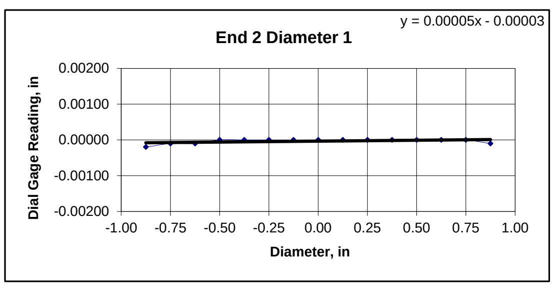
Difference between max and min readings, in:
0° = 0.0002 90° = 0.0001

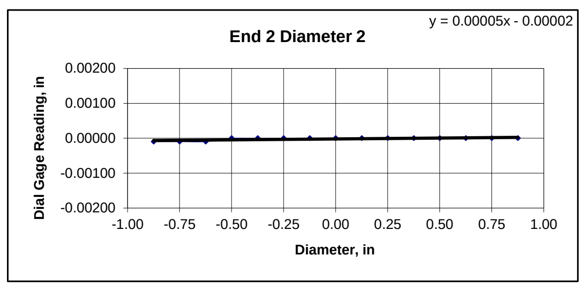
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00015

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:		
	Slope of Best Fit Line	0.00000
	Angle of Best Fit Line:	0.00000
End 2:		
	Slope of Best Fit Line	0.00005
	Angle of Best Fit Line:	0.00286
Maximum Angular Difference:		0.00286

Parallelism Tolerance Met? **YES**
Spherically Seated

DIAMETER 2

End 1:		
	Slope of Best Fit Line	0.00000
	Angle of Best Fit Line:	0.00000
End 2:		
	Slope of Best Fit Line	0.00005
	Angle of Best Fit Line:	0.00286
Maximum Angular Difference:		0.00286

Parallelism Tolerance Met? **YES**
Spherically Seated

PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00030	1.865	0.00016	0.009	YES
Diameter 2, in (rotated 90^o)	0.00000	1.865	0.00000	0.000	YES
END 2					
Diameter 1, in	0.00020	1.865	0.00011	0.006	YES
Diameter 2, in (rotated 90^o)	0.00010	1.865	0.00005	0.003	YES

Maximum angle of departure must be $\leq$ 0.25°

Perpendicularity Tolerance Met? **YES**

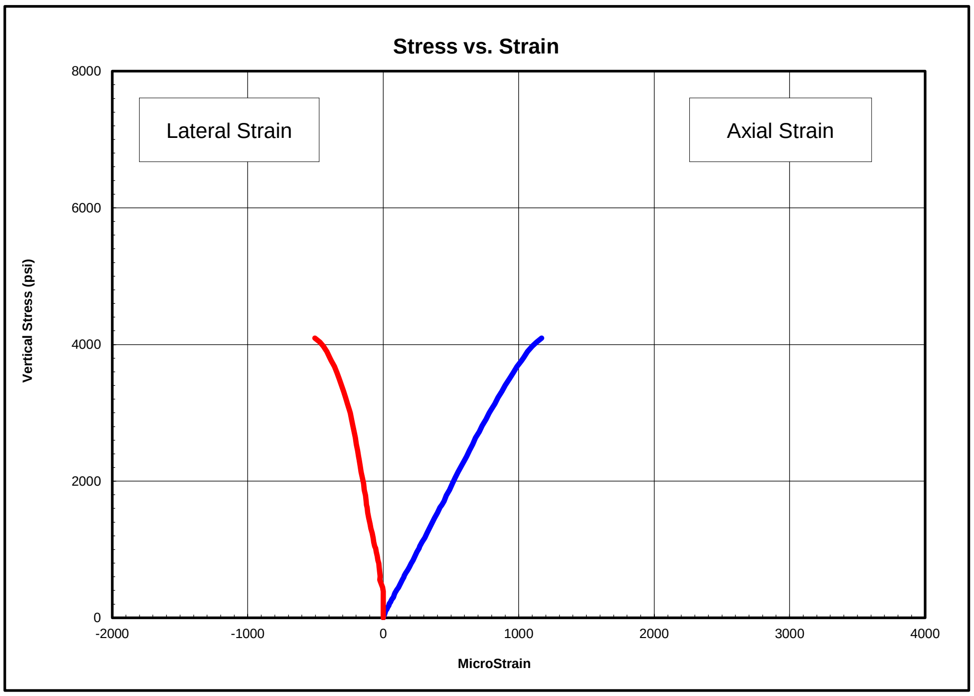
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-11
Depth, ft:	112.7-113.08

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-13
Depth, ft:	120.96-121.3
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 4,104 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
400-1500	3,780,000	0.37
1500-2600	3,880,000	0.33
2600-3500	3,490,000	0.49

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-09		
Sample ID:	R-13		
Depth:	120.96-121.3 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average		
Specimen Length, in:	4.01	4.01	4.01		
Specimen Diameter, in:	1.86	1.86	1.86		
Specimen Mass, g:	389.52				
Bulk Density, lb/ft^3	136	**Minimum Diameter Tolerence Met?**		**NO**	
Length to Diameter Ratio:	2.2	**Length to Diameter Ratio Tolerance Met?**		**YES**	

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap $\leq$ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00040	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00010	-0.00020
Diameter 2, in (rotated 90°)	0.00000	0.00000	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00020	-0.00010

Difference between max and min readings, in:

0° = 0.00040 90° = 0.00020

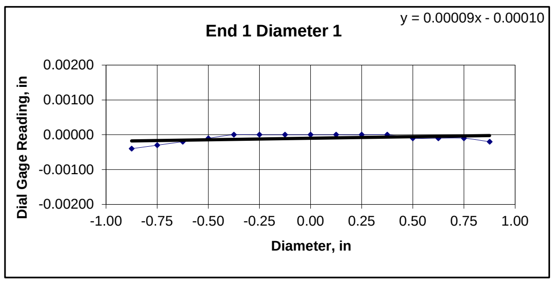
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00010	0.00000	0.00000	0.00010	0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00010	0.00020	0.00020
Diameter 2, in (rotated 90°)	0.00010	0.00010	0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

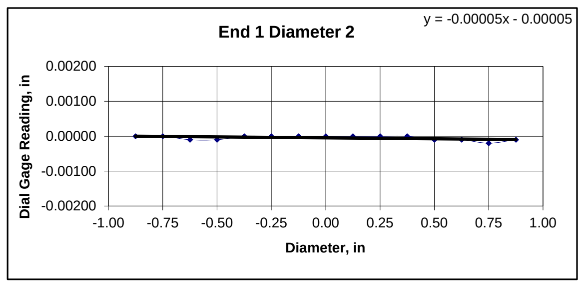
Difference between max and min readings, in:

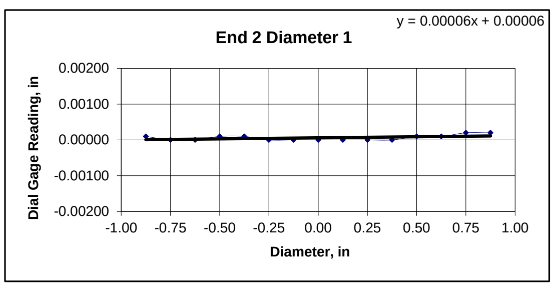
0° = 0.0002 90° = 0.0001

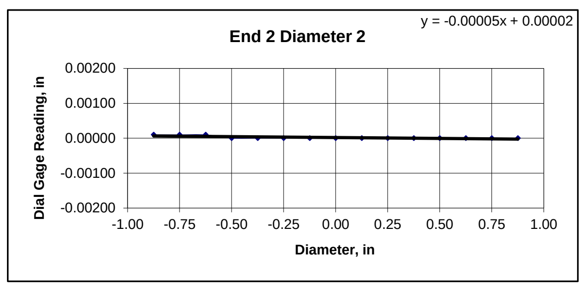
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00020

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:
- Slope of Best Fit Line 0.00009
- Angle of Best Fit Line: 0.00516

End 2:
- Slope of Best Fit Line 0.00006
- Angle of Best Fit Line: 0.00344

Maximum Angular Difference: 0.00172

Parallelism Tolerance Met? **YES**
Spherically Seated

DIAMETER 2

End 1:
- Slope of Best Fit Line 0.00005
- Angle of Best Fit Line: 0.00286

End 2:
- Slope of Best Fit Line 0.00005
- Angle of Best Fit Line: 0.00286

Maximum Angular Difference: 0.00000

Parallelism Tolerance Met? **YES**
Spherically Seated

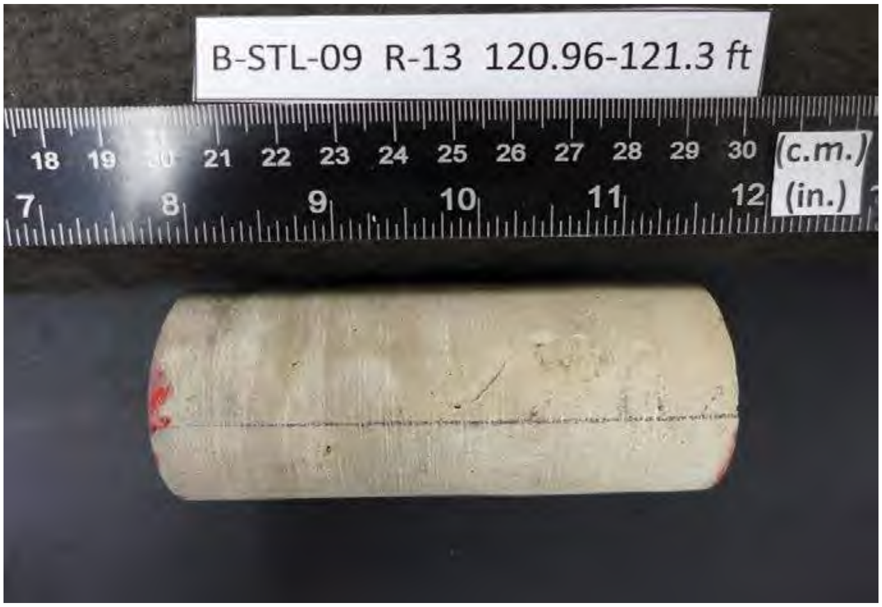
PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00040	1.860	0.00022	0.012	YES
Diameter 2, in (rotated 90°)	0.00020	1.860	0.00011	0.006	YES
END 2					
Diameter 1, in	0.00020	1.860	0.00011	0.006	YES
Diameter 2, in (rotated 90°)	0.00010	1.860	0.00005	0.003	YES

Maximum angle of departure must be $\leq$ 0.25°

Perpendicularity Tolerance Met? **YES**

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-13
Depth, ft:	120.96-121.3

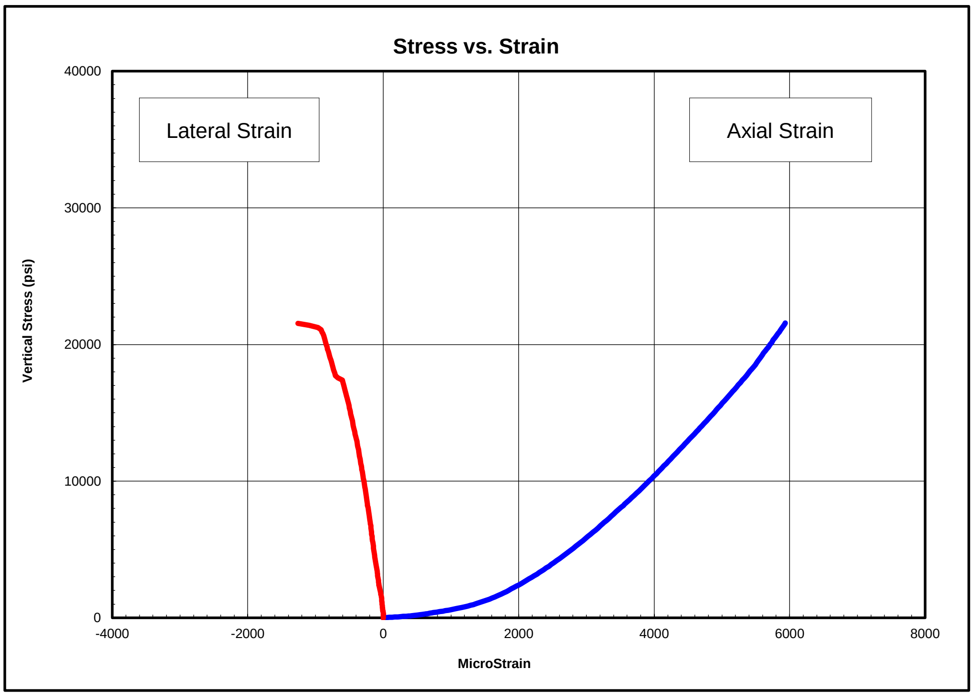


After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-16
Depth, ft:	138.6-138.95
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 21,574 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
2200-7900	3,690,000	0.10
7900-13700	4,990,000	0.17
13700-19400	5,750,000	0.43

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-09		
Sample ID:	R-16		
Depth:	138.6-138.95 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average
Specimen Length, in:	4.10	4.10	4.10
Specimen Diameter, in:	1.87	1.87	1.87
Specimen Mass, g:	493.52		
Bulk Density, lb/ft^3	167	**Minimum Diameter Tolerence Met?**	**NO**
Length to Diameter Ratio:	2.2	**Length to Diameter Ratio Tolerance Met?**	**YES**

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap $\leq$ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00000	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010
Diameter 2, in (rotated 90^o)	-0.00010	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Difference between max and min readings, in:

0° = 0.00010 90° = 0.00020

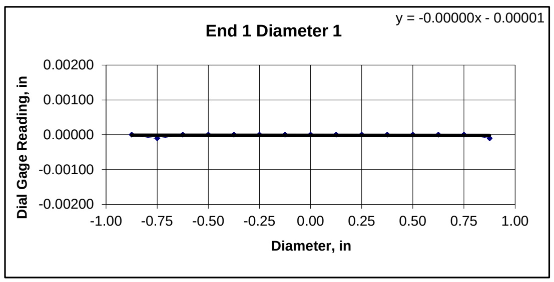
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Diameter 2, in (rotated 90^o)	-0.00020	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

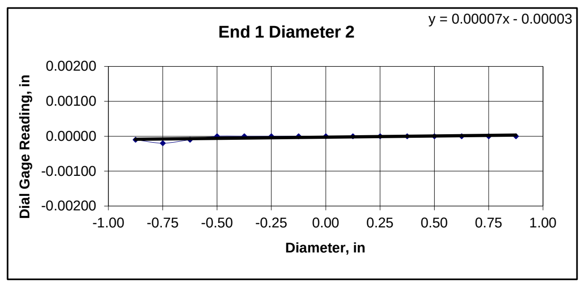
Difference between max and min readings, in:

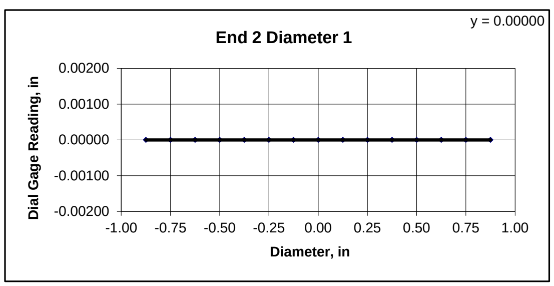
0° = 0 90° = 0.0002

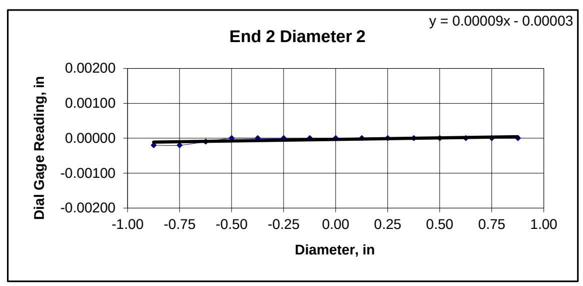
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00010

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:	
Slope of Best Fit Line	0.00000
Angle of Best Fit Line:	0.00000
End 2:	
Slope of Best Fit Line	0.00000
Angle of Best Fit Line:	0.00000
Maximum Angular Difference:	0.00000

Parallelism Tolerance Met? **YES**
Spherically Seated

DIAMETER 2

End 1:	
Slope of Best Fit Line	0.00007
Angle of Best Fit Line:	0.00401
End 2:	
Slope of Best Fit Line	0.00009
Angle of Best Fit Line:	0.00516
Maximum Angular Difference:	0.00115

Parallelism Tolerance Met? **YES**
Spherically Seated

PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00010	1.870	0.00005	0.003	YES
Diameter 2, in (rotated 90^o)	0.00020	1.870	0.00011	0.006	YES
END 2					
Diameter 1, in	0.00000	1.870	0.00000	0.000	YES
Diameter 2, in (rotated 90^o)	0.00020	1.870	0.00011	0.006	YES

Maximum angle of departure must be $\leq$ 0.25°

Perpendicularity Tolerance Met? **YES**

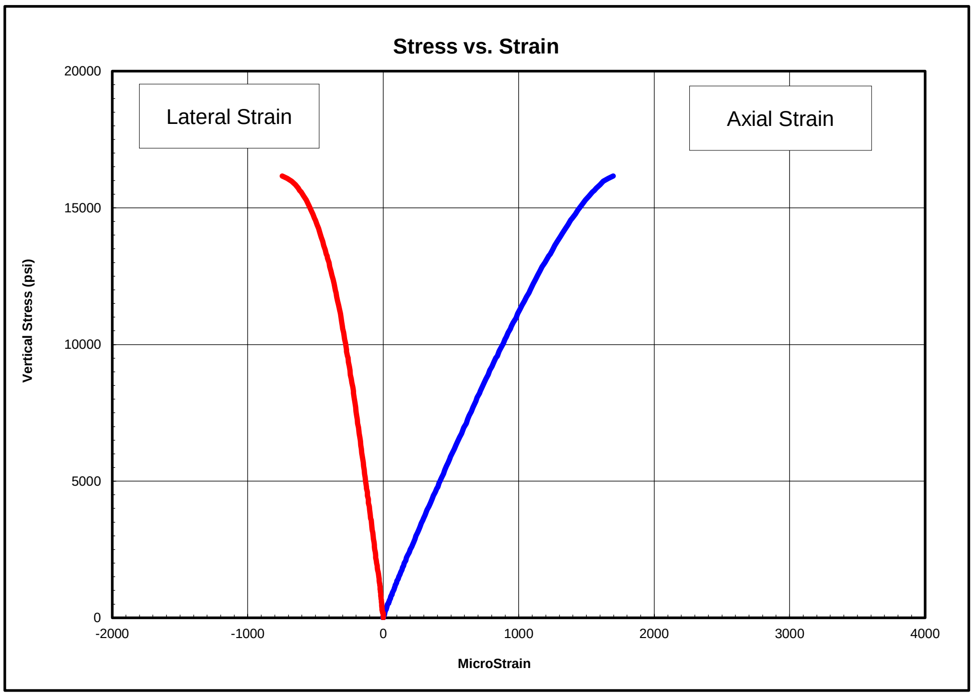
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-09
Sample ID:	R-16
Depth, ft:	138.6-138.95

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-10
Sample ID:	R-7
Depth, ft:	90.63-90.98
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 16,189 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
1600-5900	11,400,000	0.31
5900-10200	10,800,000	0.33
10200-14500	9,070,000	0.44

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-10		
Sample ID:	R-7		
Depth:	90.63-90.98 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average
Specimen Length, in:	3.97	3.97	3.97
Specimen Diameter, in:	1.87	1.87	1.87
Specimen Mass, g:	475.95		
Bulk Density, lb/ft^3	166	**Minimum Diameter Tolerence Met?**	**NO**
Length to Diameter Ratio:	2.1	**Length to Diameter Ratio Tolerance Met?**	**YES**

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:
Is the maximum gap ≤ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00020	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020	0.00000
Diameter 2, in (rotated 90^o)	0.00010	0.00000	-0.00010	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	0.00000

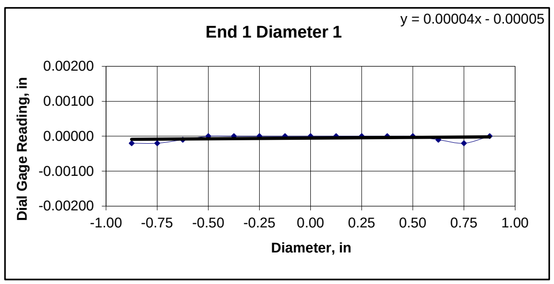
Difference between max and min readings, in:
0° = 0.00020 90° = 0.00030

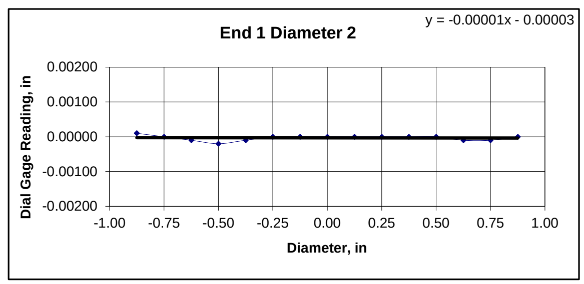
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00010	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00020
Diameter 2, in (rotated 90^o)	0.00020	0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00010

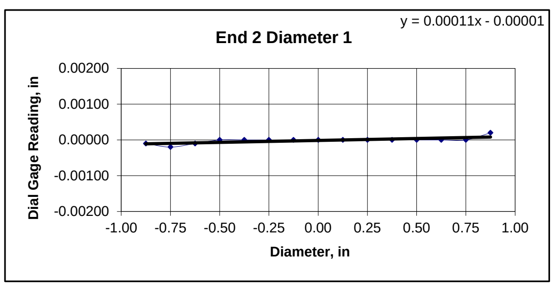
Difference between max and min readings, in:
0° = 0.0004 90° = 0.0002

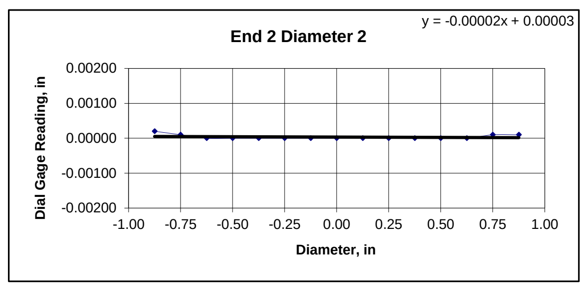
Maximum difference must be < 0.0020 in. Difference = ± 0.00020

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:	Slope of Best Fit Line	0.00004
	Angle of Best Fit Line:	0.00229
End 2:	Slope of Best Fit Line	0.00011
	Angle of Best Fit Line:	0.00630
Maximum Angular Difference:		0.00401

Parallelism Tolerance Met? **YES**
Spherically Seated

DIAMETER 2

End 1:	Slope of Best Fit Line	0.00001
	Angle of Best Fit Line:	0.00057
End 2:	Slope of Best Fit Line	0.00002
	Angle of Best Fit Line:	0.00115
Maximum Angular Difference:		0.00057

Parallelism Tolerance Met? **YES**
Spherically Seated

PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00020	1.870	0.00011	0.006	YES
Diameter 2, in (rotated 90^o)	0.00030	1.870	0.00016	0.009	YES
END 2					
Diameter 1, in	0.00040	1.870	0.00021	0.012	YES
Diameter 2, in (rotated 90^o)	0.00020	1.870	0.00011	0.006	YES

Maximum angle of departure must be ≤ 0.25°

Perpendicularity Tolerance Met? **YES**

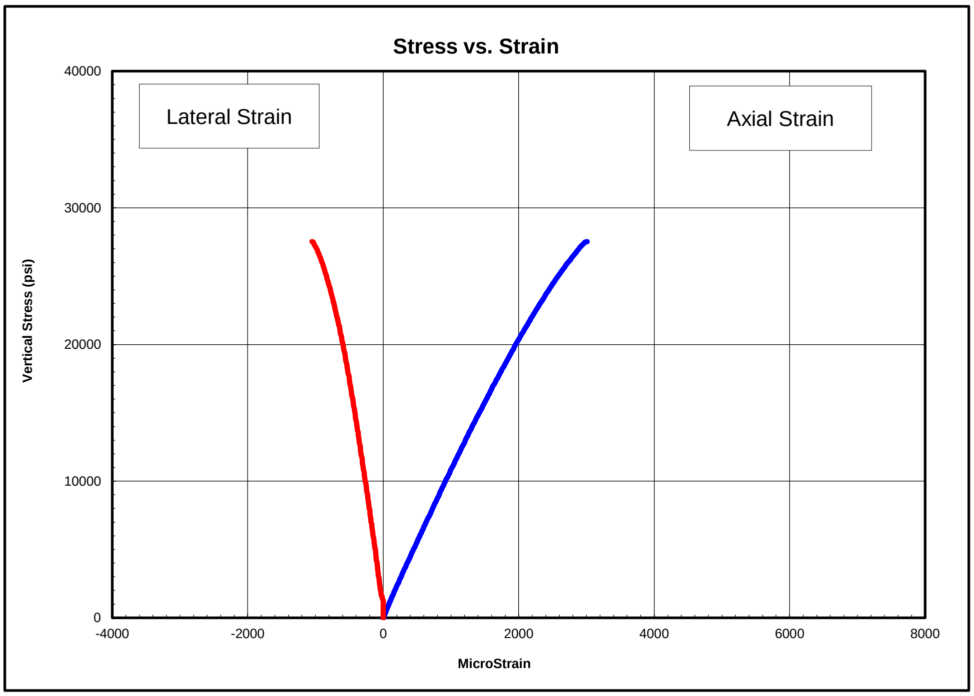
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-10
Sample ID:	R-7
Depth, ft:	90.63-90.98

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-10
Sample ID:	R-10
Depth, ft:	106.3-106.65
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 27,536 psi

One lateral strain gauge failed to record meaningful data. Poisson's Ratio reported based on results of a single lateral strain gauge.

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
2800-10100	10,700,000	0.30
10100-17400	9,850,000	0.31
17400-24800	8,430,000	0.37

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-10		
Sample ID:	R-10		
Depth:	106.3-106.65 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average	
Specimen Length, in:	4.11	4.11	4.11	
Specimen Diameter, in:	1.87	1.86	1.87	
Specimen Mass, g:	491.59			
Bulk Density, lb/ft^3	166	**Minimum Diameter Tolerence Met?**	**NO**	
Length to Diameter Ratio:	2.2	**Length to Diameter Ratio Tolerance Met?**	**YES**	

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap $\leq$ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00040	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00010	-0.00010
Diameter 2, in (rotated 90°)	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010

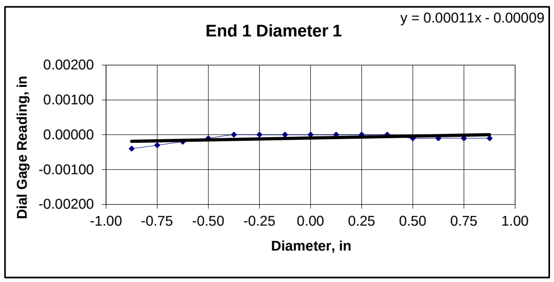
Difference between max and min readings, in:
0° = 0.00040 90° = 0.00030

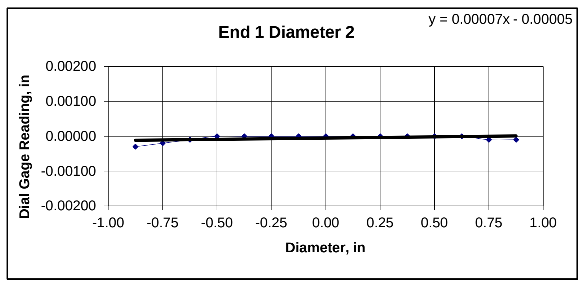
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00020
Diameter 2, in (rotated 90°)	-0.00040	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020	-0.00030	-0.00030

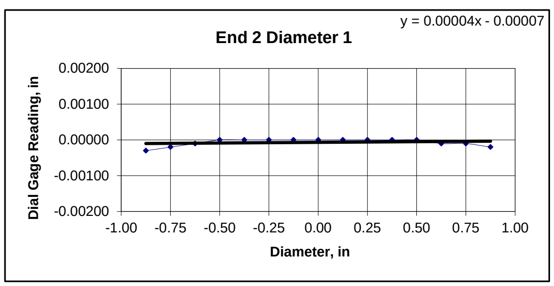
Difference between max and min readings, in:
0° = 0.0003 90° = 0.0004

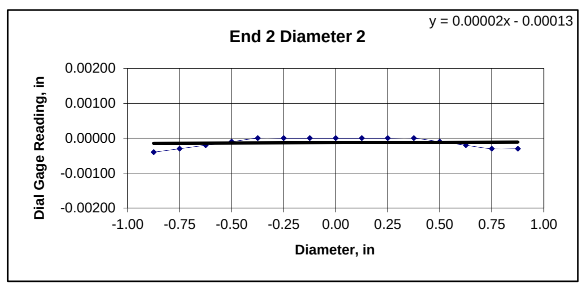
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00020

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:		
	Slope of Best Fit Line	0.00011
	Angle of Best Fit Line:	0.00630
End 2:		
	Slope of Best Fit Line	0.00004
	Angle of Best Fit Line:	0.00229
Maximum Angular Difference:		0.00401

Parallelism Tolerance Met? **YES**
Spherically Seated

DIAMETER 2

End 1:		
	Slope of Best Fit Line	0.00007
	Angle of Best Fit Line:	0.00401
End 2:		
	Slope of Best Fit Line	0.00002
	Angle of Best Fit Line:	0.00115
Maximum Angular Difference:		0.00286

Parallelism Tolerance Met? **YES**
Spherically Seated

PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00040	1.865	0.00021	0.012	YES
Diameter 2, in (rotated 90°)	0.00030	1.865	0.00016	0.009	YES
END 2					
Diameter 1, in	0.00030	1.865	0.00016	0.009	YES
Diameter 2, in (rotated 90°)	0.00040	1.865	0.00021	0.012	YES

Maximum angle of departure must be $\leq$ 0.25°

Perpendicularity Tolerance Met? **YES**

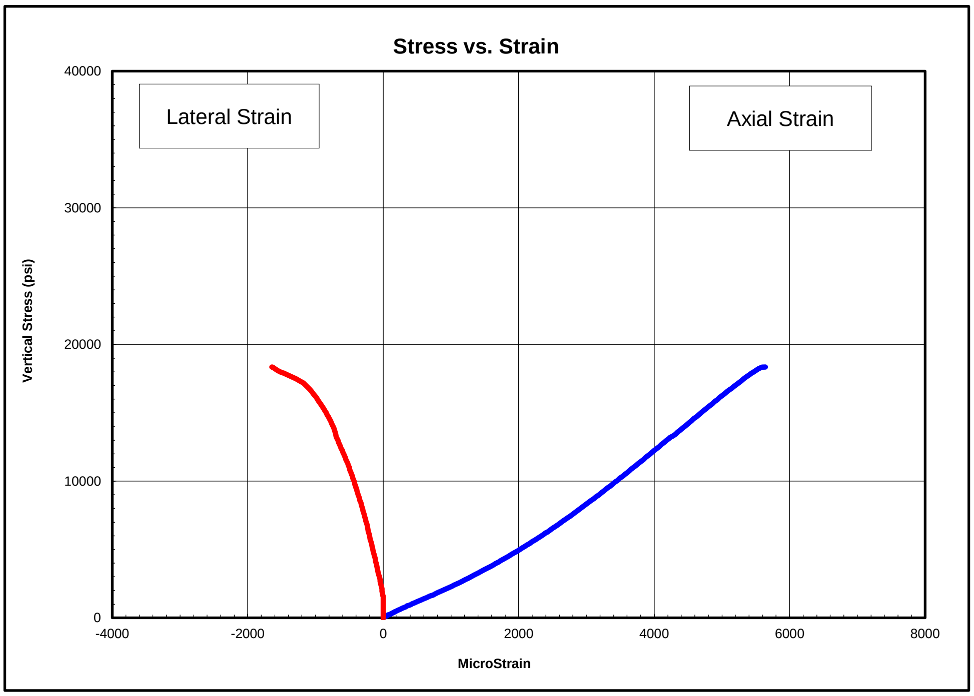
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-10
Sample ID:	R-10
Depth, ft:	106.3-106.65

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-10
Sample ID:	R-12
Depth, ft:	116.9-117.29
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 18,565 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
1800-6700	2,790,000	0.13
6700-11600	3,790,000	0.24
11600-16500	4,010,000	0.40

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-10		
Sample ID:	R-12		
Depth:	116.9-117.29 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average
Specimen Length, in:	4.03	4.04	4.04
Specimen Diameter, in:	1.86	1.86	1.86
Specimen Mass, g:	476.77		
Bulk Density, lb/ft^3	165		
Length to Diameter Ratio:	2.2		

Minimum Diameter Tolerence Met? NO

Length to Diameter Ratio Tolerance Met? YES

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap ≤ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? YES

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00010	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020
Diameter 2, in (rotated 90°)	0.00000	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010

Difference between max and min readings, in:

0° = 0.00020 90° = 0.00020

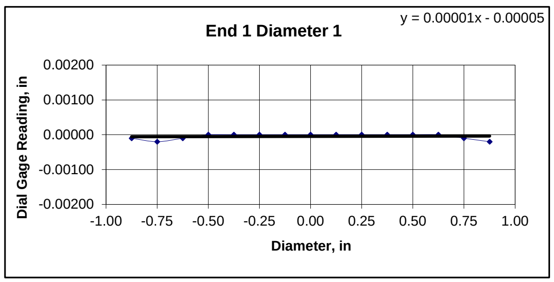
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00040	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020	-0.00030	-0.00010
Diameter 2, in (rotated 90°)	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010

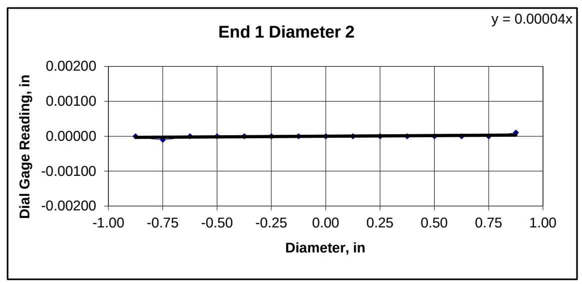
Difference between max and min readings, in:

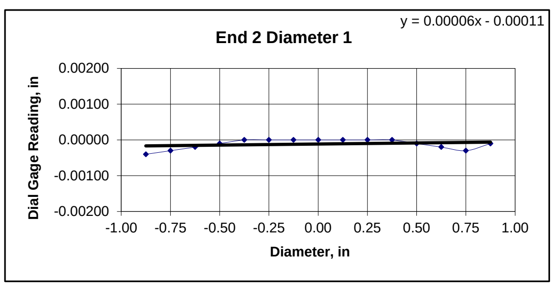
0° = 0.0004 90° = 0.0001

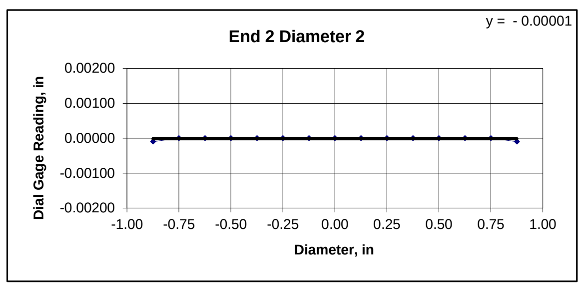
Maximum difference must be < 0.0020 in. Difference = ± 0.00020

Flatness Tolerance Met? YES









DIAMETER 1

End 1:

Slope of Best Fit Line	0.00001
Angle of Best Fit Line:	0.00057

End 2:

Slope of Best Fit Line	0.00006
Angle of Best Fit Line:	0.00344

Maximum Angular Difference: 0.00286

Parallelism Tolerance Met? YES

Spherically Seated

DIAMETER 2

End 1:

Slope of Best Fit Line	0.00004
Angle of Best Fit Line:	0.00229

End 2:

Slope of Best Fit Line	0.00001
Angle of Best Fit Line:	0.00057

Maximum Angular Difference: 0.00172

Parallelism Tolerance Met? YES

Spherically Seated

PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00020	1.860	0.00011	0.006	YES
Diameter 2, in (rotated 90°)	0.00020	1.860	0.00011	0.006	YES
END 2					
Diameter 1, in	0.00040	1.860	0.00022	0.012	YES
Diameter 2, in (rotated 90°)	0.00010	1.860	0.00005	0.003	YES

Maximum angle of departure must be ≤ 0.25°

Perpendicularity Tolerance Met? YES

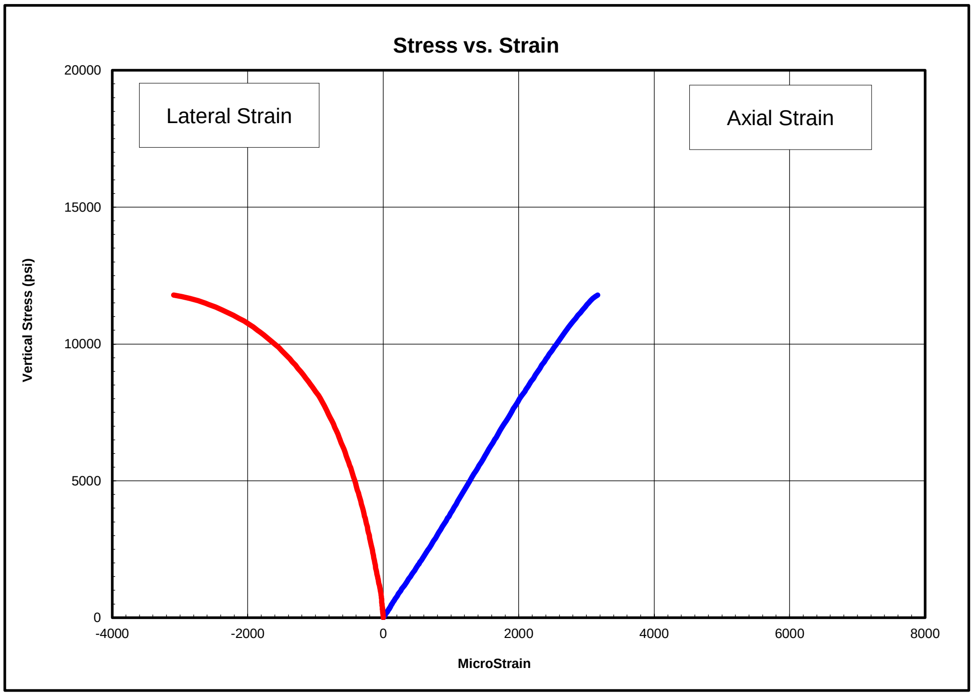
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-10
Sample ID:	R-12
Depth, ft:	116.9-117.29

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-10
Sample ID:	R-14
Depth, ft:	128.65-129.00
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 11,786 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
1200-4300	3,900,000	0.34
4300-7500	4,120,000	---
7500-10600	3,680,000	---

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-10		
Sample ID:	R-14		
Depth:	128.65-129.00 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average		
Specimen Length, in:	4.07	4.07	4.07		
Specimen Diameter, in:	1.87	1.87	1.87		
Specimen Mass, g:	422.24				
Bulk Density, lb/ft^3	144			**Minimum Diameter Tolerence Met?**	**NO**
Length to Diameter Ratio:	2.2			**Length to Diameter Ratio Tolerance Met?**	**YES**

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap $\leq$ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00020	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00030
Diameter 2, in (rotated 90^o)	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010

Difference between max and min readings, in:

0° = 0.00050 90° = 0.00030

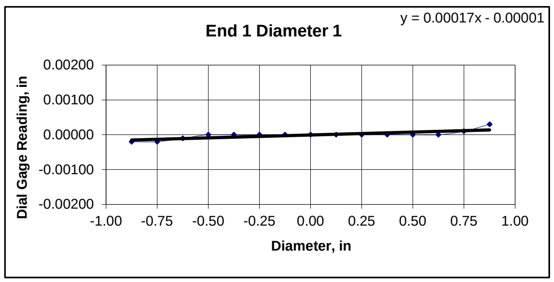
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00030	-0.00020	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	0.00000	0.00010
Diameter 2, in (rotated 90^o)	-0.00020	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00020

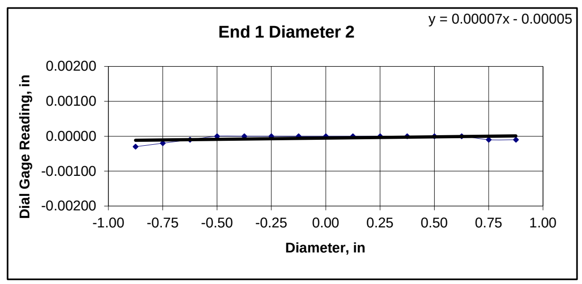
Difference between max and min readings, in:

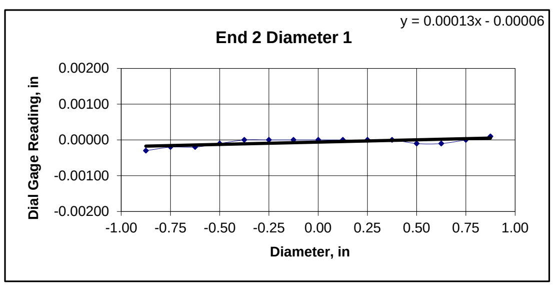
0° = 0.0004 90° = 0.0004

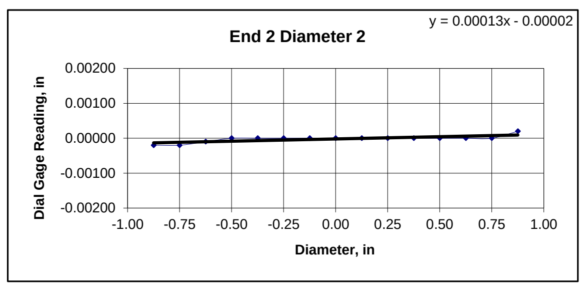
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00025

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:	
Slope of Best Fit Line	0.00017
Angle of Best Fit Line:	0.00974
End 2:	
Slope of Best Fit Line	0.00013
Angle of Best Fit Line:	0.00745
Maximum Angular Difference:	0.00229

Parallelism Tolerance Met? **YES**

Spherically Seated

DIAMETER 2

End 1:	
Slope of Best Fit Line	0.00007
Angle of Best Fit Line:	0.00401
End 2:	
Slope of Best Fit Line	0.00013
Angle of Best Fit Line:	0.00745
Maximum Angular Difference:	0.00344

Parallelism Tolerance Met? **YES**

Spherically Seated

PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00050	1.870	0.00027	0.015	YES
Diameter 2, in (rotated 90^o)	0.00030	1.870	0.00016	0.009	YES
END 2					
Diameter 1, in	0.00040	1.870	0.00021	0.012	YES
Diameter 2, in (rotated 90^o)	0.00040	1.870	0.00021	0.012	YES

Maximum angle of departure must be $\leq$ 0.25°

Perpendicularity Tolerance Met? **YES**

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-10
Sample ID:	R-14
Depth, ft:	128.65-129.00

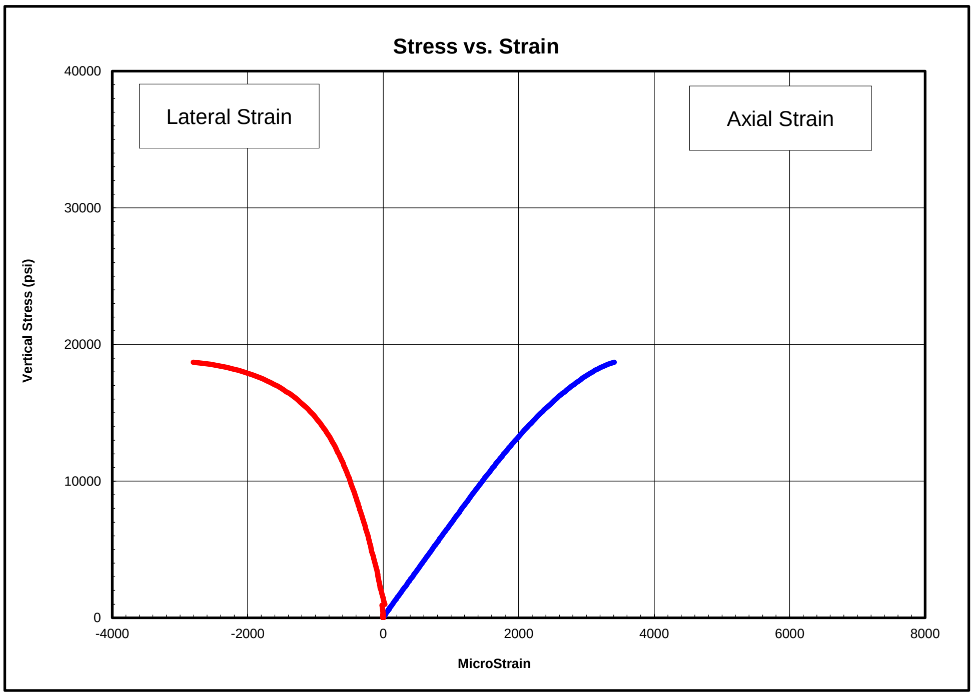
After cutting and grinding

After break

GeoTesting EXPRESS

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-10
Sample ID:	R-17
Depth, ft:	140.0-140.34
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 18,700 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
1900-6900	6,840,000	0.34
6900-11800	6,570,000	0.47
11800-16800	5,090,000	---

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

GeoTesting EXPRESS

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-10		
Sample ID:	R-17		
Depth:	140.0-140.34 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average		
Specimen Length, in:	4.09	4.09	4.09		
Specimen Diameter, in:	1.87	1.86	1.87		
Specimen Mass, g:	473.24				
Bulk Density, lb/ft^3	161	**Minimum Diameter Tolerence Met?**		**NO**	
Length to Diameter Ratio:	2.2	**Length to Diameter Ratio Tolerance Met?**		**YES**	

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap $\leq$ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00010	-0.00020	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Diameter 2, in (rotated 90^o)	0.00000	-0.00010	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010

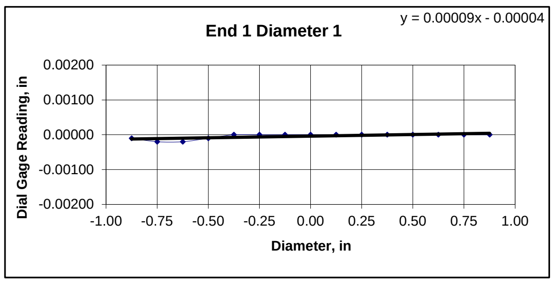
Difference between max and min readings, in:
0° = 0.00020 90° = 0.00020

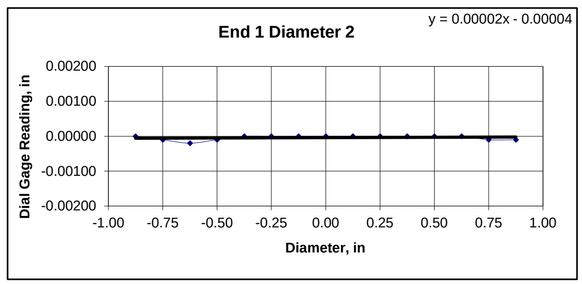
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00020	-0.00020	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Diameter 2, in (rotated 90^o)	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00010

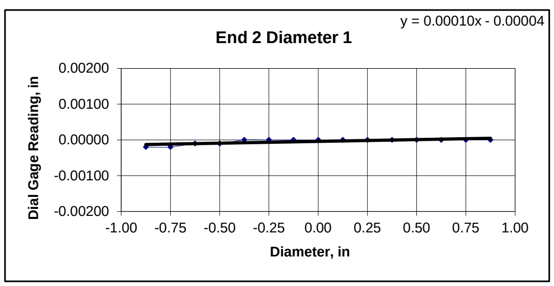
Difference between max and min readings, in:
0° = 0.0002 90° = 0.0002

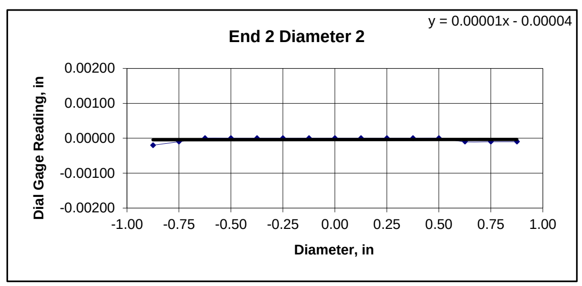
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00010

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:

Slope of Best Fit Line	0.00009
Angle of Best Fit Line:	0.00516

End 2:

Slope of Best Fit Line	0.00010
Angle of Best Fit Line:	0.00573

Maximum Angular Difference: 0.00057

Parallelism Tolerance Met? **YES**
Spherically Seated

DIAMETER 2

End 1:

Slope of Best Fit Line	0.00002
Angle of Best Fit Line:	0.00115

End 2:

Slope of Best Fit Line	0.00001
Angle of Best Fit Line:	0.00057

Maximum Angular Difference: 0.00057

Parallelism Tolerance Met? **YES**
Spherically Seated

PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00020	1.865	0.00011	0.006	YES
Diameter 2, in (rotated 90^o)	0.00020	1.865	0.00011	0.006	YES
END 2					
Diameter 1, in	0.00020	1.865	0.00011	0.006	YES
Diameter 2, in (rotated 90^o)	0.00020	1.865	0.00011	0.006	YES

Maximum angle of departure must be $\leq$ 0.25°

Perpendicularity Tolerance Met? **YES**

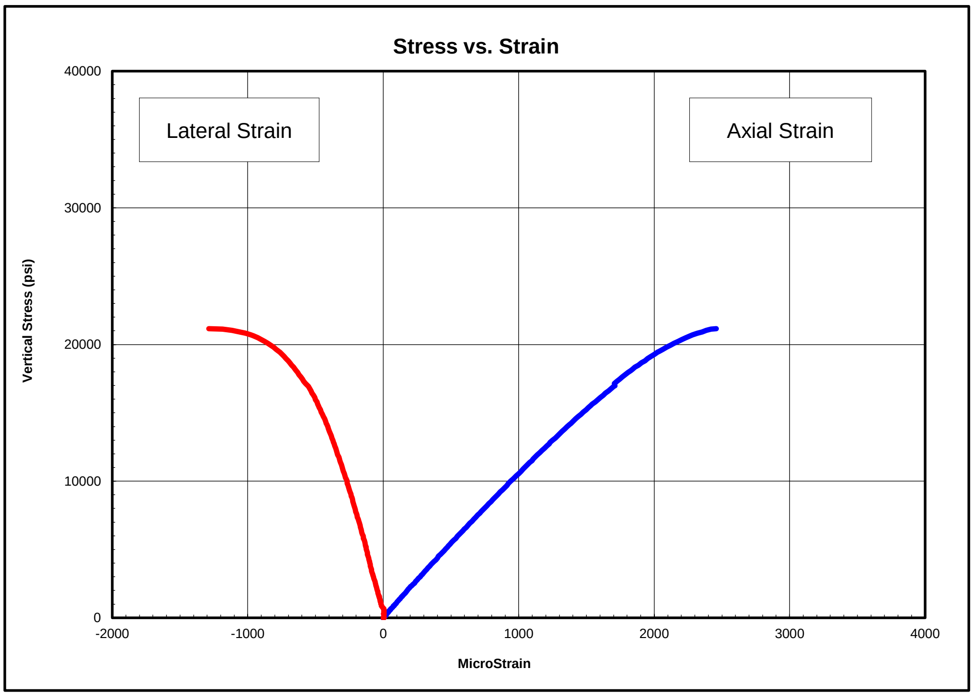
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/14/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-10
Sample ID:	R-17
Depth, ft:	140.0-140.34

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-11
Sample ID:	R-1
Depth, ft:	74.10-74.45
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 21,119 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
2100-7800	10,600,000	0.28
7800-13400	9,850,000	0.33
13400-19000	8,620,000	---

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-11		
Sample ID:	R-1		
Depth:	74.10-74.45 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average		
Specimen Length, in:	4.07	4.07	4.07		
Specimen Diameter, in:	1.86	1.86	1.86		
Specimen Mass, g:	484.52				
Bulk Density, lb/ft^3	167	**Minimum Diameter Tolerence Met?**		**NO**	
Length to Diameter Ratio:	2.2	**Length to Diameter Ratio Tolerance Met?**		**YES**	

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap ≤ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00030	-0.00040	-0.00040	-0.00040	-0.00030	-0.00020	-0.00010	0.00000	0.00000	-0.00020	-0.00020	-0.00020	-0.00020	-0.00030	-0.00040
Diameter 2, in (rotated 90°)	-0.00010	-0.00020	-0.00020	-0.00020	-0.00020	-0.00010	-0.00010	0.00000	-0.00010	-0.00020	-0.00030	-0.00030	-0.00030	-0.00020	-0.00010

Difference between max and min readings, in:

0° = 0.00040 90° = 0.00030

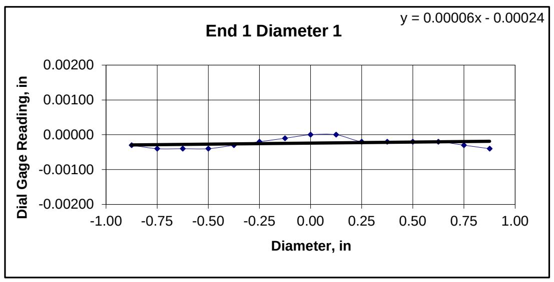
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00030	-0.00040	-0.00040	-0.00040	-0.00040	-0.00040	-0.00010	0.00000	0.00000	0.00000	0.00000	-0.00020	-0.00030	-0.00030	-0.00030
Diameter 2, in (rotated 90°)	-0.00010	-0.00010	-0.00010	-0.00010	-0.00030	-0.00030	0.00000	0.00000	0.00000	0.00000	-0.00020	-0.00020	-0.00020	-0.00020	-0.00020

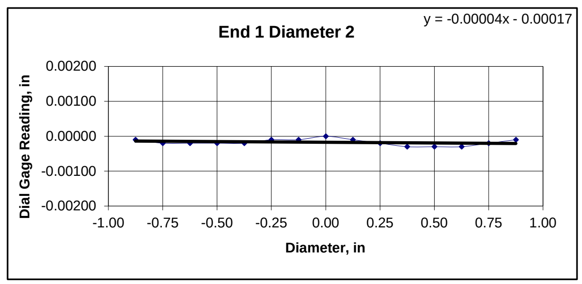
Difference between max and min readings, in:

0° = 0.0004 90° = 0.0003

Maximum difference must be < 0.0020 in. Difference = ± 0.00020

Flatness Tolerance Met? **YES**





DIAMETER 1

End 1:

Slope of Best Fit Line	0.00006
Angle of Best Fit Line:	0.00344

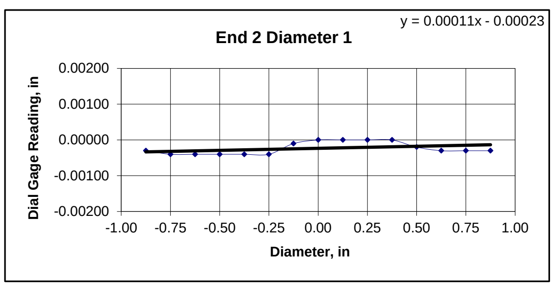
End 2:

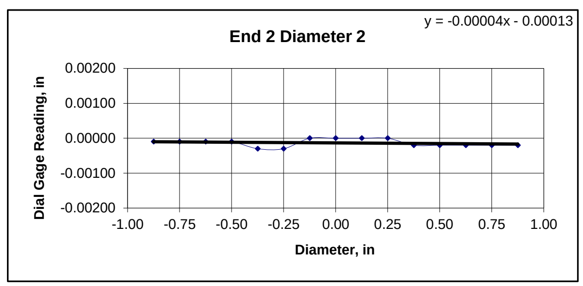
Slope of Best Fit Line	0.00011
Angle of Best Fit Line:	0.00630

Maximum Angular Difference: 0.00286

Parallelism Tolerance Met? **YES**

Spherically Seated





DIAMETER 2

End 1:

Slope of Best Fit Line	-0.00004
Angle of Best Fit Line:	-0.00229

End 2:

Slope of Best Fit Line	-0.00004
Angle of Best Fit Line:	-0.00229

Maximum Angular Difference: 0.00000

Parallelism Tolerance Met? **YES**

Spherically Seated

PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00040	1.860	0.00022	0.012	YES
Diameter 2, in (rotated 90°)	0.00030	1.860	0.00016	0.009	YES
END 2					
Diameter 1, in	0.00040	1.860	0.00022	0.012	YES
Diameter 2, in (rotated 90°)	0.00030	1.860	0.00016	0.009	YES

Maximum angle of departure must be ≤ 0.25°

Perpendicularity Tolerance Met? **YES**

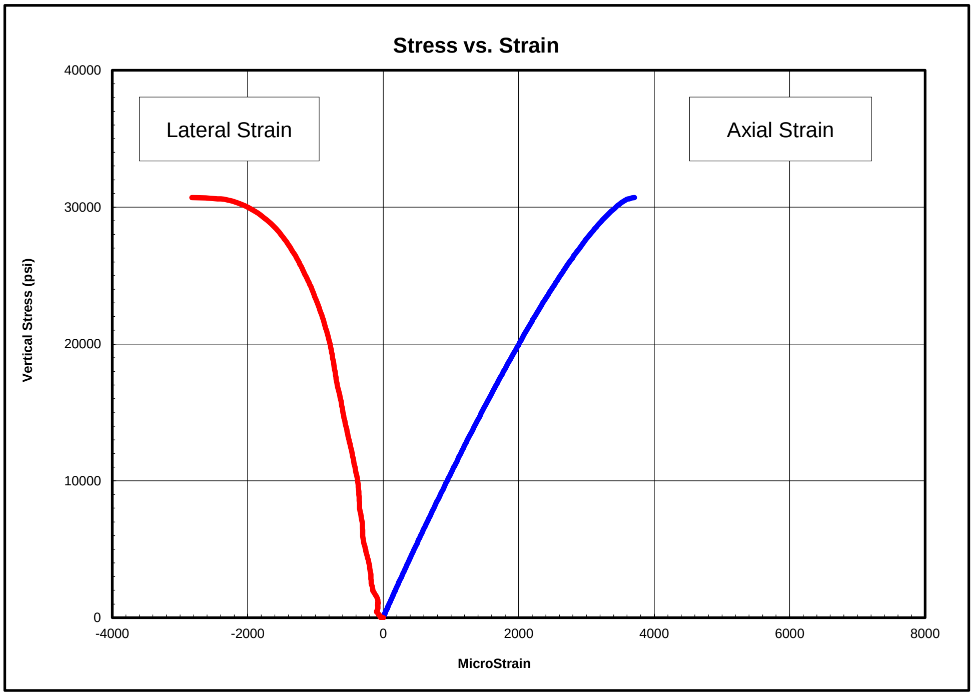
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-11
Sample ID:	R-1
Depth, ft:	74.10-74.45

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-11
Sample ID:	R-4
Depth, ft:	87.50-87.85
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 30,696 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
3100-11300	10,300,000	0.30
11300-19400	9,400,000	0.39
19400-27600	7,820,000	---

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/12/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-11		
Sample ID:	R-4		
Depth:	87.50-87.85 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average
Specimen Length, in:	4.10	4.10	4.10
Specimen Diameter, in:	1.86	1.86	1.86
Specimen Mass, g:	487.02		
Bulk Density, lb/ft^3	166		
Length to Diameter Ratio:	2.2		

Minimum Diameter Tolerence Met? NO

Length to Diameter Ratio Tolerance Met? YES

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap $\leq$ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? YES

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	-0.00020	-0.00030	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020	-0.00040
Diameter 2, in (rotated 90^o)	-0.00030	-0.00030	-0.00030	-0.00030	-0.00030	-0.00010	-0.00010	0.00000	0.00000	-0.00020	-0.00020	-0.00020	-0.00020	-0.00020	-0.00010

Difference between max and min readings, in:

0° = 0.00040 90° = 0.00030

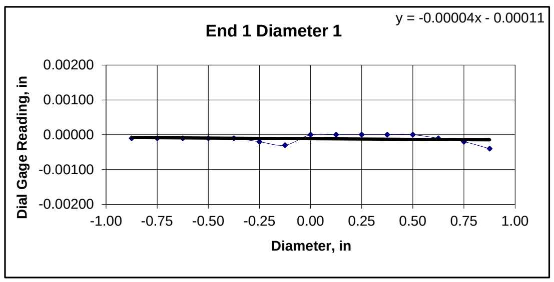
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00020	-0.00020	-0.00020	-0.00010	-0.00010	-0.00010	-0.00010	0.00000	0.00000	0.00000	-0.00030	-0.00030	-0.00030	-0.00030	-0.00030
Diameter 2, in (rotated 90^o)	-0.00020	-0.00020	-0.00020	-0.00020	-0.00030	-0.00030	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00020	-0.00020

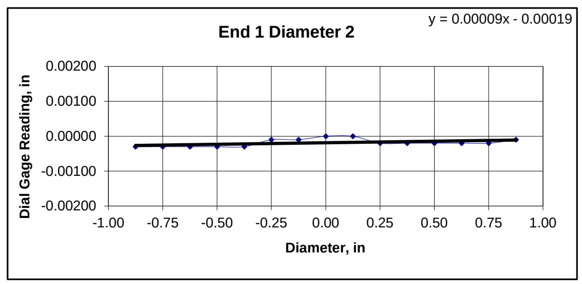
Difference between max and min readings, in:

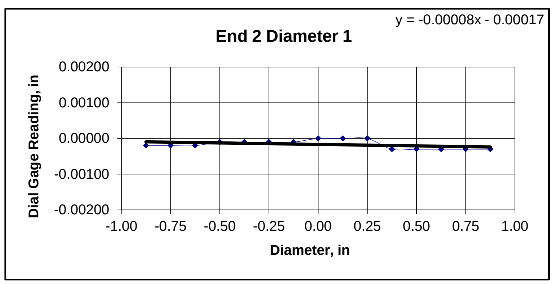
0° = 0.0003 90° = 0.0003

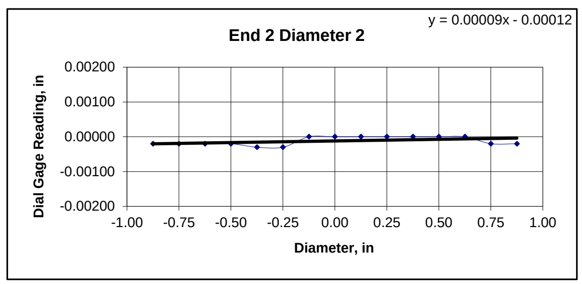
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00020

Flatness Tolerance Met? YES









DIAMETER 1

End 1:
- Slope of Best Fit Line: -0.00004
- Angle of Best Fit Line: -0.00229

End 2:
- Slope of Best Fit Line: -0.00008
- Angle of Best Fit Line: -0.00458

Maximum Angular Difference: 0.00229

Parallelism Tolerance Met? YES

Spherically Seated

DIAMETER 2

End 1:
- Slope of Best Fit Line: 0.00009
- Angle of Best Fit Line: 0.00516

End 2:
- Slope of Best Fit Line: 0.00009
- Angle of Best Fit Line: 0.00516

Maximum Angular Difference: 0.00000

Parallelism Tolerance Met? YES

Spherically Seated

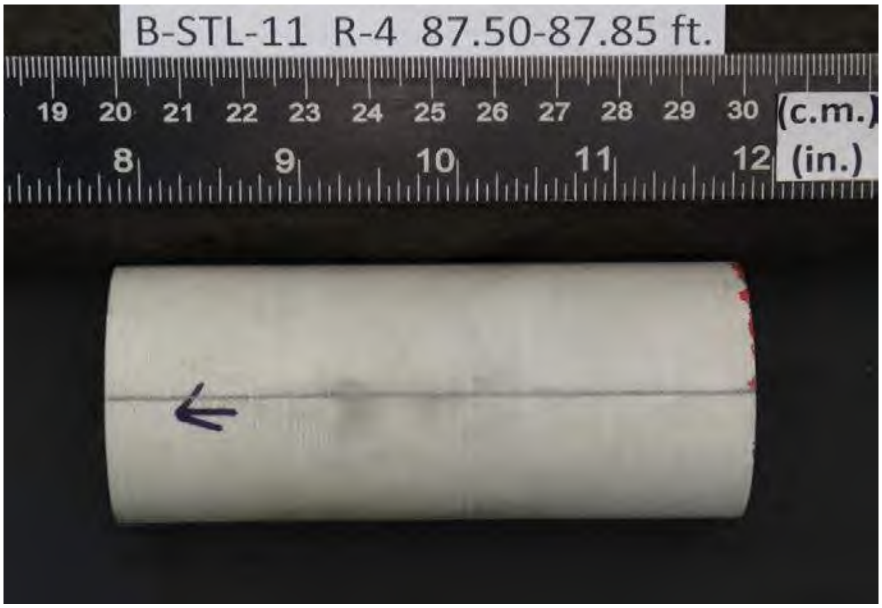
PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00040	1.860	0.00022	0.012	YES
Diameter 2, in (rotated 90^o)	0.00030	1.860	0.00016	0.009	YES
END 2					
Diameter 1, in	0.00030	1.860	0.00016	0.009	YES
Diameter 2, in (rotated 90^o)	0.00030	1.860	0.00016	0.009	YES

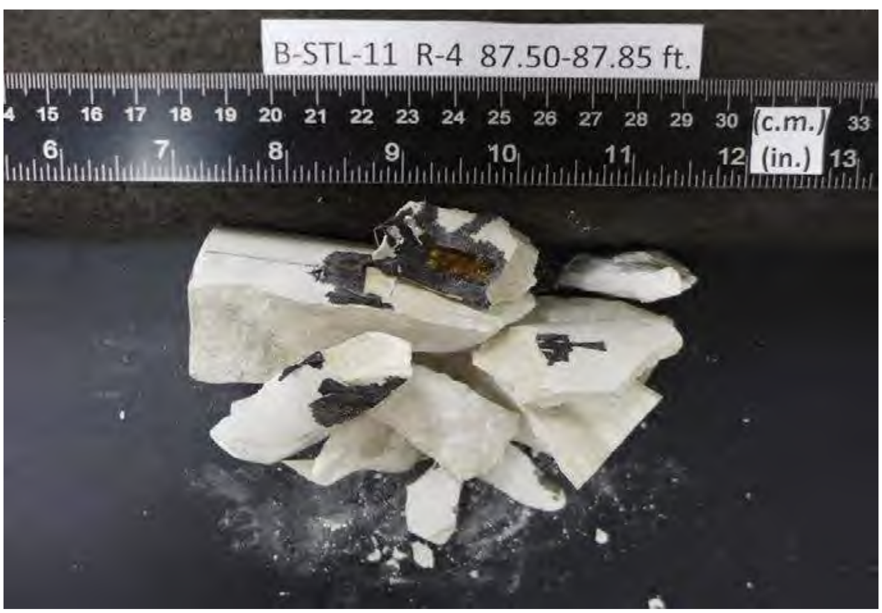
Maximum angle of departure must be $\leq$ 0.25°

Perpendicularity Tolerance Met? YES

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-11
Sample ID:	R-4
Depth, ft:	87.50-87.85



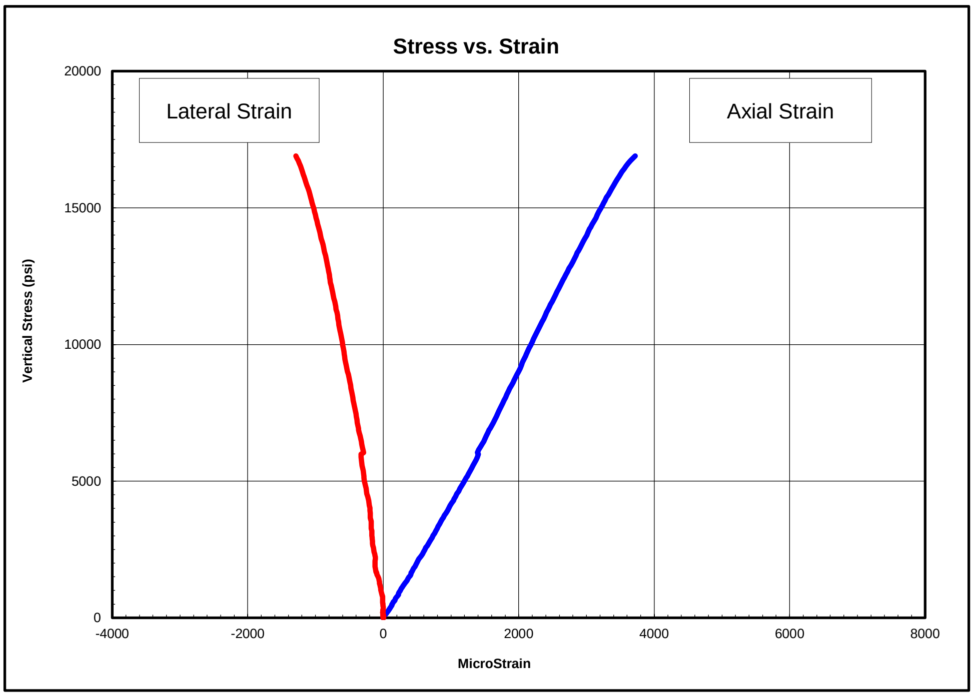
After cutting and grinding



After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-11
Sample ID:	R-5
Depth, ft:	93.45-93.80
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 16,943 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
1700-6200	4,360,000	0.23
6200-10700	5,080,000	0.39
10700-15200	4,780,000	0.42

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

GeoTesting EXPRESS

Client:	TSI Geotechnical	Test Date:	4/13/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-11		
Sample ID:	R-5		
Depth:	93.45-93.80 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average
Specimen Length, in:	4.18	4.18	4.18
Specimen Diameter, in:	1.86	1.86	1.86
Specimen Mass, g:	494.25		
Bulk Density, lb/ft^3	165	**Minimum Diameter Tolerence Met?**	NO
Length to Diameter Ratio:	2.2	**Length to Diameter Ratio Tolerance Met?**	YES

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:
Is the maximum gap ≤ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? YES

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00040	-0.00040	-0.00040	-0.00030	-0.00020	-0.00020	-0.00010	0.00000	0.00000	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010
Diameter 2, in (rotated 90°)	0.00020	0.00020	0.00020	0.00020	0.00020	0.00020	0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

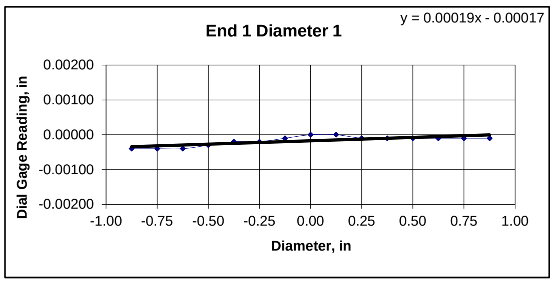
Difference between max and min readings, in:
0° = 0.00040 90° = 0.00020

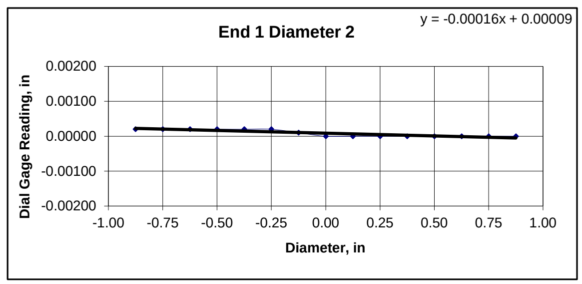
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00020	0.00030	0.00030
Diameter 2, in (rotated 90°)	0.00010	0.00010	0.00010	0.00020	0.00020	0.00020	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00040

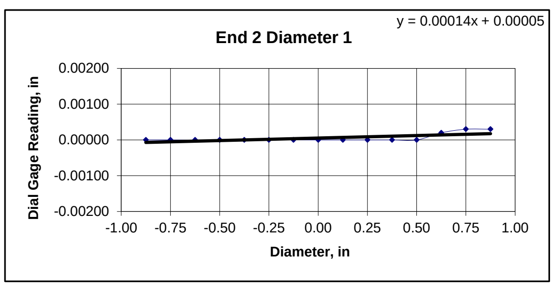
Difference between max and min readings, in:
0° = 0.0003 90° = 0.0006

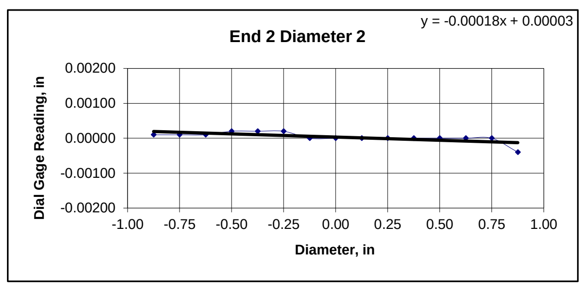
Maximum difference must be < 0.0020 in. Difference = ± 0.00030

Flatness Tolerance Met? YES









DIAMETER 1

End 1:
Slope of Best Fit Line 0.00019
Angle of Best Fit Line: 0.01089

End 2:
Slope of Best Fit Line 0.00014
Angle of Best Fit Line: 0.00802

Maximum Angular Difference: 0.00286

Parallelism Tolerance Met? YES
Spherically Seated

DIAMETER 2

End 1:
Slope of Best Fit Line -0.00016
Angle of Best Fit Line: -0.00917

End 2:
Slope of Best Fit Line -0.00018
Angle of Best Fit Line: -0.01031

Maximum Angular Difference: 0.00115

Parallelism Tolerance Met? YES
Spherically Seated

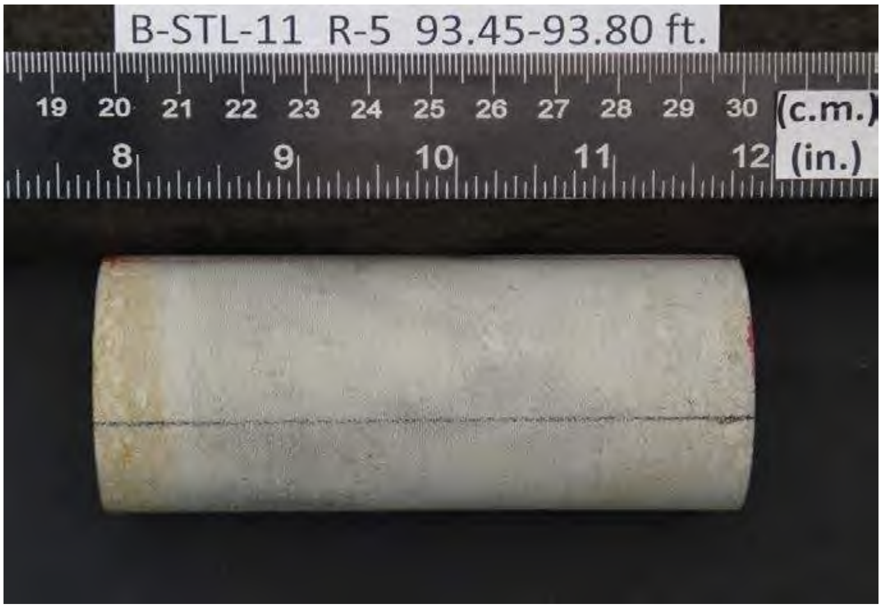
PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00040	1.860	0.00022	0.012	YES
Diameter 2, in (rotated 90°)	0.00020	1.860	0.00011	0.006	YES
END 2					
Diameter 1, in	0.00030	1.860	0.00016	0.009	YES
Diameter 2, in (rotated 90°)	0.00060	1.860	0.00032	0.018	YES

Maximum angle of departure must be ≤ 0.25°

Perpendicularity Tolerance Met? YES

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-11
Sample ID:	R-5
Depth, ft:	93.45-93.80

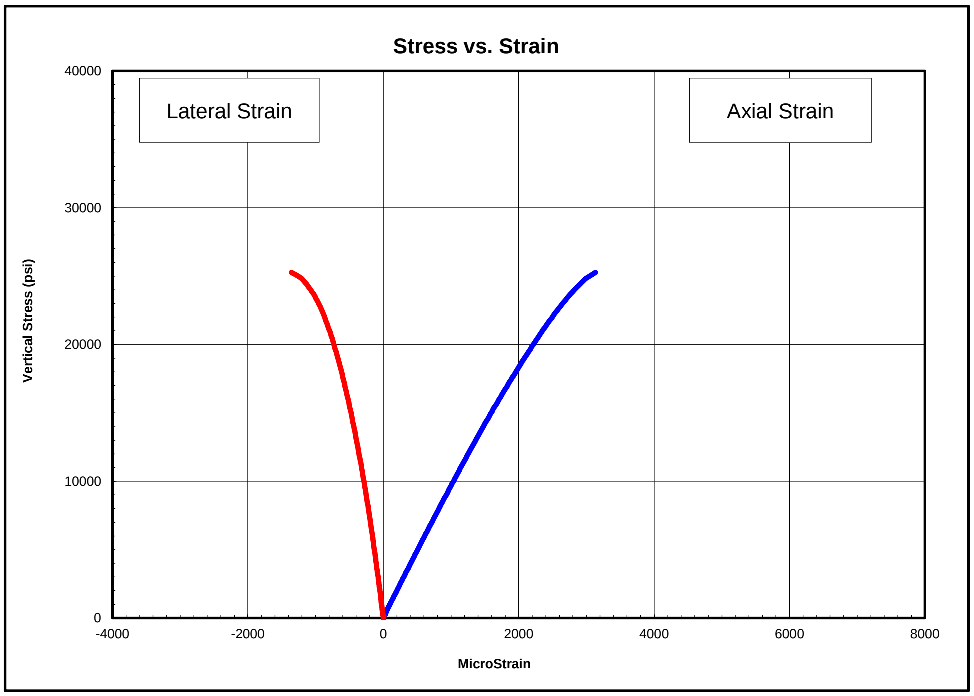


After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-11
Sample ID:	R-7
Depth, ft:	100.70-101.05
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 25,310 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
2500-9300	9,580,000	0.28
9300-16000	8,920,000	0.34
16000-22700	7,590,000	0.45

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/13/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-11		
Sample ID:	R-7		
Depth:	100.70-101.05 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average	
Specimen Length, in:	4.07	4.07	4.07	
Specimen Diameter, in:	1.86	1.86	1.86	
Specimen Mass, g:	486.69			
Bulk Density, lb/ft^3	167	**Minimum Diameter Tolerence Met?**		**NO**
Length to Diameter Ratio:	2.2	**Length to Diameter Ratio Tolerance Met?**		**YES**

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap $\leq$ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00000	-0.00010	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00010	0.00000
Diameter 2, in (rotated 90°)	0.00010	0.00000	0.00000	0.00000	0.00010	0.00010	0.00010	0.00000	0.00000	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010

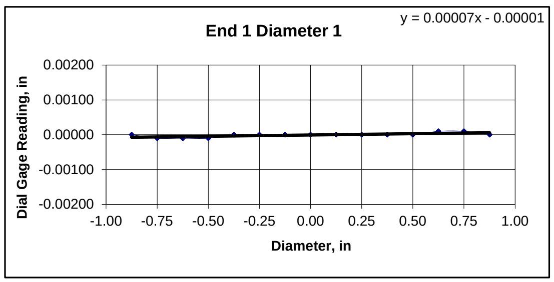
Difference between max and min readings, in:
0° = 0.00020 90° = 0.00010

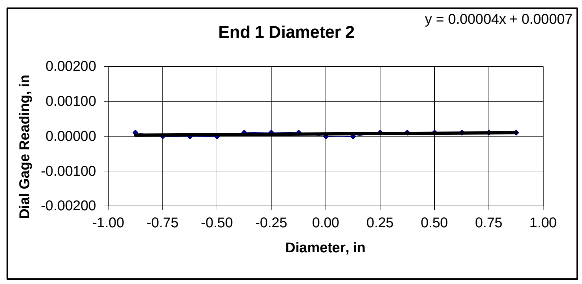
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00000	0.00000	0.00000	-0.00010	-0.00010	0.00000	0.00000	0.00000	-0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
Diameter 2, in (rotated 90°)	0.00010	0.00000	0.00010	0.00010	0.00010	0.00010	0.00010	0.00000	0.00000	0.00020	0.00020	0.00020	0.00010	0.00010	0.00020

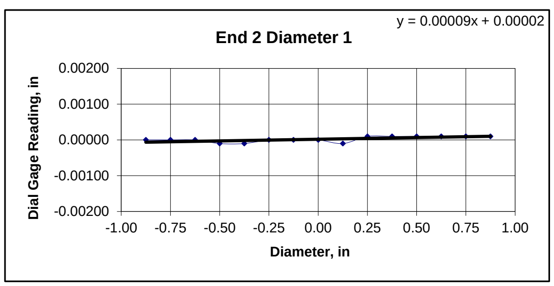
Difference between max and min readings, in:
0° = 0.0002 90° = 0.0002

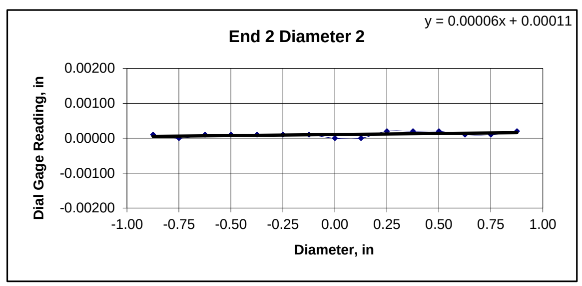
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00010

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:

Slope of Best Fit Line	0.00007
Angle of Best Fit Line:	0.00401

End 2:

Slope of Best Fit Line	0.00009
Angle of Best Fit Line:	0.00516

Maximum Angular Difference: 0.00115

Parallelism Tolerance Met? **YES**
Spherically Seated

DIAMETER 2

End 1:

Slope of Best Fit Line	0.00004
Angle of Best Fit Line:	0.00229

End 2:

Slope of Best Fit Line	0.00006
Angle of Best Fit Line:	0.00344

Maximum Angular Difference: 0.00115

Parallelism Tolerance Met? **YES**
Spherically Seated

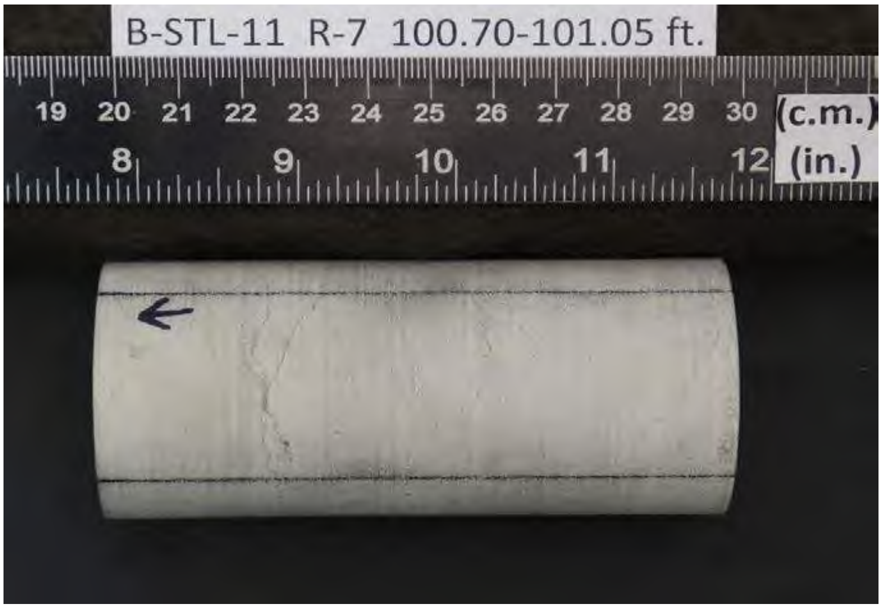
PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00020	1.860	0.00011	0.006	YES
Diameter 2, in (rotated 90°)	0.00010	1.860	0.00005	0.003	YES
END 2					
Diameter 1, in	0.00020	1.860	0.00011	0.006	YES
Diameter 2, in (rotated 90°)	0.00020	1.860	0.00011	0.006	YES

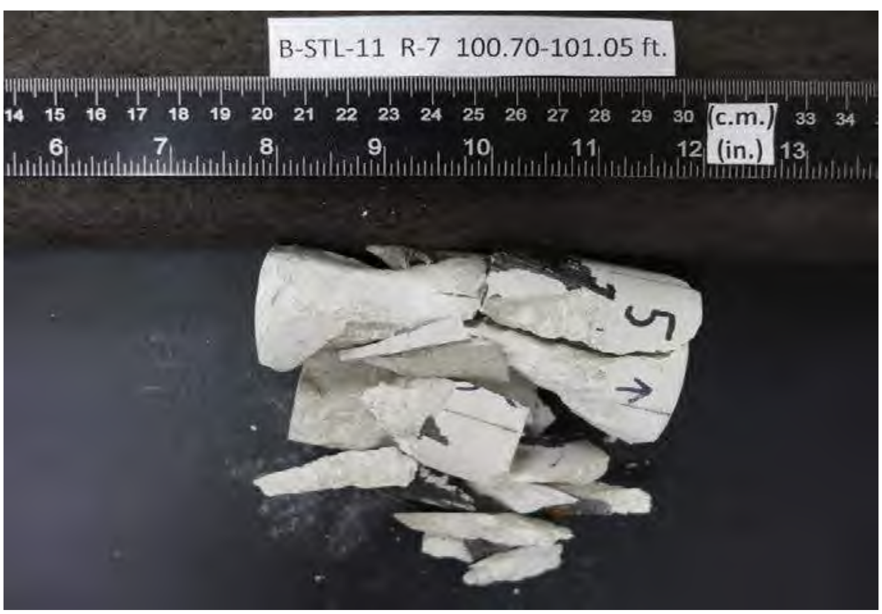
Maximum angle of departure must be $\leq$ 0.25°

Perpendicularity Tolerance Met? **YES**

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-11
Sample ID:	R-7
Depth, ft:	100.70-101.05



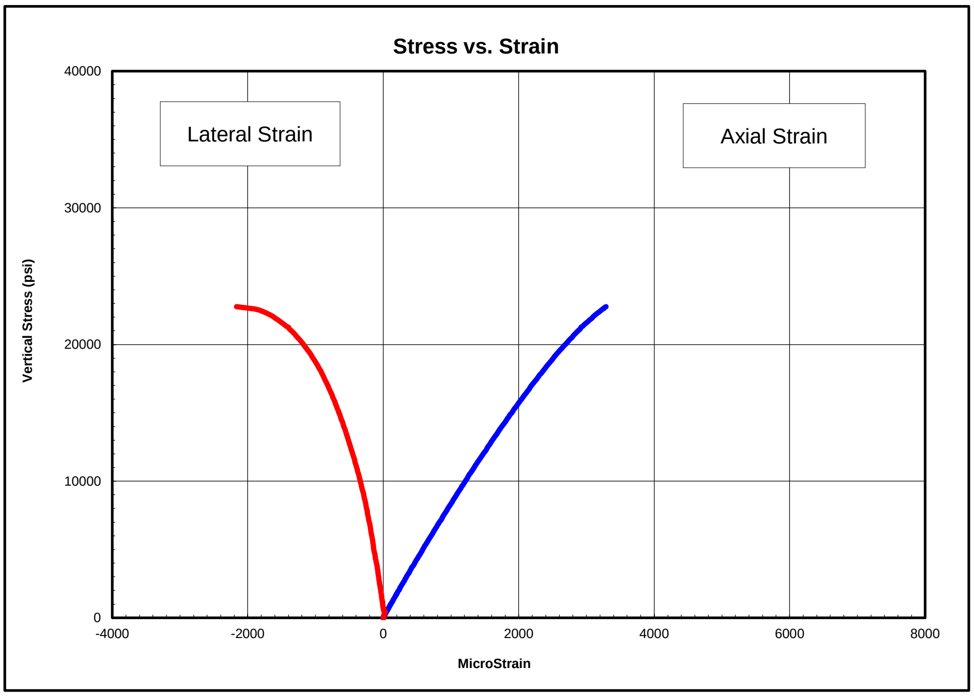
After cutting and grinding



After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-11
Sample ID:	R-10
Depth, ft:	117.60-117.95
Sample Type:	rock core
Sample Description:	See photographs Intact material failure Diameter < 1.88 in

Compressive Strength and Elastic Moduli of Rock by ASTM D7012 - Method D



Peak Compressive Stress: 22,757 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
2300-8300	8,200,000	0.29
8300-14400	7,490,000	0.43
14400-20500	6,370,000	---

Notes: Test specimen tested at the approximate as-received moisture content and at standard laboratory temperature.
The axial load was applied continuously at a stress rate that produced failure in a test time between 2 and 15 minutes.
Young's Modulus and Poisson's Ratio calculated using the tangent to the line in the stress range listed.
Calculations assume samples are isotropic, which is not necessarily the case.

Client:	TSI Geotechnical	Test Date:	4/13/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-11		
Sample ID:	R-10		
Depth:	117.60-117.95 ft		
Visual Description:	See photographs		

UNIT WEIGHT DETERMINATION AND DIMENSIONAL AND SHAPE TOLERANCES OF ROCK CORE SPECIMENS BY ASTM D4543

BULK DENSITY

	1	2	Average		
Specimen Length, in:	3.99	3.99	3.99		
Specimen Diameter, in:	1.86	1.86	1.86		
Specimen Mass, g:	462.59				
Bulk Density, lb/ft^3	162	**Minimum Diameter Tolerence Met?**		**NO**	
Length to Diameter Ratio:	2.1	**Length to Diameter Ratio Tolerance Met?**		**YES**	

DEVIATION FROM STRAIGHTNESS (Procedure S1)

Maximum gap between side of core and reference surface plate:

Is the maximum gap $\leq$ 0.02 in.? YES

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **YES**

END FLATNESS AND PARALLELISM (Procedure FP1)

END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00020	-0.00020	-0.00030	-0.00020	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00010	-0.00020	-0.00020
Diameter 2, in (rotated 90°)	-0.00020	-0.00020	-0.00020	-0.00020	-0.00030	-0.00010	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00020	-0.00010	-0.00010	-0.00010

Difference between max and min readings, in:

0° = 0.00030 90° = 0.00030

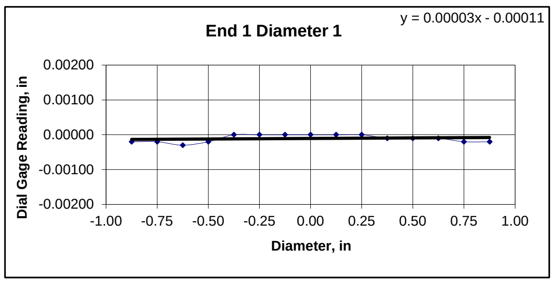
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00020	-0.00020	-0.00010	0.00000	-0.00010	-0.00010	0.00000	0.00000	0.00010	0.00010	-0.00020	-0.00020	-0.00020	-0.00010	-0.00010
Diameter 2, in (rotated 90°)	0.00000	-0.00010	-0.00010	0.00000	0.00000	0.00010	0.00000	0.00000	0.00000	0.00010	-0.00010	-0.00010	0.00000	0.00010	0.00000

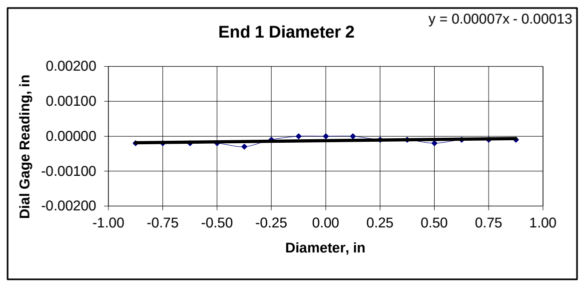
Difference between max and min readings, in:

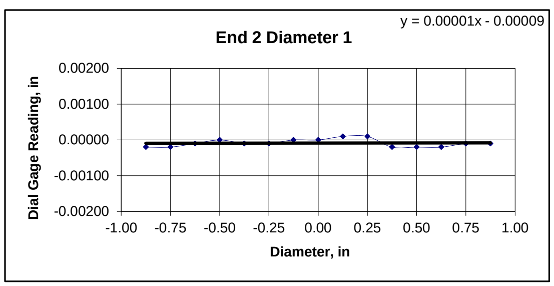
0° = 0.0003 90° = 0.0002

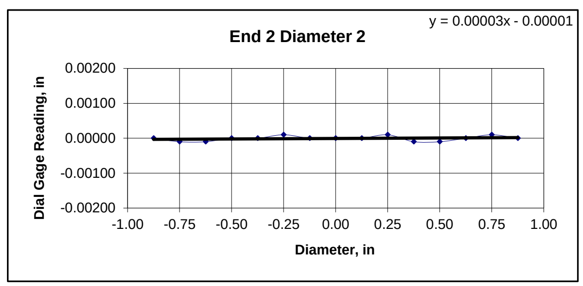
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00015

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:

Slope of Best Fit Line	0.00003
Angle of Best Fit Line:	0.00172

End 2:

Slope of Best Fit Line	0.00001
Angle of Best Fit Line:	0.00057

Maximum Angular Difference: 0.00115

Parallelism Tolerance Met? **YES**

Spherically Seated

DIAMETER 2

End 1:

Slope of Best Fit Line	0.00007
Angle of Best Fit Line:	0.00401

End 2:

Slope of Best Fit Line	0.00003
Angle of Best Fit Line:	0.00172

Maximum Angular Difference: 0.00229

Parallelism Tolerance Met? **YES**

Spherically Seated

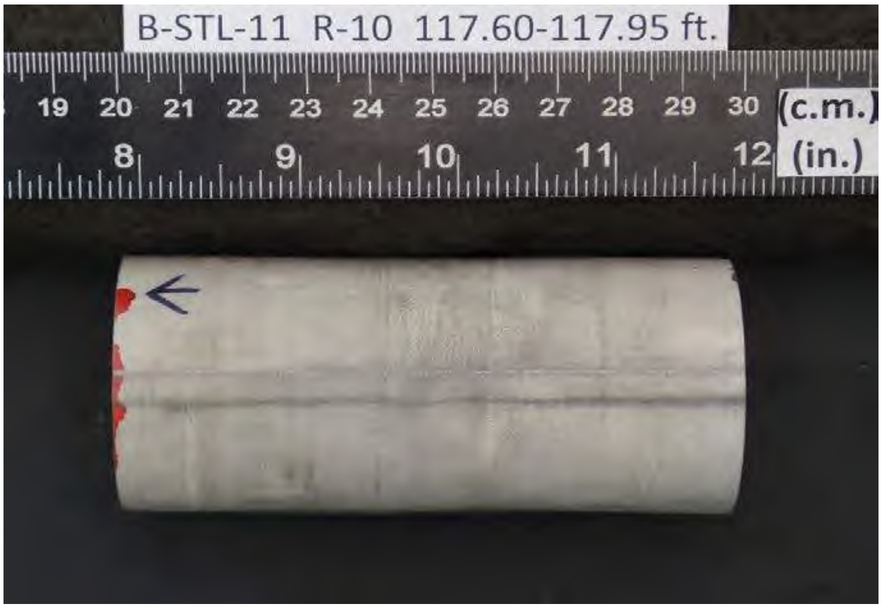
PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00030	1.860	0.00016	0.009	YES
Diameter 2, in (rotated 90°)	0.00030	1.860	0.00016	0.009	YES
END 2					
Diameter 1, in	0.00030	1.860	0.00016	0.009	YES
Diameter 2, in (rotated 90°)	0.00020	1.860	0.00011	0.006	YES

Maximum angle of departure must be $\leq$ 0.25°

Perpendicularity Tolerance Met? **YES**

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/17/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-11
Sample ID:	R-10
Depth, ft:	117.60-117.95



After cutting and grinding

After break

SITE LOCATION

Spire Pipeline Borings ■ St. Louis, MO
May 18, 2018 ■ Terracon Project No. 15185108

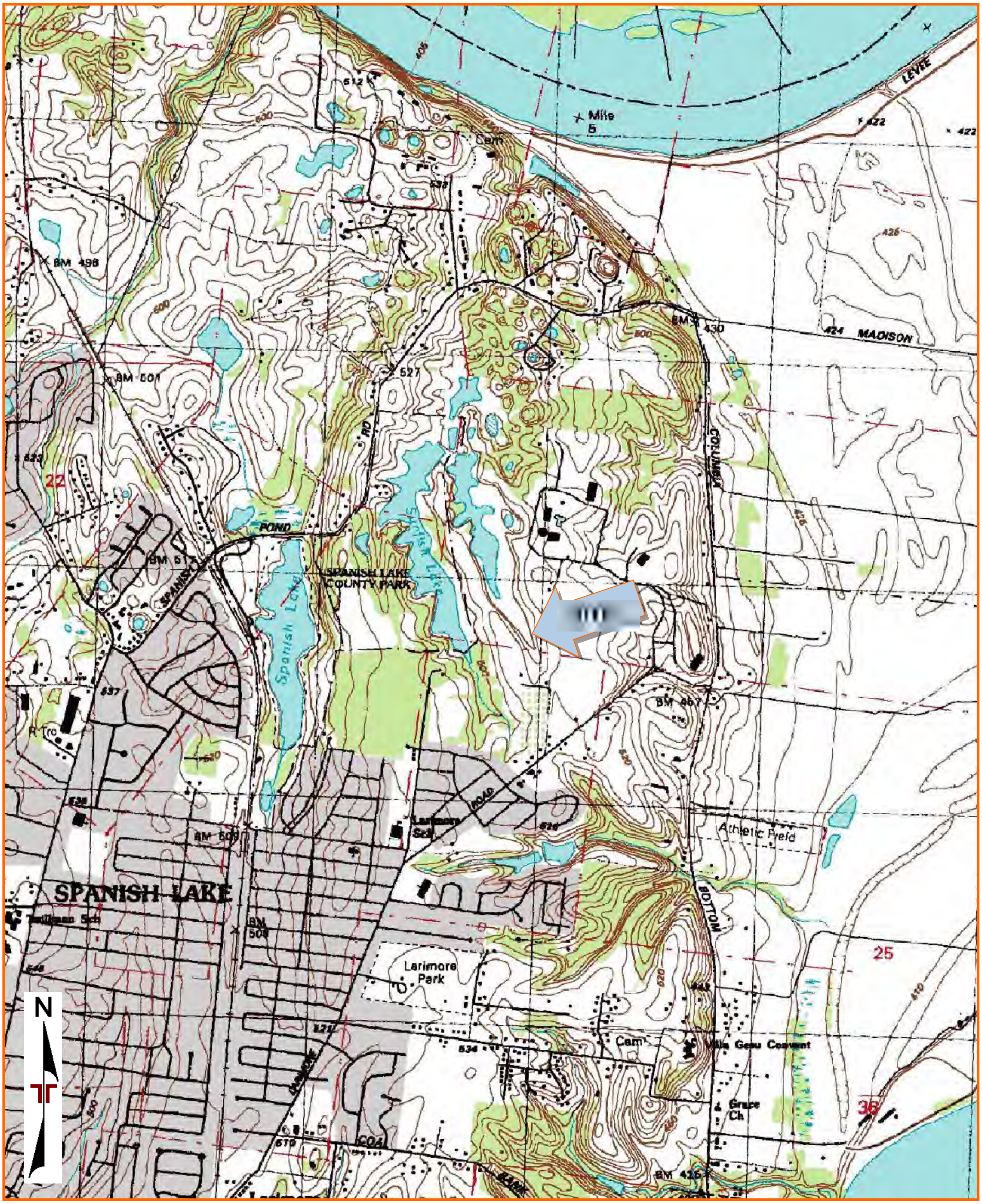


DIAGRAM IS FOR GENERAL LOCATION ONLY, AND IS NOT INTENDED FOR CONSTRUCTION PURPOSES

TOPOGRAPHIC MAP IMAGE COURTESY OF THE U.S. GEOLOGICAL SURVEY QUADRANGLES INCLUDE: COLUMBIA BOTTOM, MO (1/1/1998).

EXPLORATION PLAN

Spire Pipeline Borings ■ St. Louis, MO
May 18, 2018 ■ Terracon Project No. 15185108

DIAGRAM IS FOR GENERAL LOCATION ONLY, AND IS NOT INTENDED FOR CONSTRUCTION PURPOSES

AERIAL PHOTOGRAPHY PROVIDED BY MICROSOFT BING MAPS

BORING LOG NO. B-26

PROJECT: Emerald Greens Golf Club

CLIENT: Spire St. Louis, MO

SITE: 12385 Larimore Road St. Louis, MO

LOCATION See Exploration Plan

Latitude: 38.7966° Longitude: -90.1918°

Approximate Surface Elev: 517.5 (Ft.) +/-

GRAPHIC LOG	DEPTH / ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	SAMPLE NUMBER	HAND PENETROMETER (tsf)	WATER CONTENT (%)	ATTERBERG LIMITS LL-PL-PI
	LEAN CLAY (CL), brown									
		5		X	14	7-7-12 N=19	1	1.5		
		10		X	8	8-12-17 N=29	2	1.0		
		15		X	12	7-7-11 N=18	3	1.0		
		20		X	16	7-8-9 N=17	4	1.0		
		25		X	18	5-6-5 N=11	5	1.5		
		30		X	18	4-3-7 N=10	6	2.0		
		35		X	18	9-8-10 N=18	7	2.0		
	37.0 / 480.5+/-		▽							
	SANDY LEAN CLAY (CL), brown									
		40		X	18	10-11-12 N=23	8	1.0		
		45		X	18	3-3-4 N=7	9	2.0		
	47.0 / 470.5+/-									
	SAND (SP), trace clay, brown									
		50		X	18	11-10-14 N=24	10			

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
0-40 ft.: Hollow-stem augers
40-81 ft.: Mud rotary
Set casing to 81 ft.
81-150 ft.: Rock coring

Abandonment Method:
Boring backfilled with bentonite grout upon completion

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were provided by others.

Notes:

WATER LEVEL OBSERVATIONS

▽ *While drilling*

Terracon
11600 Lilburn Park Rd
Saint Louis, MO

Boring Started: 05-02-2018	Boring Completed: 05-04-2018
Drill Rig: #721	Driller: JM
Project No.: 15185108	

BORING LOG NO. B-26

PROJECT: Emerald Greens Golf Club

CLIENT: Spire St. Louis, MO

SITE: 12385 Larimore Road St. Louis, MO

LOCATION See Exploration Plan

Latitude: 38.7966° Longitude: -90.1918°

Approximate Surface Elev: 517.5 (Ft.) +/-

DEPTH	MATERIAL DESCRIPTION	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	SAMPLE NUMBER	HAND PENETROMETER (tsf)	WATER CONTENT (%)	ATTERBERG LIMITS LL-PL-PI
	SAND (SP), trace clay, brown *(continued)*										
			55			16	8-12-16 N=28	11			
			60			12	9-11-14 N=25	12			
			65			14	7-9-11 N=20	13			
			70			16	6-7-9 N=16	14			
			75			18	7-10-11 N=21	15			
77.0	**SANDY LEAN CLAY (CL)**, brown	440.5+/-									
79.0	**LIMESTONE**	438.5+/-				9	11-50/3"	16			
			80								
			85				Rec.: 77% RQD: 55%	R1			
86.0	**HIGHLY WEATHERED LIMESTONE**, quick coring	431.5+/-									
88.0	**LIMESTONE**	429.5+/-									
			90								
			95				Rec.: 100% RQD: 85%	R2			
			100								

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
0-40 ft.: Hollow-stem augers
40-81 ft.: Mud rotary
Set casing to 81 ft.
81-150 ft.: Rock coring

Abandonment Method:
Boring backfilled with bentonite grout upon completion

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were provided by others.

Notes:

WATER LEVEL OBSERVATIONS

While drilling

Terracon
11600 Lilburn Park Rd
Saint Louis, MO

Boring Started: 05-02-2018	Boring Completed: 05-04-2018
Drill Rig: #721	Driller: JM
Project No.: 15185108	

BORING LOG NO. B-26

PROJECT: Emerald Greens Golf Club

CLIENT: Spire
St. Louis, MO

SITE: 12385 Larimore Road
St. Louis, MO

GRAPHIC LOG	LOCATION See Exploration Plan Latitude: 38.7966° Longitude: -90.1918° Approximate Surface Elev: 517.5 (Ft.) +/- DEPTH / ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	SAMPLE NUMBER	HAND PENETROMETER (tsf)	WATER CONTENT (%)	ATTERBERG LIMITS LL-PL-PI
	LIMESTONE *(continued)*	105				Rec.: 98% RQD: 89%	R3			
		110–115				Rec.: 100% RQD: 82%	R4			
		120–125				Rec.: 100% RQD: 77%	R5			
		130–135				Rec.: 95% RQD: 78%	R6			
		140–145				Rec.: 97% RQD: 85%	R7			
	150.0 367.5+/-	150								
	Boring Terminated at 150 Feet									

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
0-40 ft.: Hollow-stem augers
40-81 ft.: Mud rotary
Set casing to 81 ft.
81-150 ft.: Rock coring

Abandonment Method:
Boring backfilled with bentonite grout upon completion

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were provided by others.

Notes:

WATER LEVEL OBSERVATIONS

While drilling

Terracon
11600 Lilburn Park Rd
Saint Louis, MO

Boring Started: 05-02-2018	Boring Completed: 05-04-2018
Drill Rig: #721	Driller: JM
Project No.: 15185108	

BORING LOG NO. B-17B

PROJECT: Emerald Greens Golf Club

CLIENT: Spire
St. Louis, MO

SITE: 12385 Larimore Road
St. Louis, MO

LOCATION See Exploration Plan

Latitude: 38.7987° Longitude: -90.1948°

Approximate Surface Elev: 515 (Ft.) +/-

DEPTH	Description	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	SAMPLE NUMBER	HAND PENETROMETER (tsf)	WATER CONTENT (%)	ATTERBERG LIMITS LL-PL-PI
	LEAN CLAY (CL), brown										
			5		X	12	3-4-5 N=9	1	2.5		
			10		X	15	2-4-6 N=10	2	2.5		
			15		X	6	2-4-4 N=8	3	0.5		
			20		X	18	2-4-5 N=9	4	1.5		
			25		X	18	2-3-4 N=7	5	2.5		
			30		X	18	3-3-4 N=7	6	0.5		
32.0		483+/-									
	SANDY LEAN CLAY (CL), brown			▽							
			35		X	18	1-2-1 N=3	7	0.25		
			40		X	18	3-6-6 N=12	8			
42.0		473+/-									
	SAND (SP), trace clay, brown										
			45		X	10	3-5-5 N=10	9			
			50		X	10	5-5-5 N=10	10			

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
0-40 ft.: Hollow-stem augers
40-60 ft.: Mud rotary
Set casing to 60 ft.
60-150 ft.: Rock coring

Abandonment Method:
Boring backfilled with bentonite grout upon completion

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were provided by others.

Notes:

WATER LEVEL OBSERVATIONS

▽ *While drilling*

Terracon
11600 Lilburn Park Rd
Saint Louis, MO

Boring Started: 05-08-2018	Boring Completed: 05-10-2018
Drill Rig: #721	Driller: JM
Project No.: 15185108	

BORING LOG NO. B-17B

PROJECT: Emerald Greens Golf Club

CLIENT: Spire
St. Louis, MO

SITE: 12385 Larimore Road
St. Louis, MO

LOCATION See Exploration Plan

Latitude: 38.7987° Longitude: -90.1948°

Approximate Surface Elev: 515 (Ft.) +/-

DEPTH	Description	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	SAMPLE NUMBER	HAND PENETROMETER (tsf)	WATER CONTENT (%)	ATTERBERG LIMITS LL-PL-PI
52.0		463+/-									
	SANDY LEAN CLAY (CL), brown		55			18	2-2-3 N=5	11	0.25		
58.5		456.5+/-									
	LIMESTONE					1	50/2"	12	1.5		
61.0		454+/-	60				Rec.: 56% RQD: 33%	R1			
62.0	**Apparent Void**	453+/-									
	LIMESTONE		65				Rec.: 93% RQD: 62%	R2			
			75				Rec.: 96% RQD: 83%	R3			
			85				Rec.: 100% RQD: 100%	R4			
			95				Rec.: 98% RQD: 96%	R5			
			100								

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
0-40 ft.: Hollow-stem augers
40-60 ft.: Mud rotary
Set casing to 60 ft.
60-150 ft.: Rock coring

Abandonment Method:
Boring backfilled with bentonite grout upon completion

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were provided by others.

Notes:

WATER LEVEL OBSERVATIONS

While drilling

Terracon
11600 Lilburn Park Rd
Saint Louis, MO

Boring Started: 05-08-2018	Boring Completed: 05-10-2018
Drill Rig: #721	Driller: JM
Project No.: 15185108	

BORING LOG NO. B-17B

PROJECT: Emerald Greens Golf Club

CLIENT: Spire St. Louis, MO

SITE: 12385 Larimore Road St. Louis, MO

LOCATION See Exploration Plan

Latitude: 38.7987° Longitude: -90.1948°

Approximate Surface Elev: 515 (Ft.) +/-

DEPTH / ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	SAMPLE NUMBER	HAND PENETROMETER (tsf)	WATER CONTENT (%)	ATTERBERG LIMITS LL-PL-PI
LIMESTONE *(continued)*	105				Rec.: 98% RQD: 57%	R6			
	115				Rec.: 99% RQD: 54%	R7			
	120				Rec.: 92% RQD: 75%	R8			
	125				Rec.: 100% RQD: 88%	R9			
	135				Rec.: 99% RQD: 57%	R10			
	145				Rec.: 98% RQD: 82%	R11			
150.0 / 365+/-	150								

Boring Terminated at 150 Feet

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
0-40 ft.: Hollow-stem augers
40-60 ft.: Mud rotary
Set casing to 60 ft.
60-150 ft.: Rock coring

Abandonment Method:
Boring backfilled with bentonite grout upon completion

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were provided by others.

Notes:

WATER LEVEL OBSERVATIONS

While drilling

Terracon
11600 Lilburn Park Rd
Saint Louis, MO

Boring Started: 05-08-2018	Boring Completed: 05-10-2018
Drill Rig: #721	Driller: JM
Project No.: 15185108	