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ATTACHMENT L

HDD Reports

STL Pipeline
24-inch Cold Water Creek Crossing
by Horizontal Directional Drilling

HDD Design Report

August 8, 2018

Prepared for

Spire STL Pipeline LLC
700 Market Street
Saint Louis, MO 63101

Prepared by

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

2424 E 21st St, Suite 510
Tulsa, Oklahoma 74114-1723

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

2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114
Tel 918-747-9945
Fax 918-742-7408
www.jdhair.com

August 8, 2018

Spire STL Pipeline LLC
700 Market Street
St. Louis, MO 63101

Attention: Mr. Russell English

SUBJECT: HDD Design Report
STL Pipeline – Coldwater Creek Crossing

Dear Mr. English:

J. D. Hair & Associates, Inc. (JDH&A) is pleased to submit Revision 1 of the report titled *HDD Design Report, Spire STL Pipeline, 24-inch Coldwater Creek 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
8-8-18

Jeffrey M. Scholl, P.E.
Vice President

STATE OF MISSOURI
JEFFREY M. SCHOLL
NUMBER
PE-2017022062
PROFESSIONAL ENGINEER

Executive Summary

The following report presents a summary of design considerations and engineering calculations associated with the proposed 24-inch pipeline crossing beneath Coldwater Creek installed using horizontal directional drilling (HDD). The proposed HDD crossing is in the northern suburbs of St. Louis, MO. 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 Coldwater Creek crossing utilizes a 16-degree entry angle, a 10-degree exit angle, and a radius of curvature equal to 2,400 feet. The crossing achieves 80 feet of cover beneath Coldwater Creek, and more than 100 feet beneath U.S. Highway 67 and the BNSF & Santa Fe railroad tracks. The horizontal reference length of the crossing is 3,318 feet while the true drilled length is 3,353 feet.

Mott MacDonald administered a subsurface investigation at the proposed crossing site. The results of the investigation revealed that overburden consisted primarily of clay and silt. Overburden N-values varied from soft to stiff. Limestone was encountered at depths ranging from approximately 35 feet to 55 feet. Geotechnical drilling exposed vuggy texture and porous karst features within the limestone bedrock. 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 along the proposed HDD alignment. Two EI surveys indicated the presence of karst features on the east side of Coldwater Creek. THG also conducted a microgravity survey (MG) on the west side of the crossing. The MG did not indicate solution cavities or karst features.

It is the opinion of JDH&A that, although subsurface conditions present risk of HDD operational problems, the technical feasibility of using HDD cannot be ruled out.

A hydrofracture evaluation was conducted 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 Coldwater Creek. The low potential for inadvertent drilling fluid returns due to hydrofracture is largely because the crossing will be installed through sedimentary bedrock as it passes beneath the creek. However, given the local karst topography, there is an increased risk of loss of drilling fluid circulation 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 Coldwater Creek is low. The risk of hydrofracture increases west of Coldwater Creek due to the possibility of drilling through sediment-filled sinkholes. 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 by HDD will be within acceptable limits provided the actual geometry of the 24-inch pullsection does not vary significantly from that used in the installation loading models, the HDD contractor does not employ any improper construction procedures and that unanticipated problematic subsurface conditions will not be 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 74 days. The estimate assumes a six-day workweek with single, 10-hour shifts during pilot hole, reaming, and pullback operations, and does not include contingency.

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APPENDICES

1 INTRODUCTION

This purpose of this report is to provide a summary of design considerations and engineering calculations associated with a proposed 24-inch pipeline crossing beneath Coldwater Creek 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 STL 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, GR. X70 steel pipe specification provided by Spire STL Pipeline LLC.
- Geotechnical Memorandum prepared by Mott Macdonald, Inc. titled “Spire STL Pipeline – Coldwater Creek Crossing” dated August 31, 2017.

3 HDD DESIGN CONSIDERATIONS

3.1 Background and General Site Description

The proposed project site is located roughly six miles west of the convergence of the Missouri River and Mississippi River at the intersection of Lindbergh Boulevard and U.S. Highway 367 in northeast St. Louis County, Missouri. 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 are New Jamestown Road, U.S. Highway 367 and associated entrance/exit ramps, BNSF & Santa Fe railroad tracks, and Coldwater Creek. The proposed alignment generally trends east to west crossing north of the intersection of U.S. Highway 367 and Lindbergh Boulevard. Coldwater Creek is a shallow stream that is approximately 150 feet wide from bank to bank. The proposed crossing extends from a wooded parcel at the intersection of Lindbergh Boulevard and New Jamestown Road to a cultivated field on the east side of the crossing. Refer to Figure 2 for a detail view of the proposed crossing alignment.

The topography in the vicinity is variable, best characterized as rolling hills. From east to west along the proposed alignment, there is an elevation drop of approximately 40 feet down to the central portion of the crossing that contains Coldwater Creek. The topography rises steeply on the immediate west bank of Coldwater Creek, rising approximately 45 to 50 feet up to the BNSF railway. The elevation continues to rise toward the west, with an additional 40 feet of relief between the BNSF railway and the proposed entry point located just west of New Jamestown Road. East of the creek, the topography is relatively constant for approximately 750 feet before a series of steep hills that finally gain an additional 40 feet of relief toward the exit point.

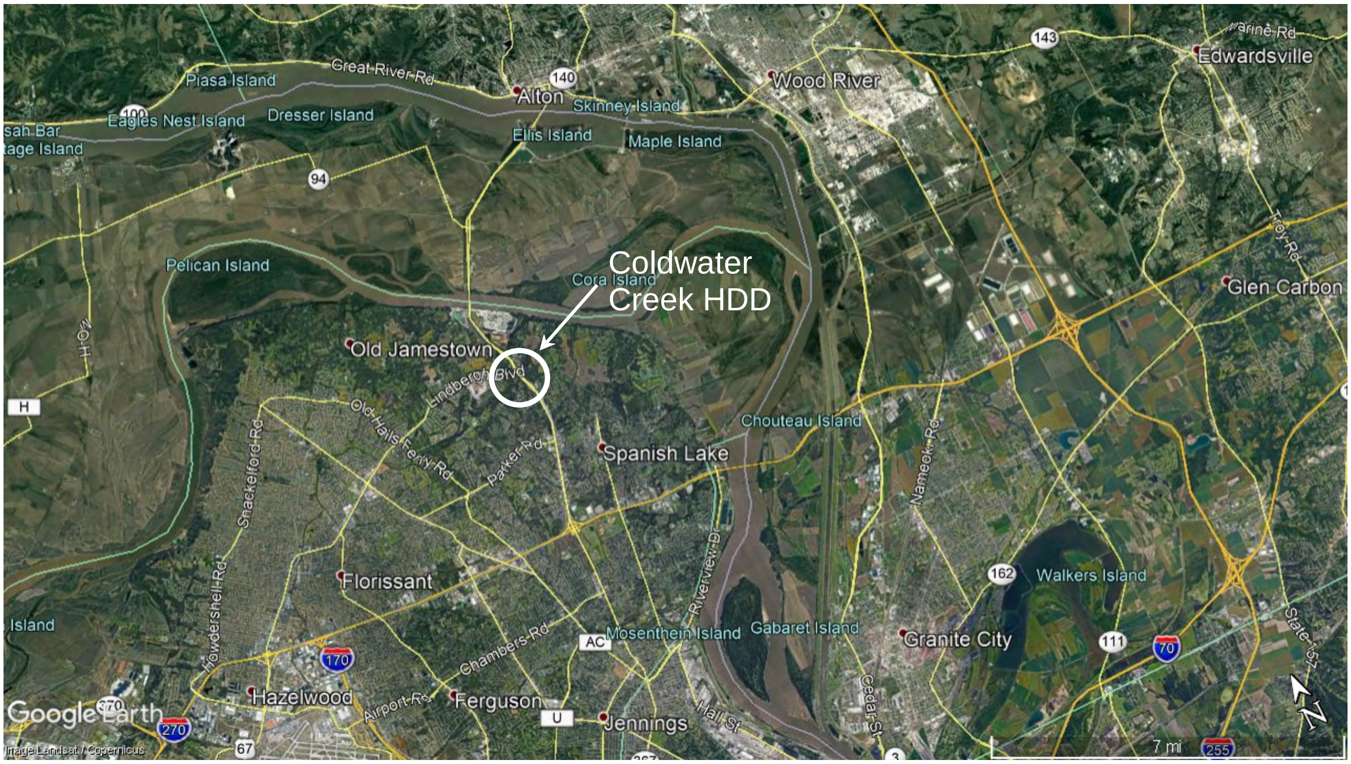

Figure 1: Area Vicinity Map

Figure 2: Detailed view of the proposed crossing

3.2 HDD Design Geometry

The plan and profile design for the proposed Coldwater Creek HDD crossing is provided in Appendix 1. It has been designed in general accordance with standard HDD industry practices. The proposed HDD alignment is designed with a 6.75-degree side bend to avoid having the alignment pass under foundation footings associated with the U.S. 367 and Lindbergh Boulevard.

The HDD entry point is located on the west side of the crossing, north of Lindbergh Boulevard and approximately 300 feet west of New Jamestown Road. It employs a 16-degree entry angle. The steeper angle is necessary to avoid overlap between the vertical sag bends and horizontal side bend (compound curve), which is desirable from a design standpoint. Compound curves involve greater difficulty with respect to steering and also require incorporating larger horizontal and vertical radii during the design process to compensate for the fact that the combined radius is approximately 30 percent less than the individual horizontal and vertical radii. To reduce the risk of inadvertent drilling fluid returns surfacing within the creek, as well as to reduce the risk of encountering dissolution features such as sinkholes, JDH&A designed the crossing to penetrate deep into the bedrock, achieving a minimum depth of 80 feet beneath Coldwater Creek and Highway 367 and over 100 feet beneath BNSF railroad. The HDD exit point is located on the east side of the crossing within a cultivated field. The east side was chosen as the exit location because of the ample linear open space for pullsection staging along the proposed right-of-way (ROW). The exit angle is set to 10 degrees. The HDD design radius of curvature is 2,400 feet for both the horizontal and vertical curves. The resulting horizontal reference length of the crossing is 3,318 feet while the true drilled length is 3,353 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

Permanent easement and workspace limits available for HDD operations are shown on the plan and profile drawing in Appendix 1.

3.3.1 Entry Side

Workspace for HDD rig side operations is located on the west side of the crossing in what is currently a wooded parcel. In addition to the existing 50-foot wide ROW, a block of temporary workspace that is 250 feet wide by 250 feet long is available, which 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 Side

Workspace for HDD pipe side operations and pullsection fabrication will be located on the east side of the crossing. In addition to the existing ROW, there is a block of temporary workspace surrounding the desired exit point that is approximately 250 feet wide by 286 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. Pullsection fabrication and layout will generally follow the proposed permanent ROW that runs parallel to the BNSF railway. There is approximately 1,962 feet available for pullsection staging between the exit point and Bellefontaine Road. Because the crossing is longer than the available pullsection workspace, the pipe will need to be staged in at least two sections. This will force the contractor into completing a tie-in weld during pullback. Although welds during pullback are undesirable and can increase the risk of the product pipe becoming stuck due to extended downtime, it is common practice in the industry. In this case, because the installation will pass primarily through limestone bedrock, the reamed hole should generally be stable, remaining open during downtime associated with welding, etc., with little to no loose material falling into the reamed hole. Because of this, the risk of the pipeline becoming stuck is minimal.

3.4 Subsurface Conditions

Mott Macdonald, in coordination with Spire, performed a geotechnical site investigation for the proposed crossing. Three geotechnical borings, in addition to a subsequent geophysical survey, were taken at the site. Boring B-STL-01 was taken on the west side of New Jamestown Road, close to 350 feet away from the entry point and nearly 130 feet offset from the alignment. Boring B-STL-03 was taken 120 feet north of the alignment near the horizontal point of tangency. Finally, Boring B-STL-08 occurred 195 feet west of the exit point and just 11 feet north of the alignment. Due to the heavily wooded area north of the railroad between the horizontal point of tangency and the exit point, no geotechnical borings were taken in the area, leaving roughly 1,880 feet between borings B-STL-03 and B-STL-08. Boring termination depths for B-STL-01 and B-STL-03 were 200 feet while B-STL-08 was terminated 150 feet below the ground surface.

The geotechnical borings indicate subsurface overburden conditions consisting primarily of clay and silt ranging from soft to stiff. Gravel was observed within the first 10 feet of B-STL-08. Underlying the overburden is limestone with occasional thin layers of mudstone. Rock quality designation (RQD) values generally fell within the good to excellent range, with the direct average being approximately 76 percent, indicating good quality bedrock. Unconfined compressive strength of the limestone ranged from 9,680 psi to 30,000 psi, with the average being 18,825 psi. The limestone generally contains pitting (vuggs) with solution cavities noted, particularly in boring B-STL-03, which encountered clay filled voids ranging in size from 0.3 feet to 8 feet from 54 to 77 feet below the ground surface.

Overall, based specifically on the results of the site-specific geotechnical borings, the limestone bedrock that will be penetrated is conducive to the HDD process. There are, however, a few features associated with it that may result in HDD operational problems. 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 and interbedded chert were encountered in all three borings at varying depths. Another feature of the limestone worth noting is that clay-filled solution cavities/voids were encountered. 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 only the only boring that encountered a large cavity was B-STL-03, their presence across the rest of the alignment is possible. The desktop study conducted by Mott Macdonald indicated the crossing is within a region characterized by karst topography, therefore there is relatively high risk of encountering additional voids.

To further characterize the subsurface and possibly assess the possibility of the presence of additional solution features in the limestone, Mott Macdonald retained THG Geophysics to conduct non-intrusive geophysical surveys along the HDD alignment. THG conducted microgravity and electrical imaging surveys as part of their scope of services. The microgravity (MG) surveys were taken on the west side of the crossing, generally extending from the west side of New Jamestown Road over 980 feet to Coldwater Creek. The MG results did not indicate the presence of voids. Depressions in the readings were interpreted as resulting from urban fill as opposed to solution cavities. THG conducted three electrical imaging (EI) surveys. The first survey was conducted west of US Highway 367 along the hillside near the entry point. The second profile extended from the east bank of Coldwater Creek to the end of the cultivated field east of the exit point. The third was completed in a direction perpendicular to the proposed alignment in the wooded area east of Coldwater Creek.

According to the summary report completed by THG, voids were not interpreted in the first survey west of New Jamestown Road. karst features were, however, found in EI surveys 2 and 3. THG’s interpretation of EI survey 2 indicates possible voids consistent with sediment-filled historic sinkholes starting approximately 350 feet east of Coldwater Creek. THG’s interpretation indicates the bottom of the sediments may fall below elevation 380. The results of THG’s geophysical survey are questionable however, because EI survey 2 indicates a deep soil horizon extending to elevation 380 at the approximate location of boring B-STL-8. The depth of bedrock in boring B-STL-8 was elevation 480. Therefore, the EI results do not correlate well with the known site-conditions. That said, the area where the voids are noted falls within a topographic low, which could have resulted over geologic time through the gradual weather and dissolution of the bedrock material.

A copy of the complete Coldwater Creek site geotechnical investigation report is included in Appendix 6.

3.5 Assessment of Feasibility

With a length of 3,353 feet and a diameter of 24-inches, the proposed installation is within current HDD industry capabilities for installations through bedrock. Based on the site-specific geotechnical investigation, subsurface conditions are conducive to the HDD process with the exception that there is the possibility of encountering solution cavities or sinkholes. 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 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 a large cavity/open cave during the pilot hole. Multiple pilot holes were attempted but all resulted in drill pipe failures. More recently, however, JDH&A was involved with a successful HDD crossing where significant karst features were present, including several sinkholes visible near the alignment. We believe one reason for the success of the recent crossing is that the dissolution features and voids were filled with unconsolidated sediment which helped restrain the drill pipe and prevented failure. We believe one reason for the success of the recent crossing is that the predominant karst features were near-surface in the form of sinkholes. The sinkholes contained unconsolidated sediment which helped restrain the drill pipe. Another probable reason for the success is that HDD contractors have moved away from using 5.000-inch O.D. drill pipe and now commonly use 6.625-inch diameter drill pipe (and greater). The larger drill pipe has higher strength and greater resistance to deflection, which reduces the risk of drill pipe failure. It is because of the success of this recent crossing through relatively similar subsurface conditions that we do not believe the technical feasibility of Coldwater Creek can be ruled out.

4 PIPE STRESS ANALYSIS

4.1 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 and a summary of the estimated pulling loads is provided in provided in Table 2.

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: 1,600'	9 ppg 12 ppg	Empty	Assumed Negligible

[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.

Table 2: Summary of Results –Installation Stress Analysis

Loading Scenario	Path Geometry	Drilling Fluid Weight	Pulling Load (lbs.)	PRCI Stress Checks
Number 1	As-Designed	9 ppg 12 ppg	191,541 273,688	Pass
Number 2	Worse-Case	9 ppg 12 ppg	213,618 296,906	Pass

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 pull section segment will not exceed the length or depth of the loading scenarios 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. 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 rock ledge or boulder, which under certain circumstances, could cause indentation of the product pipeline.

4.2 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. Three 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	1,440	60	80
Number 2 (Operation)	50% of Design	1,440	60	80
Number 3 (Hydrostatic Testing)	50% of Design	2,200	60	80

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. As with the other scenarios, it shows combined stress within reasonable limits. Refer to Appendix 3 for detailed results.

5 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.

5.1 Soil Confining Capacity

The soil confining capacity for the proposed crossing 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 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 not yet been adopted in the HDD industry. One of the reasons for this is the fact that annular pressures associated with HDD operations are very low relative to pressures typically necessary to initiate bedrock fracturing; therefore, hydrofracture in rock has historically been classified as a low risk occurrence in the HDD industry. 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.

5.2 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

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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

drilling fluid to continue flowing. Frictional pressure losses for HDD pilot hole operations were 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 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

5.3 Results of Hydrofracture Calculations

The results of JDH&A's 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. Formation 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 occur during pilot hole operations, the potential for hydrofracture during the reaming process was not calculated. As mentioned previously, the confining capacity of the limestone has not been considered as part of the evaluation since hydrofracture of competent bedrock is not typically considered 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 formation 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.

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

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 250 feet of the crossing prior to the crossing penetrating bedrock. The high risk is a function of the relatively shallow depth of the HDD segment as well as subsurface material that consists of cohesive soils which are subject to plastic deformation under relatively low pressure.

On the exit side of the crossing, the calculations indicate that the annular pressure will exceed the strength of the overburden soils over the last approximate 150 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 within an environmental resource that are not easily accessible, and therefore can 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 and the mud system turned off, in that event that drilling fluid surfaces.

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.

6 RISK IDENTIFICATION AND ASSESSMENT

6.1 Geotechnical Conditions

Based on site-specific data, it appears that the HDD segment may encounter sinkholes and or solution cavities on the east side of Coldwater Creek. The crossing has been designed to penetrate deep into bedrock to improve the chance of avoiding areas containing solution features. If the HDD segment does pass through a karst feature, we believe the sediments within the sinkhole or cavity will serve to restrain the drill pipe and reduce the risk of drill pipe failure. That is not to say that drilling from bedrock, into a softer sediment, and then back into bedrock will be easy. Rather, it will involve operational risks typical of partial rock crossings, such as tools hanging up on the rock ledge due to misalignment of the reamed hole, or the pullsection getting lodged due to misalignment during pullback.

Since the crossing will be installed primarily through relatively hard limestone bedrock with average UCS values averaging18,825 psi, the crossing will involve risk of operational problems consistent with 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 occur when passing through regions of bedrock containing high percentages of quartz minerals. It is rare that operational problems such as those noted above prevent an installation entirely. Rather, they result in construction delays, which in some cases have the potential to impact the planned in-service date of the pipeline.

6.2 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 will occur. Although inadvertent drilling fluid returns 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. In addition to impacting the environment, there is also a possibility that drilling fluid can impact utilities or other structures. It is possible that drilling fluid could flow to the surface beneath New Jamestown Road or U.S. Highway 367, resulting in heaving of the asphalt or concrete, 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 much of its duration, the risk of inadvertent drilling fluid returns due to hydrofracture is low over much 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. Though it is difficult to fully quantify since site-specific samples from the area are not available, there is also an increased risk of hydrofracture in the wooded area west of Coldwater Creek if the HDD segment passes out of rock and into unconsolidated sediment.

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 the exploratory borings, the crossing has a higher than average risk of drilling fluid loss into the formation. Given the depth of the proposed HDD design New Jamestown Road and U.S. Highway 367, however, drilling fluid impact to the ground surface is not expected.

6.2.1 Minimizing Drilling Fluid Impact

Although the risk of inadvertent drilling fluid returns cannot be eliminated, it can be managed. It is critical that the HDD contractor take a proactive approach to maintain drilling fluid circulation and minimize annular pressure. From an operational standpoint, using good drilling practices such as swabbing the hole after each joint and routinely tripping back to flush the hole when drilling fluid circulation is diminishing can go a long way in reducing the risk of inadvertent drilling fluid returns. Other operational measures such as using an annular pressure tool during pilot hole drilling, measuring and adjusting drilling fluid to optimize drilling fluid rheology, using temporary surface casing to provide an open conduit for drilling fluid returns, have all been shown to promote drilling fluid circulation and reduce the risk of drilling fluid impact.

In additional to operational protocols, the other component to managing the risk associated with inadvertent drilling fluid returns and reducing environmental impact is through establishing a robust monitoring plan so that if inadvertent returns do occur, they will be detected sooner rather than later. Detecting drilling fluid that makes its way to the surface early will reduce the total footprint of the impact area. When drilling fluid returns to the entry point are prominent with full drilling fluid circulation, we recommend routine monitoring of the construction easement at intervals of once every two hours. When drilling fluid circulation to the entry point is lost or significantly diminished, and restoration attempts are unsuccessful, we recommend full time monitoring of the easement and adjacent land areas. With respect to the Coldwater Creek crossing, full time ROW monitoring over the area east of the crossing where there are potential sinkholes and/or voids is recommended.

7 CONSTRUCTION DURATION

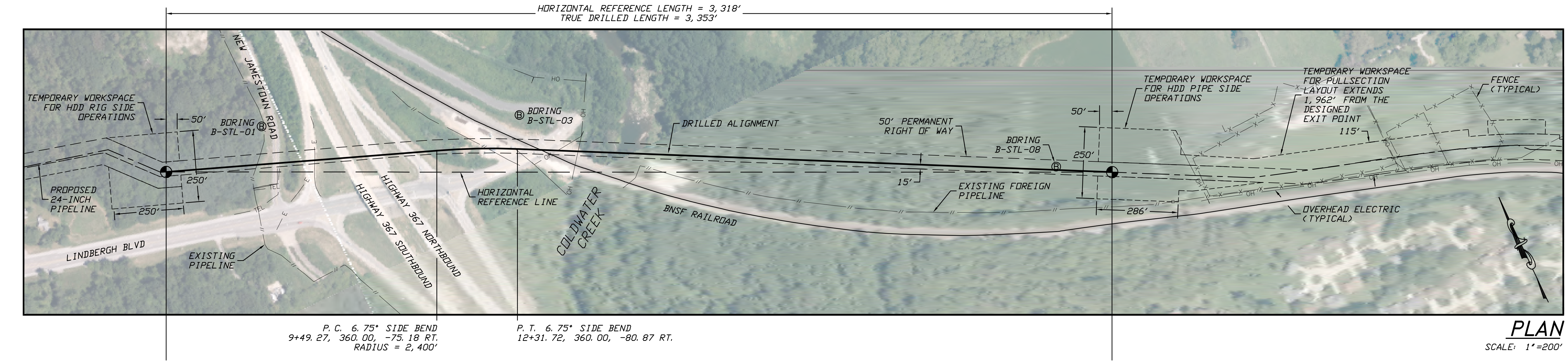
The estimated duration of construction for the Coldwater Creek crossing is 74 days. The estimate assumes a 6-day work week with single 10-hour shifts during pilot hole, reaming, and pullback operations. The pilot hole production rate and reaming travel speeds were estimated by JDH&A based on information contained within the Pipeline Research Council International's "*Installation of Pipelines by Horizontal Directional Drilling*"[5], as well as experience in similar subsurface conditions. Refer to Appendix 5 for details relative to the estimate.

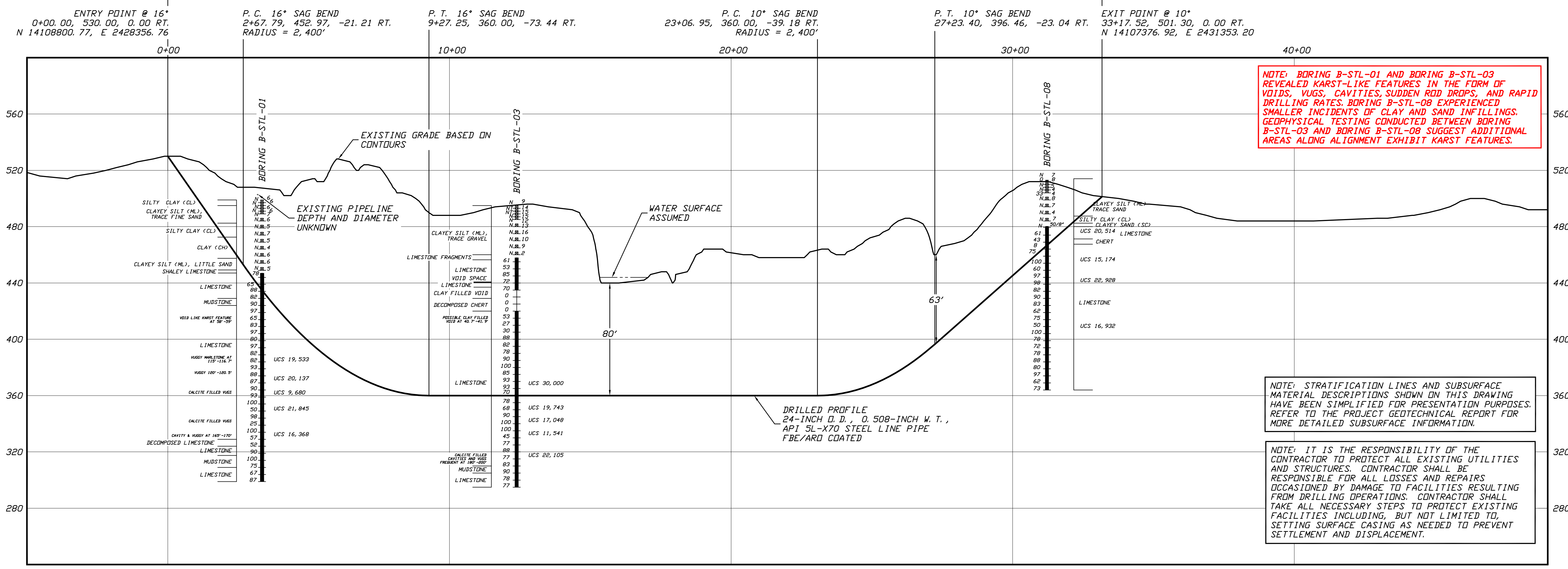
Please note that the estimated duration is based on operations proceeding according to plan and does not include contingency. The occurrence of unanticipated operational problems could increase the duration of operations by 50 to 100 percent.

[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





GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

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 MOTT MACDONALD, ISELIN, NJ. REFER TO THE PROJECT GEOTECHNICAL REPORT 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 JUDGMENT 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 WORKSHEET
24-INCH PIPELINE CROSSING OF COLDWATER CREEK BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: ST. LOUIS COUNTY, MISSOURI

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
LKB	07/11/18	ACM	---	SHOWN FOR D-SIZED PLOT	COLDWATER CREEK	P0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

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

PROJECT NO. SP/1816

SHEET NO. 1

APPENDIX 2

Installation Loading and Stress Analysis

HDD Pulling Load and Pipe Stress Analysis

Project Description			
Project: STL Pipeline	User :	KWW	
Crossing: Cold Water Creek	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	530.00		0.00	74.00	4.53					191,541
				279.45				yes	no	1,000	Straight	
PC Vertical	267.79	21.22	452.97		0.00	74.00	4.53					184,920
				670.21				yes	no	163,543	163,543	
PT Vertical	927.25	73.46	360.00		0.00	90.00	4.53				0	142,165
				22.07				yes	no	68,840	Straight	
PC Horz	949.25	75.21	360.00		0.00	90.00	4.53					141,109
				282.69				yes	no	130,259	130,259	
PT Horz	1231.72	80.90	360.00		0.00	90.00	-2.22				0	119,409
				1076.04				yes	no	64,101	Straight	
PC Vertical	2306.95	39.22	360.00		0.00	90.00	-2.22					67,942
				418.88				yes	no	52,699	52,699	
PT Vertical	2723.40	23.08	396.46		0.00	100.00	-2.22				0	37,457
				603.75				yes	no	1,000	Straight	
Exit Point	3317.53	0.05	501.30		0.00	100.00	-2.22					0
										Above Ground Load		
True Length (ft)				3,353.1								
Drilling Mud (ft)			501.0									
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	75,845	54,141	61,555	191,541	5,109	ok	0	ok	0	ok	0.08	ok	0.01	ok
					4,932	ok	0	ok	530	ok	0.08	ok	0.02	ok
PC Vertical	69,524	53,842	61,555	184,920										
					4,932	ok	12,083	ok	530	ok	0.34	ok	0.11	ok
					3,792	ok	12,083	ok	1557	ok	0.32	ok	0.15	ok
PT Vertical	54,364	61,680	26,120	142,165										
					3,792	ok	0	ok	1557	ok	0.06	ok	0.05	ok
					3,764	ok	0	ok	1557	ok	0.06	ok	0.05	ok
PC Horz	53,865	61,124	26,120	141,109										
					3,764	ok	12,086	ok	1557	ok	0.32	ok	0.15	ok
					3,185	ok	12,086	ok	1557	ok	0.31	ok	0.14	ok
PT Horz	47,471	53,997	17,942	119,409										
					3,185	ok	0	ok	1557	ok	0.05	ok	0.05	ok
					1,812	ok	0	ok	1557	ok	0.03	ok	0.04	ok
PC Vertical	23,131	26,869	17,942	67,942										
					1,812	ok	12,083	ok	1557	ok	0.29	ok	0.13	ok
					999	ok	12,083	ok	1154	ok	0.28	ok	0.09	ok
PT Vertical	13,657	23,801	0	37,457										
					999	ok	0	ok	1154	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: Cold Water Creek	Date :	17-Jul-18	
Installation model 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	530.00		0.00	74.00	4.53					273,688
				279.45				yes	no	1,000	Straight	
PC Vertical	267.79	21.22	452.97		0.00	74.00	4.53					266,817
				670.21				yes	no	237,703	237,703	
PT Vertical	927.25	73.46	360.00		0.00	90.00	4.53				0	208,590
				22.07				yes	no	68,840	Straight	
PC Horz	949.25	75.21	360.00		0.00	90.00	4.53					207,068
				282.69				yes	no	191,975	191,975	
PT Horz	1231.72	80.90	360.00		0.00	90.00	-2.22				0	176,881
				1076.04				yes	no	64,101	Straight	
PC Vertical	2306.95	39.22	360.00		0.00	90.00	-2.22					102,656
				418.88				yes	no	80,039	80,039	
PT Vertical	2723.40	23.08	396.46		0.00	100.00	-2.22				0	57,423
				603.75				yes	no	1,000	Straight	
Exit Point	3317.53	0.05	501.30		0.00	100.00	-2.22					0
										Above Ground Load		
True Length (ft)				3,353.1								
Drilling Mud (ft)			501.0									
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	75,845	99,559	98,284	273,688	7,300	ok	0	ok	0	ok	0.12	ok	0.02	ok
					7,117	ok	0	ok	707	ok	0.11	ok	0.03	ok
PC Vertical	69,524	99,008	98,284	266,817										
					7,117	ok	12,083	ok	707	ok	0.38	ok	0.14	ok
					5,564	ok	12,083	ok	2076	ok	0.35	ok	0.21	ok
PT Vertical	54,364	113,423	40,803	208,590										
					5,564	ok	0	ok	2076	ok	0.09	ok	0.09	ok
					5,523	ok	0	ok	2076	ok	0.09	ok	0.09	ok
PC Horz	53,865	112,399	40,803	207,068										
					5,523	ok	12,086	ok	2076	ok	0.35	ok	0.21	ok
					4,718	ok	12,086	ok	2076	ok	0.34	ok	0.20	ok
PT Horz	47,471	99,294	30,117	176,881										
					4,718	ok	0	ok	2076	ok	0.07	ok	0.09	ok
					2,738	ok	0	ok	2076	ok	0.04	ok	0.08	ok
PC Vertical	23,131	49,408	30,117	102,656										
					2,738	ok	12,083	ok	2076	ok	0.31	ok	0.17	ok
					1,532	ok	12,083	ok	1539	ok	0.29	ok	0.12	ok
PT Vertical	13,657	43,766	0	57,423										
					1,532	ok	0	ok	1539	ok	0.02	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: Cold Water Creek	Date :	17-Jul-18
Installation model based on Worse Case model. Assumes geometry 50 feet longer, 25 deeper, with radius 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	530.00		0.00	74.00	4.53					213,618
				538.80				yes	no	1,000	Straight	
PC Vertical	516.31	40.91	381.49		0.00	74.00	4.53					200,853
				335.10				yes	no	182,831	182,831	
PT Vertical	846.04	67.03	335.00		0.00	90.00	4.53				0	164,808
				174.30				yes	no	68,840	Straight	
PC Horz	1019.79	80.80	335.00		0.00	90.00	4.53					156,471
				141.40				yes	no	144,522	144,522	
PT Horz	1161.08	83.65	335.00		0.00	90.00	-2.22				0	132,573
				1166.20				yes	no	64,101	Straight	
PC Vertical	2326.41	38.47	335.00		0.00	90.00	-2.22					76,793
				209.40				yes	no	64,652	64,652	
PT Vertical	2534.59	30.40	353.23		0.00	100.00	-2.22				0	52,511
				846.40				yes	no	1,000	Straight	
Exit Point	3367.51	-1.89	500.20		0.00	100.00	-2.22					0
											Above Ground Load	
True Length (ft)				3,411.6								
Drilling Mud (ft)			501.0									
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	77,169	68,918	67,531	213,618	5,698	ok	0	ok	0	ok	0.09	ok	0.01	ok
					5,357	ok	0	ok	1320	ok	0.09	ok	0.05	ok
PC Vertical	64,981	68,341	67,531	200,853										
					5,357	ok	24,167	ok	1320	ok	0.61	ok	0.35	ok
					4,396	ok	24,167	ok	1833	ok	0.60	ok	0.37	ok
PT Vertical	57,401	72,260	35,146	164,808										
					4,396	ok	0	ok	1833	ok	0.07	ok	0.07	ok
					4,174	ok	0	ok	1833	ok	0.07	ok	0.07	ok
PC Horz	53,459	67,866	35,146	156,471										
					4,174	ok	24,162	ok	1833	ok	0.59	ok	0.37	ok
					3,536	ok	24,162	ok	1833	ok	0.58	ok	0.36	ok
PT Horz	50,260	64,301	18,011	132,573										
					3,536	ok	0	ok	1833	ok	0.06	ok	0.07	ok
					2,048	ok	0	ok	1833	ok	0.03	ok	0.06	ok
PC Vertical	23,882	34,900	18,011	76,793										
					2,048	ok	24,171	ok	1833	ok	0.56	ok	0.33	ok
					1,401	ok	24,171	ok	1632	ok	0.55	ok	0.30	ok
PT Vertical	19,145	33,366	0	52,511										
					1,401	ok	0	ok	1632	ok	0.02	ok	0.05	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: Cold Water Creek	Date :	17-Jul-18	
Installation model based on Worse Case model. Assumes geometry 50 feet longer, 25 deeper, with radius 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	530.00		0.00	74.00	4.53					296,906
				538.80				yes	no	1,000	Straight	
PC Vertical	516.31	40.91	381.49		0.00	74.00	4.53					283,657
				335.10				yes	no	259,594	259,594	
PT Vertical	846.04	67.03	335.00		0.00	90.00	4.53				0	235,530
				174.30				yes	no	68,840	Straight	
PC Horz	1019.79	80.80	335.00		0.00	90.00	4.53					223,507
				141.40				yes	no	208,722	208,722	
PT Horz	1161.08	83.65	335.00		0.00	90.00	-2.22				0	193,936
				1166.20				yes	no	64,101	Straight	
PC Vertical	2326.41	38.47	335.00		0.00	90.00	-2.22					113,492
				209.40				yes	no	96,997	96,997	
PT Vertical	2534.59	30.40	353.23		0.00	100.00	-2.22				0	80,501
				846.40				yes	no	1,000	Straight	
Exit Point	3367.51	-1.89	500.20		0.00	100.00	-2.22					0
											Above Ground Load	
True Length (ft)				3,411.6								
Drilling Mud (ft)			501.0									
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	77,169	126,732	93,005	296,906	7,919	ok	0	ok	0	ok	0.13	ok	0.02	ok
					7,566	ok	0	ok	1760	ok	0.12	ok	0.08	ok
PC Vertical	64,981	125,671	93,005	283,657										
					7,566	ok	24,167	ok	1760	ok	0.65	ok	0.43	ok
					6,282	ok	24,167	ok	2444	ok	0.63	ok	0.48	ok
PT Vertical	57,401	132,878	45,251	235,530										
					6,282	ok	0	ok	2444	ok	0.10	ok	0.13	ok
					5,962	ok	0	ok	2444	ok	0.09	ok	0.13	ok
PC Horz	53,459	124,798	45,251	223,507										
					5,962	ok	24,162	ok	2444	ok	0.62	ok	0.47	ok
					5,173	ok	24,162	ok	2444	ok	0.61	ok	0.45	ok
PT Horz	50,260	118,242	25,433	193,936										
					5,173	ok	0	ok	2444	ok	0.08	ok	0.12	ok
					3,027	ok	0	ok	2444	ok	0.05	ok	0.11	ok
PC Vertical	23,882	64,177	25,433	113,492										
					3,027	ok	24,171	ok	2444	ok	0.58	ok	0.41	ok
					2,147	ok	24,171	ok	2176	ok	0.56	ok	0.36	ok
PT Vertical	19,145	61,356	0	80,501										
					2,147	ok	0	ok	2176	ok	0.03	ok	0.09	ok
Exit Point		0		0										

APPENDIX 3

Operational & Testing Stress Calculations

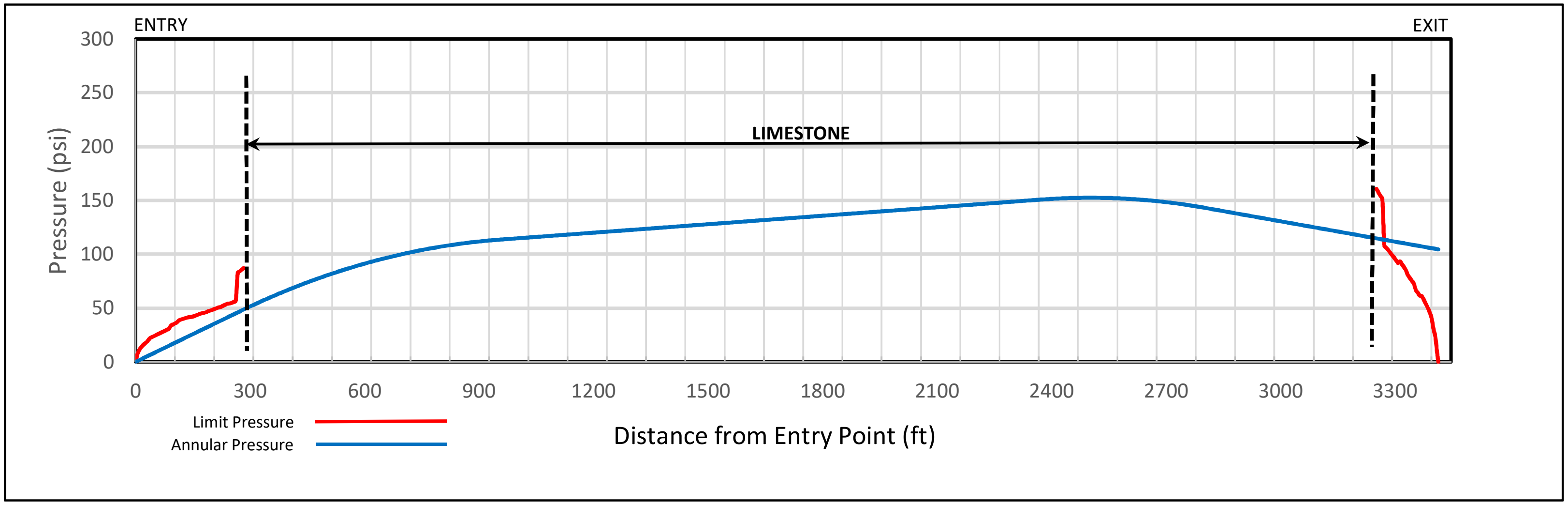
Operating Stress Analysis

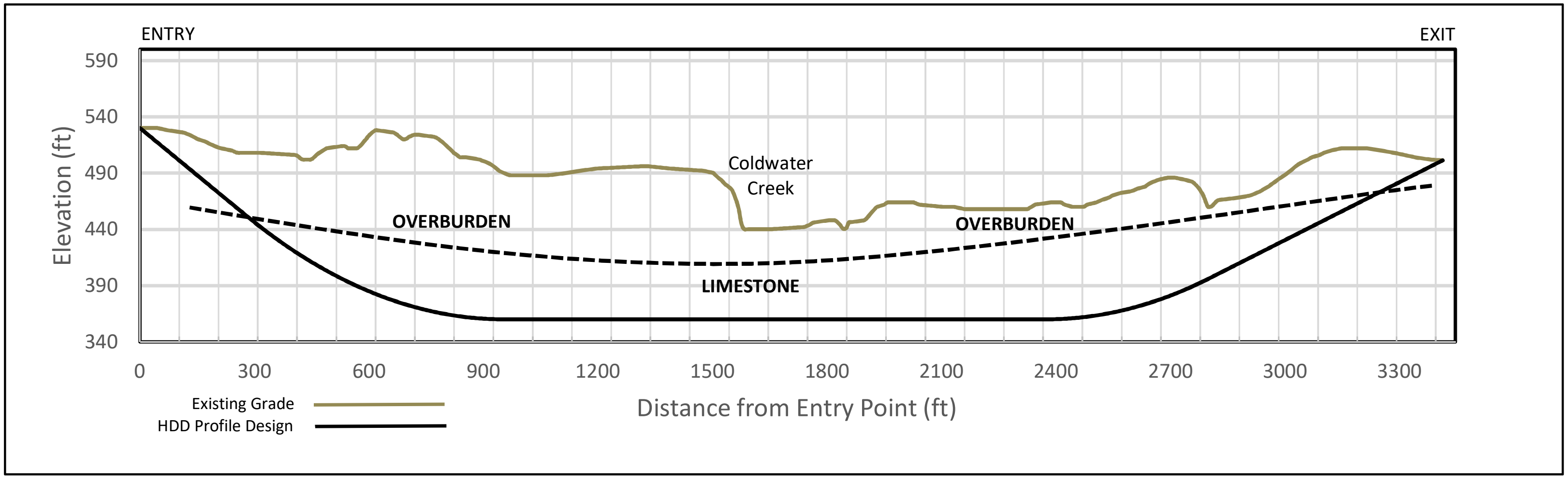
PROJECT: Spire STI Pipeline Project - 24-inch Coldwater Creek Crossing
Operating Stress

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	1,200	ft	1,200	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	24,167	psi	24,167	psi
% SMYS =	17%		35%		35%	
Net Longitudinal Stress (taking bending in tension) =	18,518	psi	30,601	psi	39,757	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	26%	ok	44%	ok	57%	
Net Longitudinal Stress (taking bending in compression) =	-5,649	psi	-17,732	psi	-8,576	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	8%	ok	25%	ok	12%	
Combined Stress (NLS w/bending in tension) - Max. Shear Stress Theory =	15,498	psi	3,414	psi	12,211	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	22%	ok	5%	ok	17%	
Combined Stress (NLS w/bending in compression) - Max. Shear Stress Theory =	39,664	psi	51,748	psi	60,545	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	57%	ok	74%	ok	86%	
Combined Stress (NLS w/bending in tension) - Max. Distortion Energy Theory =	29,497	psi	32,444	psi	47,066	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	42%	ok	46%	ok	67%	
Combined Stress (NLS w/bending in compression) - Max. Distortion Energy Theory =	37,163	psi	45,548	psi	56,745	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	53%	ok	65%	ok	81%	

APPENDIX 4

Hydrofracture Evaluation





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

HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
24" COLDWATER CREEK CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 8/8/2018 Revision: 0

APPENDIX 5

HDD Construction Duration

Construction Duration - HDD Operations

General Data		Comments
Work Schedule, hours/shift =	10.0	24-inch Cold Water Creek Crossing.
days/week =	6.0	
Drilled Length, feet =	3,353	
Pilot Hole		
Production Rate, feet/hour =	20	
shifts/day =	1	
Drilling Duration, hours =	167.7	
shifts =	16.8	
Trips to change tools, shifts =	1.0	
Pilot Hole Duration, days =	17.8	

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 =	227.1	227.1				10.6	10.6	475.5
shifts =	22.7	22.7				1.1	1.1	47.5
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 =	24.2	24.2				1.6	2.1	52.0

Summary	
HDD Duration at Site, days =	73.8

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	

ENGINEER: Jeff Scholl 8/8/2018

APPENDIX 6

Geotechnical Data

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spire

Spire STL Pipeline – Coldwater Creek Crossing
Geotechnical Memorandum
Mott MacDonald Project #372453

August 31, 2017

111 Wood Avenue South
Iselin NJ 08830-4112
United States of America

T +1 (800) 832 3272
F +1 (973) 376 1072
mottmac.com/americas

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 Coldwater Creek Crossing location in St. Louis County, Missouri. Mott MacDonald understands that the proposed pipeline is being considered to be installed beneath Coldwater Creek and US Highway 67 using Horizontal Directional Drill (HDD) method. A Site Vicinity Map depicting the approximate crossing location has been provided as Figure 1. Our subsurface investigation program, performed in two phases, consisted of exploratory soil borings to gather geotechnical information specific to the potential trenchless 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.

Mott MacDonald has prepared this geotechnical memorandum to present the observed subsurface conditions at the proposed crossing location. A total of three borings were advanced at this crossing: B-STL-01, B-STL-03, and B-STL-08. The third borehole, B-STL-08, was accessed and completed in July of 2017 upon landowner permission. It is noted that originally-planned boreholes B-STL-02, B-STL-06, and B-STL-07 were removed from the investigation program as B-STL-01, 03, and 08 provided sufficient information to establish feasibility of the crossing. These three formerly-proposed boreholes will therefore not be advanced nor reported as part of this memorandum.

Locations of the three advanced borings are represented in the Boring Location Plan, included as Attachment A.

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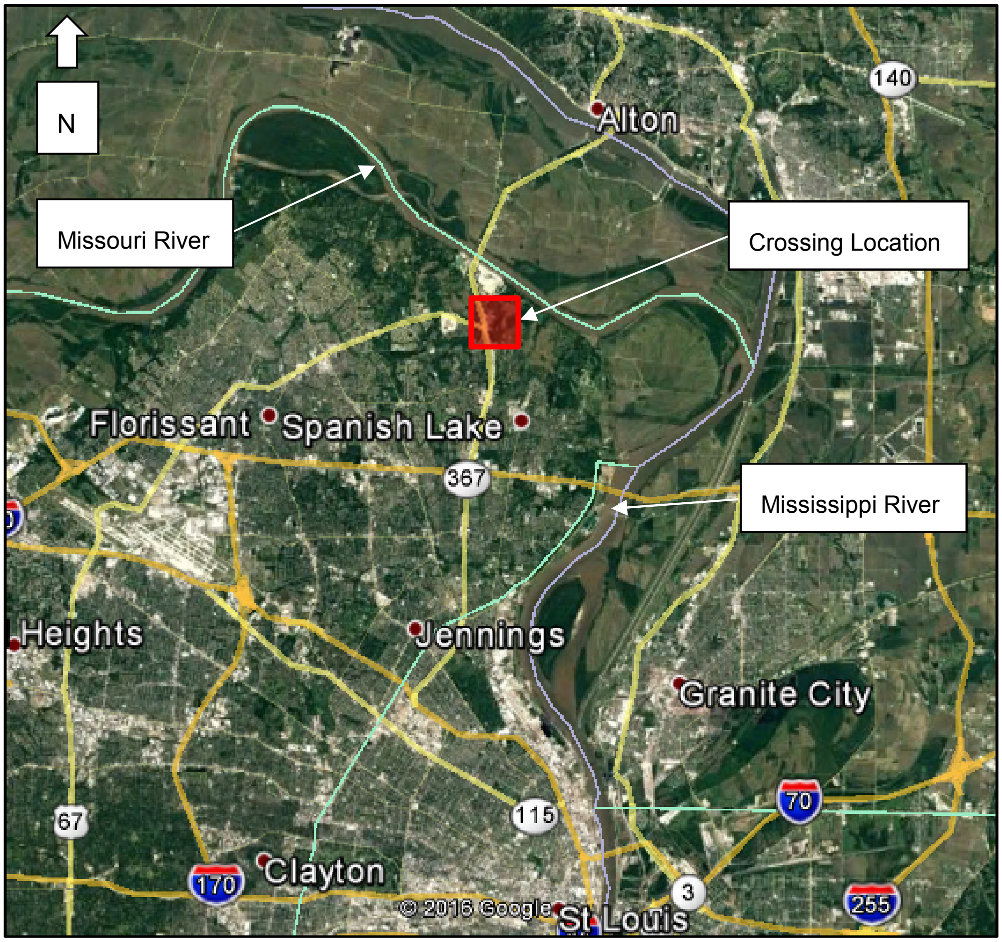

Figure 1: Site Vicinity Map

2.0 Methodology

Drilling and sampling activities were conducted by TSI Geotechnical, Inc. of St. Louis, Missouri and were overseen and logged by a 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. Obtained cores were measured for recovery and RQD[2], logged for discontinuities, and described based on type, color, hardness, weathering,

[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.

bedding thickness, dip angle, and discontinuity spacing. Soil boring termination depths and approximate ground surface elevations are presented in Table 1.

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-01	499	200’ *(299)*	52’ *(447)*
B-STL-03	495	200’ *(295)*	38.5’ *(456.5)*
B-STL-08	514	150’ *(364)*	34’ *(480)*

[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.

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. United States Geological Survey (USGS) mapping indicates the Coldwater Creek Crossing exists primarily within the Genevieve Limestone Unit, which consists of limestone with occasional chert components, and can extend up to 150 feet in thickness. Additionally, the proposed crossing is shown to extend into the Cherokee Group Unit, which is comprised of cycles of sandstone, siltstone, shale, clay, and coal. The thickness of the Cherokee Group can be as much as 100 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 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.

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.

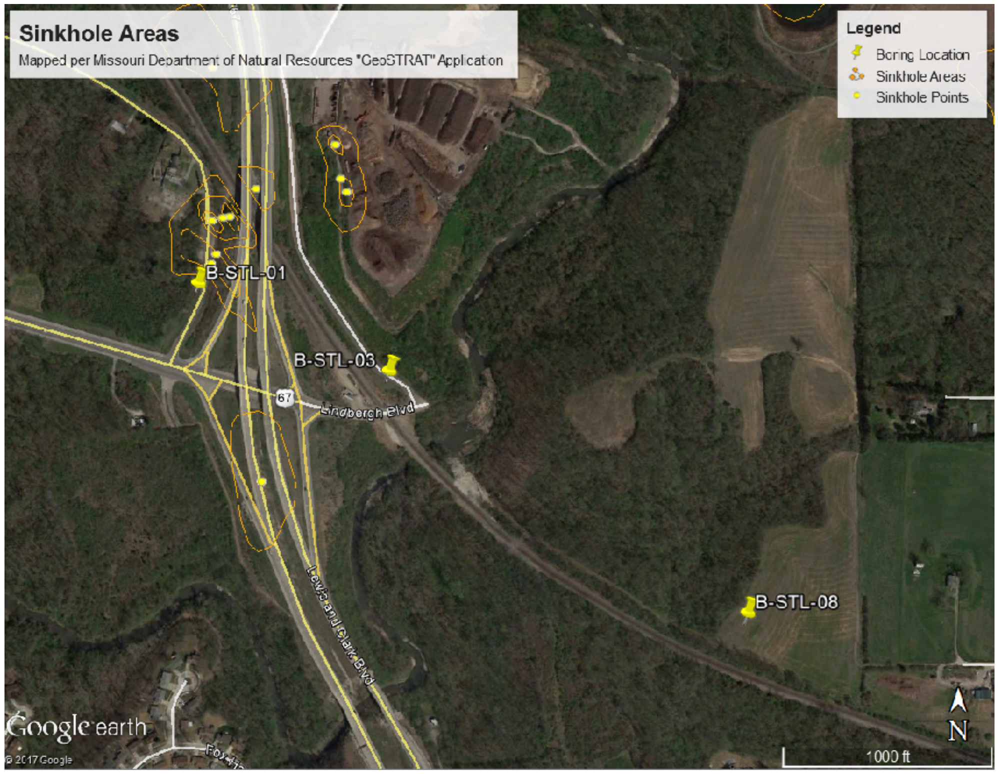

Figure 2: Missouri DNR Documented Sinkhole and Boring Location Map

Based on the presence of carbonate formations and known, mapped sinkholes in the vicinity of the crossing, Mott MacDonald retained THG Geophysics of Murrysville, PA to conduct geophysical surveys to identify the presence of anomalies. These anomalies, expected to be karstic features, were evaluated in the context of trenchless feasibility and risk of inadvertent returns and steering concerns. A summary of the conducted geophysical survey is provided as Section 5, and the THG report is provided as a reference as Attachment D.

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 generalized 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 on-site materials, and individual soil boring logs, provided as Attachment C, should be consulted for detailed information specific to each boring location.

4.1 Generalized Subsurface Profile

- **TOPSOIL:** was encountered within the top 4 inches of grade within boring B-STL-01.
- **SILT/CLAY (ML/CL):** was encountered underlying the topsoil layer. This stratum was identified as primarily silt material with varying clay layers

observed in boring B-STL-01. This material can be generally described as medium stiff in consistency with average N-values around 7 blows per foot (bpf) between the three borings. This stratum consisted of predominately low plasticity material, although high plasticity clays were observed within B-STL-01 from 26.5 to 41.5 feet below ground surface (bgs), and medium plasticity clay in B-STL-08 from 26.5 to 31.5 feet bgs. The silt/clay material generally extended down to top of bedrock. It should be noted that a thin layer of very loose clayey sand was identified within B-STL-08 immediately above bedrock, which may be indicative of a karstic slump zone.

- **LIMESTONE:** was observed to be the primary bedrock material, encountered at 52, 38.5 and 34 feet below grade within borings B-STL-01, B-STL-03, and B-STL-08, respectively. Rock coring activities rendered recovery and RQD values ranging from 0 to 100 and percent. Mott MacDonald notes that voids ranging from 0.3 to 8 feet in size were encountered within B-STL-03 from approximately 54 to 77 feet bgs, which may be indicative of karst conditions. Recovered limestone material was generally observed to be slightly 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.
- **MUDSTONE:** was identified as a secondary bedrock material at depths of 181.5 to 190 and 185 to 190 feet bgs within borings B-STL-01 and B-STL-03, respectively. This material was classified as slightly to moderately weathered bedrock with weak to medium strong properties. Mott MacDonald notes that some mudstone interbedding was identified within the limestone material at various depths.

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

4.2 Observed Karst Conditions

Mott MacDonald notes that observations recorded during drilling activities within boring B-STL-03 indicate the existence of karst-like features as documented within our desktop review of local geology. An approximate total of 21 inches of material was retrieved within rock cores between 58.75 and 77 feet bgs, equaling less than 10 percent recovery. Field observations of sudden rod drops and rapid drilling rates confirmed the presence of clay-filled voids at this borehole location. 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.

5.0 Geophysical Survey

Upon identification of potential karst-like features, Mott MacDonald retained THG Geophysics to conduct geophysical surveys along the proposed alignment at the Coldwater Creek crossing location. THG performed their survey work in two phases, conducted in May and July of 2017, based on limited access agreements with property owners. Geophysical surveys were performed using a combination of electrical resistivity imaging (ERI) and microgravity (MG) methods.

Upon analysis of data collected from the field surveys THG has identified three (3) subsurface anomalies along the proposed alignment, one of which has been classified as a "void", the other two classified as "possible voids". Mott MacDonald notes that observations recorded during a site walk of the eastern extent of the

Coldwater Creek survey area indicates three additional surficial features which may be indicative of sinkhole or karst conditions.

Complete results of THG's geophysical investigation and graphical representations of the surveyed anomalies is provided as Attachment D. Mott MacDonald notes that THG also performed survey activities at the proposed Spanish Lake crossing which are included within their combined report.

6.0 Laboratory Testing

Representative 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 in Section 5.1 below. It is noted that two overburden soil samples from boring B-STL-08 were submitted for testing of Sieve Analysis (ASTM D422) and Atterberg Limits (ASTM D4318); the results of which have also been summarized in Section 6.2.

6.1 Lab 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-01: R-13 (112'-115'), R-16 (126'-128'), R-18 (138'-140'), R-20 (148'-150'), R-24 (166'-169')
  - B-STL-03: R-19 (126'-128'), R-22 (143'-145'), R-24 (152'-154'), R-26 (161'-164'), R-29 (177'-180')
    - B-STL-08: R-1 (35'-40'), R-5 (55'-60'), R-8 (70'-75'), R-15 (105'-110')
- **ASTM D5731 – Point Load Strength**
  - B-STL-01: R-13 (112'-115'), R-16 (126'-128'), R-18 (138'-140'), R-20 (148'-150'), R-24 (166'-169')
  - B-STL-03: R-19 (126'-128'), R-22 (143'-145'), R-24 (152'-154'), R-26 (161'-164'), R-29 (177'-180')
  - B-STL-08: R-1 (35'-40'), R-5 (55'-60'), R-8 (70'-75'), R-15 (105'-110')
- **ASTM D2216 – Moisture Content**
  - B-STL-08: S-2 (2'-4')
- **ASTM D4318 – Moisture Content**
  - B-STL-08: S-5 (8'-10')
- **ASTM D422 – Grain Size Analysis**
  - B-STL-08: S-2 (2'-4')

6.2 Lab Testing Results

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

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Table 2: Rock Testing Results

Boring No.	Run	Depth	Maximum Axial Point Load (psi)	Unconfined Compressive Stress (psi)
B-STL-01	R-13	112'-115'	970	19,533
	R-16	126'-128'	1,020	20,137
	R-18	138'-140'	1,900	9,680
	R-20	148'-150'	1,200	21,845
	R-24	166'-169'	1,700	16,368
B-STL-03	R-19	126'-128'	1,500	30,000
	R-22	143'-145'	1,000	19,743
	R-24	152'-154'	890	17,048
	R-26	161'-164'	1,000	11,541
	R-29	177'-180'	1,380	22,105
B-STL-08	R-1	37'-40'	1,200	20,514
	R-5	58'-60'	1,100	15,174
	R-8	73'-75'	1,100	22,928
	R-15	105'-108'	1,000	16,932

Table 3: Soil Testing Results

Boring No.	Sample	Depth	% Gravel	% Sand	% Silt	% Clay
B-STL-08	S-2	2'-4'	0	0	75	0

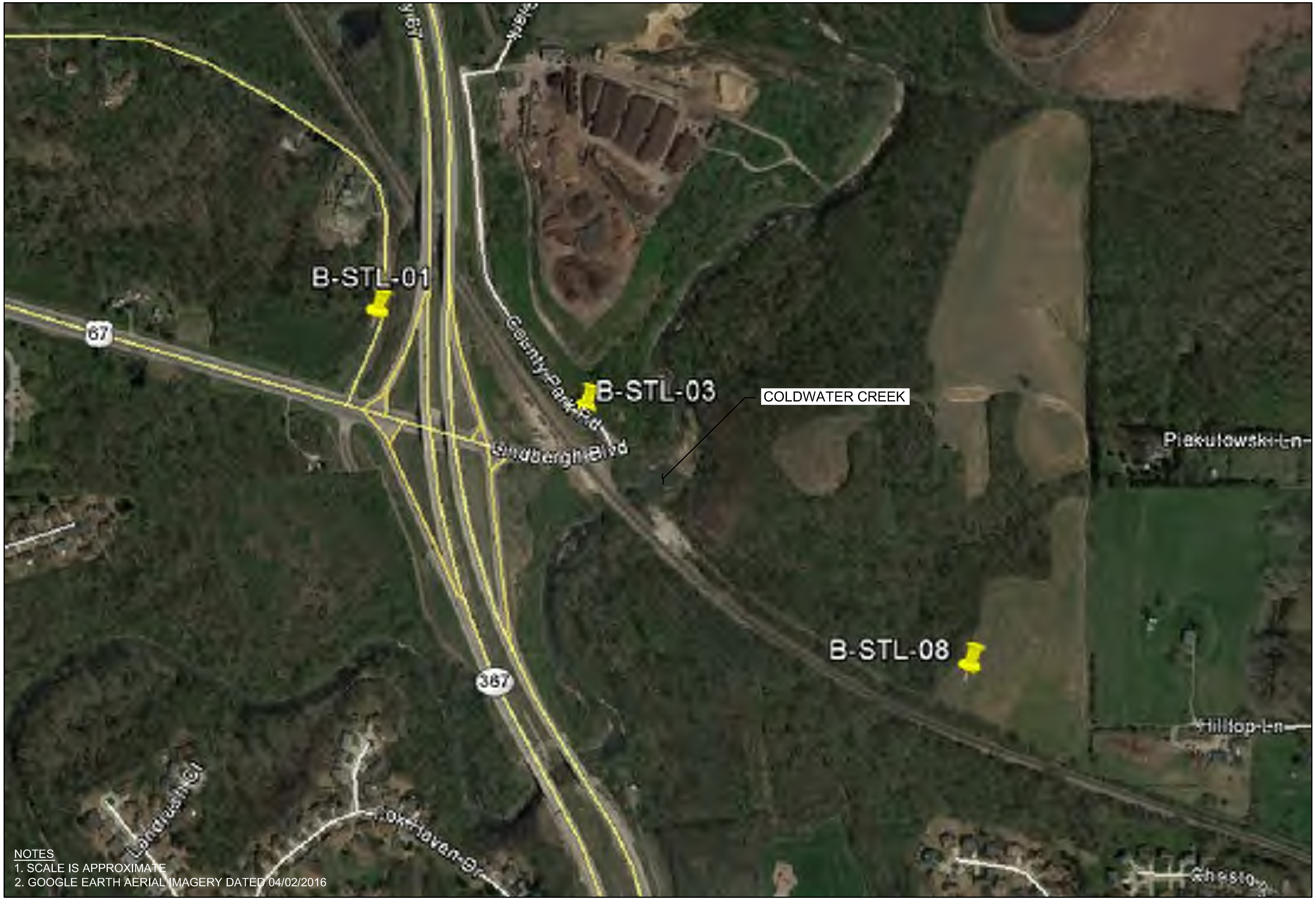
Boring No.	Sample	Depth	Liquid Limit	Plastic Limit	Plasticity Index	% Moisture
B-STL-08	S-2	2'-4'	-	-	-	26.6
	S-5	8'-10'	33	26	7	-

7.0 Limitations

The information presented in this geotechnical memorandum are based on the results of laboratory testing supplemented by observations recorded during Mott MacDonald's geotechnical and geophysical investigations advanced in March through 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

MOTT MACDONALD

111 Wood Avenue South
Iselin, New Jersey 08830-1005
United States

T +1 973-379-3400
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

0 400 800
SCALE: 1" = 400'

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

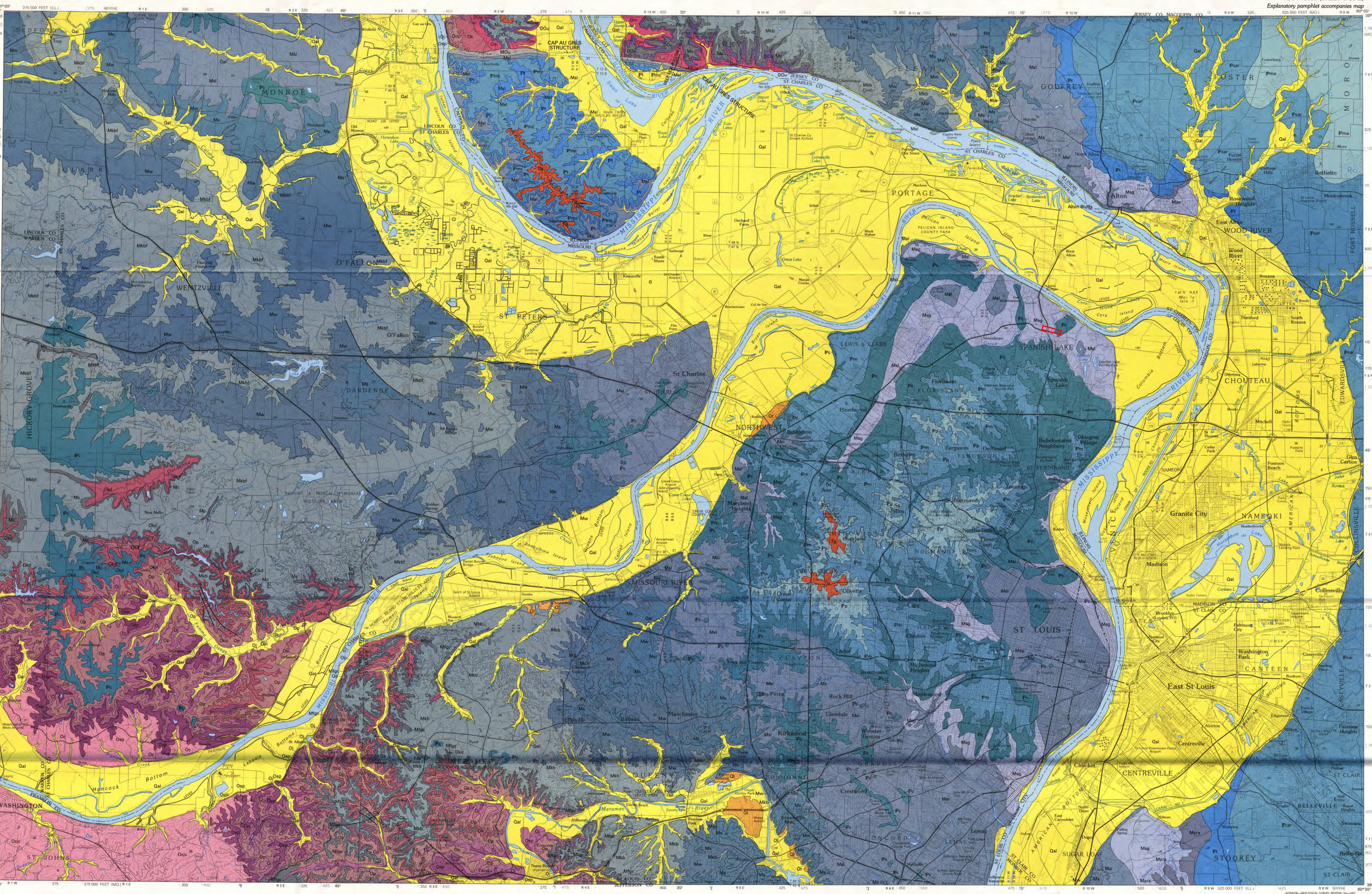
Project Number	B/O	Total	Drawing Number
372453	1	1	BLP-CC-1

Title
SPIRE STL PIPELINE
COLDWATER CREEK 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

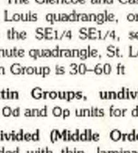


Base from U.S. Geological Survey, 1985
Projection and 10,000-meter grid, Universal Transverse Mercator, zone 15
25,000-foot grid based on Missouri coordinate system, east zone, and Illinois coordinate system, west zone
1927 North American datum

APPROXIMATE MEAN DECLINATION, 1997

SCALE 1:100 000

CONTOUR INTERVAL 20 METERS
SUPPLEMENTARY CONTOUR INTERVAL 10 METERS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

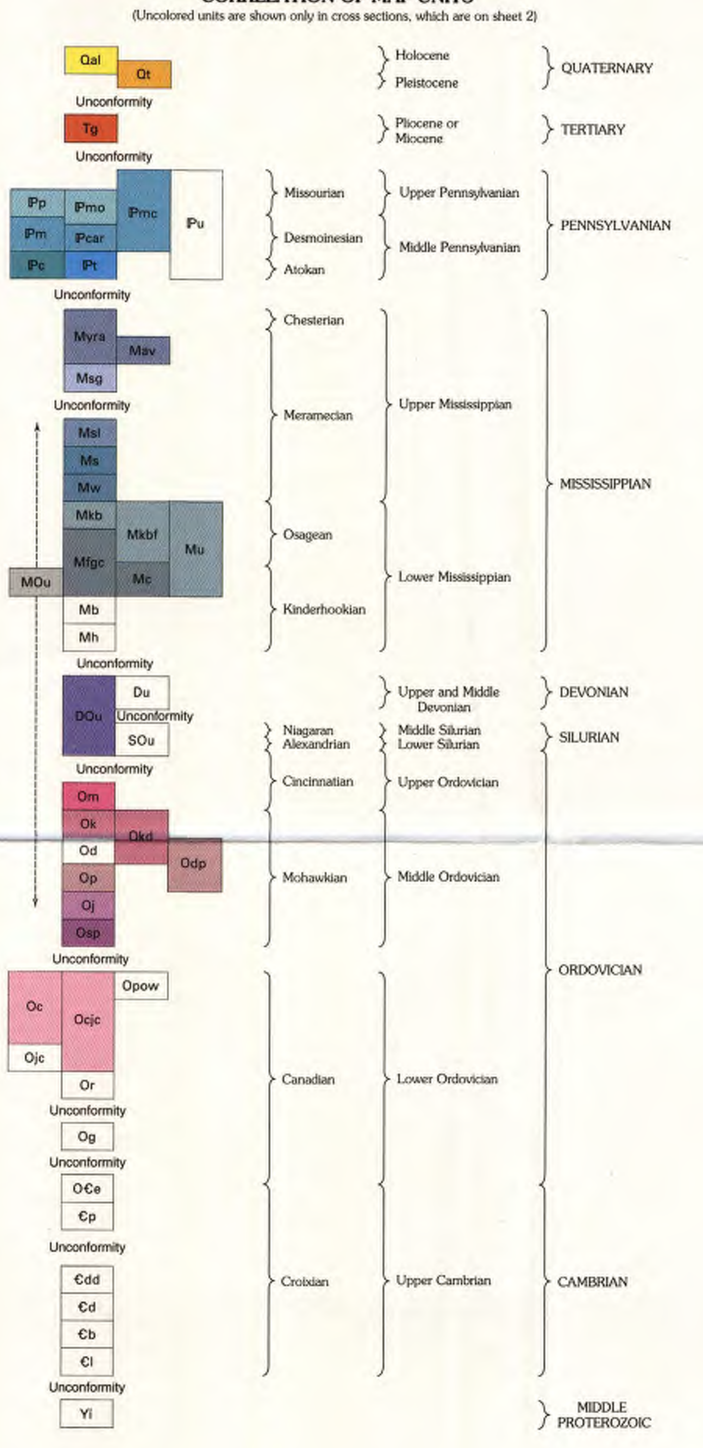


QUADRANGLE LOCATION

Geology compiled in 1992

CORRELATION OF MAP UNITS

(Uncolored units are shown only in cross sections, which are on sheet 2)



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

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

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

Pmc **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

Pmo **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

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

Pcar **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

Pc **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

Pt **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

Msg **Ste. Genevieve Limestone (Upper Mississippian, Meramecian)**—White, massive, coarsely crystalline (sparse finely crystalline beds), sandy, clastic limestone. Oolitic beds are common and the lower part of the formation contains prominent crossbeds and ripple marks. Gray chert is also common. Locally, black or red chert is found. Some fine-grained, calcareous sandstone beds occur in the upper part of the formation and are separated by 2 to 4 in. of shaly limestone or shale partings. Laterally, the lithology of individual beds changes abruptly, making them difficult to trace. Atherton and others (1975) stated that in the St. Louis area, this unit has a conglomeratic base and rests unconformably upon an eroded top of the St. Louis Limestone; elsewhere the two formations are conformable and interfinger. As much as 150 ft thick

MOu **Rocks of the Cap au Grès structure**—Mississippian through Ordovician, undivided

Msl **St. Louis Limestone (Upper Mississippian, Meramecian)**—Dark-gray, finely crystalline to lithographic, thin- to medium-bedded to massive limestone. Thin beds of bluish-gray shale are found throughout the formation. At most places, the lower part contains multiple intervals of intraformational breccia that has a shale matrix. Algal stromatolites are common. This highly variable unit also contains beds of dolomite, cherty limestone, fossiliferous limestone, and evaporites. Some beds are sandy and cross laminated. Type section is the downtown St. Louis area. From 100 to 250 ft thick

Ms **Salem Formation (Upper Mississippian, Meramecian)**—Fossiliferous calcarenite consisting of broken fossil fragments and small fossils set in a matrix that ranges from micrite to sparite. Banded overgrowths around fossils are common. Numerous minor lithologies are also present in the unit, including fine-grained limestone, sandstone, chert, and evaporites. A distinctive chert zone ("cannonball" or "bulls-eye") occurs near the top of the formation in the St. Louis area (Thompson, 1986). From 70 to 180 ft thick

Mw **Warsaw Formation (Upper Mississippian, Meramecian)**—Dark, fissile shale and intercalated argillaceous and silty dolomite or dolomitic limestone in the upper half; shaly to argillaceous, cherty, very fossiliferous, finely crystalline, dolomitic limestone in the lower half. Contains an abundance of the corkscrew bryozoan *Archimedes*. From 60 to 100 ft thick

Mu **Mississippian rocks, undivided (Lower Mississippian, Osagean and Kinderhookian)**—Chouteau Limestone, Fern Glen Formation, Burlington Limestone, and Keokuk Limestone, undivided. Mapped only in Illinois between the Illinois and Mississippi Rivers. See **Mkb**, **Mkbf**, and **Mc** units for descriptions

Mkb **Keokuk and Burlington Limestones, undivided (Lower Mississippian, Osagean)**

Keokuk Limestone—Medium crystalline limestone and lesser finely and coarsely crystalline limestone. Crinoidal fossil horizons are common. Light-gray, nodular chert is also common in the lowermost and uppermost thirds of the formation. Quite similar to the underlying Burlington Limestone into which it grades. However, one contrast is that the Keokuk contains a greater heterogeneity of fossils, with more abundant bryozoans, corals, and brachiopods (Willman and others, 1975)

Burlington Limestone—Light-colored, medium to coarsely crystalline limestone. Large crinoid stems are abundant and many beds consist entirely of crinoidal debris. Beds are medium to thick, and are commonly cross stratified. Some beds are glauconitic. Chert occurs erratically, in highly concentrated zones 1–10 ft thick, separated by chert-free zones 30–50 ft thick. In the St. Louis area, the lower 18–30 ft of this unit contains 50 percent chert and is called the "lower Burlington Limestone" by Kissling (1961) and Thompson (1975). The combined formations are approximately 175–200 ft thick

Mkbf **Keokuk and Burlington Limestones, and Fern Glen Formation, undivided (Lower Mississippian, Osagean)**

Keokuk and Burlington Limestones—See **Mkb** above for descriptions

Fern Glen Formation—Red and green calcareous shale, shaly limestone, and a basal bed of massive, dolomitic limestone. Composite type section of this unit is a composite of two railroad cuts on either side of Fern Glen, Mo., on the north bank of the Meramec River, center SE1/4 sec. 14, and NW1/4 SW1/4 SW1/4, sec. 13, T. 44 N., R. 4 E. in the south-central part of the St. Louis quadrangle (Thompson, 1986). From 30 to 60 ft thick; in marked contrast to most stratigraphic units in the region, it thickens away from the Illinois basin (Kissling, 1961)

Mfgc **Fern Glen Formation and Chouteau Limestone, undivided (Lower Mississippian, Osagean and Kinderhookian)**—See **Mkbf** and **Mc** units for descriptions

Mc **Chouteau Limestone (Lower Mississippian, Kinderhookian)**—Gray, 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'*

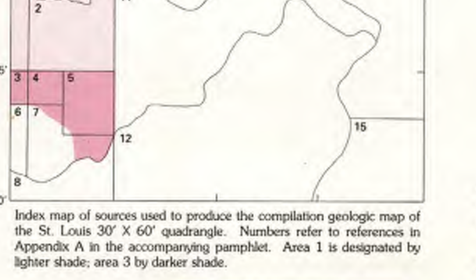
€l **Lamotte Formation (Upper Cambrian, Croixian)**—Fine- to coarse-grained quartzose sandstone and conglomerate. Grains are typically well rounded. Conglomerate contains pebbles and boulders of Precambrian lithologies. Shown only on cross sections. From 0 to 520 ft thick; absent over Precambrian knob 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 Appendix A in the accompanying pamphlet. Area 1 is designated by lighter shade; area 3 by darker shade.

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

Compiled by
Richard W. Harrison
1997

For sale by U.S. Geological Survey, Map Distribution, Box 25286, Federal Center, Denver, CO 80225

Map Scale: 1:5,730 if printed on A landscape (11" x 8.5") sheet.

N

Meters: 0, 50, 100, 200, 300

Feet: 0, 250, 500, 1000, 1500

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	6.4	8.8%
60003	Menfro silt loam, 9 to 14 percent slopes, eroded	0.2	0.3%
60004	Menfro silt loam, 14 to 20 percent slopes, eroded	9.6	13.2%
60005	Menfro silt loam, 20 to 45 percent slopes	35.6	49.0%
60025	Urban land-Harvester complex, 2 to 9 percent slopes	5.6	7.7%
60165	Menfro silt loam, 2 to 5 percent slopes	0.2	0.3%
60223	Urban land-Harvester complex, 9 to 20 percent slopes	15.1	20.8%
Totals for Area of Interest		**72.8**	**100.0%**

St. Louis County and St. Louis City, Missouri

60005—Menfro silt loam, 20 to 45 percent slopes

Map Unit Setting

National map unit symbol: 2tbqs
Elevation: 400 to 4,000 feet
Mean annual precipitation: 37 to 49 inches
Mean annual air temperature: 52 to 59 degrees F
Frost-free period: 172 to 232 days
Farmland classification: Not prime farmland

Map Unit Composition

Menfro and similar soils: 89 percent
Minor components: 11 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: 20 to 45 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

Rock outcrop

Percent of map unit: 1 percent
Landform: Interfluves
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Interfluve
Down-slope shape: Convex
Across-slope shape: Convex
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

60223—Urban land-Harvester complex, 9 to 20 percent slopes

Map Unit Setting

National map unit symbol: 2qp6z
Elevation: 950 to 1,050 feet
Mean annual precipitation: 36 to 43 inches
Mean annual air temperature: 54 to 59 degrees F
Frost-free period: 172 to 232 days
Farmland classification: Not prime farmland

Map Unit Composition

Urban land: 55 percent
Harvester and similar soils: 25 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: Hillslopes
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear
Across-slope shape: Linear
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: 9 to 20 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): 6e
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

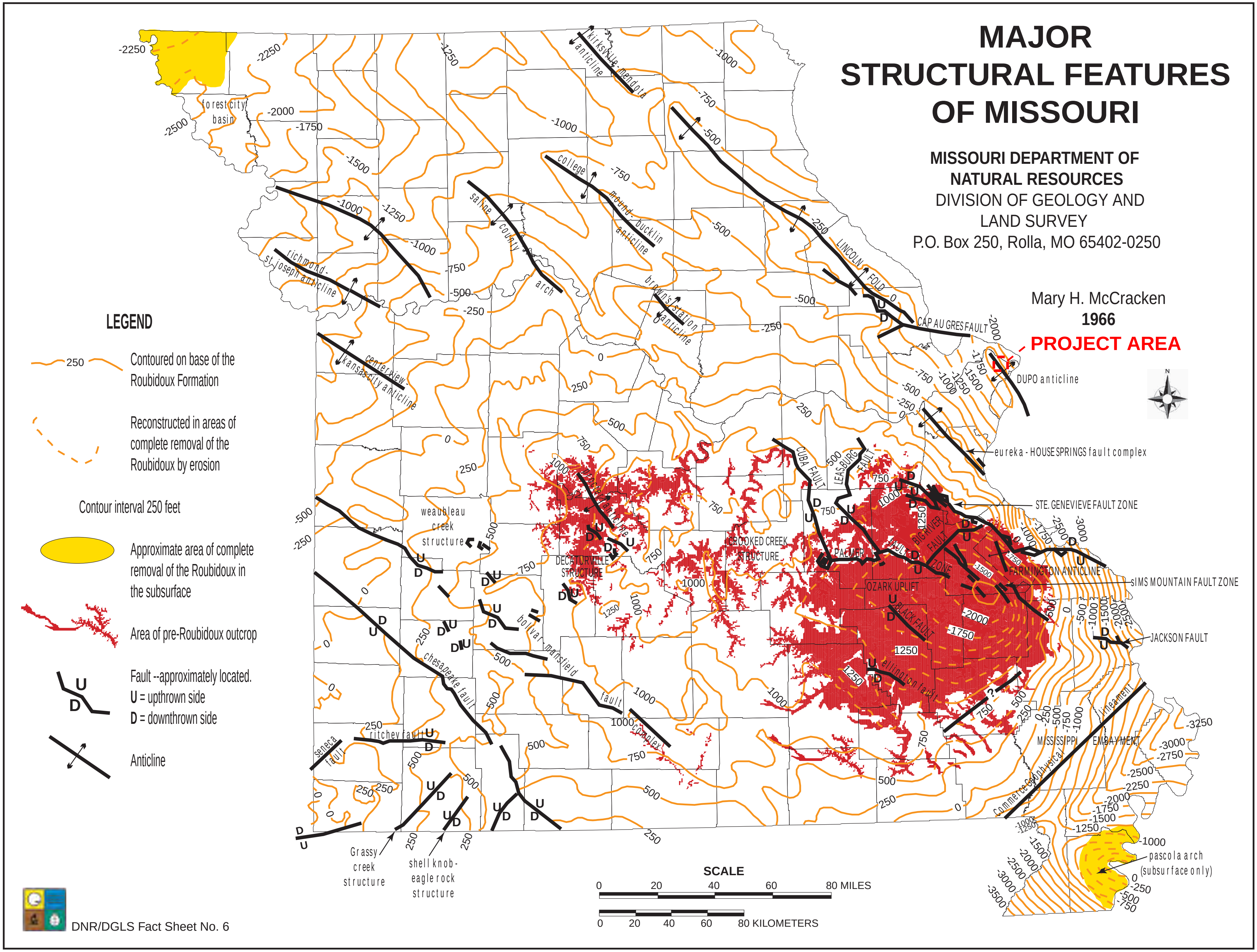
Minor Components

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

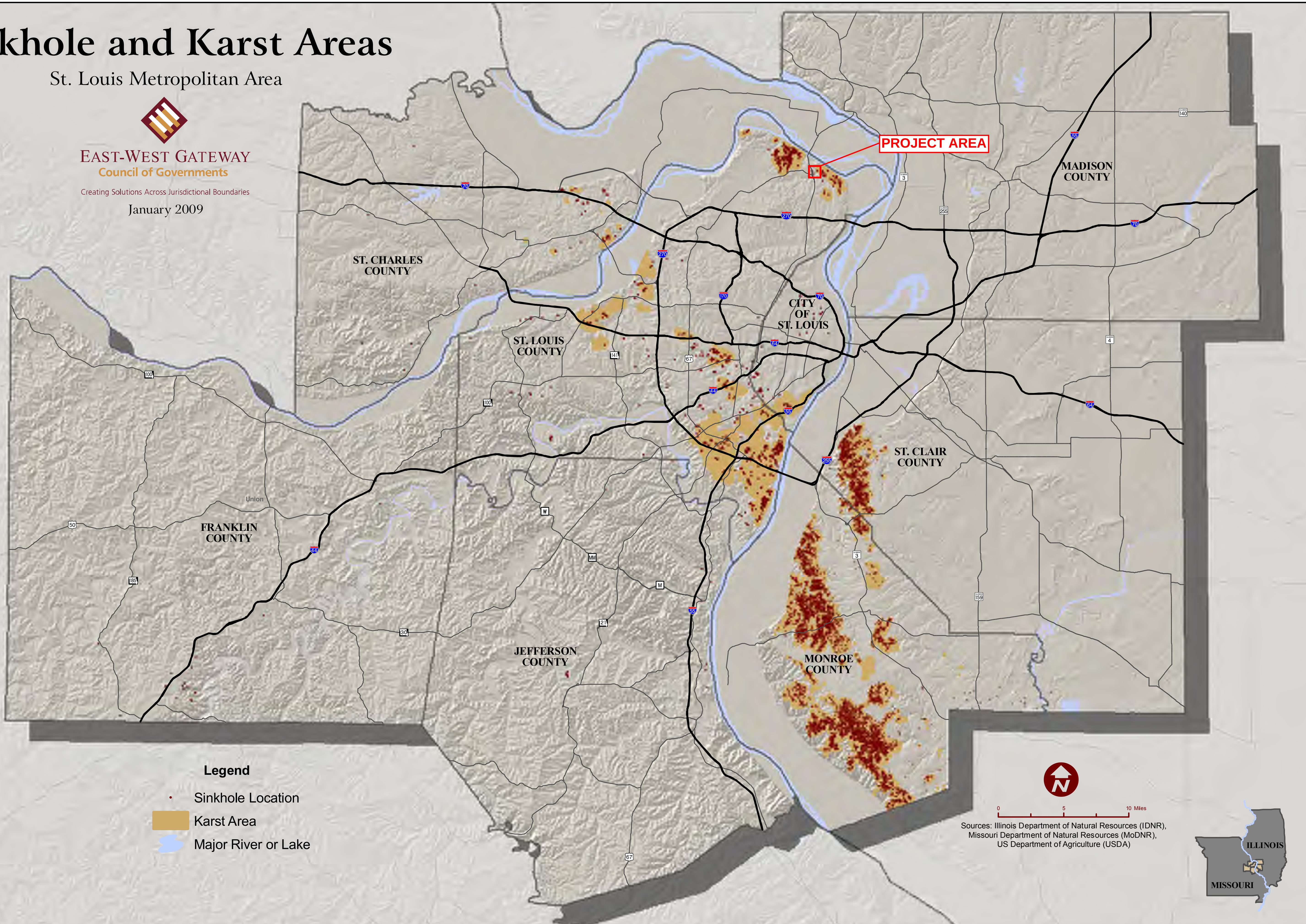

MAJOR STRUCTURAL FEATURES OF MISSOURI
MISSOURI DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGY AND LAND SURVEY
P.O. Box 250, Rolla, MO 65402-0250
Mary H. McCracken
1966
PROJECT AREA
LEGEND
Contoured on base of the Roubidoux Formation
Reconstructed in areas of complete removal of the Roubidoux by erosion
Contour interval 250 feet
Approximate area of complete removal of the Roubidoux in the subsurface
Area of pre-Roubidoux outcrop
Fault --approximately located.
U = upthrown side
D = downthrown side
Anticline
SCALE
0 20 40 60 80 MILES
0 20 40 60 80 KILOMETERS
DNR/DGLS Fact Sheet No. 6
forest city basin
kirksville - mendota anticline
college - mound - bucklin anticline
saline county arch
richmond - st. joseph anticline
centerview - kansas city anticline
brown's station anticline
LINCOLN FOLD
CAP AU GRES FAULT
DUPO anticline
eureka - HOUSE SPRINGS fault complex
STE. GENEVIEVE FAULT ZONE
FARMINGTON ANTICLINE
SIMS MOUNTAIN FAULT ZONE
JACKSON FAULT
CUBA FAULT
LEASBURG FAULT
BIG RIVER FAULT ZONE
PALMER FAULT
OZARK UPLIFT
BLACK FAULT
ellington fault
CROOKED CREEK STRUCTURE
DECATURVILLE STRUCTURE
weaubleau creek structure
bolivar - mansfield fault complex
chesapeake fault
ritchey fault
seneca fault
Grassy creek structure
shell knob - eagle rock structure
MISSISSIPPI EMBAYMENT
Commerce Geophysical lineament
pascola arch (subsurface only)

Sinkhole and Karst Areas

St. Louis Metropolitan Area

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

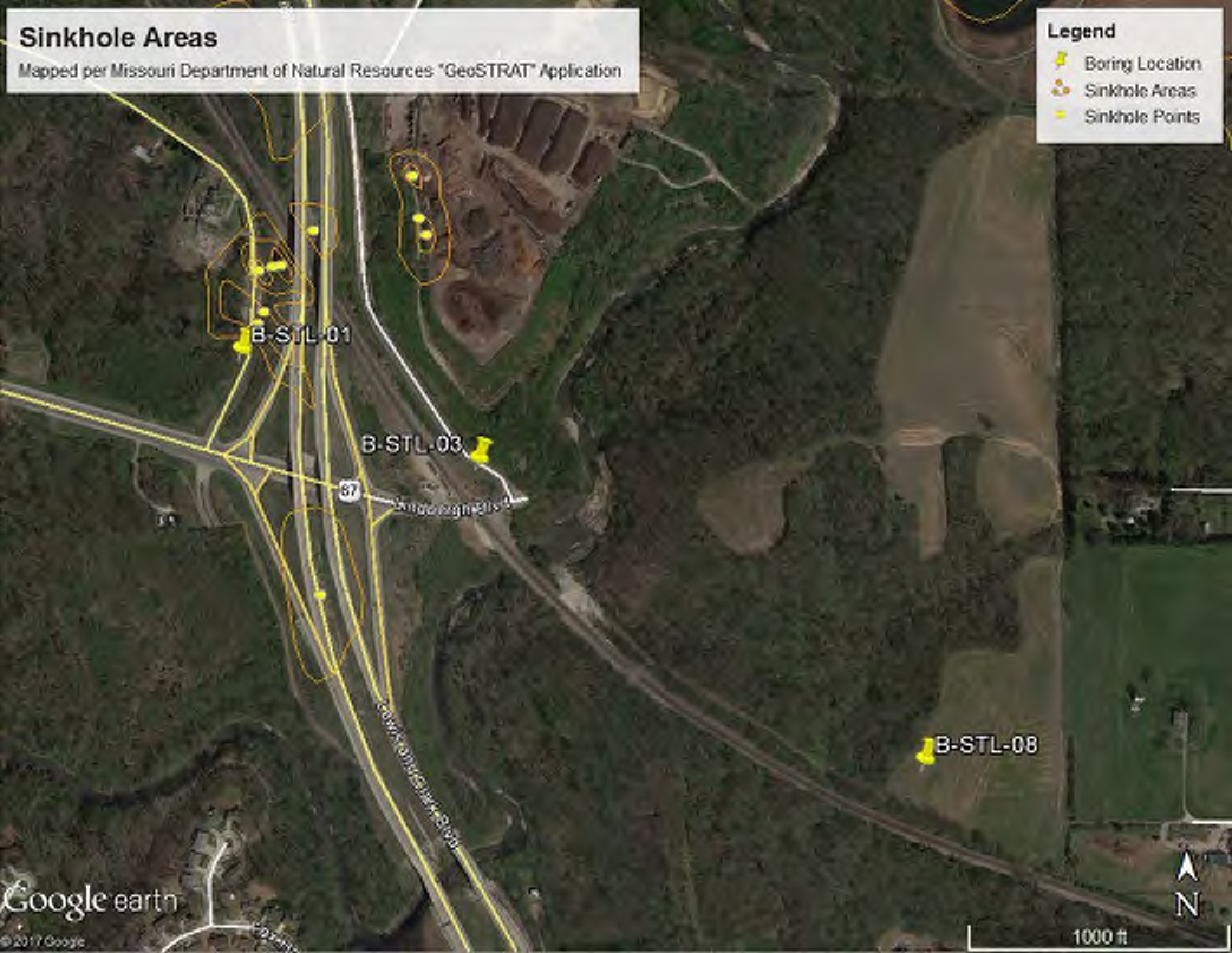
January 2009



Legend

Sinkhole Location
Karst Area
Major River or Lake

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 Location
Sinkhole Areas
Sinkhole Points
B-STL-01
B-STL-03
67
B-STL-08
Google earth
© 2017 Google
N
1000 ft

C. Soil Boring and Rock Core Logs

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-STL-01**

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 9, 2017 at 7:00 am
Driller/Helper:	Randy Kelly /Lance Leonard	**Date/Time Finished:**	March 10, 2017 at 1:30 pm

Elevation: 499 ft. | **Vertical Datum:** WGS84 | **Boring Location:** Approximately 26 feet from edge of pavement on New Jamestown Road | **Coord.:** **N:** 38.819367 **E:** -90.232424 | **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 3 4			0.3 Top 4" - Topsoil with roots	-	M	L	M	P.P. = 2.25 tsf.
					CL	Medium stiff, yellowish red to brownish yellow Silty CLAY, moist (CL)					
	S-2 2.0'- 4.0'	8	2 3 3 3		CL	Medium stiff, yellowish red SIlty CLAY, moist (CL)	-	M	L	M	P.P. = 2.75 tsf.
						4.0					
5	S-3 4.0'- 6.0'	15	2 3 3 3		ML	Medium stiff, yellowish red Clayey SILT, trace fine Sand, moist (ML)	-	M	L	M	P.P. = 1.3 tsf.
	S-4 6.0'- 8.0'	22	3 3 3 5		ML	Medium stiff, yellowish red Clayey SILT, trace fine Sand, moist (ML)	-	M	L	M	P.P. = 2.5 tsf.
490	S-5 8.0'- 10.0'	20	2 3 4 4		ML	Medium stiff, yellowish red Clayey SILT, trace fine Sand, moist (ML)	-	M	L	M	P.P. = 2.6 tsf.
10											
	S-6 13.0'- 15.0'	24	2 3 3 3		ML	Medium stiff, brownish yellow Clayey SILT, trace fine Sand, moist (ML)	-	M	L	H	P.P. = 1.6 tsf.
15											
						16.5					
480	S-7 18.0'- 20.0'	24	2 2 3 4		CL	Medium stiff, brownish yellow Silty CLAY, trace fine Sand, moist (CL)	-	M	L	M	P.P. = 1.9 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-01**

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	3 3 4 5		CL	Medium stiff, brown to light gray Silty CLAY, moist (CL)	-	H	M	H	P.P. = 3.5 tsf. Soil mottling of brownish yellow, yellowish red and light brown.
25											
						26.5					
	S-9 28.0'-30.0'	24	2 2 3 4		CH	Medium stiff, gray CLAY, moist (CH)	-	H	H	VH	P.P. = 1.9 tsf.
470											
30											
	S-10 33.0'-35.0'	24	1 2 2 3		CH	Medium stiff, gray CLAY, moist (CH)	-	H	H	VH	P.P. = 1.6 tsf.
35											
	S-11 38.0'-40.0'	24	2 3 3 4		CH	Medium stiff, gray CLAY, trace fine Sand, moist (CH)	-	H	H	VH	P.P. = 1.7 tsf.
460											
40											
						41.5					
	S-12 43.0'-45.0'	24	1 3 3 3		ML	Medium stiff, dark brown Clayey SILT, little fine Sand, wet (ML)	-	M	L	M	P.P. = 1.5 tsf.
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)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
450	S-13 48.0'- 50.0'	19	2 2 3 10		ML	Top 22" - Medium stiff, Clayey SILT, little fine Sand, wet (ML)	-	M	L	M	P.P. = 1.6 tsf. Groundwater encountered at 51 feet bgs while drilling.
50						49.8 Bottom 2" - White, fine grained Shaley Limestone					
						52.0 Auger refusal at 52.0 feet bgs. See rock core log.					
55											
440											
60											
65											
430											
70											
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 M M

CORE BORING LOG

BORING NO.: **B-STL-01**

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 9, 2017 at 7:00 am
Driller/Helper:	Randy Kelly /Lance Leonard	**Date/Time Finished:**	March 10, 2017 at 1:30 pm

Elevation: 499 ft.		**Vertical Datum:** WGS84		**Boring Location:** Approximately 26 feet from edge of pavement on New Jamestown Road	**Coord.: N:** 38.819367 **E:** -90.232424
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	Remarks
	1.75	52.0							LIMESTONE, white to light gray, fine grained, slightly weathered, strong, very close to moderately spaced discontinuities	
	2.5		R-1	36 100%	28 78%	R4	SL			
55	3.2	55.0								
	2.9	55.0							LIMESTONE, white to light gray, fine grained, slightly weathered, strong, very close to moderately spaced discontinuities 58' - 59' Possible void-like karst feature Frequent stylolites	
	2.5									
	3		R-2	48 80%	39 65%	R4	SL			
	0									
440	2.2	60.0								
60	1.6	60.0							LIMESTONE, white to light gray, fine grained, slightly weathered, medium strong, extremely close to moderately spaced discontinuities Frequent stylolites	
	3									
	2.5		R-3	56 93%	53 88%	R3	SL			
	3.1									
	3	65.0								
65	2.7	65.0							LIMESTONE, light gray, fine grained, slightly weathered, medium strong, extremely close to wide spaced discontinuities Frequent stylolites	
	2.6									
	2.1		R-4	60 100%	49 82%	R3	SL			
	1.4									
430	2	70.0						70.0		
70	1.6	70.0							Calcerous MUDSTONE with interbedded Limestone, light gray to olive gray, fine grained, moderately weathered, weak, close to wide discontinuities 71.7'-72.85' Friable & extremely weak olive gray calcerous mudstone.	
	1.9									

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
52.00	J	16	U,Sm	DS	O	N
53.20	J	33	U,Sm	DS	O	N
53.60	J	30	U,R	FR	O	N
54.00	J	5	U,Sm	DS	O	N
54.90	Sty	7	U,R	DG	O	CL
55.00	J	52	U,R	FR	W	N
55.70	J	28	U,Sm	FR	T	N
56.30	J	55	S,Sm	FR	W	N
57.80	MB	33	U,Sm	FR	W	N
58.90	MB	0	U,Sm	FR	W	N
60.50	MB	0	P,Sm	FR	W	N
62.50	Sty	7	U,R	DS	O	N
64.10	Sty	9	U,R	DS	O	N
67.10	J	12	U,Sm	DG	O	N
67.40	J	6	U,R	DG	MW	CL
67.70	J	5	U,Sm	DG	O	CL
71.70	J	3	U,Sm	DG	T	CL

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)
	1.7		R-5	57 95%	54 90%	R2	M		
	1.6								
	1.6	75.0							75.0
75	1.75	75.0							LIMESTONE, light gray, fine grained, fresh (un)weathered, strong, close to wide spaced discontinuities
	1.75								
	1.9		R-6	60 100%	58 97%	R4	FR		
	2								
420	2	80.0							
80	2.5	80.0							LIMESTONE, light gray, fine grained, slightly weathered, strong, close to moderately spaced discontinuities Frequent stylolites
	2								
	2.1		R-7	60 100%	39 65%	R4	SL		
	2								
	2	85.0							
85	2.1	85.0							LIMESTONE, light gray, fine grained, slightly weathered, medium strong, close to moderately spaced discontinuities Frequent stylolites 89.7' - 89.9' 1-inch chert nodules
	2.3								
	1.8		R-8	60 100%	50 83%	R3	SL		
410	2.1								
	2.2	90.0							
90	2.5	90.0							LIMESTONE, white to gray, fine grained, slightly weathered, strong, very close to wide spaced discontinuities Frequent 0.5" to 2" thick chert nodules Frequent stylolites
	5.7								
	5.4		R-9	60 100%	58 97%	R4	SL		
	5.7								
	6.1	95.0							
95	4	95.0							LIMESTONE, light gray to white, fine grained, moderately weathered, medium strong, extremely close to moderately spaced discontinuities Frequent stylolites Clay filled discontinuities
	4								
	4			60	48				

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
72.20	J	9	U,Sm	DG	O	CL	
72.65	J	3	U,Sm	DE	O	CL	
75.50	J	5	P,Sm	DG	MW	SD	/ML
77.30	J	9	U,Sm	DG	MW	N	
78.20	J	14	P,Sm	FR	T	N	
80.50	Sty	2	U,R	DS	O	QZ	
81.50	Sty	0	U,R	DS	O	N	
81.90	J	0	P,Sm	DS	O	N	
82.70	J	8	P,R	DS	MW	N	
83.00	J	2	P,Sm	DS	MW	CL	
83.50	J	2	U,Sm	DS	MW	N	
84.50	J	0	U,Sm	DS	O	N	
85.40	Sty	15	U,Sm	DG	MW	CL	
86.65	J	12	U,Sm	DG	MW	CL	
87.70	Sty	0	U,R	DG	MW	CL	
88.90	Sty	0	U,R	DG	MW	CL	
92.25	Sty	3	U,R	DS	O	QZ	
93.60	B	3	U,Sm	DE	O	ML	
94.80	J	11	U,R	DS	PO	N	
95.10	J	2	P,R	DG	MW	CL	
95.40	J	0	P,Sm	DG	O	CL	
96.50	Sty	4	U,R	DG	O	CL	
97.05	Sty	10	U,R	DG	O	CL	

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)
– 100.0	R-10	100%	80%	R3	M	
100.0 – 105.0	R-11	60 100%	58 97%	R3	M	LIMESTONE, white to light gray, fine grained, moderately weathered, medium strong, extremely close to wide spaced discontinuities Very frequent stylolites
105.0 – 110.0	R-12	60 100%	49 82%	R3	SL	LIMESTONE, white, fine grained, slightly weathered, medium strong, close to moderately spaced discontinuities Very frequent stylolites Highly strained zones containing coarse to fine quartz fragments and some zones of decreasing strength
110.0 – 115.0	R-13	60 100%	49 82%	R3	M	LIMESTONE, white to light gray, fine grained, moderately weathered, medium strong, extremely close to wide spaced discontinuities Frequent 1/4" to 1/2" Hardened clay-filled discontinuities
115.0 – 120.0	R-14	60 100%	56 93%	R3	SL	LIMESTONE, gray to white, fine grained, slightly weathered, medium strong, close to moderately spaced discontinuities 115' to 116.7' Gray vuggy marlstone Frequent stylolites
120.0 –	R-15	60 100%	53 88%	R4	SL	LIMESTONE, light gray to light brown, fine grained, slightly weathered, strong, close to moderately spaced discontinuities Frequent stylolites 120' to 120.5' Dark brown, vuggy, argellaceous limestone 121' to 125' Frequent 1/4" to 1.5"

Depth/Elev. (ft) markers: 400 (elev.), 100, 105, 390 (elev.), 110, 115, 380 (elev.), 120

Depth interval	Avg Core Rate (min/ft)
97–98	4
98–99	3.2
99–100	3.6
100–101	2.8
101–102	3.1
102–103	2.7
103–104	3.2
104–105	3.4
105–106	2.5
106–107	2.3
107–108	3.2
108–109	3.6
109–110	3.6
110–111	2.7
111–112	2.5
112–113	2.6
113–114	2.5
114–115	3.4
115–116	3.5
116–117	2
117–118	2.5
118–119	2.4
119–120	2.3
120–121	1.9
121–122	2.6
122–123	2.7

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
97.60	J	9	U,Sm	DG	MW	CL	
98.40	J	18	X,R	DG	W	CL	
99.00	F	3	U,Sm	DE	MW	CL	
101.80	F	0	U,Sm	DE	MW	CL	
102.40	J	19	U,Sm	DG	O	CL	
104.80	Sty	0	U,R	DE	MW	CL	
106.80	Sty	4	U,Sm	DE	O	CL	
107.20	J	11	U,R	DE	O	CL	
108.35	Sty	3	U,R	DG	O	CL	
110.80	J	3	U,Sm	DG	O	CL	
111.80	J	13	U,Sm	DG	T	CL	
112.40	J	3	U,Sm	DG	T	CL	
112.90	J	9	U,Sm	DG	O	CL	
114.00	Sty	12	U,R	DS	T	N	
114.70	Sty	0	U,R	DG	MW	CL	
115.00	Sty	10	U,R	DS	PO	N	
116.70	B	10	U,Sm	DG	MW	CL	
117.80	J	4	U,Sm	DG	PO	CL	
118.20	J	0	U,Sm	DG	T	N	
119.30	J	2	U,Sm	DG	T	N	
119.70	J	7	U,Sm	DG	PO	N	
120.50	B	19	S,R	DG	W	N	
121.50	Sty	6	U,R	DG	O	N	
121.90	J	1	U,R	FR	MW	N	

NOTES:

Depth/Elev. (ft) markers: 125, 370 (elev.), 130, 135, 360 (elev.), 140, 145

Avg Core Rate (min/ft): 3.3, 3.9, 2.1, 3.1, 2.9, 2.5, 3.5, 3.2, 3.2, 3.3, 3.6, 4.1, 2.5, 2.9, 2.9, 3.2, 3.2, 1.9, 2, 2.1, 2.4, 2.7, 2.3, 2.9, 2.7, 2.2

Depth (ft)	Run/(Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic
– 125.0						Limestone
125.0 – 130.0	R-16	60 100%	52 87%	R4	SL	Limestone
130.0 – 135.0	R-17	60 100%	54 90%	R3	SL	Limestone
135.0 – 140.0	R-18	60 100%	56 93%	R3	SL	Limestone
140.0 – 145.0	R-19	60 100%	60 100%	R4	FR	Limestone
145.0 –	R-20	60 100%	30 50%	R2	M	Limestone

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

Depth (ft)	Description
125.0	LIMESTONE, light gray, fine grained, slightly weathered, strong, close to moderately spaced discontinuities Frequent stylolites
130.0	LIMESTONE, light gray, fine grained, slightly weathered, medium strong, extremely close to moderately spaced discontinuities Frequent stylolites
135.0	LIMESTONE, light gray, fine grained, slightly weathered, medium strong, close to wide spaced discontinuities Calcite filled vugs
140.0	LIMESTONE, gray to white, fine grained, fresh, strong, wide spaced discontinuities 140' - 142.65' Argellaceous gray limestone 142.65' - 145' Frequent stylolites
145.0	LIMESTONE, light gray to olive gray, fine grained, moderately weathered, weak, very close to wide spaced discontinuities 145' - 148' Hardened olive gray clay-infilled fractures

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
123.05	Sty	9	U,R	DG	O	N	
123.65	Sty	11	U,R	DG	O	N	
125.60	B	21	U,Sm	DS	MW	N	
126.50	J	16	U,Sm	DS	MW	Fe	
128.30	Sty	0	P,Sm	DS	O	N	
129.20	Sty	7	U,R	DS	O	N	
129.50	Sty	12	U,R	FR	O	N	
130.75	Sty	0	U,R	DG	O	CL	
131.60	Sty	10	U,R	DG	MW	CL	/Qz
132.60	J	1	U,Sm	DE	O	CL	
132.80	J	0	P,Sm	FR	W	N	
133.60	Sty	5	U,R	DG	PO	CL	
136.00	Sty	4	U,R	DS	O	CL	
137.10	J	0	U,Sm	DG	O	CL	
138.00	J	3	U,Sm	DS	T	N	
139.00	J	11	U,Sm	DS	T	N	
139.75	J	9	U,Sm	DS	T	N	
142.65	B	22	P,Sm	DS	O	N	
145.90	F	5	U,R	DG	MW	CL	
147.80	F	45	U,R	DE	O	CL	

NOTES:

Depth/Elev. (ft)	Avg Core Rate (min/ft)
350	2.2
	2.5
150	2.2
	2.5
	1.9
	2.2
	2.9
155	3.1
	1.7
	2.3
	2.4
340	2.5
160	3
	3.9
	2.5
	2.4
	2.2
165	1.7
	1.8
	1.9
	2.7
330	1.5
170	1.2
	1
	1.4
	1.7

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)
– 150.0						
150.0 – 155.0	R-21	60 100%	59 98%	R4	FR	LIMESTONE, light gray, fine grained, fresh (un)weathered, medium strong, close to wide spaced discontinuities Calcite-filled vugs
155.0 – 160.0	R-22	50 83%	15 25%	R2	H	LIMESTONE, light gray, fine grained, highly weathered, weak, extremely close to moderately spaced discontinuities 155.9' - 157.3' Vertical fracture with calcite infilling 157.8' - 158.6' Olive gray calcerous mudstone
160.0 – 165.0	R-23	60 100%	60 100%	R3	H	LIMESTONE, light gray to olive gray, fine grained, highly weathered, weak, wide spaced discontinuities Rock core has calcite-filled fractures 163.9' - 165' Hardened olive gray clay-infilled discontinuities
165.0 – 170.0	R-24	60 100%	34 57%	R2	H	DECOMPOSED LIMESTONE, gray to olive gray, fine grained, highly weathered, close to moderately spaced discontinuities 165' - 170' Cavity & vuggy decomposed limestone
170.0 –	R-25	60 100%	31 52%	R2	H	170.0 LIMESTONE with interbedded Marlstone, brown to light gray, fine grained, highly weathered, weak, close to moderate discontinuities 170' - 172.4' Decomposed limestone with vugs & cavities 173.4 - 175' Decomposed limestone with vugs & cavities

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
151.80	Sty	11	U,R	DS	PO	N	
153.70	Sty	0	U,R	DS	T	N	
154.40	Sty	0	P,Sm	DS	O	N	
155.70	Sty	0	U,R	DG	O	ML	
157.30	Sty	5	U,R	DG	MW	ML	
157.80	Sty	6	U,R	DG	MW	CL	
163.90	Sty	28	U,R	DE	O	CL	
166.30	J	0	U,R	DS	O	N	
167.20	J	5	U,R	DG	MW	CL	
167.80	F	10	U,R	DG	W	Ca	Rock fragments Qz.
168.30	B	7	U,Sm	DE	T	CL	
169.50	J	22	U,R	DG	O	N	
171.10	J	24	U,R	DS	MW	N	
171.40	J	16	U,R	DS	MW	N	
172.30	J	20	U,R	DG	MW	N	
172.70	J	0	U,Sm	DG	MW	N	

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)	Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1	175.0						175.0	174.40	J	10	U,R	DG	O	N	
175	1.7	175.0						LIMESTONE, brown to gray, fine to medium grained, moderately weathered, medium strong, close to moderately spaced discontinuities								
	1.7							178.4' - 179.1' Decomposed limestone with cavities & vugs	176.30	Sty	3	U,R	DS	MW	N	
	2.1		R-26	60 100%	54 90%	R3	M									
	1.3								178.10	B	24	X,R	DS	MW	N	
320	2.3	180.0							178.80 179.10	J B	0 9	U,R U,Sm	DG DG	PO W	N CL	
180	2.5	180.0						LIMESTONE with interbedded Mudstone, gray to brown, fine grained, slightly weathered, weak, wide discontinuities								
	1.9							181.5 181.5' - 185' Mudstone	181.60	J	4	U,R	DG	PO	N	
	1.5		R-27	60 100%	60 100%	R2	SL									
	1.9															
	1.8	185.0														
185	1.1	185.0						MUDSTONE, gray to brown, fine grained, moderately weathered, weak, very close to wide discontinuities 186.3' - 187.3 Highly fractured								
	1.7								186.30	J	7	U,Sm	DS	PO	N	
	1.4		R-28	60 100%	45 75%	R2	M		187.30	J	4	U,Sm	DS	O	N	
	1.3															
310	1.2	190.0						190.0								
190	1.2	190.0						MARLSTONE with interbedded Limestone, gray to brown, fine grained, highly weathered, weak, extremely close to moderate discontinuities	190.30	J	25	S,R	DS	MW	Ca	
	1.3							190' - 191.8' Completely weathered and highly fractured with loss of precipitate 191.8' - 195' Marlstone with occasional cavities	191.80	J	10	U,Sm	DS	MW	N	
	1.7		R-29	60 100%	40 67%	R2	H		192.60	J	20	P,R	DS	W	N	
	1.9								193.50	B	4	U,Sm	DE	O	CL	
	2.1	195.0							194.20	J	3	U,Sm	DS	T	N	
195	1.9	195.0						LIMESTONE, gray, fine grained, slightly weathered, medium strong, extremely close to wide discontinuities Frequent crystalization of minerals within cavities & vugs Occasional chert nodules								
	1.9															
	2.0		R-30	60 100%	52 87%	R3	SL		197.30 197.50	B B	0 16	P,R U,R	DE DE	MW MW	CL CL	
	1.8								197.90	J	16	U,Sm	DS	PO	N	
300	2.9								198.80	J	3	U,Sm	DG	PO	QZ	

(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	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
200	2.9	200.0							200.0 End of Boring at 200 feet BGS. Borehole backfilled with cement grout.								
205																	
290																	
210																	
215																	
280																	
220																	
225																	

(See Legend for Rock Description System)

NOTES:

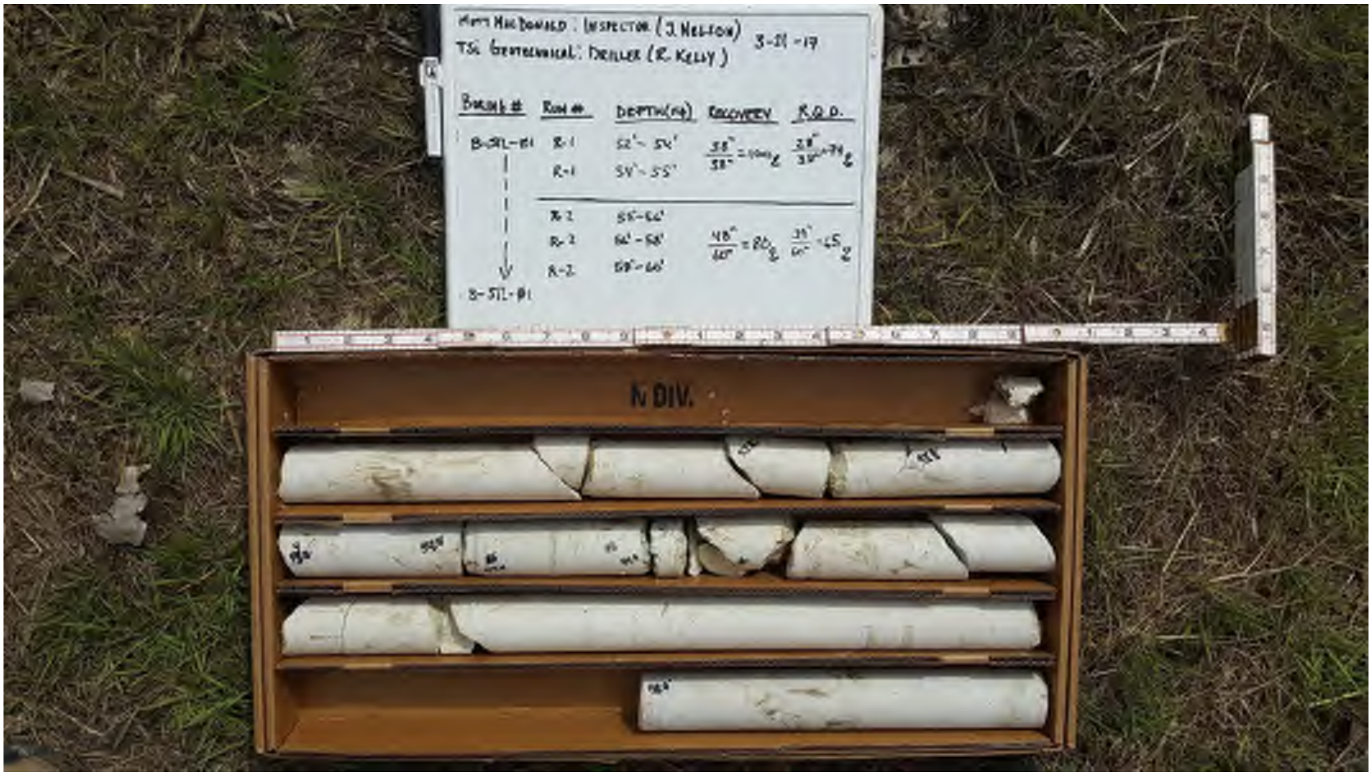


Figure B-STL-01.1
B-STL-1 Box 1 Runs 1-2 Dry

Figure B-STL-01.2
B-STL-1 Box 1 Runs 1-2 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-01

Figure B-STL-01.3
B-STL-1 Box 2 Runs 3-4 Dry

Figure B-STL-01.4
B-STL-1 Box 2 Runs 3-4 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-01

Figure B-STL-01.5
B-STL-1 Box 3 Runs 5-6 Dry

Figure B-STL-01.6
B-STL-1 Box 3 Runs 5-6 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-01

Figure B-STL-01.7
B-STL-1 Box 4 Runs 7-8 Dry

Figure B-STL-01.8
B-STL-1 Box 4 Runs 7-8 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-01

Figure B-STL-01.9
B-STL-1 Box 5 Runs 9-10 Dry

Figure B-STL-01.10
B-STL-1 Box 5 Runs 9-10 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-01

Figure B-STL-01.11
B-STL-1 Box 6 Runs 11-12 Dry

Figure B-STL-01.12
B-STL-1 Box 6 Runs 11-12 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-01

Figure B-STL-01.13
B-STL-1 Box 7 Runs 13-14 Dry

Figure B-STL-01.14
B-STL-1 Box 7 Runs 13-14 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-01

Figure B-STL-01.15
B-STL-1 Box 8 Runs 15-16 Dry

Figure B-STL-01.16
B-STL-1 Box 8 Runs 15-16 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-01

Figure B-STL-01.17
B-STL-1 Box 9 Runs 17-18 Dry

Figure B-STL-01.18
B-STL-1 Box 9 Runs 17-18 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-01

Figure B-STL-01.19
B-STL-1 Box 10 Runs 19-20 Dry

Figure B-STL-01.20
B-STL-1 Box 10 Runs 19-20 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-01

Figure B-STL-01.21
B-STL-1 Box 11 Runs 21-22 Dry

Figure B-STL-01.22
B-STL-1 Box 11 Runs 21-22 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-01

Figure B-STL-01.23
B-STL-1 Box 12 Runs 23-24 Dry

Figure B-STL-01.24
B-STL-1 Box 12 Runs 23-24 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-01

Figure B-STL-01.25
B-STL-1 Box 13 Runs 25-26 Dry

Figure B-STL-01.26
B-STL-1 Box 13 Runs 25-26 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-01

Figure B-STL-01.27
B-STL-1 Box 14 Runs 27-28 Dry

Figure B-STL-01.28
B-STL-1 Box 14 Runs 27-28 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-01

Figure B-STL-01.29
B-STL-1 Box 15 Runs 29-30 Dry

Figure B-STL-01.30
B-STL-1 Box 15 Runs 29-30 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-01

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-STL-03**

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 15, 2017 at 7:00 am
Driller/Helper:	Randy Kelly /Lance Leonard	**Date/Time Finished:**	March 21, 2017 at 5:00 pm

Elevation: 495 ft. **Vertical Datum:** WGS84 **Boring Location:** 25 feet from closest edge of pavement on New Jamestown Rd. **Coord.:** N: 38.818333 E: -90.229537 **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

Rig			Hammer Type	Drilling Fluid	Drill Rod Size:
☐ Truck	☐ Tripod	☐ Cat-Head	☐ Safety	☑ Bentonite	**Casing Advance**
☑ ATV	☐ Geoprobe	☑ Winch	☐ Doughnut	☐ Polymer	Hollow Stem Auger/Mud Rotary
☐ Track	☐ Air Track	☐ Roller Bit	☑ Automatic	☑ Water	
☐ Skid	☐ ______	☑ Cutting Head	☐ ______	☑ None	

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'	15	2 3 6 7		ML	Stiff, yellowish red SILT, moist (ML)	-	L	NP	L	Some roots present near grade.
	S-2 2.0'- 4.0'	14	4 6 8 7		ML	Stiff, yellowish red SILT, trace coarse to fine Gravel, dry (ML)	-	L	NP	L	
5 490	S-3 4.0'- 6.0'	15	3 6 9 8		ML	Stiff, yellowish red SILT, trace coarse to fine Gravel, wet (ML)	-	L	NP	L	
	S-4 6.0'- 8.0'	19	4 6 9 11		ML	Stiff, yellowish red Clayey SILT, trace fine Sand, wet (ML)	-	M	L	M	
	S-5 8.0'- 10.0'	15	6 6 6 6		ML	Stiff, yellowish red Clayey SILT, moist (ML)	-	M	L	M	
10											
	S-6 13.0'- 15.0'	17	3 6 7 6		ML	Stiff, dark brown SILT, little fine Sand, wet (ML)	-	L	-	L	
15 480											
	S-7 18.0'- 20.0'	16	2 7 9 10		ML	Very stiff, brown SILT, trace fine Sand, dry (ML)	-	L	-	L	

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-03**

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	4 4 6 7		ML	Stiff, yellowish red to brownish yellow SILT, moist (ML)	-	L	-	L	
25 470											
	S-9 28.0'- 30.0'	24	2 4 5 5		ML	Stiff, dark brown Clayey SILT, moist (ML)	-	L	-	L	P.P. = 2.5 tsf Brief Hard Drilling at 32 feet BGS.
30											
	S-10 33.0'- 35.0'	21	1 1 1 2		ML	Very soft, brown Clayey SILT, moist (ML)	-	M	L	M	Cutting through rock at 35 feet BGS.
35 460						35.0					
	S-11 38.0'- 40.0' 38.5'-'		50/2"			38.5 Very dense, white, LIMESTONE FRAGMENTS, dry	N	-	NP	N	
						Top of Rock at 38.5 feet BGS. See Rock Coring Log.	-	-	-	-	Refusal at 38.5 feet BGS.
40											
45 450											

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.

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 15, 2017 at 7:00 am
Driller/Helper:	Randy Kelly /Lance Leonard	**Date/Time Finished:**	March 21, 2017 at 5:00 pm

Elevation: 495 ft.		**Vertical Datum:** WGS84		**Boring Location:** 25 feet from closest edge of pavement on New Jamestown Rd.	**Coord.: N:** 38.818333 **E:** -90.229537
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
	0.2	37.0							LIMESTONE, light gray, fine grained, slightly weathered, medium strong, very close to moderate discontinuities								
	1.0		R-1	27 75%	22 61%	R3	SL			38.45	J	22	P,Sm	FR	MW	N	
	1.2	40.0															
40	1.1	40.0							LIMESTONE, light gray, fine grained, slightly weathered, medium strong, extremely close to moderate discontinuities 40.4' - 40.7' Highly Weathered zone 40.7' - 41.9' Possibly clay-filled void	40.40	J	68	U,Sm	DE	W	CL	Loss of water from 40 to 45 feet BGS.
	1.1									41.90	J	3	U,Sm	FR	W	N	
	2.1		R-2	53 88%	32 53%	R3	SL			42.70	J	3	U,Sm	FR	O	N	
	2.3																
	2.6	45.0								44.80	J	0	P,R	DE	W	CL	
45 450	2.75	45.0							LIMESTONE, light gray to light brown, fine grained, slightly weathered, medium strong, close to wide spaced discontinuities Iron deposits 46' - 47.65' Core turns to light brown								Used approximately 250 gallons of water from 45 to 50 feet BGS.
	2.50																
	1.60		R-3	60 100%	51 85%	R3	SL			47.65	J	8	U,R	DG	MW	CL	
	2.70									48.40	Sty	20	U,R	DS	T	N	
	3.30	50.0							49.3' - 50' 1/16" Fracture (70 degrees)	49.80	Sty	60	U,R	DS	PO	Ca	
50	2.50	50.0							LIMESTONE, white to light brown, medium to fine grained, moderately weathered, weak, extremely close to moderately spaced discontinuities Frequent stylolites								Used approximately 250 gallons of water from 50 to 55 feet BGS.
	3.00									51.00	Sty	20	U,R	DE	O	CL	
										51.70	F	45	S,R	FR	PO	N	Rod dropped from 54.3 to 54.65 feet BGS.
	3.20		R-4	57 95%	43 72%	R2	M			52.65	J	8	U,Sm	FR	T	N	
	0.60								53.5' - 54.35' Completely Weathered	53.40	J	8	U,Sm	DS	PO	N	
										53.70	B	0	U,Sm	DE	MW	CL	
	3.10	55.0						54.3 54.7	54.3' - 54.65' Void	54.35	J	6	U,R	DS	W	N	
										54.65	J	22	U,Sm	FR	W	N	
55 440	3.00	55.0							LIMESTONE, White, fine grained, fresh, medium strong, close to moderately spaced discontinuities Occasional stylolities								Rod dropped from 58 to 60 feet BGS.
	2.60																

Discontinuities: (See Legend for Rock Description System)

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Depth in feet to: 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
	2.75		R-5	44 73%	42 70%	R3	RS		58.0	56.95 57.10 57.50	Sty J J	0 36 65	U,R U,Sm U,R	DS DG FR	T VW O	N CL N	
	1.20	60.0							58' - 66' Clay filled Void								
60		60.0 / 65.0	R-6	0 0%	0 0%	-	-		No Recovery								
65 430		65.0							66.0								Clay filled void with little Gravel.
	0.60								Decomposed Clayey CHERT and mostly Quartzite fragments, fine grained, completely weathered, weak, extremely close spaced discontinuities								
	0.20		R-7	4 7%	0 0%		C										
	0.10	70.0							68' - 68.5' Very soft brownish yellow to gray								
70	0.00	70.0							Decomposed Clayey CHERT and Quartzite fragments, brownish yellow to gray, medium to fine grained, completely weathered, weak, extremely close spaced discontinuites								Clay filled void with little Gravel.
	0.10																
	0.10		R-8	7 12%	0 0%	R2	C										
	0.10																
	0.15	75.0							75.0								
75 420	0.70	75.0							LIMESTONE, light gray to white, fine grained, slightly weathered, medium strong, close to moderately spaced discontinuities Frequent stylolites								Rod dropped from 76 to 77.2 feet BGS.
	0.90																
	1.90		R-9	36 60%	32 53%	R3	SL			77.00 77.80	MB J	8 9	P,R U,Sm	DS DS	W T	N N	
	1.70																
	2.10	80.0								79.20	J	6	P,Sm	DS	PO	N	
80	4.00	80.0							LIMESTONE, white to light gray, fine grained, moderately weathered, medium strong, extremely close to close spaced discontinuities Frequent stylolites Clay infilled stylolites	79.80 80.00 80.70	Sty Sty Sty	14 11 13	U,R U,R U,R	DG DS DS	CA O W	QZ N N	
	3.20									81.50	Sty	13	U,Sm	DS	MW	CL	
	3.00			49	16												

(See Legend for Rock Description System)

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
	3.00		R-10	82%	27%	R3	M	
	3.00							
	3.75	85.0						
85 410	2.70	85.0						
	3.30							
	3.10		R-11	50 83%	18 30%	R3	M	
	3.60							
	3.10	90.0						
90	3.30	90.0						
	3.70							
	3.50		R-12	60 100%	53 88%	R3	M	
	3.60							
	4.10	95.0						
95 400	5.50	95.0						
	4.50							
	4.50		R-13	60 100%	49 82%	R4	SL	
	3.60							
	4.10	100.0						
100	3.40	100.0						
	4.00							
	3.60		R-14	60 100%	47 78%	R3	SL	
	4.50							
	3.50	105.0						
105 390	3.40	105.0						
	4.00							
	3.60		R-15	60 100%	54 90%	R3	SL	

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

LIMESTONE, white to light gray, fine grained, moderately weathered, medium strong, extremely close to moderately spaced discontinuities
Frequent stylolites
85'- 87' Highly Fractured zone

LIMESTONE with interbedded Chert, white to dark gray, fine grained, moderately weathered, medium strong, very close to moderately spaced discontinuites
Frequent stylolites
Chert modules typically 1/4" to 2" long

LIMESTONE, white to olive green, fine grained, slightly weathered, strong, close to moderately spaced discontinuities
Frequent stylolites

98' - 100' Clay filled discontinuities

LIMESTONE, white to light gray, fine grained, slightly weathered, medium strong, close to moderately spaced discontinuities
Frequent stylolites
Clay filled discontinuities

LIMESTONE, white to light gray, fine grained, medium strong, slightly weathered, close to wide spaced discontinuities
Frequent stylolites

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
82.30	Sty	0	U,R	DS	MW	N	
82.90	Sty	12	U,R	DS	W	CL	
83.20	Sty	8	U,R	DS	W	CL	
83.70	Sty	11	U,R	DS	MW	CL	
84.30	J	16	U,Sm	DG	W	CL	
88.20	Sty	9	U,R	DS	PO	N	
88.60	Sty	15	U,Sm	DS	MW	N	
90.55	Sty	5	U,R	DS	MW	N	
90.75	J	10	U,Sm	DS	MW	N	
92.30	J	9	U,R	DS	O	N	
93.90	J	0	P,Sm	-	MW	N	
94.60	J	5	U,Sm	FR	MW	N	
94.90	J	3	U,Sm	FR	O	N	
95.20	Sty	10	U,R	DS	T	N	
96.65	Sty	0	U,R	DS	PO	N	
97.15	Sty	20	U,R	DS	O	N	
98.00	J	10	U,Sm	DE	MW	CL	
98.60	Sty	11	U,R	DE	O	CL	
100.70	Sty	11	U,R	DS	PO	CL	
101.00	J	14	U,R	DS	MW	CL	
101.40	J	8	U,Sm	DE	PO	CL	
103.50	Sty	u	U,R	DE	O	CL	
104.20	Sty	12	U,R	DE	PO	CL	
106.00	Sty	3	U,R	DS	O	N	
107.10	Sty	13	U,Sm	DG	MW	ML	

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.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	4.50									108.90	Sty	12	U,Sm	DE	MW	ML	
	3.50	110.0															
110	2.90	110.0							LIMESTONE, white to light gray, fine grained, medium strong, moderately weathered, very close to moderately spaced discontinuities Frequent tension fractures	110.00	Sty	12	U,R	DS	PO	N	
	3.00									111.00 111.60	J J	8 15	U,Sm U,Sm	DS DS	PO PO	CL CL	
	3.10		R-16	60 100%	60 100%	R3	M			112.40 112.70	J J	8 0	U,Sm U,Sm	DE DE	O MW	CL CL	
	3.10									113.60	J	3	U,Sm	DE	MW	CL	
	3.60	115.0								114.20	J	8	U,Sm	DE	MW	CL	
115 380	2.50	115.0							LIMESTONE, white to olive gray, fine grained, medium strong, moderately weathered, close to moderately spaced discontinuities Frequent stylolites	115.40	J	10	U,Sm	DG	O	ML	
	3.10								116.6' - 117.2' Calcerous Mudstone	116.60	J	5	U,Sm	DS	O	N	
	3.60		R-17	59 98%	51 85%	R3	M			117.20	J	31	U,Sm	DS	MW	N	
	3.70									118.30	Sty	0	U,R	DS	O	N	
	4.00	120.0															
120	2.70	120.0							LIMESTONE, light gray, fine grained, slightly weathered, strong, close to wide spaced discontinuities Frequent stylolites								
	2.70									121.40	Sty	26	U,R	FR	PO	N	
	2.80		R-18	60 100%	56 93%	R4	SL										
	2.70									123.55	J	47	U,Sm	FR	MW	N	
	3.30	125.0							124.6' - 124.7' Chert nodules	124.20 124.40	J Sty	59 10	P,R U,R	DS DS	PO PO	N N	
125 370	3.50	125.0							LIMESTONE, light gray, fine grained, slightly weathered, strong, close to wide spaced discontinuities Frequent stylolites 125' - 126' Chert nodules	125.70	Sty	8	U,R	DS	T	N	
	3.20																
	3.10		R-19	60 100%	56 93%	R4	SL										
	3.00									128.00	J	7	U,Sm	DE	MW	CL	
	3.00	130.0								129.05	J	15	U,Sm	DE	O	CL	
130	2.70	130.0							LIMESTONE, light gray, slightly weathered, medium strong, extremely close to moderately spaced discontinuities Frequent stylolites	130.35	Sty	0	U,R	DS	O	N	
	2.90																
	2.50		R-20	60 100%	42 70%	R3	SL										
	3.10									133.00	Sty	0	U,R	DS	O	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)	Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	3.10									133.80	Sty	12	U,R	DS	O	Ca	
	2.70	135.0								134.70	J	15	U,Sm	DS	O	N	
135 360	2.90	135.0	R-21	60 100%	47 78%	R3	SL		LIMESTONE, light gray, fine grained, slightly weathered, medium strong, extremely close to moderately spaced discontinuities Frequent stylolites								
	2.90									136.15	J	12	U,Sm	DG	MW	CL	
	2.10									137.15	J	5	S,R	DG	MW	CL	
	2.70									138.75	Sty	12	U,R	DS	O	QZ	
	2.60	140.0								139.60	J	17	U,Sm	DG	MW	CL	
140	2.10	140.0	R-22	60 100%	41 68%	R3	SL		LIMESTONE, light gray, medium to fine grained, slightly weathered, medium strong, extremely close to wide spaced discontinuities Frequent stylolites								
	2.80								141.5' - 142.1' Vertical Fractures	141.80	F	87	U,R	DS	MW	N	
	2.40									142.10	MB	26	U,R	FR	O	N	
										142.70	J	10	P,Sm	DG	PO	CL	
	2.30																
	3.10	145.0															
145 350	2.40	145.0	R-23	60 100%	54 90%	R3	SL		LIMESTONE, light gray, fine grained, moderately weathered, medium strong, close to wide spaced discontinuities Frequent stylolites								
	2.30																
	2.10									147.30	S	15	U,R	DS	O	N	
	2.40									147.95	Sty	8	U,R	DS	O	N	
										148.40	J	24	U,R	DS	W	N	
	2.30	150.0															
150	1.70	150.0	R-24	60 100%	60 100%	R3	SL		LIMESTONE, light gray, fine grained, slightly weathered, medium strong, moderate to wide spaced discontinuities Frequent stylolites	150.70	Sty	17	U,R	DS		N	
	1.80																
	1.90																
	1.90																
	1.90	155.0															
155 340	2.20	155.0	R-25	60 100%	60 100%	R3	SL		LIMESTONE, light gray to white, fine grained, slightly weathered, medium strong, close to wide spaced discontinuities Frequent stylolites								
	1.90																
	2.00									157.40	Sty	21	U,R	DS	MW	QZ	/Ca
	2.30									158.50	Sty	32	U,R	DS	MW	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)	Remarks
	2.10	160.0							
160	1.75	160.0	R-26	58 97%	27 45%	R3	M	LIMESTONE, light gray to white, fine grained, moderately weathered, medium strong, extremely close to moderately spaced discontinuities Frequent stylolites	Rod dropped from 160.3 to 160.5 feet BGS.
	1.75								
	1.70								
	1.80								
	1.70	165.0							
165 330	2.00	165.0	R-27	60 100%	46 77%	R2	H	LIMESTONE, light gray to olive gray, fine grained, highly weathered, weak, extremely close to moderately spaced discontinuities 165' - 170' Silt/Clay infilled and hardened fractures	
	1.90								
	1.70								
	1.50								
	2.10	170.0							
170	2.20	170.0	R-28	60 100%	53 88%	R2	M	LIMESTONE with interbedded Mudstone, light gray to light brown, medium to fine grained, moderately weathered, weak, extremely close to moderately spaced discontinuities Frequent stylolites/slightly porous 171.5' - 173' Frequent Chert nodules	
	2.10								
	1.90								
	2.30								
	2.30	175.0							
175 320	3.10	175.0	R-29	60 100%	46 77%	R3	SL	LIMESTONE, light gray to light brown, fine grained, slightly weathered, medium strong, extremely close to wide spaced discontinuities Frequent stylolites 175.3' - 175.7' Chert nodules	
	3.10								
	3.60								
	1.80								
	3.20	180.0							
180	2.20	180.0	R-30	60 100%	50 83%	R3	SL	LIMESTONE, light gray to white, fine grained, slightly weathered, medium strong, close to wide spaced discontinuities Frequent Calcite infilled cavities/vugs	
	2.50								
	2.10								
	2.20								
	2.90								

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
160.40	J	0	U,R	DS	MW	N
162.30	Sty	18	U,R	DG	O	CL
162.70	S	67	U,Sm	DS	PO	N
163.10	Sty	13	U,R	DS	PO	N
164.35	Sty	23	U,R	DG	W	CL
166.10	Sty	24	U,R	DE	W	CL
166.30	Sty	41	U,R	DE	W	CL
166.65	Sty	17	U,R	DE	O	CL
167.00	Sty	11	U,R	DG	MW	CL
168.30	J	13	U,R	DS	O	CL
170.60	J	5	U,Sm	DG	O	N
171.05	J	11	U,Sm	DG	O	N
171.50	J	17	U,Sm	DG	O	N
171.85	J	0	U,Sm	DS	MW	N
172.40	J	35	U,Sm	DE	W	CL
173.40	Sty	12	U,Sm	DE	O	CL
174.50	J	10	U,Sm	DG	W	CL
175.30	J	5	U,Sm	DS	T	QZ
175.70	J	10	U,Sm	FR	PO	N
176.90	Sty	10	U,R	DS	W	N
178.30	Sty	19	U,R	DG	W	N
179.65	J	10	P,R	DS	MW	N
183.00	J	7	U,Sm	DS	W	N
184.20	J	19	U,Sm	DS	MW	Ca

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)
	2.90	185.0							185.0
185 310	2.00	185.0	R-31	60 100%	54 90%	R2	SL		Calcerous MUDSTONE, brown, fine grained, slightly weathered, weak, extremely close to moderately spaced discontinuities Frequent stylolites
	1.90								
	1.80								
	1.70								
	1.90	190.0							190.0
190	1.20	190.0	R-32	58 97%	47 78%	R3	M		Argillaceous LIMESTONE, brown, fine grained, moderately weathered, medium strong, extremely close to moderately spaced discontinuities Frequent Sand pockets Calcite filled cavities and vugs 1/3" to 1/4" laminations dark brown
	1.30								
	1.30								
	1.20								
	1.40	195.0							
195 300	1.70	195.0	R-33	60 100%	46 77%	R3	M		Argillaceous LIMESTONE, brown, fine grained, moderately wearthered, medium strong, extremely close to moderately spaced discontinuities Few stylolites 199.1' - 199.8' Calcite filled cavities
	1.70								
	1.90								
	1.90								
	2.10	200.0							200.0
200									End of Boring at 200 feet BGS. Borehole backfilled with cement grout.
205 290									
210									

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
185.55	J	12	U,Sm	DS	O	Ca	
186.30	V	6	U,R	DS	MW	Ca	
187.10	Sty	9	U,Sm	DS	MW	N	
188.15	V	40	U,R	DS		Ca	
191.00	J	5	U,Sm	DS	O	N	
191.15	B	10	U,Sm	DS	MW	N	
192.30	V	56	U,Sm	DS	W	Ca	
193.20	V	53	P,Sm	DS	W	Ca	
193.90	B	9	U,Sm	DG	MW	ML	
196.50	Sty	10	U,R	DS	MW	N	
196.70	B	5	U,R	DE	W	CL	
197.40	V	70	P,R	DS	PO	Ca	
197.90	J	7	U,Sm	DG	O	CL	
198.50	Sty	17	U,Sm	DE	W	CL	
199.70	J	7	U,Sm	DS	PO	Ca	

Figure B-STL-03.1
B-STL-03 Box 1 Runs 1-2 Dry

Figure B-STL-03.2
B-STL-03 Box 1 Runs 1-2 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-03

Figure B-STL-03.3
B-STL-03 Box 2 Runs 3-4 Dry

Figure B-STL-03.4
B-STL-03 Box 2 Runs 3-4 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-03

Figure B-STL-03.5
B-STL-03 Box 3 Runs 5-9 Dry

Figure B-STL-03.6
B-STL-03 Box 3 Runs 5-9 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-03

Figure B-STL-03.7
B-STL-03 Box 4 Runs 10-11 Dry

Figure B-STL-03.8
B-STL-03 Box 4 Runs 10-11 Wet

Figure B-STL-03.9
B-STL-03 Box 5 Runs 12-13 Dry

Figure B-STL-03.10
B-STL-03 Box 5 Runs 12-13 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-03

Figure B-STL-03.11
B-STL-03 Box 6 Runs 14-15 Dry

Figure B-STL-03.12
B-STL-03 Box 6 Runs 14-15 Wet

Figure B-STL-03.13
B-STL-03 Box 7 Runs 16-17 Dry

Figure B-STL-03.14
B-STL-03 Box 7 Runs 16-17 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-03

Figure B-STL-03.15
B-STL-03 Box 8 Runs 18-19 Dry

Figure B-STL-03.16
B-STL-03 Box 8 Runs 18-19 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-03

Figure B-STL-03.17
B-STL-03 Box 9 Runs 20-21 Dry

Figure B-STL-03.18
B-STL-03 Box 9 Runs 20-21 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-03

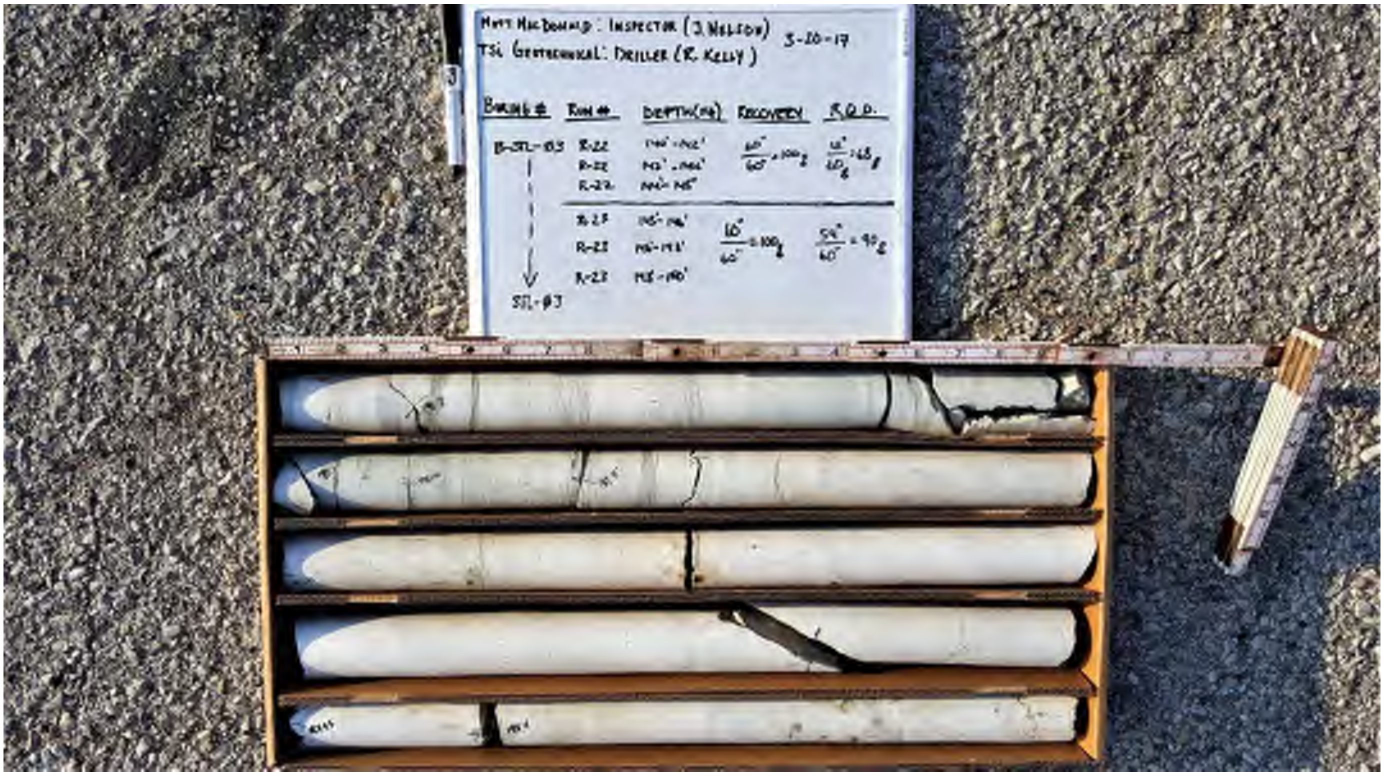


Figure B-STL-03.19
B-STL-03 Box 10 Runs 22-23 Dry

Figure B-STL-03.20
B-STL-03 Box 10 Runs 22-23 Wet

Figure B-STL-03.21
B-STL-03 Box 11 Runs 24-25 Dry

Figure B-STL-03.22
B-STL-03 Box 11 Runs 24-25 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-03

Figure B-STL-03.23
B-STL-03 Box 12 Runs 26-27 Dry

Figure B-STL-03.24
B-STL-03 Box 12 Runs 26-27 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-03

Figure B-STL-03.25
B-STL-03 Box 13 Runs 28-29 Dry

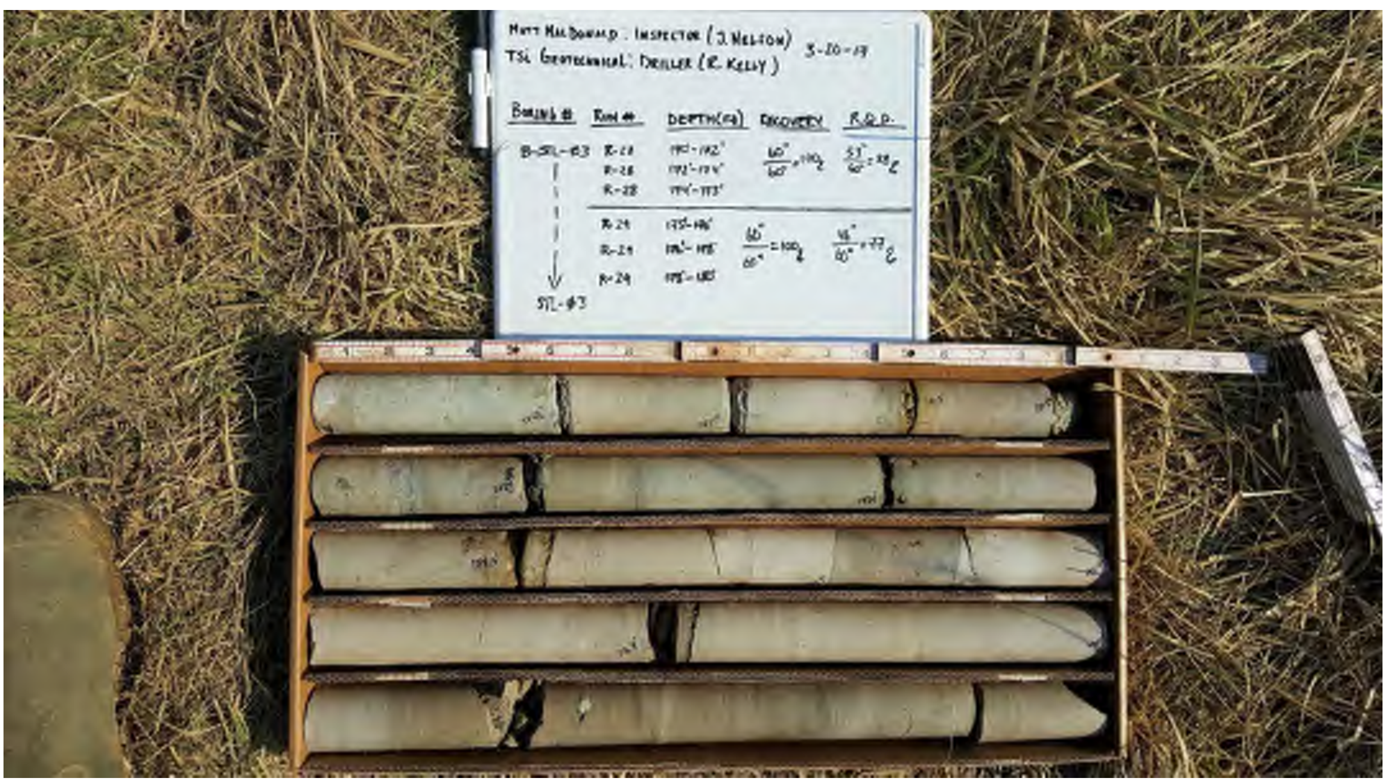


Figure B-STL-03.26
B-STL-03 Box 13 Runs 28-29 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-03

Figure B-STL-03.27
B-STL-03 Box 14 Runs 30-31 Dry

Figure B-STL-03.28
B-STL-03 Box 14 Runs 30-31 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-03

Figure B-STL-03.29
B-STL-03 Box 15 Runs 32-33 Dry

Figure B-STL-03.30
B-STL-03 Box 15 Runs 32-33 Wet

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SOIL BORING LOG

BORING NO.: **B-STL-08**

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:**	July 24, 2017 at 10:00 am
Driller/Helper:	Ronnie Meyer / Devin Davis	**Date/Time Finished:**	July 26, 2017 at 6:00 pm

Elevation: 514 ft. **Vertical Datum:** WGS84
Boring Location: Offset 220 feet northeast from closest edge of train track.
Coord.: N: 38.815533 **E:** -90.223948
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
					ML	Augered down from 0 to 1 foot. Yellowish red Clayey SILT, trace fine Sand, dry (ML)					
	S-1 1.0'- 2.0'	9	4 3		ML	Yellowish red Clayey SILT, trace fine Sand, dry (ML)	-	L	L	L	
	S-2 2.0'- 4.0'	16	3 3 5 3		ML	Medium stiff, yellowish red Clayey SILT, trace fine Sand, dry (ML)	-	L	L	L	
510	S-3 4.0'- 6.0'	16	2 2 3 3		ML	Medium stiff, yellowish red Clayey SILT, trace fine Sand, dry (ML)	-	L	L	M	P.P. = 1.6 tsf.
5											
	S-4 6.0'- 8.0'	18	2 2 2 2		ML	Medium stiff, yellowish red Clayey SILT, trace fine Sand, dry (ML)	-	L	L	M	P.P. = 1.1 tsf.
	S-5 8.0'- 10.0'	22	2 2 2 3		ML	Medium stiff, yellowish red Clayey SILT, trace fine Sand, dry (ML)	-	L	L	M	P.P. = 1.3 tsf.
10											
	S-6 13.0'- 15.0'	24	2 3 5 3		ML	Medium stiff, yellowish red Clayey SILT, trace fine Sand, dry (ML)	-	L	L	M	P.P. = 1.5 tsf.
500											
15											
	S-7 18.0'- 20.0'	24	3 3 4 5		ML	Medium stiff, yellowish red Clayey SILT, dry (ML)	-	L	L	M	P.P. = 1.5 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-08**

Field Test Legend: Dilatancy: N - None S - Slow R - Rapid; Plasticity: NP - Non-Plastic L - Low M - Medium H - High; Toughness: 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 / 25	S-8 23.0'-25.0'	24	2 2 2 2		ML	Medium stiff, yellowish red Clayey SILT, dry (ML)	-	L	L	M	P.P. = 2.3 tsf.
						26.5					
30	S-9 28.0'-30.0'	24	2 3 4 4		CL	Medium stiff, yellowish red to brownhish yellow Silty CLAY, dry (CL)	-	H	M	H	P.P. = 1.5 tsf.
						31.5					
480 / 35	S-10 33.0'-34.5'	7	WOH WOH 50/2"		SC	Top 12" Very loose, reddish brown Clayey coarse to fine SAND, moist (SC)	-	L	L	M	Potential karstic slump zone above bedrock.
						34.0					
						34.2 Bottom 6" Very dense, light gray DECOMPOSED LIMESTONE, dry					
						Top of Rock at 34 feet BGS Augered down to coreable rock at 35.5 feet BGS See Rock Coring Log					
40											
470 / 45											

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

PROJECT NO.: **372453**

BORING NO.: **B-STL-08**

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 M M

CORE BORING LOG

BORING NO.: **B-STL-08**

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:**	July 24, 2017 at 10:00 am
Driller/Helper:	Ronnie Meyer / Devin Davis	**Date/Time Finished:**	July 26, 2017 at 6:00 pm

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: Offset 220 feet northeast from closest edge of train track.

Horizontal Datum: WGS84

Rig Make & Model: CME-550X

Coord.: N: 38.815533 **E:** -90.223948

Drilling Method: Wireline

SEE TEST BORING LOG FOR OVERBURDEN DETAILS

Depth/Elev. (ft)	Avg Core Rate (min/ft)	Depth (ft)	Run/(Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath
	3.0	35.5					
	1.9						
	1.9		R-1	51 94%	33 61%	R2	H
	1.8						
	1.9	40.0					
40	2.2	40.0					
	2.5						
	3.0		R-2	54 90%	26 43%	R3	M
	5.7						
470	6.5	45.0					
45	10.2	45.0					
	5.4						
	6.9		R-3	55 92%	5 8%	R5	H
	4.1						
	3.3	50.0					
50	3.8	50.0					
	4.1						
	4.2		R-4	60 100%	45 75%	R4	SL
	3.9						
460	4.0	55.0					

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

LIMESTONE, light brown, fine grained, highly weathered, weak, extremely close to close spaced discontinuities

35.5' - 40' Highly fractured zone

Frequent 1/8" to 1/2" thick Oolitic clast cementation

Bedding around 3 degrees

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

Oolitic clast

42.8

CHERT, reddish brown to gray, fine grained, very strong, close to moderately spaced discontinuities

CHERT & ARGILLACEOUS LIMESTONE, reddish brown to light gray, fine grained, very strong, extremely close to close spaced discontinuities

45' - 46.5' Chert

46.5

45' - 50' Highly Fractured zone

46.5' - 50' Argillaceous limestone

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

Frequent thin bedded sand infilled zones

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
38.10	J	13	U,Sm	DS	MW	N
39.00	J	3	U,Sm	DS	O	N
39.70	J	3	U,R	DS	O	N
40.50	J	10	U,Sm	DS	MW	N
41.30	J	20	U,R	DS	MW	N
42.20	J	7	U,R	DS	O	SD
42.80	B	10	U,R	DG	MW	N
43.50	B	13	U,R	DS	MW	N
46.00	J	9	U,Sm	DS	MW	N
46.55	B	2	U,Sm	DG	MW	CL
47.40	J	3	U,Sm	DS	MW	N
48.00	B	1	U,Sm	DG	MW	CL
50.65	J	6	U,Sm	DS	O	N
51.50	J	7	U,Sm	DS	MW	N
53.30	J	3	P,Sm	DS	O	SD
53.70	J	6	U,Sm	FR	MW	N
54.30	B	2	P,Sm	FR	MW	N

Remarks

Loss of water from the start of drilling at 35.5 feet BGS.

35.5' - 40' Approximately 500 gallons of water lost.

40' - 45' Pull down thrust 285 to 295 psi.

Rig chatter at 43' BGS; Depth where the rock transitioned to Chert.

40' - 45' Approximately 450 gallons of water lost.

45' - 50' Approximately 750 gallons of water lost.

Water Level Data

Date	Time	Elapsed Time (hr)	Bot. of Casing	Bottom of Hole	Water
		-			

Notes:

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CORE BORING LOG
(continued)

BORING NO.:	B-STL-08
Page	2 of 5

Depth (ft)	Run/(Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath
55.0 – 60.0	R-5	60 100%	60 100%	R4	FR
60.0 – 65.0	R-6	60 100%	36 60%	R4	FR
65.0 – 70.0	R-7	60 100%	58 97%	R4	FR
70.0 – 75.0	R-8	60 100%	59 98%	R4	SL
75.0 – 80.0	R-9	60 100%	49 82%	R3	SL

Depth/Elev. (ft)	Avg Core Rate (min/ft)
	3.0
	2.9
	3.0
	3.1
	2.9
60	3.2
	3.2
	2.6
	1.6
450	3.3
65	2.5
	2.6
	2.5
	2.3
	2.3
70	2.1
	2.3
	2.0
	4.0
440	3.1
75	2.7
	2.8
	2.7
	2.6
	2.8

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

ARGILLACEOUS LIMESTONE, light gray, medium to fine grained, fresh, strong, moderate to wide spaced discontinuities

SANDY LIMESTONE, light gray, medium to fine grained, fresh, strong, extremely close to moderate spaced discontinuities

Frequent stylolites

60.5' - 60.7' 2" thick Chert nodule
63' - 64' Vertical fracture

ARGILLACEOUS LIMESTONE, light gray, coarse to fine grained, fresh, strong, close to wide spaced discontinuities

Frequent 1/16" - 1/4" Planar banded sand infillings

LIMESTONE, light gray to light brown, fine grained, slightly weathered, strong, close to wide spaced discontinuities

Frequent stylolites

Fossiliferous
Occassional pyrite infilling

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

Frequent stylolites

78.5' - 79.5' Slightly brecciated
Fossiliferous
Occassional pyrite infilling
78.5' - 79.5' Slightly brecciated

Discontinuities
(See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
56.70	B	3	P,Sm	FR	O	N	
60.30	J	8	U,Sm	DS	O	N	
61.30	B	13	U,R	DS	MW	CL	
62.30	Sty	5	U,Sm	DS	O	N	
64.00	F	71	U,R	DS	O	Fe	
66.00	J	22	P,Sm	FR	O	N	
68.35	J	0	P,Sm	FR	O	N	
72.15	B	10	U,Sm	DS	O	N	
72.60	J	4	U,R	DS	O	N	
73.50	Sty	5	U,R	DS	O	N	
74.20	Sty	6	U,R	DS	O	N	
76.30	Sty	4	U,R	DS	O	N	
77.70	J	3	U,Sm	DG	MW	CL	
78.80	J	3	U,Sm	DS	O	N	
79.50	F	40	U,Sm	DS	O	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
	2.2	80.0	R-10	60 100%	54 90%	R3	SL
	2.3						
	1.8						
	1.8						
430	2.6	85.0					
85	2.0	85.0	R-11	60 100%	50 83%	R3	SL
	2.6						
	2.6						
	2.7						
	2.6	90.0					
90	1.9	90.0	R-12	60 100%	37 62%	R3	SL
	2.1						
	2.5						
	2.5						
420	2.6	95.0					
95	2.5	95.0	R-13	60 100%	45 75%	R4	SL
	3.2						
	2.5						
	3.2						
	3.1	100.0					
100	3.5	100.0	R-14	60 100%	30 50%	R4	SL
	3.5						
	4.2						
	2.7						
410	2.6	105.0					

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

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

78.5' - 79.5' Slightly brecciated

Frequent stylolites
Fossiliferous
Occassional pyrite infilling

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

Frequent stylolites

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

Frequent stylolites

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

Frequent stylolites

99' - 100' Chert nodule inclusions

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

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
80.80	Sty	6	U,R	DS	O	N	
81.20	J	10	P,Sm	DS	O	N	
82.00	Sty	22	U,R	DS	O	N	
82.70	Sty	8	U,R	DS	O	N	
84.50	Sty	9	U,R	DS	O	N	
85.20	J	3	U,Sm	DS	MW	N	
85.80	Sty	9	U,R	DS	MW	N	
86.40	Sty	2	U,R	DS	MW	N	
88.10	Sty	2	U,R	DS	MW	N	
88.90	Sty	15	U,R	DS	MW	N	
89.50	Sty	2	U,R	DS	O	N	
90.20	Sty	6	U,R	DG	MW	CL	
90.70	Sty	6	U,R	DG	MW	CL	
91.70	Sty	1	P,Sm	DS	MW	N	
92.70	J	1	U,Sm	DS	MW	N	
93.90	J	1	U,Sm	DS	MW	N	
94.40	J	2	U,Sm	DG	O	CL	
95.70	Sty	3	U,R	DG	MW	CL	
96.30	Sty	1	P,R	DG	MW	CL	
97.20	Sty	2	U,R	DG	MW	CL	
104.30	B	10	U,R	DS	O	N	54' - 105' Approximately 2250 gallons of water lost.

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)
	2.6	105.0	R-15	60 / 100%	60 / 100%	R4	SL	ARGILLACEOUS LIMESTONE, gray to light gray, fine grained, slightly weathered, strong, close to moderate spaced discontinuities 105.8' - 108.1' 1/8- to 1/2-inch thick vertical calcite vein Fossiliferous
	3.5							
	3.5							
	3.1							
110	3.6	110.0						
	3.9	110.0	R-16	60 / 100%	47 / 78%	R4	SL	ARGILLACEOUS LIMESTONE, gray to light gray, fine grained, slightly weathered, strong, close to moderate spaced discontinuities Fossiliferous Frequent stylolites 1/8- to 1/4-inch argillaceous clasts
	3.2							
	4.0							
400	3.6							
115	3.2	115.0						
	4.0	115.0	R-17	60 / 100%	43 / 72%	R3	SL	ARGILLACEOUS LIMESTONE, light gray, fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities Frequent stylolites
	3.0							
	3.1							
	2.6							
120	3.1	120.0						
	3.0	120.0	R-18	60 / 100%	47 / 78%	R3	SL	ARGILLACEOUS LIMESTONE, light gray, fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities 121' - 123' 1/4-inch thick clay/shale bands spaced every 4- to 6-inches Frequent stylolites
	2.9							
	3.1							
390	2.9							
125	3.0	125.0						
	3.4	125.0	R-19	60 / 100%	53 / 88%	R4	SL	LIMESTONE, gray to light gray, fine grained, slightly weathered, strong, very close to wide spaced discontinuities 125.7' - 127.7' Porous rock Frequent stylolites Clay-infilled joints
	2.0							
	2.9							
	2.5							
	3.0	130.0						

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
105.80	J	2	U,Sm	DG	O	Ca
106.20	J	2	U,Sm	DG	O	Ca
106.55	J	3	U,Sm	DG	PO	Ca
107.00	J	3	U,R	DG	O	Ca
107.70	J	5	U,Wa	DG	O	CL
108.20	J	4	U,Sm	DG	O	CL
109.00	J	5	U,Sm	DG	O	CL
110.50	J	3	U,Sm	DG	MW	CL
111.80	Sty	2	U,R	DS	O	N
112.10	Sty	2	U,R	DS	O	N
113.00	Sty	1	U,Sm	DS	O	N
113.40	Sty	3	U,Sm	DS	MW	N
114.20	J	7	U,Sm	DS	MW	N
115.40	Sty	7	U,Sm	DG	MW	CL
116.40	Sty	6	U,Sm	DG	MW	CL
117.30	Sty	3	U,Sm	DG	O	N
118.30	J	3	U,R	DG	MW	CL
119.00	J	12	U,Sm	DG	MW	CL
120.80	J	4	U,Sm	DG	O	CL
122.80	J	3	U,Sm	DG	O	CL
123.40	J	3	U,Sm	DE	O	CL
124.20	J	6	U,Sm	DE	O	CL
124.70	J	5	U,Sm	DG	MW	CL
125.70	B	3	U,Sm	DE	MW	CL
127.70	B	3	U,Sm	DS	MW	N
128.80	Sty	3	P,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	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
	2.9, 2.7, 3.0, 2.7, 2.6	130.0 – 135.0	R-20	60 100%	48 80%	R4	SL	ARGILLACEOUS LIMESTONE, light gray to dark gray, fine grained, slightly weathered, strong, close to wide spaced discontinuities 130' - 131' Chert nodule inclusions Frequent stylolites Fossiliferous	130.20	B	8	U,Sm	DS	MW	N	
									130.50	B	8	U,Sm	DS	T	N	
									131.70	Sty	5	U,Sm	DS	O	N	
									132.00	J	4	U,Sm	DS	MW	CL	
380																
135	2.7, 2.6, 2.3, 2.0, 2.5	135.0 – 140.0	R-21	60 100%	58 97%	R3	SL	ARGILLACEOUS LIMESTONE, light gray to dark gray, fine grained, slightly weathered, medium strong, very close to wide spaced discontinuities Frequent stylolites Fossiliferous	136.60	Sty	3	U,R	DG	MW	CL	
									138.50	Sty	11	U,R	DS	PO	N	
140	2.9, 3.2, 2.4, 2.1, 2.3	140.0 – 145.0	R-22	60 100%	37 62%	R3	SL	ARGILLACEOUS LIMESTONE, light gray to dark gray, fine grained, slightly weathered, medium strong, very close to wide spaced discontinuities Frequent stylolites Fossiliferous 144' - 145' Vertical stylolititc fracture	140.50	Sty	10	U,R	DS	O	N	
									141.60	J	4	P,Sm	DG	MW	CL	
									142.10	J	3	U,Sm	DS	O	N	
370									144.20	J	6	U,Sm	DS	O	N	
									144.50	J	2	P,Sm	DS	O	N	
									144.60	J	85	U,Sm	DS	O	N	
145	3.0, 3.1, 2.5, 3.8, 3.1	145.0 – 150.0	R-23	60 100%	44 73%	R3	SL	ARGILLACEOUS LIMESTONE, light gray to dark gray, fine grained, slightly weathered, medium strong, very close to wide spaced discontinuities Frequent stylolites Fossiliferous	145.30	Sty	4	U,Sm	DS	O	N	
									146.10	Sty	10	U,R	DG	O	N	
									146.80	B	4	P,R	DG	MW	CL	
									147.30	B	11	U,Sm	DG	MW	CL	105' - 150' Approximately 1350 gallons of water lost.
150								150.0 End of Boring at 150 feet BGS. Borehole grouted with cement and bentonite hole plug.								
360																

(See Legend for Rock Description System)

NOTES:

Figure B-STL-08.1
B-STL-8 Box 1 Runs 1-2 Dry

Figure B-STL-08.2
B-STL-8 Box 1 Runs 1-2 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-08

Figure B-STL-08.3
B-STL-8 Box 2 Runs 3-4 Dry

Figure B-STL-08.4
B-STL-8 Box 2 Runs 3-4 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-08

Figure B-STL-08.5
B-STL-8 Box 3 Runs 5-6 Dry

Figure B-STL-08.6
B-STL-8 Box 3 Runs 5-6 Wet

Figure B-STL-08.7
B-STL-8 Box 4 Runs 7-8 Dry

Figure B-STL-08.8
B-STL-8 Box 4 Runs 7-8 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-08

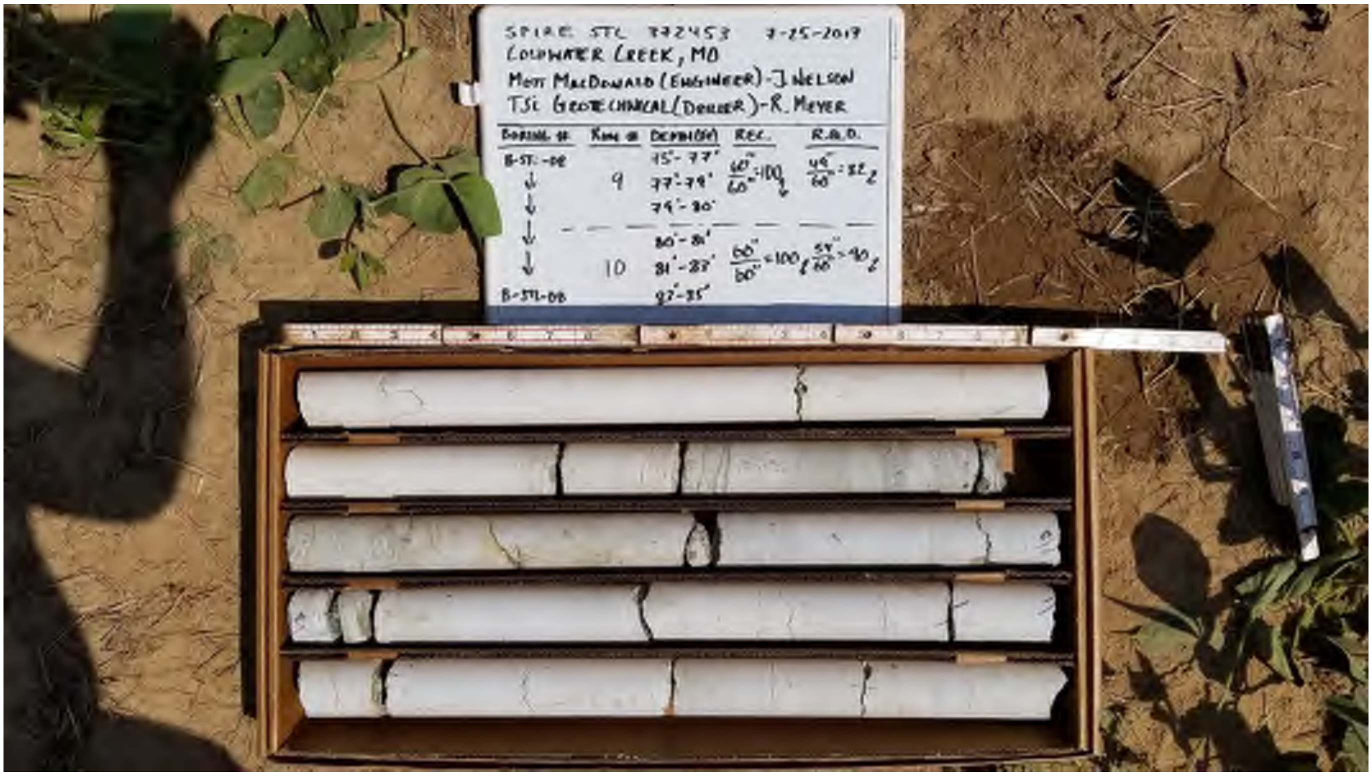

Figure B-STL-08.9
B-STL-8 Box 5 Runs 9-10 Dry

Figure B-STL-08.10
B-STL-8 Box 5 Runs 9-10 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-08

Figure B-STL-08.11
B-STL-8 Box 6 Runs 11-12 Dry

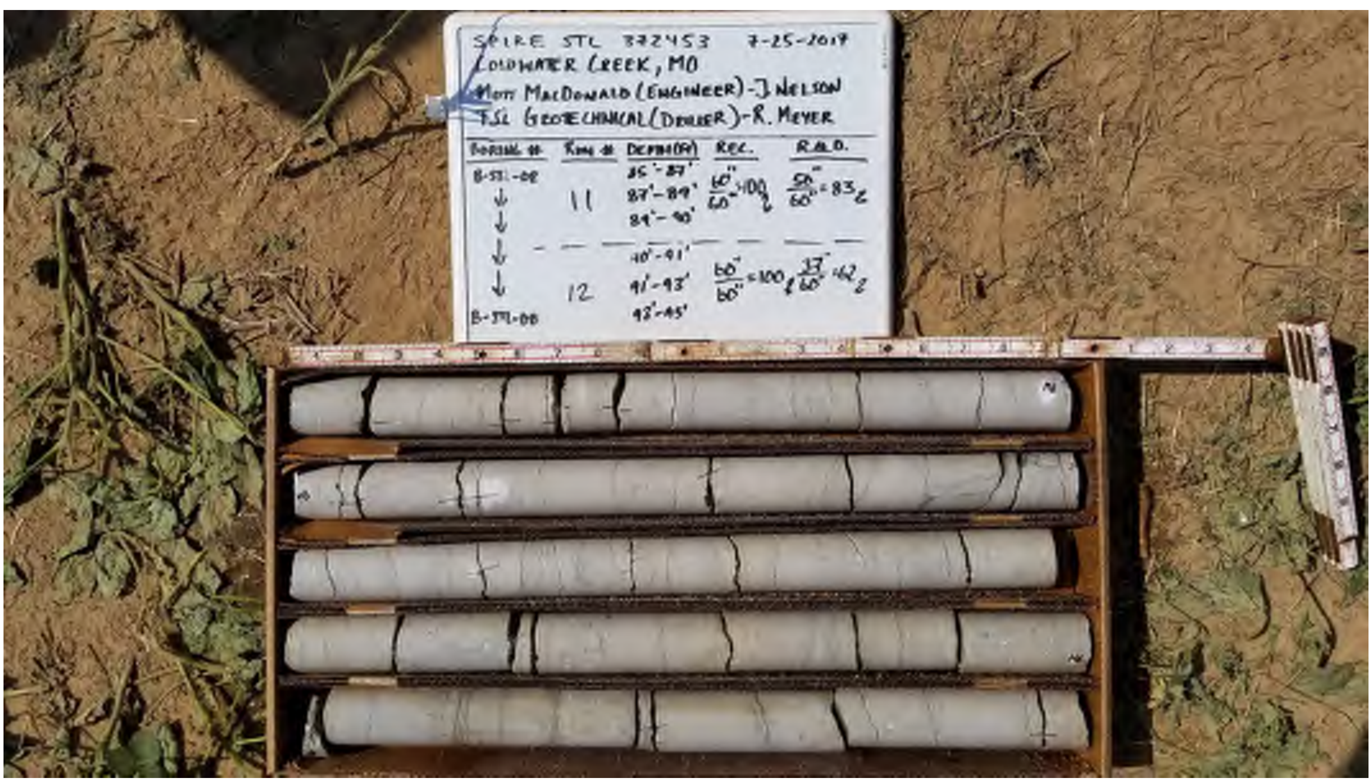

Figure B-STL-08.12
B-STL-8 Box 6 Runs 11-12 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-08

Figure B-STL-08.13
B-STL-8 Box 7 Runs 13-14 Dry

Figure B-STL-08.14
B-STL-8 Box 7 Runs 13-14 Wet

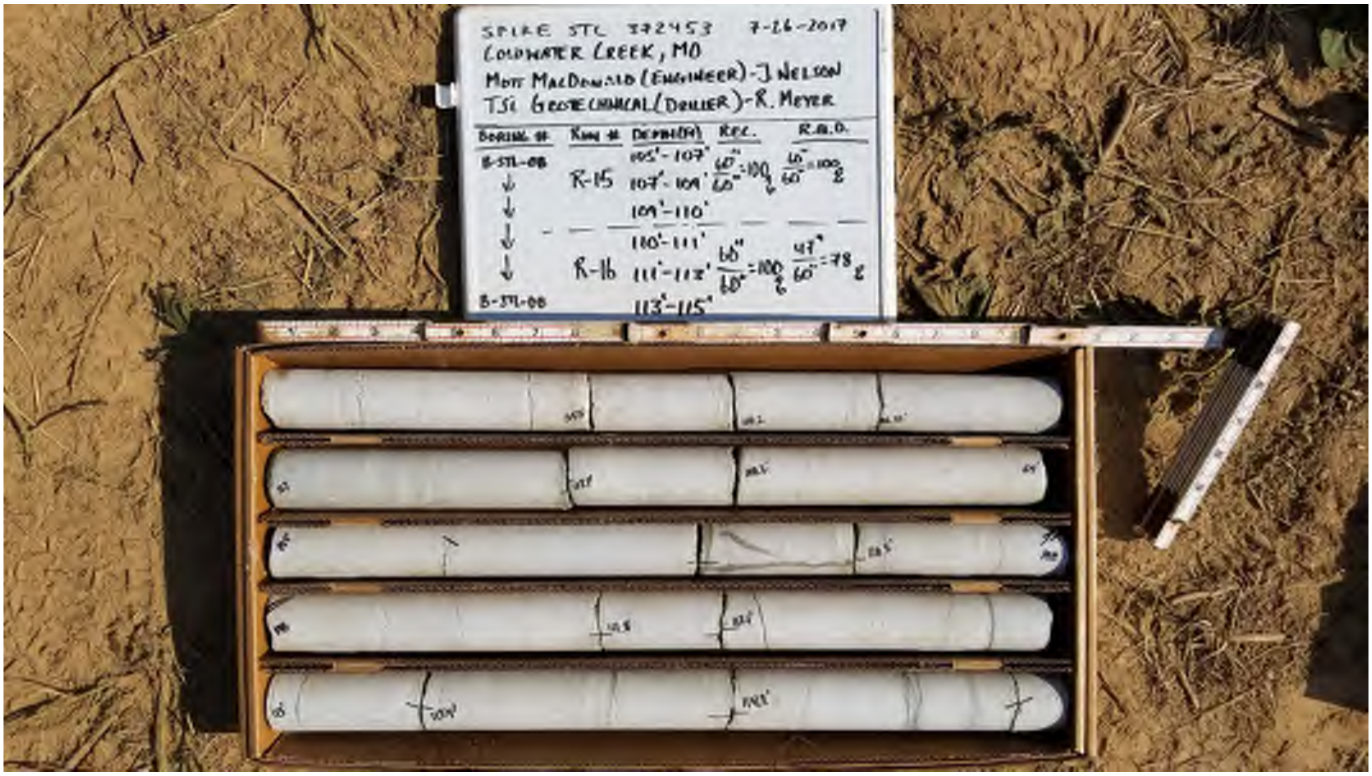

Figure B-STL-08.15
B-STL-8 Box 8 Runs 15-16 Dry

Figure B-STL-08.16
B-STL-8 Box 8 Runs 15-16 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-08

Figure B-STL-08.17
B-STL-8 Box 9 Runs 17-18 Dry

Figure B-STL-08.18
B-STL-8 Box 9 Runs 17-18 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-08

Figure B-STL-08.19
B-STL-8 Box 10 Runs 19-20 Dry

Figure B-STL-08.20
B-STL-8 Box 10 Runs 19-20 Wet

MOTT MACDONALD	Spire STL Pipeline Rock Core Photographs	BORING NO.: B-STL-08

Figure B-STL-08.21
B-STL-8 Box 11 Runs 21-22 Dry

Figure B-STL-08.22
B-STL-8 Box 11 Runs 21-22 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-08

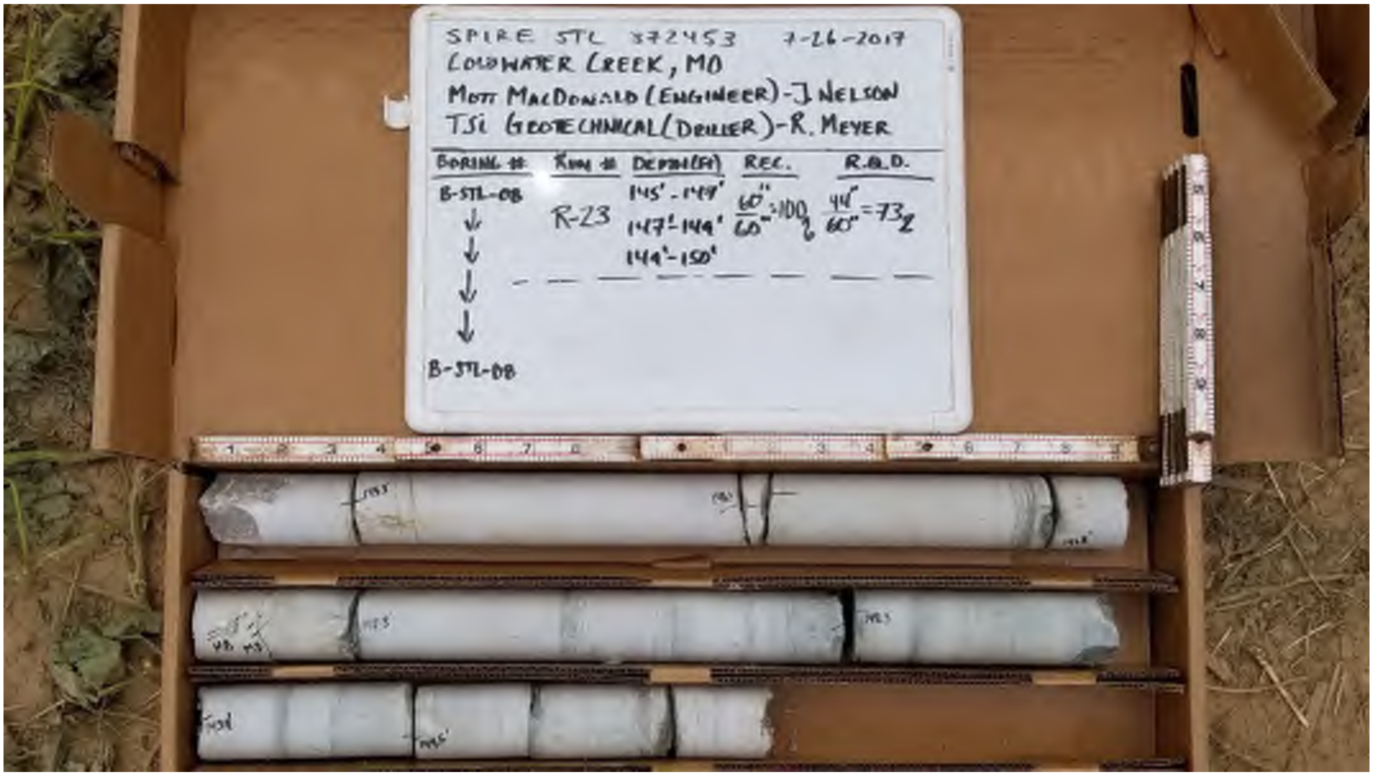

Figure B-STL-08.23
B-STL-8 Box 12 Runs 23 Dry

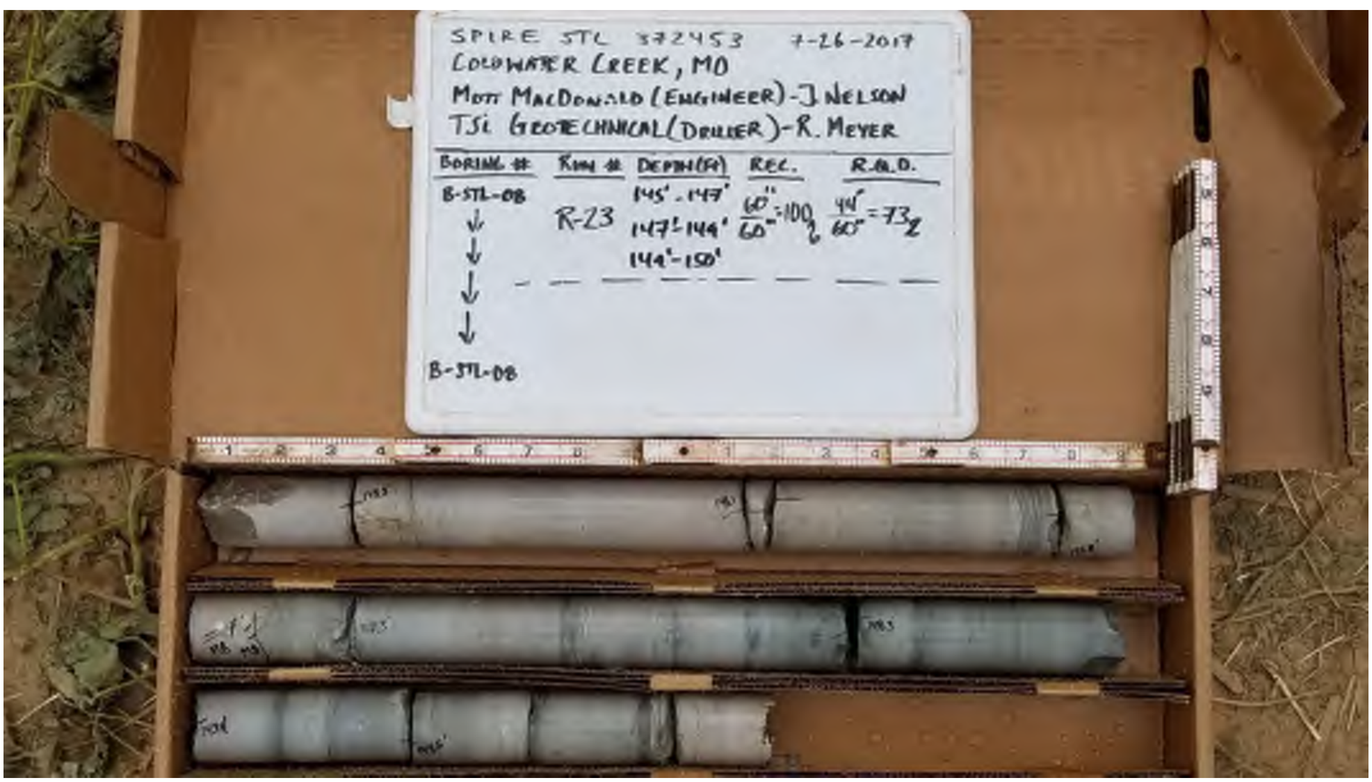

Figure B-STL-08.24
B-STL-8 Box 12 Runs 23 Wet

MOTT MACDONALD	**Spire STL Pipeline** **Rock Core Photographs**	**BORING NO.:** B-STL-08

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.

<u>Microgravity Survey</u>

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

<u>References</u>

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). <u>Field Geophysics</u>. Open University Press and Halstead Press, New York, NY, 182 p

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Nettleton L.L., (1976). Gravity and Magnetics in Oil Prospecting. McGraw-Hill Pub., New York, 464 pp.

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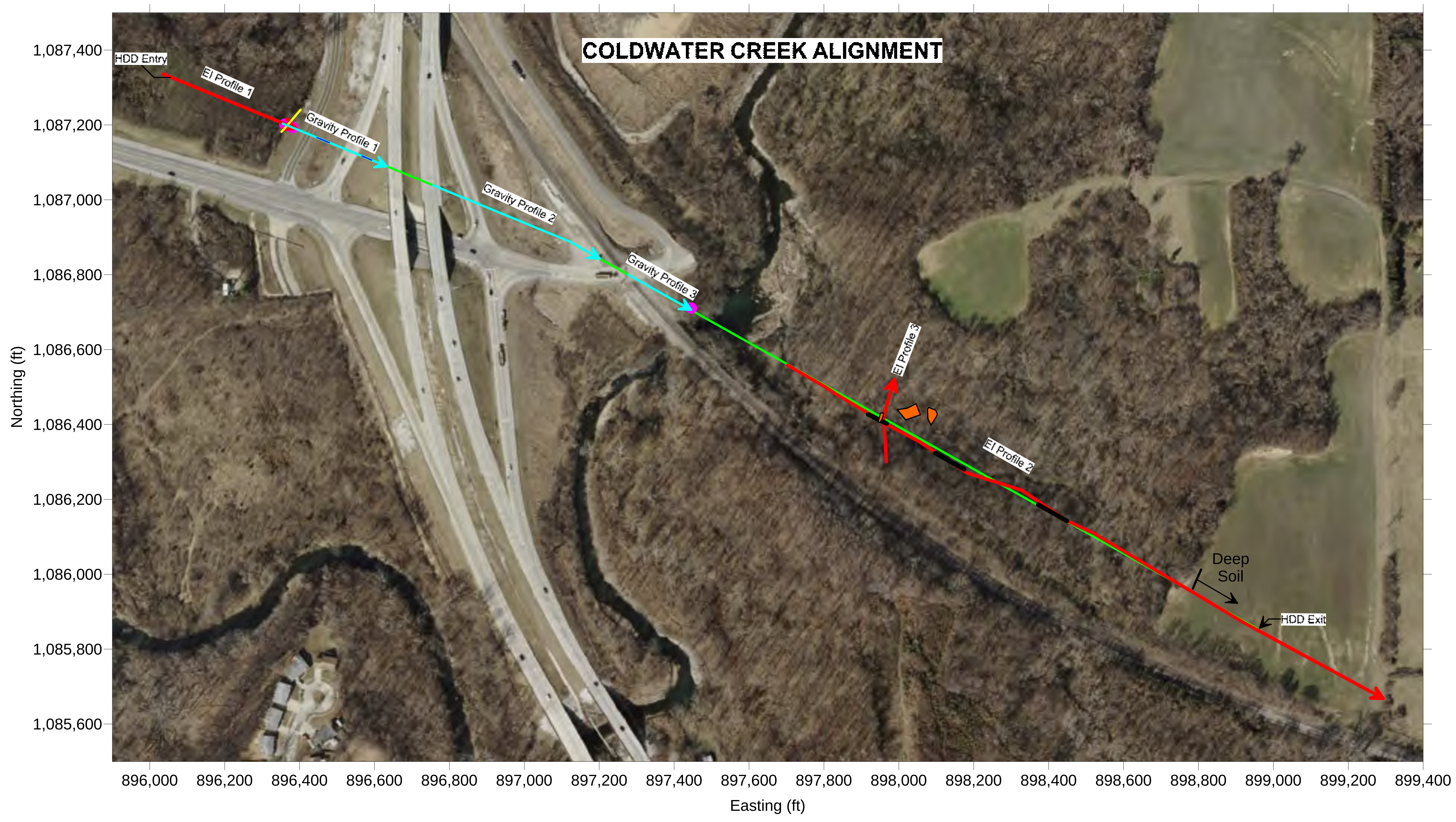
Stewart, M.T., 1980, Gravity surveys of a deep buried valley, Ground Water, v. 18, pp. 24-30.



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.

THG GEOPHYSICS
4280 Old William Penn Hwy
Murrysville, Pennsylvania 15668
(724) 325-3996 Fax: (724) 733-7901
www.thggeophysics.com

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

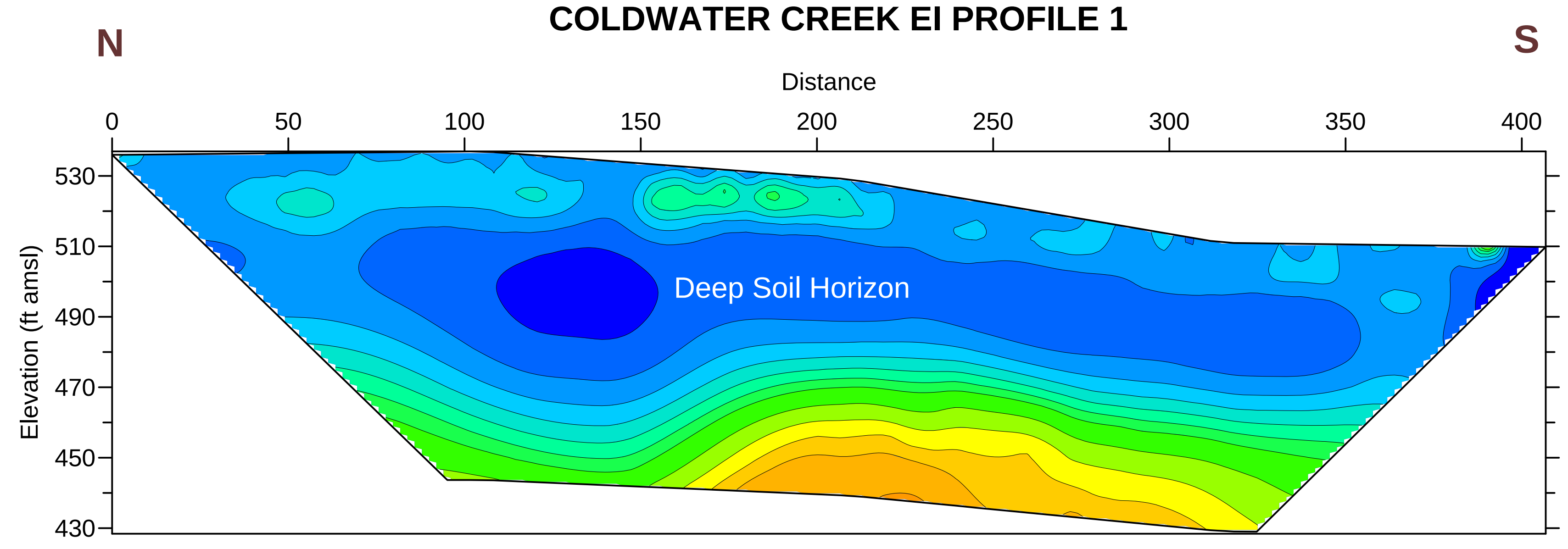
DRAWING NO.: **Figure 1**
Location Map

PREPARED FOR: MOTT MACDONALD

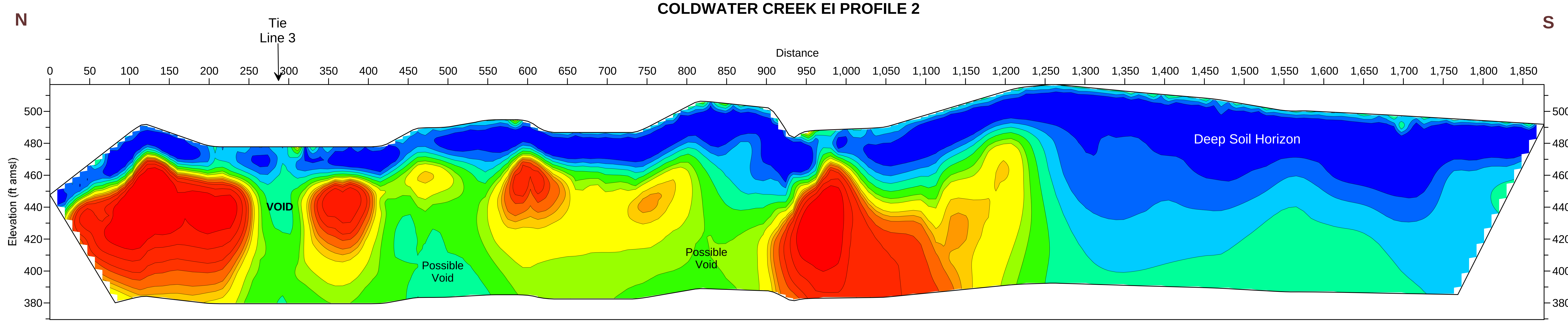
PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F1

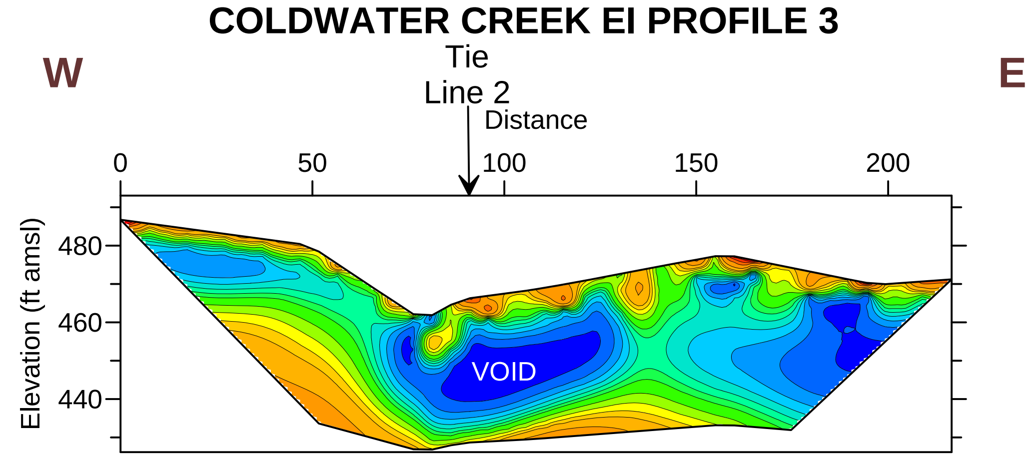
COLDWATER CREEK EI PROFILE 1



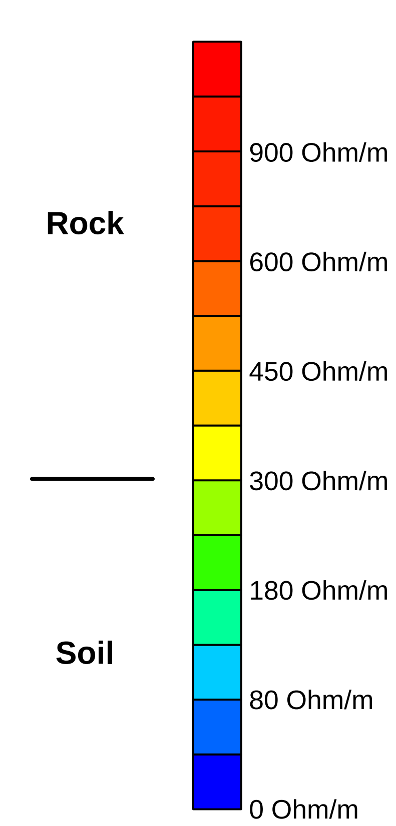
COLDWATER CREEK EI PROFILE 2



COLDWATER CREEK EI PROFILE 3



Legend



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.

THG GEOPHYSICS

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Murrysville, Pennsylvania 15668
(724) 325-3996 Fax: (724) 733-7901
www.thggeophysics.com

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:

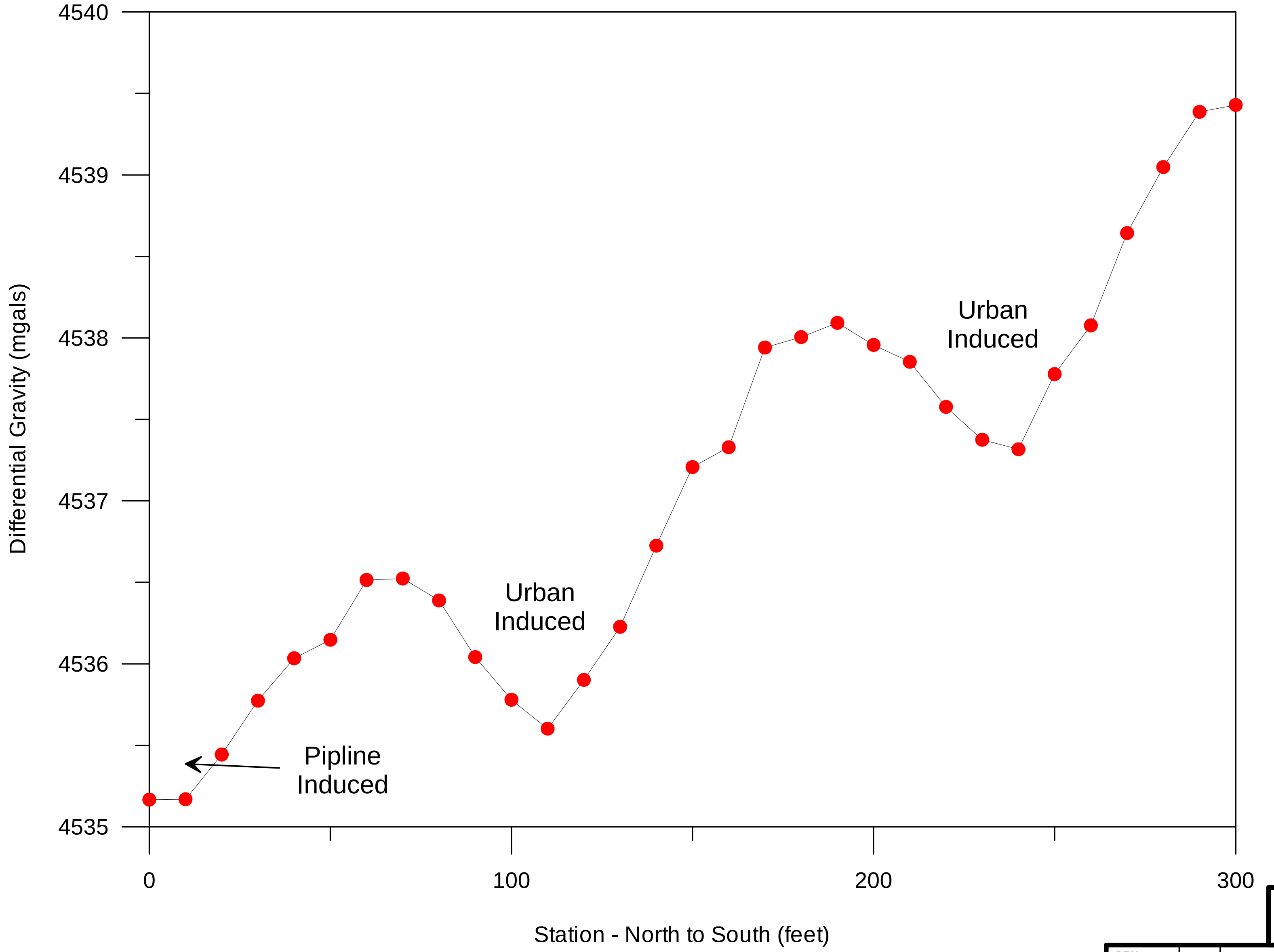
PROJECT:
Geophysical Investigation
Spire Pipeline
St. Louis, Missouri

DRAWING NO.:
Figure 2
Coldwater Creek EI Profiles

PREPARED FOR: MOTT MACDONALD

PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F2



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Murrysville, Pennsylvania 15668
(724) 325-3996 Fax: (724) 733-7901
www.thggeophysics.com

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

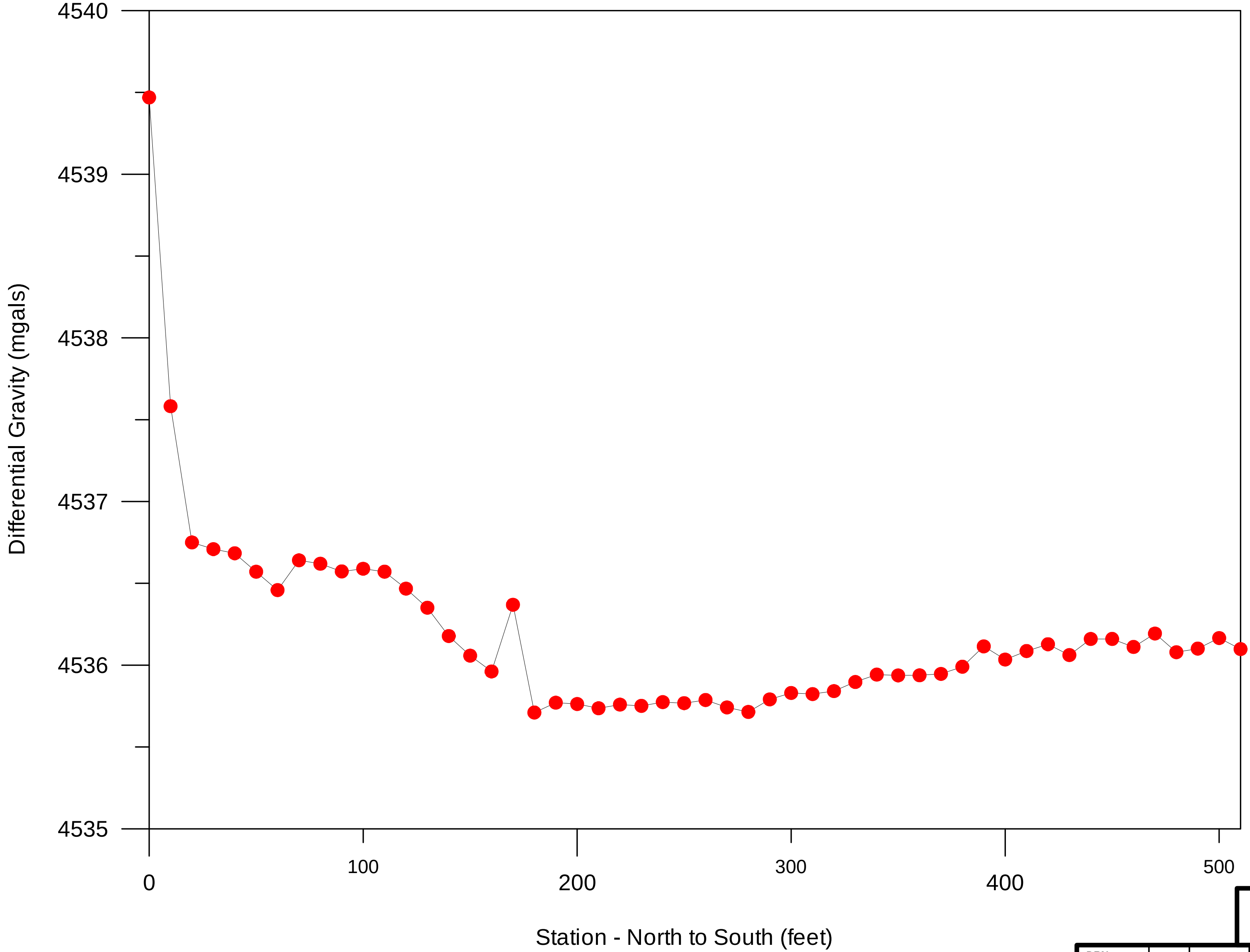
SOURCE:

DRAWING NO.: **Figure 3**
Coldwater Creek
Gravity Profile 1

PREPARED FOR: M M MOTT MACDONALD

PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F3



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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

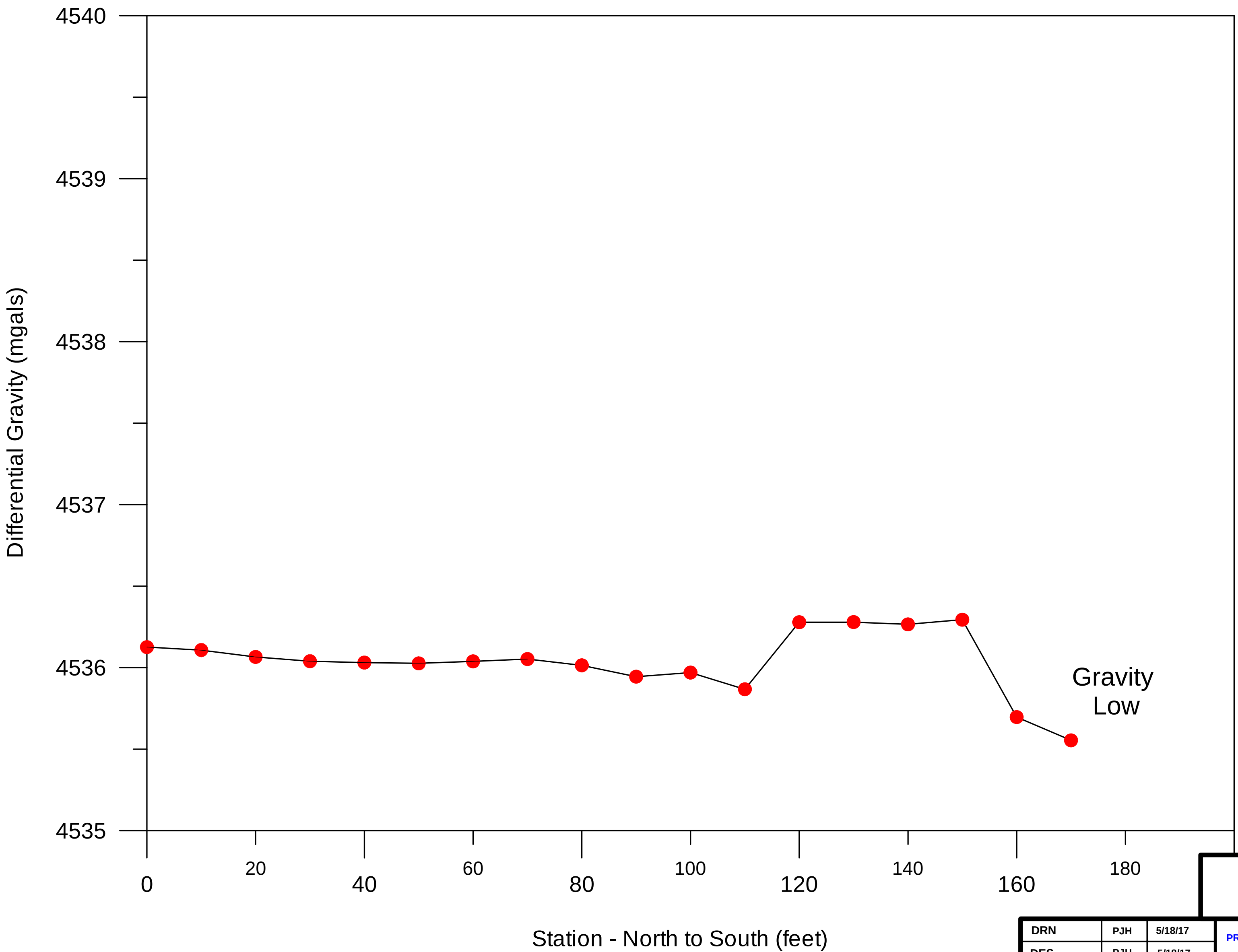
SOURCE:

DRAWING NO.:
Figure 4
Coldwater Creek
Gravity Profile 2

PREPARED FOR:
MOTT MACDONALD

PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F4



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4280 Old William Penn Hwy
Murrysville, Pennsylvania 15668
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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:

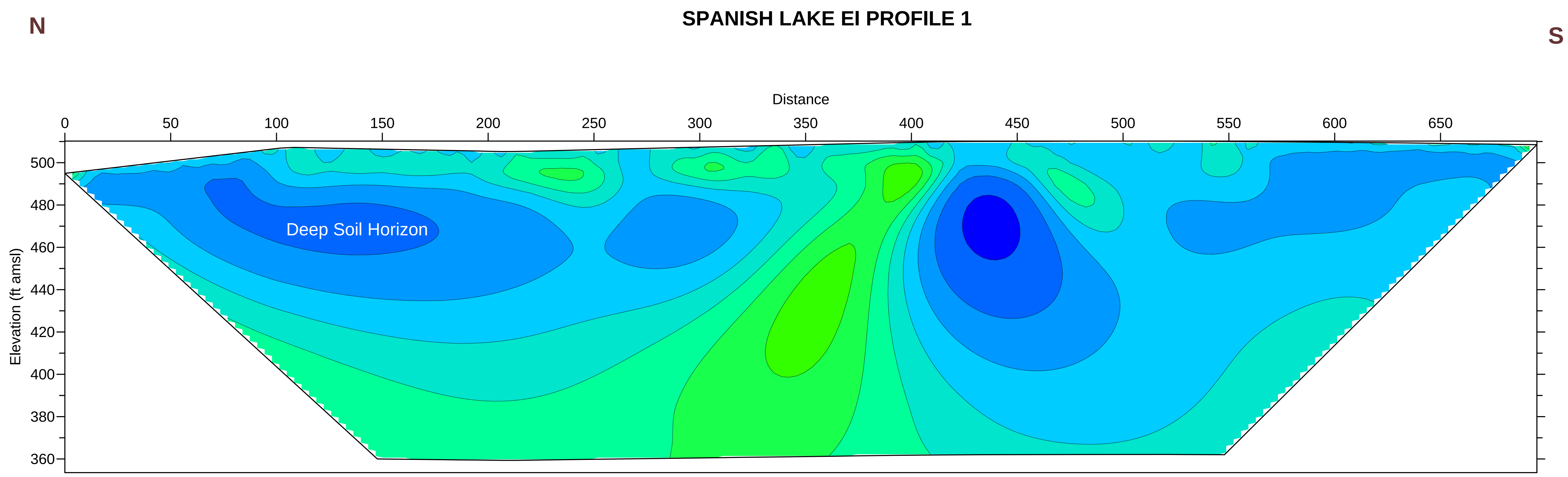
PROJECT:
Geophysical Investigation
Spire Pipeline
St. Louis, Missouri

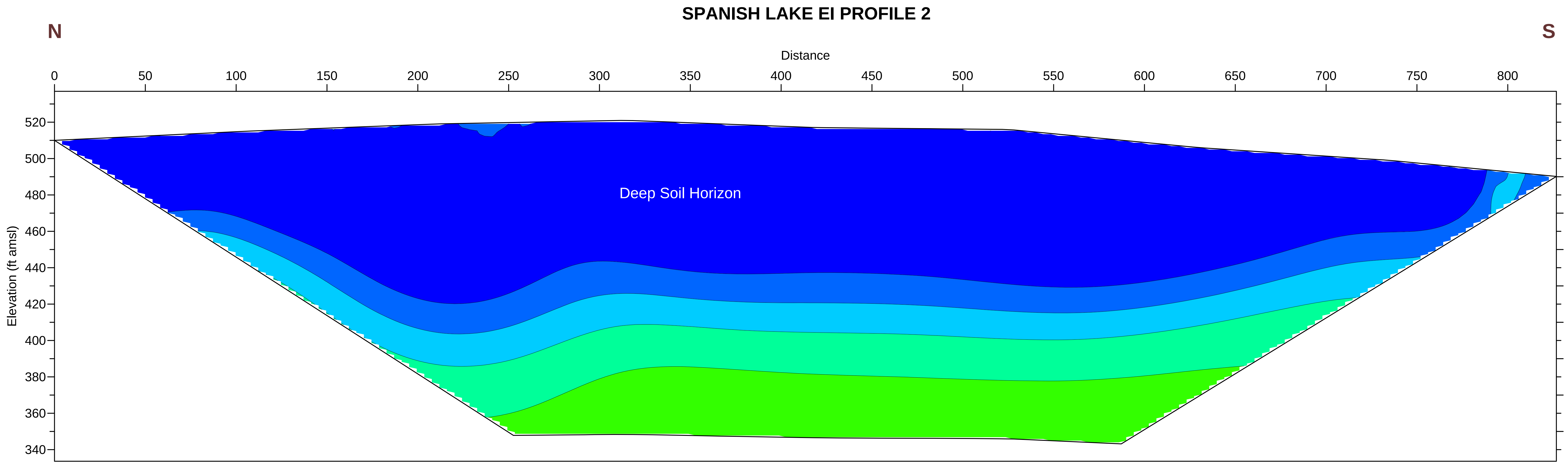
DRAWING NO.:
Figure 5
Coldwater Creek
Gravity Profile 3

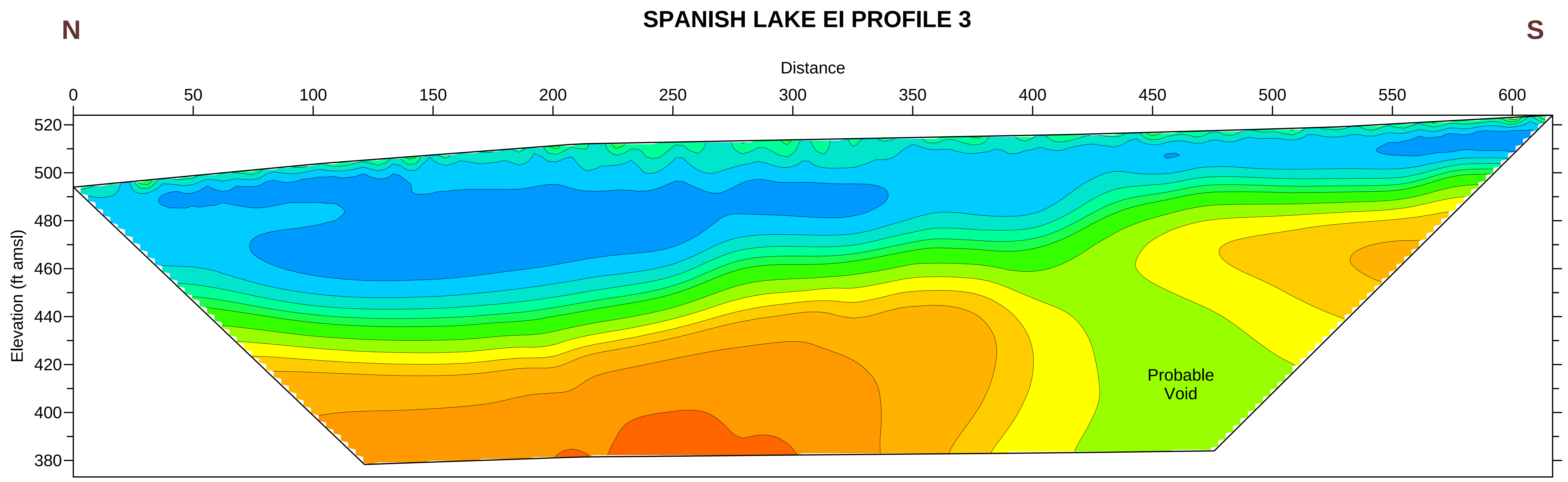
PREPARED FOR: MOTT MACDONALD

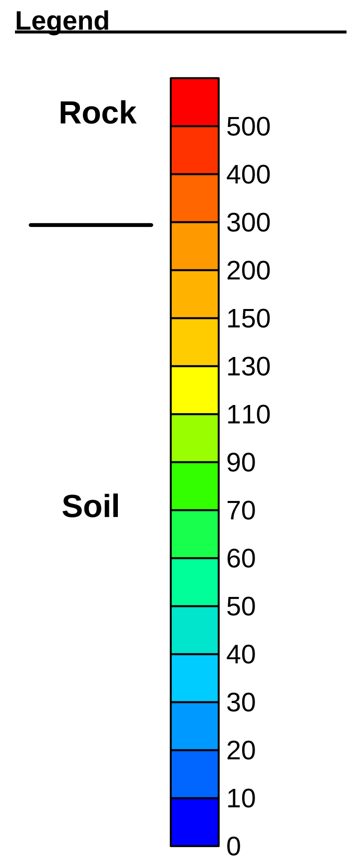
PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F5









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
Vertical 1" = 50'
Horizontal 1" = 50'

Locations are approximate.

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

SCALE: As noted

SOURCE:

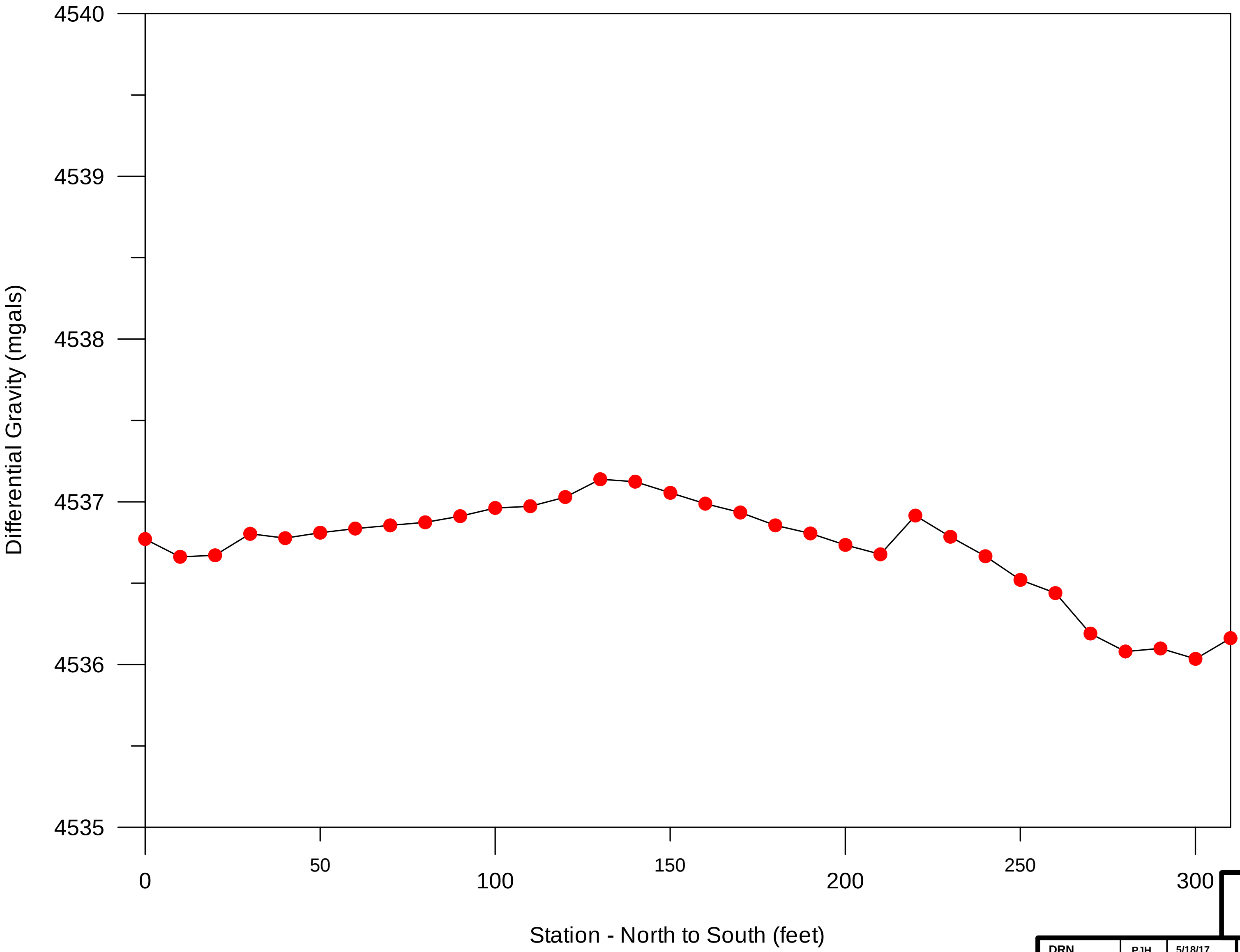
PROJECT:
Geophysical Investigation
Spire Pipeline
St. Louis, Missouri

DRAWING NO.:
Figure 6
Spanish Lake EI Profiles

PREPARED FOR: MOTT MACDONALD

PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F6



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Murrysville, Pennsylvania 15668
(724) 325-3996 Fax: (724) 733-7901
www.thggeophysics.com

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 7
Spanish Lake
Gravity Profile 1

PREPARED FOR: MOTT MACDONALD

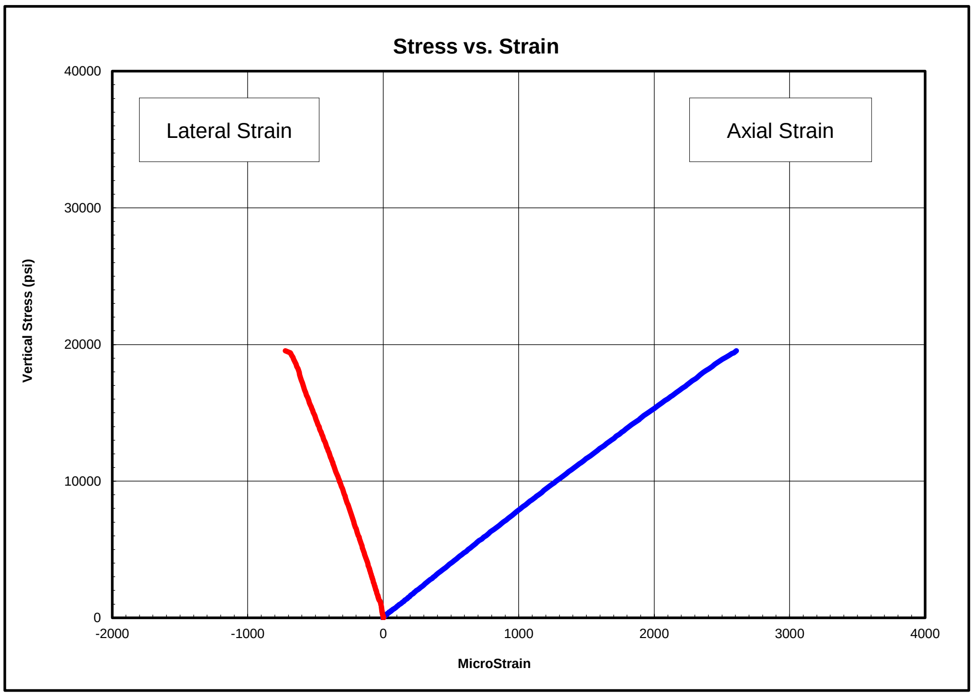
PROJECT NO.: 639-6549

SHEET TITLE: DWG6549F7

E. Laboratory Testing Results

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/13/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-01
Sample ID:	R-13
Depth, ft:	111.24-111.59
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: 19,533 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
2000-7200	7,830,000	0.26
7200-12400	7,540,000	0.27
12400-17600	7,230,000	0.28

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-01		
Sample ID:	R-13		
Depth:	111.24-111.59 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:	4.13	4.13	4.13
Specimen Diameter, in:	1.87	1.87	1.87
Specimen Mass, g:	492.63		
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	-0.00010	-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
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° = 0.00020 90° = 0.00020

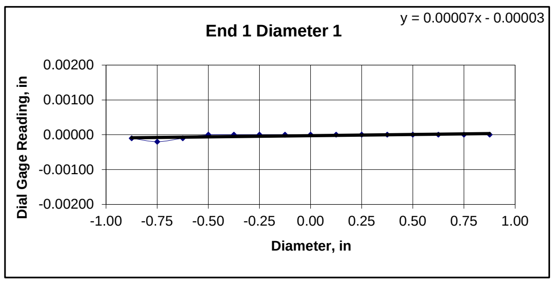
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00010	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Diameter 2, in (rotated 90^o)	-0.00010	-0.00020	-0.00010	0.00000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

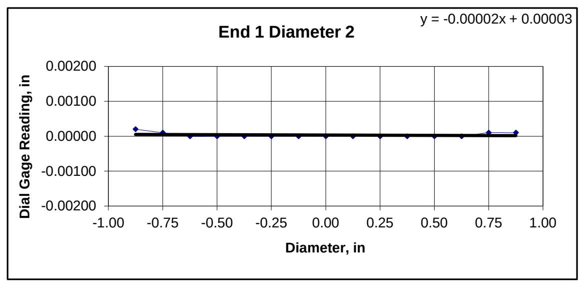
Difference between max and min readings, in:

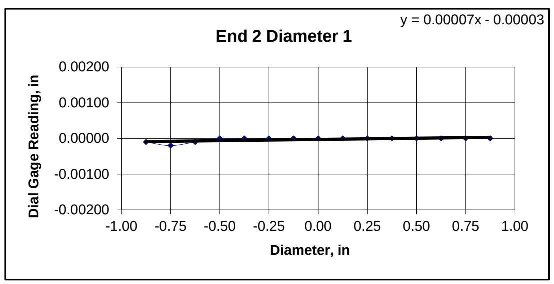
0° = 0.0002 90° = 0.0002

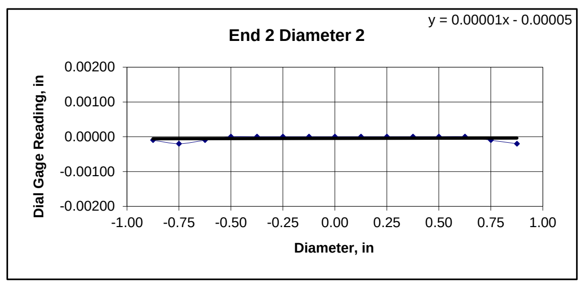
Maximum difference must be < 0.0020 in. Difference = ± 0.00010

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	0.00007
	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)	0.00020	1.870	0.00011	0.006	YES
END 2					
Diameter 1, in	0.00020	1.870	0.00011	0.006	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**

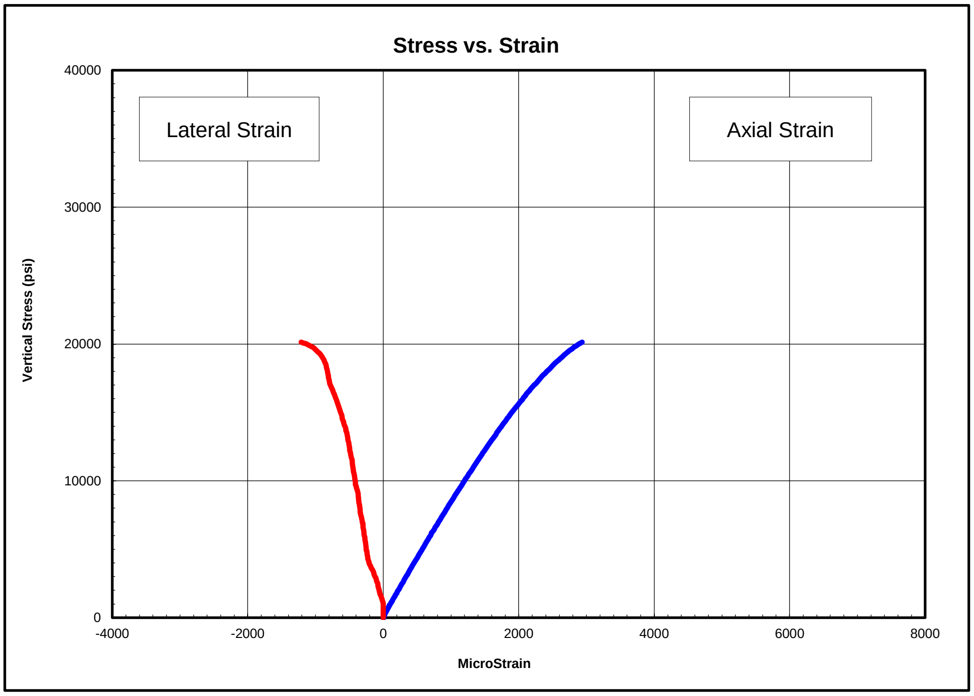
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/13/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-01
Sample ID:	R-13
Depth, ft:	111.24-111.59

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-01
Sample ID:	R-16
Depth, ft:	127.0-127.50
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: 20,137 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
2000-7400	8,370,000	---
7400-12800	7,630,000	0.27
12800-18100	6,210,000	0.41

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:	4/4/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-01		
Sample ID:	R-16		
Depth:	127.0-127.50 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:	4.27	4.27	4.27
Specimen Diameter, in:	1.87	1.87	1.87
Specimen Mass, g:	486.54		
Bulk Density, lb/ft^3	158	**Minimum Diameter Tolerence Met?**	**NO**
Length to Diameter Ratio:	2.3	**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	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00010	-0.00010	-0.00020
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	-0.00020	-0.00020	-0.00010	-0.00010

Difference between max and min readings, in:

0° = 0.00020 90° = 0.00020

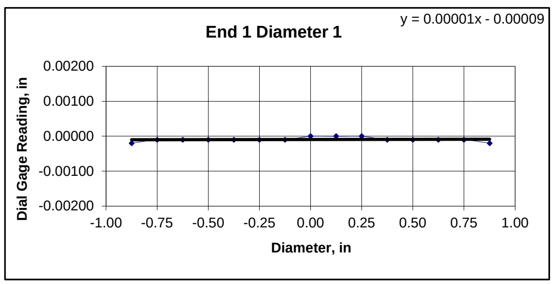
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00010	0.00010	0.00010	0.00000	0.00000	0.00000	0.00010	0.00000	0.00000	0.00010	0.00010	0.00000	0.00000	0.00000	0.00000
Diameter 2, in (rotated 90°)	0.00000	0.00000	0.00000	-0.00010	-0.00010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

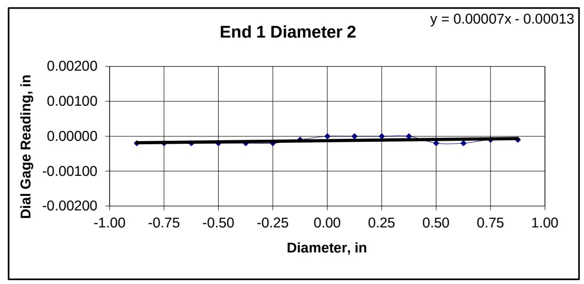
Difference between max and min readings, in:

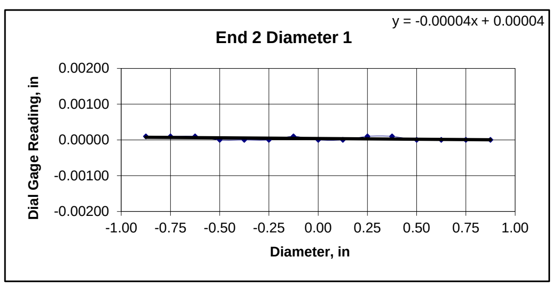
0° = 0.0001 90° = 0.0001

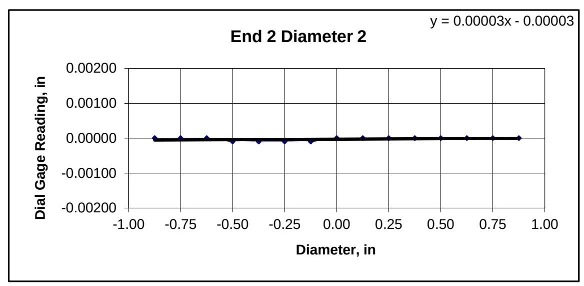
Maximum difference must be < 0.0020 in. Difference = ± 0.00010

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	-0.00004
Angle of Best Fit Line:	-0.00229
Maximum Angular Difference:	0.00286

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	0.00020	1.870	0.00011	0.006	YES
Diameter 2, in (rotated 90°)	0.00020	1.870	0.00011	0.006	YES
END 2					
Diameter 1, in	0.00010	1.870	0.00005	0.003	YES
Diameter 2, in (rotated 90°)	0.00010	1.870	0.00005	0.003	YES

Maximum angle of departure must be ≤ 0.25°

Perpendicularity Tolerance Met? **YES**

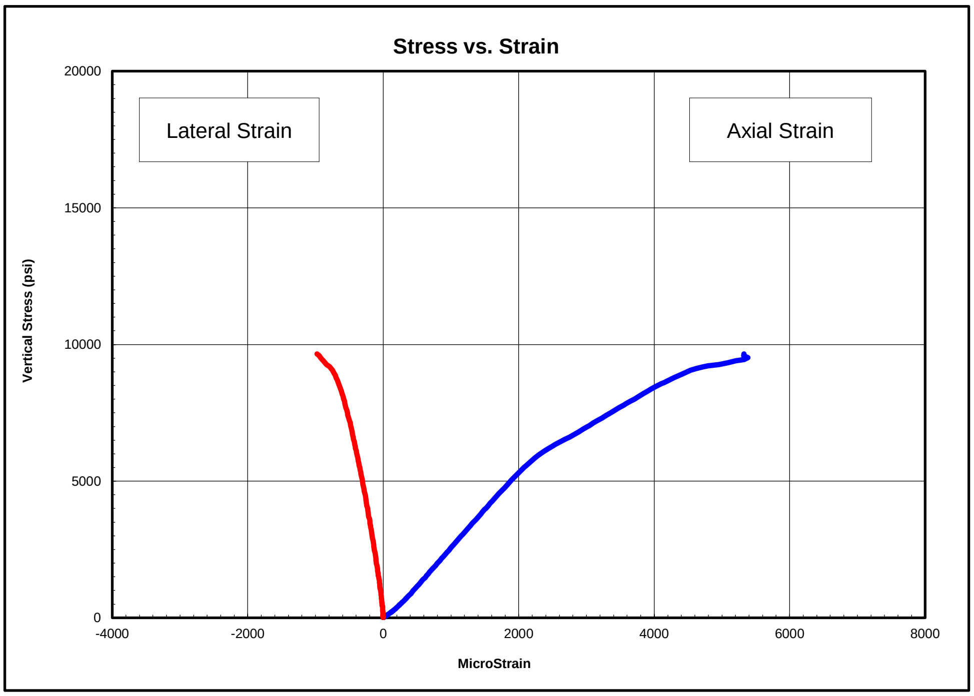
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-01
Sample ID:	R-16
Depth, ft:	127.0-127.50

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-01
Sample ID:	R-18
Depth, ft:	138.50-139.0
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: 9,680 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
1000-3500	2,830,000	0.18
3500-6100	2,590,000	0.20
6100-8700	1,430,000	---

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:	4/5/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-01		
Sample ID:	R-18		
Depth:	138.50-139.0 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:	4.15	4.15	4.15
Specimen Diameter, in:	1.87	1.87	1.87
Specimen Mass, g:	494.89		
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	-0.00010	-0.00010	0.00000	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00010	-0.00020
Diameter 2, in (rotated 90°)	-0.00010	-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	-0.00010

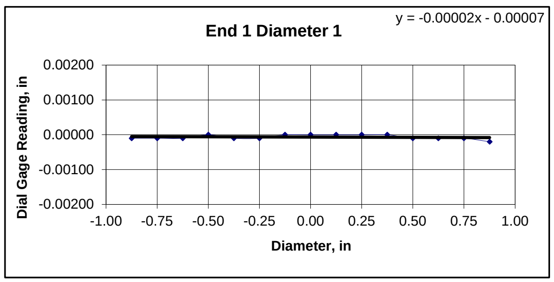
Difference between max and min readings, in:
0° = 0.00020 90° = 0.00010

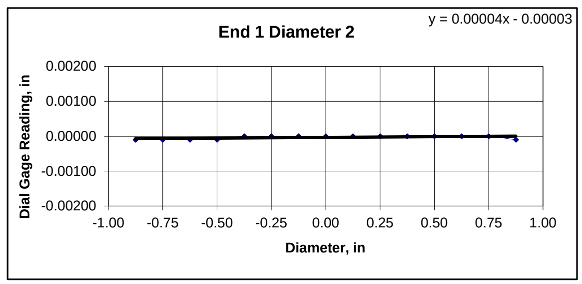
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00000	0.00000	0.00000	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00050
Diameter 2, in (rotated 90°)	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00020

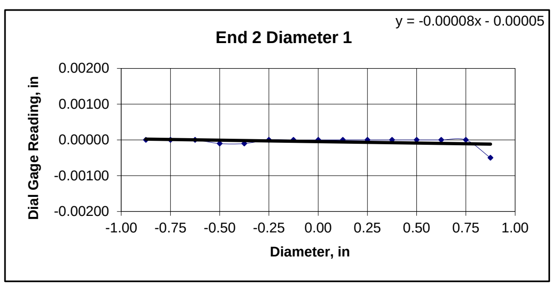
Difference between max and min readings, in:
0° = 0.0005 90° = 0.0002

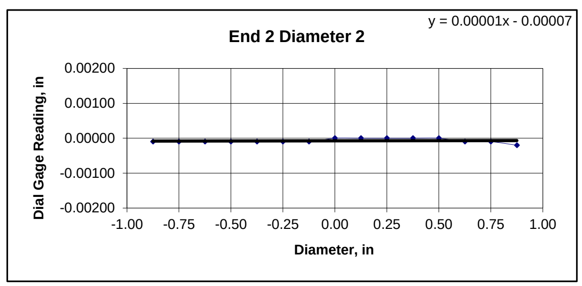
Maximum difference must be < 0.0020 in. Difference = ± 0.00025

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: 0.00004
- 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	1.870	0.00011	0.006	YES
Diameter 2, in (rotated 90°)	0.00010	1.870	0.00005	0.003	YES
END 2					
Diameter 1, in	0.00050	1.870	0.00027	0.015	YES
Diameter 2, in (rotated 90°)	0.00020	1.870	0.00011	0.006	YES

Maximum angle of departure must be ≤ 0.25°

Perpendicularity Tolerance Met? YES

GeoTesting EXPRESS

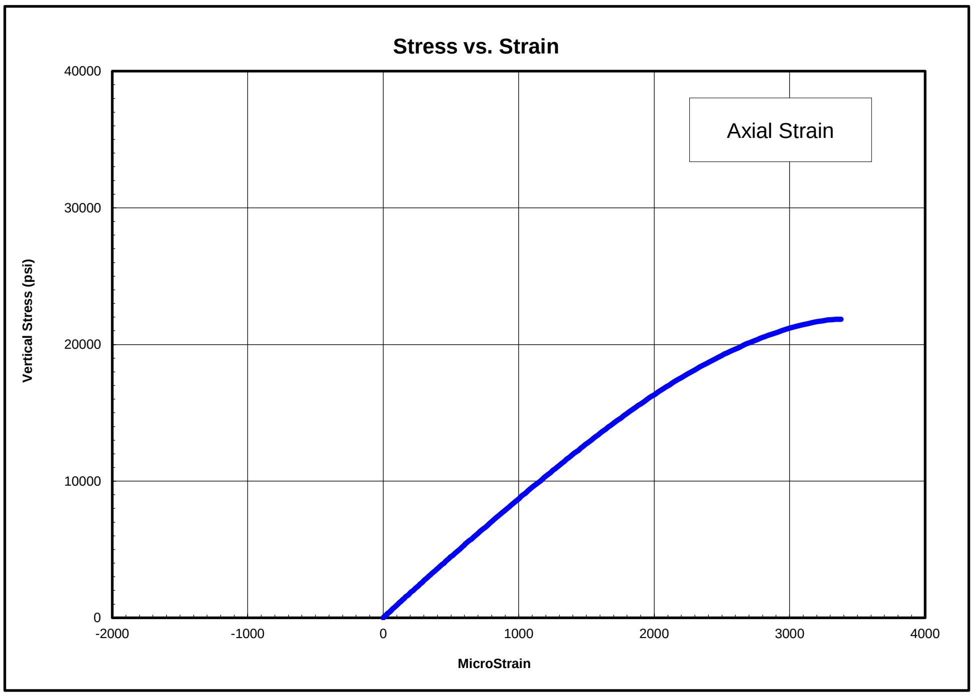
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-01
Sample ID:	R-18
Depth, ft:	138.50-139.0

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-01
Sample ID:	R-20
Depth, ft:	149.10-149.60
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: 21,845 psi

Both lateral strain gauges failed to record meaningful data. Poisson's Ratio could not be determined.

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
2200-8000	8,640,000	---
8000-13800	8,000,000	---
13800-19700	6,180,000	---

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:	4/5/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-01		
Sample ID:	R-20		
Depth:	149.10-149.60 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:	4.24	4.24	4.24
Specimen Diameter, in:	1.87	1.87	1.87
Specimen Mass, g:	490.02		
Bulk Density, lb/ft^3	160		
Length to Diameter Ratio:	2.3		

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	-0.00030	-0.00030	-0.00030	-0.00020	-0.00010	-0.00010	-0.00010	0.00000	0.00000	-0.00010	-0.00010	-0.00010	0.00000	0.00000	-0.00010
Diameter 2, in (rotated 90^o)	-0.00030	-0.00030	-0.00010	-0.00010	-0.00010	-0.00020	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° = 0.00030

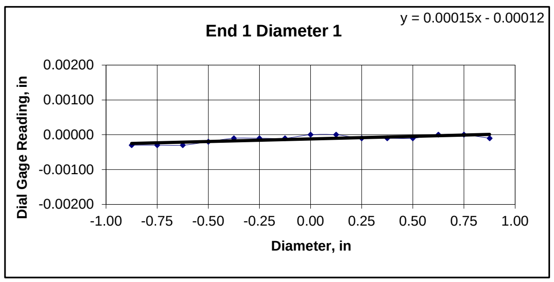
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00010	-0.00020	-0.00020	-0.00010	-0.00010	-0.00010	-0.00010	0.00000	0.00000	-0.00010	-0.00010	0.00000	0.00000	0.00000	-0.00010
Diameter 2, in (rotated 90^o)	-0.00040	-0.00020	-0.00020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

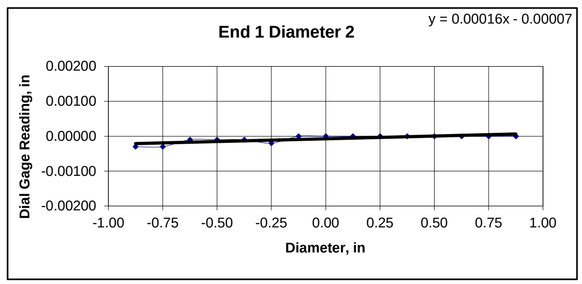
Difference between max and min readings, in:

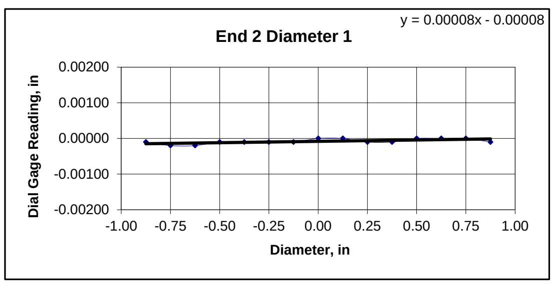
0° = 0.0002 90° = 0.0004

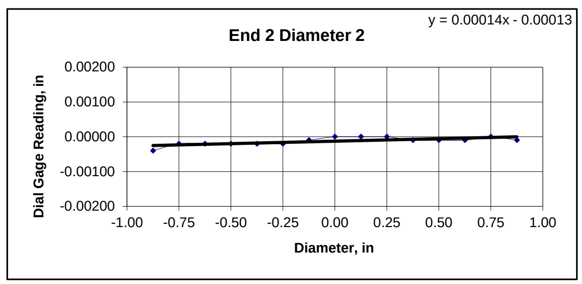
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00020

Flatness Tolerance Met? YES









DIAMETER 1

End 1:

Slope of Best Fit Line	0.00015
Angle of Best Fit Line:	0.00859

End 2:

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

Maximum Angular Difference: 0.00401

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	0.00014
Angle of Best Fit Line:	0.00802

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	0.00030	1.870	0.00016	0.009	YES
Diameter 2, in (rotated 90^o)	0.00030	1.870	0.00016	0.009	YES
END 2					
Diameter 1, in	0.00020	1.870	0.00011	0.006	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

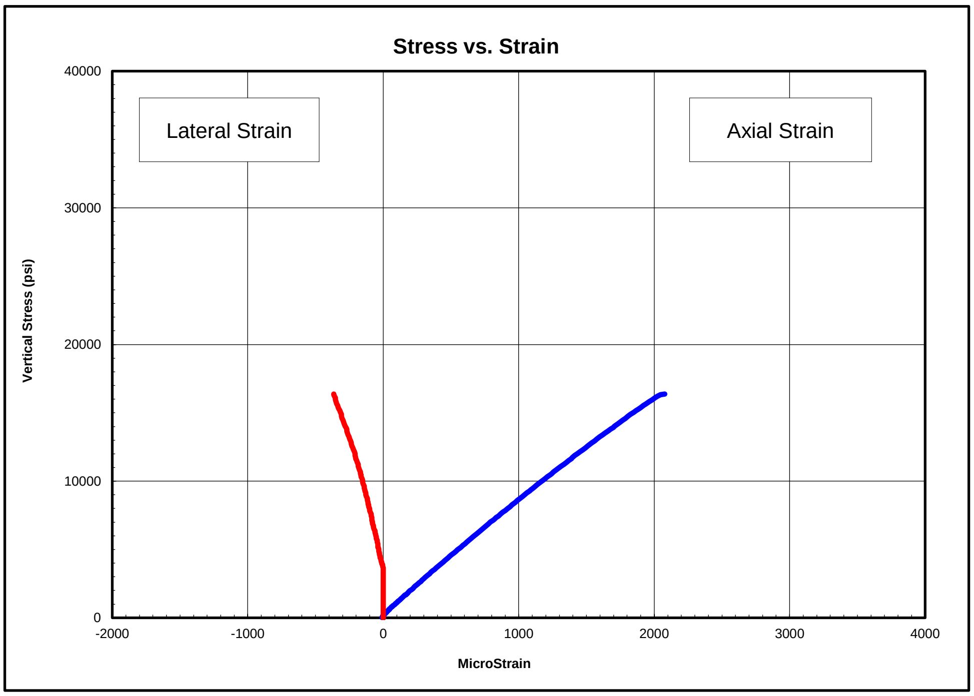
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-01
Sample ID:	R-20
Depth, ft:	149.10-149.60

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-01
Sample ID:	R-24
Depth, ft:	166.50-167.0
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: 16,368 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
1600-6000	8,520,000	0.13
6000-10400	7,990,000	0.19
10400-14700	7,450,000	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.

Client:	TSI Geotechnical	Test Date:	4/5/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-01		
Sample ID:	R-24		
Depth:	166.50-167.0 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	4.11	4.11
Specimen Diameter, in:	1.86	1.87	1.87
Specimen Mass, g:	476.84		
Bulk Density, lb/ft^3	162		
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.? NO

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? NO

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	-0.00030	-0.00020	-0.00030	-0.00030	-0.00020	0.00000	0.00000	-0.00020	-0.00030	-0.00030	-0.00010	-0.00020	-0.00020
Diameter 2, in (rotated 90°)	-0.00020	-0.00020	-0.00020	-0.00020	-0.00020	-0.00030	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010

Difference between max and min readings, in:

0° = 0.00040 90° = 0.00040

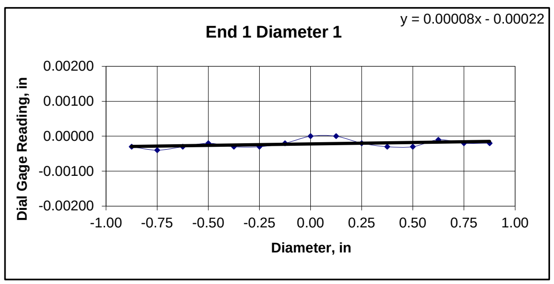
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00010	0.00010	0.00010	0.00000	0.00000	0.00020	0.00020	0.00000	0.00030	0.00030	0.00020	0.00010	0.00020	0.00020	0.00010
Diameter 2, in (rotated 90°)	-0.00020	-0.00010	0.00000	0.00000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

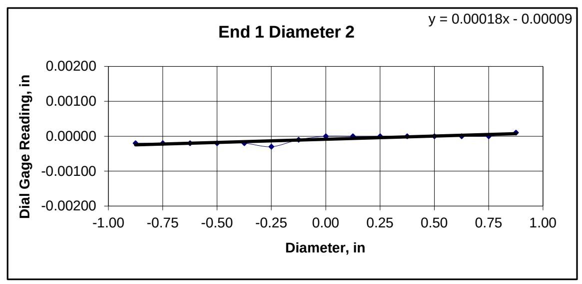
Difference between max and min readings, in:

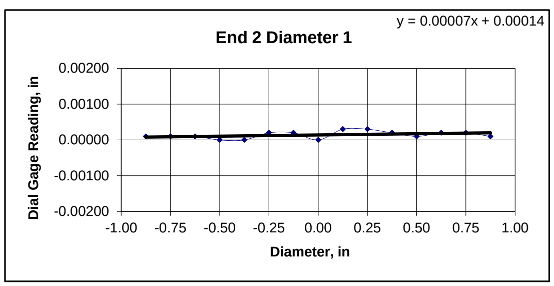
0° = 0.0003 90° = 0.0005

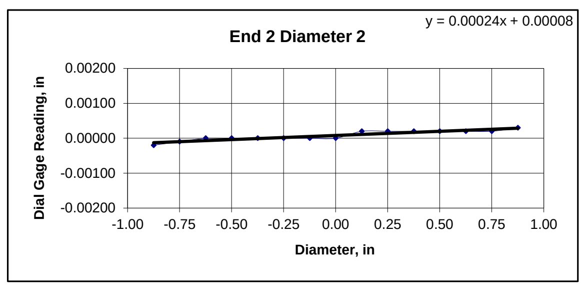
Maximum difference must be < 0.0020 in. Difference = ± 0.00025

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	0.00007
	Angle of Best Fit Line:	0.00401
Maximum Angular Difference:		0.00057

Parallelism Tolerance Met? YES

Spherically Seated

DIAMETER 2

End 1:	Slope of Best Fit Line	0.00018
	Angle of Best Fit Line:	0.01031
End 2:	Slope of Best Fit Line	0.00024
	Angle of Best Fit Line:	0.01375
Maximum Angular Difference:		0.00344

Parallelism Tolerance Met? YES

Spherically Seated

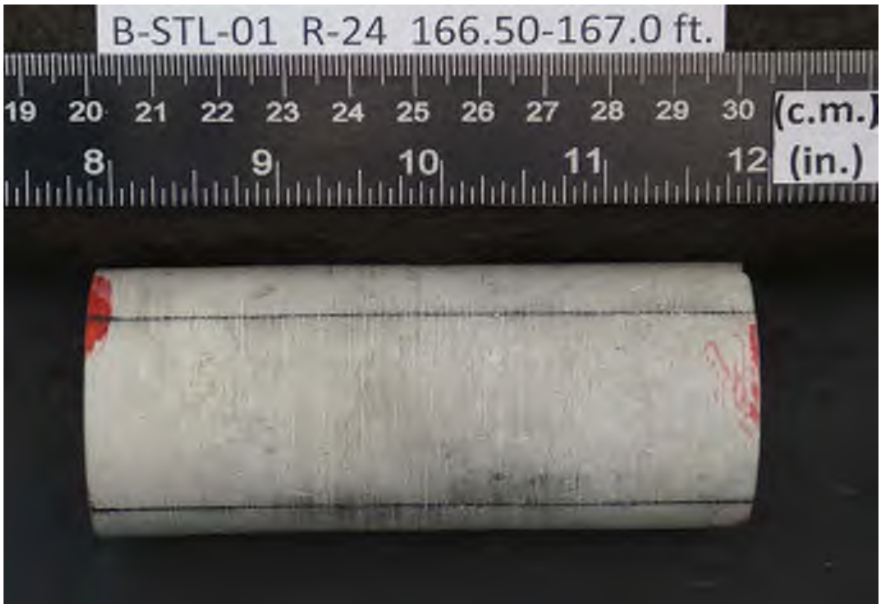
PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00040	1.865	0.00021	0.012	YES
Diameter 2, in (rotated 90°)	0.00040	1.865	0.00021	0.012	YES
END 2					
Diameter 1, in	0.00030	1.865	0.00016	0.009	YES
Diameter 2, in (rotated 90°)	0.00050	1.865	0.00027	0.015	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:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-01
Sample ID:	R-24
Depth, ft:	166.50-167.0

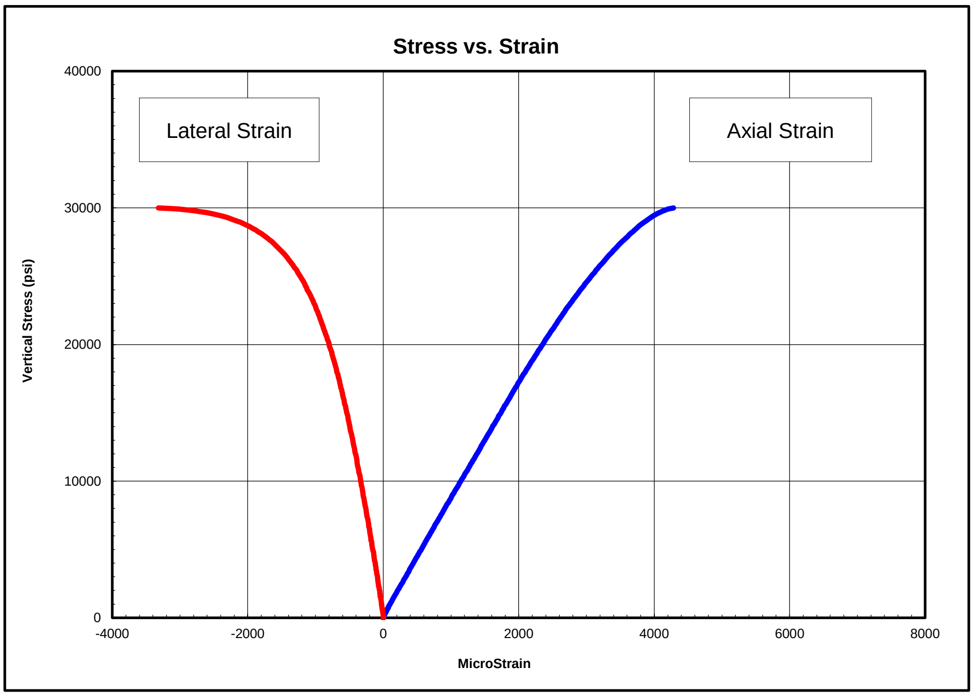


After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-03
Sample ID:	R-19
Depth, ft:	126.0-126.50
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: 30,000 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
3000-11000	8,570,000	0.30
11000-19000	8,410,000	0.38
19000-27000	6,710,000	---

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:	4/5/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-03		
Sample ID:	R-19		
Depth:	126.0-126.50 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:	4.27	4.27	4.27		
Specimen Diameter, in:	1.86	1.87	1.87		
Specimen Mass, g:	510.34				
Bulk Density, lb/ft^3	166			**Minimum Diameter Tolerence Met?**	NO
Length to Diameter Ratio:	2.3			**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.? NO

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? NO

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	-0.00020	-0.00010	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00010	0.00010
Diameter 2, in (rotated 90°)	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

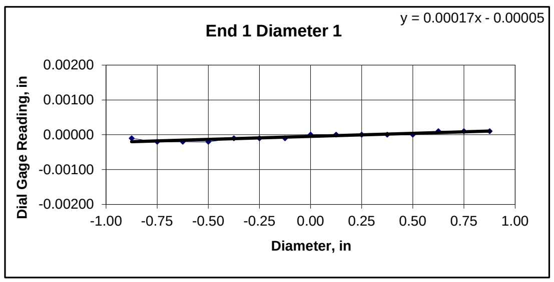
Difference between max and min readings, in:
0° = 0.00030 90° = 0.00000

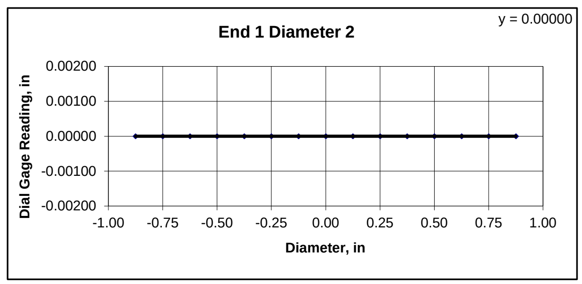
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00010	0.00010	0.00010	0.00020
Diameter 2, in (rotated 90°)	0.00000	0.00000	0.00000	0.00000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

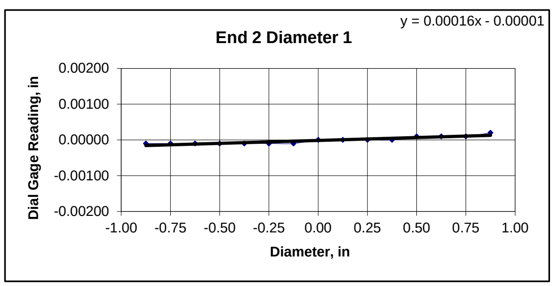
Difference between max and min readings, in:
0° = 0.0003 90° = 0.0001

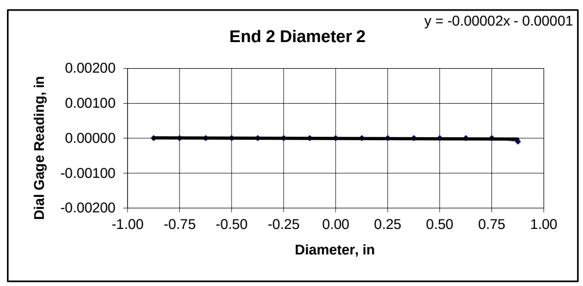
Maximum difference must be < 0.0020 in. Difference = ± 0.00015

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 0.00016
Angle of Best Fit Line: 0.00917

Maximum Angular Difference: 0.00057

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 -0.00002
Angle of Best Fit Line: -0.00115

Maximum Angular Difference: 0.00115

Parallelism Tolerance Met? YES
Spherically Seated

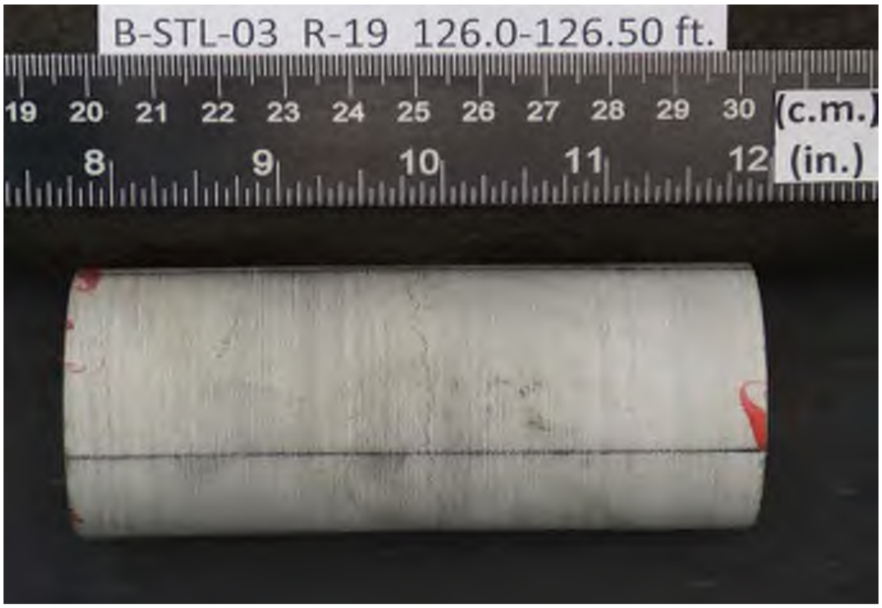
PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00030	1.865	0.00016	0.009	YES
Diameter 2, in (rotated 90°)	0.00000	1.865	0.00000	0.000	YES
END 2					
Diameter 1, in	0.00030	1.865	0.00016	0.009	YES
Diameter 2, in (rotated 90°)	0.00010	1.865	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:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-03
Sample ID:	R-19
Depth, ft:	126.0-126.50



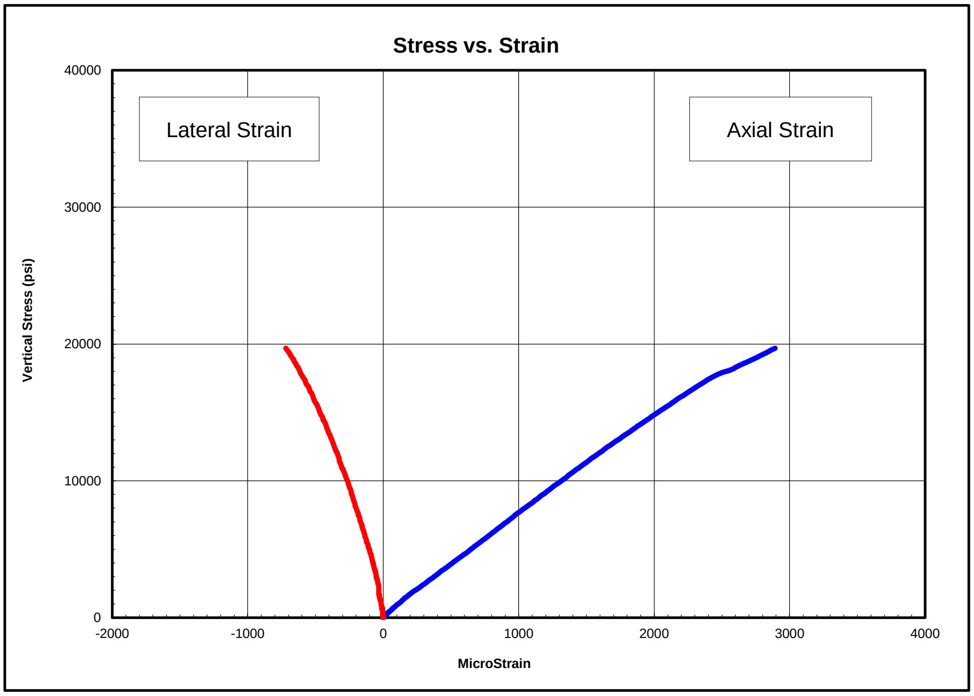
After cutting and grinding

After break

GeoTesting EXPRESS

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-03
Sample ID:	R-22
Depth, ft:	143.30-143.80
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: 19,743 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
2000-7200	7,420,000	0.21
7200-12500	7,330,000	0.26
12500-17700	6,640,000	0.30

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:	4/5/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-03		
Sample ID:	R-22		
Depth:	143.30-143.80 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:	4.20	4.20	4.20		
Specimen Diameter, in:	1.86	1.87	1.87		
Specimen Mass, g:	497.84				
Bulk Density, lb/ft^3	165	**Minimum Diameter Tolerence Met?**		**NO**	
Length to Diameter Ratio:	2.3	**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.? NO

Maximum difference must be < 0.020 in.
Straightness Tolerance Met? **NO**

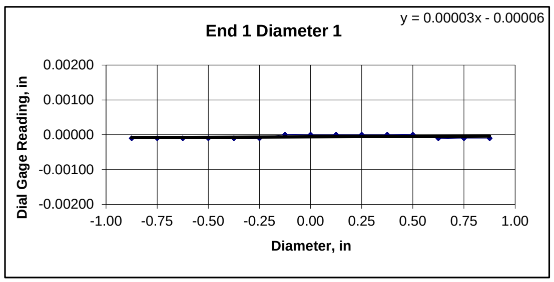
END FLATNESS AND PARALLELISM (Procedure FP1)

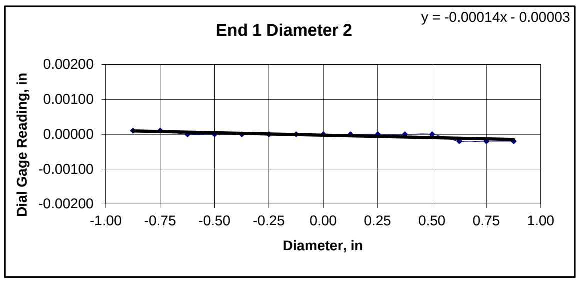
END 1	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00010
Diameter 2, in (rotated 90^o)	0.00010	0.00010	0.00000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

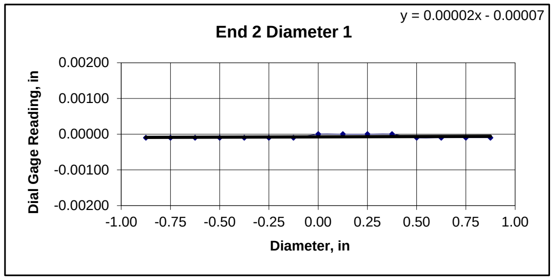
Difference between max and min readings, in:
0° = 0.00010 90° = 0.00030

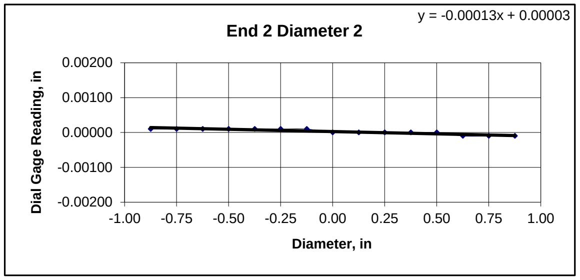
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00010	-0.00010
Diameter 2, in (rotated 90^o)	0.00010	0.00010	0.00010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

Difference between max and min readings, in:
0° = 0.0001 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 0.00002
Angle of Best Fit Line: 0.00115

Maximum Angular Difference: 0.00057

Parallelism Tolerance Met? **YES**
Spherically Seated

DIAMETER 2

End 1:
Slope of Best Fit Line -0.00014
Angle of Best Fit Line: -0.00802

End 2:
Slope of Best Fit Line -0.00013
Angle of Best Fit Line: -0.00745

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	0.00010	1.865	0.00005	0.003	YES
Diameter 2, in (rotated 90^o)	0.00030	1.865	0.00016	0.009	YES
END 2					
Diameter 1, in	0.00010	1.865	0.00005	0.003	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:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-03
Sample ID:	R-22
Depth, ft:	143.30-143.80

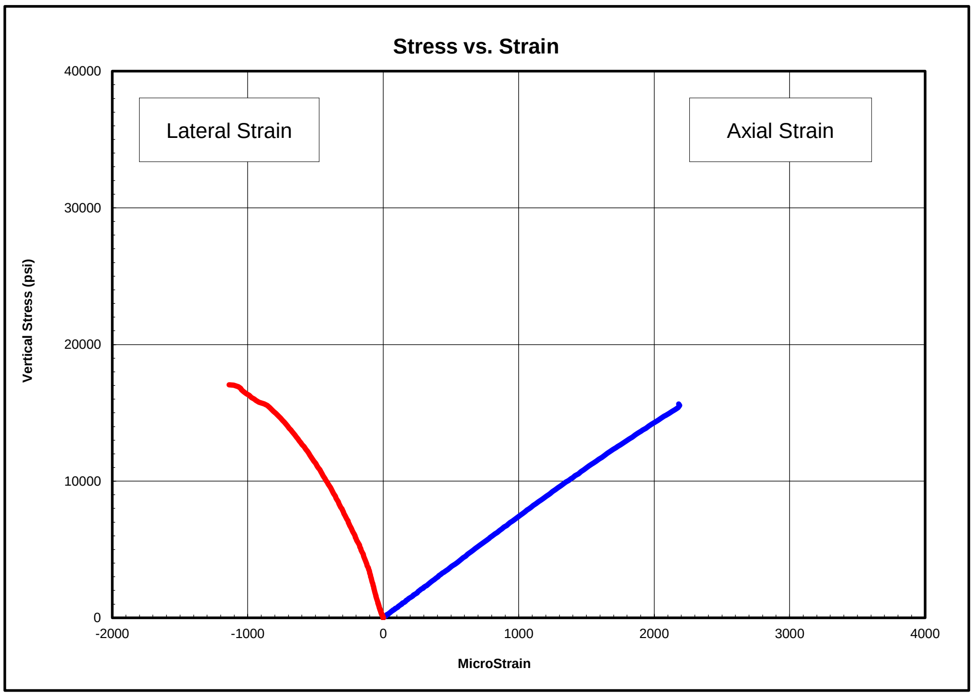
After cutting and grinding

After break

GeoTesting EXPRESS

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/13/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-03
Sample ID:	R-24
Depth, ft:	152.0-152.35
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: 17,048 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
1700-6300	7,450,000	0.27
6300-10800	7,170,000	0.39
10800-15300	6,540,000	---

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-03		
Sample ID:	R-24		
Depth:	152.0-152.35 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:	3.89	3.89	3.89
Specimen Diameter, in:	1.87	1.87	1.87
Specimen Mass, g:	448.79		
Bulk Density, lb/ft^3	160		
Length to Diameter Ratio:	2.1		

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	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020	-0.00030
Diameter 2, in (rotated 90°)	0.00020	0.00020	0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020	-0.00030	-0.00040

Difference between max and min readings, in:

0° = 0.00040 90° = 0.00060

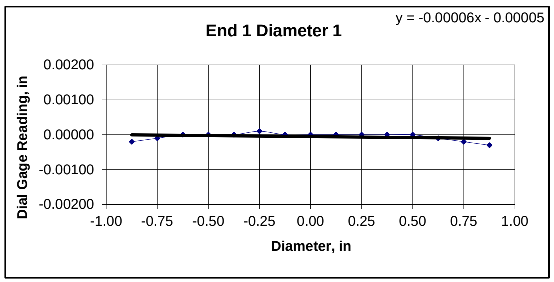
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00020	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	0.00000
Diameter 2, in (rotated 90°)	-0.00020	-0.00010	0.00000	-0.00010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

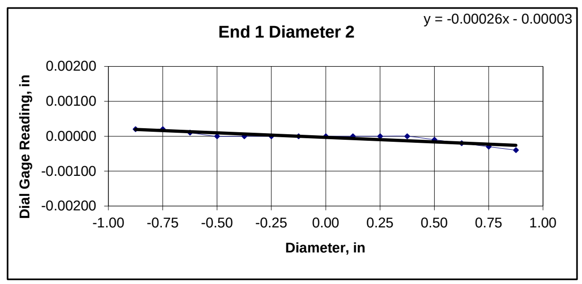
Difference between max and min readings, in:

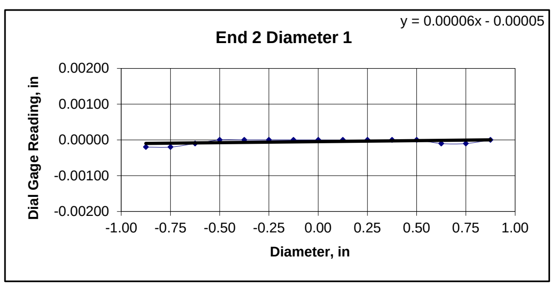
0° = 0.0002 90° = 0.0005

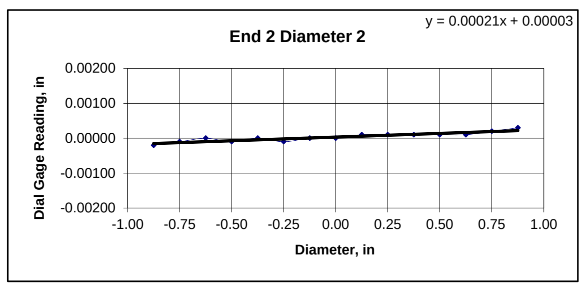
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00030

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	0.00006
Angle of Best Fit Line:	0.00344

Maximum Angular Difference: 0.00000

Parallelism Tolerance Met? YES

Spherically Seated

DIAMETER 2

End 1:

Slope of Best Fit Line	0.00026
Angle of Best Fit Line:	0.01490

End 2:

Slope of Best Fit Line	0.00021
Angle of Best Fit Line:	0.01203

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	1.870	0.00021	0.012	YES
Diameter 2, in (rotated 90°)	0.00060	1.870	0.00032	0.018	YES
END 2					
Diameter 1, in	0.00020	1.870	0.00011	0.006	YES
Diameter 2, in (rotated 90°)	0.00050	1.870	0.00027	0.015	YES

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

Perpendicularity Tolerance Met? YES

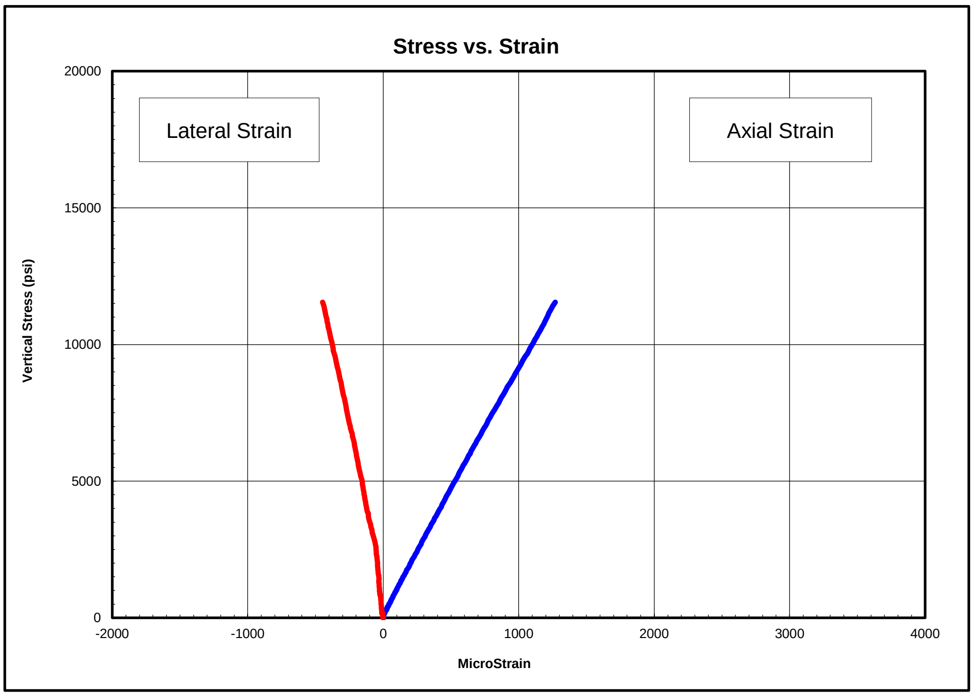
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/13/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-03
Sample ID:	R-24
Depth, ft:	152.0-152.35

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa
Checked By:	jsc
Boring ID:	B-STL-03
Sample ID:	R-26
Depth, ft:	161.50-162.0
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: 11,541 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
1200-4200	9,240,000	0.32
4200-7300	9,000,000	0.37
7300-10400	8,560,000	0.38

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:	4/10/2017
Project Name:	Spire STL Pipeline	Tested By:	daa
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-03		
Sample ID:	R-26		
Depth:	161.50-162.0 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:	4.26	4.26	4.26
Specimen Diameter, in:	1.87	1.87	1.87
Specimen Mass, g:	486.92		
Bulk Density, lb/ft^3	158	**Minimum Diameter Tolerence Met?**	**NO**
Length to Diameter Ratio:	2.3	**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.? NO

Maximum difference must be < 0.020 in.

Straightness Tolerance Met? **NO**

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	-0.00030	-0.00010	0.00000	0.00000	-0.00010	0.00000	0.00000	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	-0.00010
Diameter 2, in (rotated 90^o)	0.00040	0.00040	0.00040	0.00030	0.00030	0.00020	0.00010	0.00000	0.00000	0.00000	0.00000	0.00020	0.00030	0.00030	0.00030

Difference between max and min readings, in:

0° = 0.00030 90° = 0.00040

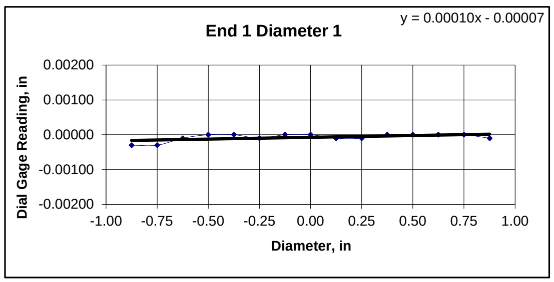
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00000	-0.00010	-0.00010	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00010	0.00010	0.00000	0.00000	0.00010	0.00010	0.00000
Diameter 2, in (rotated 90^o)	-0.00010	-0.00010	-0.00010	-0.00010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

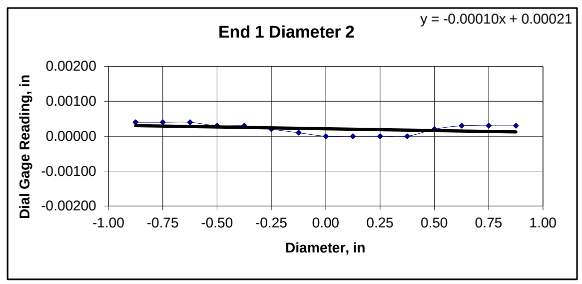
Difference between max and min readings, in:

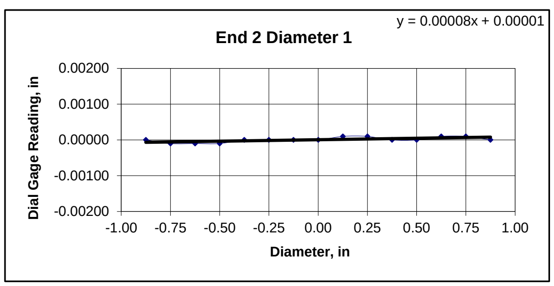
0° = 0.0002 90° = 0.0004

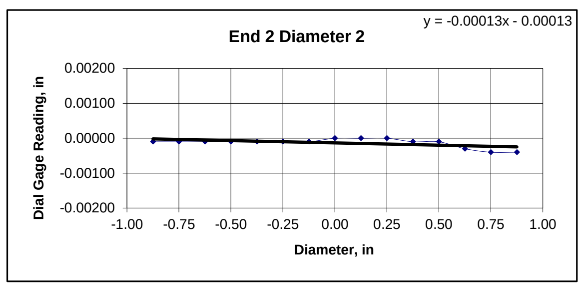
Maximum difference must be < 0.0020 in. Difference = ± 0.00020

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:

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

End 2:

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

Maximum Angular Difference: 0.00115

Parallelism Tolerance Met? **YES**

Spherically Seated

DIAMETER 2

End 1:

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

End 2:

Slope of Best Fit Line	-0.00013
Angle of Best Fit Line:	-0.00745

Maximum Angular Difference: 0.00172

Parallelism Tolerance Met? **YES**

Spherically Seated

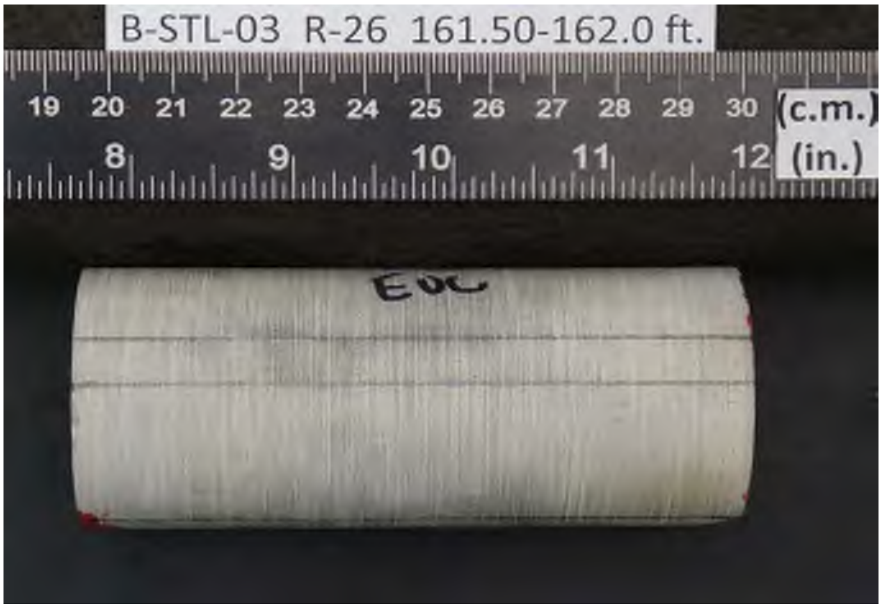
PERPENDICULARITY (Procedure P1) (Calculated from End Flatness and Parallelism measurements above)

END 1	Difference, Maximum and Minimum (in.)	Diameter (in.)	Slope	Angle°	Perpendicularity Tolerance Met?
Diameter 1, in	0.00030	1.870	0.00016	0.009	YES
Diameter 2, in (rotated 90^o)	0.00040	1.870	0.00021	0.012	YES
END 2					
Diameter 1, in	0.00020	1.870	0.00011	0.006	YES
Diameter 2, in (rotated 90^o)	0.00040	1.870	0.00021	0.012	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:	4/10/2017
Tested By:	daa
Checked By:	jsc
Boring ID:	B-STL-03
Sample ID:	R-26
Depth, ft:	161.50-162.0

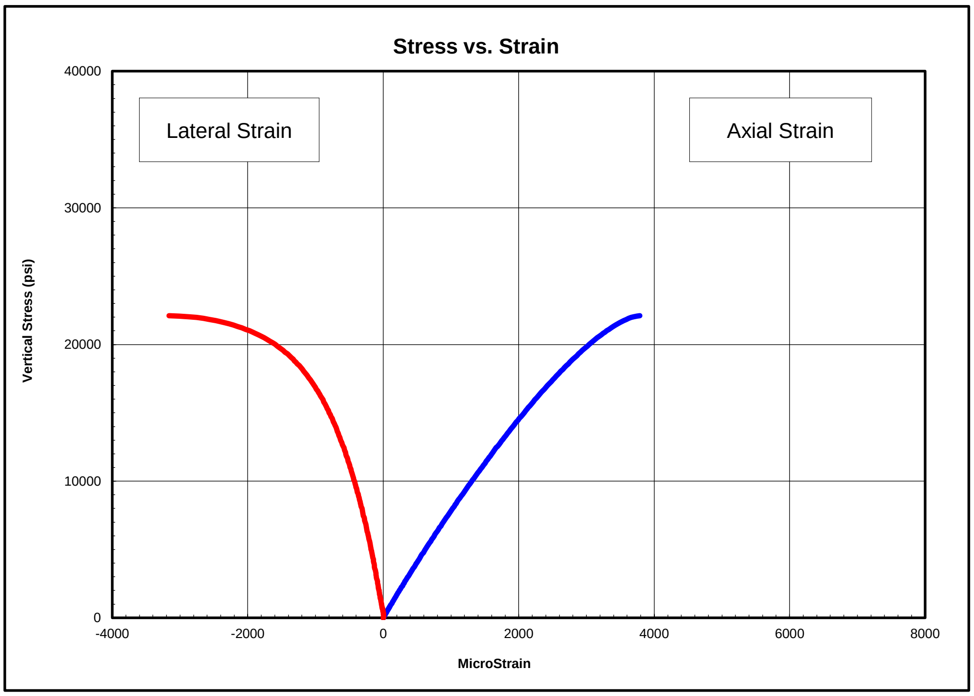


After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa
Checked By:	jsc
Boring ID:	B-STL-03
Sample ID:	R-29
Depth, ft:	177.50-178.0
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: 22,105 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
2200-8100	7,640,000	0.32
8100-14000	6,760,000	0.44
14000-19900	5,370,000	---

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.

GeoTesting EXPRESS

Client:	TSI Geotechnical	Test Date:	4/5/2017
Project Name:	Spire STL Pipeline	Tested By:	daa/rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-03		
Sample ID:	R-29		
Depth:	177.50-178.0 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:	4.24	4.24	4.24
Specimen Diameter, in:	1.87	1.87	1.87
Specimen Mass, g:	489.07		
Bulk Density, lb/ft^3	160	**Minimum Diameter Tolerence Met?**	**NO**
Length to Diameter Ratio:	2.3	**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	-0.00050	-0.00050	-0.00010	-0.00010	-0.00010	-0.00030	0.00000	0.00000	0.00000	-0.00010	-0.00010	0.00010	0.00010	0.00000
Diameter 2, in (rotated 90°)	-0.00010	-0.00010	-0.00010	-0.00010	-0.00010	-0.00020	-0.00010	0.00000	0.00000	-0.00010	-0.00030	-0.00040	-0.00020	-0.00020	-0.00020

Difference between max and min readings, in:

0° = 0.00060 90° = 0.00040

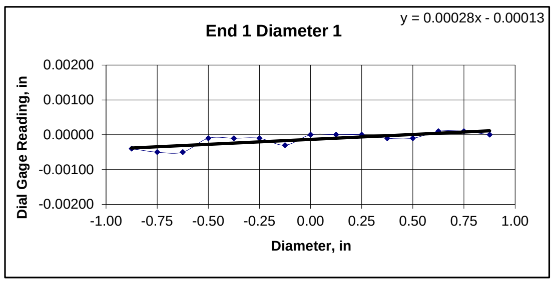
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00060	-0.00060	-0.00040	-0.00030	-0.00020	-0.00040	-0.00020	0.00000	0.00000	-0.00020	-0.00020	-0.00010	0.00000	-0.00020	-0.00010
Diameter 2, in (rotated 90°)	-0.00010	-0.00010	-0.00010	-0.00010	-0.00030	-0.00030	-0.00010	0.00000	0.00000	-0.00030	-0.00030	-0.00030	-0.00020	-0.00020	-0.00050

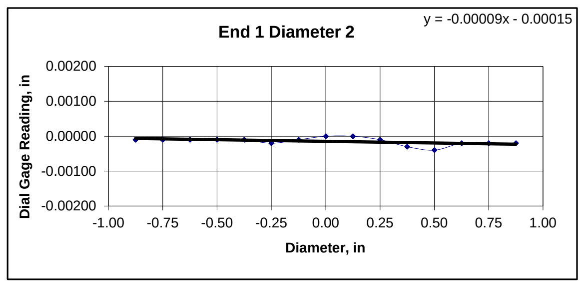
Difference between max and min readings, in:

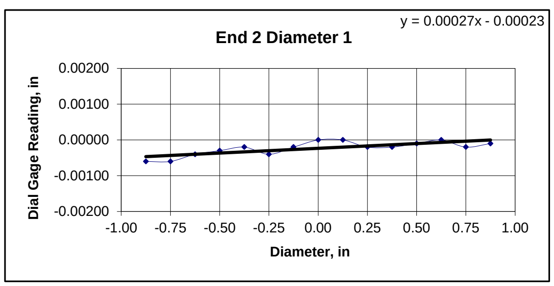
0° = 0.0006 90° = 0.0005

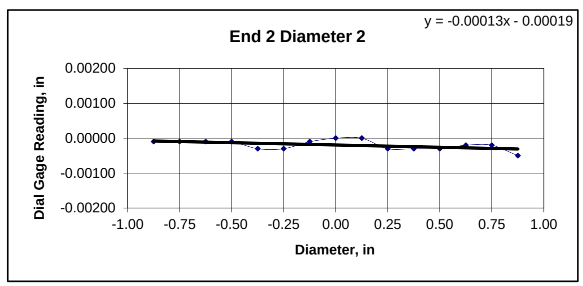
Maximum difference must be < 0.0020 in. Difference = ± 0.00030

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:
Slope of Best Fit Line 0.00028
Angle of Best Fit Line: 0.01604

End 2:
Slope of Best Fit Line 0.00027
Angle of Best Fit Line: 0.01547

Maximum Angular Difference: 0.00057

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 -0.00013
Angle of Best Fit Line: -0.00745

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	0.00060	1.870	0.00032	0.018	YES
Diameter 2, in (rotated 90°)	0.00040	1.870	0.00021	0.012	YES
END 2					
Diameter 1, in	0.00060	1.870	0.00032	0.018	YES
Diameter 2, in (rotated 90°)	0.00050	1.870	0.00027	0.015	YES

Maximum angle of departure must be ≤ 0.25°

Perpendicularity Tolerance Met? **YES**

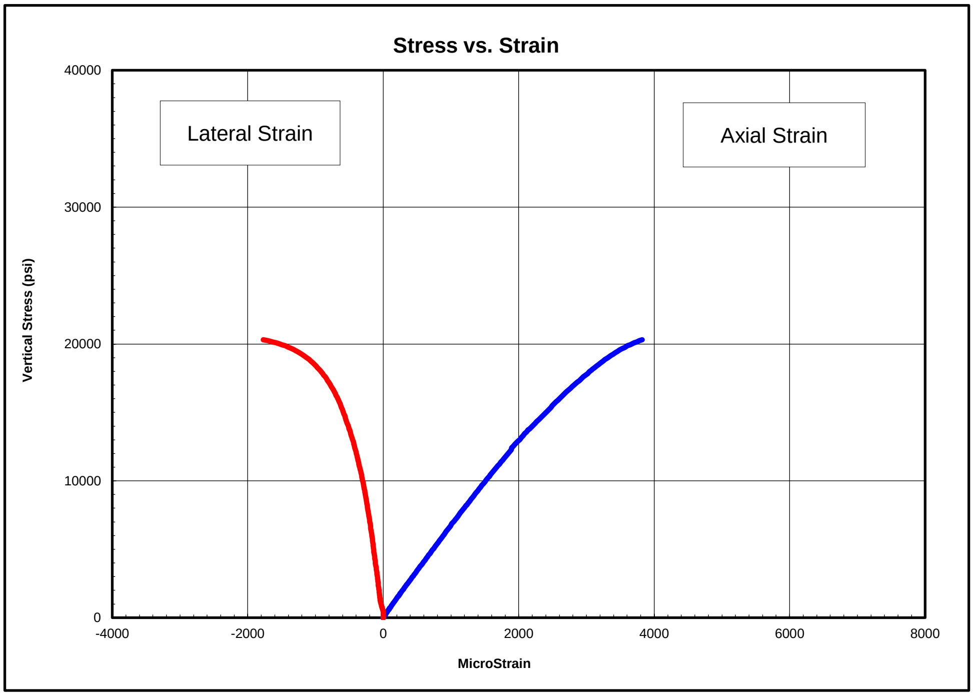
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	4/10/2017
Tested By:	daa/rlc
Checked By:	jsc
Boring ID:	B-STL-03
Sample ID:	R-29
Depth, ft:	177.50-178.0

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	8/9/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-08
Sample ID:	R-1
Depth, ft:	38.1-38.5
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: 20,514 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
2100-7500	6,640,000	0.18
7500-13000	6,170,000	0.27
13000-18500	4,750,000	0.47

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:	8/8/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-08		
Sample ID:	R-1		
Depth:	38.1-38.5 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:	4.25	4.25	4.25
Specimen Diameter, in:	1.86	1.86	1.86
Specimen Mass, g:	493.63		
Bulk Density, lb/ft^3	163	**Minimum Diameter Tolerence Met?**	**NO**
Length to Diameter Ratio:	2.3	**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	0.00000	-0.00010	-0.00010	0.00010	0.00000
Diameter 2, in (rotated 90°)	-0.00020	-0.00010	0.00000	0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00030	0.00000

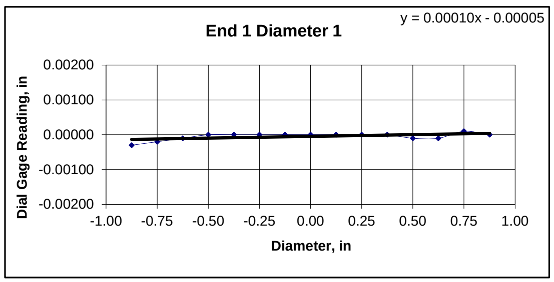
Difference between max and min readings, in:
0° = 0.00040 90° = 0.00050

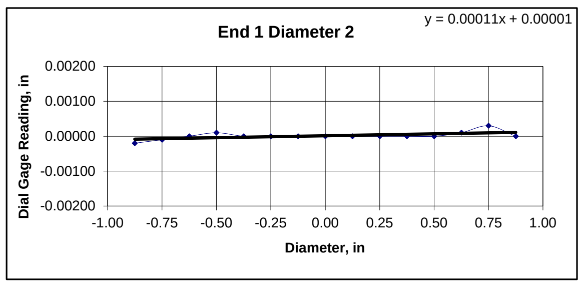
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00000
Diameter 2, in (rotated 90°)	-0.00030	-0.00020	-0.00010	0.00000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

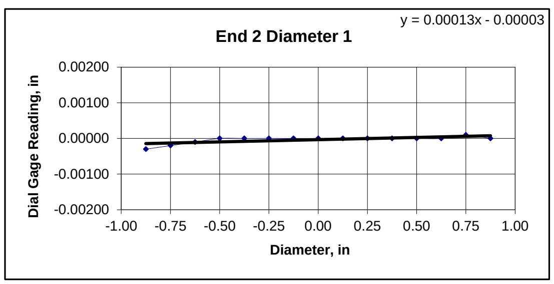
Difference between max and min readings, in:
0° = 0.0004 90° = 0.0004

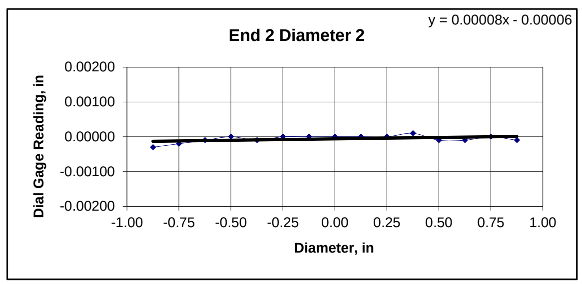
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00025

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:
Slope of Best Fit Line 0.00010
Angle of Best Fit Line: 0.00573

End 2:
Slope of Best Fit Line 0.00013
Angle of Best Fit Line: 0.00745

Maximum Angular Difference: 0.00172

Parallelism Tolerance Met? **YES**
Spherically Seated

DIAMETER 2

End 1:
Slope of Best Fit Line 0.00011
Angle of Best Fit Line: 0.00630

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

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	0.00040	1.860	0.00022	0.012	YES
Diameter 2, in (rotated 90°)	0.00050	1.860	0.00027	0.015	YES
END 2					
Diameter 1, in	0.00040	1.860	0.00022	0.012	YES
Diameter 2, in (rotated 90°)	0.00040	1.860	0.00022	0.012	YES

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

Perpendicularity Tolerance Met? **YES**

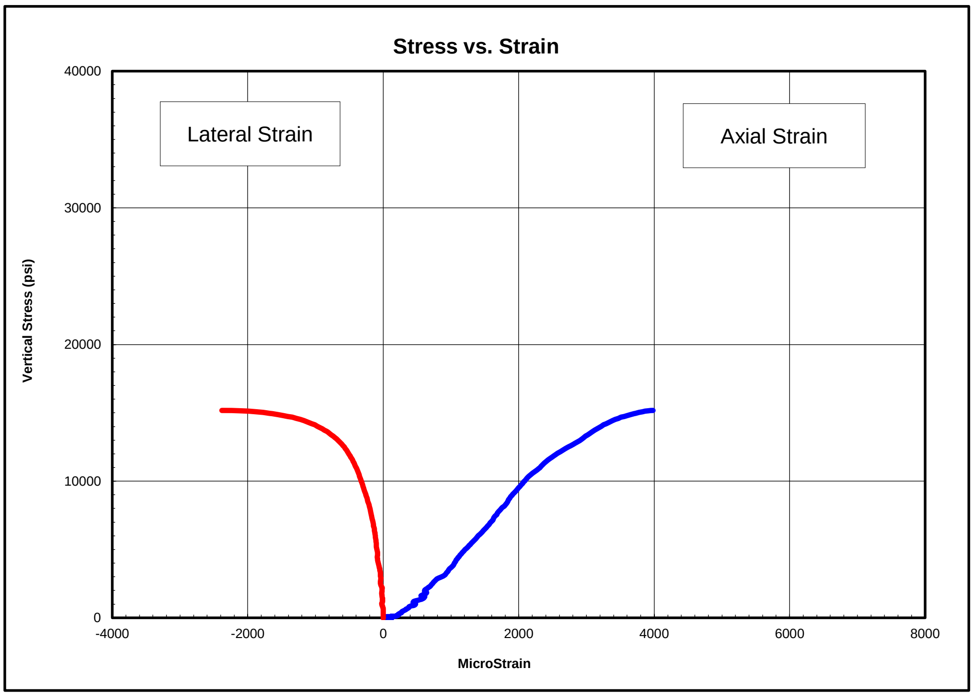
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	8/9/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-08
Sample ID:	R-1
Depth, ft:	38.1-38.5

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	8/9/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-08
Sample ID:	R-5
Depth, ft:	58.0-58.5
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: 15,174 psi

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

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
1500-5600	5,170,000	0.13
5600-9600	5,980,000	0.29
9600-13700	3,590,000	0.48

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:	8/8/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-08		
Sample ID:	R-5		
Depth:	58.0-58.5 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:	3.84	3.84	3.84
Specimen Diameter, in:	1.84	1.84	1.84
Specimen Mass, g:	401.36		
Bulk Density, lb/ft^3	149	**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	0.00000	0.00000	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020	-0.00030
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	0.00000	-0.00010	-0.00020	-0.00020

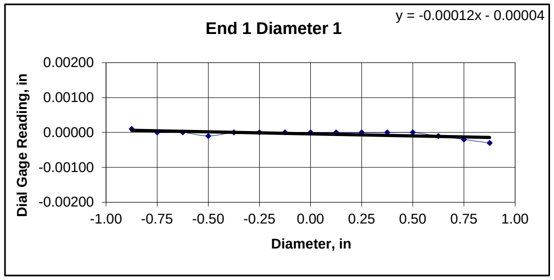
Difference between max and min readings, in:
0° = 0.00040 90° = 0.00040

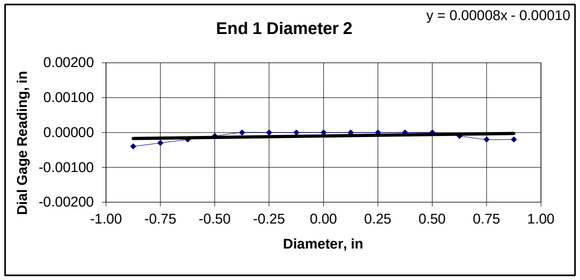
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00000	-0.00010	-0.00010	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00010	-0.00020	-0.00030
Diameter 2, in (rotated 90°)	0.00000	0.00000	0.00000	0.00000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

Difference between max and min readings, in:
0° = 0.0003 90° = 0.0002

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

Flatness Tolerance Met? **YES**





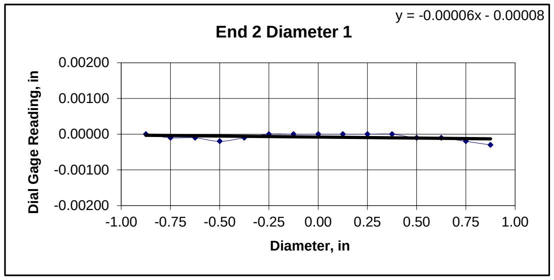
DIAMETER 1

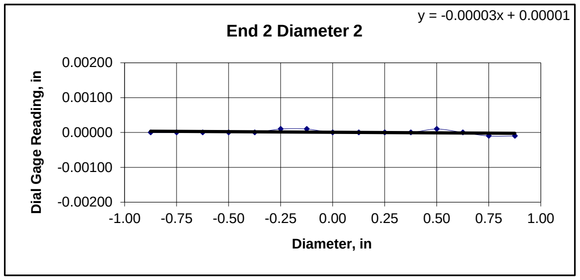
End 1:
Slope of Best Fit Line 0.00012
Angle of Best Fit Line: 0.00688

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

Maximum Angular Difference: 0.00344

Parallelism Tolerance Met? **YES**
Spherically Seated





DIAMETER 2

End 1:
Slope of Best Fit Line 0.00008
Angle of Best Fit Line: 0.00458

End 2:
Slope of Best Fit Line 0.00003
Angle of Best Fit Line: 0.00172

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	1.840	0.00022	0.012	YES
Diameter 2, in (rotated 90°)	0.00040	1.840	0.00022	0.012	YES
END 2					
Diameter 1, in	0.00030	1.840	0.00016	0.009	YES
Diameter 2, in (rotated 90°)	0.00020	1.840	0.00011	0.006	YES

Maximum angle of departure must be ≤ 0.25°

Perpendicularity Tolerance Met? **YES**

GeoTesting EXPRESS

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	8/9/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-08
Sample ID:	R-5
Depth, ft:	58.0-58.5

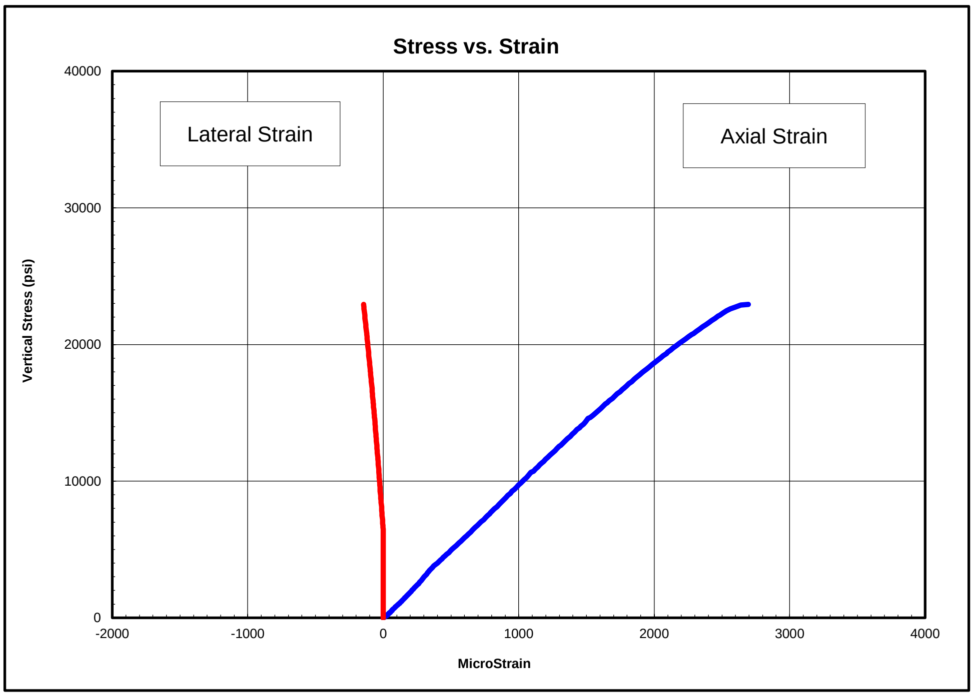
After cutting and grinding

After break

GeoTesting EXPRESS

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	8/9/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-08
Sample ID:	R-8
Depth, ft:	73.0-73.5
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: 22,928 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
2300-8400	9,590,000	0.03
8400-14500	9,410,000	0.07
14500-20600	8,210,000	0.08

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:	8/8/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-08		
Sample ID:	R-8		
Depth:	73.0-73.5 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:	4.22	4.22	4.22
Specimen Diameter, in:	1.86	1.86	1.86
Specimen Mass, g:	500.24		
Bulk Density, lb/ft^3	166	**Minimum Diameter Tolerence Met?**	**NO**
Length to Diameter Ratio:	2.3	**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	-0.00030	-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
Diameter 2, in (rotated 90°)	-0.00010	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00000	0.00000	0.00000	0.00000	0.00000

Difference between max and min readings, in:

0° = 0.00050 90° = 0.00030

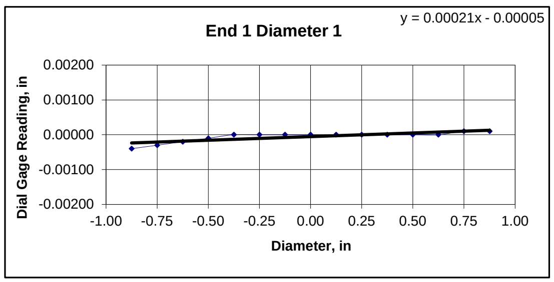
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00020	0.00030	0.00040	0.00050
Diameter 2, in (rotated 90°)	0.00010	0.00020	0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010

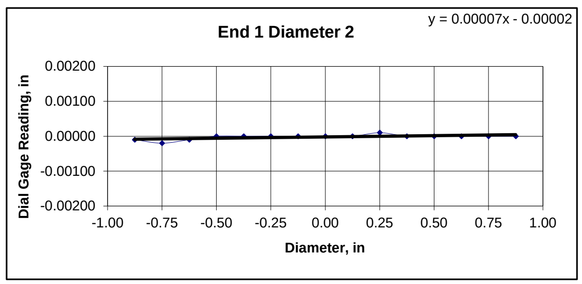
Difference between max and min readings, in:

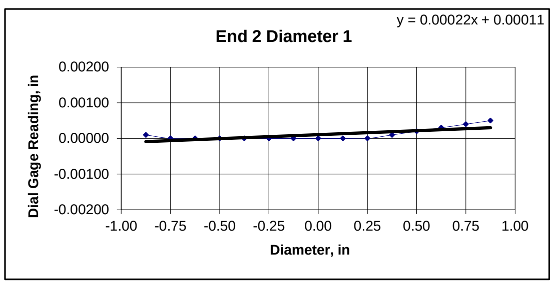
0° = 0.0005 90° = 0.0003

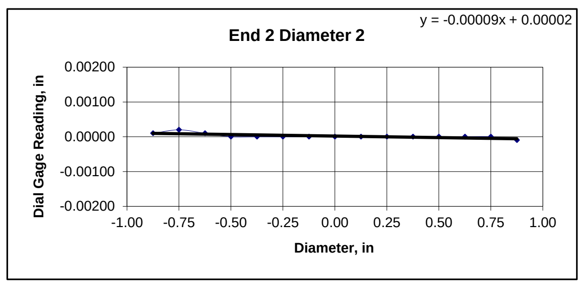
Maximum difference must be < 0.0020 in. Difference = ± 0.00025

Flatness Tolerance Met? YES









DIAMETER 1

End 1:		
	Slope of Best Fit Line	0.00021
	Angle of Best Fit Line:	0.01203
End 2:		
	Slope of Best Fit Line	0.00022
	Angle of Best Fit Line:	0.01261
Maximum Angular Difference:		0.00057

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	0.00050	1.860	0.00027	0.015	YES
Diameter 2, in (rotated 90°)	0.00030	1.860	0.00016	0.009	YES
END 2					
Diameter 1, in	0.00050	1.860	0.00027	0.015	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

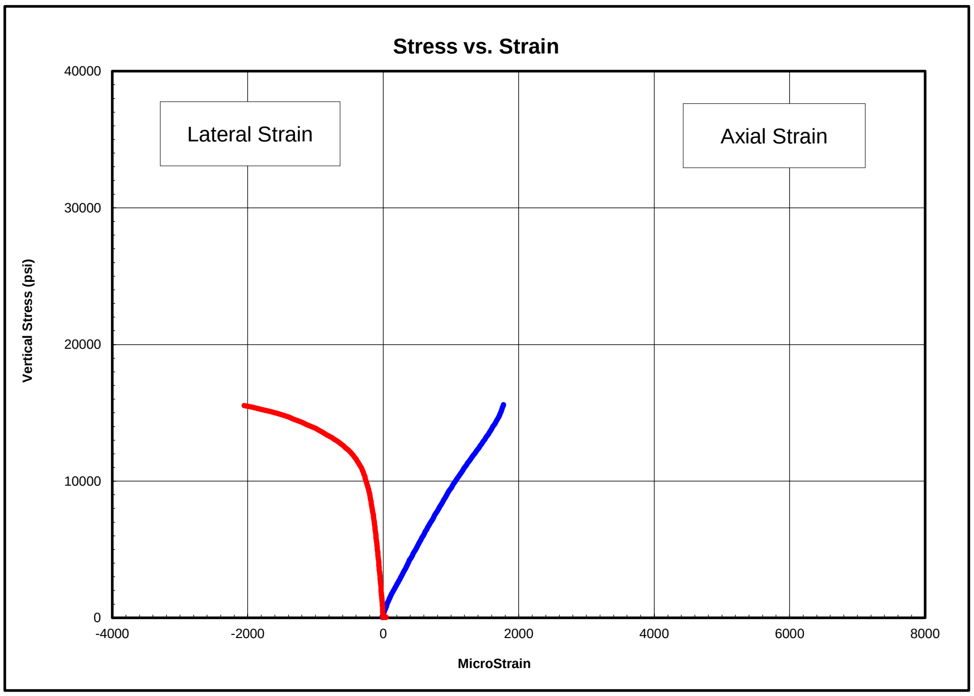
Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	8/9/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-08
Sample ID:	R-8
Depth, ft:	73.0-73.5

After cutting and grinding

After break

Client:	TSI Geotechnical
Project Name:	Spire STL Pipeline
Project Location:	Portage Des Sioux, MO
GTX #:	305821
Test Date:	8/9/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-08
Sample ID:	R-15
Depth, ft:	106.55-107.0
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: 16,932 psi

Stress Range, psi	Young's Modulus, psi	Poisson's Ratio
1700-6200	9,240,000	0.18
6200-10700	8,240,000	0.34
10700-15200	7,370,000	---

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:	8/8/2017
Project Name:	Spire STL Pipeline	Tested By:	rlc
Project Location:	Portage Des Sioux, MO	Checked By:	jsc
GTX #:	305821		
Boring ID:	B-STL-08		
Sample ID:	R-15		
Depth:	106.55-107.0 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:	4.15	4.15	4.15		
Specimen Diameter, in:	1.86	1.86	1.86		
Specimen Mass, g:	489.46				
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 $\leq$ 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	0.00010	0.00000	0.00000	0.00000	0.00010	0.00000	0.00000	0.00000	-0.00010	-0.00010
Diameter 2, in (rotated 90^o)	-0.00040	-0.00030	-0.00020	-0.00010	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° = 0.00050 90° = 0.00040

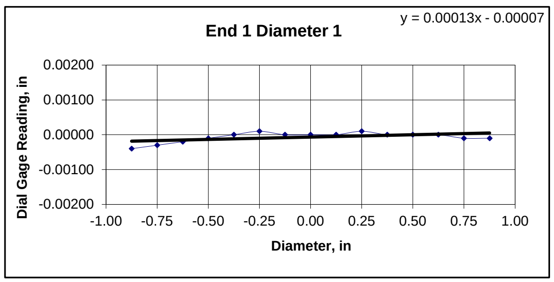
END 2	-0.875	-0.750	-0.625	-0.500	-0.375	-0.250	-0.125	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875
Diameter 1, in	-0.00040	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	-0.00010	0.00000	-0.00020
Diameter 2, in (rotated 90^o)	-0.00050	-0.00030	-0.00020	-0.00010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00010	-0.00020

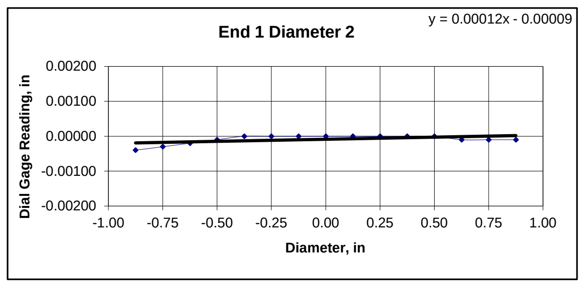
Difference between max and min readings, in:

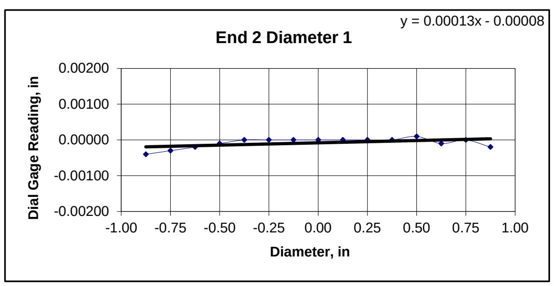
0° = 0.0005 90° = 0.0005

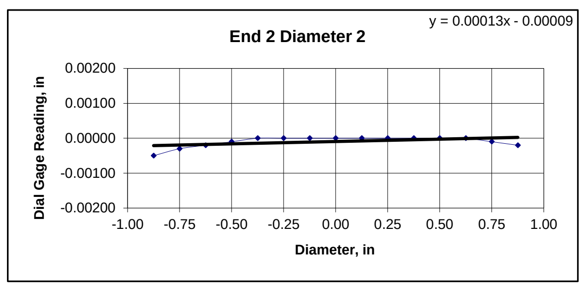
Maximum difference must be < 0.0020 in. Difference = $\pm$ 0.00025

Flatness Tolerance Met? **YES**









DIAMETER 1

End 1:		
	Slope of Best Fit Line	0.00013
	Angle of Best Fit Line:	0.00745
End 2:		
	Slope of Best Fit Line	0.00013
	Angle of Best Fit Line:	0.00745
Maximum Angular Difference:		0.00000

Parallelism Tolerance Met? **YES**

Spherically Seated

DIAMETER 2

End 1:		
	Slope of Best Fit Line	0.00012
	Angle of Best Fit Line:	0.00688
End 2:		
	Slope of Best Fit Line	0.00013
	Angle of Best Fit Line:	0.00745
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	0.00050	1.860	0.00027	0.015	YES
Diameter 2, in (rotated 90^o)	0.00040	1.860	0.00022	0.012	YES
END 2					
Diameter 1, in	0.00050	1.860	0.00027	0.015	YES
Diameter 2, in (rotated 90^o)	0.00050	1.860	0.00027	0.015	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:	8/9/2017
Tested By:	rlc
Checked By:	jsc
Boring ID:	B-STL-08
Sample ID:	R-15
Depth, ft:	106.55-107.0

After cutting and grinding

After break

Point Load Testing - Lab Worksheet
For Axial Tests

Project	Spire Pipeline		Tested By / Date:	JAS	3/31/17
Location	St. Louis, Missouri		Calculated By / Date:	CMB	4/3/17
Job No.	41-1-37762-003		Checked By / Date:	CMB	4/3/17
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-01	R-13	112.0 - 112.4	a ⊥	1.962	25	21	970	7074
B-STL-01	R-16	127.5 - 128.0	a ⊥	1.965	24	22	1020	7075
B-STL-01	R-18	138.0 - 138.5	a ⊥	1.965	25	22	1900	7076
B-STL-01	R-20	148.6 - 149.1	a ⊥	1.965	25	24	1200	7077
B-STL-01	R-24	168.6 - 169.1	a ⊥	1.960	24	22	1700	7078
B-STL-03	R-19	127.0 - 127.5	a ⊥	1.965	24	22	1500	7069
B-STL-03	R-22	144.5 - 145.0	a ⊥	1.965	24	22	1000	7070
B-STL-03	R-24	153.4 - 153.9	a ⊥	1.965	24	23	890	7071
B-STL-03	R-26	163.1 - 163.6	a ⊥	1.965	25	23	1000	7072
B-STL-03	R-29	177.0 - 177.5	a ⊥	1.965	25	23	1380	7073

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	3/31/17
Calculated By / Date:	CMB	4/3/17
Checked By / Date:	CMB	4/3/17
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-01	R-13	112.0 - 112.4	a ⊥	25	21	4	21	50	1332	9.65	7.24	0.87	6.28	128
B-STL-01	R-16	127.5 - 128.0	a ⊥	24	22	2	22	50	1398	10.15	7.26	0.88	6.37	129
B-STL-01	R-18	138.0 - 138.5	a ⊥	25	22	3	22	50	1398	18.90	13.52	0.88	11.86	241
B-STL-01	R-20	148.6 - 149.1	a ⊥	25	24	1	24	50	1525	11.94	7.83	0.89	7.00	142
B-STL-01	R-24	168.6 - 169.1	a ⊥	24	22	2	22	50	1395	16.91	12.13	0.88	10.63	216
B-STL-03	R-19	127.0 - 127.5	a ⊥	24	22	2	22	50	1398	14.92	10.67	0.88	9.36	190
B-STL-03	R-22	144.5 - 145.0	a ⊥	24	22	2	22	50	1398	9.95	7.11	0.88	6.24	127
B-STL-03	R-24	153.4 - 153.9	a ⊥	24	23	1	23	50	1462	8.9	6.1	0.89	5.4	109
B-STL-03	R-26	163.1 - 163.6	a ⊥	25	23	2	23	50	1462	9.9	6.8	0.89	6.0	122
B-STL-03	R-29	177.0 - 177.5	a ⊥	25	23	2	23	50	1462	13.7	9.4	0.89	8.3	169

a = axial

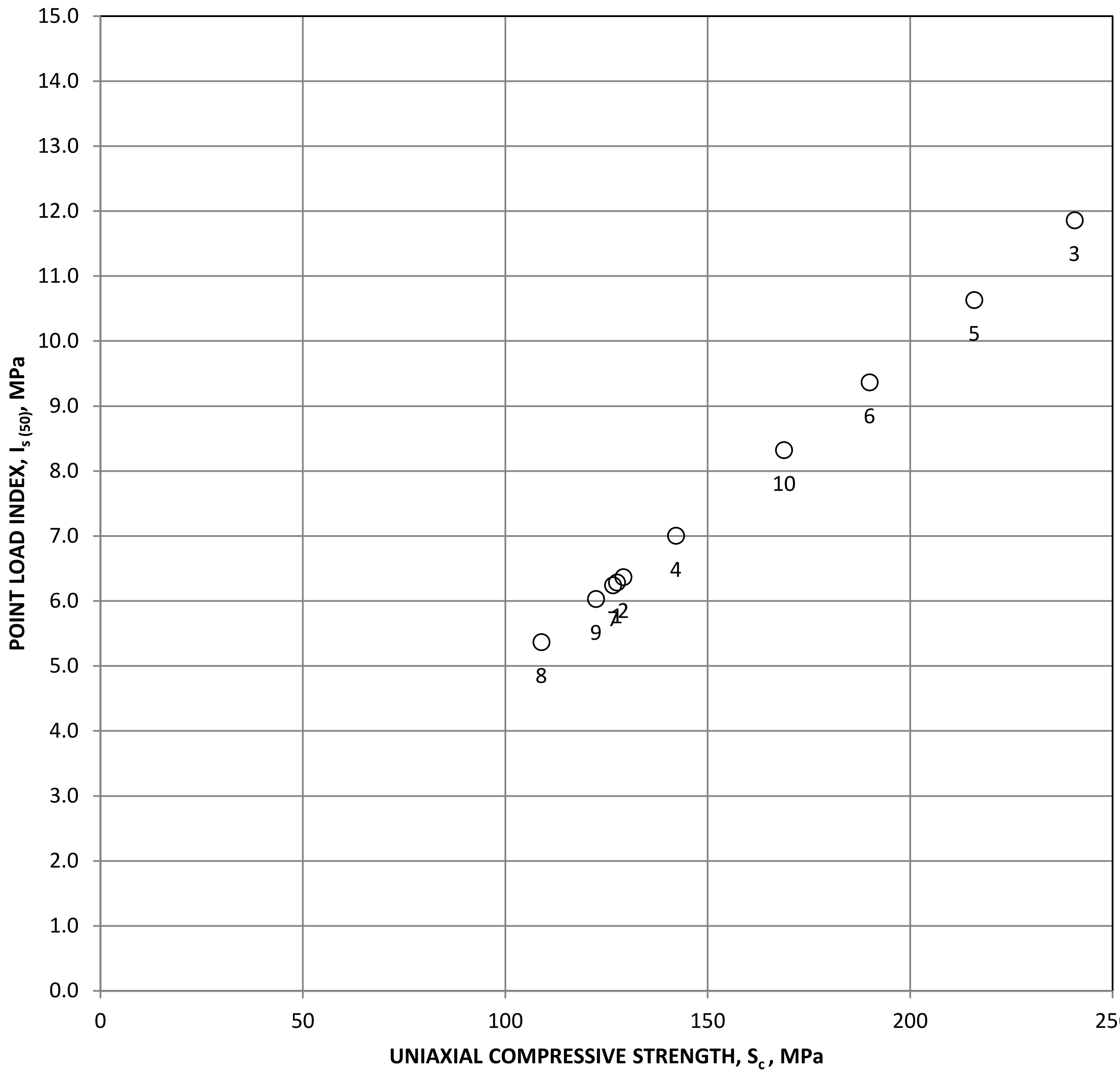
⊥ = perdendicular to rock core

* = 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 $I_{s(50)\ //}$	7.75
$Ia_{(50)}$	2.21

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-13	128	6.28	10	R-29	169	8.32
2	R-16	129	6.37				
3	R-18	241	11.86				
4	R-20	142	7.00				
5	R-24	216	10.63				
6	R-19	190	9.36				
7	R-22	127	6.24				
8	R-24	109	5.37				
9	R-26	122	6.03				

Spire Pipeline
St. Louis, Missouri

Point Load Test Results
Borings B-STL-01,03

March 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		Tested By / Date:	JAS	3/31/17
Location	St. Louis, Missouri		Calculated By / Date:	CMB	4/3/17
Job No.	41-1-37762-003		Checked By / Date:	CMB	4/3/17
File	41-1-37762-003 D5731		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-01	R-13	112.0 - 112.4	a ⊥	0.98	0.83	0.16	0.83	1.96	2.07	2169	1050	912	18504
B-STL-01	R-16	127.5 - 128.0	a ⊥	0.94	0.87	0.08	0.87	1.97	2.17	2281	1052	923	18736
B-STL-01	R-18	138.0 - 138.5	a ⊥	0.98	0.87	0.12	0.87	1.97	2.17	4248	1960	1720	34900
B-STL-01	R-20	148.6 - 149.1	a ⊥	0.98	0.94	0.04	0.94	1.97	2.36	2683	1135	1016	20616
B-STL-01	R-24	168.6 - 169.1	a ⊥	0.94	0.87	0.08	0.87	1.96	2.16	3801	1759	1542	31306
B-STL-03	R-19	127.0 - 127.5	a ⊥	0.94	0.87	0.08	0.87	1.97	2.17	3354	1548	1358	27552
B-STL-03	R-22	144.5 - 145.0	a ⊥	0.94	0.87	0.08	0.87	1.97	2.17	2236	1032	905	18368
B-STL-03	R-24	153.4 - 153.9	a ⊥	0.94	0.91	0.04	0.91	1.97	2.27	1990	878	778	15796
B-STL-03	R-26	163.1 - 163.6	a ⊥	0.98	0.91	0.08	0.91	1.97	2.27	2236	987	875	17748
B-STL-03	R-29	177.0 - 177.5	a ⊥	0.98	0.91	0.08	0.91	1.97	2.27	3086	1362	1207	24492

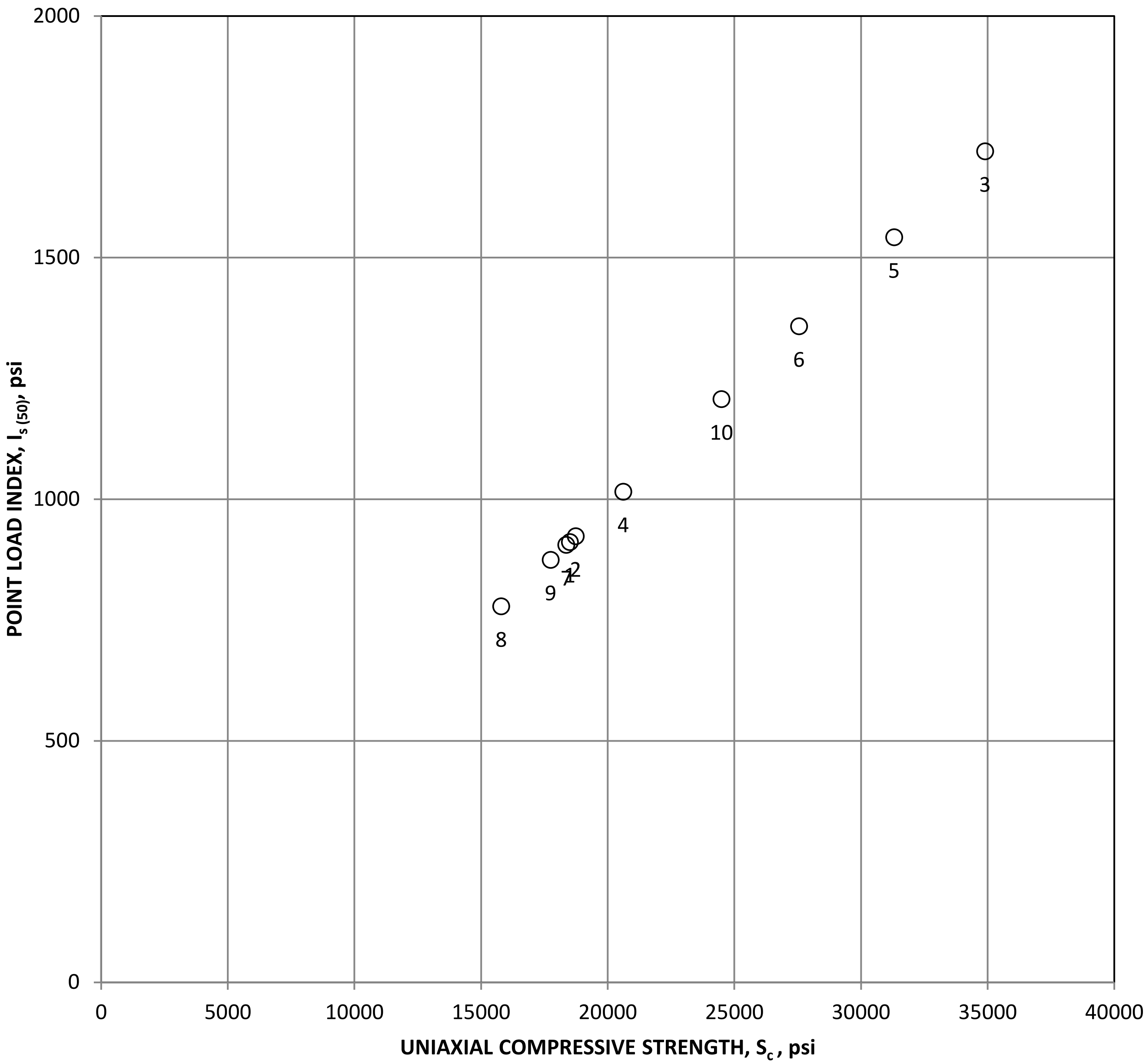
a = axial

⊥ = perdendicular to rock core

Moisture Content During Testing = Laboratory Air Dry

Statistics	
Mean $I_{s(2)\ //}$	1124
$I_{a(2)}$	2

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-13	18504	912	10	R-29	24492	1207
2	R-16	18736	923				
3	R-18	34900	1720				
4	R-20	20616	1016				
5	R-24	31306	1542				
6	R-19	27552	1358				
7	R-22	18368	905				
8	R-24	15796	778				
9	R-26	17748	875				

Spire Pipeline
St. Louis, Missouri

Point Load Test Results
Borings B-STL-01,03

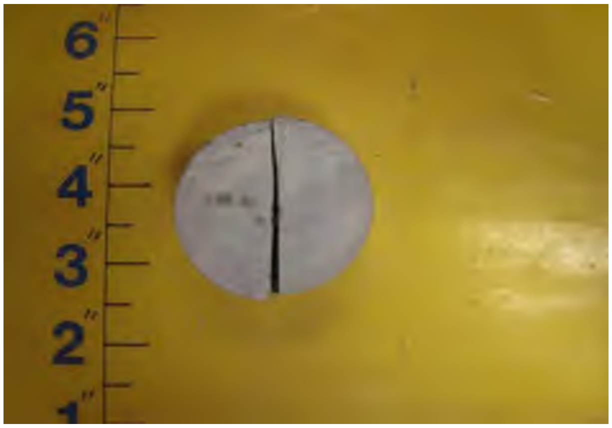
March 2017 41-1-37762-003

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

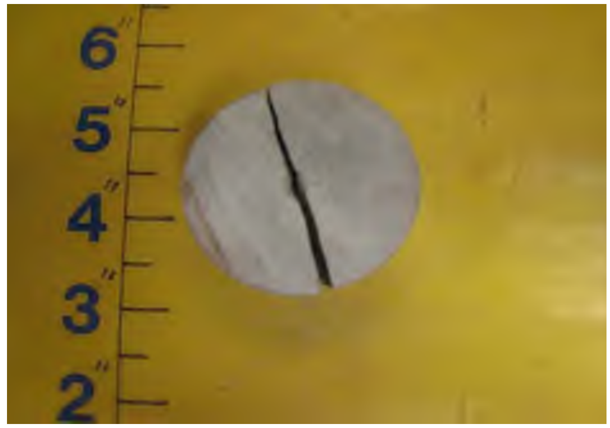
FIG.

Point Load Test Photographs

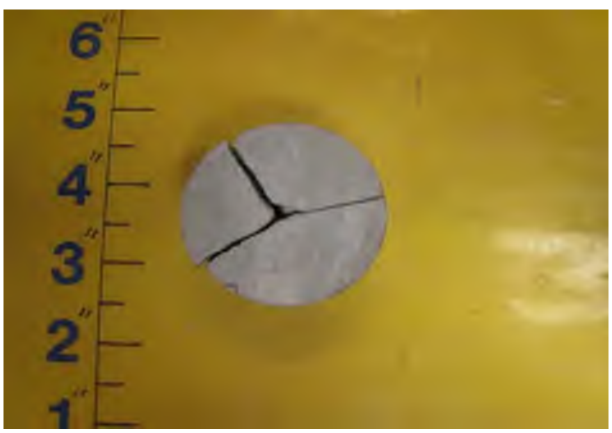
Project Spire Pipeline
Location St. Louis, Missouri
Job No. 41-1-37762-003



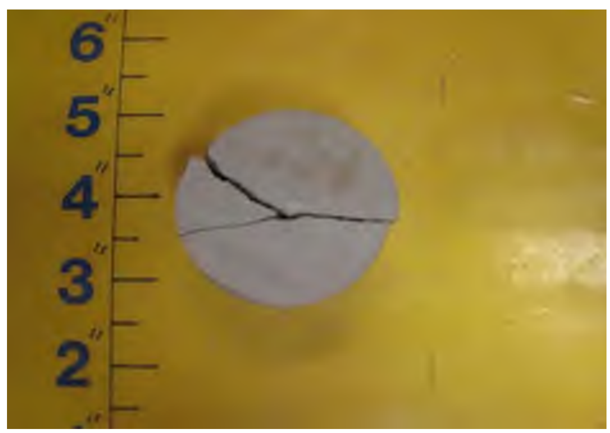
Boring Number B-STL-01
Run Number R-13
Depth (ft.) 112.0 - 112.4



Boring Number B-STL-01
Run Number R-16
Depth (ft.) 127.5 - 128.0



Boring Number B-STL-01
Run Number R-18
Depth (ft.) 138.0 - 138.5



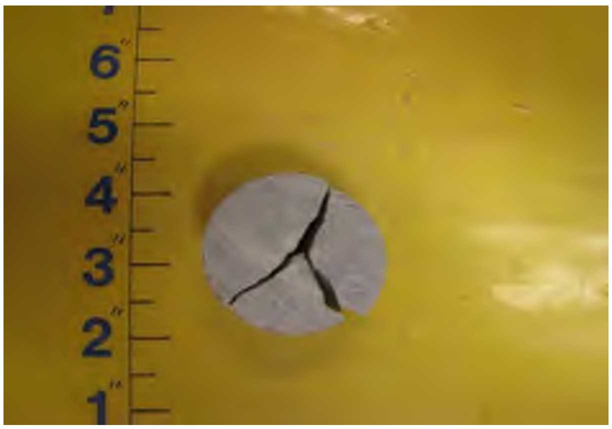
Boring Number B-STL-01
Run Number R-20
Depth (ft.) 148.6 - 149.1

Point Load Test Photographs

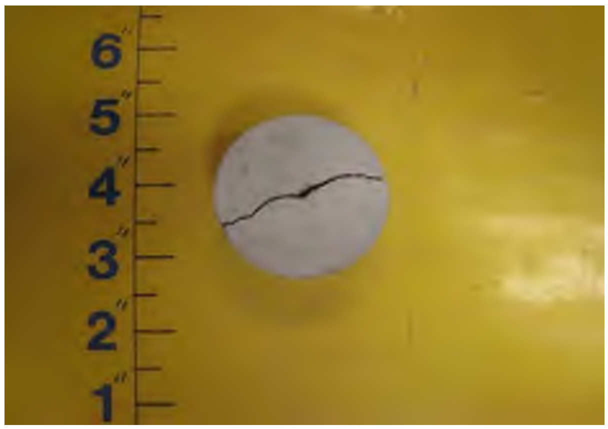
Project Spire Pipeline
Location St. Louis, Missouri
Job No. 41-1-37762-003

Boring Number B-STL-01
Run Number R-24
Depth (ft.) 168.6 - 169.1

Boring Number B-STL-03
Run Number R-19
Depth (ft.) 127.0 - 127.5



Boring Number B-STL-03
Run Number R-22
Depth (ft.) 144.5 - 145.0



Boring Number B-STL-03
Run Number R-24
Depth (ft.) 153.4 - 153.9

Point Load Test Photographs

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

Boring Number B-STL-03
Run Number R-26
Depth (ft.) 163.1 - 163.6

Boring Number B-STL-03
Run Number R-29
Depth (ft.) 177.0 - 177.5

Point Load Testing - Lab Worksheet
For Axial Tests

Project	Spire Pipeline		Tested By / Date:	TLC	8/7/17
Location	St. Louis, Missouri		Calculated By / Date:	CMB	8/8/17
Job No.	41-1-37762-003		Checked By / Date:	CMB	8/8/17
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-08	R-8	74.6 - 75.0	a ⊥	1.859	24	23	1100	7166
B-STL-08	R-15	107.2 - 107.7	a ⊥	1.858	25	23	1000	7167
B-STL-08	R-1	38.5 - 39.0	a ⊥	1.852	25	23	1200	7168
B-STL-08	R-5	58.5 - 59.0	a ⊥	1.855	25	23	1100	7169

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:	TLC	8/7/17
Calculated By / Date:	CMB	8/8/17
Checked By / Date:	CMB	8/8/17
Procedure	ASTM D5731	

				Penetration Data, mm										
Boring Number	Run Number	Depth (feet)	Test Type	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-08	R-8	74.6 - 75.0	a ⊥	24	23	1	23	47	1383	10.94	7.91	0.88	6.93	142
B-STL-08	R-15	107.2 - 107.7	a ⊥	25	23	2	23	47	1382	9.95	7.20	0.88	6.30	129
B-STL-08	R-1	38.5 - 39.0	a ⊥	25	23	2	23	47	1378	11.94	8.66	0.87	7.58	156
B-STL-08	R-5	58.5 - 59.0	a ⊥	25	23	2	23	47	1380	10.94	7.93	0.87	6.94	143

a = axial

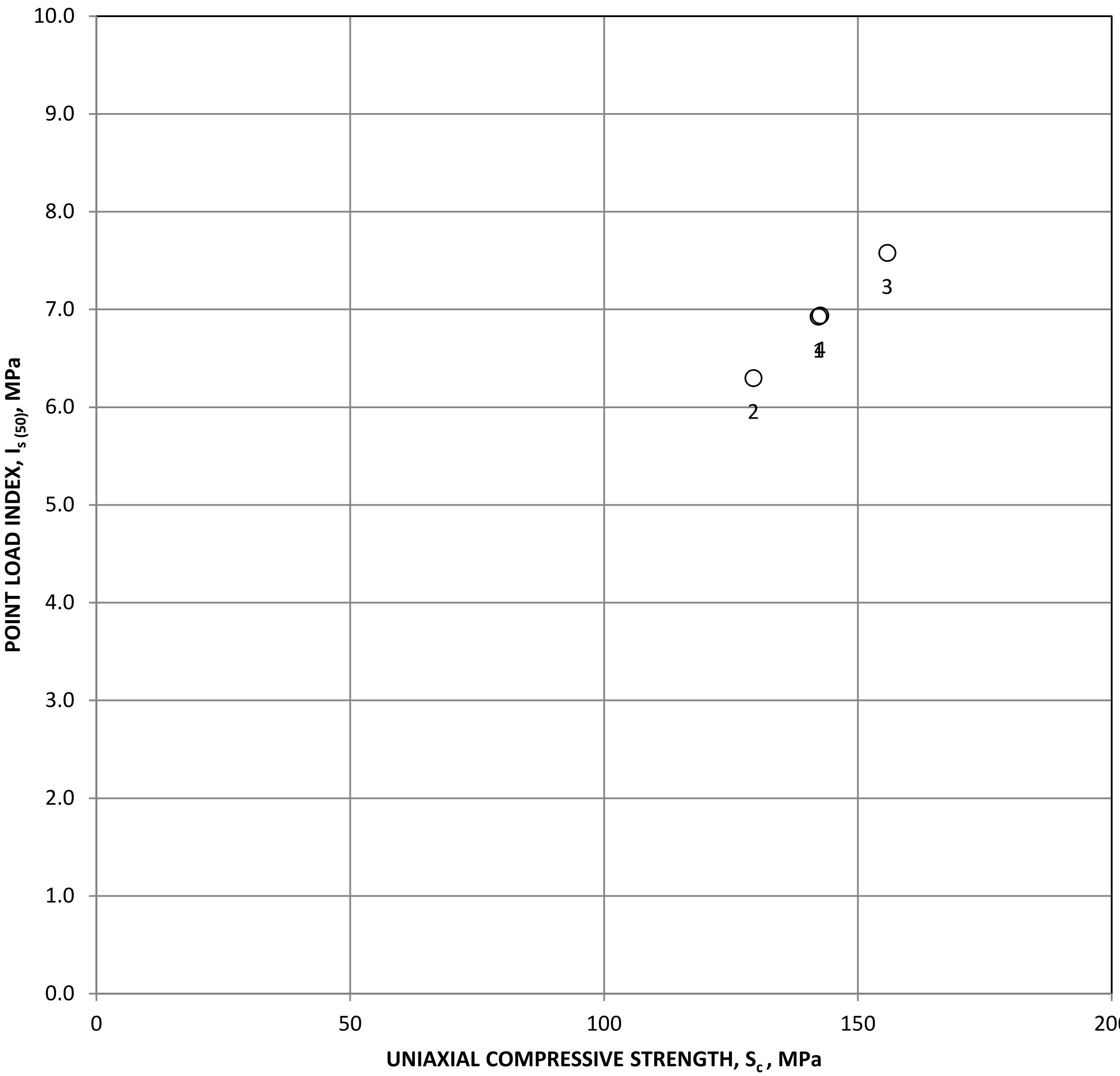
⊥ = perdendicular to rock core

* = 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 $I_{s(50)\ //}$	6.93
$Ia_{(50)}$	1.20

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-8	142	6.93				
2	R-15	129	6.30				
3	R-1	156	7.58				
4	R-5	143	6.94				

Spire Pipeline
St. Louis, Missouri

Point Load Test Results
Boring B-STL-08

August 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:	TLC	8/7/17
Calculated By / Date:	CMB	8/8/17
Checked By / Date:	CMB	8/8/17
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-08	R-8	74.6 - 75.0	a ⊥	0.94	0.91	0.04	0.91	1.86	2.14	2460	1148	1004	20636
B-STL-08	R-15	107.2 - 107.7	a ⊥	0.98	0.91	0.08	0.91	1.86	2.14	2236	1044	913	18770
B-STL-08	R-1	38.5 - 39.0	a ⊥	0.98	0.91	0.08	0.91	1.85	2.14	2683	1257	1099	22597
B-STL-08	R-5	58.5 - 59.0	a ⊥	0.98	0.91	0.08	0.91	1.86	2.14	2460	1150	1006	20681

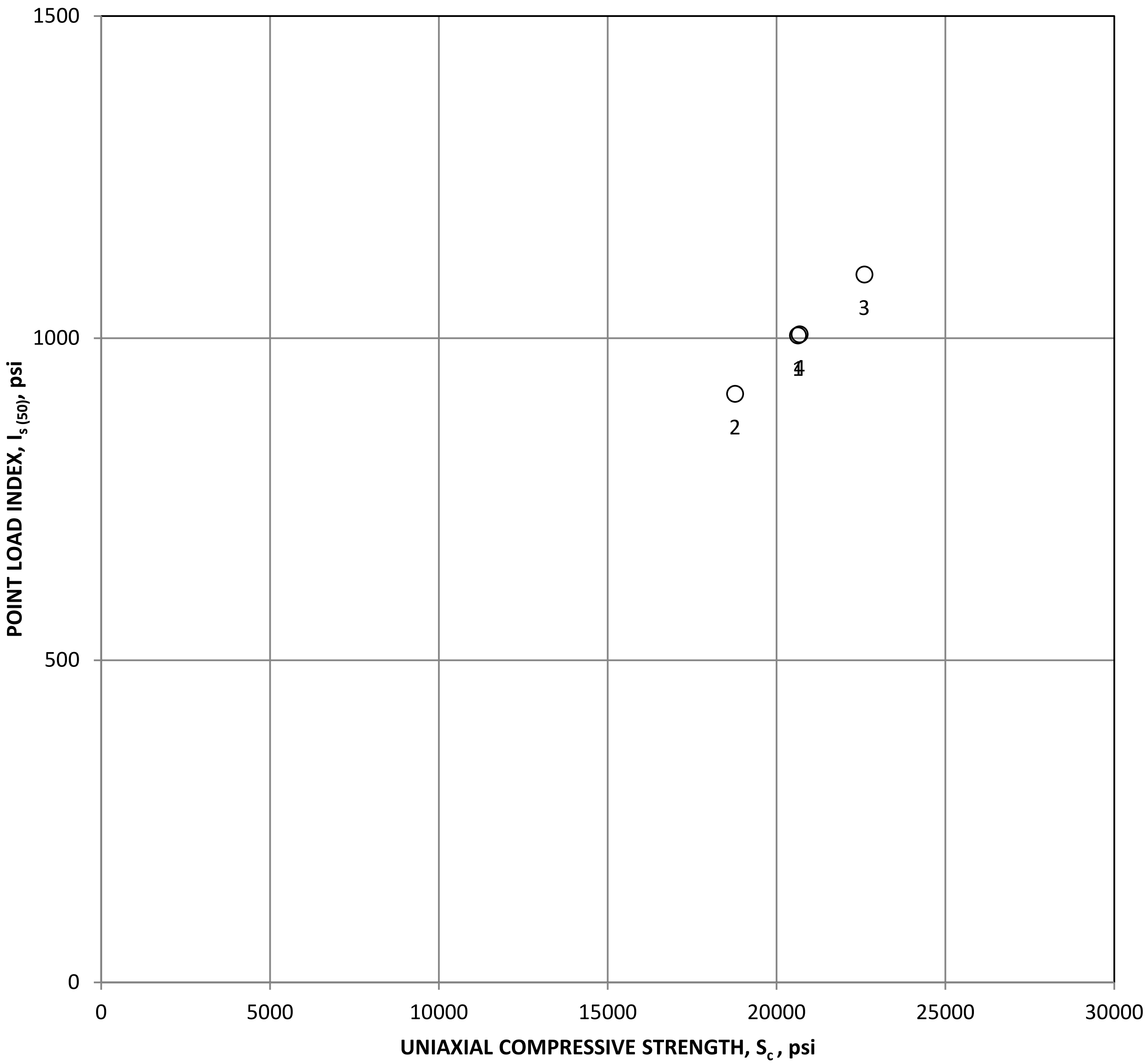
a = axial

⊥ = perdendicular to rock core

Moisture Content During Testing = Laboratory Air Dry

Statistics	
Mean $I_{s(2)\,//}$	1006
$I_{a(2)}$	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-8	20636	1004				
2	R-15	18770	913				
3	R-1	22597	1099				
4	R-5	20681	1006				

Spire Pipeline
St. Louis, Missouri

Point Load Test Results
Boring B-STL-08

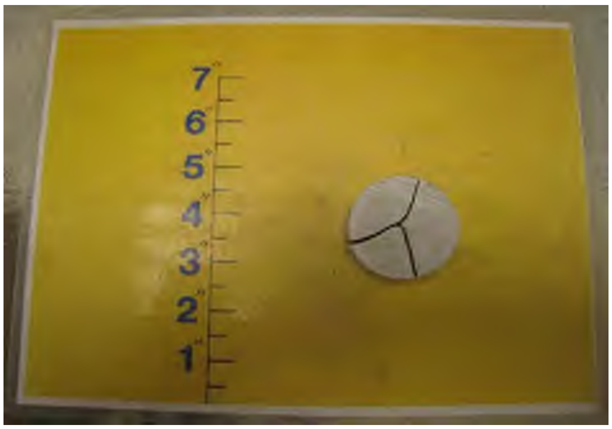
August 2017 41-1-37762-003

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

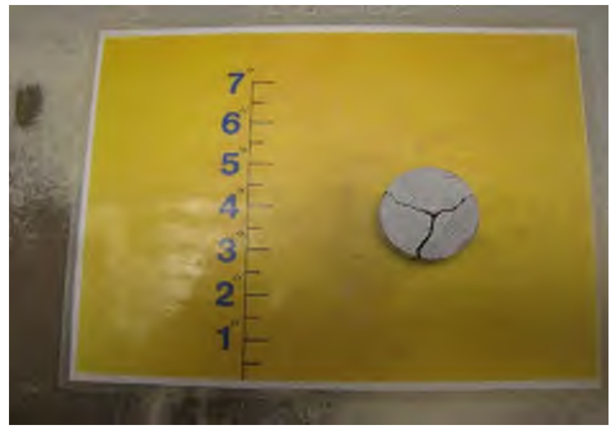
FIG.

Point Load Test Photographs

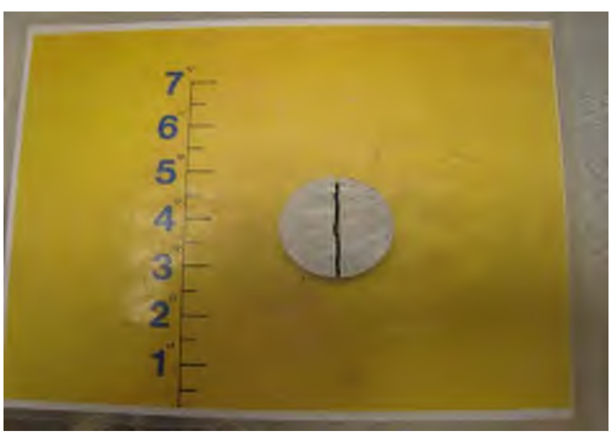
Project Spire Pipeline
Location St. Louis, Missouri
Job No. 41-1-37762-003



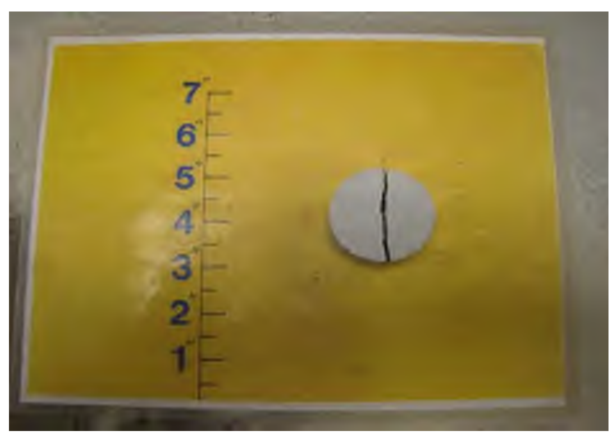
Boring Number B-STL-08
Run Number R-8
Depth (ft.) 74.6 - 75.0



Boring Number B-STL-08
Run Number R-15
Depth (ft.) 107.2 - 107.7



Boring Number B-STL-08
Run Number R-1
Depth (ft.) 38.5 - 39.0



Boring Number B-STL-08
Run Number R-5
Depth (ft.) 58.5 - 59.0

TSI geotechnical, inc.

VISUAL (ASTM D2487) AND MOISTURE CONTENT (ASTM D2216) DATA SHEET

Project Name: Spire STL Pipeline

Project Number: 20161229

Project Engineer: ______________

Boring Number: B-STL-08	Sample Number: S-2	Depth: 2.0-4.0	
VISUAL CLASSIFICATION		**MOISTURE CONTENT, %**	
Color, Soil Description, (USCS Class.), other materials		Tare Number	ELZ
		Wet Weight + Tare, grams	20.90
		Dry Weight + Tare, grams	16.68
RIMAC- Dial Reading:	Strain:	Tare Weight, grams	.82
Hand Penetrometer / Torvane, tsf		Moisture Content, %	26.6 %

Boring Number: B-STL-08	Sample Number:	Depth:	
VISUAL CLASSIFICATION		**MOISTURE CONTENT, %**	
Color, Soil Description, (USCS Class.), other materials		Tare Number	
		Wet Weight + Tare, grams	
		Dry Weight + Tare, grams	
RIMAC- Dial Reading:	Strain:	Tare Weight, grams	
Hand Penetrometer / Torvane, tsf		Moisture Content, %	

Boring Number: B-STL-08	Sample Number:	Depth:	
VISUAL CLASSIFICATION		**MOISTURE CONTENT, %**	
Color, Soil Description, (USCS Class.), other materials		Tare Number	
		Wet Weight + Tare, grams	
		Dry Weight + Tare, grams	
RIMAC- Dial Reading:	Strain:	Tare Weight, grams	
Hand Penetrometer / Torvane, tsf		Moisture Content, %	

Boring Number: B-STL-08	Sample Number:	Depth:	
VISUAL CLASSIFICATION		**MOISTURE CONTENT, %**	
Color, Soil Description, (USCS Class.), other materials		Tare Number	
		Wet Weight + Tare, grams	
		Dry Weight + Tare, grams	
RIMAC- Dial Reading:	Strain:	Tare Weight, grams	
Hand Penetrometer / Torvane, tsf		Moisture Content, %	

Boring Number:	Sample Number:	Depth:	
VISUAL CLASSIFICATION		**MOISTURE CONTENT, %**	
Color, Soil Description, (USCS Class.), other materials		Tare Number	
		Wet Weight + Tare, grams	
		Dry Weight + Tare, grams	
RIMAC- Dial Reading:	Strain:	Tare Weight, grams	
Hand Penetrometer / Torvane, tsf		Moisture Content, %	

Soil Description: modifier then main soil (fat CLAY, silty SAND). If two distinct materials nearly equal in quantity are encountered use "and" (fat CLAY and LIMESTONE pieces). If coarse grained material note grain size (fine SAND).

Other Materials: Trace: < 15%; With: 15 to 30%; Modifier: > 30% (sandy lean CLAY). Note thickness of any layers, seams, changes in color, gravel/limestone pieces, etc. If old fill material, look for brick, stone, concrete, wood, etc, describe then state as (FILL).

Tested By: AST Date: 7/31/17

Calculated By: ASE Date: 8/1/17

Checked By: SLY Date: 8/3/17

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LIQUID AND PLASTIC LIMITS (ASTM D4318) 79

engineering, inc.

Project Name: Spire STL Pipeline
Project Number: 20161229 Project Engineer:
Boring Number: B-STL-08 Sample Number: S-5 Depth: 8'-10'
Visual Classification: Brown lean Clay (CL-ML) more silty

Sample Preparation	Natural State	Mixed and Cured for:	Passed through No. 40 Sieve
	☐ Air Dried ☐ Oven Dried	☐ Overnight ☐ Other________	☐ No ☐ Yes ☐ Other________

NATURAL MOISTURE CONTENT

Tare Number		
Weight of Wet Soil + Tare, grams		
Weight of Dry Soil + Tare, grams		
Weight of Water, grams		
Weight of Tare, grams		
Dry Weight of Soil, grams		
MOISTURE CONTENT, %		

PLASTIC LIMIT

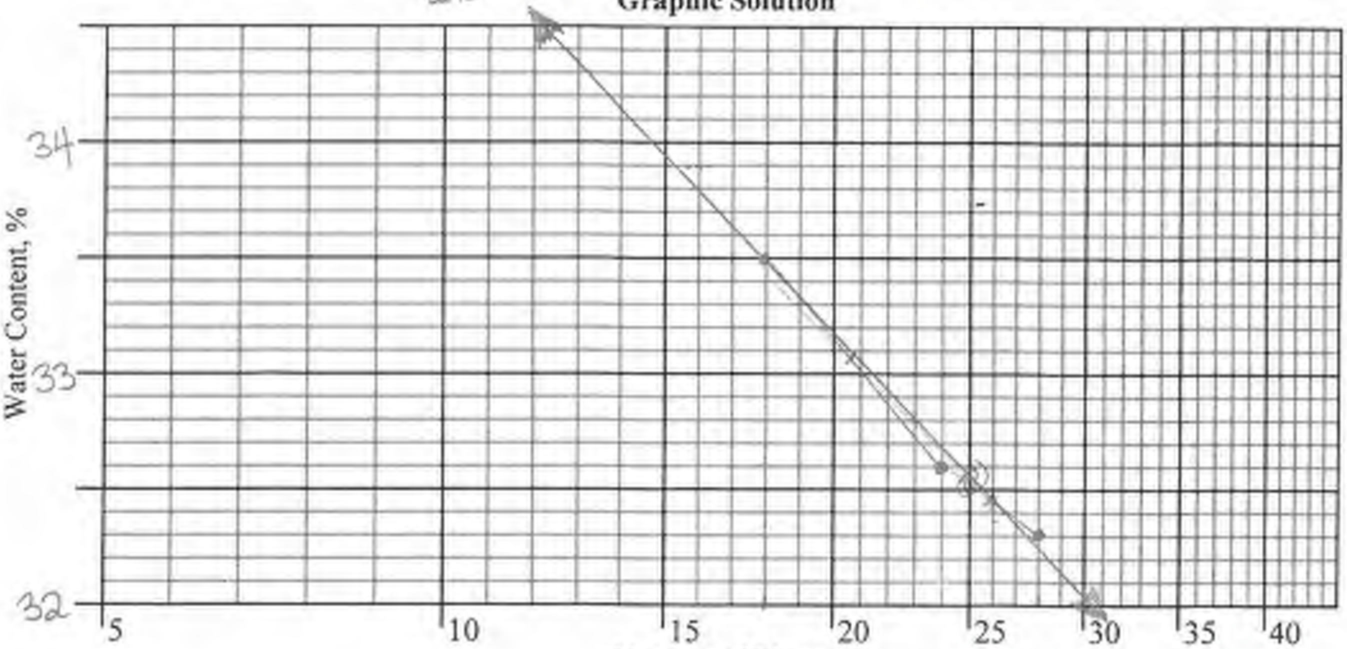
DK3	BO4	
6.43	6.18	
5.26	5.06	
.73	.75	
25.8 ✓	26.0 ✓	
Average Plastic Limit, %		26

LIQUID LIMIT

Determination (Number of Blows)	1 (15 - 25)	2 (20 - 30)	3 (25 - 35)		
Tare Number	C05	M04	QM2		
Weight of Wet Soil + Tare, grams	12.63	12.62	13.84		
Weight of Dry Soil + Tare, grams	9.66	9.70	10.64		
Weight of Water, grams					
Weight of Tare, grams	.79	.74	.72		
Dry Weight of Soil, grams					
MOISTURE CONTENT, %	33.5 ✓	32.6 ✓	32.3 ✓		
Number of Blows	18	24	28		
Liquid Limit, %	33 ✓	Plasticity Index	7 ✓	USCS Class.	ML-CL ✓

32.5

Graphic Solution



Comments: ______________________

Tested By: AdJ Date: 7-31-17
Calculated By: KSF Date: 8-1-17
Checked By: SLY Date: 8/3/17

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TSi Engineering, Inc.
HYDROMETER ANALYSIS (ASTM D422)

Project Name: Spire
Boring Number: B-SU-1B
Sample Number: S-2
Sample Depth: 2.0-4.0
Visual Description: Brown lean CLAY (CL),

Project Number:
Tested by:
Calculated by:
Checked by:

Coarse Analysis

Initial Air Dry Mass: 66.55 grams

Sieve	Particle Size, mm	Cummulative Mass Retained, grams	Percent Retained	Percent Passing
1"	25.40	0	0	100
1/2"	12.70	0	↓	↓
3/8"	9.53	0	↓	↓
No.4	4.75	0	↓	↓
No.10	2.00	0	↓	↓
Pan		66.55		

Fine Analysis

71 HB

Initial Air Dry Mass: 66.55 grams

89.57g wet 90

85.32

Sieve	Particle Size, mm	Cummulative Mass Retained, grams	Percent Retained	Percent Passing
No.20	0.85	0.05		
No.40	0.43	0.07		
No.60	0.25	0.11		
No.100	0.15	0.21		
No.200	0.08	0.33	=	
Pan		0.34		

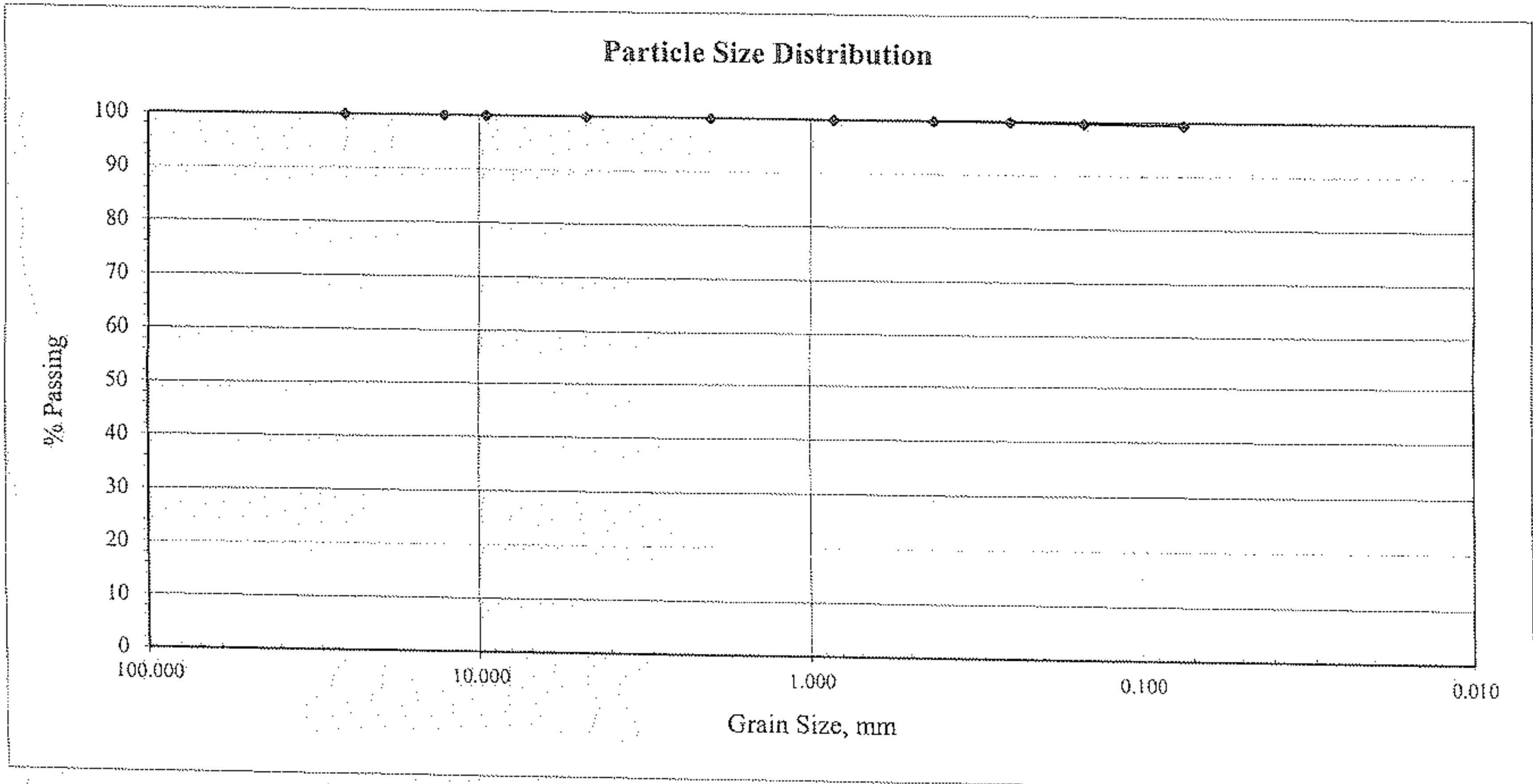
Hydrometer analysis

Specific Gravity		Hydrometer Reading		Combined Correction:			
Constant, a				Hygroscopic Corrected Mass, g.			
Elapsed Time minutes	Temperature °C	Uncorrected, Ra	Corrected, Rc	Effective Depth, L cm	Constant K	Particle Size mm	Percent Passing
2	22.8	48-4.0	44				
5	22.7	39-4.1	34.9				
15	22.7	29-4.1	24.9				
30	22.7	25-4.1	20.9				
60	22.5	22-4.0	18				
3:18 120	22.9	20-4.0	16				
3:.. 240	22.[illegible]	19-3.8	15.2				
7:30 480	24.1	16-3.6	12.4				
1440	21.6	15-4.5	10.5				

Hygroscopic Moisture Correction
Air Dry Mass + Tare:
Oven Dry Mass + Tare:
Tare:
Correction Factor:

TSi Geotechnical, Inc.
HYDROMETER ANALYSIS (ASTM D422)

Project Name:	Spire Pipeline	**Project Number:**	20161229.00
Boring Number:	B-STL-08	**Tested by:**	SLY - 08-02-17
Sample Number:	S-2	**Calculated by:**	SLY - 08-04-17
Sample Depth:	2.0-4.0	**Checked by:**	
Visual Description:	Brown, lean CLAY (CL)		



TSi Geotechnical, Inc.
HYDROMETER ANALYSIS (ASTM D422)

Project Name: Spire Pipeline
Boring Number: B-STL-08
Sample Number: S-2
Sample Depth: 2.0-4.0
Visual Description: Brown, lean CLAY (CL)

Project Number: 20161229.00
Tested by: SLY - 08-03-17
Calculated by: SLY - 08-04-17
Checked by:

Coarse Analysis

Initial Air Dry Mass: 66.55 grams

Sieve	Particle Size, mm	Cummulative Mass Retained, grams	Percent Retained	Percent Passing
1"	25.40	0	0.00	100
1/2"	12.70	0	0.00	100
3/8"	9.53	0	0.00	100
No.4	4.75	0	0.00	100
No.10	2.00	0	0.00	100
Pan		66.55		

Fine Analysis

Initial Air Dry Mass: 66.55 grams

Sieve	Particle Size, mm	Cummulative Mass Retained, grams	Percent Retained	Percent Passing
No.20	0.85	0.05	0.08	100
No.40	0.43	0.07	0.93	100
No.60	0.25	0.11	0.06	100
No.100	0.15	0.21	0.15	100
No.200	0.08	0.33	0.18	100
Pan				

Hydrometer analysis

Specific Gravity	2.70	Hydrometer Reading						
Constant, a	0.99				Hygroscopic Corrected Mass, g.		66.55	
Elapsed Time minutes	Temp. °C	Uncorrected, Ra	Combined Defloc and Temp. Correction Factor	Corrected, Rc	Effective Depth, L cm	Constant K	Particle Size mm	Percent Passing
2	22.8	48.0	4.0	44.0	9.1	0.01300	0.0277	65
5	22.7	39.0	4.1	34.9	10.7	0.01302	0.0190	52
15	22.7	29.0	4.1	24.9	12.4	0.01302	0.0118	37
30	22.7	25.0	4.1	20.9	13.0	0.01302	0.0086	31
60	22.8	22.0	4.0	18.0	13.3	0.01300	0.0061	27
120	22.9	20.0	4.0	16.0	13.7	0.01299	0.0044	24
240	23.3	19.0	3.8	15.2	13.8	0.01293	0.0031	23
480	24.1	16.0	3.6	12.4	14.3	0.01281	0.0022	18
1440	21.6	15.0	4.5	10.5	14.7	0.01318	0.0013	16

Hygroscopic Moisture Correction	
Air Dry Mass + Tare:	15
Oven Dry Mass + Tare:	15
Tare:	0.75
Correction Factor:	1

TSi Geotechnical, Inc.
HYDROMETER ANALYSIS (ASTM D422)

Project Name: Spire Pipeline
Project Number: 20161229.00
Boring Number: B-STL-08
Tested by: SLY - 08-02-17
Sample Number: S-2
Calculated by: SLY - 08-04-17
Sample Depth: 2.0-4.0
Checked by: CAV 1-29-13
Visual Description: Brown, lean CLAY (CL)

Sieve	Particle Size, mm	Percent Finer
1"	25.40	100
1/2"	12.70	100
3/8"	9.53	100
No.4	4.75	100
No.10	2.00	100
No.20	0.85	100
No.40	0.425	100
No.60	0.250	100
No.100	0.150	100
No.200	0.075	100
Hydrometer Analysis	0.0277	65
	0.0190	52
	0.0118	37
	0.0086	31
	0.0061	27
	0.0044	24
	0.0031	23
	0.0022	18
	0.0013	16

Particle Size Description
Unified Soil Classification System

Particle	Size Range, mm	Percent of Specimen
Gravel	4.75 to 76.4	0
Coarse Sand	2.00 to 4.75	0
Medium Sand	0.43 to 2.00	0
Fine Sand	0.075 to 0.43	0
Silt	0.005 to 0.075	75
Clay	<0.005	25