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GEOTECHNICAL REPORT

# Horseshoe Bend Landslide
# 7-085(110)127, PCN 22304

MCKENZIE COUNTY, ND

February 2020

Shannon & Wilson No: 102116

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Submitted To: North Dakota Department of Transportation
608 East Boulevard Avenue
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Attn: Mr. Colter Schwagler

Subject: GEOTECHNICAL REPORT, HORSESHOE BEND LANDSLIDE
7-085(110)127, PCN 22304, MCKENZIE COUNTY, ND

Shannon & Wilson prepared this report and participated in this project as a consultant to the North Dakota Department of Transportation (NDDOT). Our scope of services was specified in Contract Number 19190118 with the NDDOT dated April 24, 2019. This report presents our interpretation of subsurface conditions and recommendations for measures to mitigate landslide activity at the site and was prepared by the undersigned.

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

Sincerely,

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# 1 INTRODUCTION

This report presents our geologic and geotechnical characterization of the Horseshoe Bend (HSB) landslide (the HSB landslide), which is affecting US Highway 85 (US-85) between approximately Reference Points (RP) 127.7 and 128.0 in McKenzie County, North Dakota. The report summarizes existing data provided by the North Dakota Department of Transportation (NDDOT) and data obtained by Shannon & Wilson for the current study and prior studies along the US-85 corridor.

# 2 PROJECT DESCRIPTION

The HSB portion of the US-85 alignment is located approximately 1¼ miles north of the Little Missouri River (see Figure 1). Multiple landslides, which coalesce into a large landslide complex, have been mapped in this area. Landslide activity has affected the roadway at HSB since at least the 1970s, resulting in two roadway realignments. The first realignment occurred in the 1980s and involved eliminating a hairpin alignment east of the current alignment (see Exhibit 2-1). In 2011, significant landslide movement occurred adjacent to the roadway (see Exhibit 2-2). As a result, NDDOT realigned the roadway further to the east. Since realigning the roadway, landslide movement has continued as indicated by pavement distress and inclinometer monitoring, requiring regular maintenance and repaving at the area of distress noted in Exhibit 2-1.

Smaller scale landslide activity has also been observed on a slope immediately above the north side of the roadway (see Exhibits 2-1 and 2-3) and in a cut slope on the east side of the roadway (see Exhibits 2-1 and 2-4). Landslide activity in the north slope has resulted in debris flows reaching the roadway ditch, negatively impacting drainage and requiring maintenance to remove debris and maintain drainage. The east cut slope failure has created similar maintenance issues.

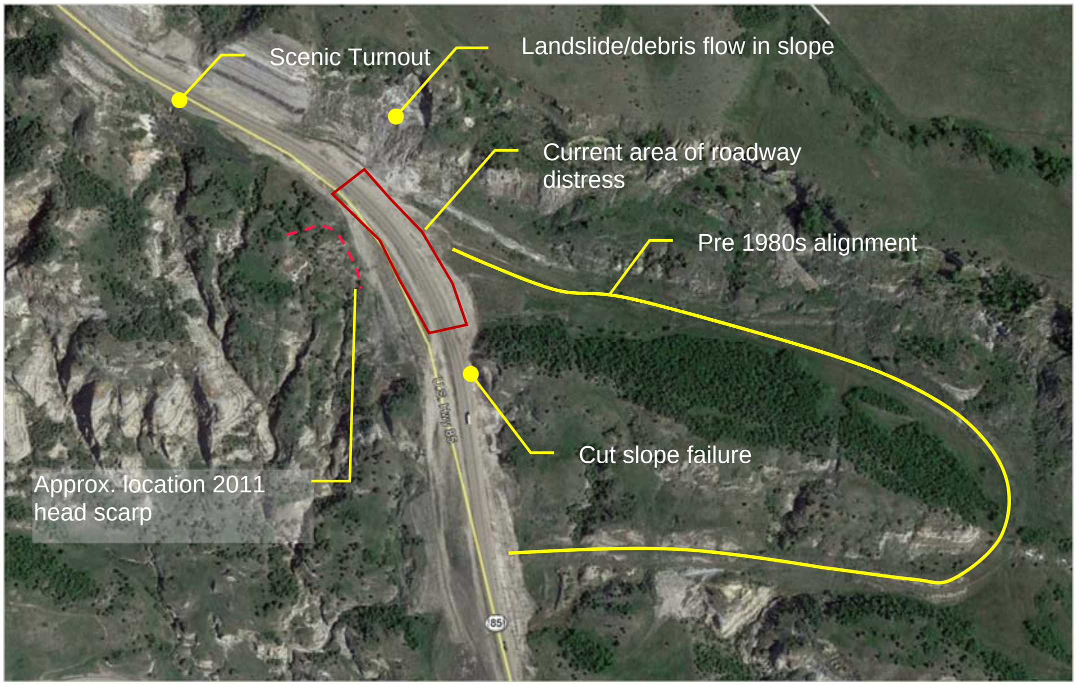


Exhibit 2-1: Horseshoe Bend Area (Image Courtsey of Google Earth Pro)

Exhibit 2-2: Head Scarp of Landslide in 2011; View Northwest (Image Courtsey of North Dakota Department of Transportation)

Exhibit 2-3: Landslide in Slope Above Area of Roadway Distress; View North

Exhibit 2-4: Cut Slope Failure on East Side of the Roadway; View Southeast

The purpose of this geotechnical study is to characterize the landslide(s) affecting the US-85 roadway at the locations shown in Exhibit 2-1, which NDDOT intends to stabilize. Advanced Differential Interferometric Synthetic Aperture Radar (A-DInSAR) data suggests a potentially active larger landslide complex, which is beyond the scope of our work and likely not feasible to stabilize given the constraints of the proposed project.

# 3 PREVIOUS STUDIES AND DATA

## 3.1 Data from North Dakota Department of Transportation

Following the landslide at the study area in April 2011, the NDDOT advanced three borings, designated HSB-1 through HSB-3, at the site. Borings HSB-1 and HSB-2 were completed with inclinometer casing. In October 2011, NDDOT advanced an additional boring (HSB-4) and completed the borehole with inclinometer casing. The locations of these borings are shown in Figure 2, and a summary of the completed explorations is provided in Table 1. Boring logs and laboratory test results provided by the NDDOT for these borings are included in Appendix C. Data from inclinometers HSB-1, HSB-2, and HSB-4 are provided in Appendix E and summarized in Table 2.

## 3.2 Previous Shannon & Wilson Studies

Shannon & Wilson previously completed geotechnical studies to support the environmental evaluation and preliminary design of widening US-85 (NDDOT Project 9-085(085)075, PCN 20046). This work included an evaluation of the landside and conceptual-level evaluation of mitigation options. Relevant reports prepared as part of these previous studies are listed below.

- Geotechnical Data Report (GDR) (Shannon & Wilson, Inc. 2016a)
- Subsurface Characterization Report (SCR) (Shannon & Wilson, Inc. 2016b)
- Technical Memorandum TM-2, Revision 1, Preliminary Cut and Fill Slope Recommendations (TM-2) (Shannon & Wilson, Inc. 2017a)
- Technical Memorandum TM-5, Horseshoe Bend Landslide Mitigation Considerations (TM-5) (Shannon & Wilson, Inc. 2017b)
- Technical Memorandum TM-5 Addendum (A1TM-5) (Shannon & Wilson, Inc. 2017c)
- Geotechnical Data Report Addendum (A1GDR) (Shannon & Wilson, Inc. 2017d)
- Subsurface Characterization Report Addendum (A1SCR) (Shannon & Wilson, Inc. 2017e)

As part of the above studies, we completed numerous explorations near the HSB area. These explorations are summarized in Table 1 and provided in Appendix D (including associated laboratory test results). The boring locations are shown on Figures 2 and 4. As indicated in Table 1, several explorations were completed with instrumentation, which included inclinometers to measure slope movement, vibrating wire piezometers (VWPs) to measure groundwater pressures, and Sondex extensometers to measure settlement. Data collected from these instruments are also provided in Appendix D. Figures 2 and 4 show the locations of the inclinometers and arrows denoting the direction of movement indicated by each inclinometer.

The recommendations and analyses provided herein supersede those provided in the prior reports by Shannon & Wilson.

# 4 CURRENT EXPLORATIONS, INSTRUMENTATION, AND REMOTE SENSING

## 4.1 Field Explorations and Instrumentation

Shannon & Wilson completed six additional explorations in June and August 2019, to characterize subsurface conditions at the site. The locations of the explorations are shown in Figure 4. Appendix A presents a discussion of the drilling and sampling procedures used in completing these borings. Appendix A also presents individual exploration logs and an explanation of the symbols and terminology used on the logs.

As noted in Table 1, inclinometers and VWPs were installed in selected borings to characterize landslide movement and groundwater conditions. Data from the inclinometers are provided in Appendix A and summarized in Table 2. Figures 2 and 4 show the locations of the inclinometers and arrows denoting the direction of movement indicated by each inclinometer.

## 4.2 Remote Sensing

Shannon & Wilson retained Natural Hazards Control and Assessments, S.R.L. (NHAZCA) of Rome, Italy to complete a remote sensing study of the project area using A-DInSAR. The purpose of the study was to characterize the direction and extent of landslide movement at and adjacent to the project area. A-DInSAR uses satellite-based radar to evaluate ground movement.

Interpretations of the data by NHAZCA indicate a landslide boundary based on horizontal movement greater than 1 inch per year (Appendix F). The hypothesized limits of the landslide boundary are presented on Figure 3 and are comparable to our mapped area for the potential deep landslide described in Section 5.8. A westward trend with constant velocities throughout the central portion of the landslide mass was detected. It was not possible to evaluate the northern and southern component of landslide movement in this study due to limitations in the ability to detect movement towards and away from the satellite. A report summarizing NHAZCA's study, including a detailed description of their methods and findings, is included in Appendix E.

# 5 SITE GEOLOGY AND SUBSURFACE CONDITIONS

## 5.1 Regional Geology

We reviewed geologic mapping of the Long X Divide Quadrangle, which includes the project site and vicinity, by Murphy and Gonzalez (2003). The map indicates that the project area generally consists of several Quaternary landslides that coalesce into a single large landslide complex. Deposits of Quaternary-age alluvium and colluvium are mapped south of the site, near the Little Missouri River. Bedrock of the Sentinel Butte formation, which is Tertiary in age, is mapped north and west of the project area.

## 5.2 Landslide Movement and Roadway Distress

Landslide movement has been affecting the HSB area since at least the 1970s. Based on records provided by NDDOT, the original roadway alignment was affected by landslide movement on the northside of the switchback in the 1970s. As a result of this movement, the roadway was realigned near its current location in the early 1980s. However, significant landslide movement occurred in 2011, affecting the roadway and resulting in NDDOT realigning the roadway further east to its current location.

Based on photographs and information provided by NDDOT, the 2011 landslide resulted in a significant head scarp that encompassed part of the roadway pavement (see Exhibits 2-1 and 2-2). Following the failure, NDDOT completed repairs that consisted of regrading the area, including flattening embankment slopes to about 3 horizontal to 1 vertical (3H:1V), replacing cross drains, and shifting the roadway alignment to the east by a maximum of about 120 feet.

Since the 2011 realignment, roadway distress has continued to occur. The two main locations of distress are indicated in Figure 3 (see Exhibit 5-1 for details of the distress).

Movement is occurring at these areas, resulting in bumps in the road that require regular maintenance and repaving. Secondary areas of roadway distress are occurring south of the areas of primary distress, as shown in Figure 3. However, we understand that distress at these areas is less significant and requires less frequent maintenance. As such, NDDOT does not currently intend to mitigate distress at the secondary areas.

Exhibit 5-1: Two Primary Locations of Pavement Distress. Left, Approx. Sta 6742+00 (View East), Right, Approx. Sta 6737+00 (View South)

## 5.3 Reconnaissance

In addition to initial field reconnaissance completed in November of 2014 and 2015, Shannon & Wilson personnel conducted a focused reconnaissance in the project area in March and April of 2017. The effort was split into two areas, one on the west side of US Highway 85 and the other on the east side. The purpose was to identify areas of landslide movement compared to areas of “intact” or presumed in-place bedrock, and to identify other indicators of slope instability, such as seepage, ponded water, roadway distress, landslide scarps and other notable features. An abundance of scarps, wet and hummocky ground, and discontinuous upended bedding were observed both west and east of the existing highway in the project area.

## 5.4 Soil and Rock Units

This section presents a discussion of the geologic units that we characterized in this study. These units and their descriptions supersede those presented in prior studies. We did not recharacterize prior boring logs (Appendix D) to reflect the current units and descriptions.

### 5.4.1 Fill

Fill materials associated with the existing US-85 roadway embankment were encountered in several borings. Fill consisted of stiff to hard (generally stiff to very stiff), lean to fat clay with sand, bedrock fragments and carbonaceous fragments. The fill had a maximum thickness of about 70 feet in boring RP-127-01 (see Appendix D).

### 5.4.2 Landslide Debris

For the purpose of this report, we defined landslide debris as overburden surficial soil deposits or bedrock of the Tertiary Sentinel Butte Formation that have moved as part of a landslide and do not exhibit significant bedrock structure. Surficial landslides and debris flows were generally shallow failures through the soil and/or weathered bedrock. The deeper-seated landslide deposits consisted of both soil and displaced bedrock.

Landslide debris consisted of medium stiff to hard, yellow-brown, brown, and gray, fat to lean clay with varying amounts of sand. Overall thickness of the landslide debris, as indicated in the borings, ranged from 11 feet to 21 feet. Landslide debris overlies displaced bedrock, which tends to be much thicker, and potentially displaced bedrock.

### 5.4.3 Displaced Bedrock

For the purpose of this report, we defined displaced bedrock (displaced Sentinel Butte Formation) as deposits with bedrock structure where direct visual evidence from a boring or inclinometer monitoring data indicated that the material has moved in the past. With respect to visual observation of rock samples, we considered the presence of tilted bedding to be indicative of prior landslide activity but not necessarily active movement. However, the absence of tilted bedding by itself was not a reliable indicator of intact bedrock (material that has not experienced prior landslide movement) because translational failures could result in landslide movement without significant rotation. Therefore, we also designated deposits as displaced bedrock when movement was observed in inclinometer data.

Displaced bedrock was characterized by extremely weak to very weak, slightly weathered to fresh claystone, siltstone, sandstone, and coal. These deposits were up to 80 feet thick with laminated bedding that was frequently observed dipping approximately 10 to

90 degrees. Deposits with massive structure or laminated bedding that was observed to be horizontal were also designated as displaced bedrock if tilted bedding was observed below these units.

### 5.4.4 Potentially Displaced Bedrock

For the purpose of this report, we defined potentially displaced bedrock (potentially displaced Sentinel Butte Formation) as material with bedrock structure but with no direct evidence from our borings or inclinometers that indicate the material has moved in the past, i.e., no tilted laminations or inclinometer movement was observed. Based on new data, our interpretation of the depth to bedrock evolved as part of this current study, hence reflecting the designation of "potentially displaced bedrock" in this report and on the most recent boring logs (Appendix A). Based on the data below, it appears that a large coherent landslide mass has moved in the past and could be actively moving.

- Long X Butte Quadrangle, Murphy and Gonzalez (2003) indicates several landslides that coalesce into one large landslide mass in the project area.
- A-DInSAR data (NHAZCA) suggests constant and spatially homogeneous movement of a large landslide mass within and beyond the extent of the HSB landslide (see Figure 3 and Appendix E for the A-DInSAR study)
- Boring RP-127-03 (see Appendix D) encountered deep displaced bedrock to a depth of 163 feet (elevation 1,939 feet).
- Poor correlation of stratigraphy between borings (see Figures 5 and 6 and Figures 8 and 9) suggests a deeper landslide mass. A detailed discussion of stratigraphic correlations is presented in Section 5.4.6.

### 5.4.5 Bedrock

The bedrock at the site is the Tertiary Sentinel Butte Formation and predominately consisted of gray claystone interbedded with siltstone, sandstone, and coal (lignite) seams. Most of the bedrock consisted of very low strength, brown, yellow-brown, gray, and greenish-gray claystone. The brown and yellow-brown bedrock was typically moderately to highly weathered, whereas the gray and greenish-gray claystone was typically slightly weathered to fresh. The structure of the claystone ranged from massive to laminated; blocky structure was occasionally observed. Both low angle and high angle joints with iron oxide stains and slickensides were observed. Trace to few carbonaceous fragments, organic plant matter, and fossils were present in some claystone layers.

The siltstone beds were very low strength and light gray, light gray-brown, red, tan-yellow, tan, brown, gray, dark gray, and black. The sandstone beds were very low to low strength and light gray, gray, green-gray, yellow-brown, red-brown, tan, and brown.

Several very low strength, black to dark-brown coal layers were encountered during the field exploration program and also observed along the highway cut slopes and natural slopes. The coal layers are presumed to be lignite, which is the lowest grade of coal and has a relatively low carbon content, low energy content and high sulfur content when compared to the other grades of coal (sub-bituminous, bituminous, and anthracite).

### 5.4.6 Correlation of Bedrock Units

As discussed in the A1SCR, we were able to correlate stratigraphic units using our stratigraphic column and marker beds from borings such as sandstone, siltstone, and different coal seams. As part of the current study, we were able to correlate units from a boring drilled on the plateau (RP-127-06) and for the north slope failure (Landslide Area 4 - boring RP-127-12) (see Figure 7). However, as indicated above, there were several inconsistencies with stratigraphic correlation of borings in the HSB landslide area, which is suggestive of landslide movement at some time.

## 5.5 Groundwater

Groundwater levels measured during drilling are indicated on the boring logs. For boring RP-127-12, groundwater was not measured during drilling because water was used from the ground surface to advance the borehole. Data obtained from the VWPs installed at the site are presented in Appendix A. The data indicate variable groundwater levels over relatively short distances (i.e., adjacent borings). In our opinion, this is typical for fine-grained bedrock materials, in which groundwater conditions are often governed by fractures and more permeable zones (e.g., sandstone and coal layers). Fluctuations in groundwater level are possible and likely depend on many factors, including seasonal variations, local precipitation, and the surface elevation of the Little Missouri River and other local water bodies.

## 5.6 Landslide Limits

The interpreted limits of the HSB landslide affecting the roadway are shown in Figure 3. This landslide is designated as Landslide Area 3 in this report (previously described as Landslide Area 18 in the A1SCR). Boring RP-128-04 (located at the scenic turnout) encountered intact rock beneath the roadway fill, which constrains the northern extent of the HSB landslide. In relation to the affected portion of US-85, potentially separated culverts were discovered in the embankment at Station 6744+00 near the 2011 landslide scarp and at Station 6738+00, which also assisted in identifying the active limits of the HSB landslide.

## 5.7 Failure Surfaces and High Plasticity Zones

The HSB landslide is characterized by localized areas of both shallow and deep movement. Figures 6, 8, and 9 (Profiles B-B', D-D' and E-E') present our interpretation of the subsurface and depth of slope movement through the landslide mass.

Our interpretation of the geometry of the HSB landslide failure surfaces is based on inclinometer monitoring over the periods indicated in Table 2, field reconnaissance, review of aerial imagery and geologic maps, the A-DInSAR study, and visual observation of soil/rock samples recovered from the borings. Data from both the NDDOT and our inclinometers typically indicate at least two active failure surfaces; one shallow (upper) faster moving failure surface (moving at greater than 1 inch per year over the monitoring period) and a lower relatively slower moving landslide (moving less than 1 inch per year over the monitoring period). The upper failure surface ranges from about elevation 2,167 to 2,172 feet, and the lower failure ranges from about elevation 2,105 to 2,115 feet.

We previously developed a stratigraphic column within the Sentinel Butte Formation and designated five high plasticity zones (Shannon & Wilson, 2017e). These weak layers have been corelated to some of the failure surfaces for landslides in other areas along US Highway 85. The upper slip surface may correlate to High Plasticity Zone B. However, the lower slip surface (2,105 to 2,115 feet) does not correlate to any of the previously identified weak layers described in the A1SCR, which suggests the current failures could be occurring within previous displaced landslide material.

## 5.8 Potential Deep Landslide

There is evidence of other landslides adjacent to and below the HSB landslide, including a deeper and larger one (Landslide Area 1) described and discussed in detail in the A1SCR (previously discussed as Landslide Area 16). In our opinion, the failure surface elevation of this larger landslide complex is approximately at 1,940 feet based on visual observation data from boring log RP-127-03 (see Appendix D) and may correlate to High Plasticity Zone D and the large landslide occurring on the south bank of the Little Missouri River (Shannon & Wilson, 2018). Figure 5 (Profile A-A’) presents our interpretation of the subsurface conditions of the larger landslide mass encompassing the HSB landslide. To the extent that such a deeper failure exists, it is uncertain if the failure is still active. However, to the extent that the larger landslide is active, mitigation of such a deep landslide is not generally feasible or practical and it is beyond the limits of the proposed landslide mitigation project.

## 5.9 Cut Slope Failure

A cut slope failure (within Landslide Area 2) is located between Stations 6734+50 and 6736+00, east of US-85 (see Figure 3). The failure is approximately 175 feet wide and 160 feet long and was previously described as Landslide Area 17 in the A1SCR (Shannon & Wilson, 2017e). Boring RP-127-11 encountered landslide debris over displace bedrock to a depth of 43 feet. Potentially displaced claystone was observed at 43 feet to the bottom of the boring at 91 feet. See Figure 5 (Profile A-A') for our interpretation of the subsurface conditions at this location.

## 5.10 North Slope Landslide

The north slope landslide (Landslide Area 4) is located between Stations 6744+00 and 6750+00, on the north side of the roadway (see Figure 3). The entire landslide area is approximately 500 feet wide and 500 feet long and was previously described as Landslide Area 19 in the A1SCR (Shannon & Wilson, 2017e). Shallow bedrock encountered from boring RP-127-12 indicates that debris from the upper part of the landslide area (zone of depletion) has spilled downslope over an intact section of claystone bedrock (zone of accretion). Based on our observations, it appears that the spillover debris remaining on the steep slope commonly experiences localized failures and downslope movement in addition to ongoing debris-flow activity along the southeast margin of the landslide area. Figure 7 (Profile C-C') presents an interpretation of the subsurface conditions at this location.

# 6 LANDSLIDE MITIGATION AND SLOPE STABILITY ANALYSIS

In TM-5 and A1TM-5, we completed conceptual-level evaluation of potential landslide mitigation alternatives in the HSB area (Shannon & Wilson, 2017b and 2017c). As part of those studies, we evaluated the following options:

- Realigning the roadway to avoid the HSB landslide area.
- Rebuilding the existing embankment with lightweight fill.
- Regrading the landslide area to construct a stabilizing buttress or shear key.
- Installing subsurface drainage features (e.g., drilled horizontal drains, trench drains).
- Installing ground anchors and concrete reaction blocks.

- Constructing an anchored drilled shaft structure.

Based on a review by the NDDOT and its consultants and considering impacts to the adjacent Theodore Roosevelt National Park, cost, constructability and risk, an anchored drilled shaft system was selected as the preferred alternative to mitigate the landslide. This section presents limit-equilibrium slope stability analyses that were used to advance the design of the anchored drilled shaft structure. Final design of the structure will be based on subsequent soil-structure interaction analyses completed using the finite difference method.

## 6.1 Alignment and Orientation of Stabilization

We worked with the NDDOT and discussed mitigation concepts with contractors to assist in developing the anchored drilled shaft alignment. We considered the following factors during our initial design (see Appendix F for the preliminary structure alignment).

- **Place all structural components in the existing NDDOT easement or right of way (ROW):** While temporary easements can likely be obtained for temporary work outside of the ROW, all structural components will be designed within the existing easement or ROW. Any grading outside of the existing easement or ROW will be returned to existing grade.
- **Minimize cuts and fills within the easement/ROW:** Where cuts and fills are required, we sought to maintain or increase the existing temporary factor of safety (FS).
- **Minimize elevation changes throughout the alignment:** Discussion with two contractors indicated that they prefer a horizontal working platform to place crane mats. Grade changes would need to be restricted to 6% or less to allow the cranes to transport the reinforcement cages. To minimize grade changes, we bifurcated the wall at one location and kept the two sections of wall at constant elevations of 2,180 feet and 2,190 feet.
- **Orient the stabilization perpendicular to the direction of movement:** The drilled shafts and anchors are aligned perpendicular to the 2011 failure and historical and recent inclinometer movements. This orientation also aligns with existing contours.
- **Minimize stabilization structural quantities:** The bifurcated wall provides the required FS while minimizing the length and size of drilled shafts and ground anchors. Placing the entire wall at an elevation of 2,190 feet would require an extra 10 feet of drilled shaft length and an extra 15 to 20 feet of ground anchors and would increase moments within the drilled shaft that could increase the drilled shaft diameter.
- **Maintain a 50-foot wide construction bench:** Two contractors indicated that a flat 50-foot wide construction bench on the downslope side of the drilled shafts is needed to efficiently complete the construction. This 50-foot wide bench allows for two crane mats to be placed and allows for construction traffic behind the crane. While the work is

possible with a narrower construction bench, such a condition will likely increase the cost of the project.

- **Maintain 2H:1V construction slopes, where possible:** Based on the existing topography and instability of the Project site, we used construction slopes of 2H:1V except at the following locations: (1) at the south end of the stabilization area (from approximately STA 21+20 to STA 23+00), we recommend 3H:1V fill slopes because of the hummocky nature of the ground and the possibility of 2H:1V slopes loading up the top of existing head scarps; (2) we recommend a temporary fill wall be placed from STA 27+15 to Sta 27+30 to avoid spilling of fill for a significant distance down the slope; and (3) we recommend a cut wall be considered between STA 19+90 and STA 21+10 if maintaining a 50-foot wide bench is desired.

## 6.2 Analysis Methodology

We completed two-dimensional limit-equilibrium stability analyses using the software SLOPE/W 2019 (Geo-Slope International, Ltd., 2019). We used the Morgenstern and Price (1965) method of slices, which satisfies force and moment equilibrium, to compute FS values. Because the slope has been in place for several years, we assumed excess pore water pressures in the slope have dissipated. Thus, we completed drained, or long-term, stability analyses. Based on the relatively low seismic hazard for the site, we did not consider seismic loading.

## 6.3 Analysis Cross-Sections

We analyzed seven slip surfaces through the HSB landslide area. Six of these sections were selected at locations perpendicular to the drilled shaft layout and aligned with the direction of slope movement indicated by the inclinometers, and the seventh was selected through the historic 2011 landslide area. We created our cross sections from various digital terrain models provided by the NDDOT. We considered the existing ground surface, proposed construction grading, and final four-lane buildout for our analyses. The location of these cross sections is provided in Appendix F.

## 6.4 Material Properties

For our analyses, we divided the subsurface profile into the units listed below, with the specified properties.

Exhibit 6-1: Soil/Rock Parameters Used for Stability Analysis

| Unit | Total Unit Weight (pcf) | Effective Stress Friction Angle (deg) | Effective Stress Cohesion (psf) |
|---|---|---|---|
| Fill | 125 | 25 | 0 |
| Landslide Debris/Displaced Bedrock | 120 | 25 | 50 |
| Potentially Displaced Bedrock/Bedrock | 125 | 24 | 200 |
| Slip Surface | 125 | Non-linear shear strength envelope (see below) | |

pcf = pounds per cubic foot, deg = degrees, psf = pounds per square foot

For the overburden and bedrock, we selected shear strength parameters based on correlations with plasticity and our judgement. For the slip surfaces, we utilized published correlations for residual shear strength envelopes based on liquid limits and clay size fraction (Gamez and Stark, 2016). Based on laboratory testing of selected samples of the comparatively weaker material, we assumed a liquid limit (LL) of 90 and 105 for the upper and lower slip surfaces, respectively (except as described below). The displaced claystone laboratory data LL in the Landslide varies from 39 to 134, but generally falls between 80 to 100. We used a clay size fraction (CF) of 30, and the laboratory data falls between 15 and 58. We then made slight adjustments to the assumed piezometric surface (see Section 6.6) to produce a back-calculated FS of 1.0 for existing conditions.

In order to produce a back-calculated FS of 1.0 for upper stability Section B, we utilized a residual shear strength envelope based on a LL of 110 and CF of 30 to maintain a piezometric surface that was reasonable based on the available groundwater data. Similarly, for Sections E and F we utilized a residual shear strength envelope based on a LL of 100 and 110, respectively, with a CF of 50.

## 6.5 Slip Surface Geometry

As discussed in Section 5.7, inclinometers at the site generally indicate two failure surfaces, a shallow surface with a base near elevation ±2,170 feet and a deep surface with a base near elevation ±2,110 feet. Points on the slip surfaces indicated by inclinometer movement were modeled across the six cross-sections cut perpendicular to the drilled shafts. For the seventh cross-section, the slip surface was modeled at the depth of inclinometer movement and matching the historical scarp and toe of the slide.

## 6.6 Groundwater Conditions

We used a piezometric line to represent pore water pressures. The piezometric surfaces were selected based on groundwater levels measured by data loggers connected to the previously installed VWPs, groundwater levels measured during drilling, and our judgment. Groundwater levels were slightly modified to back calculate a FS of 1.0 at each cross-section.

## 6.7 Back-Analysis

Because the slope has moved significantly, the FS of the slope can be considered to be 1.0 at the time of failure (Duncan and Wright, 2005). Assuming an FS of 1.0, a stability model that is representative of conditions at the time of failure can then be developed and used as a baseline for comparison with various landslide mitigation alternatives. The results of the back-analysis to an FS of 1.0 are shown in Appendix F.

## 6.8 Preliminary Design

We analyzed the seven sections to determine the drilled shaft shear load and ground anchor loads required to resist the landslide loading and provide a minimum FS of 1.3. We also analyzed a failure mode where the upper (shallower) landslide slides over the top of the stabilization elements.

For our analyses, we assumed that the ground anchors installed through a cap beam atop the drilled shafts will consist of 6-strand anchors, with a 45-foot long bond length, and horizontal spacing of 10 feet. Based on our experience with ground anchors installed in similar geologic conditions in North Dakota, we assumed an ultimate load transfer of 8.4 kips per foot and a FS of 2.25, which corresponds to an allowable tensile capacity of 168 kips per anchor (17 kips per linear foot of wall). We selected a FS of 2.25 based on load testing data on ground anchors in similar formations. We then varied the shear force for the drilled shaft elements to produce a minimum FS of 1.3 for the upper and lower failure surfaces.

Based on our analyses, we determined that the drilled shafts will need to resist a maximum loading ranging from 50 to 260 kips per linear foot of wall. The results for these analyses are shown in Appendix F. Based on our experience with the design of similar structures and the shear force required for an FS of 1.3, we anticipate that the drilled shafts will consist of 5- to 6-foot diameter shafts with a spacing of 2 to 3 shaft diameters. However, final design of the structure, including determining the sizing and spacing of the ground anchors and drilled shafts, will subsequently be completed using numerical modeling.

# 7 ADDITIONAL CONSIDERATIONS

## 7.1 Scenic Turnout

A steep, erosion-prone slope exists about 26 feet away from the edge of pavement at the scenic turnout. Our subsurface exploration (boring RP-128-04) suggests that the slope is formed in intact Sentinel Butte Formation bedrock. Therefore, it is our opinion that the slope in this area is currently stable. However, based on other data, including field reconnaissance and our understanding of the dispersive nature of soil and bedrock in the area, we recommend flattening the slope to the extent possible to reduce erosion potential and encroachment of the slope toward the scenic turnout. In addition, the slope should be protected with a turf reinforcement mat or similar erosion control products.

## 7.2 North Slope Failure

As discussed in Section 5.10, boring RP-127-12 encountered a thin veneer of landslide debris over bedrock at a depth of approximately 11 feet at the bench elevation of this landslide. The boring confirms our prior assumptions that this slope is draped in a relatively thin veneer of landslide debris. We provided recommendations for this failure in technical memorandum TM-2, Preliminary Cut and Fill Slope Recommendations (Shannon & Wilson, 2016b). We will prepare a separate report that updates the recommendations in TM-2 based on the new data collected such that a design could be developed by others at a later date.

## 7.3 Temporary Fill/Cut Slopes and Walls

Section 6.1 presents temporary cut and fill slopes and wall locations along the proposed anchored drilled shaft alignment. We recommend that the plans and specifications require that temporary cut and fill slope angles be no steeper than those indicated in Section 6.1 to reduce the potential for slope instability during construction. Similarly, we recommend the plans and specifications allow temporary wall locations only at the locations indicated in Section 6.1. The documents should clearly indicate that the contractor is responsible for the design of temporary walls. The design calculations for any temporary walls should be a construction submittal to the NDDOT for review.

In addition, the plans and specifications should indicate that the contractor is responsible for finding material for the platform and maintaining the platform throughout the project.

# 8 LIMITATIONS

This report was prepared for the exclusive use of the North Dakota Department of Transportation for specific application to the Horseshoe Bend Landslide. It should not be made available for purposes other than those described in this report.

Within the limitations of the scope, schedule and budget, the analyses, conclusions and recommendations presented in this report were prepared in accordance with generally accepted professional geotechnical engineering principles and practices in this area at the time this report was prepared. Subsurface conditions assumed for our opinions and evaluations presented herein were based on the explorations and instrumentation data included in this report and our GDR (Shannon & Wilson, 2016a and 2017d). Our opinions could change depending on additional inclinometer and groundwater monitoring. We make no other warranty, either express or implied. Our analyses, conclusions, and recommendations are based on our understanding of the project, as described in this report, and site conditions as they existed at the time our reconnaissance was performed.

Unanticipated soil conditions are commonly encountered and cannot be fully determined by a review of published maps, limited explorations, and site reconnaissance of surficial features. Such conditions frequently require that additional expenditures be made to attain properly constructed projects.

If, during construction, subsurface conditions differ from those indicated by the previous explorations and our reconnaissance are observed or appear to be present, we should be advised at once so we can review these conditions and reconsider our recommendations as necessary. If conditions have changed due to construction operations at or adjacent to the site, we should be notified so we may determine the applicability of the conclusions and recommendations in our report considering the changed conditions.

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

# 9 REFERENCES

Duncan, J. M. and Wright, S. G., 2005, Soil strength and slope stability: Hoboken, N. J., John Wiley & Sons, 297 p.

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# Table 1 - Summary of Subsurface Explorations and Instrumentation

| Boring Designation | Top Elevation (ft) | Total Depth (ft) | Bottom Elevation (ft) | Date Completed | Instrumentation Inclinometer | VWP | Sondex | Comment |
|---|---|---|---|---|---|---|---|---|
| RP-127-01 | 2223 | 176.5 | 2047 | 12/13/2014 | x | x | | Elev. Est'd based on dtm |
| RP-127-01A | 2223 | 140 | 2083 | 4/24/2017 | x | | x | Elev. Est'd based on dtm |
| RP-127-02 | 2154 | 150 | 2004 | 7/21/2016 | | | | Elev. Est'd based on dtm |
| RP-127-03 | 2102 | 175.5 | 1927 | 7/28/2016 | | | | Elev. Est'd based on dtm |
| RP-127-04 | 2077 | 140 | 1937 | 7/13/2016 | x | | | Elev. Est'd based on dtm |
| RP-127-05 | 2192 | 170 | 2022 | 7/19/2016 | x | | | Elev. Est'd based on dtm |
| RP-127-06 | 2491 | 202 | 2289 | 8/4/2016 | | | | Elev. Est'd based on dtm |
| RP-127-07 | 2250 | 131.5 | 2119 | 4/28/2017 | x | x | x | Elev. Est'd based on dtm |
| RP-127-08 | 2204.5 | 101 | 2103.5 | 6/28/2017 | x | | | |
| RP-127-09 | 2172.7 | 100.4 | 2072.3 | 6/27/2019 | x | | | |
| RP-127-10 | 2197.7 | 111 | 2086.7 | 6/26/2019 | x | | | |
| RP-127-11 | 2267.9 | 91 | 2176.9 | 6/29/2019 | | | | |
| RP-127-12 | 2350 | 80.8 | 2269 | 8/15/2019 | x | | | Elev. Est'd based on dtm |
| RP-128-04 | 2327.8 | 91 | 2236.8 | 6/28/2019 | | | | |
| HSB-1 | 2240 | 105 | 2135 | 4/13/2011 | x | | | Elev. Est'd based on dtm |
| HSB-2 | 2224 | 112 | 2112 | 4/14/2011 | x | | | Elev. Est'd based on dtm |
| HSB-3 | 2260 | 27 | 2233 | 4/20/2011 | | | | Elev. Est'd based on dtm |
| HSB-4 | 2185 | 85 | 2100 | 10/13/2011 | x | | | Elev. Est'd based on dtm |

NOTES:
1 Elevations of borings RP-127-08 through RP-127-11 and RP- 128-04 obtained by NDDOT survey.
2 Elevations of all other borings and borings completed by NDDOT (designated by "HSB" prefix) were estimated based on digital terrain model provided by KLJ.

ft = feet

## Table 2 - Summary of Inclinometer Installations and Readings

| Inclinometer Designation | Ground Surface Elevation (ft) | Bottom Elevation (ft) | A+ Direction Aziumuth[1] (deg) | Initialization Date | Latest Reading Date | Average Displacement Rate[2] (in/year) | Approx. Direction of Movement (deg) | Slip Surface Elevation (ft) | Comment |
|---|---|---|---|---|---|---|---|---|---|
| RP-127-01 | 2223 | 2047 | 259 | 8/20/2015 | 10/9/2019 | 0.07 | 210 | 2106 | |
| RP-127-01A | 2223 | 2083 | 283 | 5/19/2017 | 10/9/2019 | 0.09 | 236 | 2105 | |
| RP-127-04 | 2077 | 1937 | 273 | 8/16/2016 | 10/9/2019 | 0.09 | 229 | 2056 | |
| RP-127-05 | 2192 | 2022 | 199 | 8/16/2016 | 3/29/2017 | 5.38 | 228 | 2169 | Sheared to failure |
| RP-127-07 | 2250 | 2119 | 268 | 5/9/2017 | 10/9/2019 | 0.41 | 200 | 2196 | |
| RP-127-08 | 2204.5 | 2103.5 | 232 | 7/17/2019 | 10/9/2019 | 0.04 | 232 | 2187 | Possible additional shears at EL 2164 ft and EL 2148 |
| RP-127-09 | 2172.7 | 2072.3 | 218 | 7/17/2019 | 10/9/2019 | 0.22 | | | Possible shear at EL 2111 ft and EL 2090 ft |
| RP-127-10 | 2197.7 | 2086.7 | 203 | 7/17/2019 | 10/9/2019 | 7.97 | 210 | 2168 | |
| RP-127-12 | 2350 | 2279 | 230 | 8/26/2019 | 10/9/2019 | - | - | - | Inclinometer exhibts tilting at EL 2339 ft |
| HSB-1 | 2240 | 2135 | 200 [3] | 4/18/2011 | 9/28/2011 | 7.17 | 195 | 2167 | |
| HSB-2 | 2224 | 2112 | 245 [3] | 5/18/2011 | 9/28/2011 | | | | Possible shear at EL 2137 ft, but appears to be settlement related |
| HSB-4 | 2185 | 2100 | 254 | 10/12/2011 | 10/22/2015 | 0.75 | 196 | 2115, 2123, 2155, 2163 | Sheared to failure |

NOTES:
1 Azimuth values measured using compass and have been corrected for magnetic declination.
2 Displacement rate based on displacement immediately above lowest slip surface in given inclinometer.
3 Azimuth estimated assuming A+ oriented parallel to embankment slope.

ft = feet; deg = degrees; in/year = inches per year


N

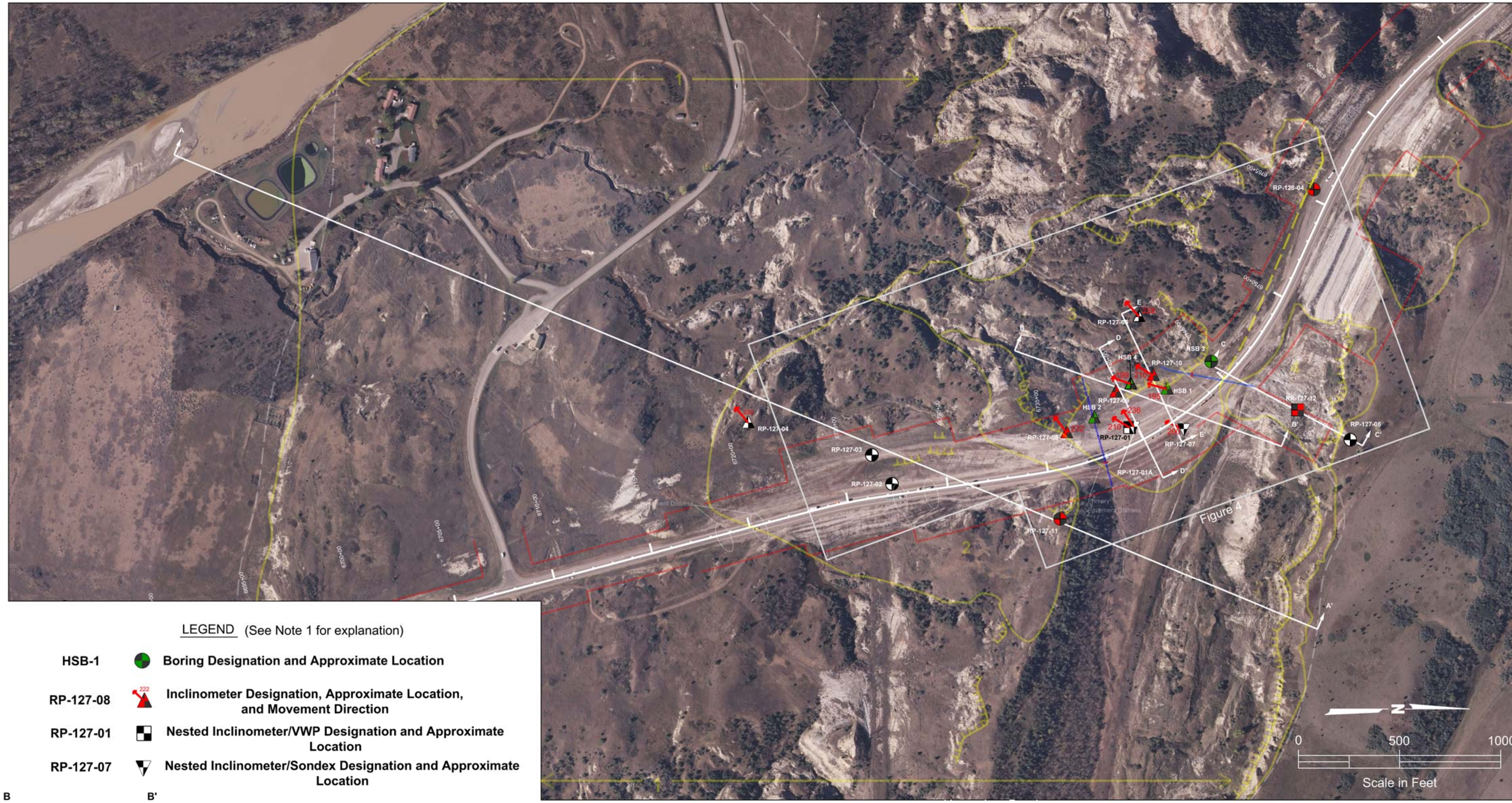
0 2000 4000

Approximate Scale in Feet

NOTE

Map adapted from aerial imagery provided by Google Earth Pro, reproduced by permission granted by Google Earth ™ Mapping Service.

| | |
|---|---|
| Horseshoe Bend Landslide<br>7-085(110)127, PCN 22304<br>McKenzie County, North Dakota | |
| **VICINITY MAP** | |
| February 2020 | 102116-200 |
| SHANNON & WILSON, INC.<br>GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS | **FIG. 1** |




LEGEND (See Note 1 for explanation)

| | |
|---|---|
| HSB-1 | Boring Designation and Approximate Location |
| RP-127-08 | Inclinometer Designation, Approximate Location, and Movement Direction |
| RP-127-01 | Nested Inclinometer/VWP Designation and Approximate Location |
| RP-127-07 | Nested Inclinometer/Sondex Designation and Approximate Location |
| B B' | Subsurface Profile |
| | Approximate Surfcial Limits of Landslide Area |
| | NDDOT ROW Boundary |
| | InSAR Hypothesis of Landslide Boundary |
| | Existing Culvert and Seperation Areas |
| | Pavement Distress Areas |
| | Landslide Area Number |

NOTES

1) Boring and instrument designations shown in red completed as part of this report, borings and instrument designations shown in green were completed by the NDDOT, and designations shown in white were previously completed by Shannon & Wilson.

2) Figure developed from KLJ files Photo_North_NDDOTPrelim_McKenzie.dgn, control_mckenzie.dgn. and RW_BNDRY_McKenzie_ExstLineWorkOnly.dgn.

Horseshoe Bend Landslide
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**SITE PLAN AND EXPLORATION PLAN**

February 2020 102116-200

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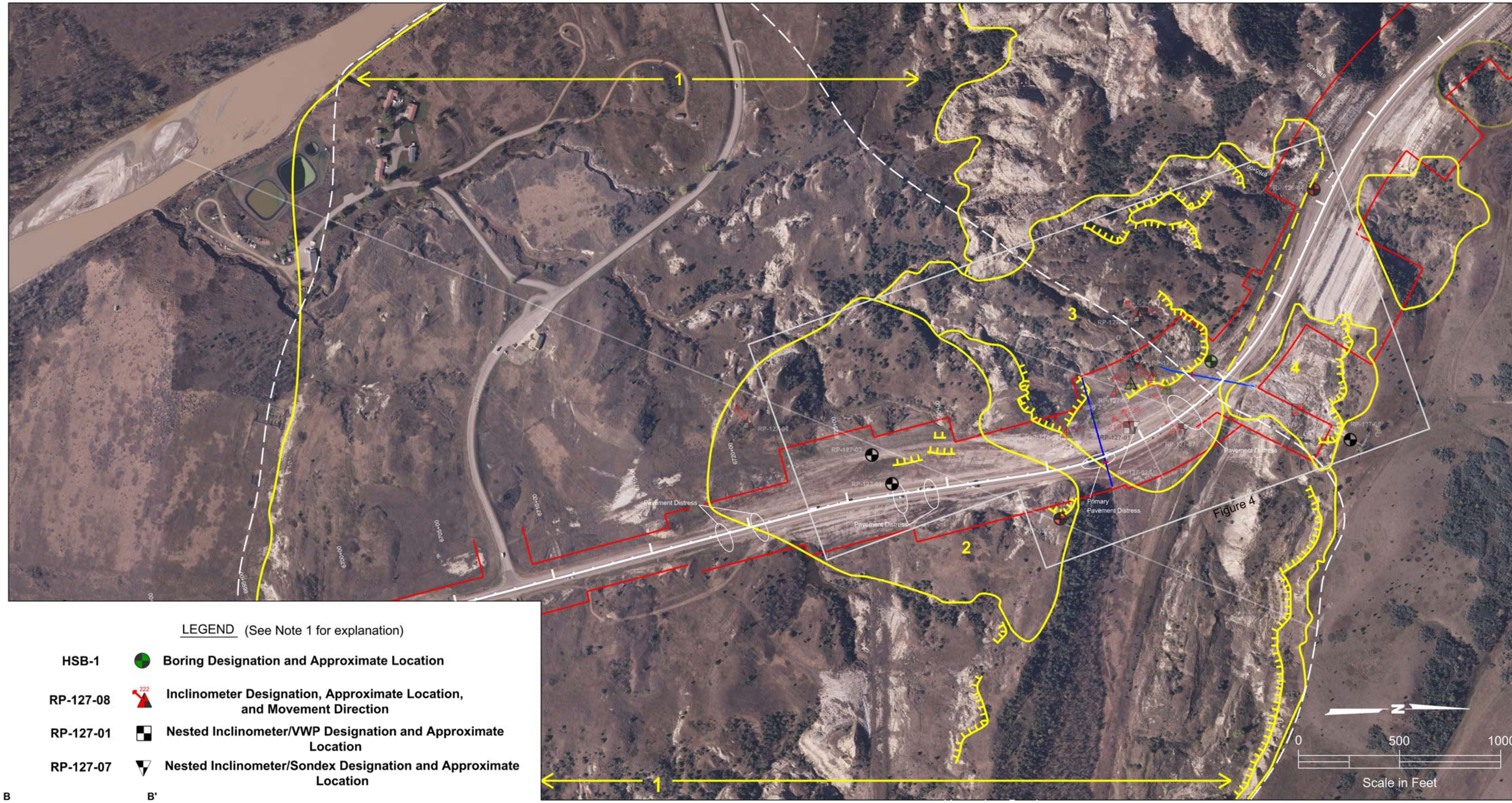
**FIG. 2**




LEGEND (See Note 1 for explanation)

| | | |
|---|---|---|
| HSB-1 | | Boring Designation and Approximate Location |
| RP-127-08 | | Inclinometer Designation, Approximate Location, and Movement Direction |
| RP-127-01 | | Nested Inclinometer/VWP Designation and Approximate Location |
| RP-127-07 | | Nested Inclinometer/Sondex Designation and Approximate Location |
| B — B' | | Subsurface Profile |
| | | Approximate Surfcial Limits of Landslide Area |
| | | NDDOT ROW Boundary |
| | | InSAR Hypothesis of Landslide Boundary |
| | | Existing Culvert and Seperation Areas |
| | | Pavement Distress Areas |
| | | Landslide Area Number |

NOTES

1) Boring and instrument designations shown in red completed as part of this report, borings and instrument designations shown in green were completed by the NDDOT, and designations shown in white were previously completed by Shannon & Wilson.

2) Figure developed from KLJ files Photo_North_NDDOTPrelim_McKenzie.dgn, control_mckenzie.dgn. and RW_BNDRY_McKenzie_ExstLineWorkOnly.dgn.

Horseshoe Bend Landslide
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**LANDSLIDE MAP**

February 2020 — 102116-200

SHANNON & WILSON, INC.
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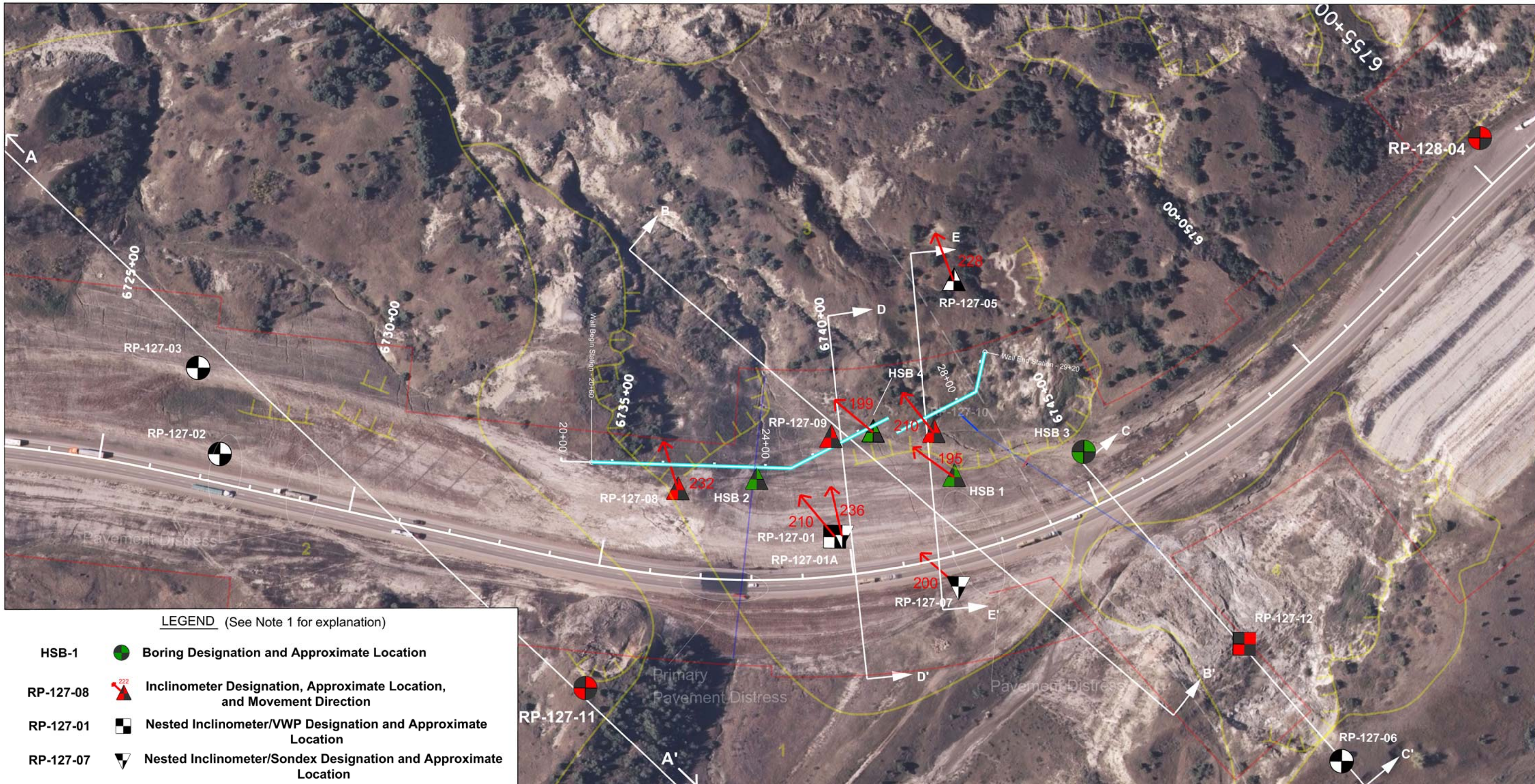
**FIG. 3**




LEGEND (See Note 1 for explanation)

| | |
|---|---|
| HSB-1 | Boring Designation and Approximate Location |
| RP-127-08 | Inclinometer Designation, Approximate Location, and Movement Direction |
| RP-127-01 | Nested Inclinometer/VWP Designation and Approximate Location |
| RP-127-07 | Nested Inclinometer/Sondex Designation and Approximate Location |
| B — B' | Subsurface Profile |
| | Approximate Surfcial Limits of Landslide Area |
| | NDDOT ROW Boundary |
| | InSAR Hypothesis of Landslide Boundary |
| | Existing Culvert and Seperation Areas |
| | Pavement Distress Areas |
| 1 | Landslide Area Number |

NOTES

1) Boring and instrument designations shown in red were completed as part of this report, borings and instrument designations shown in green were completed by the NDDOT, and designations shown in white were previously drilled and/or installed by Shannon & Wilson.

2) Figure developed from KLJ files Photo_North_NDDOTPrelim_McKenzie.dgn and control_mckenzie.dgn. and RW_BNDRY_McKenzie_ExstLineWorkOnly.dgn.

0 200 400

Scale in Feet

N

Horseshoe Bend Landslide
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**DETAILED MAP SHEET**

February 2020 102116-200

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**FIG. 4**


GEOLOGIC UNITS

- Fill
- Displaced Bedrock
- Claystone (Gray to Dark Brown)
- Siltstone/Sandstone

LEGEND

RP 127-06 — Boring Designation
(Proj. 55' SE.) — Projected Distance
Standard Penetration Test Sample
Penetration Resistance in Blows/Foot or Blows/Inches Driven
Modified California Sample
Depth of Inclinometer Movement
VWP Location and Groundwater Level
Shelby Tube Sample
Approximate Geologic Contact
Inferred Geologic Contact
USCS Symbol
Bottom of Boring
09-12-15 — Date of Completion

0 100 200
Scale in Feet

NOTES

Surface profile developed from KLJ file control_mckenzie_dtm.dgn. and alignment stationing was aquired from KJL file MasterAlignment_Photo.dgn.

Subsurface profile lines represent our interpretation of geologic conditions based on our field reconnaissances, observation of drilling activities, and laboratory test results. Actual subsurface conditions between borings may differ from this profile drawing.

Groundwater levels shown reflects the highest level recorded during drilling or from vibrating wire piezometer.

Profile is oblique from the alignment (see figures 2 & 3).

HSB Inclinometer elevations are estimated from control_mckenzie-dtm.dgn

Refer to Section 5.4 for description of soil and rock units.

Horseshoe Bend Landslide
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**GENERALIZED SUBSURFACE PROFILE A - A'**

February 2020 | 102116-200

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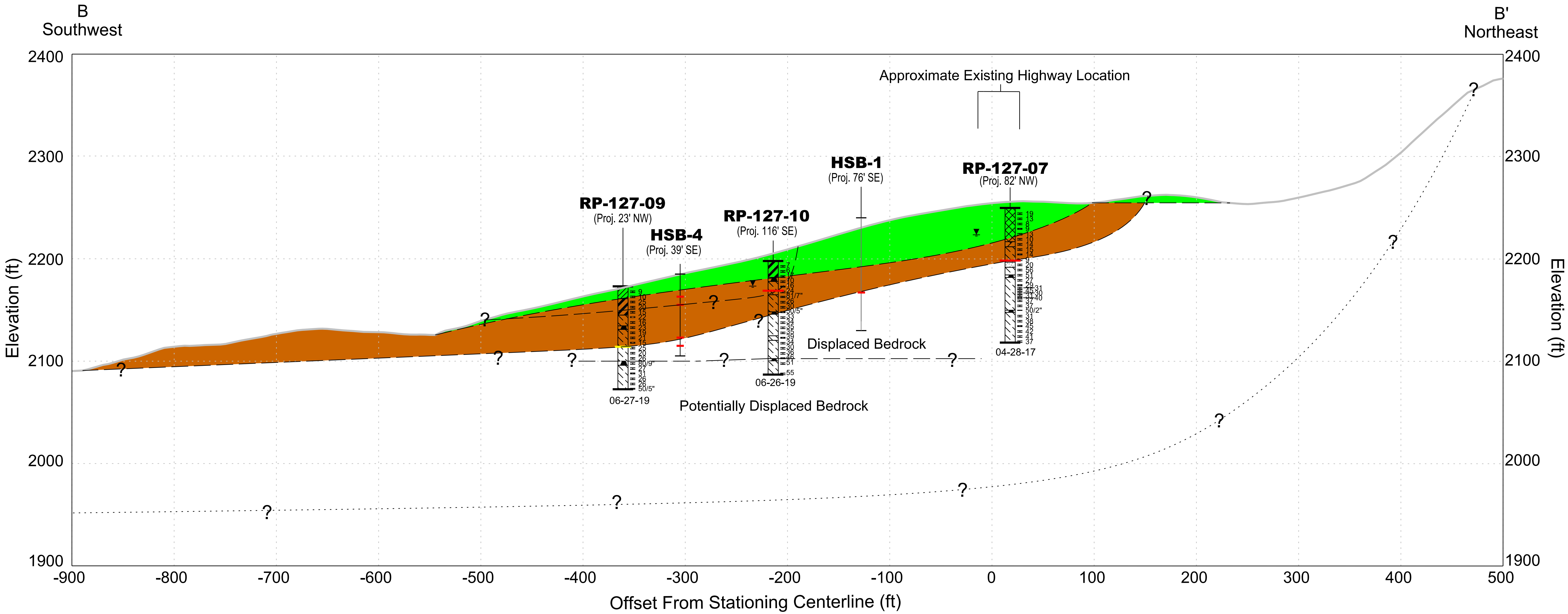
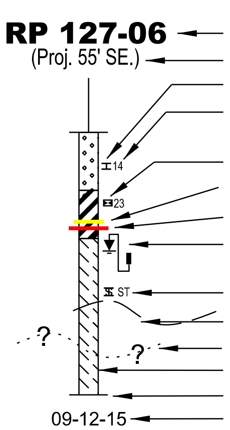
**FIG. 5**




LEGEND




- Boring Designation
- Projected Distance
- Standard Penetration Test Sample
- Penetration Resistance in Blows/Foot or Blows/Inches Driven
- Modified California Sample
- Depth of Possible Inclinometer Movement
- Depth of Inclinometer Movement
- VWP Location and Groundwater Level
- Shelby Tube Sample
- Approximate Geologic Contact
- Inferred Geologic Contact
- USCS Symbol
- Bottom of Boring
- Date of Completion

GEOLOGIC UNITS

- Fill
- Landslide Debris / Displaced Bedrock

NOTES

1) Surface profile developed from KLJ file control_mckenzie_dtm.dgn. and alignment stationing was aquired from KJL file MasterAlignment_Photo.dgn.

2) Subsurface profile lines represent our interpretation of geologic conditions based on our field reconnaissances, observation of drilling activities, and laboratory test results. Actual subsurface conditions between borings may differ from this profile drawing.

3) Groundwater levels shown reflects the highest level recorded during drilling or from vibrating wire piezometer.

4) Profile is oblique from the alignment (see figures 2 & 3).

5) HSB Inclinometer elevations are estimated from control_mckenzie-dtm.dgn.

6) Inclinometer in boring RP-127-10 has not shown any movement below 29 feet as of 10-09-2019.

7) Refer to Section 5.4 for description of soil and rock units.

0 100 200

Scale in Feet

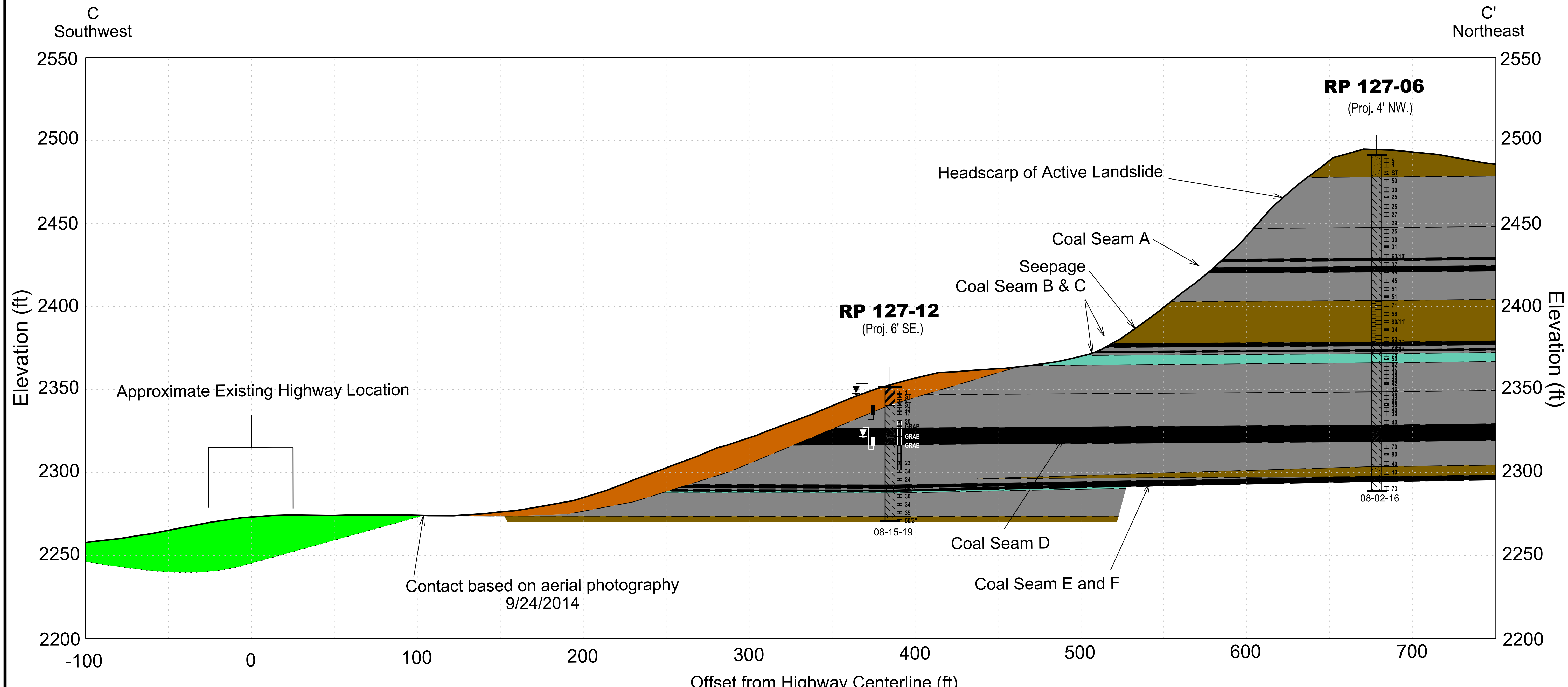
Horseshoe Bend Landslide
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**GENERALIZED SUBSURFACE PROFILE B - B'**
**STATION 6742+51**

February 2020 | 102116-200

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. 6**




LEGEND

RP 127-06 — Boring Designation
(Proj. 55' SE.) — Projected Distance
Standard Penetration Test Sample
Penetration Resistance in Blows/Foot or Blows/Inches Driven
Modified California Sample
Depth of Possible Inclinometer Movement
Depth of Inclinometer Movement
VWP Location and Groundwater Level
Shelby Tube Sample
Approximate Geologic Contact
Inferred Geologic Contact
USCS Symbol
Bottom of Boring
09-12-15 — Date of Completion

GEOLOGIC UNITS

- Fill
- Landslide Debris/Displaced Bedrock
- Colluvium
- Claystone (greenish gray)
- Claystone (Gray to Dark Brown)
- Siltstone/Sandstone
- Coal

NOTES

1) Surface profile developed from KLJ file control_mckenzie_dtm.dgn. and alignment stationing was aquired from KJL file MasterAlignment_Photo.dgn.

2) Subsurface profile lines represent our interpretation of geologic conditions based on our field reconnaissances, observation of drilling activities, and laboratory test results. Actual subsurface conditions between borings may differ from this profile drawing.

3) Groundwater levels shown reflects the highest level recorded during drilling or from vibrating wire piezometer.

4) Profile is oblique from the alignment (see figures 2 & 3).

5) HSB Inclinometer elevations are estimated from control_mckenzie-dtm.dgn

0 60 120
Scale in Feet

Horseshoe Bend Landslide
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**GENERALIZED SUBSURFACE PROFILE C - C' STATION 6745+30**

February 2020 102116-200

**SHANNON & WILSON, INC.**
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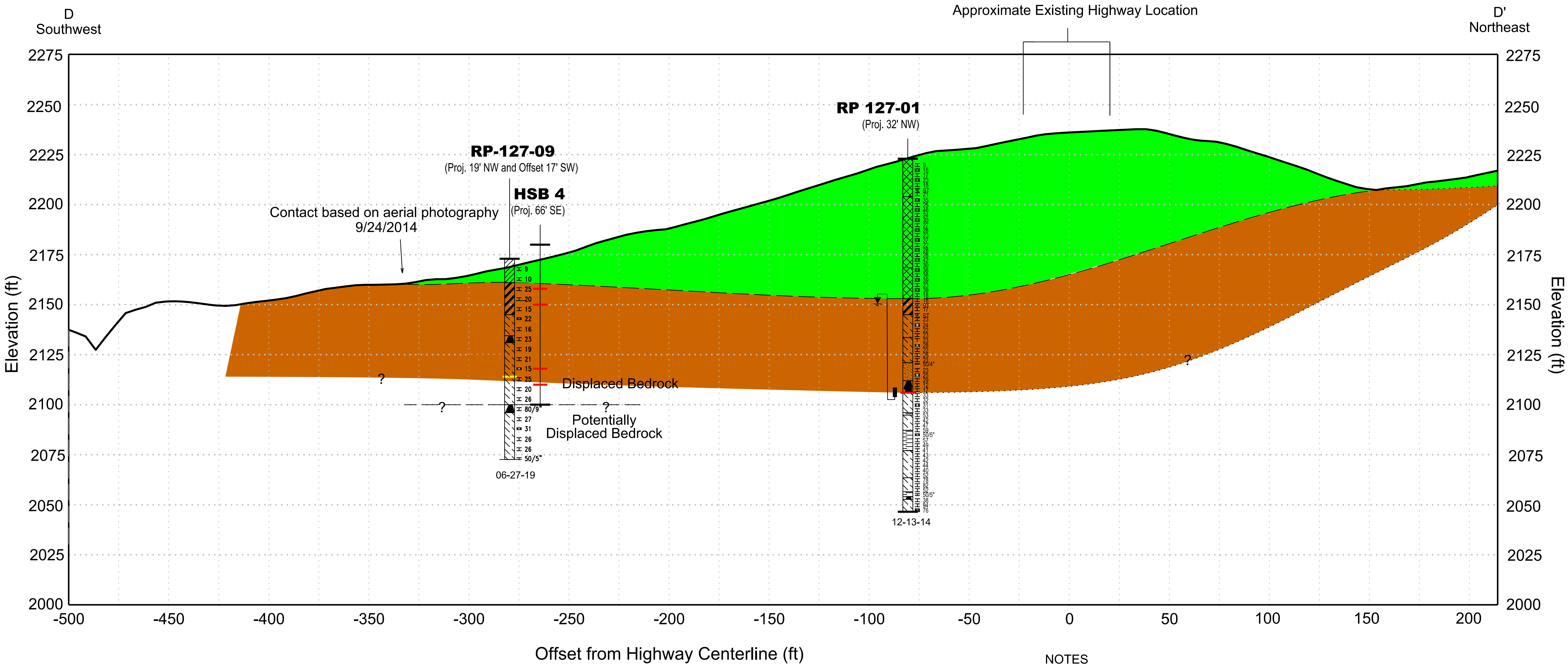
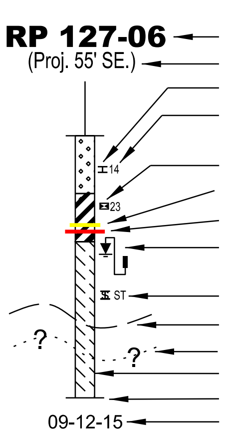
**FIG. 7**




LEGEND




- Boring Designation
- Projected Distance
- Standard Penetration Test Sample
- Penetration Resistance in Blows/Foot or Blows/Inches Driven
- Modified California Sample
- Depth of Possible Inclinometer Movement
- Depth of Inclinometer Movement
- VWP Location and Groundwater Level
- Shelby Tube Sample
- Approximate Geologic Contact
- Inferred Geologic Contact
- USCS Symbol
- Bottom of Boring
- Date of Completion

GEOLOGIC UNITS

- Fill
- Landslide Debris / Displaced Bedrock

NOTES

1) Surface profile developed from KLJ file control_mckenzie_dtm.dgn. and alignment stationing was aquired from KJL file MasterAlignment_Photo.dgn.

2) Subsurface profile lines represent our interpretation of geologic conditions based on our field reconnaissances, observation of drilling activities, and laboratory test results. Actual subsurface conditions between borings may differ from this profile drawing.

3) Groundwater levels shown reflects the highest level recorded during drilling or from vibrating wire piezometer.

4) Profile is oblique from the alignment (see figures 2 & 3).

5) HSB Inclinometer elevations are estimated from control_mckenzie-dtm.dgn

6) Refer to Section 5.4 for description of soil and rock units.

0 50 100

Scale in Feet

Horseshoe Bend Landslide
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**GENERALIZED SUBSURFACE PROFILE D - D' STATION 6740+00**

February 2020 102116-200

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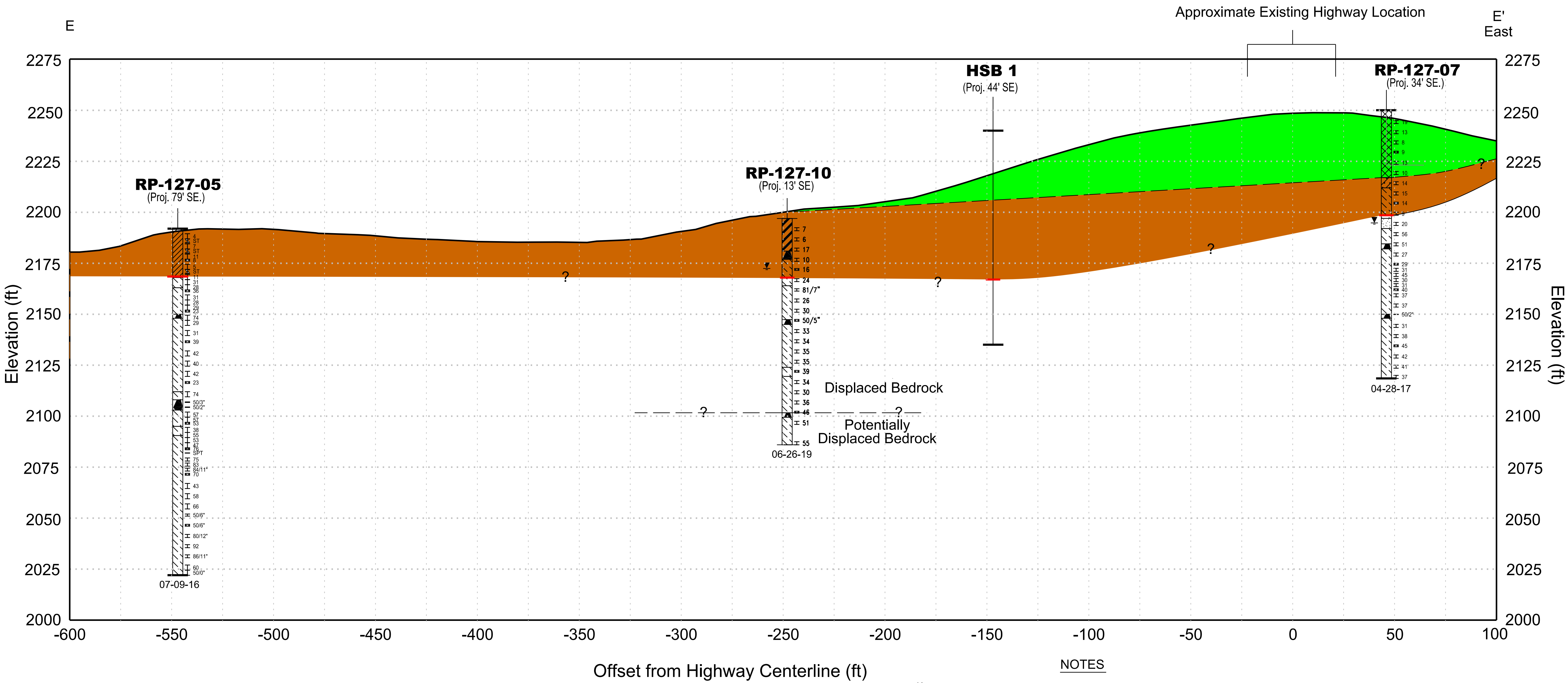
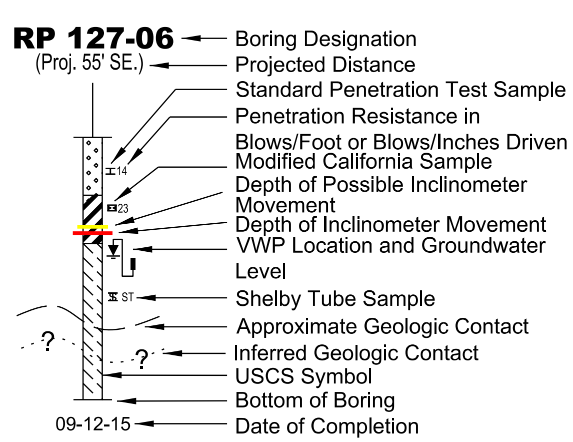
**FIG. 8**




## LEGEND




## GEOLOGIC UNITS

Fill

Landslide Debris/Displaced Bedrock

## NOTES

1) Surface profile developed from KLJ file control_mckenzie_dtm.dgn. and alignment stationing was aquired from KJL file MasterAlignment_Photo.dgn.

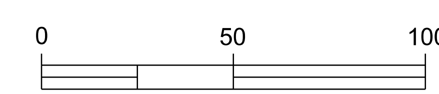
2) Subsurface profile lines represent our interpretation of geologic conditions based on our field reconnaissances, observation of drilling activities, and laboratory test results. Actual subsurface conditions between borings may differ from this profile drawing.

3) Groundwater levels shown reflects the highest level recorded during drilling or from vibrating wire piezometer.

4) Profile is oblique from the alignment (see figures 2 & 3).

5) HSB Inclinometer elevations are estimated from control_mckenzie-dtm.dgn

6) Refer to Section 5.4 for description of soil and rock units.



Scale in Feet

Horseshoe Bend Landslide
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**GENERALIZED SUBSURFACE PROFILE E - E'**
**STATION 6741+60**

February 2020

102116-200

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**FIG. 9**

APPENDIX A: CURRENT FIELD EXPLORATIONS

## Appendix A

# Current Field Explorations

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APPENDIX A: CURRENT FIELD EXPLORATIONS

## A.1 INTRODUCTION

The field exploration program for the Horseshoe Bend Landslide Repair project was conducted from June 25, 2019 through June 29, 2019 and August 12, 2019 through August 15, 2019. The program consisted of drilling six geotechnical borings, designated RP-127-08 through RP-127-12, and RP-128-04. A representative from Shannon & Wilson, Inc. (Shannon & Wilson) observed the drilling, sampling and instrumentation operations; retrieved representative samples for laboratory testing; and prepared descriptive field logs of the borings. The methods used to conduct the field exploration program are described below.

## A.2 EXPLORATIONS

The drilling was coordinated (including site access, permitting, traffic control, subcontractor coordination and utility locates) and observed by our field representative. Individual boring logs are presented on Figures A-3 through A-8. These exploration logs represent our interpretation of the subsurface conditions encountered at the time of drilling and the results of laboratory testing. The location of each boring (as shown in Figure 2) was surveyed in the field by the North Dakota Department of Transportation (NDDOT) upon drilling completion and coordinates of the boring locations are indicated on each log.

Five of the six borings were drilled by Interstate Drilling Services, LLP (IDS) of Grand Forks, North Dakota under subcontract to Shannon & Wilson using a Diedrich D-50 turbo diesel track-mounted drill rig. These borings were advanced with an 8-inch-outer-diameter, hollow stem auger (HSA) to depths between 14 and 20 feet. When the subsurface conditions became too hard for HSA, IDS used mud rotary techniques with a 4.25-inch diameter drill bit to advance the borings to depths up to 111 feet.

A sixth boring (RP-127-12) with difficult access was drilled by Salisbury & Associates, Inc. (Salisbury) of Spokane, Washington under subcontract to Shannon & Wilson using a Burley 2500 Geotechnical Drill. The drill rig, supporting equipment, and supplies were all airlifted on to the site using a Eurocopter AS350 A-Star B3 / B3e helicopter. This boring was advanced using a variety of drilling methods including HWT casing advance (4.5-inch diameter), HQ3 coring techniques, and HQ casing advance (3.9-inch diameter).

During drilling, the Shannon & Wilson field representative measured the approximate depth to groundwater using an electronic water level indicator (when possible). Due to the presence of drilling fluid, it was not possible to measure groundwater levels in borings advanced using mud rotary techniques, HQ3 core, or casing advancer. Upon the completion of drilling, the boreholes were backfilled with bentonite-cement grout (see section A-3). The groundwater levels measured during drilling, as applicable, are noted on the individual boring logs.

### A.2.1 Soil and Rock Classification System

During drilling, the Shannon & Wilson representative collected soil/bedrock samples and prepared a field log of each boring. Soil classifications were based on ASTM International (ASTM) Designation: D2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), and ASTM Designation: D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure). The system is referred to as the Unified Soil Classification System and is summarized on Figure A-1. The Shannon & Wilson representative classified rock samples, when displaced as landslide deposits, in general accordance with the International Society of Rock Mechanics classification method. According to this system, rock is classified based on the stratigraphic structure, rock strength, degree of weathering, and other properties. The rock classification system is summarized on Figure A-2.

The bedrock encountered in the borings was generally found to be very dense and hard when considered as a lithified soil material. However, when compared to other types of bedrock using the International Society of Rock Mechanics classification of rock strength, the rock resembles a very weak rock. Therefore, for completeness, the boring logs contain dual descriptions of the bedrock using the USCS and rock classification systems, where appropriate.

### A.2.2 Standard Penetration Test (SPT)

Disturbed samples were obtained in the borings in general accordance with SPT procedures (ASTM D1586) and consisted of driving a 2-inch outside diameter, 1.375-inch inside diameter split-spoon sampler a distance of 18 inches. Samplers were driven using an automatic 140-pound hammer free-falling a distance of 30 inches. SPT samples driven by Salisbury were done using a 140-pound hammer using a cathead also with a 30-inch free-falling distance. During sampling, the Shannon & Wilson field representative recorded the number of blows for each 6-inch increment of penetration and summed the blow counts for the last two 6-inch increments. This sum is recorded as the penetration resistance number, or N-value. If high penetration resistance prevented driving the total length of the sampler, the Shannon & Wilson field representative recorded the partial penetration depth and blow count. The N-values provide a means for evaluating the relative density or compactness of cohesionless (granular) soils and consistency or stiffness of cohesive (fine-grained) soils (see Figure A-1). The raw N-values are shown on the individual boring logs. Representative portions of the split-spoon sample obtained in conjunction with the SPT were placed in a screw-top plastic jar and transported to our laboratory in Denver, Colorado.

### A.2.3 Modified California (MC) Drive Samples

Disturbed soil and rock samples were also obtained using a MC sampler. The MC test procedure is similar to the SPT, except a larger diameter barrel sampler (2½-inch O.D., lined with 2-inch-diameter brass tubing) is used and driven 12 inches. During sampling, the field representative recorded the number of blows for each 6-inch increment of penetration. As a result of the larger diameter, the MC sampler yields slightly higher raw blow count numbers when compared to SPT N-values for similar soils. Because the difference in blow counts does not significantly impact our evaluation, we used the field MC blow counts over the 12-inch increment to evaluate the relative density and consistency/stiffness of the subsurface materials following SPT terminology. Representative samples were sealed in the brass liner tubes with plastic caps and transported to our laboratory in Denver, Colorado.

### A.2.4 Shelby Tube Sampling

Relatively undisturbed soil/rock samples were obtained using Shelby tube samplers in general accordance with ASTM D1587, Standard Practice for Thin-Walled Tube Geotechnical Sampling of Soils. The locations of these samples are shown on the individual boring logs. These samples were collected by using the hydraulic ram of the drill rig to push the thin-walled tube sample into the soil/rock at the bottom of the borehole at the desired depth. The thin-walled tube was connected to the drill rods via a rigid sampling head. After pushing, the drill rods were retracted, and the tube was detached from the sampling head. The Shelby tubes were then capped and transported to our office for laboratory testing.

## A.3 INSTRUMENTATION INSTALLATION

Upon the completion of drilling, a slope inclinometer was installed in boreholes RP-127-08, RP-127-09, RP-127-10, and RP-127-12. Two vibrating wire piezometers (VWPs) were installed in borehole RP-127-12. The construction of individual inclinometers and VWPs are depicted on boring logs, along with the highest groundwater level readings from the VWPs. VWP and inclinometer installation methods are described below.

### A.3.1 Inclinometer Installation

The inclinometers consisted of 2.75-inch diameter Slope Indicator casing. After the casing was lowered to the bottom of the borehole, a bentonite-cement grout mixture was pumped to the bottom of the borehole through a hose that was secured to the outside of the inclinometer casing. To counter buoyancy, water was added to the inclinometer casing before grouting. Following the installation, the instrumentation was completed with a 4-inch by 4-inch stick up monument.

### A.3.2 Vibrating Wire Piezometer Installation

Two VWPs (Geokon Model No. 4500S) were installed in borehole RP-127-12. One with a pressure range of 350 kilopascals (approximately 25 psi) and the other with a pressure range of 700 kilopascals (approximately 50 psi). Each VWP consisted of a pressure transducer contained in a stainless steel housing. Water pressure acts against a low air entry filter at one end of the housing. Each installation of a VWP was observed by a Shannon & Wilson representative.

Approximate locations where the VWPs were installed are shown in Figure 2 and locations are summarized on each individual boring log (Appendix A). The fully grouted borehole installation method described in Section 2.3 of the manufacturer's manual (Geokon, 2014[1]) was used to complete the installation of the VWPs.

The VWPs were attached at the desired installation depth to the Slope Indicator inclinometer casing, which was lowered to the bottom of the borehole. The boreholes were grouted full as described in Section A.3.1.

## A.4 INCLINOMETER READINGS

On October 9, 2019, NDDOT took readings from seven inclinometers in the Horseshoe Bend (HSB) area. The new inclinometer results are provided in Figures A-9 through A-12 and the previously installed inclinometer results are provided in Appendix E and supersede the cumulative displacement plots in the A1GDR.

Rotational and bias corrections were applied to individual inclinometers if data drift was apparent and is indicated on each plot. We have applied a rotational correction to Figure A-9 (RP-127-08). This correction was minor and related to the interaction of a small misalignment of the sensors within the inclinometer probe relative to the profile of the casing. We have also added a bias correction to Figure A-10 (RP-127-09) to remove erroneous apparent deformations along the length of casing.

[1] Geokon, 2018, Instruction Manual, Model 4500 Vibrating Wire Piezometer: Geokon, Inc., Lebanon, New Hampshire, Rev. T, March, 26 p.

## A.5 GROUNDWATER ELEVATION CALCULATION

Vibrating Wire Piezometers (VWP) were used to determine the approximate depth of groundwater at the time of reading. The VWP were connected to a signal cable that was routed up the borehole to the ground surface. Prior to installation, the VWP transducer was saturated and readings were recorded (pressure and temperature) while under zero water head. The readings were used in conjunction with factory calibration data summarized in Table A-1. The values were taken as a baseline to compare against future readings.

Subsequent readings were taken by NDDOT personnel. The data from the VWPs was reduced to determine the water pressure, which can be used to determine the approximate groundwater depth at the time of sampling. Table A-2 summarizes the calculated groundwater depths and elevations. The highest groundwater elevation measurements are shown on individual boring logs in Appendix A.

# Table A-1 - Calibration Data for Groundwater Calculation

| Exploration Designation | Model Number | Serial Number | Installation Depth (feet) | Linear Gage Factor (psi/digit) | Thermal Factor (psi/ C) | Factory Zero Reading (digits) | Temperature ( C) | Barometer (mbar) |
|---|---|---|---|---|---|---|---|---|
| RP-127-12 | 4500S-350kPa | 1527929 | 11 | -0.01603 | -0.008238 | 8642 | 18.6 | 997.2 |
| RP-127-12 | 4500S-700kPa | 1525251 | 30 | -0.02472 | 0.006799 | 8795 | 19.4 | 995.9 |

NOTES:
C = Degrees in Celsius; mbar = millibar ; psi = pounds per square inch

# Table A-2 - Summary of Groundwater Depths Calculated from Vibrating Wire Piezometers

| Exploration Designation | Ground Elevation[1] (feet) | Installed Vibrating Wire Piezometers Depth (feet) | Elevation (feet) | Lithology of Installation | Highest Piezometer Groundwater Readings Depth (feet) | Elevation (feet) |
|---|---|---|---|---|---|---|
| RP-127-12 | ~2350 | 11.0 | 2339 | Fat Clay | 3.9 | 2346.1 |
| RP-127-12 | ~2350 | 30.00 | 2320 | Coal | 29.8 | 2320.2 |

NOTES:
1 A tilde (~) represents elevations (z) estimated using the digital terrain model provided by KLJ.

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

## S&W INORGANIC SOIL CONSTITUENT DEFINITIONS

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

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

## MOISTURE CONTENT TERMS

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

## STANDARD PENETRATION TEST (SPT) SPECIFICATIONS

| | |
|---|---|
| Hammer: | 140 pounds with a 30-inch free fall. Rope on 6- to 10-inch-diam. cathead 2-1/4 rope turns, > 100 rpm<br><br>NOTE: If automatic hammers are used, blow counts shown on boring logs should be adjusted to account for efficiency of hammer. |
| Sampler: | 10 to 30 inches long<br>Shoe I.D. = 1.375 inches<br>Barrel I.D. = 1.5 inches<br>Barrel O.D. = 2 inches |
| N-Value: | Sum blow counts for second and third 6-inch increments.<br>Refusal: 50 blows for 6 inches or less; 10 blows for 0 inches. |

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

## PARTICLE SIZE DEFINITIONS

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

## RELATIVE DENSITY / CONSISTENCY

**COHESIONLESS SOILS**

| N, SPT, BLOWS/FT. | RELATIVE DENSITY |
|---|---|
| < 4 | Very loose |
| 4 - 10 | Loose |
| 10 - 30 | Medium dense |
| 30 - 50 | Dense |
| > 50 | Very dense |

**COHESIVE SOILS**

| N, SPT, BLOWS/FT. | RELATIVE CONSISTENCY |
|---|---|
| < 2 | Very soft |
| 2 - 4 | Soft |
| 4 - 8 | Medium stiff |
| 8 - 15 | Stiff |
| 15 - 30 | Very stiff |
| > 30 | Hard |

## WELL AND BACKFILL SYMBOLS

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

## PERCENTAGES TERMS [1, 2]

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

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

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

Horseshoe Bend Landslide
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McKenzie County, North Dakota

**SOIL DESCRIPTION AND LOG KEY**

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**FIG. A-1**
Sheet 1 of 3

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

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

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

NOTES

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

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

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**SOIL DESCRIPTION AND LOG KEY**

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**FIG. A-1**
Sheet 2 of 3

## GRADATION TERMS

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

## CEMENTATION TERMS[1]

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

## PLASTICITY[2]

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

## ADDITIONAL TERMS

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

## PARTICLE ANGULARITY AND SHAPE TERMS[1]

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

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

## ACRONYMS AND ABBREVIATIONS

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

## STRUCTURE TERMS[1]

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

Horseshoe Bend Landslide
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**SOIL DESCRIPTION AND LOG KEY**

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**FIG. A-1**
Sheet 3 of 3

2013_BORING_CLASS3 102116-200 HSB.GPJ SWNEW.GDT 2/4/20

### WEATHERING

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

### STRENGTH

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

### JOINT ROUGHNESS COEFFICIENT (JRC)

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

### DISCONTINUITY DATA

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

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

### DISCONTINUITY TERMS

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

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

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

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

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

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

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

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

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

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

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

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

## ROCK CLASSIFICATION AND LOG KEY

February 2020 102116-200

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**FIG. A-2**
Sheet 1 of 2

# ROCK CLASSIFICATION SYMBOLS

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

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7-085(110) 127, PCN 22304
McKenzie County, North Dakota

**ROCK CLASSIFICATION AND LOG KEY**

February 2020 102116-200

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**FIG. A-2**
Sheet 2 of 2

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 101 ft. | Northing: | 233,707 ft. | Drilling Method: | HSA to Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2204.5 ft. | Easting: | 1,288,345 ft. | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | State Plane | Offset: | - | Other Comments: | To mud rotary at 14.5 feet | | |

**SOIL DESCRIPTION**

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

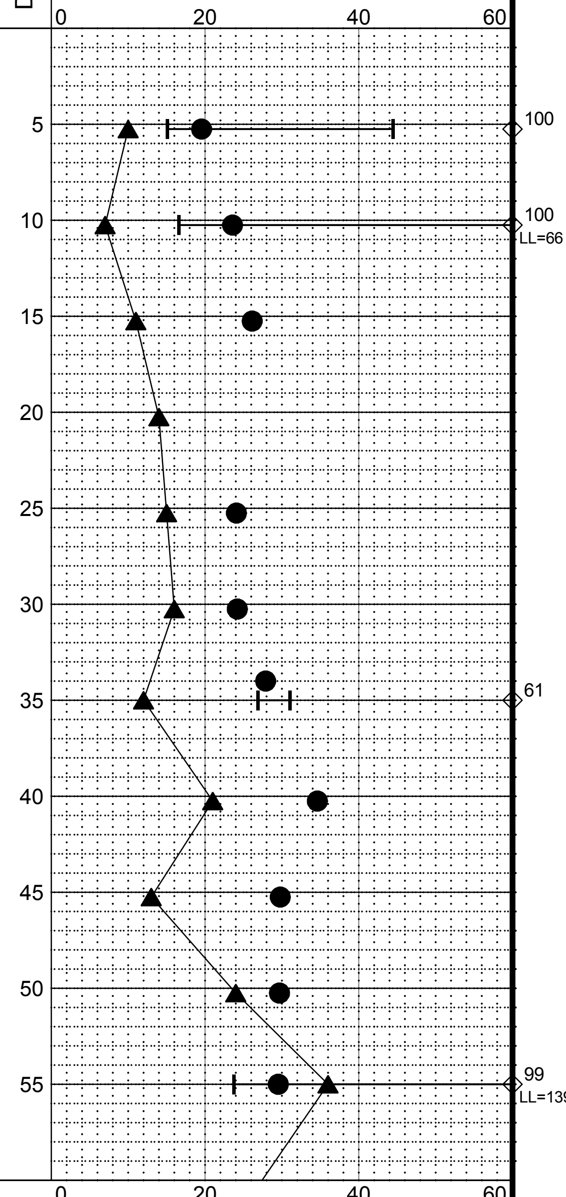
| Soil Description | Depth, ft. | Samples |
|---|---|---|
| Stiff, mottled brown, *Lean Clay (CL);* moist; few carbonaceous fragments. Fill | 8.0 | S-1 |
| Medium stiff to stiff, brown to tan, *Fat Clay (CH);* moist. Landslide Debris | 15.8 | S-2, S-3 |
| Medium dense, tan, *Silt (ML);* moist. Landslide Debris | 21.0 | S-4* |
| DISPLACED CLAYSTONE: extremely weak, tan to light gray; laminated; moderately to slightly weathered (Displaced Sentinel Butte Formation). [Stiff to very stiff, *Fat Clay (CH);* moist.] | 33.0 | S-5, S-6 |
| DISPLACED SILTSTONE: extremely weak, brown; moderately weathered (Displaced Sentinel Butte Formation). [Stiff, *Sandy Silt (ML);* moist.] | 36.0 | S-7 |
| DISPLACED CLAYSTONE: extremely weak, gray; laminated; slightly weathered; trace carbonaceous fragments (Displaced Sentinel Butte Formation). [Stiff to hard, *Fat Clay (CH);* moist; trace sand.] - Interbedded coal layers from 39.7 to 39.9, 40.7 to 40.9, and 55.0 to 55.2 feet. | 57.0 | S-8, S-9, S-10, S-11 |
| POTENTIALLY DISPLACED CLAYSTONE: | | |

Ground Water: Groundwater Not Encountered During Drilling.

CONTINUED NEXT SHEET

**PENETRATION RESISTANCE** (blows/foot)

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




◇ % Fines (<0.075mm)

● % Water Content

Plastic Limit ├─●─┤ Liquid Limit

Natural Water Content

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- Piezometer Screen and Sand Filter
- Bentonite-Cement Grout
- Bentonite Chips/Pellets
- Surface Concrete Seal

NOTES

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

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

**LOG OF BORING RP-127-08**

February 2020 102116-200

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**FIG. A-3**
Sheet 1 of 2

*REV 3*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 101 ft. | Northing: | 233,707 ft. | Drilling Method: | HSA to Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2204.5 ft. | Easting: | 1,288,345 ft. | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | State Plane | Offset: | - | Other Comments: | To mud rotary at 14.5 feet | | |

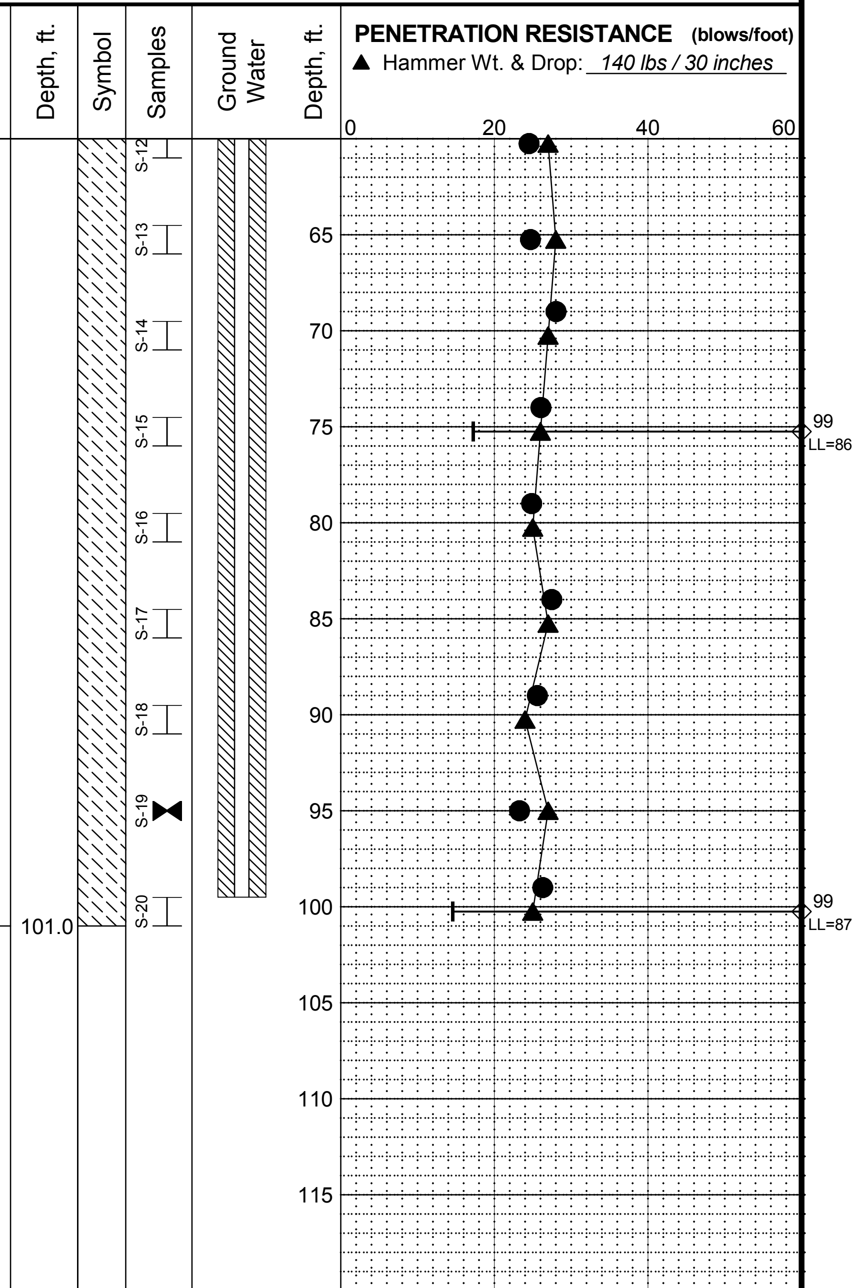
**SOIL DESCRIPTION**

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

POTENTIALLY DISPLACED CLAYSTONE: extremely weak, gray to brown; laminated; slightly weathered; trace carbonaceous fragments (Potentially Displaced Sentinel Butte Formation).
[Very stiff, *Fat Clay (CH);* moist; trace sand.]

101.0

BOTTOM OF BORING
COMPLETED ON 06/28/2019




LEGEND

* Sample Not Recovered
Standard Penetration Test
Modified California Sampler
Piezometer Screen and Sand Filter
Bentonite-Cement Grout
Bentonite Chips/Pellets
Surface Concrete Seal

◇ % Fines (<0.075mm)
● % Water Content
Plastic Limit ├──●──┤ Liquid Limit
Natural Water Content

NOTES

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

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

**LOG OF BORING RP-127-08**

February 2020 102116-200

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**FIG. A-3**
Sheet 2 of 2

*REV 3*

MASTER_LOG_E 102116-200 HSB.GPJ SHAN_WIL.GDT 2/4/20

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 100.4 ft. | Northing: | 233,951 ft. | Drilling Method: | HSA to Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2172.7 ft. | Easting: | 1,288,143 ft. | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | State Plane | Offset: | - | Other Comments: | To mud rotary at 15.0 feet | | |

**SOIL DESCRIPTION**

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

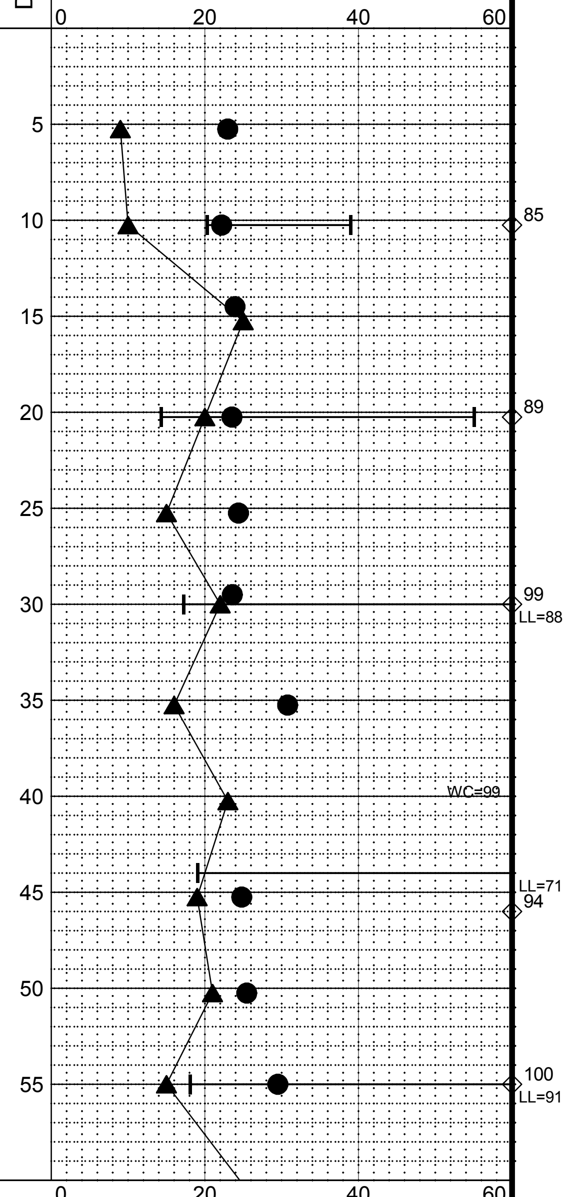
| Soil Description | Depth, ft. | Samples |
|---|---|---|
| Stiff, brown mottled gray, *Lean Clay with Sand (CL);* moist; trace carbonaceous fragments and bedrock fragments; interbedded sand layers. Fill | | S-1, S-2 |
| Siff to very stiff, brown mottled, *Fat Clay (CH);* moist; few sand; few carbonaceous fragments and bedrock fragments. Landslide Debris | 12.0 | S-3, S-4, S-5 |
| DISPLACED CLAYSTONE: extremely weak, brown; laminated; moderately weathered; 20 to 30 degree laminations (Displaced Sentinel Butte Formation). [Very stiff, *Fat Clay (CH);* moist; trace sand.] | 28.0 | S-6, S-7 |
| DISPLACED COAL: extremely weak, black (Displaced Sentinel Butte Formation). | 38.5 | S-8 |
| DISPLACED CLAYSTONE: extremely weak, gray; laminated; slightly weathered; 10 to 20 degree laminations (Displaced Sentinel Butte Formation). [Very stiff, *Fat Clay (CH);* moist; trace to few sand.] | 42.0 | S-9, S-10, S-11 |

Groundwater Not Encountered During Drilling.

CONTINUED NEXT SHEET

**PENETRATION RESISTANCE** (blows/foot)

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




◇ % Fines (<0.075mm)
● % Water Content
Plastic Limit ├─●─┤ Liquid Limit
Natural Water Content

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- Piezometer Screen and Sand Filter
- Bentonite-Cement Grout
- Bentonite Chips/Pellets
- Surface Concrete Seal

NOTES

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

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

## LOG OF BORING RP-127-09

February 2020 102116-200

**SHANNON & WILSON, INC.**
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**FIG. A-4**
Sheet 1 of 2

REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 100.4 ft. | Northing: | 233,951 ft. | Drilling Method: | HSA to Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2172.7 ft. | Easting: | 1,288,143 ft. | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | State Plane | Offset: | - | Other Comments: | To mud rotary at 15.0 feet | | |

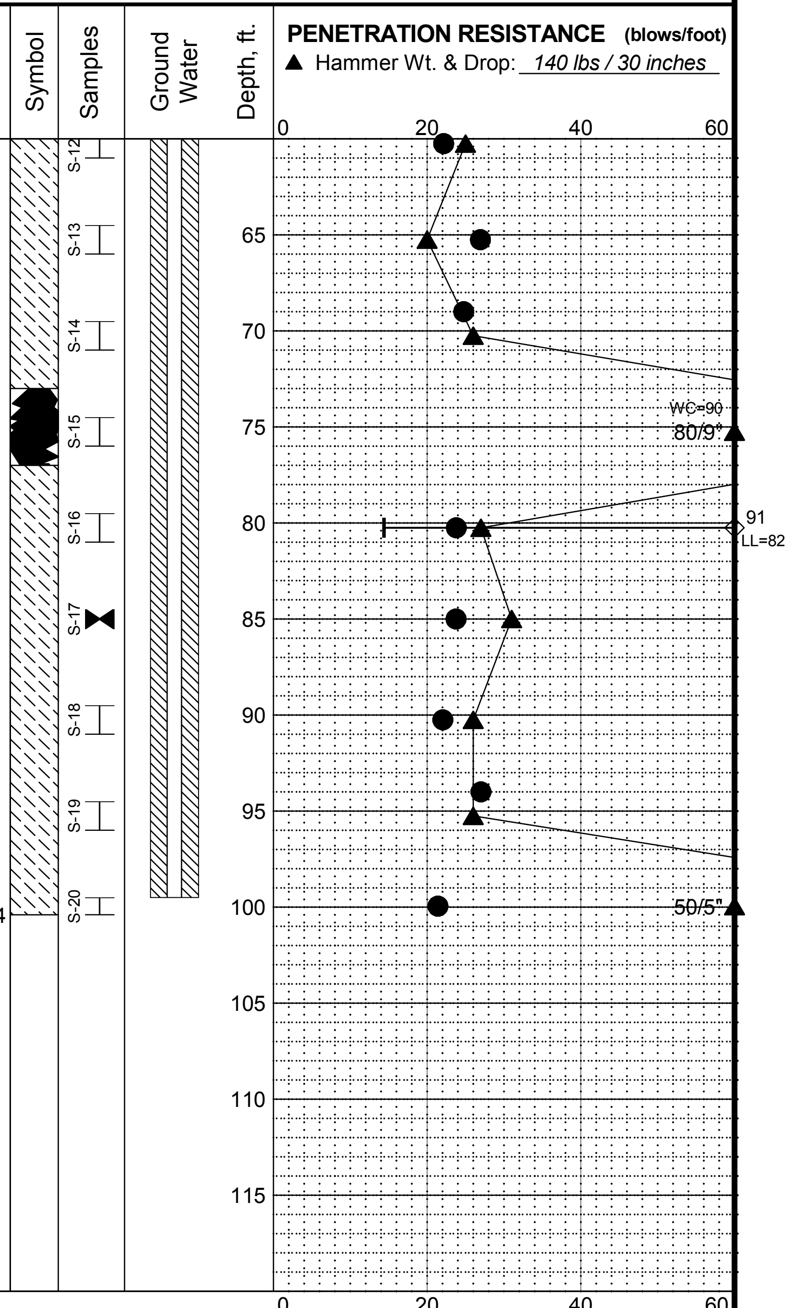
**SOIL DESCRIPTION**

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

| SOIL DESCRIPTION | Depth, ft. | Samples |
|---|---|---|
| DISPLACED CLAYSTONE (continued)<br><br>- Trace carbonaceous fragments from 68 to 73 feet. | 73.0 | S-12, S-13, S-14 |
| POTENTIALLY DISPLACED COAL: very weak, black (Potentially Displaced Sentinel Butte Formation). | 77.0 | S-15 |
| POTENTIALLY DISPLACED CLAYSTONE: extremely weak, gray; laminated; slightly weathered; trace carbonaceous fragments (Potentially Displaced Sentinel Butte Formation).<br>[Very stiff to hard, *Fat Clay (CH);* moist; few sand.] | 100.4 | S-16, S-17, S-18, S-19, S-20 |
| BOTTOM OF BORING<br>COMPLETED ON 06/27/2019 | | |

**PENETRATION RESISTANCE** (blows/foot)

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




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- Piezometer Screen and Sand Filter
- Bentonite-Cement Grout
- Bentonite Chips/Pellets
- Surface Concrete Seal

◇ % Fines (<0.075mm)
● % Water Content
Plastic Limit ├─●─┤ Liquid Limit
Natural Water Content

NOTES

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

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

**LOG OF BORING RP-127-09**

February 2020 102116-200

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**FIG. A-4**
Sheet 2 of 2

*REV 3*

MASTER_LOG_E 102116-200 HSB.GPJ SHAN_WIL.GDT 2/4/20

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 111 ft. | Northing: | 234,136 ft. | Drilling Method: | HSA to Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2197.7 ft. | Easting: | 1,288,062 ft. | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | State Plane | Offset: | - | Other Comments: | To mud rotary at 25.0 feet | | |

**SOIL DESCRIPTION**

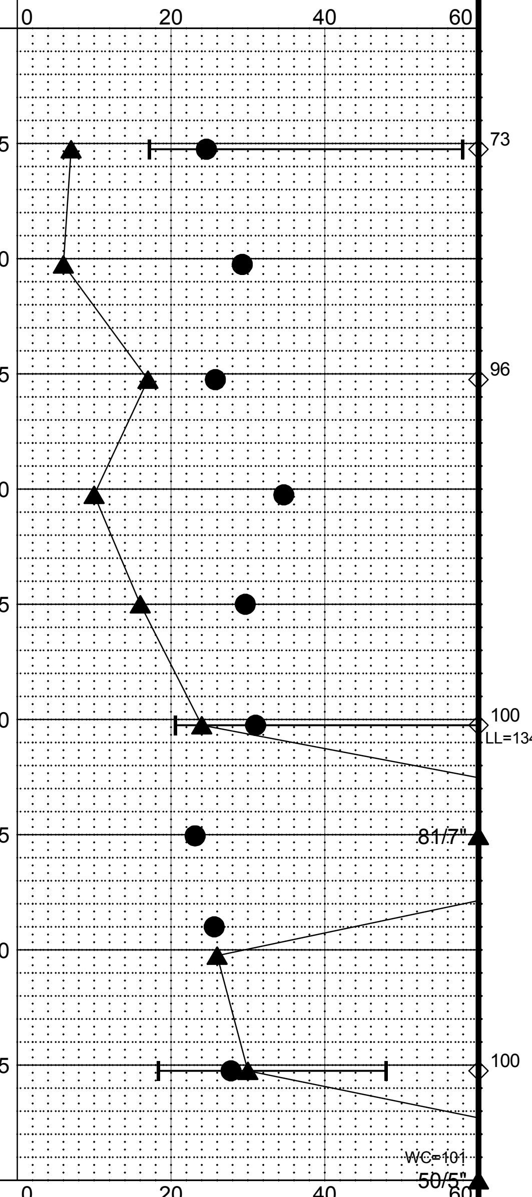
*Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.*

| Soil Description | Depth, ft. | Samples |
|---|---|---|
| Medium stiff to very stiff, brown, *Fat Clay with Sand (CH)* to *Fat Clay (CH);* moist; trace carbonaceous fragments. Landslide Debris | | S-1, S-2, S-3 |
| DISPLACED COAL: extremely weak, black; wet (Displaced Sentinel Butte Formation). | 16.0 | |
| DISPLACED CLAYSTONE: extremely weak, gray; massive; moderately to slightly weathered (Displaced Sentinel Butte Formation). [Stiff to very stiff, *Fat Clay (CH);* moist.] - Carbonaceous from 30.4 to 30.8 feet and green-gray, blocky from 30.8 to 31.0 feet. | 20.0 | S-4, S-5, S-6 |
| DISPLACED CLAYSTONE: extremely weak to very weak, gray; laminated; slightly weathered (Displaced Sentinel Butte Formation). [Very stiff to hard, *Lean Clay (CL);* moist.] | 33.0 | S-7, S-8, S-9 |
| CONTINUED NEXT SHEET | 49.6 | |

Ground Water: During Drilling ∇ (at 25 ft)

**PENETRATION RESISTANCE** (blows/foot)

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




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- Piezometer Screen and Sand Filter
- Bentonite-Cement Grout
- Bentonite Chips/Pellets
- Surface Concrete Seal
- ∇ Ground Water Level ATD

◇ % Fines (<0.075mm)
● % Water Content
Plastic Limit ├─●─┤ Liquid Limit
Natural Water Content

NOTES

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

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

**LOG OF BORING RP-127-10**

February 2020 | 102116-200

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**FIG. A-5**
Sheet 1 of 3

REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 111 ft. | Northing: | 234,136 ft. | Drilling Method: | HSA to Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2197.7 ft. | Easting: | 1,288,062 ft. | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | State Plane | Offset: | - | Other Comments: | To mud rotary at 25.0 feet | | |

**SOIL DESCRIPTION**

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

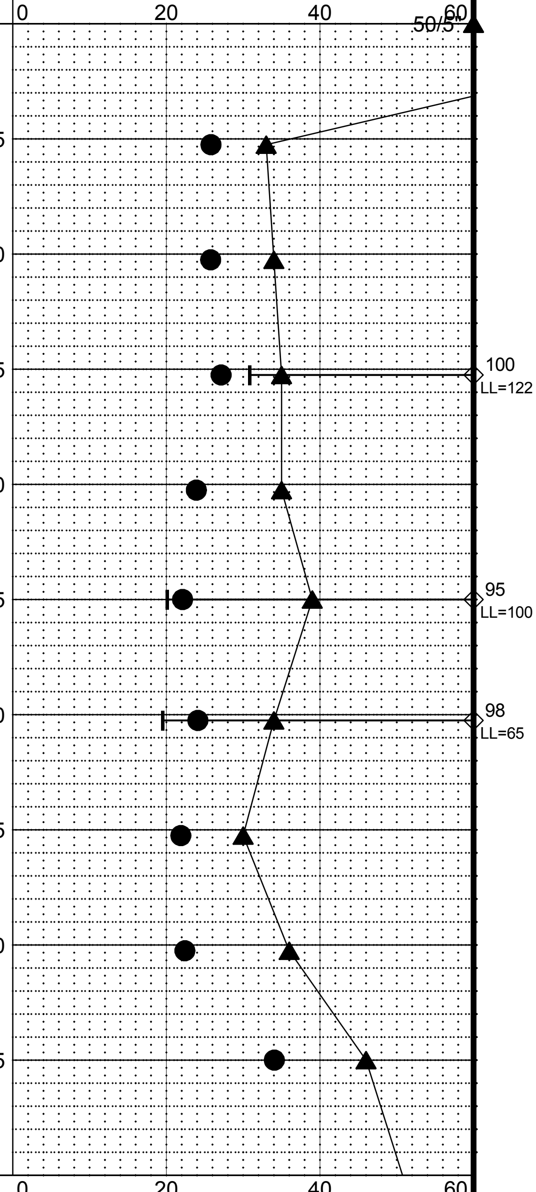
Depth, ft. | Symbol | Samples | Ground Water | Depth, ft.

**PENETRATION RESISTANCE** (blows/foot)

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

| Soil Description | Depth, ft. | Samples |
|---|---|---|
| DISPLACED COAL: very weak, black (Displaced Sentinel Butte Formation). | 52.0 | S-10 |
| DISPLACED CLAYSTONE: extremely weak, gray; laminated; slightly weathered; trace carbonaceous fragments (Displaced Sentinel Butte Formation). [Hard, *Fat Clay (CH);* moist.] | 73.0 | S-11, S-12, S-13, S-14 |
| DISPLACED CLAYSTONE: extremely weak, gray; slightly weathered (Displaced Sentinel Butte Formation). [Hard, *Fat Clay (CH);* moist; trace to few sand.] | 77.5 | S-15 |
| DISPLACED CLAYSTONE: extremely weak, gray; laminated; slightly weathered; 30 degree laminations (Displaced Sentinel Butte Formation). [Hard, *Fat Clay (CH);* moist.] | 95.3 | S-16, S-17, S-18, S-19 |
| POTENTIALLY DISPLACED COAL: extremely weak, black (Potentially Displaced Sentinel Butte Formation). | 97.5 | |

CONTINUED NEXT SHEET




◇ % Fines (<0.075mm)

● % Water Content

Plastic Limit ├─●─┤ Liquid Limit

Natural Water Content

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- Piezometer Screen and Sand Filter
- Bentonite-Cement Grout
- Bentonite Chips/Pellets
- Surface Concrete Seal
- Ground Water Level ATD

NOTES

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

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McKenzie County, North Dakota

**LOG OF BORING RP-127-10**

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Geotechnical and Environmental Consultants

**FIG. A-5**
Sheet 2 of 3

*REV 3*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 111 ft. | Northing: | 234,136 ft. | Drilling Method: | HSA to Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2197.7 ft. | Easting: | 1,288,062 ft. | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | State Plane | Offset: | - | Other Comments: | To mud rotary at 25.0 feet | | |

**SOIL DESCRIPTION**

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

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

**PENETRATION RESISTANCE** (blows/foot)
▲ Hammer Wt. & Drop: *140 lbs / 30 inches*

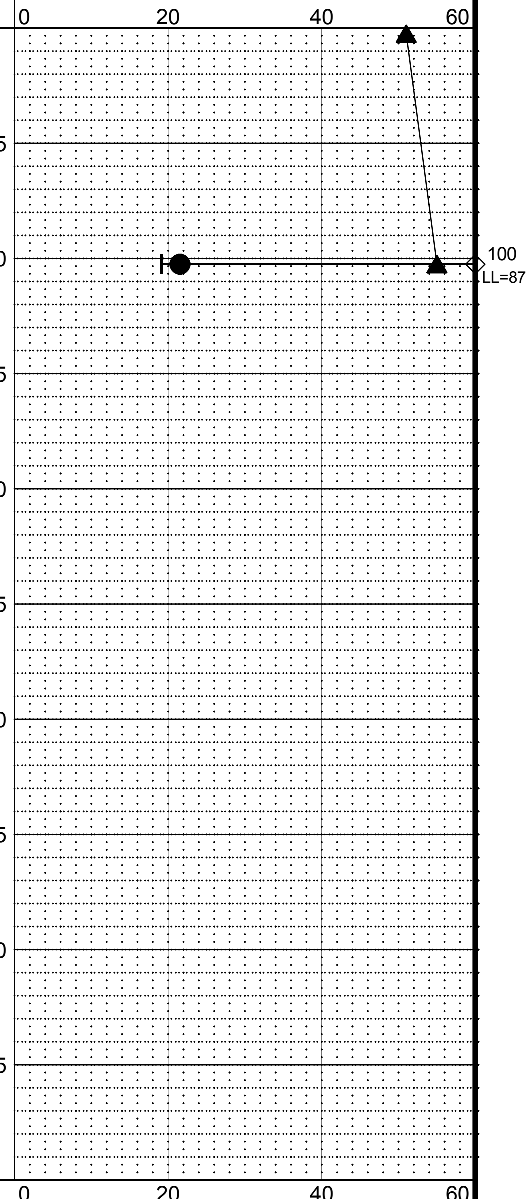
POTENTIALLY DISPLACED CLAYSTONE: extremely weak, gray to green-gray; laminated; slightly weathered to fresh (Potentially Displaced Sentinel Butte Formation). [Hard, *Fat Clay (CH);* moist.]

S-20

S-21

111.0

BOTTOM OF BORING
COMPLETED ON 06/26/2019




◇ % Fines (<0.075mm)
● % Water Content
Plastic Limit |—●—| Liquid Limit
Natural Water Content

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- Piezometer Screen and Sand Filter
- Bentonite-Cement Grout
- Bentonite Chips/Pellets
- Surface Concrete Seal
- Ground Water Level ATD

NOTES

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

Horseshoe Bend Landslide
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McKenzie County, North Dakota

**LOG OF BORING RP-127-10**

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**FIG. A-5**
Sheet 3 of 3

REV 3

MASTER_LOG_E 102116-200 HSB.GPJ SHAN_WIL.GDT 2/4/20

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 91 ft. | Northing: | 233,675 ft. | Drilling Method: | HSA to Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2267.9 ft. | Easting: | 1,288,771 ft. | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | State Plane | Offset: | - | Other Comments: | To mud rotary at 15.0 feet | | |

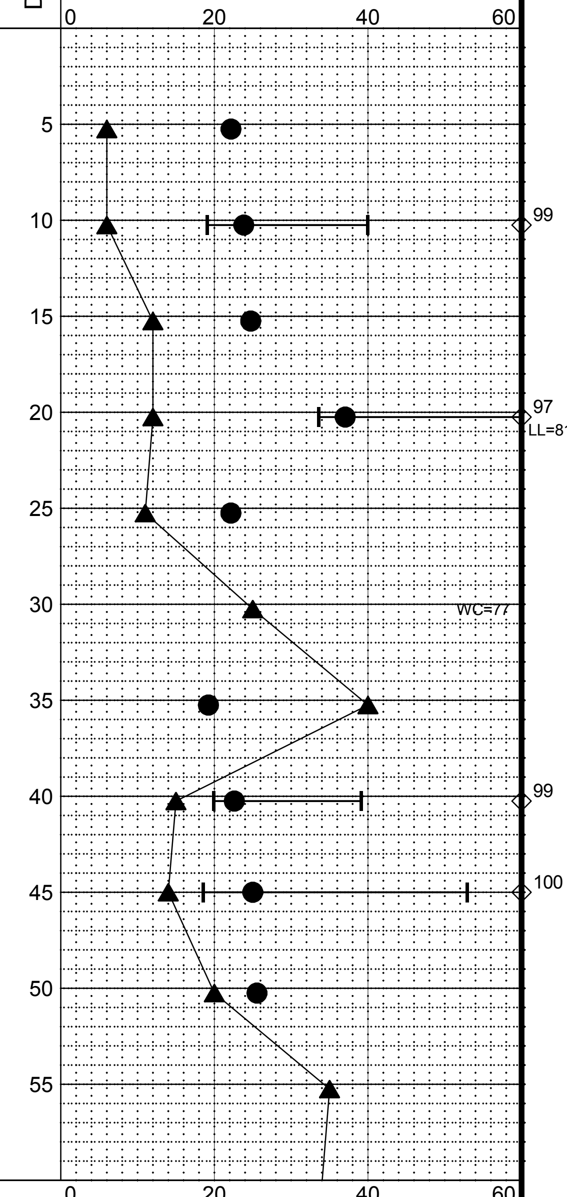
| SOIL DESCRIPTION<br>*Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.* | Depth, ft. |
|---|---|
| Medium stiff to stiff, brown to gray, *Lean Clay (CL);* moist; trace sand. Landslide Debris | 17.0 |
| Stiff, dark brown, *Fat Clay (CH);* moist; trace sand; few to little carbonaceous fragments. Landslide Debris | 23.0 |
| DISPLACED CLAYSTONE: extremely weak, brown; laminated; moderately weathered; 60 degree laminations (Displaced Sentinel Butte Formation). [Stiff, *Fat Clay (CH);* moist.] | 28.0 |
| DISPLACED COAL: extremely weak, black (Displaced Sentinel Butte Formation). | 32.0 |
| DISPLACED CLAYSTONE: extremely weak, brown; laminated; moderately weathered; 60 to 70 degree laminations (Displaced Sentinel Butte Formation). [Stiff to hard, *Lean Clay (CL);* moist; trace sand.] - Gray well cemented layer from 35.5 to 36.0 feet. | 43.0 |
| POTENTIALLY DISPLACED CLAYSTONE: extremely weak, gray; laminated; slightly weathered (Sentinel Butte Formation). [Stiff to hard, *Fat Clay (CH)* to *Lean Clay (CL);* moist.] | |

CONTINUED NEXT SHEET

Samples: S-1, S-2, S-3, S-4, S-5, S-6, S-7, S-8, S-9, S-10, S-11 *

Ground Water: Groundwater Not Encountered During Drilling.

**PENETRATION RESISTANCE** (blows/foot)
▲ Hammer Wt. & Drop: 140 lbs / 30 inches




LEGEND

* Sample Not Recovered
Standard Penetration Test
Modified California Sampler

◇ % Fines (<0.075mm)
● % Water Content
Plastic Limit ├─●─┤ Liquid Limit
Natural Water Content

NOTES

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

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

# LOG OF BORING RP-127-11

February 2020 102116-200

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. A-6**
Sheet 1 of 2

REV 3

MASTER_LOG_E 102116-200 HSB.GPJ SHAN_WIL.GDT 2/4/20

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 91 ft. | Northing: | 233,675 ft. | Drilling Method: | HSA to Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2267.9 ft. | Easting: | 1,288,771 ft. | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | State Plane | Offset: | - | Other Comments: | To mud rotary at 15.0 feet | | |

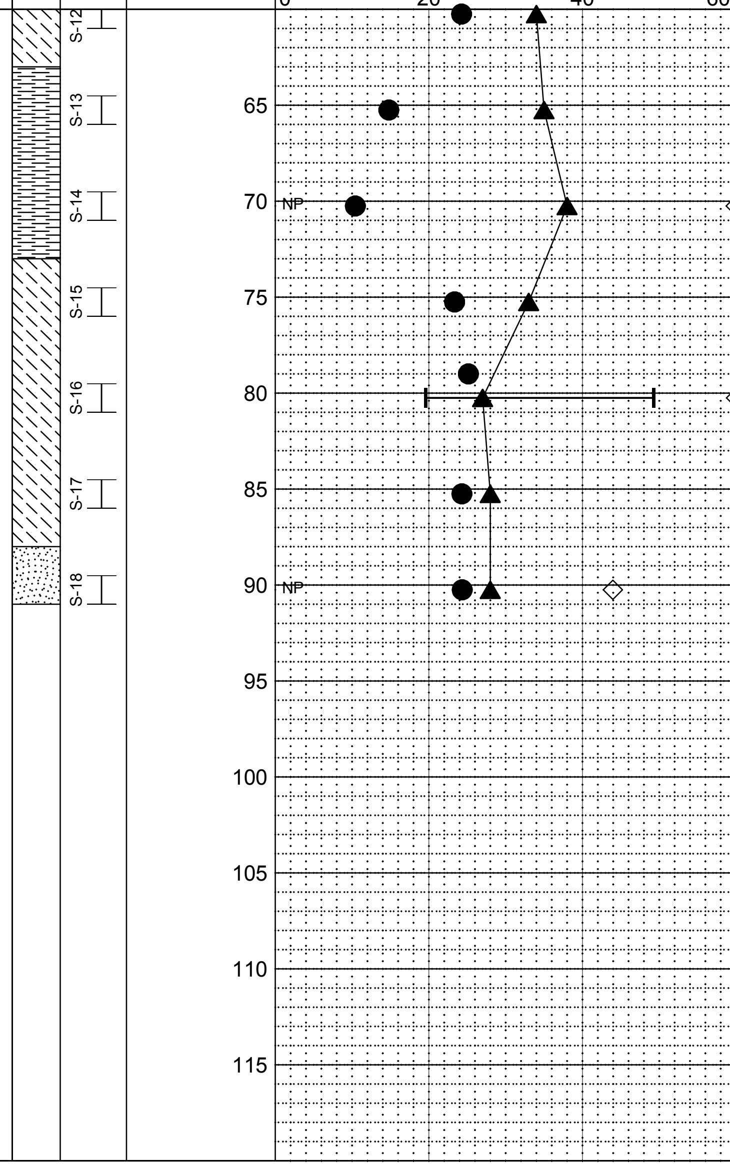
**SOIL DESCRIPTION**

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

| SOIL DESCRIPTION | Depth, ft. | Samples |
|---|---|---|
| POTENTIALLY DISPLACED CLAYSTONE (continued) | | S-12 |
| POTENTIALLY DISPLACED SILTSTONE: extremely weak, brown to tan; laminated; slightly weathered (Sentinel Butte Formation). [Dense, *Sandy Silt (ML);* moist.] | 63.0 | S-13, S-14 |
| POTENTIALLY DISPLACED CLAYSTONE: extremely weak, gray; laminated; slightly weathered (Sentinel Butte Formation). [Very stiff to hard, *Lean Clay (CL);* moist.] | 73.0 | S-15, S-16, S-17 |
| POTENTIALLY DISPLACED SANDSTONE: extremely weak, brown to tan; laminated; slightly weathered (Sentinel Butte Formation). [Medium dense, *Silty Sand (SM);* moist.] | 88.0 | S-18 |
| BOTTOM OF BORING COMPLETED ON 06/29/2019 | 91.0 | |

**PENETRATION RESISTANCE** (blows/foot)

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




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler

◇ % Fines (<0.075mm)

● % Water Content

Plastic Limit ├──●──┤ Liquid Limit

Natural Water Content

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

NOTES

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

## LOG OF BORING RP-127-11

February 2020 102116-200

**SHANNON & WILSON, INC.**
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**FIG. A-6**
Sheet 2 of 2

REV 3

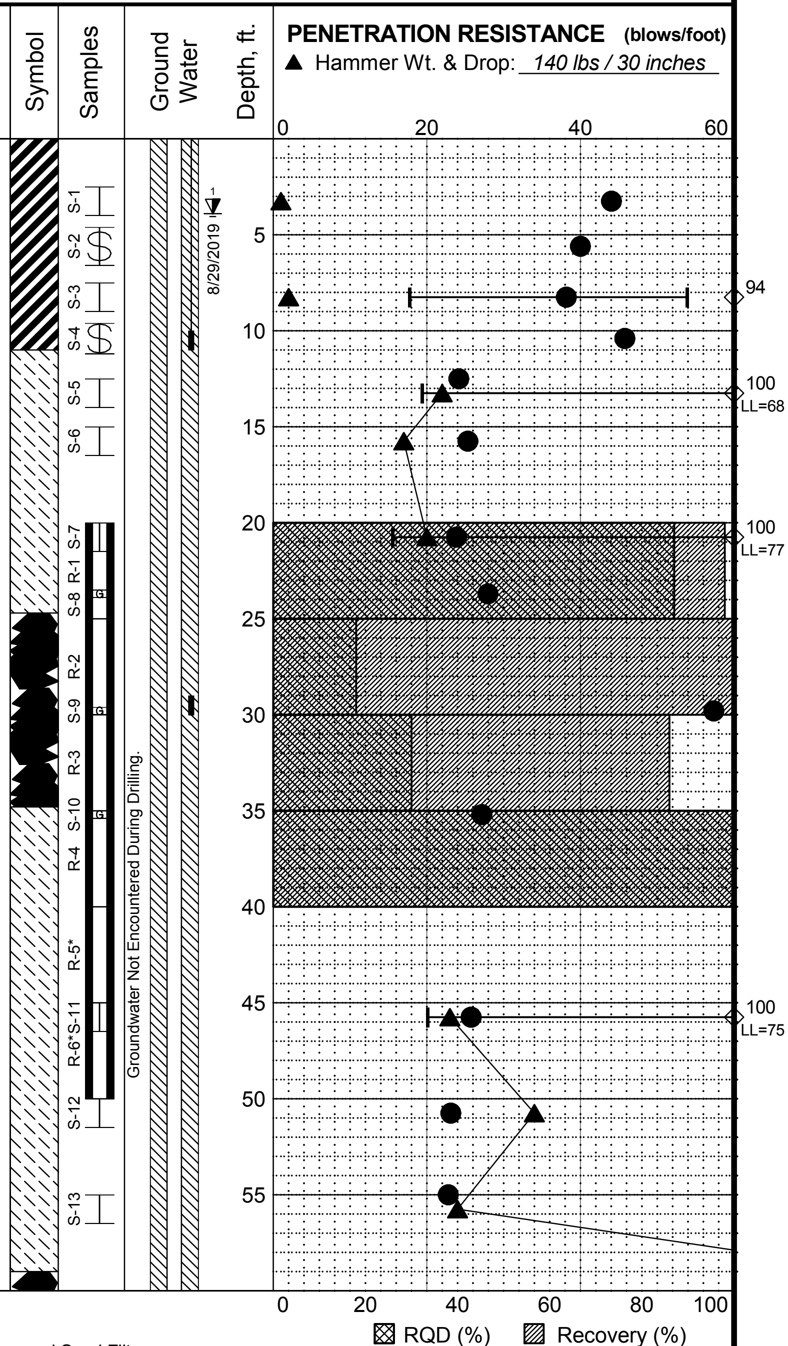
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 80.8 ft. | Northing: | 1,121 ft. | Drilling Method: | HQ Casing Advance | Hole Diam.: | 4.5 in. |
| Top Elevation: | 2350 ft. | Easting: | 13,113 ft. | Drilling Company: | Salisbury & Associates | Rod Type.: | NWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Burley | Hammer Type: | Cathead |
| Horiz. Datum: | State Plane | Offset: | | Other Comments: | | | |

**SOIL DESCRIPTION**

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

| SOIL DESCRIPTION | Depth, ft. |
|---|---|
| Very soft to soft, gray to brown, *Fat Clay (CH);* moist to wet; few carbonaceous fragments. Landslide Debris. | 11.0 |
| CLAYSTONE: extremely weak, gray; laminated; slightly weathered to fresh (Sentinel Butte Formation).<br><br>[Very stiff, *Fat Clay (CH);* moist.] | 24.7 |
| COAL: extremely weak, black (Sentinel Butte Formation).<br><br>- Very close to close spaced bedding joints at 0 degrees, smooth, and planar. | 34.8 |
| CLAYSTONE: extremely weak, gray; laminated; fresh; trace carbonaceous fragments (Sentinel Butte Formation).<br><br>[Very stiff, *Fat Clay (CH);* moist.]<br>- Green-gray from 35.0 to 35.7 feet. | 59.0 |

CONTINUED NEXT SHEET




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Rock Core
- Grab Sample
- Piezometer Screen and Sand Filter
- Bentonite-Cement Grout
- Bentonite Chips/Pellets
- Surface Concrete Seal
- Ground Water Level in VWP

NOTES

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

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

# LOG OF BORING RP-127-12

February 2020 102116-200

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. A-7**
Sheet 1 of 2

REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 80.8 ft. | Northing: | 1,121 ft. | Drilling Method: | HQ Casing Advance | Hole Diam.: | 4.5 in. |
| Top Elevation: | 2350 ft. | Easting: | 13,113 ft. | Drilling Company: | Salisbury & Associates | Rod Type.: | NWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Burley | Hammer Type: | Cathead |
| Horiz. Datum: | State Plane | Offset: | | Other Comments: | | | |

**SOIL DESCRIPTION**

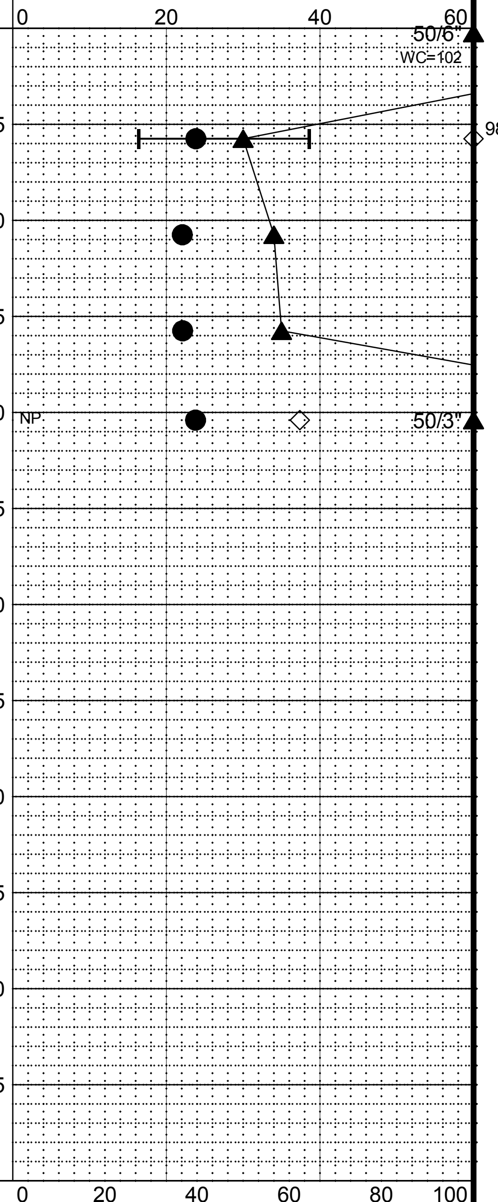
*Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.*

| Soil Description | Depth, ft. | Samples |
|---|---|---|
| COAL: very weak, black. | 61.0 | S-14 |
| CLAYSTONE: inferred from drilling fluid. | 62.0 | |
| COAL: inferred from drilling fluid. | 63.0 | |
| CLAYSTONE: extremely weak, gray; laminated; fresh; trace carbonaceous fragments; interbedded siltstone layers (Sentinel Butte Formation). [Hard, *Fat Clay (CH);* moist.] | 78.0 | S-15, S-16, S-17 |
| SANDSTONE: very weak, gray; massive; fresh (Sentinel Butte Formation). [Very dense, *Silty Sand (SM);* moist.] | 80.8 | S-18 |

BOTTOM OF BORING
COMPLETED ON 08/15/2019

**PENETRATION RESISTANCE** (blows/foot)

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




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Rock Core
- Grab Sample
- Piezometer Screen and Sand Filter
- Bentonite-Cement Grout
- Bentonite Chips/Pellets
- Surface Concrete Seal
- Ground Water Level in VWP

NOTES

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

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

## LOG OF BORING RP-127-12

February 2020 102116-200

**SHANNON & WILSON, INC.**
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**FIG. A-7**
Sheet 2 of 2

REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 91 ft. | Northing: | 234,929 ft. | Drilling Method: | HSA to Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2327.8 ft. | Easting: | 1,287,144 ft. | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | State Plane | Offset: | - | Other Comments: | To mud rotary at 15.0 feet | | |

**SOIL DESCRIPTION**

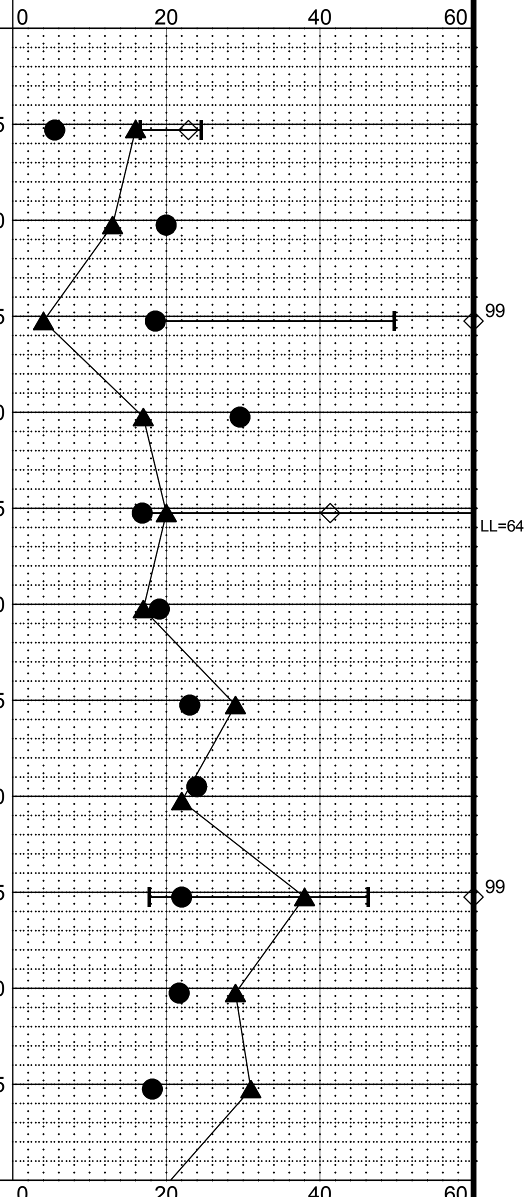
*Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.*

| SOIL DESCRIPTION | Depth, ft. | Samples |
|---|---|---|
| 8 inches of Asphalt over 10 inches of Road Base. | 0.7 / 1.5 | |
| Medium dense, brown, *Clayey Sand with Gravel (SC-SM);* moist. Fill | | S-1 |
| Stiff, mottled brown, *Fat Clay (CH);* moist; few carbonaceous fragments and bedrock fragments. Fill | 7.0 | S-2 |
| Soft to medium stiff, brown, *Fat Clay (CH);* moist; trace sand. Colluvium | 10.5 | S-3 |
| CLAYSTONE: extremely weak, brown to gray; laminated; moderately to slightly weathered (Sentinel Butte Formation). [Very stiff, *Fat Clay (CH);* moist.] | 17.0 | S-4 |
| SANDSTONE: extremely weak, brown to light brown; laminated; moderately weathered (Sentinel Butte Formation). [Medium dense, *Clayey Sand (SC);* moist.] | 23.0 | S-5, S-6 |
| COAL: extremely weak, black (Sentinel Butte Formation). | 31.0 | |
| CLAYSTONE: extremely weak, brown to gray; laminated; moderately to slightly weathered; interbedded sandstone from 33 to 45 feet; trace to few carbonaceous fragments (Sentinel Butte Formation). [Very stiff to hard, *Fat Clay (CH);* moist; trace sand.] | 33.0 | S-7, S-8, S-9, S-10 |
| SANDSTONE: continued on next page. | 55.0 | S-11 |

CONTINUED NEXT SHEET

**PENETRATION RESISTANCE** (blows/foot)

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




◇ % Fines (<0.075mm)
● % Water Content
Plastic Limit ├──●──┤ Liquid Limit
Natural Water Content

LEGEND

* Sample Not Recovered
Standard Penetration Test
Ground Water Level ATD

NOTES

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

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

## LOG OF BORING RP-128-04

February 2020 102116-200

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. A-8**
Sheet 1 of 2

REV 3

MASTER_LOG_E 102116-200 HSB.GPJ SHAN_WIL.GDT 2/4/20

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 91 ft. | Northing: | 234,929 ft. | Drilling Method: | HSA to Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2327.8 ft. | Easting: | 1,287,144 ft. | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | NAD 1983 | Station: | | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | State Plane | Offset: | - | Other Comments: | To mud rotary at 15.0 feet | | |

**SOIL DESCRIPTION**

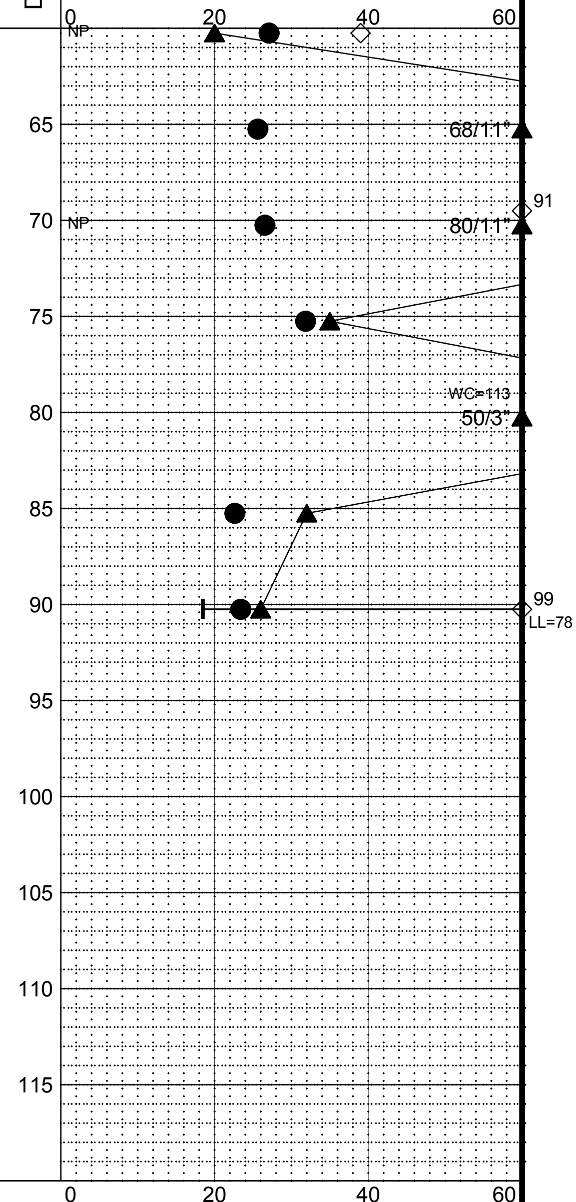
*Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.*

| SOIL DESCRIPTION | Depth, ft. | Samples |
|---|---|---|
| SANDSTONE: extremely weak, brown to gray; laminated; moderately to slightly weathered (Sentinel Butte Formation). [Medium dense to dense, *Silty Sand (SM);* moist.] | 62.0 | S-12, S-13 |
| CLAYSTONE: extremely weak, brown to gray; laminated; moderately to slightly weathered (Sentinel Butte Formation). [Very stiff, *Fat Clay (CH);* moist.] | 65.0 | S-14 |
| COAL: very weak, black (Sentinel Butte Formation). | 68.0 | S-15 |
| SILTSTONE: extremely weak to very weak, brown; laminated carboanceous fragments; slightly weathered (Sentinel Butte Formation). [Dense to very dense, *Silt (ML);* moist; few sand.] | 76.0 | S-16, S-17 |
| COAL: extremely weak to very weak, black (Sentinel Butte Formation). | 85.5 | S-18 |
| CLAYSTONE: extremely weak, gray to green-gray; laminated; slightly weathered; interbedded sandstone; trace carbonaceous fragments (Sentinel Butte Formation). [Very stiff to hard, *Fat Clay (CH);* moist; trace sand.] | 91.0 | |

BOTTOM OF BORING
COMPLETED ON 06/28/2019

Symbol | Ground Water: During Drilling

**PENETRATION RESISTANCE** (blows/foot)
▲ Hammer Wt. & Drop: 140 lbs / 30 inches




◇ % Fines (<0.075mm)
● % Water Content
Plastic Limit ⊢●⊣ Liquid Limit
Natural Water Content

LEGEND

* Sample Not Recovered
⌶ Standard Penetration Test
▽ Ground Water Level ATD

NOTES

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

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

# LOG OF BORING RP-128-04

February 2020 | 102116-200

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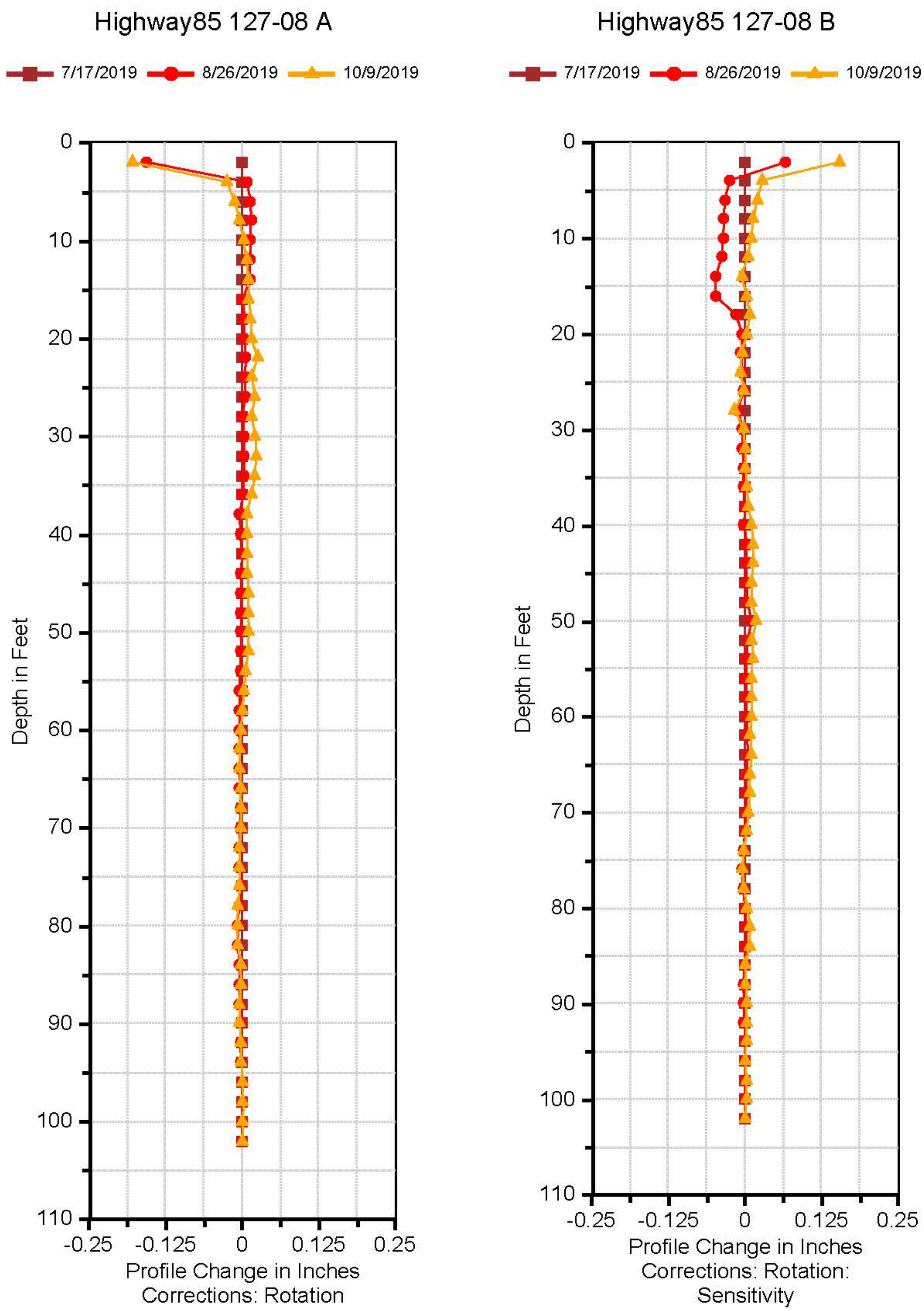
**FIG. A-8**
Sheet 2 of 2

REV 3

MASTER_LOG_E 102116-200 HSB.GPJ SHAN_WIL.GDT 2/4/20




Horseshoe Bend Landslide Repair
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**INCLINOMETER CUMULATIVE DISPLACEMENT, BORING RP-127-08**

February 2020 | 102116-200

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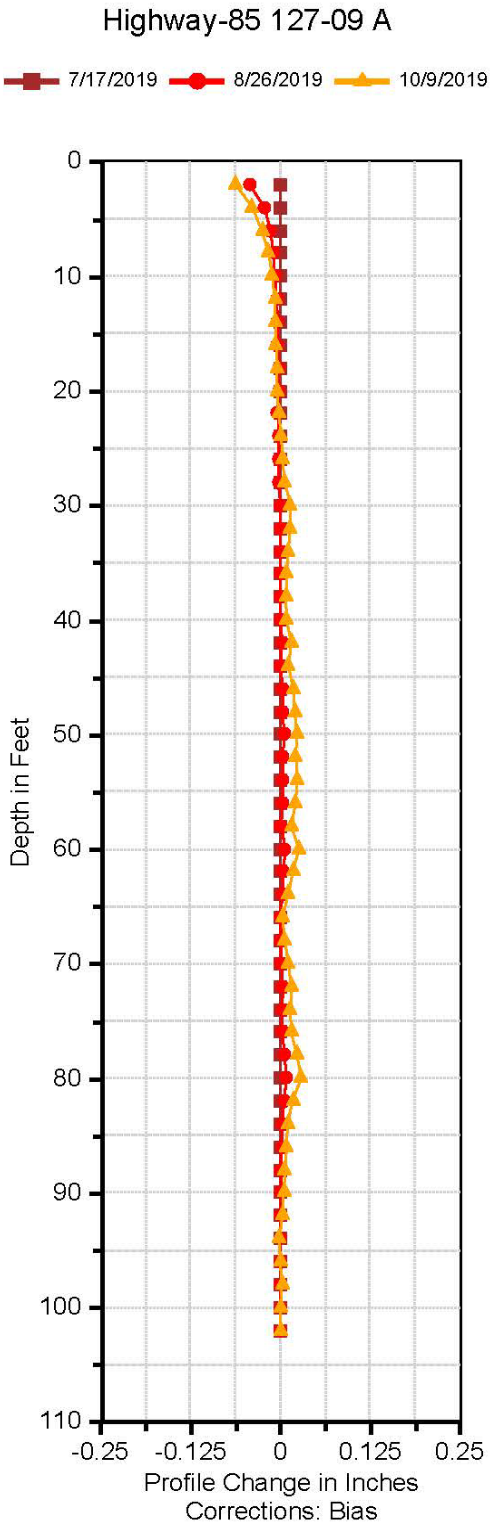
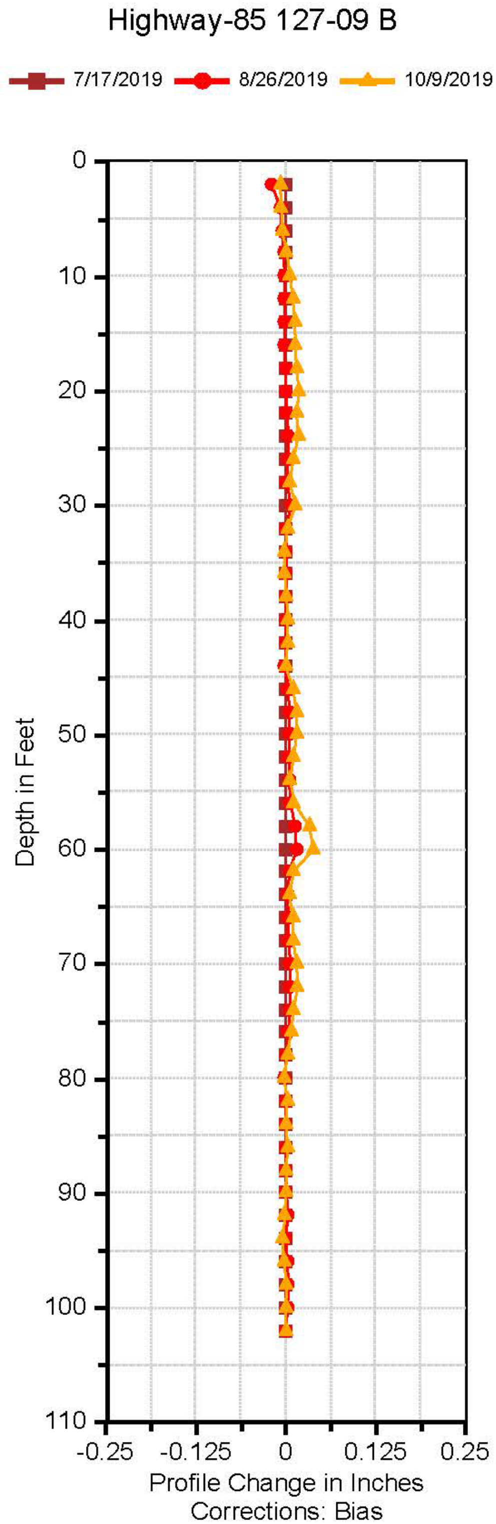
**FIG. A-9**




Horseshoe Bend Landslide Repair
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**INCLINOMETER CUMULATIVE DISPLACEMENT, BORING RP-127-09**

February 2020 | 102116-200

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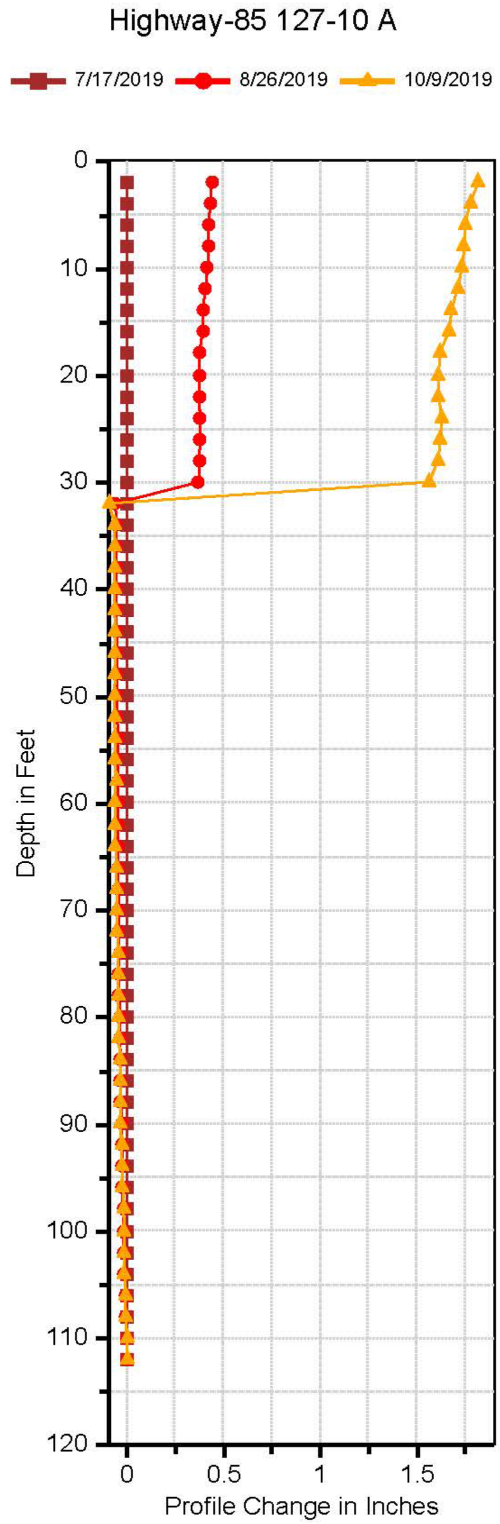
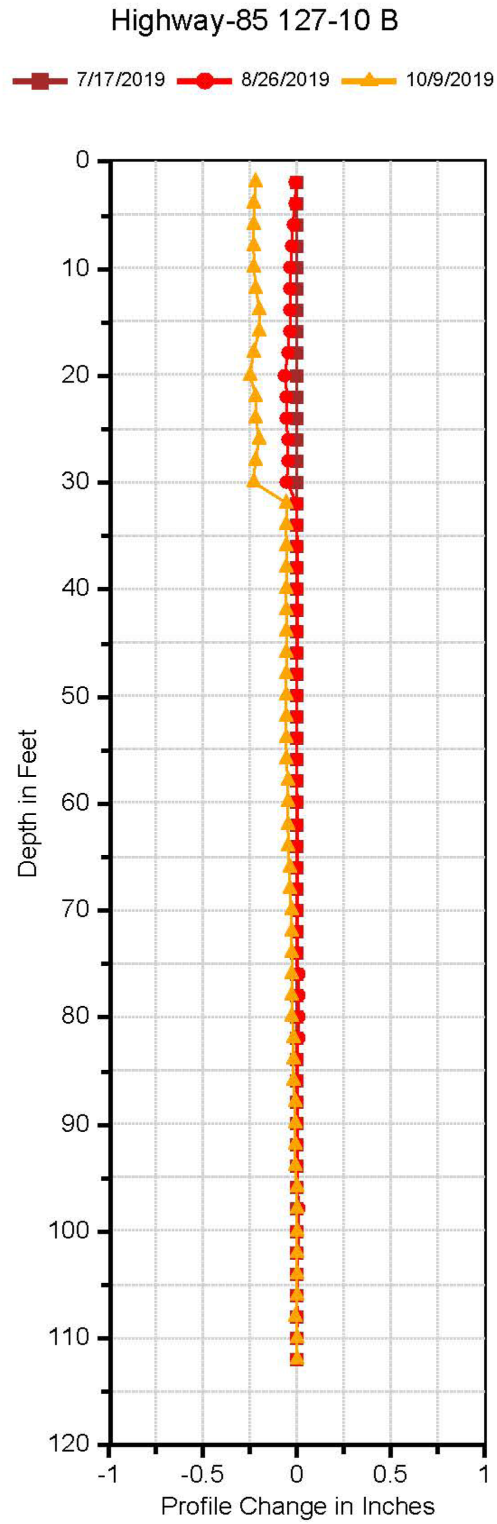
**FIG. A-10**




Horseshoe Bend Landslide Repair
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**INCLINOMETER CUMULATIVE DISPLACEMENT, BORING RP-127-10**

February 2020 102116-200

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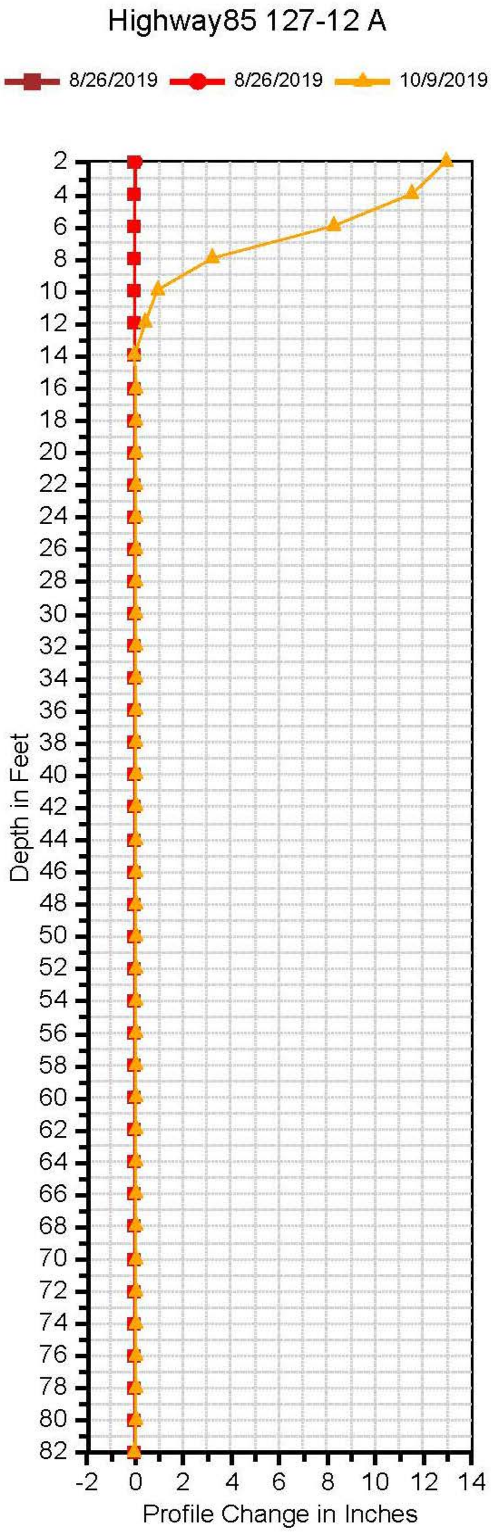
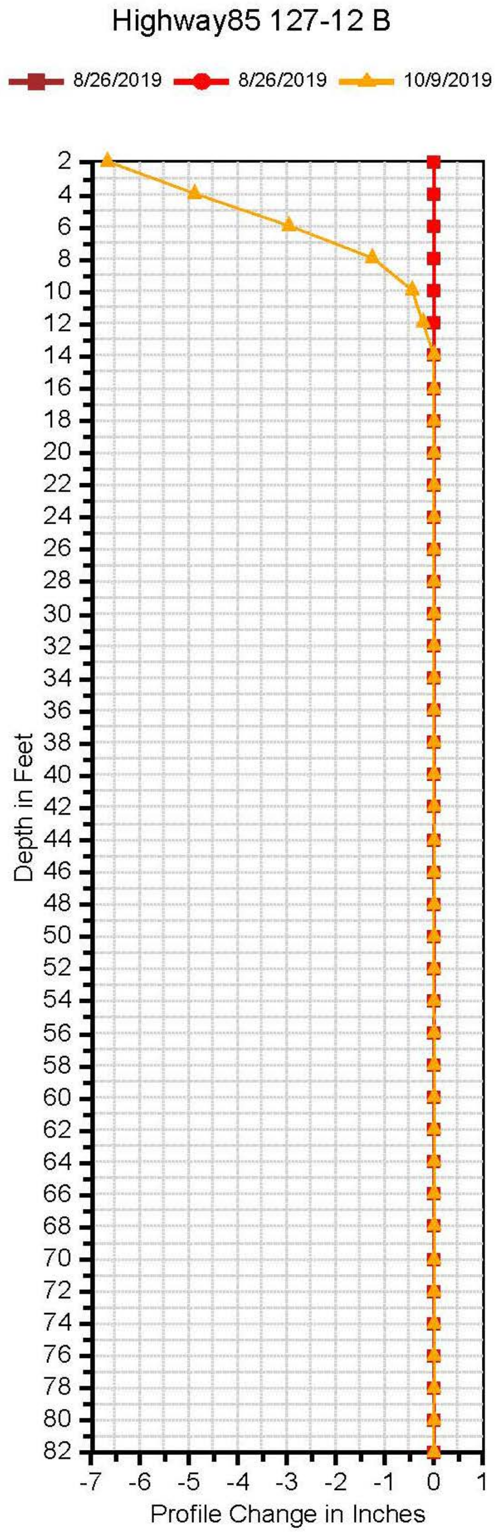
**FIG. A-11**




Horseshoe Bend Landslide Repair
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**INCLINOMETER CUMULATIVE DISPLACEMENT, BORING RP-127-12**

February 2020 | 102116-200

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Geotechnical and Environmental Consultants

**FIG. A-12**

APPENDIX B: LABORATORY TEST RESULTS

Appendix B

# Current Laboratory Test Results

## CONTENTS

B.1 Introduction ....... B-1

B.2 Geotechnical Tests ....... B-1

B.2.1 Water Content ....... B-1

B.2.2 Grain Size Distribution and Hydrometer Analyses ....... B-1

B.2.3 Atterberg Limits ....... B-2

B.2.4 Corrosion ....... B-2

## Table

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

## Figures

Figure B-1: Grain Size Distribution

Figure B-2: Plasticity Chart

## B.1 INTRODUCTION

Laboratory tests were completed on soil samples retrieved from the boring in general accordance with the American Association of State Highway and Transportation Officials (AASHTO) and ASTM International (ASTM) testing methods. The laboratory testing program was performed to classify the materials into similar geologic groups and provide data that can be used for design of the project. The geotechnical laboratory testing was performed at our laboratory in Denver, Colorado and by Colorado Analytical Laboratories, Inc. A summary of the laboratory test results is presented in Table B-1. The following sections describe the laboratory testing procedures.

## B.2 GEOTECHNICAL TESTS

### B.2.1 Water Content

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

### B.2.2 Grain Size Distribution and Hydrometer Analyses

The grain size distribution of selected samples was determined in general accordance with ASTM D6913, Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. Results of these analyses are presented as grain size distribution curves on Figure B-1; gravel, sand, and fines fractions are summarized in Table B-1. For select samples, only the fines content (percentage by mass of particles passing the U.S. Standard No. 200 Sieve or 0.075-millimeter opening) was determined. Fines content analysis testing was completed in accordance with ASTM D1140, Standard Test Methods for Amount of Material in Soils Finer than No. 200 (75-µm) Sieve. The percent fines (silt and clay-sized particles passing the No. 200 sieve) are shown graphically on the boring logs in Appendix A and are also summarized in Table B-1.

### B.2.3 Atterberg Limits

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

### B.2.4 Corrosion

Corrosion testing of select samples was performed by Colorado Analytical for pH, resistivity, sulfate content, and chloride content. Testing for pH were done in general accordance with ASTM G51-77 and resistivity were done in general accordance with AASHTO T288-91. Sulfate and chloride content testing was done in accordance with AASHTO T290-91 / ASTM D4327 and AASHTO T291-91 / ASTM D4327, respectively. Test results for sulfate and chloride content are given in units of percent by weight. The test results are summarized in Table B-1.

# Table 1 - Summary of Laboratory Testing

| SAMPLE DATA | | | | | | GRAIN SIZE ANALYSIS | | | ATTERBERG LIMITS | | | CORROSION SUITE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Classification | Water Content (%) | Gravel (%) | Sand (%) | Fines[4] (%) | Liquid Limit | Plastic Limit | Plasticity Index | pH | Resistivity (omh-cm) | Sulfates (%) | Chlorides (%) |
| RP-127-08 | S-1 | 4.5 | 6.0 | CL | 19.5 | | | 100 | 44 | 15 | 29 | | | | |
| | S-2 | 9.5 | 11.0 | CH | 23.6 | | | 100 | 66 | 17 | 49 | | | | |
| | S-3 | 14.5 | 16.0 | | 26.1 | | | | | | | | | | |
| | S-5 | 24.5 | 26.0 | | 24.1 | | | | | | | | | | |
| | S-6 | 29.5 | 31.0 | | 24.2 | | | | | | | | | | |
| | S-7 | 34.5 | 35.5 | ML | 27.9 | | | 61 | 31 | 27 | 4 | | | | |
| | S-8 | 39.5 | 41.0 | | 34.6 | | | | | | | | | | |
| | S-9 | 44.5 | 46.0 | | 29.8 | | | | | | | | | | |
| | S-10 | 49.5 | 51.0 | | 29.7 | | | | | | | | | | |
| | S-11 | 54.5 | 55.5 | CH | 29.5 | | | 99 | 139 | 24 | 115 | | | | |
| | S-12 | 59.5 | 61.0 | | 24.5 | | | | | | | | | | |
| | S-13 | 64.5 | 66.0 | | 24.7 | | | | | | | | | | |
| | S-14 | 69.5 | 71.0 | | 28.0 | | | | | | | | | | |
| | S-15 | 74.5 | 76.0 | CH | 26.1 | | | 99 | 86 | 17 | 69 | | | | |
| | S-16 | 79.5 | 81.0 | | 24.8 | | | | | | | | | | |
| | S-17 | 84.5 | 86.0 | | 27.5 | | | | | | | | | | |
| | S-18 | 89.5 | 91.0 | | 25.6 | | | | | | | | | | |
| | S-19 | 94.5 | 95.5 | | 23.3 | | | | | | | | | | |
| | S-20 | 99.5 | 101.0 | CH | 26.3 | | | 99 | 87 | 15 | 72 | | | | |

## Table 1 - Summary of Laboratory Testing

| SAMPLE DATA | | | | | | GRAIN SIZE ANALYSIS | | | ATTERBERG LIMITS | | | CORROSION SUITE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Classification | Water Content (%) | Gravel (%) | Sand (%) | Fines[4] (%) | Liquid Limit | Plastic Limit | Plasticity Index | pH | Resistivity (omh-cm) | Sulfates (%) | Chlorides (%) |
| RP-127-09 | S-1 | 4.5 | 6.0 | | 23.0 | | | | | | | | | | |
| | S-2 | 9.5 | 11.0 | CL | 22.2 | | | 85 | 39 | 20 | 19 | | | | |
| | S-3 | 14.5 | 16.0 | | 23.9 | | | | | | | | | | |
| | S-4 | 19.5 | 21.0 | CH | 23.5 | | | 89 | 55 | 14 | 41 | | | | |
| | S-5 | 24.5 | 26.0 | | 24.4 | | | | | | | 7.8 | 315 | 0.249 | 0.0021 |
| | S-6 | 29.5 | 30.5 | CH | 23.6 | | | 99 | 88 | 17 | 71 | | | | |
| | S-7 | 34.5 | 36.0 | | 30.8 | | | | | | | | | | |
| | S-8 | 39.5 | 41.0 | | 98.6 | | | | | | | | | | |
| | S-9 | 44.5 | 46.0 | CH | 24.8 | 0 | 6 | 78 / 16 | 71 | 19 | 52 | | | | |
| | S-10 | 49.5 | 51.0 | | 25.5 | | | | | | | | | | |
| | S-11 | 54.5 | 55.5 | CH | 29.5 | 0 | 0 | 52 / 48 | 91 | 18 | 73 | | | | |
| | S-12 | 59.5 | 61.0 | | 22.2 | | | | | | | | | | |
| | S-13 | 64.5 | 66.0 | | 26.9 | | | | | | | | | | |
| | S-14 | 69.5 | 71.0 | | 24.8 | | | | | | | | | | |
| | S-15 | 74.5 | 76.0 | | 89.8 | | | | | | | | | | |
| | S-16 | 79.5 | 81.0 | CH | 23.8 | 0 | 9.1 | 71 / 20 | 82 | 14 | 68 | | | | |
| | S-17 | 84.5 | 85.5 | | 23.8 | | | | | | | | | | |
| | S-18 | 89.5 | 91.0 | | 22.0 | | | | | | | | | | |
| | S-19 | 94.5 | 96.0 | | 27.0 | | | | | | | 9.2 | 675 | 0.01 | 0.0021 |
| | S-20 | 99.5 | 100.4 | | 21.4 | | | | | | | | | | |

# Table 1 - Summary of Laboratory Testing

| SAMPLE DATA | | | | | | GRAIN SIZE ANALYSIS | | | ATTERBERG LIMITS | | | CORROSION SUITE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | | | | | | | | | | | | | |
| Boring | Sample | Top (feet) | Bottom (feet) | USCS Classification | Water Content (%) | Gravel (%) | Sand (%) | Fines[4] (%) | Liquid Limit | Plastic Limit | Plasticity Index | pH | Resistivity (omh-cm) | Sulfates (%) | Chlorides (%) |
| | S-1 | 4.5 | 6.0 | CH | 24.6 | | | 73 | 58 | 17 | 41 | | | | |
| | S-2 | 9.5 | 11.0 | | 29.3 | | | | | | | | | | |
| | S-3 | 14.5 | 16.0 | | 25.8 | | | 96 | | | | | | | |
| | S-4 | 19.5 | 21.0 | | 34.7 | | | | | | | | | | |
| | S-5 | 24.5 | 25.5 | | 29.7 | | | | | | | 9.6 | 691 | 0.025 | 0.002 |
| | S-6 | 29.5 | 31.0 | CH | 31.0 | 0 | 0 | 42 / 58 | 134 | 21 | 113 | | | | |
| | S-7 | 34.5 | 35.6 | | 23.1 | | | | | | | | | | |
| | S-8 | 39.5 | 41.0 | | 25.6 | | | | | | | | | | |
| | S-9 | 44.5 | 46.0 | CL | 27.8 | 0 | 0 | 68 / 32 | 48 | 18 | 30 | | | | |
| | S-10 | 49.5 | 50.5 | | 101.1 | | | | | | | | | | |
| RP-127-10 | S-11 | 54.5 | 56.0 | | 25.8 | | | | | | | | | | |
| | S-12 | 59.5 | 61.0 | | 25.8 | | | | | | | | | | |
| | S-13 | 64.5 | 66.0 | CH | 27.1 | | | 100 | 122 | 31 | 91 | | | | |
| | S-14 | 69.5 | 71.0 | | 23.9 | | | | | | | | | | |
| | S-15 | 74.5 | 75.5 | CH | 22.1 | | | 95 | 100 | 20 | 80 | | | | |
| | S-16 | 79.5 | 81.0 | CH | 24.1 | 0 | 2 | 76 / 22 | 65 | 19 | 46 | | | | |
| | S-17 | 84.5 | 86.0 | | 21.9 | | | | | | | | | | |
| | S-18 | 89.5 | 91.0 | | 22.4 | | | | | | | | | | |
| | S-19 | 94.5 | 95.5 | | 34.1 | | | | | | | | | | |
| | S-20 | 99.5 | 101.0 | | | | | | | | | 9.4 | 540 | 0.018 | 0.0024 |
| | S-21 | 109.5 | 111.0 | CH | 21.5 | | | 100 | 87 | 19 | 68 | | | | |

# Table 1 - Summary of Laboratory Testing

| SAMPLE DATA | | | | | | GRAIN SIZE ANALYSIS | | | ATTERBERG LIMITS | | | CORROSION SUITE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Classification | Water Content (%) | Gravel (%) | Sand (%) | Fines[4] (%) | Liquid Limit | Plastic Limit | Plasticity Index | pH | Resistivity (omh-cm) | Sulfates (%) | Chlorides (%) |
| RP-127-11 | S-1 | 4.5 | 6.0 | | 22.2 | | | | | | | | | | |
| | S-2 | 9.5 | 11.0 | CL | 23.8 | | | 99 | 40 | 19 | 21 | | | | |
| | S-3 | 14.5 | 16.0 | | 24.7 | | | | | | | | | | |
| | S-4 | 19.5 | 21.0 | CH | 37.0 | | | 97 | 81 | 34 | 47 | | | | |
| | S-5 | 24.5 | 26.0 | | 22.1 | | | | | | | | | | |
| | S-6 | 29.5 | 31.0 | | 76.6 | | | | | | | | | | |
| | S-7 | 34.5 | 36.0 | | 19.2 | | | | | | | | | | |
| | S-8 | 39.5 | 41.0 | CL | 22.6 | | | 85 / 15 | 39 | 20 | 19 | | | | |
| | S-9 | 44.5 | 45.5 | CH | 25.0 | | | 60 / 40 | 53 | 19 | 34 | | | | |
| | S-10 | 49.5 | 51.0 | | 25.5 | | | | | | | | | | |
| | S-12 | 59.5 | 61.0 | | 24.3 | | | | | | | | | | |
| | S-13 | 64.5 | 66.0 | | 14.8 | | | | | | | | | | |
| | S-14 | 69.5 | 71.0 | ML | 10.4 | | | 60 | NV | NP | | | | | |
| | S-15 | 74.5 | 76.0 | | 23.3 | | | | | | | | | | |
| | S-16 | 79.5 | 81.0 | CL | 25.1 | | | 100 | 49 | 20 | 29 | | | | |
| | S-17 | 84.5 | 86.0 | | 24.3 | | | | | | | | | | |
| | S-18 | 89.5 | 91.0 | SM | 24.3 | | | 44 | NV | NP | | | | | |

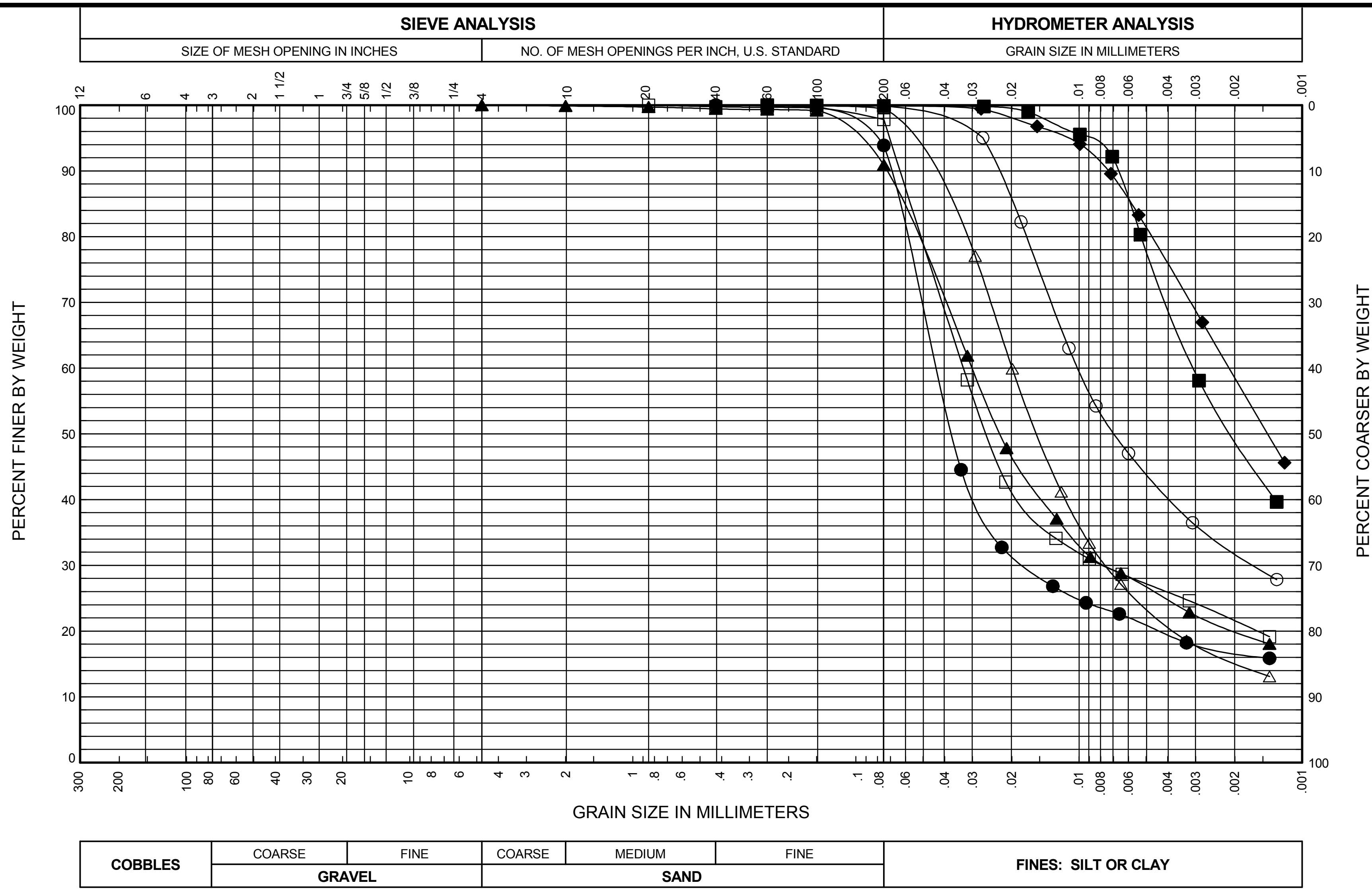
## Table 1 - Summary of Laboratory Testing

| SAMPLE DATA | | | | | | GRAIN SIZE ANALYSIS | | | ATTERBERG LIMITS | | | CORROSION SUITE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | | | | | | | | | | | | | |
| Boring | Sample | Top (feet) | Bottom (feet) | USCS Classification | Water Content (%) | Gravel (%) | Sand (%) | Fines[4] (%) | Liquid Limit | Plastic Limit | Plasticity Index | pH | Resistivity (omh-cm) | Sulfates (%) | Chlorides (%) |
| RP-127-12 | S-1 | 2.5 | 4.0 | | 44.0 | | | | | | | | | | |
| | S-2 | 4.6 | 6.6 | | 40.0 | | | | | | | | | | |
| | S-3 | 7.5 | 9.0 | CH | 38.2 | | | 95 | 54 | 18 | 36 | | | | |
| | S-4 | 9.6 | 11.2 | | 45.8 | | | | | | | | | | |
| | S-5 | 12.5 | 14.0 | CH | 24.2 | | | 100 | 68 | 19 | 49 | | | | |
| | S-6 | 15.0 | 16.5 | | 25.3 | | | | | | | | | | |
| | S-7 | 20.0 | 21.5 | CH | 23.9 | | | 100 | 77 | 16 | 61 | | | | |
| | S-8 | 23.5 | 23.9 | | 28.0 | | | | | | | | | | |
| | S-9 | 29.6 | 30.0 | | 57.4 | | | | | | | | | | |
| | S-10 | 35.0 | 35.4 | | 27.2 | | | | | | | | | | |
| | S-11 | 45.0 | 46.5 | CH | 25.8 | | | 100 | 75 | 20 | 55 | | | | |
| | S-12 | 50.0 | 51.5 | | 23.1 | | | | | | | | | | |
| | S-13 | 55.0 | 56.5 | | 22.8 | | | | | | | | | | |
| | S-14 | 60.0 | 60.5 | | 101.8 | | | | | | | | | | |
| | S-15 | 65.0 | 66.5 | CL | 23.8 | | | 98 | 39 | 16 | 23 | | | | |
| | S-16 | 70.0 | 71.5 | | 22.1 | | | | | | | | | | |
| | S-17 | 75.0 | 76.5 | | 22.1 | | | | | | | | | | |
| | S-18 | 80.0 | 80.8 | SM | 23.8 | | | 37 | NV | NP | | | | | |

## Table 1 - Summary of Laboratory Testing

| SAMPLE DATA | | | | | | GRAIN SIZE ANALYSIS | | | ATTERBERG LIMITS | | | CORROSION SUITE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Classification | Water Content (%) | Gravel (%) | Sand (%) | Fines[4] (%) | Liquid Limit | Plastic Limit | Plasticity Index | pH | Resistivity (omh-cm) | Sulfates (%) | Chlorides (%) |
| RP-128-04 | S-1 | 4.5 | 6.0 | SC-SM | 5.5 | 29.7 | 47.5 | 23 | 25 | 17 | 8 | | | | |
| | S-2 | 9.5 | 11.0 | | 20.0 | | | | | | | | | | |
| | S-3 | 14.5 | 16.0 | CH | 18.6 | | | 99 | 50 | 19 | 31 | | | | |
| | S-4 | 19.5 | 21.0 | | 29.6 | | | | | | | | | | |
| | S-5 | 24.5 | 26.0 | SC | 16.9 | | | 41 | 64 | 17 | 47 | | | | |
| | S-6 | 29.5 | 31.0 | | 19.1 | | | | | | | | | | |
| | S-7 | 34.5 | 36.0 | | 23.0 | | | | | | | | | | |
| | S-8 | 39.5 | 41.0 | | 24.0 | | | | | | | | | | |
| | S-9 | 44.5 | 46.0 | CL | 22.0 | | | 99 | 46 | 18 | 28 | | | | |
| | S-10 | 49.5 | 51.0 | | 21.7 | | | | | | | | | | |
| | S-11 | 54.5 | 56.0 | | 18.2 | | | | | | | | | | |
| | S-12 | 59.5 | 61.0 | SM | 27.1 | | | 39 | NV | NP | | | | | |
| | S-13 | 64.5 | 66.0 | | 25.6 | | | | | | | | | | |
| | S-14 | 69.5 | 71.0 | ML | 26.5 | | | 91 | NV | NP | | | | | |
| | S-15 | 74.5 | 76.0 | | 31.8 | | | | | | | | | | |
| | S-16 | 79.5 | 81.0 | | 112.6 | | | | | | | | | | |
| | S-17 | 84.5 | 86.0 | | 22.6 | | | | | | | | | | |
| | S-18 | 89.5 | 91.0 | CH | 23.4 | 0 | 1 | 69 / 30 | 78 | 18 | 60 | | | | |

NOTES:
1 Refer to Appendix A, Figure A-1 for definitions.
2 Gravel defined as particles larger than the No. 4 sieve size, Sand as particles between the No. 4 and No. 200 sieve sizes, and Fines as particles passing the No. 200 sieve.
3 Silt particles are defined as fines (passing the #200 sieve) larger than 2 μm; clay particles are defined as fines smaller than 2 μm. USCS designation is based on Atterberg limit testing.
4 For samples that hydrometer tests were performed on, silt particles are presented first followed a backslash and by clay fraction values
ohm-cm = ohm-centimeters; NP = Non Plastic ; NV = No Value; pcf = pounds per cubic foot; psf = pounds per square foot; μm = micrometers




GSA_MAIN 102116-200 HSB.GPJ CLONE FROM THIS PROJECT.GPJ 2/4/20

| SAMPLE ID | DEPTH (feet) | U.S.C.S. SYMBOL | SAMPLE DESCRIPTION | FINES % | NAT. W.C. % | LL % | PL % | PI % |
|---|---|---|---|---|---|---|---|---|
| ● RP-127-09, S-9 | 45.3 | CH | DISPLACED CLAYSTONE | 93.9 | 24.8 | 71 | 19 | 52 |
| ■ RP-127-09, S-11 | 55.0 | CH | DISPLACED CLAYSTONE | 99.9 | 29.5 | 91 | 18 | 73 |
| ▲ RP-127-09, S-16 | 80.3 | CH | DISPLACED CLAYSTONE | 90.9 | 23.8 | 82 | 14 | 68 |
| ◆ RP-127-10, S-6 | 30.3 | CH | DISPLACED CLAYSTONE | 99.9 | 31.0 | 134 | 21 | 113 |
| ○ RP-127-10, S-9 | 45.3 | CL | DISPLACED CLAYSTONE | 99.9 | 27.8 | 48 | 18 | 30 |
| □ RP-127-10, S-16 | 80.3 | CH | DISPLACED CLAYSTONE | 97.8 | 24.1 | 65 | 19 | 46 |
| △ RP-127-11, S-8 | 40.3 | CL | DISPLACED CLAYSTONE | 99.5 | 22.6 | 39 | 20 | 19 |

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**FIG. B-1**
Sheet 1 of 2

FIG. B-1
Sheet 1 of 2

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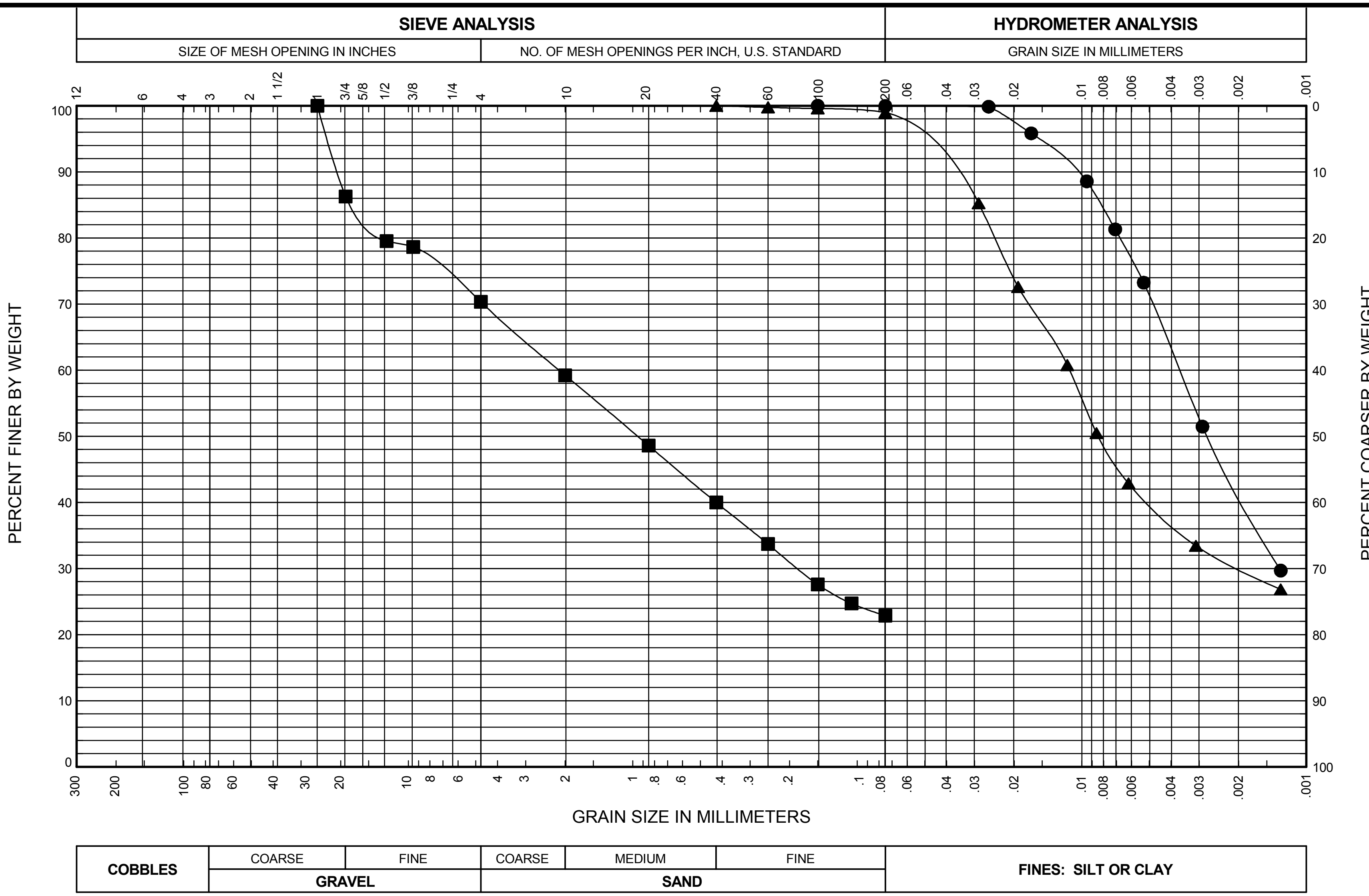


| SAMPLE ID | DEPTH (feet) | U.S.C.S. SYMBOL | SAMPLE DESCRIPTION | FINES % | NAT. W.C. % | LL % | PL % | PI % |
|---|---|---|---|---|---|---|---|---|
| ● RP-127-11, S-9 | 45.0 | CH | CLAYSTONE | 100.0 | 25.0 | 53 | 19 | 34 |
| ■ RP-128-04, S-1 | 5.3 | SC | Clayey Sand with Gravel | 22.9 | 5.5 | 25 | 17 | 8 |
| ▲ RP-128-04, S-18 | 90.3 | CH | CLAYSTONE | 99.0 | 23.4 | 78 | 18 | 60 |

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**FIG. B-1**
Sheet 2 of 2

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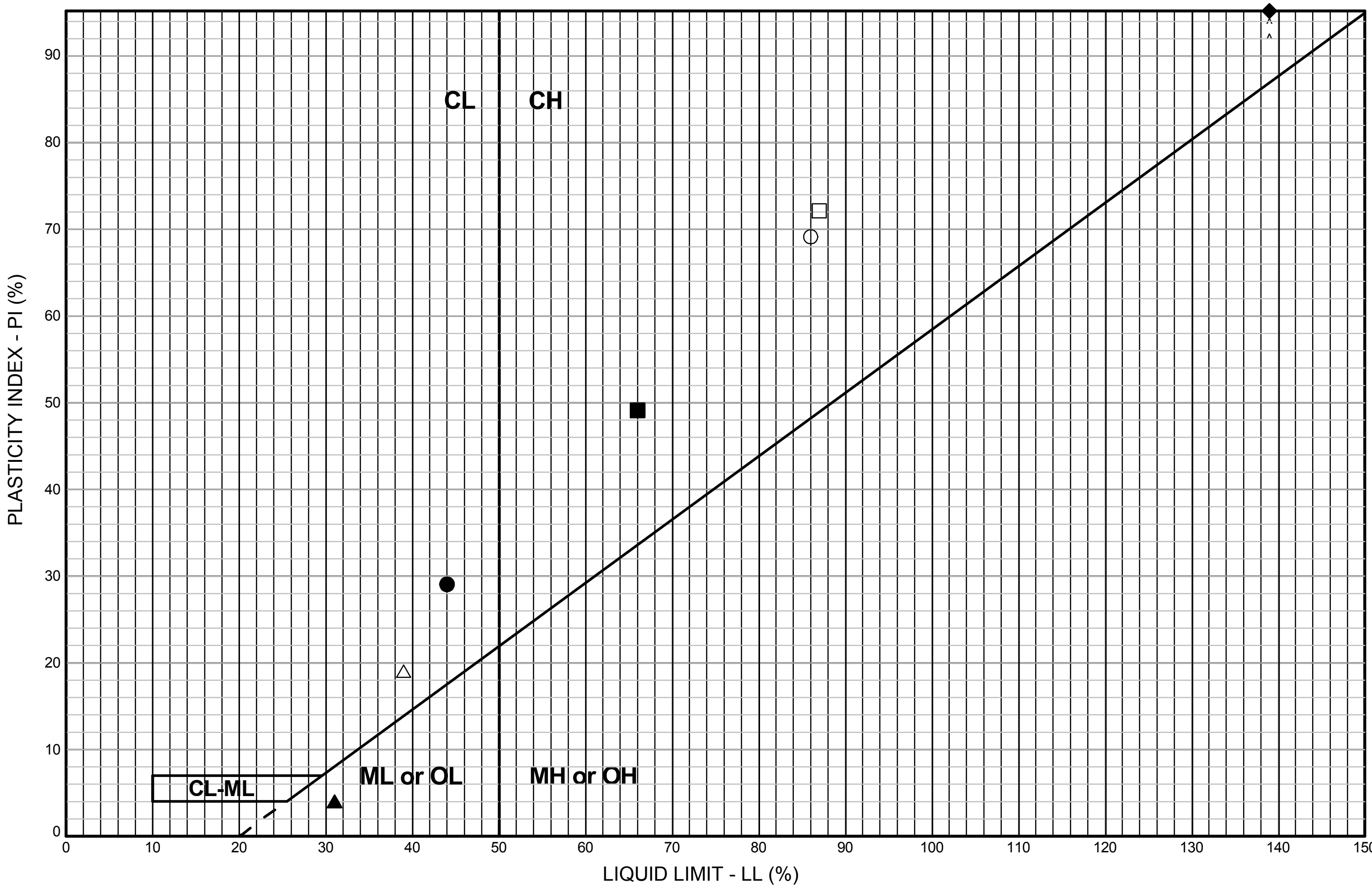
FIG. B-1
Sheet 2 of 2




## LEGEND

**CL:** Low plasticity inorganic clays; sandy and silty clays

**CH:** High plasticity inorganic clays

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

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

**CL-ML:** Silty clays and clayey silts

| BORING AND SAMPLE NO. | DEPTH (feet) | U.S.C.S. SYMBOL | SOIL CLASSIFICATION | LL % | PL % | PI % | NAT. W.C. % | PASS. #200, % |
|---|---|---|---|---|---|---|---|---|
| ● RP-127-08, S-1 | 5.3 | CL | Lean Clay | 44 | 15 | 29 | 19.5 | 99.6 |
| ■ RP-127-08, S-2 | 10.3 | CH | Fat Clay | 66 | 17 | 49 | 23.6 | 99.5 |
| ▲ RP-127-08, S-7 | 35.0 | ML | DISPLACED SILTSTONE | 31 | 27 | 4 | 27.9 | 60.8 |
| ◆ RP-127-08, S-11 | 55.0 | CH | DISPLACED CLAYSTONE | 139 | 24 | 115 | 29.5 | 99.0 |
| ○ RP-127-08, S-15 | 75.3 | CH | DISPLACED CLAYSTONE | 86 | 17 | 69 | 26.1 | 99.1 |
| □ RP-127-08, S-20 | 100.3 | CH | DISPLACED CLAYSTONE | 87 | 15 | 72 | 26.3 | 99.2 |
| △ RP-127-09, S-2 | 10.3 | CL | Lean Clay with Sand | 39 | 20 | 19 | 22.2 | 85.1 |

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# PLASTICITY CHART

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**FIG. B-2**
Sheet 1 of 6

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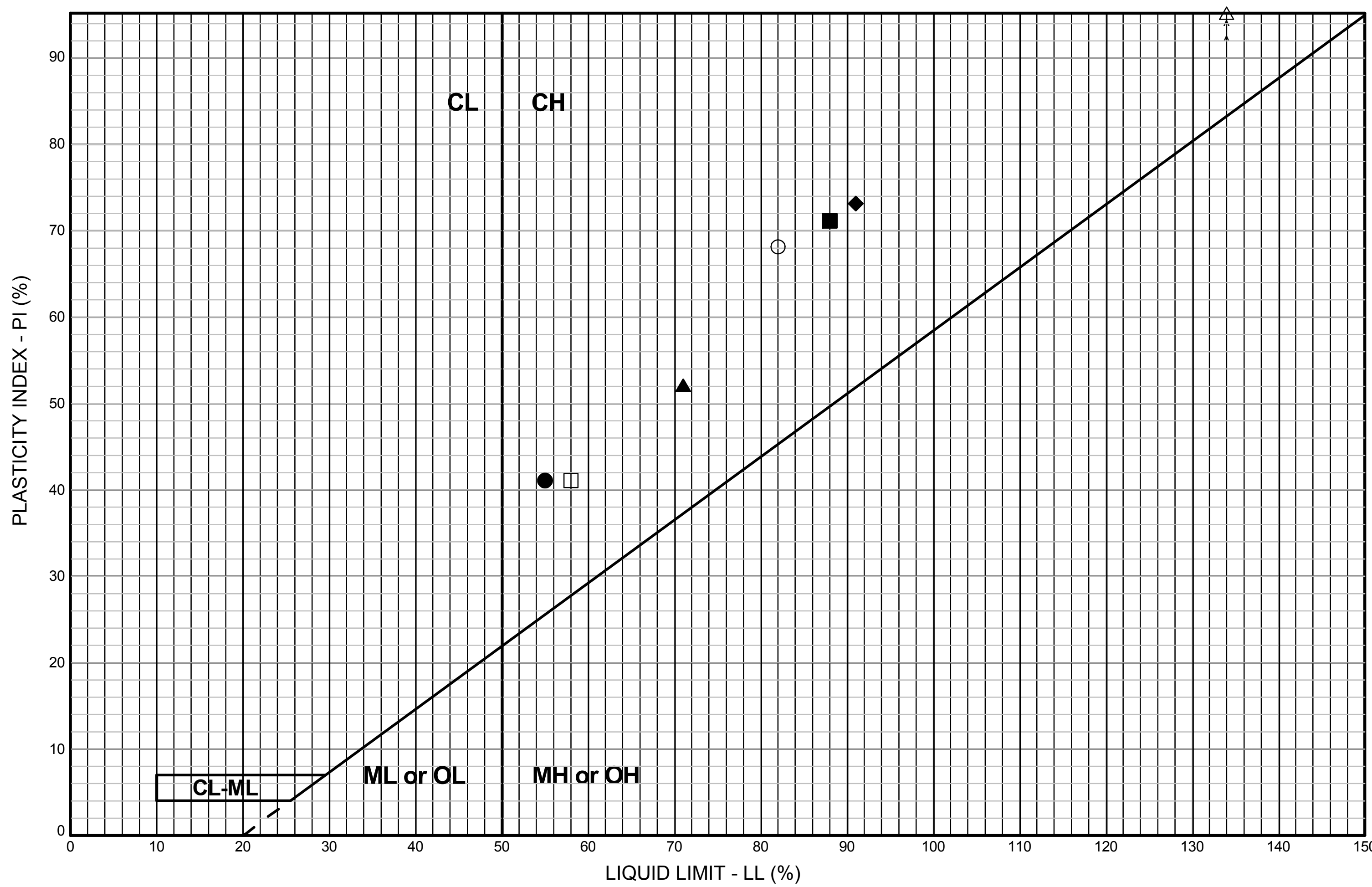
FIG. B-2




## LEGEND

**CL:** Low plasticity inorganic clays; sandy and silty clays

**CH:** High plasticity inorganic clays

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

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

**CL-ML:** Silty clays and clayey silts

ATT MAIN(HIGH LL) 102116-200 HSB.GPJ SHAN_WIL.GDT 2/4/20

| BORING AND SAMPLE NO. | DEPTH (feet) | U.S.C.S. SYMBOL | SOIL CLASSIFICATION | LL % | PL % | PI % | NAT. W.C. % | PASS. #200, % |
|---|---|---|---|---|---|---|---|---|
| ● RP-127-09, S-4 | 20.3 | CH | Fat Clay; few sand | 55 | 14 | 41 | 23.5 | 89.1 |
| ■ RP-127-09, S-6 | 30.0 | CH | DISPLACED CLAYSTONE | 88 | 17 | 71 | 23.6 | 99.1 |
| ▲ RP-127-09, S-9 | 45.3 | CH | DISPLACED CLAYSTONE | 71 | 19 | 52 | 24.8 | 93.9 |
| ◆ RP-127-09, S-11 | 55.0 | CH | DISPLACED CLAYSTONE | 91 | 18 | 73 | 29.5 | 99.9 |
| ○ RP-127-09, S-16 | 80.3 | CH | DISPLACED CLAYSTONE | 82 | 14 | 68 | 23.8 | 90.9 |
| □ RP-127-10, S-1 | 5.3 | CH | Fat Clay with Sand | 58 | 17 | 41 | 24.6 | 72.7 |
| △ RP-127-10, S-6 | 30.3 | CH | DISPLACED CLAYSTONE | 134 | 21 | 113 | 31.0 | 99.9 |

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# PLASTICITY CHART

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**FIG. B-2**
Sheet 2 of 6

FIG. B-2

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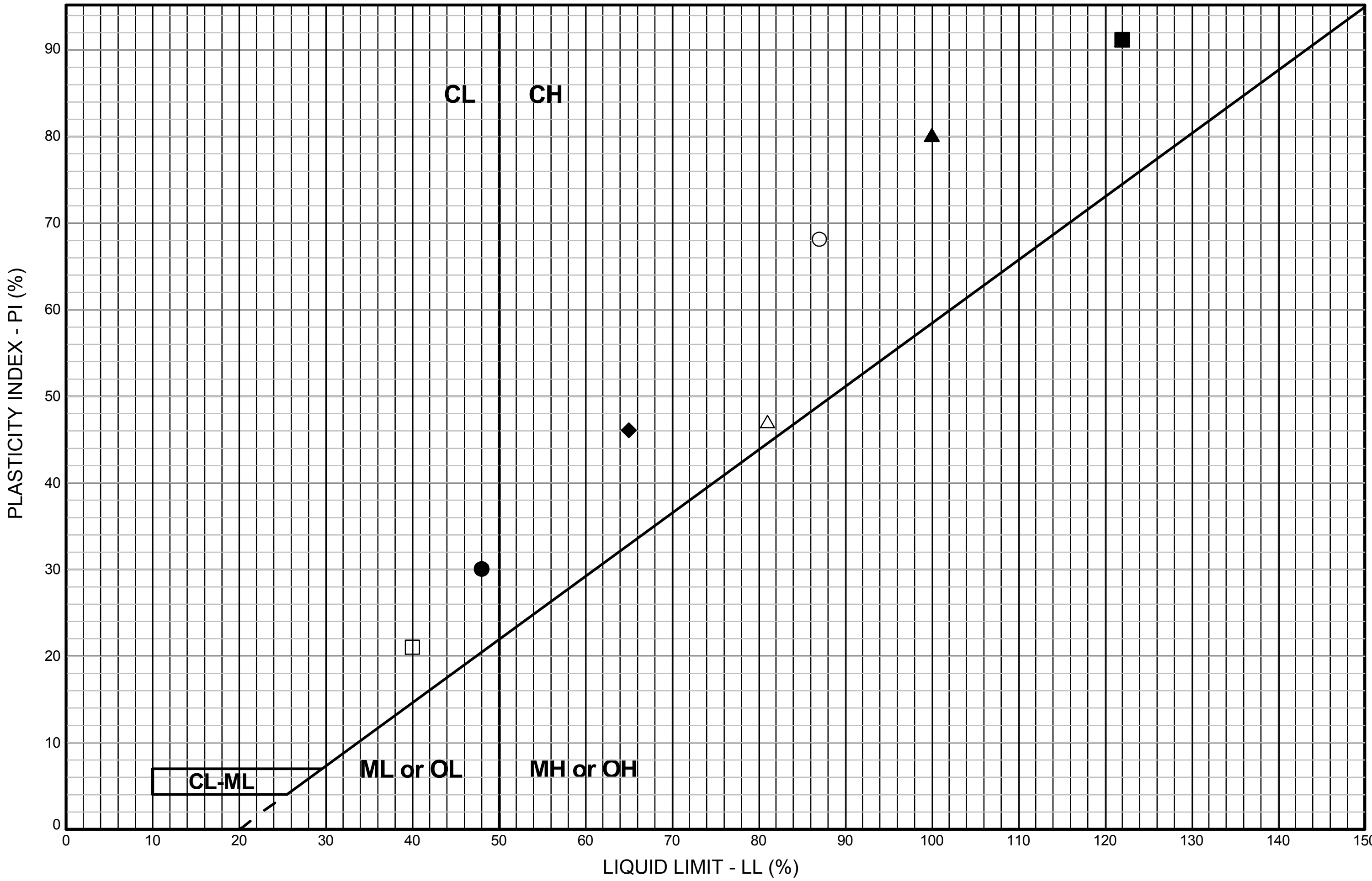


## LEGEND

**CL:** Low plasticity inorganic clays; sandy and silty clays

**CH:** High plasticity inorganic clays

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

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

**CL-ML:** Silty clays and clayey silts

| BORING AND SAMPLE NO. | DEPTH (feet) | U.S.C.S. SYMBOL | SOIL CLASSIFICATION | LL % | PL % | PI % | NAT. W.C. % | PASS. #200, % |
|---|---|---|---|---|---|---|---|---|
| ● RP-127-10, S-9 | 45.3 | CL | DISPLACED CLAYSTONE | 48 | 18 | 30 | 27.8 | 99.9 |
| ■ RP-127-10, S-13 | 65.3 | CH | DISPLACED CLAYSTONE | 122 | 31 | 91 | 27.1 | 99.9 |
| ▲ RP-127-10, S-15 | 75.0 | CH | DISPLACED CLAYSTONE | 100 | 20 | 80 | 22.1 | 94.9 |
| ◆ RP-127-10, S-16 | 80.3 | CH | DISPLACED CLAYSTONE | 65 | 19 | 46 | 24.1 | 97.8 |
| ○ RP-127-10, S-21 | 110.3 | CH | DISPLACED CLAYSTONE | 87 | 19 | 68 | 21.5 | 99.9 |
| □ RP-127-11, S-2 | 10.3 | CL | Lean Clay; trace sand | 40 | 19 | 21 | 23.8 | 99.3 |
| △ RP-127-11, S-4 | 20.3 | CH | Fat Clay; trace sand | 81 | 34 | 47 | 37.0 | 96.5 |

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# PLASTICITY CHART

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**FIG. B-2**
Sheet 3 of 6

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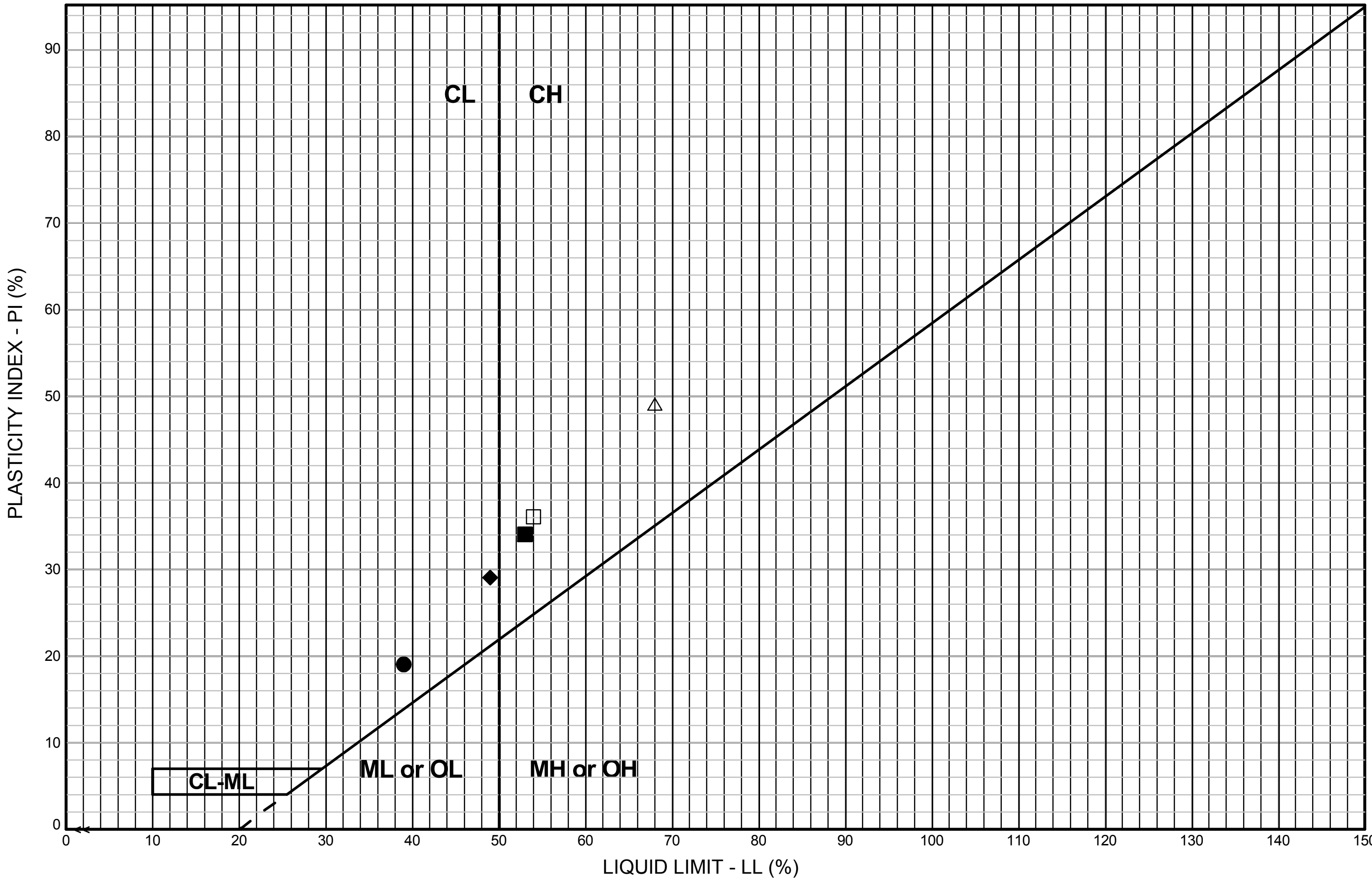


## LEGEND

**CL:** Low plasticity inorganic clays; sandy and silty clays

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**CL-ML:** Silty clays and clayey silts

| BORING AND SAMPLE NO. | DEPTH (feet) | U.S.C.S. SYMBOL | SOIL CLASSIFICATION | LL % | PL % | PI % | NAT. W.C. % | PASS. #200, % |
|---|---|---|---|---|---|---|---|---|
| ● RP-127-11, S-8 | 40.3 | CL | DISPLACED CLAYSTONE | 39 | 20 | 19 | 22.6 | 99.5 |
| ■ RP-127-11, S-9 | 45.0 | CH | CLAYSTONE | 53 | 19 | 34 | 25.0 | 100.0 |
| RP-127-11, S-14 | 70.3 | ML | SILTSTONE | NP | NP | NP | 10.4 | 60.0 |
| ◆ RP-127-11, S-16 | 80.3 | CL | CLAYSTONE | 49 | 20 | 29 | 25.1 | 100.0 |
| RP-127-11, S-18 | 90.3 | SM | SANDSTONE | NP | NP | NP | 24.3 | 44.0 |
| □ RP-127-12, S-3 | 8.3 | CH | Fat Clay; trace carbonaceous fragments | 54 | 18 | 36 | 38.2 | 94.5 |
| △ RP-127-12, S-5 | 13.3 | CH | CLAYSTONE | 68 | 19 | 49 | 24.2 | 99.8 |

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7-085(110) 127, PCN 22304
McKenzie County, North Dakota

## PLASTICITY CHART

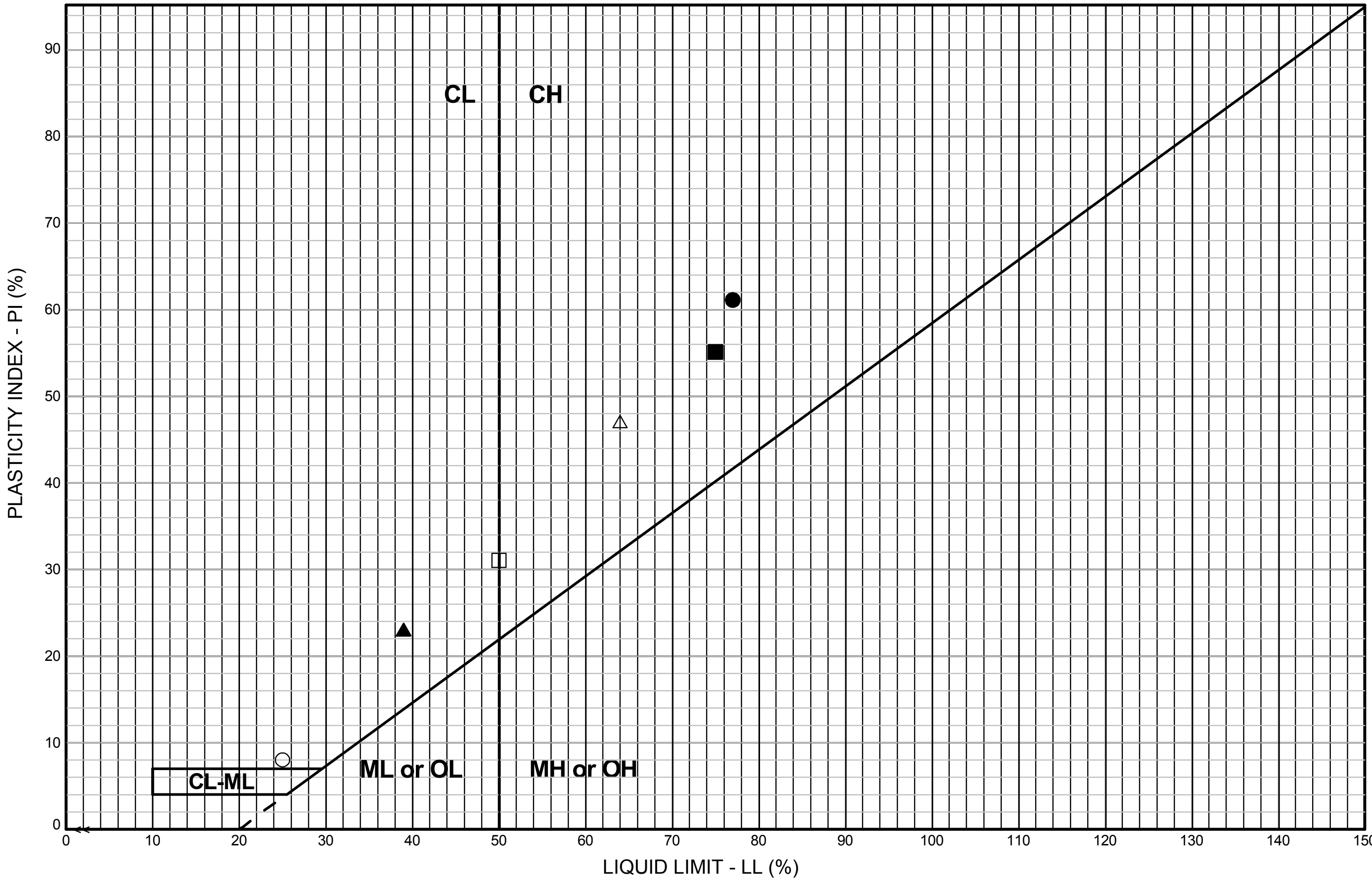
February 2020 102116-200

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. B-2**
Sheet 4 of 6

North Dakota Department of Transportation

**FIG. B-2**




## LEGEND

**CL:** Low plasticity inorganic clays; sandy and silty clays

**CH:** High plasticity inorganic clays

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

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

**CL-ML:** Silty clays and clayey silts

ATT_MAIN(HIGH_LL) 102116-200 HSB.GPJ SHAN_WIL.GDT 2/4/20

| BORING AND SAMPLE NO. | DEPTH (feet) | U.S.C.S. SYMBOL | SOIL CLASSIFICATION | LL % | PL % | PI % | NAT. W.C. % | PASS. #200, % |
|---|---|---|---|---|---|---|---|---|
| ● RP-127-12, S-7 | 20.8 | CH | CLAYSTONE | 77 | 16 | 61 | 23.9 | 99.7 |
| ■ RP-127-12, S-11 | 45.8 | CH | CLAYSTONE | 75 | 20 | 55 | 25.8 | 99.6 |
| ▲ RP-127-12, S-15 | 65.8 | CL | CLAYSTONE | 39 | 16 | 23 | 23.8 | 98.4 |
| RP-127-12, S-18 | 80.4 | SM | SANDSTONE | NP | NP | NP | 23.8 | 37.4 |
| ○ RP-128-04, S-1 | 5.3 | SC | Clayey Sand with Gravel | 25 | 17 | 8 | 5.5 | 22.9 |
| □ RP-128-04, S-3 | 15.3 | CH | Fat Clay; trace sand | 50 | 19 | 31 | 18.6 | 98.7 |
| △ RP-128-04, S-5 | 25.3 | SC | SANDSTONE | 64 | 17 | 47 | 16.9 | 41.3 |

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

# PLASTICITY CHART

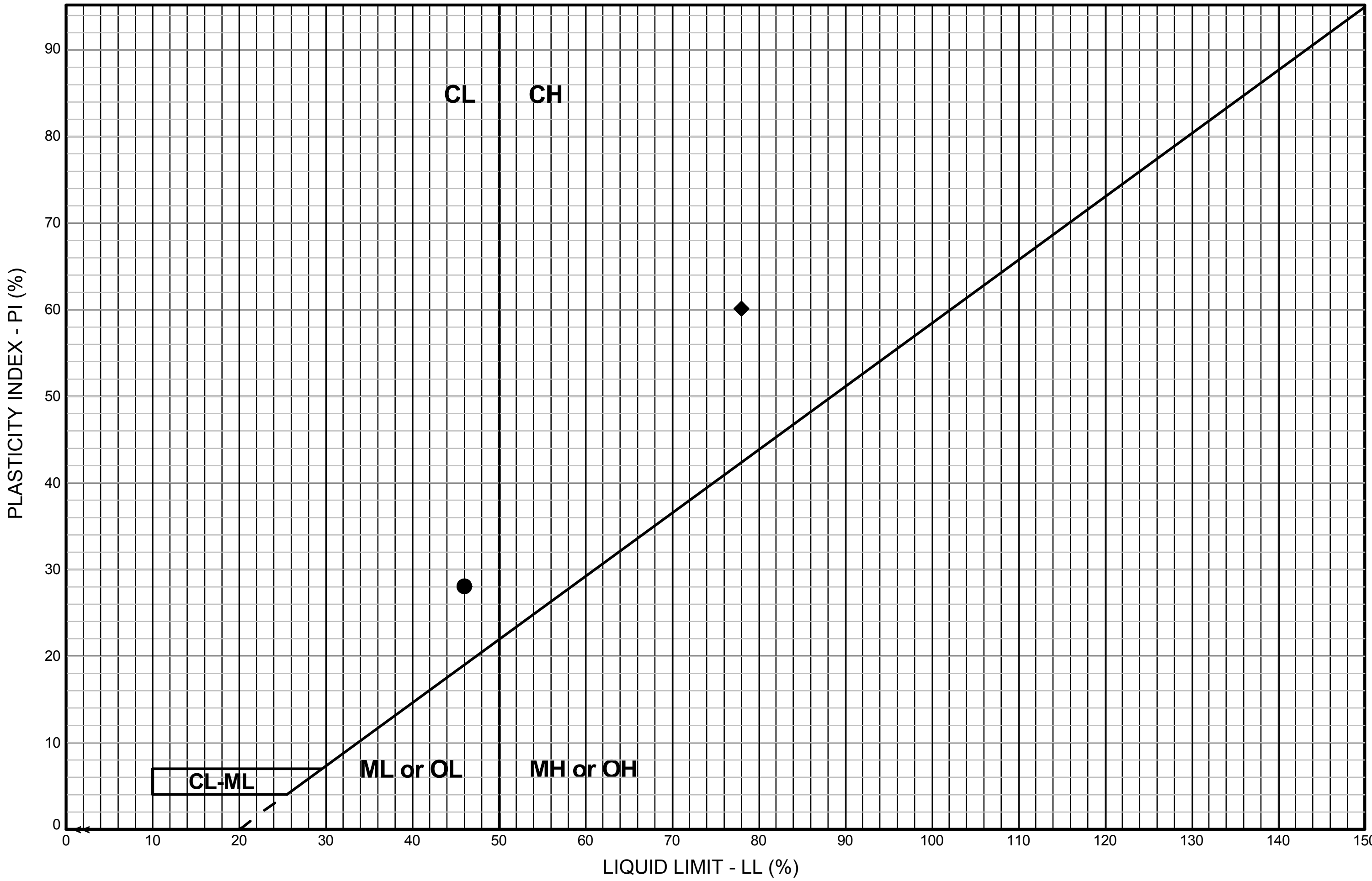
February 2020 102116-200

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. B-2**
Sheet 5 of 6

North Dakota Department of Transportation

**FIG. B-2**




## LEGEND

**CL:** Low plasticity inorganic clays; sandy and silty clays

**CH:** High plasticity inorganic clays

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

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

**CL-ML:** Silty clays and clayey silts

| BORING AND SAMPLE NO. | DEPTH (feet) | U.S.C.S. SYMBOL | SOIL CLASSIFICATION | LL % | PL % | PI % | NAT. W.C. % | PASS. #200, % |
|---|---|---|---|---|---|---|---|---|
| ● RP-128-04, S-9 | 45.3 | CL | CLAYSTONE | 46 | 18 | 28 | 22.0 | 99.2 |
| RP-128-04, S-12 | 60.3 | SM | SANDSTONE | NP | NP | NP | 27.1 | 39.0 |
| RP-128-04, S-14 | 70.3 | ML | SILTSTONE | NP | NP | NP | 26.5 | 90.5 |
| ◆ RP-128-04, S-18 | 90.3 | CH | CLAYSTONE | 78 | 18 | 60 | 23.4 | 99.0 |

Horseshoe Bend Landslide
7-085(110) 127, PCN 22304
McKenzie County, North Dakota

# PLASTICITY CHART

February 2020 102116-200

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. B-2**
Sheet 6 of 6

North Dakota Department of Transportation

ATT_MAIN(HIGH_LL) 102116-200 HSB.GPJ SHAN_WIL.GDT 2/4/20

FIG. B-2

APPENDIX C: PREVIOUS NDDOT FIELD EXPLORATIONS

Appendix C

# Previous NDDOT Field Explorations

## Figures

Figure C-1: HSB1 and HSB2 Field Logs
Figure C-2: HSB2 Field Log
Figure C-3: HSB4 Field Log
Figure C-4: HSB4 Lab Data

| STATE | PROJECT NO. | SECTION NO. | SHEET NO. |
|---|---|---|---|
| ND | SER-7-085(063)127 | 175 | 1 |

## BORING NO. 1

Elevation scale: 2240, 2230, 2220, 2210, 2200, 2190, 2180, 2170, 2160, 2150, 2140

| Elev. | Depth | Blows | Description |
|---|---|---|---|
| 2240 | 0.0 | | |
| | 2.0 | 4 | BRN CLY, $\gamma_d$=102.6 pcf, $q_u$=2559 psf, w=26.7% |
| | 4.0 | | BRN CLY, *c=500 psf, w=31.4% |
| | 7.0 | 12 | BRN CLY, $\gamma_d$=91.8 pcf, $q_u$=1728 psf, w=28.7% |
| | | | BRN CLY, *c=1500 psf, w=15.1% |
| | 9.5 | | |
| 2228 | 12.0 | 8 | BRN SLTY CLY, $\gamma_d$=95.0 pcf, c=1111 psf, w=28.0% |
| | | | BRN\TAN CLY, *c=1000 psf, w=23.7% |
| | 15.0 | 16 | BRN CLY, $\gamma_d$=94.4 pcf, $q_u$=5493 psf, w=30.1% |
| | 17.0 | | BRN\GRY CLY, *c=2000 psf, w=23.7% |
| | 19.0 | | |
| | 22.0 | 14 | BRN\GRY CLY, $\gamma_d$=104.7 pcf, c=3070 psf, w=20.5% |
| | | | BRN\GRY CLY, *c=1750 psf, w=23.3% |
| | 24.5 | | |
| | 27.0 | 22 | BRN\GRY CLY, $\gamma_d$=103.0 pcf, $q_u$=6418 psf, w=18.2% |
| | | | BRN\GRY CLY, *c=2750 psf, w=17.3% |
| | 29.5 | | |
| | 32.0 | 18 | BRN\GRY CLY, $\gamma_d$=103.0 pcf, $q_u$=5225 psf, w=21.2% |
| | | | BRN\GRY CLY, *c=2250 psf, w=15.6% |
| | 35.0 | | BRN\GRY CLY, $\gamma_d$=100.2 pcf, c=2831 psf, w=24.4% |
| 2203 | 37.0 | 14 | BRN\GRY SLTY CLY LM, *c=1750 psf, w=18.6% |
| | 40.0 | | BRN\GRY CLY, $\gamma_d$=96.5 pcf, c=3711 psf, w=24.8% |
| | 42.0 | 12 | BRN\GRY CLY, c=1500 psf, w=19.8% |
| | 44.0 | | BRN\GRY CLY, $\gamma_d$=108.4 pcf, $q_u$=4578 psf, w=19.0% |
| 2193 | 47.0 | 12 | BRN SLTY CLY LM, *c=1500 psf, w=20.8% |
| | 49.5 | | BRN CLY, $\gamma_d$=102.3 pcf, $q_u$=1537 psf, w=23.1% |
| | 52.0 | 5 | BRN CLY, *c=625 psf, w=16.4% |
| | 54.5 | | BRN SLTY CLY, $\gamma_d$=102.4 pcf, $q_u$=2694 psf, w=24.8% |
| 2183 | 57.0 | 6 | BRN CLY, *c=750 psf, w=27.6% |
| | 59.0 | | BRN CLY, $\gamma_d$=101.3 pcf, c=1643 psf, w=25.0% |
| | 62.0 | 13 | BRN\GRY CLY, *c=1625 psf, w=21.7% |
| | 65.0 | | GRY CLY, $\gamma_d$=97.4 pcf, c=2875 psf, w=27.5% |
| | 67.0 | 18 | GRY CLY, *c=2250 psf, w=23.9% |
| | 70.0 | | GRY CLY, $\gamma_d$=96.4 pcf, c=4813 psf, w=27.9% |
| | 72.0 | 41 | GRY CLY, *c=5125 psf, w=25.7% |
| | 74.0 | | GRY CLY, w=27.7% |
| 2164 | 76.0 | 27 | GRY SLTY CLY, *c=3375 psf, w=14.7% |
| | 78.0 | | |
| | 80.0 | 32 | GRY SLTY CLY, *c=4000 psf, w=20.9% |
| | 82.0 | 28 | GRY SLTY CLY, *c=3500 psf, w=22.8% |
| | 84.5 | 30 | GRY SLTY CLY LM, *c=3750 psf, w=14.0% |
| 2153 | 87.0 | 30 | GRY SLTY CLY, *c=3750 psf, w=20.9% |
| | 89.5 | 30 | GRY CLY, *c=3750 psf, w=23.9% |
| | 92.0 | 95 | GRY\BLK CLY, *c=11875 psf, w=22.3% |
| | 94.0 | 29 | GRY CLY, *c=3625 psf, w=19.5% |
| 2143 | 97.0 | 35 | GRY SLTY CLY, *c=4375 psf, w=21.4% |
| | 99.0 | | |
| 2135 | 105.0 | 30 | GRY SLTY CLY, *c=3750 psf, w=20.6% |

BORING NO. 1
STA 6745+18 offset 59 ft Lt of ℄
DRILLED ON 4/13/11 to 4/13/11

## BORING NO. 2

Elevation scale: 2220, 2210, 2200, 2190, 2180, 2170, 2160, 2150, 2140, 2130, 2120

| Elev. | Depth | Blows | Description |
|---|---|---|---|
| 2224 | 0.0 | | |
| | 2.0 | 11 | BRN CLY, $\gamma_d$=103.4 pcf, c=1202 psf, w=23.8% |
| | 4.0 | | BRN CLY, *c=1375 psf, w=14.3% |
| | 7.0 | 17 | BRN\GRY\BLK CLY, $\gamma_d$=107.5 pcf, c=3266 psf, w=21.0% |
| | | | BRN\GRY\BLK CLY, *c=2125 psf, w=25.7% |
| | 9.5 | | BRN\GRY\BLK SLTY CLY, $\gamma_d$=95.3 pcf, $q_u$=5993 psf, w=21.0% |
| 2212 | 12.0 | 15 | BRN\GRY\BLK CLY, *c=1875 psf, w=19.7% |
| | 15.0 | | BRN\GRY CLY, $\gamma_d$=104.9 pcf, $q_u$=7083 psf, w=22.3% |
| | 17.0 | 13 | BRN\GRY CLY, *c=1625 psf, w=25.3% |
| | 19.0 | | TAN CLY, $\gamma_d$=106.6 pcf, $q_u$=8339 psf, w=20.7% |
| | 22.0 | 13 | TAN CLY, *c=1625 psf, w=19.2% |
| | 24.5 | | BRN\BLK CLY, $\gamma_d$=85.9 pcf, $q_u$=5640 psf, w=29.9% |
| | 27.0 | 24 | BRN\BLK CLY, *c=3000 psf, w=16.2% |
| | 29.0 | | BRN CLY, $\gamma_d$=103.2 pcf, $q_u$=5679 psf, w=20.5% |
| | 32.0 | 18 | BRN CLY, *c=2250 psf, w=17.8% |
| | 34.5 | | BRN CLY LM, $\gamma_d$=103.0 pcf, $q_u$=5052 psf, w=19.1% |
| 2187 | 37.0 | 17 | BRN CLY, *c=2125 psf, w=21.5% |
| | 40.0 | | BRN CLY, $\gamma_d$=100.6 pcf, $q_u$=7484 psf, w=19.9% |
| | 42.0 | 27 | BRN CLY, *c=3375 psf, w=26.9% |
| | 45.0 | | BRN\GRY CLY, $\gamma_d$=101.3 pcf, $q_u$=7728 psf, w=20.0% |
| | 47.0 | 20 | BRN\GRY CLY, *c=2500 psf, w=20.5% |
| | 49.5 | | BRN\GRY SLTY LM, $\gamma_d$=103.1 pcf, $q_u$=7782 psf, w=20.4% |
| 2172 | 52.0 | 20 | BRN\GRY CLY, *c=2500 psf, w=18.4% |
| | 54.5 | | BRN\GRY CLY, $\gamma_d$=105.5 pcf, $q_u$=7747 psf, w=20.6% |
| | 57.0 | 22 | BRN\GRY CLY, *c=2750 psf, w=22.6% |
| | 59.0 | | BRN\GRY CLY, $\gamma_d$=102.2 pcf, $q_u$=8912 psf, w=18.9% |
| | 61.5 | 23 | BRN\GRY CLY, *c=2875 psf, w=16.5% |
| | 65.0 | 27 | BRN\GRY CLY, *c=3375 psf, w=18.6% |
| | 67.5 | 13 | BRN\TAN CLY, *c=1625 psf, w=15.0% |
| | 70.0 | 13 | BRN\TAN CLY, *c=1625 psf, w=9.0% |
| | 73.0 | 11 | BRN\TAN CLY, *c=1375 psf, w=15.8% |
| | 75.0 | 13 | BRN\TAN CLY, *c=1625 psf, w=14.3% |
| | 78.0 | 15 | BRN\TAN CLY, *c=1875 psf, w=22.1% |
| | 80.0 | 13 | BRN\TAN CLY, *c=1625 psf, w=25.2% |
| | 82.0 | 18 | BRN\GRY CLY, *c=2250 psf, w=21.7% |
| | 85.0 | 21 | BRN\GRY CLY, *c=2625 psf, w=28.0% |
| | 87.0 | 13 | BRN\GRY CLY, *c=1625 psf, w=34.2% |
| | 90.0 | 12 | BRN\GRY CLY, *c=1500 psf, w=31.3% |
| | 92.0 | 9 | GRY CLY, *c=1125 psf, w=33.9% |
| | 95.0 | 9 | BLK\GRY CLY, *c=1125 psf, w=34.5% |
| | 97.0 | | |
| | 100.0 | | |
| | 102.0 | 15 | BLK\GRY CLY, *c=1875 psf, w=29.2% |
| | 105.0 | 15 | BLK\GRY CLY, *c=1875 psf, w=25.0% |
| | 108.5 | | |
| 2112 | 112.0 | 27 | BLK\GRY SLTY CLY LM, *c=1125 psf, w=54.4% |

BORING NO. 2
STA 6741+76 offset 42 ft Lt of ℄
DRILLED ON 4/14/11 to 4/14/11

NOTES:

THE ENCIRCLED NUMBERS INDICATE THE NUMBER OF BLOWS DELIVERED BY A 140 POUND AUTOMATIC HAMMER FROM A HEIGHT OF 30 INCHES TO DRIVE A 2 INCH O.D. SPLIT-BARREL SAMPLER 1 FOOT.

THE BORING DATA SHOWN IS FOR NORTH DAKOTA DEPARTMENT OF TRANSPORTATION'S (NDDOT) DESIGN AND ESTIMATING PURPOSES ONLY. THE BORING LOGS ARE ONLY REPRESENTATIVE OF THE EXACT LOCATION FROM WHICH THE SAMPLES WERE TAKEN AND INTERPRETATION BETWEEN THE SAMPLE LOCATIONS IS DISCOURAGED. THE NDDOT ASSUMES NO RESPONSIBILITY IF THE SOIL CONDITIONS ENCOUNTERED DURING CONSTRUCTION DIFFER FROM THOSE SHOWN. FURTHER SOIL INFORMATION MAY BE AVAILABLE AT:

NDDOT
MATERIALS & RESEARCH DIVISION
30 AIRPORT ROAD
BISMARCK, NORTH DAKOTA 58504-6005
PHONE (701)328-6900

$q_u$=Unconfined Compressive Strength (psf)
w=Moisture Content (%)
ø=Friction Angle (deg)
c=Cohesion (psf)
$\gamma_d$=Dry Density (pcf)
*=These cohesive values and friction angles are estimated from blow counts

This document was originally issued and sealed by Jeff Jirava, Registration Number PE- 5950, on 07/14/11 and the original document is stored at the North Dakota Department of Transportation

BORING LOGS

FIG C-1

FIG C-1

# DEEP FOUNDATION BORING LOG

Department of Transportation, Materials & Research Division
SFN 10078 (Rev. 11-98)

FIG C-2
Sheet 1 of 3

| Crew Chief | Boring No. | Elevation of Boring | Station | Offset | Project No. |
|---|---|---|---|---|---|
| J NAUMANN | B 3 | | 127+4880 | | |
| **Project Location** | | **County** | **Date Started** | | **Date Finished** |
| West Ditch N of Slide | | mckenzie | 4-20-11 | | 4-20-11 |

| SAMP. TYPE | CORE NO. | CORE DEPTH FROM | CORE DEPTH TO | SPT | SAMPLE RECOV. | JAR. NO. | SAMPLE NO. | HORIZON DEPTH FROM | HORIZON DEPTH TO | COLOR | TEXT. CLASS | CONSIS-TENCY | PERM. (Y/N) | WATER BEAR. (Y/N) | PLAS-TICITY (Y/N) | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3TW #1 | 1 | 0.2 | 2.2 | | 1.5 / 2.0 | | 133 | 0.2 | 2.5 | Brn | fn snd | | | | | Top 0.2" sod. |
| SS #1 | 2 | 2.2 | 4.2 | 1 / 2 | 1.0 / 2.0 | 1 | 134 | 2.5 | 22.0 | Brn | sndy cly | Very Soft | Y | N | Y | fn Snd & sndy cly mix Coal dep. |
| Drill to 5.0 | | | | | | | | | | | | | | | | |
| 3TW #2 | 3 | 5.0 | 7.0 | | 2.0 / 2.0 | | 135 | | | Brn. | Sndy cly | | | | | Sndy Cly, Snd layers |
| SS #2 | 4 | 7.0 | 9.0 | 1 / 2 | 1.5 / 2.0 | 2 | 136 | | | Brn | Sndy Cly | Very Soft | Y | Y | Y | Snd layers. IO, coal Dep |
| Drill to 10.0 | | | | | | | | | | | | | | | | |
| 3TW #3 | 5 | 10.0 | 12.0 | | 2.0 / 2.0 | | 137 | | | Brn | Sndy cly | | | | | Snd layers |
| SS #3 | 6 | 12.0 | 14.0 | 2 / 3 | 1.5 / 2.0 | 3 | 138 | | | Brn | sndy cly | Soft | Y | Y | Y | Snd layers, IO, coal and snd stone rocks 0.5" |
| Drill to 15.0 | | | | | | | | | | | | | | | | |
| ~~3TW #4~~ | 7 | 15.0 | 17.0 | | 0.0 / 2.0 | | | | | | | | | | | no Rec. |
| Drill to 17.0 | | | | | | | | | | | | | | | | |
| SS #4 | 8 | 17.0 | 19.0 | 4 / 5 | 2.0 / 2.0 | 4 | 139 | | | Brn | Sndy cly | Soft | N | N | Y | Disturbed IO, coal Dep |
| Drill to 20.0 | | | | | | | | | | | | | | | | |
| 3TW #4 | 9 | 20.0 | 22.0 | | 2.0 / 2.0 | | 140 | | | Brn | Sndy Cly | | | | | more Snd mix |
| SS #5 | 10 | 22.0 | 24.0 | 6 / 8 | 2.0 / 2.0 | 5 | 141 | 22.0 | 25.0 | Brn | Sndy Cly | med Stiff | Y | N | Y | more snd mix IO and coal Dep. |

**DEEP FOUNDATION BORING LOG**
Department of Transportation, Materials & Research Division
SFN 10078 (Rev. 11-98)

**FIG C-2**
Sheet 2 of 3

| Crew Chief | Boring No. | Elevation of Boring | Station | Offset | Project No. |
|---|---|---|---|---|---|
| J. Naumann | B3 | | | | |

| Project Location | County | Date Started | Date Finished |
|---|---|---|---|
| West Ditch N. of Slide | McKenzie | 4-20-11 | 4-20-11 |

| SAMP. TYPE | CORE NO. | CORE DEPTH FROM | CORE DEPTH TO | SPT | SAMPLE RECOV. | JAR. NO. | SAMPLE NO. | HORIZON DEPTH FROM | HORIZON DEPTH TO | COLOR | TEXT. CLASS | CONSIS-TENCY | PERM. (Y/N) | WATER BEAR. (Y/N) | PLAS-TICITY (Y/N) | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drill to 25.0 | | | | | | | | | | | | | | | | |
| ~~ST~~ #5 | 11 | 25.0 | 25.5 | | 0.0 / 0.5 | | / | | | | | | | | | Pushed Hard no Recovery |
| ~~SS~~ #6 | 12 | 25.0 | 27.0 | 41 / 59 | 0.5 / 0.7 | 6 | 1412 | 25.0 | | Brn Tan | Fn snd | Hard Very | Y | N | N | First 0.5" Disturbed 100 blow in 0.49" Fn Snd |
| Drill to 27.0 | | | | | | | | | | | | | | | | |
| SS #7 | 13 | 27.0 | 27.0 | 100 / 0 | .05 / .05 | / | / | | | | | | | | | very Hard, 100 blow in half tenth. Small piece of Sndstone in tip. |
| Drill to 32.0 | | | | | | | | | | | | | | | | wont Drill Past 27.0' Broke off teeth and burned up auger bit. |
| Stop | | | | | | | | | | | | | | | | |

# Torvane Shear Strengths

Boring No. 3 Station ______ Offset ______

Project No. ______ Date 4-20-11 County McKenzie

| Depth (ft.) | Stress Reading | Factor | Shear Strength ($kg/cm^2$) | Shear Strength *($lbs/ft^2$) |
|---|---|---|---|---|
| 0.2-2.2 | .25 | m 1.0 | 0.25 | 512.0 |
| 5.0-7.0 | .25 | m 1.0 | 0.25 | 512.0 |
| 10.0-12.0 | .15 | m 1.0 | 0.15 | 307.2 |
| 15.0-17.0 | no Recovery | | | |
| 20.0-22.0 | .425 | s 2.5 | 1.0625 | 2176 |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
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| | | | | |
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| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

* $kg/cm^2 \times 2048 = lbs/ft^2$

# DEEP FOUNDATION BORING LOG

Department of Transportation, Materials & Research Division
SFN 10078 (Rev. 11-98)

Ground - 10.71'
Tube - 10.49'
269' w of ℄

COPY

FIG C-3
Sheet 1 of 4

| Crew Chief | Boring No. | Elevation of Boring | Station | Offset | Project No. |
|---|---|---|---|---|---|
| J. Naumann | B4 | | | | NH-7-085(063)127 |

| Project Location | County | Date Started | Date Finished |
|---|---|---|---|
| Hwy 85 Bottom of West Ditch Between B1, B2 | McKenzie | 10/10/11 | 10/13/11 |

| SAMP. TYPE | CORE NO. | CORE DEPTH FROM | CORE DEPTH TO | SPT | SAMPLE RECOV. | JAR. NO. | SAMPLE NO. | HORIZON DEPTH FROM | HORIZON DEPTH TO | COLOR | TEXT. CLASS | CONSIS-TENCY | PERM. (Y/N) | WATER BEAR. (Y/N) | PLAS-TICITY (Y/N) | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3TW #1 | 1 | 0.0 | 2.0 | | 2.0<br>2.0 | | 1032 | 0.0 | 5.0 | Brn | Sndy Cly | | | | | IO + Coal Dep. Organics |
| SS #1 | 2 | 2.0 | 4.0 | 3<br>2 | 0.2<br>2.0 | 1 | 1033 | | | Brn | Sndy Cly | Soft | N | N | Y | IO + Coal Dep. organics |
| Drill to 5.0 | | | | | | | | | | | | | | | | |
| 3TW #2 | 3 | 5.0 | 7.0 | | 1.5<br>2.0 | | 1034 | 5.0 | 10.0 | Brn | Sndy Cly Lm | | | | | IO, Coal Dep. wood in tip. |
| SS #2 | 4 | 7.0 | 9.0 | 2<br>4 | 1.0<br>2.0 | 2 | 1035 | | | Brn | Sndy Cly Lm | Soft | N | N | Y | IO, Coal Dep., Large Rock in Split Disturbed |
| Drill to 10.0 | | | | | | | | | | | | | | | | |
| 3TW #3 | 5 | 10.0 | 12.0 | | 2.0<br>2.0 | | 1036 | 10.0 | 20.0 | Blk | ~~Coal~~ Sndy Clay | | | | | Brn Sndy Cly in top, Coal in Bottom no Torvane |
| SS #3 | 6 | 12.0 | 14.0 | 6<br>9 | 1.5<br>2.0 | 3 | 1037 | | | Blk | Coal | Loose | Y | N | Y | Trace of Brn Cly mix. |
| Drill to 15.0 | | | | | | | | | | | | | | | | |
| 3TW #4 | 7 | 15.0 | 15.3 | | 0.3<br>0.3 | | 1038 | | | Blk | Coal | | | | | 0.3 push. Bagged. 2 splits |
| SS #4 | 8 | 15.3 | 17.3 | 70<br>30 | 2.0<br>2.0 | 4 | 1039 | | | Blk | Coal | Very Dence | Y | N | N | 100 blow in 0.2', coal. |
| Drill to 20.0 | | | | | | | | | | | | | | | | |
| SS #5 | 9 | 20.0 | 22.0 | 3<br>4 | 1.5<br>2.0 | 5 | 1040 | 20.0 | 25.0 | Brn Gry | Silty Cly | Soft | N | N | Y | Trace of Coal on top. IO + Coal Dep. |
| Drill to 25.0 | | | | | | | | | | | | | | | | |
| 3TW #5 | 10 | 25.0 | 27.0 | | 2.0<br>2.0 | | 1041 | 25.0 | 27.0 | Brn Gry Blk | Sndy Cly Lm | | | | | IO + Coal mix, no Torvane Bent Tube |

# DEEP FOUNDATION BORING LOG

Department of Transportation, Materials & Research Division
SFN 10078 (Rev. 11-98)

**COPY**

**FIG C-3**
Sheet 2 of 4

| Crew Chief | Boring No. | Elevation of Boring | Station | Offset | Project No. |
|---|---|---|---|---|---|
| | 4 | | | | |
| **Project Location** | | **County** | **Date Started** | | **Date Finished** |
| Hwy 85 | | | | | |

| SAMP. TYPE | CORE NO. | CORE DEPTH FROM | CORE DEPTH TO | SPT | SAMPLE RECOV. | JAR. NO. | SAMPLE NO. | HORIZON DEPTH FROM | HORIZON DEPTH TO | COLOR | TEXT. CLASS | CONSIS-TENCY | PERM. (Y/N) | WATER BEAR. (Y/N) | PLAS-TICITY (Y/N) | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SS #6 | 11 | 27.0 | 29.0 | 11<br>44 | 1.5<br>2.0 | 6 | 1042 | 27.0 | 30.0 | Brn Blk | Sndy Cly | Hard | N | N | Y | Sandston in Last 0.5' |
| Drill to 30.0 | | | | | | | | | | | | | | | | |
| 3TW #6 | 12 | 30.0 | 32.0 | | 1.5<br>2.0 | | 1043 | 30.0 | 45.0 | Tan Gry | Sndy Cly Lm | | | | | Tan on Top, Gry on Bottom Last 0.4 pulled out, no Torvane |
| SS #7 | 13 | 32.0 | 34.0 | 13<br>17 | 2.0<br>2.0 | 7 | 1044 | | | Gry | Sndy Cly Lm | Stiff | N | N | Y | Sndy Cly Lm. |
| Drill to 35.0 | | | | | | | | | | | | | | | | |
| 3TW #7 | 14 | 35.0 | 36.2 | | 1.2<br>1.2 | | 1045 | | | Gry | Sndy Cly Lm | | | | | Sndy Cly Lm. |
| SS #8 | 15 | 36.2 | 38.2 | 13<br>14 | 2.0<br>2.0 | 8 | 1046 | | | Gry | Sndy Cly Lm | Stiff | N | N | Y | Sndy Cly Lm. |
| Drill to 40.0 | | | | | | | | | | | | | | | | |
| 3TW #8 | 16 | 40.0 | 41.2 | | 1.2<br>1.2 | | 1047 | | | Gry | Sndy Cly Lm | | | | | Bent Tube no Torvane |
| SS #9 | 17 | 41.2 | 43.2 | 10<br>12 | 2.0<br>2.0 | 9 | 1048 | | | Gry | Sndy Cly Lm | Stiff | N | N | Y | Fine Slt layers throughout. Trace of IO |
| Drill to 45.0 | | | | | | | | | | | | | | | | |
| 3TW #9 | 18 | 45.0 | 45.1 | | 0.1<br>0.1 | | ~~1049~~ | 45.0 | 46.0 | Blk | Coal | | Y | Y | N | Bent Tube no Recovery Water Bearing |
| SS #10 | 19 | 45.1 | 47.1 | 53<br>4.2 | 2.0<br>2.0 | 10 | 1049 | 46.0 | 55.0 | Gry | Sndy Cly Lm | Hard | N | N | Y | Water Bearing Coal to 46.0 Gry Cly to 47.1. |
| Drill to 50.0 | | | | | | | | | | | | | | | | |

# DEEP FOUNDATION BORING LOG

Department of Transportation, Materials & Research Division
SFN 10078 (Rev. 11-98)

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FIG C-3
Sheet 3 of 4

| Crew Chief | Boring No. | Elevation of Boring | Station | Offset | Project No. |
|---|---|---|---|---|---|
| | 4 | | | | |
| **Project Location** | | **County** | **Date Started** | | **Date Finished** |
| Hwy 85 | | | | | |

| SAMP. TYPE | CORE NO. | CORE DEPTH FROM | CORE DEPTH TO | SPT | SAMPLE RECOV. | JAR. NO. | SAMPLE NO. | HORIZON DEPTH FROM | HORIZON DEPTH TO | COLOR | TEXT. CLASS | CONSIS-TENCY | PERM. (Y/N) | WATER BEAR. (Y/N) | PLAS-TICITY (Y/N) | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3TW #10 | 20 | 50.0 | 51.2 | | 1.2<br>1.2 | | 1050 | | | Gry | Sndy Cly Lm | | | | | Bent Tube, no Torvane |
| SS #11 | 21 | 51.2 | 53.2 | 12<br>15 | 2.0<br>2.0 | 11 | 1051 | | | Gry | Sndy Cly Lm | Stiff | N | N | Y | Sndy Cly Lm. |
| Drill to 55.0 | | | | | | | | | | | | | | | | |
| 3TW #11 | 22 | 55.0 | 56.0 | | 1.0<br>1.0 | | 1052 | 55.0 | 56.0 | Gry | Fn Snd | | | | | Fn Snd Bent Tube no Torvane |
| SS #12 | 23 | 56.0 | 58.0 | 13<br>13 | 2.0<br>2.0 | 12 | 1053 | 56.0 | 80.0 | Gry | Sndy Cly | Stiff | N | N | Y | Fn Snd to 56.5, Sndy Cly to 58.0 |
| Drill to 58.0 | | | | | | | | | | | | | | | | |
| 3TW #12 | 24 | 58.0 | 60.0 | | 2.0<br>2.0 | | 1054 | | | Gry | Sndy Cly Lm | | | | | Bent Tube - no Torvane<br>NO Tubes Till softer. |
| SS #13 | 25 | 60.0 | 62.0 | 13<br>15 | 2.0<br>2.0 | 13 | 1055 | | | Gry | Sndy Cly Lm | Stiff | N | N | Y | Sndy Cly. |
| Drill to 63.0 | | | | | | | | | | | | | | | | |
| SS #14 | 26 | 63.0 | 65.0 | 13<br>18 | 2.0<br>2.0 | 14 | 1056 | | | Gry | Sndy Cly Lm | Stiff | N | N | Y | Sndy Cly Lm. |
| Drill to 68.0 | | | | | | | | | | | | | | | | |
| SS #15 | 27 | 68.0 | 70.0 | 11<br>14 | 2.0<br>2.0 | 15 | 1057 | | | Gry | Sndy Cly Lm | Stiff | N | N | Y | Sndy Cly Lm |
| Drill to 73.0 | | | | | | | | | | | | | | | | |
| SS #16 | 28 | 73.0 | 75.0 | 15<br>18 | 2.0<br>2.0 | 16 | 1058 | | | Gry | Sndy Cly Lm | Very Stiff | N | N | Y | Heavy Snd mix. |
| Drill to 78.0 | | | | | | | | | | | | | | | | |

# DEEP FOUNDATION BORING LOG

Department of Transportation, Materials & Research Division
SFN 10078 (Rev. 11-98)

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FIG C-3
Sheet 4 of 4

| Crew Chief | Boring No. | Elevation of Boring | Station | Offset | Project No. |
|---|---|---|---|---|---|
| | 4 | | | | |

| Project Location | County | Date Started | Date Finished |
|---|---|---|---|
| 45 | | | |

| SAMP. TYPE | CORE NO. | CORE DEPTH FROM | CORE DEPTH TO | SPT | SAMPLE RECOV. | JAR. NO. | SAMPLE NO. | HORIZON DEPTH FROM | HORIZON DEPTH TO | COLOR | TEXT. CLASS | CONSISTENCY | PERM. (Y/N) | WATER BEAR. (Y/N) | PLASTICITY (Y/N) | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SS #17 | 29 | 78.0 | 80.0 | 13<br>17 | 2.0<br>2.0 | 17 | 1059 | 80.0 | / | Gry | Sndy Cly Lm | Stiff | N | N | Y | Sndy Cly Lm |
| Drill to 85.0 | | | | | | | | | | | | | | | | |
| Stop. | | | | | | | | | | | | | | | | |

# Deep Foundations Laboratory Analysis

Department of Transportation, Materials and Research Division
300 Airport Road, Bismarck ND 58504 (701) 328-6900

| | | | | | |
|---|---|---|---|---|---|
| **Report Number** | SS-52-2011 | **Date Reported** | 10/25/2011 | **Boring Number** | 4 |
| **County** | MCKENZIE | **Submitted By** | Naumann | **Project Number** | NH-7-085(063)127 |
| **District** | | **Structure Location** | | **PCN** | |

**Comments** Sample 1033 Not enough material to do PI test. Sample # 1037 1038 1039 are coal with no moistures or analysis

| **Lab Number** | 1032 | 1033 | 1034 | 1035 |
|---|---|---|---|---|
| | | | | |
| **Distance From CenterLine (Ft.)** | 0 ft | 0 ft | 0 ft | 0 ft |
| **Depth, Ft.** | 0.0 - 2.0 | 2.0 - 4.0 | 5.0 - 7.0 | 7.0 - 9.0 |
| **Field Sample No.** | 1032 | 1033 | 1034 | 1035 |
| **% Pass. 3/8" Sieve** | 100 | 100 | 100 | 100 |
| **% Pass. No. 4 Sieve** | 100 | 100 | 100 | 95 |
| **% Pass. No. 10 Sieve** | 100 | 100 | 100 | 92 |
| **% Coarse Sand (-No. 10 + No.40)** | 2 | 0 | 0 | 8 |
| **% Fine Sand (-No. 40 + No. 200)** | 14 | 3 | 8 | 18 |
| **% Silt (0.074 - 0.005 mm)** | 32 | 16 | 32 | 20 |
| **% Clay (-0.005 mm)** | 52 | 82 | 60 | 45 |
| **Liquid Limit (-No. 40)** | 43 | 0 | 59 | 48 |
| **Plasticity Index (-No. 40)** | 24 | 0 | 39 | 31 |
| **Plastic Limit** | 19 | 0 | 20 | 17 |
| **Soil Color** | Brn | Brn | Brn | Brn |
| **Textural Class** | CLY | CLY | CLY | CLY |
| **Soil Class (AASHTO M-145)** | A-7-6(20) | A-4(0) | A-7-6(39) | A-7-6(17) |
| **Frost Class** | F3 | F4 | F3 | F3 |
| **Optimum Moisture (%)** | | | | |
| **Maximum Dry Density (pcf)** | | | | |
| **Ph of Soil** | | | | |
| **% Organic Content** | | | | |
| **Pocket Pentrometer** | | | | |
| **Depth (Ft.) \| Moisture (%)** | | | | |
| **Avg. Moisture (%)** | 14.5 | 12.6 | 34.2 | 30.1 |

**Scott W. Wutzke**
**Testing Lab. Supervisor**
**Date Printed: 2/22/2016**



FIG C-4
Sheet 1 of 7

# Deep Foundations Laboratory Analysis

Department of Transportation, Materials and Research Division
300 Airport Road, Bismarck ND 58504 (701) 328-6900

**Report Number** SS-52-2011 **Date Reported** 10/25/2011 **Boring Number** 4
**County** MCKENZIE **Submitted By** Naumann **Project Number** NH-7-085(063)127
**District** **Structure Location** **PCN**

**Comments** Sample 1033 Not enough material to do PI test. Sample # 1037 1038 1039 are coal with no moistures or analysis

| Lab Number | 1036 | 1037 | 1038 | 1039 |
|---|---|---|---|---|
| | | | | |
| Distance From CenterLine (Ft.) | 0 ft | 0 ft | 0 ft | 0 ft |
| Depth, Ft. | 10.0 - 12.0 | 12.0 - 14.0 | 15.0 - 15.3 | 15.3 - 17.3 |
| Field Sample No. | 1036 | 1037 | 1038 | 1039 |
| % Pass. 3/8" Sieve | 100 | 0 | 0 | 0 |
| % Pass. No. 4 Sieve | 100 | 0 | 0 | 0 |
| % Pass. No. 10 Sieve | 100 | 0 | 0 | 0 |
| % Coarse Sand (-No. 10 + No.40) | 0 | 0 | 0 | 0 |
| % Fine Sand (-No. 40 + No. 200) | 3 | 0 | 0 | 0 |
| % Silt (0.074 - 0.005 mm) | 41 | 0 | 0 | 0 |
| % Clay (-0.005 mm) | 56 | 0 | 0 | 0 |
| Liquid Limit (-No. 40) | 44 | 0 | 0 | 0 |
| Plasticity Index (-No. 40) | 26 | 0 | 0 | 0 |
| Plastic Limit | 18 | 0 | 0 | 0 |
| Soil Color | Blk | Blk | Blk | Blk |
| Textural Class | CLY | | | |
| Soil Class (AASHTO M-145) | A-7-6(27) | A-1-a(1) | A-1-a(1) | A-1-a(1) |
| Frost Class | F3 | F1 | F1 | F1 |
| Optimum Moisture (%) | | | | |
| Maximum Dry Density (pcf) | | | | |
| Ph of Soil | | | | |
| % Organic Content | | | | |
| Pocket Pentrometer | | | | |
| Depth (Ft.) \| Moisture (%) | | | | |
| Avg. Moisture (%) | 28.3 | 0.0 | 0.0 | 0.0 |

FIG C-4
Sheet 2 of 7

**Scott W. Wutzke**
**Testing Lab. Supervisor**
**Date Printed: 2/22/2016**

# Deep Foundations Laboratory Analysis

Department of Transportation, Materials and Research Division
300 Airport Road, Bismarck ND 58504 (701) 328-6900

| | | | | | |
|---|---|---|---|---|---|
| **Report Number** | SS-52-2011 | **Date Reported** | 10/25/2011 | **Boring Number** | 4 |
| **County** | MCKENZIE | **Submitted By** | Naumann | **Project Number** | NH-7-085(063)127 |
| **District** | | **Structure Location** | | **PCN** | |

**Comments** Sample 1033 Not enough material to do PI test. Sample # 1037 1038 1039 are coal with no moistures or analysis

| **Lab Number** | 1040 | 1041 | 1042 | 1043 |
|---|---|---|---|---|
| | | | | |
| **Distance From CenterLine (Ft.)** | 0 ft | 0 ft | 0 ft | 0 ft |
| **Depth, Ft.** | 20.0 - 22.0 | 25.0 - 27.0 | 27.0 - 29.0 | 30.0 - 32.0 |
| **Field Sample No.** | 1040 | 1041 | 1042 | 1043 |
| **% Pass. 3/8" Sieve** | 100 | 100 | 100 | 100 |
| **% Pass. No. 4 Sieve** | 100 | 100 | 100 | 100 |
| **% Pass. No. 10 Sieve** | 100 | 100 | 100 | 100 |
| **% Coarse Sand (-No. 10 + No.40)** | 2 | 0 | 0 | 2 |
| **% Fine Sand (-No. 40 + No. 200)** | 17 | 20 | 16 | 3 |
| **% Silt (0.074 - 0.005 mm)** | 28 | 35 | 44 | 17 |
| **% Clay (-0.005 mm)** | 53 | 46 | 41 | 78 |
| **Liquid Limit (-No. 40)** | 47 | -50 | 59 | 79 |
| **Plasticity Index (-No. 40)** | 31 | -68 | 42 | 58 |
| **Plastic Limit** | 16 | 18 | 17 | 21 |
| **Soil Color** | Brn Gry | Brn Gry Blk | Brn Blk | Tan Gry |
| **Textural Class** | CLY | CLY | CLY | CLY |
| **Soil Class (AASHTO M-145)** | A-7-6(25) | A-4(0) | A-7-6(37) | A-7-6(63) |
| **Frost Class** | F3 | F4 | F3 | F3 |
| **Optimum Moisture (%)** | | | | |
| **Maximum Dry Density (pcf)** | | | | |
| **Ph of Soil** | | | | |
| **% Organic Content** | | | | |
| **Pocket Pentrometer** | | | | |
| **Depth (Ft.) \| Moisture (%)** | | | | |
| **Avg. Moisture (%)** | 23.5 | 20.5 | 27.7 | 26.7 |

**Scott W. Wutzke**
**Testing Lab. Supervisor**
**Date Printed: 2/22/2016**



FIG C-4
Sheet 3 of 7

# Deep Foundations Laboratory Analysis

Department of Transportation, Materials and Research Division
300 Airport Road, Bismarck ND 58504 (701) 328-6900

| | | | | | |
|---|---|---|---|---|---|
| **Report Number** | SS-52-2011 | **Date Reported** | 10/25/2011 | **Boring Number** | 4 |
| **County** | MCKENZIE | **Submitted By** | Naumann | **Project Number** | NH-7-085(063)127 |
| **District** | | **Structure Location** | | **PCN** | |

**Comments** Sample 1033 Not enough material to do PI test. Sample # 1037 1038 1039 are coal with no moistures or analysis

| **Lab Number** | 1044 | 1045 | 1046 | 1047 |
|---|---|---|---|---|
| | | | | |
| **Distance From CenterLine (Ft.)** | 0 ft | 0 ft | 0 ft | 0 ft |
| **Depth, Ft.** | 32.0 - 34.0 | 35.0 - 36.2 | 36.2 - 38.2 | 40.0 - 41.2 |
| **Field Sample No.** | 1044 | 1045 | 1046 | 1047 |
| **% Pass. 3/8" Sieve** | 100 | 100 | 100 | 100 |
| **% Pass. No. 4 Sieve** | 100 | 100 | 100 | 100 |
| **% Pass. No. 10 Sieve** | 100 | 96 | 98 | 99 |
| **% Coarse Sand (-No. 10 + No.40)** | 0 | 0 | 0 | 0 |
| **% Fine Sand (-No. 40 + No. 200)** | 1 | 1 | 1 | 3 |
| **% Silt (0.074 - 0.005 mm)** | 42 | 64 | 59 | 59 |
| **% Clay (-0.005 mm)** | 57 | 31 | 37 | 36 |
| **Liquid Limit (-No. 40)** | 84 | 70 | 68 | 59 |
| **Plasticity Index (-No. 40)** | 60 | 43 | 46 | 33 |
| **Plastic Limit** | 24 | 26 | 22 | 26 |
| **Soil Color** | Gry | Gry | Gry | Gry |
| **Textural Class** | CLY | SLTY CLY | SLTY CLY | SLTY CLY |
| **Soil Class (AASHTO M-145)** | A-7-6(69) | A-7-6(48) | A-7-6(50) | A-7-6(36) |
| **Frost Class** | F3 | F3 | F3 | F3 |
| **Optimum Moisture (%)** | | | | |
| **Maximum Dry Density (pcf)** | | | | |
| **Ph of Soil** | | | | |
| **% Organic Content** | | | | |
| **Pocket Pentrometer** | | | | |
| **Depth (Ft.) \| Moisture (%)** | | | | |
| **Avg. Moisture (%)** | 24.5 | 22.7 | 24.3 | 22.0 |

FIG C-4
Sheet 4 of 7

**Scott W. Wutzke**
**Testing Lab. Supervisor**
**Date Printed: 2/22/2016**

# Deep Foundations Laboratory Analysis

Department of Transportation, Materials and Research Division
300 Airport Road, Bismarck ND 58504 (701) 328-6900

**Report Number** SS-52-2011 **Date Reported** 10/25/2011 **Boring Number** 4
**County** MCKENZIE **Submitted By** Naumann **Project Number** NH-7-085(063)127
**District** **Structure Location** **PCN**

**Comments** Sample 1033 Not enough material to do PI test. Sample # 1037 1038 1039 are coal with no moistures or analysis

| Lab Number | 1048 | 1049 | 1050 | 1051 |
|---|---|---|---|---|
| | | | | |
| Distance From CenterLine (Ft.) | 0 ft | 0 ft | 0 ft | 0 ft |
| Depth, Ft. | 41.2 - 43.2 | 45.1 - 47.1 | 50.0 - 51.2 | 51.2 - 53.2 |
| Field Sample No. | 1048 | 1049 | 1050 | 1051 |
| % Pass. 3/8" Sieve | 100 | 100 | 100 | 100 |
| % Pass. No. 4 Sieve | 99 | 96 | 100 | 100 |
| % Pass. No. 10 Sieve | 97 | 95 | 100 | 100 |
| % Coarse Sand (-No. 10 + No.40) | 1 | 1 | 0 | 0 |
| % Fine Sand (-No. 40 + No. 200) | 0 | 0 | 24 | 35 |
| % Silt (0.074 - 0.005 mm) | 97 | 30 | 53 | 42 |
| % Clay (-0.005 mm) | 0 | 64 | 23 | 22 |
| Liquid Limit (-No. 40) | 97 | 69 | 72 | 74 |
| Plasticity Index (-No. 40) | 72 | 44 | 47 | 47 |
| Plastic Limit | 24 | 25 | 25 | 27 |
| Soil Color | Gry | Gry | Gry | Gry |
| Textural Class | SLTY LM | CLY | SLTY CLY LM | CLY LM |
| Soil Class (AASHTO M-145) | A-7-6(80) | A-7-6(47) | A-7-6(37) | A-7-6(29) |
| Frost Class | F3 | F3 | F3 | F3 |
| Optimum Moisture (%) | | | | |
| Maximum Dry Density (pcf) | | | | |
| Ph of Soil | | | | |
| % Organic Content | | | | |
| Pocket Pentrometer | | | | |
| Depth (Ft.) \| Moisture (%) | | | | |
| Avg. Moisture (%) | 28.6 | 30.2 | 22.3 | 23.2 |

**Scott W. Wutzke**
**Testing Lab. Supervisor**
**Date Printed: 2/22/2016**



FIG C-4
Sheet 5 of 7

# Deep Foundations Laboratory Analysis

Department of Transportation, Materials and Research Division
300 Airport Road, Bismarck ND 58504 (701) 328-6900

| | | | | | |
|---|---|---|---|---|---|
| **Report Number** | SS-52-2011 | **Date Reported** | 10/25/2011 | **Boring Number** | 4 |
| **County** | MCKENZIE | **Submitted By** | Naumann | **Project Number** | NH-7-085(063)127 |
| **District** | | **Structure Location** | | **PCN** | |

**Comments** Sample 1033 Not enough material to do PI test. Sample # 1037 1038 1039 are coal with no moistures or analysis

| **Lab Number** | 1052 | 1053 | 1054 | 1055 |
|---|---|---|---|---|
| | | | | |
| **Distance From CenterLine (Ft.)** | 0 ft | 0 ft | 0 ft | 0 ft |
| **Depth, Ft.** | 55.0 - 56.0 | 56.0 - 58.0 | 58.0 - 60.0 | 60.0 - 62.0 |
| **Field Sample No.** | 1052 | 1053 | 1054 | 1055 |
| **% Pass. 3/8" Sieve** | 100 | 100 | 100 | 100 |
| **% Pass. No. 4 Sieve** | 100 | 100 | 100 | 100 |
| **% Pass. No. 10 Sieve** | 100 | 100 | 100 | 100 |
| **% Coarse Sand (-No. 10 + No.40)** | 0 | 0 | 1 | 0 |
| **% Fine Sand (-No. 40 + No. 200)** | 62 | 1 | 3 | 0 |
| **% Silt (0.074 - 0.005 mm)** | 14 | 39 | 4 | 22 |
| **% Clay (-0.005 mm)** | 23 | 59 | 93 | 78 |
| **Liquid Limit (-No. 40)** | 58 | 90 | 81 | 91 |
| **Plasticity Index (-No. 40)** | 30 | 70 | 52 | 65 |
| **Plastic Limit** | 27 | 20 | 28 | 26 |
| **Soil Color** | Gry | Gry | Gry | Gry |
| **Textural Class** | SNDY CLY LM | CLY | CLY | CLY |
| **Soil Class (AASHTO M-145)** | A-7-6(5) | A-7-6(78) | A-7-6(59) | A-7-6(76) |
| **Frost Class** | F3 | F3 | F3 | F3 |
| **Optimum Moisture (%)** | | | | |
| **Maximum Dry Density (pcf)** | | | | |
| **Ph of Soil** | | | | |
| **% Organic Content** | | | | |
| **Pocket Pentrometer** | | | | |
| **Depth (Ft.) \| Moisture (%)** | | | | |
| **Avg. Moisture (%)** | 19.4 | 24.5 | 26.9 | 24.7 |

FIG C-4
Sheet 6 of 7

**Scott W. Wutzke**
**Testing Lab. Supervisor**
**Date Printed: 2/22/2016**

# Deep Foundations Laboratory Analysis

Department of Transportation, Materials and Research Division
300 Airport Road, Bismarck ND 58504 (701) 328-6900

**Report Number** SS-52-2011 **Date Reported** 10/25/2011 **Boring Number** 4

**County** MCKENZIE **Submitted By** Naumann **Project Number** NH-7-085(063)127

**District** **Structure Location** **PCN**

**Comments** Sample 1033 Not enough material to do PI test. Sample # 1037 1038 1039 are coal with no moistures or analysis

| **Lab Number** | 1056 | 1057 | 1058 | 1059 |
|---|---|---|---|---|
| | | | | |
| **Distance From CenterLine (Ft.)** | 0 ft | 0 ft | 0 ft | 0 ft |
| **Depth, Ft.** | 63.0 - 65.0 | 68.0 - 70.0 | 73.0 - 75.0 | 78.0 - 80.0 |
| **Field Sample No.** | 1056 | 1057 | 1058 | 1059 |
| **% Pass. 3/8" Sieve** | 100 | 100 | 100 | 100 |
| **% Pass. No. 4 Sieve** | 99 | 100 | 100 | 100 |
| **% Pass. No. 10 Sieve** | 99 | 100 | 100 | 100 |
| **% Coarse Sand (-No. 10 + No.40)** | 0 | 0 | 0 | 0 |
| **% Fine Sand (-No. 40 + No. 200)** | 0 | 20 | 1 | 2 |
| **% Silt (0.074 - 0.005 mm)** | 40 | 57 | 63 | 60 |
| **% Clay (-0.005 mm)** | 59 | 23 | 37 | 38 |
| **Liquid Limit (-No. 40)** | 87 | 79 | 74 | 73 |
| **Plasticity Index (-No. 40)** | 61 | 56 | 54 | 54 |
| **Plastic Limit** | 25 | 23 | 20 | 19 |
| **Soil Color** | Gry | Gry | Gry | Gry |
| **Textural Class** | CLY | SLTY CLY LM | SLTY CLY | SLTY CLY |
| **Soil Class (AASHTO M-145)** | A-7-6(71) | A-7-6(48) | A-7-6(61) | A-7-6(59) |
| **Frost Class** | F3 | F3 | F3 | F3 |
| **Optimum Moisture (%)** | | | | |
| **Maximum Dry Density (pcf)** | | | | |
| **Ph of Soil** | | | | |
| **% Organic Content** | | | | |
| **Pocket Pentrometer** | | | | |
| **Depth (Ft.) \| Moisture (%)** | | | | |
| **Avg. Moisture (%)** | 21.9 | 19.1 | 22.3 | 23.7 |

FIG C-4
Sheet 7 of 7

**Scott W. Wutzke**
**Testing Lab. Supervisor**
**Date Printed: 2/22/2016**

Appendix D

# Previous Shannon & Wilson Field Explorations and Laboratory Data

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D.2 Previous Shannon & Wilson Field Explorations ........ D-1
D.3 Previous Shannon & Wilson Laboratory Data ........ D-1

## Tables

Table D-1: Summary of Previous Laboratory Test Results by Boring

## Figures

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Figure D-10: Inclinometer Cumulative Displacement, Boring RP-127-01A
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Figure D-12: Inclinometer Cumulative Displacement, Boring RP-127-05
Figure D-13: Inclinometer Cumulative Displacement, Boring RP-127-07
Figure D-14: Sondex Extensometer Displacement, Boring RP-127-01A
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## D.1 INTRODUCTION

Shannon & Wilson completed geotechnical studies and laboratory testing over several different time periods starting in November 2014. Field explorations consisted of drilling 57 geotechnical boring that were conducted from:

- December 3, 2014 to January 30, 2015
- September 9, 2015 to November 10, 2015
- July 5, 2016 to August 4, 2016
- March, April, and July 2017, and
- July 2018

Only borings and laboratory data pertinent to the Horseshoe Bend Landslide are presented herein.

## D.2 PREVIOUS SHANNON & WILSON FIELD EXPLORATIONS

The previously drilled borings near the Horseshoe Bend vicinity are RP-127-01 through RP-127-07 and RP-127-01A. See Figures D-1 through D-8 for the boring logs and Figure 2 for their location. Of the eight previously drilled borings in this area, five were finished with inclinometers and two were finished with a Sondex settlement system. See Figures D-6 through D-13 for cumulative displacement plots for the borings with inclinometers and see Figures D-14 and D-15 for the Sondex displacement plots. A detailed explanation of the drilling dates and procedures for these explorations can be found in the Geotechnical Data Report (GDR) and A1GDR.

## D.3 PREVIOUS SHANNON & WILSON LABORATORY DATA

Various index tests and geotechnical engineering property tests were performed. The laboratory test results are presented in Table D-1. A detailed description of the laboratory testing procedures can be found in the GDR and A1GDR.

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA | | | | | | | | GRAIN SIZE ANALYSIS[2] | | | | ATTERBERG LIMITS | | | CORROSION | | | | TRIAXIAL TESTING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Symbol[1] | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | Gravel (%) | Sand (%) | Fines[3] (75 to 2 um) (%) | Fines[3] (< 2 um) (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category[4] | Sodium Absorption Ration (SAR)[5] |
| | S-1 | 2.5 | 4 | CH | 30.7 | | | | | 78 | | 52 | 16 | 36 | 7.5 | 280 | 0.39 | 0.051 | | | | |
| | S-2 | 5 | 6.5 | | 30.2 | | | | | | | | | | | | | | | | D1 | 8.4 |
| | S-3 | 7.5 | 9 | | 20.4 | | | | | | | | | | | | 0.42 | | | | | |
| | S-4 | 10 | 11.5 | | 31.8 | | | | | | | | | | | | | | | | | |
| | S-5 | 12.5 | 14 | | 16.5 | | | | | | | | | | | | | | | | | |
| | S-6 | 15 | 17 | | 22.2 | | | | | | | | | | | | | | | | | |
| | S-7 | 17 | 18.5 | CH | 18.7 | | | 0 | 14 | 59 | 27 | 55 | 15 | 40 | | | | | | | | |
| | S-8 | 20 | 21.5 | | 18.1 | | | | | | | | | | | | | | | | | |
| | S-9 | 22.5 | 24 | CL | 20.7 | | | | | 88 | | 48 | 18 | 30 | | | | | | | | |
| | S-10 | 25 | 26.5 | | 80.6 | | | | | | | | | | | | | | | | | |
| | S-11 | 27.5 | 29 | | 19.1 | | | | | | | | | | | | | | | | | |
| | S-12 | 30 | 31.5 | | 25.7 | | | | | | | | | | | | | | | | | |
| | S-13 | 32.5 | 34 | CL | 20.7 | | | | | 78 | | 45 | 14 | 31 | | | | | | | | |
| | S-14 | 35 | 36.5 | | 19.3 | | | | | | | | | | | | | | | | | |
| | S-15 | 37.5 | 39 | | 22.9 | | | | | | | | | | | | | | | | | |
| | S-16 | 40 | 41.5 | | 19.2 | | | | | | | | | | | | | | | | | |
| RP-127-01 | S-17 | 42.5 | 44 | | 21.4 | | | | | | | | | | | | | | | | | |
| | S-18 | 44 | 46.5 | | 23.5 | | | | | | | | | | | | | | | | | |
| | S-19 | 47.5 | 49 | CL | 20.9 | | | | | 91 | | 39 | 18 | 21 | | | | | | | | |
| | S-20 | 50 | 51.5 | | 21.9 | | | | | | | | | | | | | | | | | |
| | S-21 | 52.5 | 54 | | 22.1 | | | | | | | | | | | | | | | | | |
| | S-22 | 55 | 56.5 | CH | 17.6 | | | 3 | 11 | 59 | 27 | 51 | 16 | 35 | | | | | | | | |
| | S-23 | 57.5 | 59 | | 17.0 | | | | | | | | | | | | | | | | | |
| | S-24 | 60 | 61.5 | | 20.3 | | | | | | | | | | | | | | | | | |
| | S-25 | 62.5 | 64 | | 29.9 | | | | | | | | | | | | | | | | | |
| | S-28 | 70 | 71.5 | CL | 25.7 | | | 0 | 7 | 64 | 29 | 49 | 17 | 32 | | | | | | | | |
| | S-29 | 72.5 | 74.5 | CH | 29.5 | | | | | | | 56 | 19 | 37 | | | | | | | | |
| | S-30 | 74.5 | 76 | CH | 23.4 | | | 0 | 3 | 63 | 34 | 52 | 15 | 37 | | | | | | | | |
| | S-31 | 77.5 | 79.5 | CH | 27.5 | 124.71 | | | | | | 67 | 19 | 48 | | | | | 2000 | 3604 | | |
| | S-32 | 79.5 | 81 | | 27.7 | | | | | | | | | | | | | | | | | |
| | S-33 | 82.5 | 84 | | 27.9 | | | | | | | | | | | | | | | | | |
| | S-34 | 85 | 86.5 | CH | 26.6 | | 2.7 | 0 | 0 | 73 | 27 | 61 | 16 | 45 | | | | | | | | |
| | S-35 | 87.5 | 89 | | 25.8 | | | | | | | | | | | | | | | | | |
| | S-36 | 90 | 91.5 | CH | 26.1 | | | 0 | 1 | 77 | 22 | 56 | 16 | 40 | | | | | | | | |

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA | | | | | | | | GRAIN SIZE ANALYSIS[2] | | | | ATTERBERG LIMITS | | | CORROSION | | | | TRIAXIAL TESTING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Symbol[1] | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | Gravel (%) | Sand (%) | Fines[3] (75 to 2 um) (%) | Fines[3] (< 2 um) (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category[4] | Sodium Absorption Ration (SAR)[5] |
| RP-127-01 | S-37 | 92.5 | 94 | | 26.9 | | | | | | | | | | | | | | | | | |
| | S-38 | 95 | 96.5 | | 24.4 | | | | | | | | | | | | | | | | | |
| | S-39 | 97.5 | 99 | CH | 26.9 | | | | | 87 | | 56 | 16 | 40 | | | | | | | | |
| | S-40 | 100 | 101.5 | | 27.1 | | | | | | | | | | | | | | | | | |
| | S-41 | 102.5 | 102.8 | | 22.8 | | | | | | | | | | | | | | | | | |
| | S-42 | 105 | 106.5 | SC | 24.7 | | | | | 42 | | 56 | 15 | 41 | | | | | | | | |
| | S-44 | 110 | 111.5 | | 106.8 | | | | | | | | | | | | | | | | | |
| | S-45 | 112.5 | 114 | CL | 27.6 | | | | | 99 | | 43 | 15 | 28 | | | | | | | | |
| | S-46 | 115 | 116.5 | | 80.7 | | | | | | | | | | | | | | | | | |
| | S-47 | 117.5 | 119 | CH | 24.3 | | | 0 | 0 | 57 | 43 | 112 | 18 | 94 | | | | | | | | |
| | S-48 | 120 | 121.5 | | 25.1 | | | | | | | | | | | | | | | | | |
| | S-50 | 125 | 126.5 | | 25.3 | | | | | | | | | | | | | | | | | |
| | S-51 | 127.5 | 129 | | 32.0 | | | | | | | | | | | | | | | | | |
| | S-52 | 130 | 131.5 | | 26.1 | | | | | | | | | | | | | | | | | |
| | S-53 | 132.5 | 134 | CL | 22.5 | | | | | 100 | | 46 | 20 | 26 | | | | | | | | |
| | S-54 | 135 | 136.5 | | 25.2 | | | | | | | | | | | | | | | | | |
| | S-56 | 140 | 141.5 | ML | 29.3 | | | | | 84 | | NV | NP | NP | | | | | | | | |
| | S-57 | 142.5 | 144 | | 28.3 | | | | | | | | | | | | | | | | | |
| | S-58 | 145 | 146.5 | | 24.8 | | | | | | | | | | | | | | | | | |
| | S-59 | 147.5 | 149 | CL | 25.0 | | | | | 100 | | 42 | 20 | 22 | | | | | | | | |
| | S-60 | 150 | 151.5 | | 21.7 | | | | | | | | | | | | | | | | | |
| | S-61 | 152.5 | 154 | | 26.8 | | | | | | | | | | | | | | | | | |
| | S-63 | 157.5 | 159 | CL | 23.9 | | | 0 | 1 | 81 | 18 | 39 | 20 | 19 | | | | | | | | |
| | S-64 | 160 | 161.5 | | 27.7 | | | | | | | | | | | | | | | | | |
| | S-65 | 162.5 | 164 | | 25.8 | | | | | | | | | | | | | | | | | |
| | S-66 | 165 | 166.5 | | 26.6 | | | | | | | | | | | | | | | | | |
| | S-67 | 167.5 | 168.4 | | 45.9 | | | | | | | | | | | | | | | | | |
| | S-68 | 170 | 171.5 | | 28.4 | | | | | | | | | | | | | | | | | |
| | S-69 | 172.5 | 174 | | 26.8 | | | | | | | | | | | | | | | | | |
| | S-70 | 175 | 176.5 | | 25.2 | | | | | | | | | | | | | | | | | |

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA | | | | | | | | GRAIN SIZE ANALYSIS² | | | | ATTERBERG LIMITS | | | CORROSION | | | | TRIAXIAL TESTING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Symbol¹ | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | Gravel (%) | Sand (%) | Fines³ (75 to 2 um) (%) | Fines³ (< 2 um) (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category⁴ | Sodium Absorption Ration (SAR)⁵ |
| RP-127-02 | S-1 | 2.5 | 5 | | 16.7 | | | | | | | | | | | | | | | | | |
| | S-2 | 5 | 6 | CL | 16.6 | 118.2464 | | | | 82 | | 40 | 17 | 23 | | | | | | | | |
| | S-3 | 7.5 | 10 | | 21.2 | | | | | | | | | | | | | | | | | |
| | S-4b | 10.8 | 11 | | 20.5 | | | | | | | 52* | 19* | 33* | | | | | | | | |
| | S-5 | 12.5 | 15 | | 19.3 | | | | | | | | | | | | | | | | | |
| | S-6 | 15 | 17.5 | | 20.6 | | | | | | | | | | | | | | | | | |
| | S-7 | 17.5 | 18.5 | | 27.9 | | | | | | | | | | | | | | | | | |
| | S-8 | 20 | 22.5 | | 31.9 | | | | | | | | | | | | | | | | | |
| | S-9 | 22.5 | 25 | | 23.1 | | | | | | | | | | | | | | | | | |
| | S-10 | 25 | 27.5 | CL | 22.7 | | | | | 98 | | 41* | 19* | 22* | | | | | | | | |
| | S-11 | 27.5 | 28.5 | | 18.4 | | | | | | | | | | | | | | | | | |
| | S-12 | 30 | 32.5 | | 24.6 | | | | | | | | | | | | | | | | | |
| | S-13 | 32.5 | 35 | CL | 29.5 | | | | | 94 | | 48 | 20 | 28 | | | | | | | | |
| | S-14 | 35 | 37.5 | | 23.0 | | | | | | | | | | | | | | | | | |
| | S-15 | 37.5 | 40 | | 22.7 | | | | | | | | | | | | | | | | | |
| | S-16 | 40 | 41 | | 21.7 | 126.557 | | | | | | | | | | | | | | | | |
| | S-17 | 42.5 | 45 | | 21.7 | | | | | | | | | | | | | | | | | |
| | S-18 | 45 | 47.5 | | 20.0 | | | | | | | | | | | | | | | | | |
| | S-20 | 50 | 52.5 | | 21.1 | | | | | | | | | | | | | | | | | |
| | S-21 | 52.5 | 55 | CH | 31.4 | | | | | 84 | | 55 | 19 | 36 | | | | | | | | |
| | S-22 | 55 | 56 | | 19.5 | 110.5138 | | | | | | | | | | | | | | | | |
| | S-23 | 57.5 | 60 | | 17.1 | | | | | | | | | | | | | | | | | |
| | S-24 | 60 | 62.5 | CH | 30.0 | | | | | 97 | | 62 | 28 | 34 | | | | | | | | |
| | S-25 | 62.5 | 65 | | 22.4 | | | | | | | | | | | | | | | | | |
| | S-26 | 65 | 67.5 | | 23.0 | | | | | | | | | | | | | | | | | |
| | S-27 | 67.5 | 70 | | 20.5 | | | | | | | | | | | | | | | | | |
| | S-29 | 72.5 | 75 | | 26.5 | | | | | | | | | | | | | | | | | |
| | S-30 | 75 | 77.5 | CH | 25.2 | | | | | 100 | | 75 | 17 | 58 | | | | | | | | |
| | S-31 | 77.5 | 78.5 | | 30.4 | | | | | | | | | | | | | | | | | |
| | S-32 | 80 | 82.5 | | 24.8 | | | | | | | | | | | | | | | | | |
| | S-33 | 82.5 | 85 | | 26.7 | | | | | | | | | | | | | | | | | |
| | S-34 | 85 | 87.5 | | 75.9 | | | | | | | | | | | | | | | | | |
| | S-35 | 87.5 | 90 | CH | 24.8 | | | 0 | 4 | 42 | 54 | 94 | 18 | 76 | | | | | | | | |
| | S-36 | 90 | 92.5 | | 67.2 | | | | | | | | | | | | | | | | | |

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA | | | | | | | | GRAIN SIZE ANALYSIS² | | | | ATTERBERG LIMITS | | | CORROSION | | | | TRIAXIAL TESTING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Symbol¹ | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | Gravel (%) | Sand (%) | Fines³ (75 to 2 um) (%) | Fines³ (< 2 um) (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category⁴ | Sodium Absorption Ration (SAR)⁵ |
| RP-127-02 | S-37 | 92.5 | 95 | | 79.3 | | | | | | | | | | | | | | | | | |
| | S-38 | 95 | 97.5 | | 24.0 | | | | | | | | | | | | | | | | | |
| | S-39 | 97.5 | 98.5 | | 26.8 | | | | | | | | | | | | | | | | | |
| | S-40 | 100 | 102.5 | | 22.4 | | | | | | | | | | | | | | | | | |
| | S-41 | 102.5 | 105 | CL | 21.1 | | | | | 63 | | 35 | 17 | 18 | | | | | | | | |
| | S-42 | 105 | 107.5 | | 30.6 | | | | | | | | | | | | | | | | | |
| | S-43 | 107.5 | 110 | | 31.9 | | | | | | | | | | | | | | | | | |
| | S-44 | 110 | 111 | CH | 29.7 | 118.6266 | | | | 93 | | 65 | 24 | 41 | | | | | | | | |
| | S-45 | 112.5 | 115 | | 20.5 | | | | | | | | | | | | | | | | | |
| | S-46 | 115 | 117.5 | | 20.3 | | | | | | | | | | | | | | | | | |
| | S-47 | 117.5 | 120 | | 19.3 | | | | | | | | | | | | | | | | | |
| | S-48 | 120 | 122.5 | | 24.6 | | | | | | | | | | | | | | | | | |
| | S-49 | 122.5 | 125 | CH/CL | 22.3 | | | | | 84 | | 49 | 17 | 32 | | | | | | | | |
| | S-50 | 125 | 126 | | 23.6 | 125.5054 | | | | | | | | | | | | | | | | |
| | S-52 | 130 | 132.5 | | 19.1 | | | | | | | | | | | | | | | | | |
| | S-53 | 132.5 | 135 | CH/CL | 23.0 | | | | | 88 | | 50 | 16 | 34 | | | | | | | | |
| | S-54 | 135 | 137.5 | | 24.8 | | | | | | | | | | | | | | | | | |
| | S-55 | 137.5 | 138.5 | | 21.1 | | | | | | | | | | | | | | | | | |
| | S-56 | 140 | 142.5 | | 19.9 | | | | | | | | | | | | | | | | | |
| | S-57 | 142.5 | 145 | | 19.4 | | | | | | | | | | | | | | | | | |
| | S-58 | 145 | 147.5 | CH | 23.2 | | | | | 98.7 | | 61 | 21 | 40 | | | | | | | | |
| | S-59 | 147.5 | 150 | | 24.6 | | | | | | | | | | | | | | | | | |
| RP-127-03 | S-1 | 2.5 | 5 | | 25.2 | | | | | | | | | | | | | | | | | |
| | S-3 | 7.5 | 10 | | 23.0 | | | | | | | | | | | | | | | | | |
| | S-4 | 10 | 12.5 | CH | 22.7 | | | | | 81 | | 55 | 18 | 37 | | | | | | | | |
| | S-5 | 12.5 | 13.5 | | 18.8 | | | | | | | | | | | | | | | | | |
| | S-6 | 15 | 17.5 | | 24.4 | | | | | | | | | | | | | | | | | |
| | S-7 | 17.5 | 20 | | 16.2 | | | | | | | | | | | | | | | | | |
| | S-8 | 20 | 21 | | 21.9 | | | | | | | | | | | | | | | | | |
| | S-9 | 22.5 | 25 | | 19.6 | | | | | | | | | | | | | | | | | |
| | S-10 | 25 | 27.5 | | 24.1 | | | | | | | | | | | | | | | | | |
| | S-11 | 27.5 | 30 | | 15.1 | | | | | | | | | | | | | | | | | |
| | S-12 | 30 | 31 | CH | 21.8 | 107.8632 | | | | 58 | | 50 | 19 | 31 | | | | | | | | |
| | S-13 | 32.5 | 35 | | 26.5 | | | | | | | | | | | | | | | | | |

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA | | | | | | | | GRAIN SIZE ANALYSIS[2] | | | | ATTERBERG LIMITS | | | | CORROSION | | | TRIAXIAL TESTING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Symbol[1] | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | Gravel (%) | Sand (%) | Fines[3] (75 to 2 um) (%) | Fines[3] (< 2 um) (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category[4] | Sodium Absorption Ration (SAR)[5] |
| RP-127-03 | S-14 | 35 | 37.5 | | 27.4 | | | | | | | | | | | | | | | | | |
| | S-15 | 37.5 | 40 | | 21.1 | | | | | | | | | | | | | | | | | |
| | S-16 | 40 | 42.5 | | 24.2 | | | | | | | | | | | | | | | | | |
| | S-17 | 42.5 | 45 | | 42.4 | | | | | | | | | | | | | | | | | |
| | S-18 | 45 | 46 | | 25.2 | 125.2816 | | | | | | | | | | | | | | | | |
| | S-19 | 47.5 | 50 | CH | 27.1 | | | | | 96 | | 53 | 18 | 35 | | | | | | | | |
| | S-20 | 52.5 | 55 | | 20.4 | | | | | | | | | | | | | | | | | |
| | S-21 | 55 | 57.5 | | 24.4 | | | | | | | | | | | | | | | | | |
| | S-22 | 57.5 | 60 | | 22.7 | | | | | | | | | | | | | | | | | |
| | S-23 | 60 | 61 | | 20.5 | | | | | | | | | | | | | | | | | |
| | S-24 | 62.5 | 65 | | 25.1 | | | | | | | | | | | | | | | | | |
| | S-25 | 65 | 67.5 | CH | 24.5 | | | | | 87 | | 52 | 18 | 34 | | | | | | | | |
| | S-26 | 67.5 | 70 | | 23.0 | | | | | | | | | | | | | | | | | |
| | S-27 | 70 | 72.5 | | 20.4 | | | | | | | | | | | | | | | | | |
| | S-28 | 72.5 | 75 | | 18.7 | | | | | | | | | | | | | | | | | |
| | S-29 | 75 | 77.5 | | 18.4 | | | | | | | | | | | | | | | | | |
| | S-30 | 77.5 | 80 | CL/SC | 21.5 | | | 1 | 48 | 51 | | 34 | 14 | 20 | | | | | | | | |
| | S-31 | 80 | 82.5 | | 22.0 | | | | | | | | | | | | | | | | | |
| | S-32 | 82.5 | 85 | | 20.5 | | | | | | | | | | | | | | | | | |
| | S-33 | 85 | 87.5 | | 17.7 | | | | | | | | | | | | | | | | | |
| | S-34 | 87.5 | 90 | | 20.7 | | | | | | | | | | | | | | | | | |
| | S-35 | 90 | 92.5 | SM | 19.3 | | | | | 23 | | 22 | 21 | 1 | | | | | | | | |
| | S-36 | 92.5 | 95 | | 19.2 | | | | | | | | | | | | | | | | | |
| | S-37 | 95 | 97.5 | | 19.4 | | | | | | | | | | | | | | | | | |
| | S-38 | 97.5 | 100 | | 21.0 | | | | | | | | | | | | | | | | | |
| | S-39 | 100 | 102.5 | | 19.8 | | | | | | | | | | | | | | | | | |
| | S-40 | 102.5 | 105 | SC | 21.8 | | | 0 | 73 | 16 | 11 | 29 | 21 | 8 | | | | | | | | |
| | S-41 | 105 | 107.5 | | 19.3 | | | | | | | | | | | | | | | | | |
| | S-42 | 107.5 | 110 | | 24.8 | | | | | | | | | | | | | | | | | |
| | S-43 | 110 | 111.5 | | 20.3 | | | | | | | | | | | | | | | | | |
| | S-44 | 112.5 | 115 | | 23.2 | | | | | | | | | | | | | | | | | |
| | S-45 | 115 | 116 | | 20.6 | 127.8128 | | | | | | | | | | | | | | | | |
| | S-46 | 117.5 | 120 | | 18.9 | | | | | | | | | | | | | | | | | |
| | S-47 | 120 | 122.5 | | 21.0 | | | | | | | | | | | | | | | | | |

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Symbol[1] | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | GRAIN SIZE ANALYSIS[2] Gravel (%) | Sand (%) | Fines[3] (75 to 2 um) (%) | Fines[3] (< 2 um) (%) | ATTERBERG LIMITS Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | CORROSION pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | TRIAXIAL TESTING Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category[4] | Sodium Absorption Ration (SAR)[5] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RP-127-03 | S-48 | 122.5 | 124 | | 20.7 | | | | | | | | | | | | | | | | | |
| | S-49 | 125 | 126.5 | | 16.2 | | | | | | | | | | | | | | | | | |
| | S-50 | 127.5 | 130 | | 21.0 | | | | | | | | | | | | | | | | | |
| | S-51 | 130 | 132.5 | SC | 21.9 | | | | | 28 | | 36 | 19 | 17 | | | | | | | | |
| | S-52 | 132.5 | 135 | | 23.5 | | | | | | | | | | | | | | | | | |
| | S-53 | 135 | 137.5 | | 26.7 | | | | | | | | | | | | | | | | | |
| | S-54 | 137.5 | 140 | | 28.4 | | | | | | | | | | | | | | | | | |
| | S-55 | 140 | 142.5 | SC | 26.2 | | | | | 48 | | 46 | 15 | 31 | | | | | | | | |
| | S-56 | 142.5 | 145 | | 21.2 | | | | | | | | | | | | | | | | | |
| | S-57 | 145 | 147.5 | | 18.9 | | | | | | | | | | | | | | | | | |
| | S-58 | 147.5 | 148.4 | | 18.2 | | | | | | | | | | | | | | | | | |
| | S-59 | 155 | 156 | | 17.7 | 129.8616 | | | | | | | | | | | | | | | | |
| | S-60 | 160 | 162.5 | | 21.9 | | | | | | | | | | | | | | | | | |
| | S-61 | 165 | 166.5 | | 23.3 | | | | | | | | | | | | | | | | | |
| | S-62 | 170 | 170.9 | CH | 30.3 | | | | | 96 | | 99 | 22 | 77 | | | | | | | | |
| | S-63 | 175 | 175.5 | | 16.3 | | | | | | | | | | | | | | | | | |
| RP-127-04 | S-1 | 2.5 | 5 | | 9.0 | | | | | | | | | | | | | | | | | |
| | S-2b | 5.6 | 5.8 | CL | 12.1 | | | | | 59 | | 41* | 14* | 27* | | | | | | | | |
| | S-2c | 6 | 6.3 | | 15.5* | | | | | | | 45* | 15* | 30* | | | | | | | | |
| | S-3 | 7.5 | 10 | CL | 11.1 | | | | | 83 | | 41 | 15 | 26 | | | | | | | | |
| | S-4 | 10 | 12.5 | | 10.5 | | | | | | | | | | | | | | | | | |
| | S-5a | 12.8 | 13 | | 11.5* | | | | | | | 44* | 12* | 32* | | | | | | | | |
| | S-5b | 13.3 | 13.5 | | 8.8* | | | | | 53 | | | | | | | | | | | | |
| | S-6 | 15 | 17.5 | | 16.2 | | | | | | | | | | | | | | | | | |
| | S-7 | 17.5 | 20 | CL | 19.9 | | | | | 59 | | 42 | 13 | 29 | | | | | | | | |
| | S-8 | 20 | 22.5 | | 18.9 | | | | | | | | | | | | | | | | | |
| | S-9 | 22.5 | 25 | CH | 23.6 | | | | | 100 | | 60 | 21 | 39 | | | | | | | | |
| | S-10a | 25.2 | 25.4 | | 24.3* | | | | | | | 63* | 19* | 44* | | | | | | | | |
| | S-10b | 25.8 | 26 | | 27.2* | | | | | | | 65 | 19 | 46 | | | | | | | | |
| | S-11 | 27.5 | 30 | | 28.4 | | | | | | | | | | | | | | | | | |
| | S-12 | 30 | 31 | | 22.6 | 125.1969 | | | | | | | | | | | | | | | | |
| | S-13 | 32.5 | 35 | CH | 28.8 | | | 0 | 1 | 67 | 32 | 114 | 17 | 97 | | | | | | | | |
| | S-14 | 35 | 37.5 | | 25.0 | | | | | | | | | | | | | | | | | |
| | S-15 | 37.5 | 40 | | 24.6 | | | | | | | | | | | | | | | | | |

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA | | | | | | | | GRAIN SIZE ANALYSIS[2] | | | | ATTERBERG LIMITS | | | CORROSION | | | | TRIAXIAL TESTING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Symbol[1] | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | Gravel (%) | Sand (%) | Fines[3] (75 to 2 um) (%) | Fines[3] (< 2 um) (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category[4] | Sodium Absorption Ration (SAR)[5] |
| RP-127-04 | S-16 | 40 | 41 | | 26.6 | 125.7118 | | | | | | | | | | | | | | | | |
| | S-17 | 42.5 | 45 | CH | 27.9 | | | | | 99 | | 125 | 20 | 105 | | | | | | | | |
| | S-18 | 45 | 47.5 | | 25.4 | | | | | | | | | | | | | | | | | |
| | S-19 | 47.5 | 50 | | 30.8 | | | | | | | | | | | | | | | | | |
| | S-20 | 50 | 52 | | 26.1 | | | | | | | | | | | | | | | | | |
| | S-21 | 52.5 | 55 | | 23.2 | | | | | | | | | | | | | | | | | |
| | S-22 | 55 | 57.5 | | 23.4 | | | | | | | | | | | | | | | | | |
| | S-23a | 57.5 | 57.7 | | 24.7* | | | | | | | 101* | 14* | 87* | | | | | | | | |
| | S-24 | 60 | 62.5 | | 23.4 | | | | | | | | | | | | | | | | | |
| | S-25 | 62.5 | 65 | CH | 23.7 | | | 0 | 0 | 59 | 41 | 79 | 17 | 62 | | | | | | | | |
| | S-26 | 65 | 66 | | 83.1 | | | | | | | | | | | | | | | | | |
| | S-27 | 67.5 | 70 | CH | 22.3 | | | | | 100 | | 89 | 17 | 72 | | | | | | | | |
| | S-28 | 70 | 71 | | | | | | | | | | | | | | | | | | | |
| | S-29 | 72.5 | 75 | | 22.5 | | | | | | | | | | | | | | | | | |
| | S-30 | 75 | 77.5 | | 23.5 | | | | | | | | | | | | | | | | | |
| | S-31 | 77.5 | 80 | CH | 22.5 | | | 0 | 13 | 63 | 24 | 71 | 22 | 49 | | | | | | | | |
| | S-32 | 80 | 82.5 | | 21.9 | | | | | | | | | | | | | | | | | |
| | S-33 | 82.5 | 85 | CH | 26.5 | | | | | 94 | | 118 | 25 | 93 | | | | | | | | |
| | S-34 | 85 | 86 | | 25.0 | | | | | | | | | | | | | | | | | |
| | S-35 | 87.5 | 90 | | 23.7 | | | | | | | | | | | | | | | | | |
| | S-36 | 90 | 92.5 | | 22.5 | | | | | | | | | | | | | | | | | |
| | S-37 | 92.5 | 95 | | 23.1 | | | | | | | | | | | | | | | | | |
| | S-38 | 95 | 97.5 | CH | 22.5 | | | | | 100 | | 92 | 17 | 75 | | | | | | | | |
| | S-39 | 97.5 | 98.5 | | 20.5 | 130.8372 | | | | | | | | | | | | | | | | |
| | S-40 | 100 | 102 | | 24.5 | | | | | | | | | | | | | | | | | |
| | S-41 | 102.5 | 105 | | 22.3 | | | | | | | | | | | | | | | | | |
| | S-42 | 105 | 107.5 | | 22.3 | | | | | | | | | | | | | | | | | |
| | S-43 | 107.5 | 110 | | 24.8 | | | | | | | | | | | | | | | | | |
| | S-44 | 110 | 112.5 | CH | 29.8 | | | | | 95 | | 81 | 20 | 61 | | | | | | | | |
| | S-45 | 112.5 | 113.5 | | 22.5 | | | | | | | | | | | | | | | | | |
| | S-46 | 115 | 115.1 | | 20.4 | | | | | | | | | | | | | | | | | |
| | S-47 | 117.5 | 119 | | 20.0 | | | | | | | | | | | | | | | | | |
| | S-48 | 120 | 122.5 | CH | 24.4 | | | | | 99 | | 93 | 21 | 72 | | | | | | | | |
| | S-49 | 122.5 | 123.5 | | | | | | | | | | | | | | | | | | | |
| | S-50 | 125 | 127.5 | | 20.3 | | | | | | | | | | | | | | | | | |
| | S-51 | 127.5 | 130 | CH | 24.5 | | | | | 54 | | 69 | 19 | 50 | | | | | | | | |
| | S-52 | 130 | 132.5 | | 22.8 | | | | | | | | | | | | | | | | | |
| | S-53 | 132.5 | 133.5 | | 21.6 | | | | | | | | | | | | | | | | | |
| | S-54 | 135 | 135.9 | | 43.2 | | | | | | | | | | | | | | | | | |
| | S-55 | 137.5 | 140 | CH | 22.9 | | | | | 94 | | 88 | 17 | 71 | | | | | | | | |

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA | | | | | | | | GRAIN SIZE ANALYSIS[2] | | | | ATTERBERG LIMITS | | | CORROSION | | | | TRIAXIAL TESTING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | | | | | | | | Fines[3] | | | | | | | | | | | | |
| Boring | Sample | Top (feet) | Bottom (feet) | USCS Symbol[1] | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | Gravel (%) | Sand (%) | (75 to 2 um) (%) | (< 2 um) (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category[4] | Sodium Absorption Ration (SAR)[5] |
| RP-127-05 | S-1 | 2.5 | 5 | CH | 17.7 | | | | | 73 | | 53 | 16 | 37 | | | | | | | | |
| | S-2 | 5.4 | 5.7 | | 28.0 | | | | | | | 55 | 20 | 35 | | | | | | | | |
| | S-3 | 7.5 | 10 | | 29.5 | | | | | | | | | | | | | | | | | |
| | S-4 | 10.5 | 10.8 | | 18.1 | | | | | | | 52 | 18 | 34 | | | | | | | | |
| | S-5 | 12.5 | 15 | | 19.8 | | | | | | | | | | | | | | | | | |
| | S-6 | 15 | 16 | SC/CH | 23.5 | | | | | 51 | | 53 | 17 | 36 | | | | | | | | |
| | S-7 | 17.5 | 20 | | 25.3 | | | | | | | | | | | | | | | | | |
| | S-8 | 20.9 | 21.2 | | 26.9 | | | | | | | 66 | 18 | 48 | | | | | | | | |
| | S-9 | 22.5 | 25 | | 30.6 | | | | | | | | | | | | | | | | | |
| | S-10 | 25 | 27.5 | CH | 33.5 | | | 0 | 1 | 35 | 64 | 141 | 25 | 116 | | | | | | | | |
| | S-11 | 27.5 | 30 | | 28.8 | | | | | | | | | | | | | | | | | |
| | S-12 | 30 | 31 | | 27.0 | 129.0382 | | | | | | | | | | | | | | | | |
| | S-13 | 32.5 | 35 | CH | 24.0 | | | | | 83 | | 108 | 18 | 90 | | | | | | | | |
| | S-14 | 35 | 37.5 | | 25.2 | | | | | | | | | | | | | | | | | |
| | S-15 | 37.5 | 40 | | 23.6 | | | | | | | | | | | | | | | | | |
| | S-16 | 40 | 41 | | 28.0 | | | | | | | | | | | | | | | | | |
| | S-17 | 42.5 | 45 | | 35.3 | | | | | | | | | | | | | | | | | |
| | S-18 | 45 | 47.5 | | 29.7 | | | | | | | | | | | | | | | | | |
| | S-19 | 50 | 52.5 | CH | 23.2 | | | 0 | 2 | 76 | 22 | 80 | 19 | 61 | | | | | | | | |
| | S-20 | 55 | 56 | | 29.1 | 122.6635 | | | | | | | | | | | | | | | | |
| | S-21 | 60 | 62.5 | | 23.5 | | | | | | | | | | | | | | | | | |
| | S-22 | 65 | 67.5 | | 24.2 | | | | | | | | | | | | | | | | | |
| | S-23 | 70 | 72.5 | | 24.8 | | | | | | | | | | | | | | | | | |
| | S-24 | 75 | 76 | | 26.6 | | | | | | | | | | | | | | | | | |
| | S-25 | 80 | 82.5 | CH | 25.3 | | | | | 98 | | 119 | 22 | 97 | | | | | | | | |
| | S-26 | 85 | 85.3 | | 68.3 | | | | | | | | | | | | | | | | | |
| | S-27 | 87.5 | 87.7 | | | | | | | | | | | | | | | | | | | |
| | S-28 | 90 | 92.5 | | 21.1 | | | | | | | | | | | | | | | | | |
| RP-127-05 | S-29 | 92.5 | 95 | | 22.4 | | | | | | | | | | | | | | | | | |
| | S-30 | 95 | 96 | CH | 25.9 | 121.7271 | | | | 96 | | 122 | 24 | 98 | | | | | | | | |
| | S-31 | 97.5 | 100 | CH | 22.3 | | | | | 74.6 | | 77 | 18 | 59 | | | | | | | | |
| | S-32 | 100 | 102.5 | | 27.0 | | | | | | | | | | | | | | | | | |
| | S-33 | 102.5 | 105 | | 23.3 | | | | | | | | | | | | | | | | | |
| | S-34 | 105 | 107.5 | | 23.0 | | | | | | | | | | | | | | | | | |
| | S-35 | 107.5 | 108.5 | | 19.7 | | | | | | | | | | | | | | | | | |
| | S-36 | 110 | 110.1 | | | | | | | | | | | | | | | | | | | |
| | S-37 | 112.5 | 114 | | 21.7 | | | | | | | | | | | | | | | | | |
| | S-38 | 115 | 116.5 | CH | 21.3 | | | 0 | 0 | 57 | 43 | 71 | 21 | 50 | | | | | | | | |
| | S-39 | 117.5 | 118.9 | | 22.9 | | | | | | | | | | | | | | | | | |
| | S-40 | 120 | 121 | | 25.9 | | | | | | | | | | | | | | | | | |
| | S-41 | 125 | 127.5 | | 27.9 | | | | | | | | | | | | | | | | | |

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA | | | | | | | | GRAIN SIZE ANALYSIS[2] | | | | ATTERBERG LIMITS | | | CORROSION | | | | TRIAXIAL TESTING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | | | | | | | | Fines[3] | | | | | | | | | | | | |
| Boring | Sample | Top (feet) | Bottom (feet) | USCS Symbol[1] | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | Gravel (%) | Sand (%) | (75 to 2 um) (%) | (< 2 um) (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category[4] | Sodium Absorption Ration (SAR)[5] |
| | S-42 | 130 | 132.5 | | 25.0 | | | | | | | | | | | | | | | | | |
| | S-43 | 135 | 137.5 | | 23.3 | | | | | | | | | | | | | | | | | |
| | S-44 | 140 | 141 | CH | 30.7 | | | | | 96 | | 120 | 25 | 95 | | | | | | | | |
| | S-45 | 145 | 146 | | 21.8 | 129.7617 | | | | | | | | | | | | | | | | |
| | S-46 | 150 | 151.5 | | 24.5 | | | | | | | | | | | | | | | | | |
| | S-47 | 155 | 156.5 | | 23.0 | | | | | | | | | | | | | | | | | |
| | S-48 | 160 | 161.4 | CH | 21.7 | | | | | 100 | | 98 | 19 | 79 | | | | | | | | |
| | S-49 | 165 | 167.5 | | 22.0 | | | | | | | | | | | | | | | | | |
| | S-50 | 167.5 | 170 | | | | | | | | | | | | | | | | | | | |

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA | | | | | | | | GRAIN SIZE ANALYSIS² | | | | ATTERBERG LIMITS | | | CORROSION | | | | TRIAXIAL TESTING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Symbol¹ | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | Gravel (%) | Sand (%) | Fines³ (75 to 2 um) (%) | Fines³ (< 2 um) (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category⁴ | Sodium Absorption Ration (SAR)⁵ |
| RP-127-06 | S-1 | 2.5 | 5 | SC | 8.6 | | | | | 36 | | 28 | 17 | 11 | | | | | | | | |
| | S-2 | 5 | 7.5 | | 11.1 | | | | | | | | | | | | | | | | | |
| | S-3 | 10.5 | 10.8 | CH | 34.1 | | | | | 98 | | 100 | 26 | 74 | | | | | | | | |
| | S-4 | 15 | 16.5 | CH | 15.1 | | | 0 | 16 | 84 | | 57 | 19 | 38 | | | | | | | | |
| | S-5 | 20 | 22.5 | | 22.6 | | | | | | | | | | | | | | | | | |
| | S-6 | 25 | 26 | | 26.3 | 117.184 | | | | | | 100 | 21 | 79 | | | | | | | | |
| | S-7 | 30 | 32.5 | CH | 25.6 | | | | | 100 | | 63 | 17 | 46 | | | | | | | | |
| | S-8 | 35 | 37.5 | | 24.9 | | | | | | | | | | | | | | | | | |
| | S-9 | 40 | 42.5 | | 25.6 | | | | | | | | | | | | | | | | | |
| | S-10 | 45 | 47.5 | CL | 27.0 | | | 0 | 13 | 69 | 18 | 45 | 18 | 27 | | | | | | | | |
| | S-11 | 50 | 52.5 | | 24.9 | | | | | | | | | | | | | | | | | |
| | S-12 | 55 | 56 | | 23.9 | | | | | | | | | | | | | | | | | |
| | S-13 | 60 | 62.5 | CH | 37.0 | | | 0 | 3 | 35 | 62 | 86 | 26 | 60 | | | | | | | | |
| | S-14 | 65 | 67.5 | | 25.7 | | | | | | | | | | | | | | | | | |
| | S-15 | 70 | 71 | | 29.3 | | | | | | | | | | | | | | | | | |
| | S-16 | 75 | 77 | CL | 32.2 | | | | | 100 | | 41 | 25 | 16 | | | | | | | | |
| | S-17 | 80 | 82 | | 28.2 | | | | | | | | | | | | | | | | | |
| | S-18 | 85 | 86 | | 23.7 | 130.5439 | | | | | | | | | | | | | | | | |
| | S-19 | 90 | 91.5 | | 27.8 | | | | | | | | | | | | | | | | | |
| | S-20 | 95 | 97 | ML | 29.0 | | | | | 54 | | 24 | 24 | 0 | | | | | | | | |
| | S-21 | 100 | 101.4 | | 24.3 | | | | | | | | | | | | | | | | | |
| | S-22 | 105 | 106 | | 22.8 | | | | | | | | | | | | | | | | | |
| | S-23 | 110 | 112.5 | | 25.9 | | | | | | | | | | | | | | | | | |
| | S-24 | 112.5 | 113.3 | | 30.5 | | | | | | | | | | | | | | | | | |
| | S-25 | 115 | 115.4 | | 56.9 | | | | | | | | | | | | | | | | | |
| | S-26 | 117.5 | 117.8 | | 109.0 | | | | | | | | | | | | | | | | | |
| | S-27 | 120 | 121.5 | | 33.7 | | | | | | | | | | | | | | | | | |
| | S-28 | 122.5 | 123.5 | CH | 22.0 | 130.1267 | | | | 100 | | 121 | 19 | 102 | | | | | | | | |
| | S-29 | 125 | 127.5 | | 21.6 | | | | | | | | | | | | | | | | | |
| | S-30 | 127.5 | 130 | | 23.1 | | | | | | | | | | | | | | | | | |
| | S-31 | 130 | 132.5 | | 25.5 | | | | | | | | | | | | | | | | | |
| | S-32 | 132.5 | 135 | CH | 26.2 | | | 0 | 9 | 66 | 25 | 70 | 16 | 54 | | | | | | | | |
| | S-33 | 135 | 137.5 | | 23.4 | | | | | | | | | | | | | | | | | |
| | S-34 | 137.5 | 138.5 | | 20.9 | | | | | | | | | | | | | | | | | |
| | S-35 | 140 | 142.5 | | 21.9 | | | | | | | | | | | | | | | | | |
| | S-36 | 142.5 | 145 | | 31.2 | | | | | | | | | | | | | | | | | |
| | S-37 | 145 | 147.5 | | 32.6 | | | | | | | | | | | | | | | | | |
| | S-38 | 147.5 | 150 | | 24.9 | | | | | | | | | | | | | | | | | |
| | S-39 | 150 | 151 | | 20.8 | 131.9952 | | | | | | | | | | | | | | | | |
| | S-40 | 152.5 | 155 | | 21.5 | | | | | | | | | | | | | | | | | |
| | S-41 | 155 | 157.5 | CH | 22.5 | | | | | 98 | | 80 | 19 | 61 | | | | | | | | |

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA | | | | | | | | GRAIN SIZE ANALYSIS[2] | | | | ATTERBERG LIMITS | | | CORROSION | | | | TRIAXIAL TESTING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Symbol[1] | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | Gravel (%) | Sand (%) | Fines[3] (75 to 2 um) (%) | Fines[3] (< 2 um) (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category[4] | Sodium Absorption Ration (SAR)[5] |
| | S-42 | 160 | 162.5 | | 20.9 | | | | | | | | | | | | | | | | | |
| | S-43 | 165 | 165.8 | | 71.7 | | | | | | | | | | | | | | | | | |
| | S-44 | 170 | 170.1 | | 96.0 | | | | | | | | | | | | | | | | | |
| | S-45 | 175 | 177 | | 23.5 | | | | | | | | | | | | | | | | | |
| | S-46 | 180 | 181 | CH | 19.5 | 133.5291 | | | | 100 | | 72 | 19 | 53 | | | | | | | | |
| | S-47 | 185 | 187.5 | | 22.6 | | | | | | | | | | | | | | | | | |
| | S-48 | 190 | 192.5 | CH/SC | 22.8 | | | | | 52 | | 72 | 18 | 54 | | | | | | | | |
| | S-49 | 195 | 195.5 | | 86.1 | | | | | | | | | | | | | | | | | |
| | S-50 | 200 | 202.5 | | 20.8 | | | | | | | | | | | | | | | | | |

Table D-1 - Summary of Previous Laboratory Test Results by Boring

| SAMPLE DATA | | | | | | | | GRAIN SIZE ANALYSIS² | | | | ATTERBERG LIMITS | | | CORROSION | | | | TRIAXIAL TESTING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring | Sample | Depth Top (feet) | Depth Bottom (feet) | USCS Symbol¹ | Moisture Content (%) | Moisture Unit Weight (pcf) | Specific Gravity | Gravel (%) | Sand (%) | Fines³ (75 to 2 um) (%) | Fines³ (< 2 um) (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Limit (%) | pH | Resistivity (ohm-cm) | Sulfates (%) | Chlorides (%) | Consolidtion Pressure (psf) | Peak Principal Stress Difference (psf) | Pinhole Testing Dispersiveness Category⁴ | Sodium Absorption Ration (SAR)⁵ |
| | S-1 | 5 | 6.5 | | 21.5 | | | | | | | | | | | | | | | | | |
| | S-2 | 10 | 11.5 | CH | 26.4 | | | | | 86 | | 86 | 23 | 63 | | | | | | | | |
| | S-3 | 15 | 16.5 | | 15.6 | | | | | | | | | | | | | | | | | |
| | S-4 | 20 | 21 | | 27.0 | 116.7907 | | | | | | | | | | | | | | | | |
| | S-5 | 25 | 26.5 | CL | 26.1 | | | | | 78 | | 43 | 18 | 25 | | | | | | | | |
| | S-6 | 30 | 31.5 | | 24.8 | | | | | | | | | | 8.1 | 170 | 1.2 | 0.02 | | | | |
| | S-7 | 35 | 36.5 | SC | 6.9 | | | | | 33 | | 89 | 16 | 73 | | | | | | | | |
| | S-8 | 40 | 41.5 | | 40.4 | | | | | | | | | | | | | | | | | |
| | S-9 | 45 | 46 | CH | 28.2 | 122.2855 | | | | 59 | 41 | 90 | 20 | 70 | | | | | | | | |
| | S-10 | 50 | 51.5 | | 33.0 | | | | | | | | | | | | | | | | | |
| | S-11 | 55 | 56.5 | SM | 34.5 | | | 0 | 53 | 43 | 4 | NV | NP | NP | | | | | | | | |
| | S-12 | 60 | 61.5 | | 29.4 | | | | | | | | | | | | | | | | | |
| | S-13 | 65 | 66.5 | | 71.8 | | | | | | | | | | | | | | | | | |
| | S-14 | 70 | 71.5 | CH | 28.0 | | | | | 99 | | 101 | 25 | 76 | | | | | | | | |
| RP-127-07 | S-15 | 75 | 76 | | 28.5 | 123.7911 | | | | | | | | | | | | | | | | |
| | S-16 | 77.5 | 79 | | 30.1 | | | | | | | | | | | | | | | | | |
| | S-17 | 80 | 81.5 | | 32.7 | | | | | | | | | | | | | | | | | |
| | S-18 | 82.5 | 84 | CH | 25.2 | | | | | 99 | | 118 | 20 | 98 | | | | | | | | |
| | S-19 | 85 | 86.5 | | 26.8 | | | | | | | | | | | | | | | | | |
| | S-20 | 87.5 | 88.5 | | 23.4 | 128.0561 | | | | | | | | | | | | | | | | |
| | S-21 | 90 | 91.5 | CH | 26.5 | | | | | 99 | | 101 | 16 | 85 | | | | | | | | |
| | S-22 | 95 | 96.5 | | 25.5 | | | | | | | | | | | | | | | | | |
| | S-23 | 100 | 100.2 | | 87.0 | | | | | | | | | | | | | | | | | |
| | S-24 | 105 | 106.5 | | 22.5 | | | | | | | | | | | | | | | | | |
| | S-25 | 110 | 111.5 | | 22.7 | | | | | | | | | | | | | | | | | |
| | S-26 | 115 | 116 | CH | 23.2 | 132.3276 | | | | 100 | | 108 | 19 | 89 | | | | | | | | |
| | S-27 | 120 | 121.5 | | 24.7 | | | | | | | | | | | | | | | | | |
| | S-28 | 125 | 126.5 | | 22.9 | | | | | | | | | | | | | | | | | |
| | S-29 | 130 | 131.5 | CH | 23.9 | | | | | 100 | | 81 | 23 | 58 | | | | | | | | |

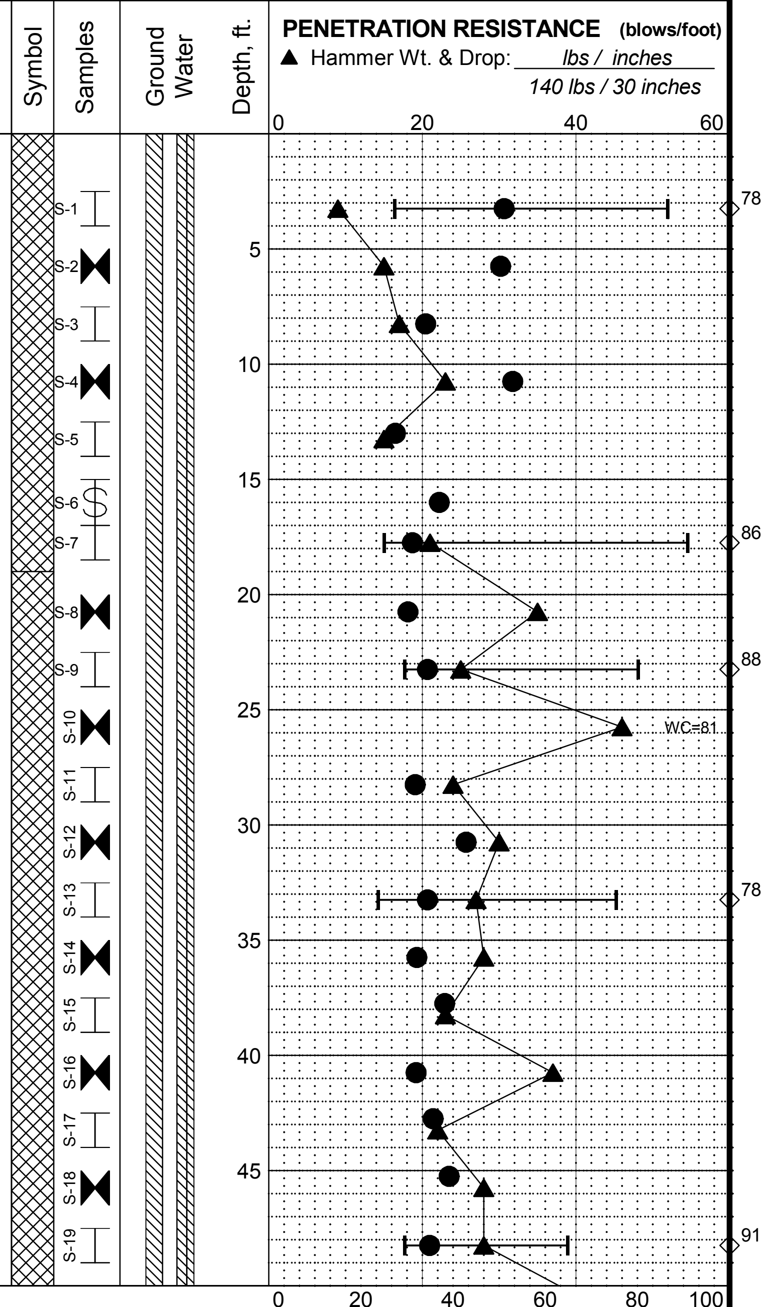
Notes:
1 Refer to Figure A-1 for definitions.
2 Gravel defined as particles larger than the No. 4 sieve size, sand as particles between the No. 4 and No. 200 sieve sizes, and fines as particles passing the No. 200 sieve.
3 Silt particles are defined as fines (passing the #200 sieve) larger than 2mm; clays are defined as particles smaller than 2mm. USCS designation is based on Atterberg limit testing.
4 Refer to Section B.3.2 for definitions.
5 Refer to Section B.3.3 for definitions.
* Sample tested by Advanced Terra Testing
NP = Non Plastic; NV = No Value; ohm-cm = ohm centimeters; pcf = pounds per cubic foot; psf = pounds per square foot

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 176.5 ft. | Latitude: | ~ 47.60799° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | ~ 2223 ft. | Longitude: | ~ -103.25869° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. |
|---|---|
| Stiff to very stiff, yellow mottled brown, *Fat Clay with Sand (CH)* to *Fat Clay (CH)*; moist; little to some bedrock debris. Fill | 19.0 |
| Very stiff to hard, brown to gray and yellow-brown, *Lean Clay (CL)* to *Lean Clay with Sand (CL)*; moist; few to little bedrock debris; trace to few silt and calcareous debris. Fill | |




CONTINUED NEXT SHEET

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- 3" O.D. Thin-Walled Tube
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough
- Inclinometer and SONDEX
- Ground Water Level in VWP
- RQD (%)
- Recovery (%)
- ◇ % Fines (<0.075mm)
- ● % Water Content ←(use scale at top)
- Plastic Limit ├──●──┤ Liquid Limit

NOTES

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

US-85 - I-94 to Watford City Bypass Addendum
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

# LOG OF BORING RP-127-01

September 2017 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-1**
Sheet 1 of 4

REV 3

MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 9/15/17

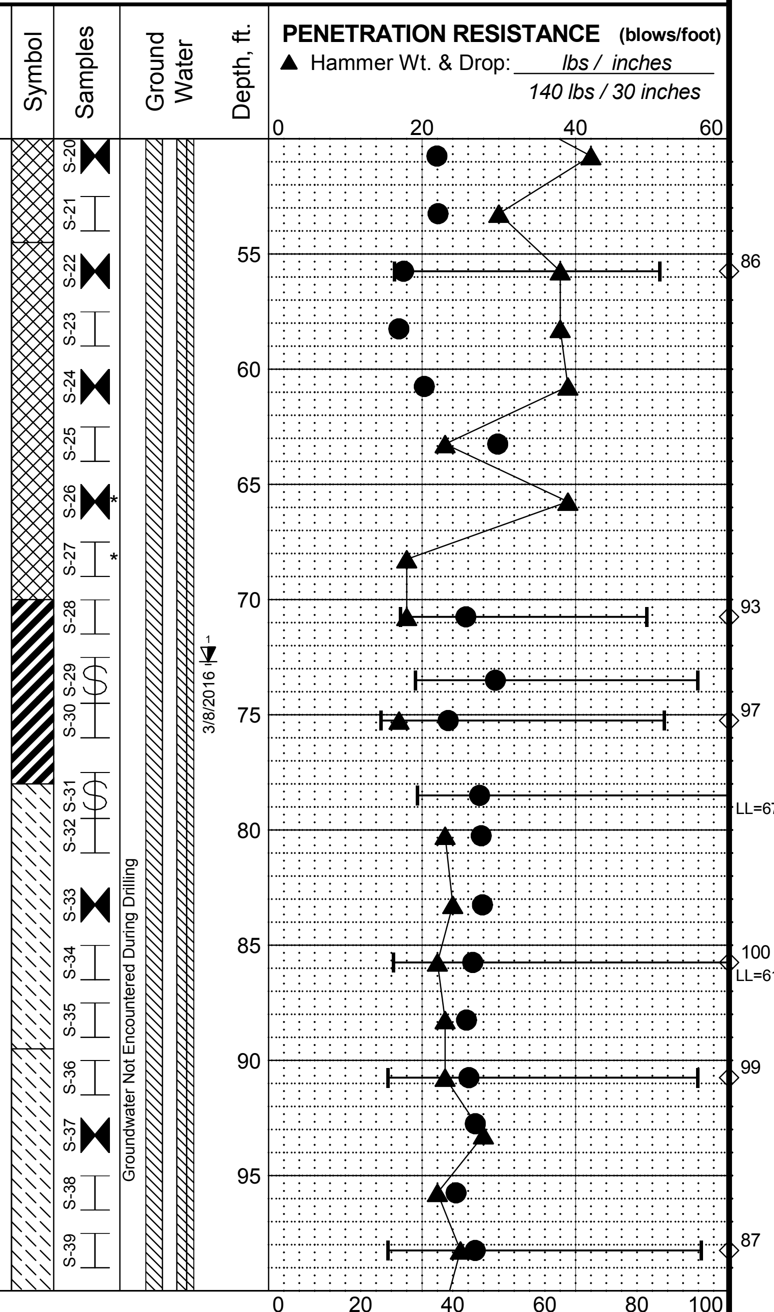
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 176.5 ft. | Latitude: | ~ 47.60799° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | ~ 2223 ft. | Longitude: | ~ -103.25869° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. |
|---|---|
| Fill (continued) | |
| Very stiff to hard, gray to red-brown, *Fat Clay (CH)*; moist; few sand; few to little red sandstone fragments. Fill | 54.5 |
| Very stiff, gray to red-brown, *Lean Clay (CL)* to *Fat Clay (CH)*; moist to wet; disturbed; trace to few sand; few to little bedrock debris. Landslide Debris | 70.0 |
| DISPLACED CLAYSTONE: very low strength, yellow-brown with iron oxide staining, slightly weathered (Sentinel Butte Formation). [Very stiff, *Fat Clay (CH)*; moist to wet.] | 78.0 |
| DISPLACED CLAYSTONE: very low strength, yellow-brown with iron oxide staining; slightly weathered; trace carbonaceous fragments (Sentinel Butte Formation). [Very stiff, *Fat Clay (CH)*; moist; trace to few sand.] - Carbonaceous lenses at 40 degrees from 100 to 102 feet. | 89.5 |

CONTINUED NEXT SHEET




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- 3" O.D. Thin-Walled Tube
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough
- Inclinometer and SONDEX
- Ground Water Level in VWP

NOTES

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

US-85 - I-94 to Watford City Bypass Addendum
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

# LOG OF BORING RP-127-01

September 2017 23-1-01453-230

**SHANNON & WILSON, INC.**
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**FIG. D-1**
Sheet 2 of 4

REV 3

MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 9/15/17

| | | | |
|---|---|---|---|
| Total Depth: 176.5 ft. | Latitude: ~ 47.60799° | Drilling Method: HSA/Mud Rotary | Hole Diam.: 8 in. |
| Top Elevation: ~ 2223 ft. | Longitude: ~ -103.25869° | Drilling Company: Interstate Drilling Service | Rod Type.: AWJ |
| Vert. Datum: | Station: ~ | Drill Rig Equipment: Diedrich D-50 Track Rig | Hammer Type: Automatic |
| Horiz. Datum: | Offset: ~ | Other Comments: | |

**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. |
|---|---|
| DISPLACED CLAYSTONE (continued) | 102.0 |
| SANDSTONE: very low strength, gray with occasional iron oxide staining; fresh to slightly weathered (Sentinel Butte Formation). [Medium dense to very dense, *Clayey Sand (SC)*; moist.] | 111.0 |
| COAL: very low strength, black (Sentinel Butte Formation). - 0.9-foot thick claystone lense at 113.6 feet. | 117.0 |
| CLAYSTONE: very low strength, gray, fresh (Sentinel Butte Formation). [Hard, *Fat Clay (CH)*;moist.] - Dark brown from 127.0 to 128.2 feet. | 128.2 |
| CLAYSTONE: very low strength, gray with iron oxide staining; fresh; trace carbonaceous fragments (Sentinel Butte Formation). [Hard, *Lean Clay (CL)*; moist.] | 135.8 |
| SILTSTONE: very low strength, gray with iron oxide staining; slightly weathered (Sentinel Butte Formation). [Hard, *Silt with Sand (ML)*; moist.] | 146.0 |
| CLAYSTONE: very low strength, gray, fresh (Sentinel Butte Formation). | |

CONTINUED NEXT SHEET

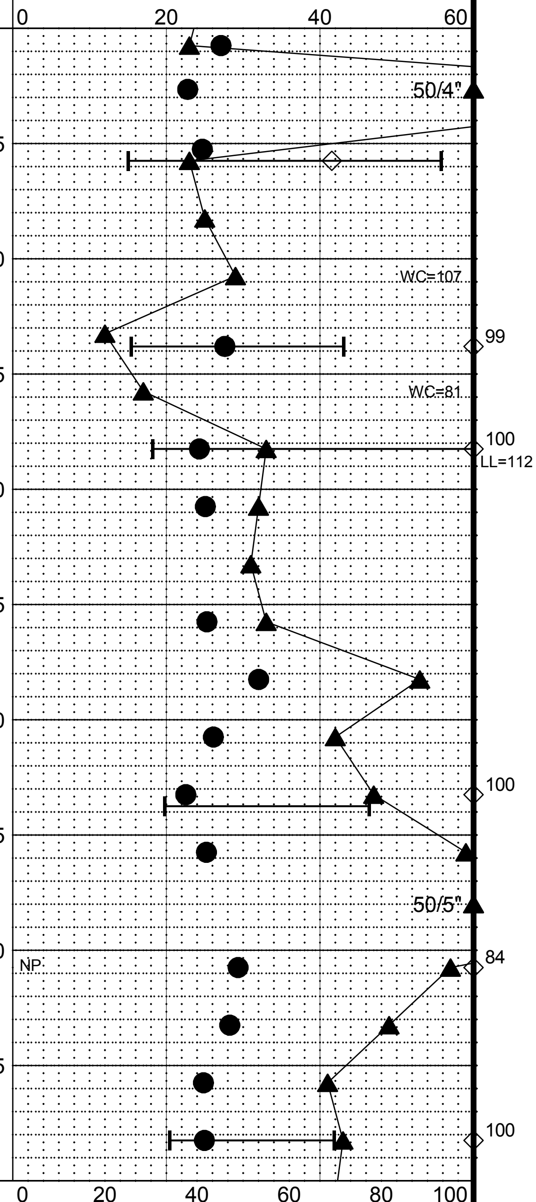
Symbol | Samples | Ground Water | Depth, ft.

Samples: S-40, S-41, S-42, S-43*, S-44, S-45, S-46, S-47, S-48, S-49*, S-50, S-51, S-52, S-53, S-54, S-55*, S-56, S-57, S-58, S-59

**PENETRATION RESISTANCE** (blows/foot)

▲ Hammer Wt. & Drop: lbs / inches

140 lbs / 30 inches




LEGEND

* Sample Not Recovered
Standard Penetration Test
Modified California Sampler
3" O.D. Thin-Walled Tube
Inclinometer and Piezometer
Piezometer
Bentonite-Cement Grout
Slough
Inclinometer and SONDEX
Ground Water Level in VWP
RQD (%) Recovery (%)
◇ % Fines (<0.075mm)
● % Water Content (use scale at top)
Plastic Limit ├─●─┤ Liquid Limit

NOTES

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

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# LOG OF BORING RP-127-01

September 2017 23-1-01453-230

**SHANNON & WILSON, INC.**
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**FIG. D-1**
Sheet 3 of 4



REV 3

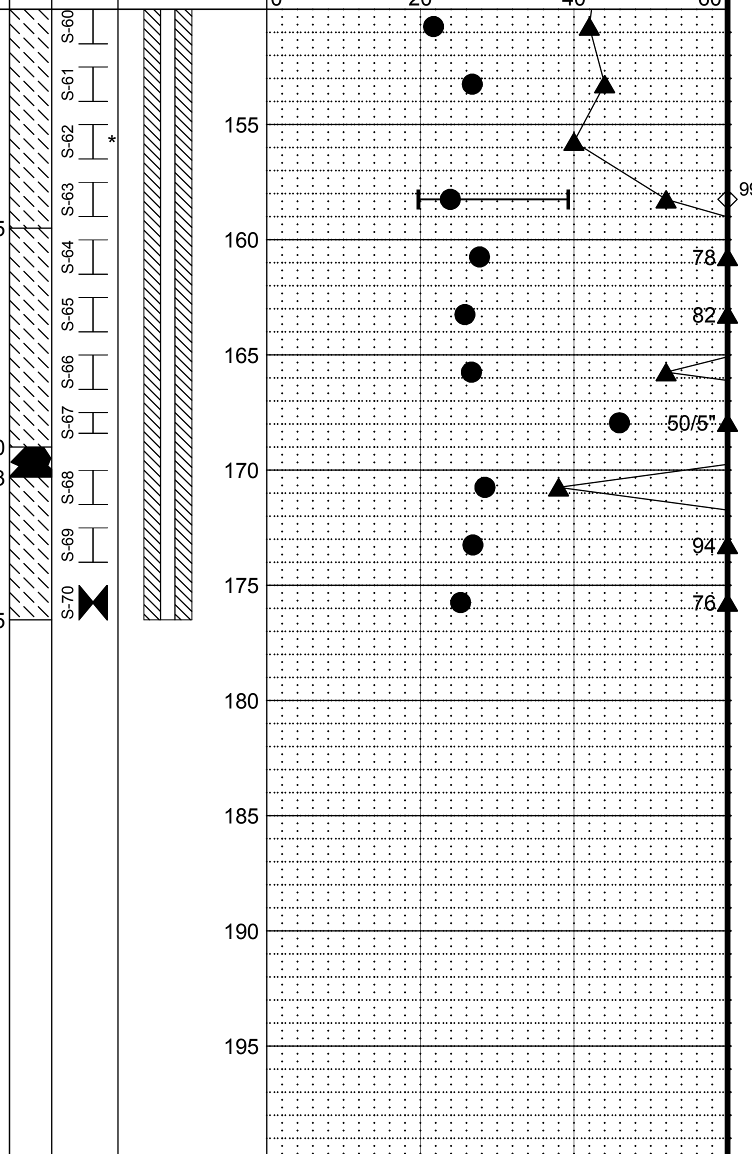
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 176.5 ft. | Latitude: | ~ 47.60799° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | ~ 2223 ft. | Longitude: | ~ -103.25869° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. |
|---|---|
| [Hard, *Lean Clay (CL)*;moist; trace sand.] | 159.5 |
| CLAYSTONE: very low strength, gray with iron oxide staining; slightly weathered to fresh (Sentinel Butte Formation). [Hard, *Fat Clay (CH)*; moist to wet; trace sand.] - Dark brown from 166.5 to 169.0 feet. | 169.0 |
| COAL: very low strength, black (Sentinel Butte Formation). | 170.3 |
| CLAYSTONE: very low strength, gray; fresh; trace to few carbonaceous lenses and carbonaceous fragments (Sentinel Butte Formation). [Hard, *Fat Clay (CH)*; moist.] | 176.5 |

BOTTOM OF BORING
COMPLETED ON 12/13/14




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- 3" O.D. Thin-Walled Tube
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough
- Inclinometer and SONDEX
- Ground Water Level in VWP
- RQD (%)
- Recovery (%)
- ◇ % Fines (<0.075mm)
- ● % Water Content ←(use scale at top)
- Plastic Limit ├─●─┤ Liquid Limit

NOTES

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

US-85 - I-94 to Watford City Bypass Addendum
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

**LOG OF BORING RP-127-01**

September 2017 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-1**
Sheet 4 of 4

REV 3

MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 9/15/17

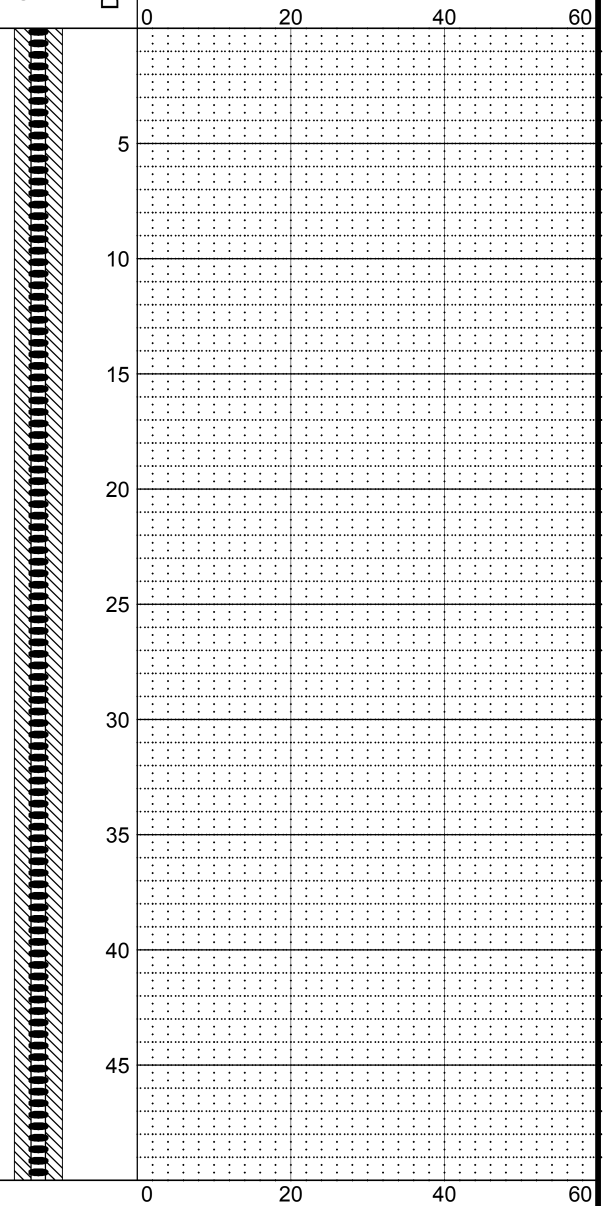
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | *140 ft.* | Latitude: | *~ 47.60797°* | Drilling Method: | *HSA/Mud Rotary* | Hole Diam.: | *8 in.* |
| Top Elevation: | *~ 2223 ft.* | Longitude: | *~ -103.25867°* | Drilling Company: | *Interstate Drilling Service* | Rod Type.: | *AWJ* |
| Vert. Datum: | | Station: | *~* | Drill Rig Equipment: | *Diedrich D-50 Track Rig* | Hammer Type: | *Automatic* |
| Horiz. Datum: | | Offset: | *~* | Other Comments: | | | |

**SOIL DESCRIPTION**

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

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

- Boring offsett approximately 8 feet south of boring RP-127-01. See Figure A-26 of the GDR dated October 14, 2016 for soil/rock descriptions.




CONTINUED NEXT SHEET

LEGEND

* Sample Not Recovered

- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough
- Inclinometer and SONDEX

NOTES

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

US-85 - I-94 to Watford City Bypass Addendum
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

# LOG OF BORING RP-127-01A

September 2017 23-1-01453-230

**SHANNON & WILSON, INC.**
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**FIG. D-2**
Sheet 1 of 3

*REV 3*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 140 ft. | Latitude: | ~ 47.60797° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | ~ 2223 ft. | Longitude: | ~ -103.25867° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

**SOIL DESCRIPTION**

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

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

0 20 40 60

See Figure A-26 (continued)

Groundwater Not Encountered During Drilling

55
60
65
70
75
80
85
90
95

CONTINUED NEXT SHEET

0 20 40 60

LEGEND

* Sample Not Recovered

Inclinometer and Piezometer
Piezometer
Bentonite-Cement Grout
Slough
Inclinometer and SONDEX

NOTES

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

US-85 - I-94 to Watford City Bypass Addendum
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Billings, McKenzie, and Stark Counties, ND

## LOG OF BORING RP-127-01A

September 2017 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-2**
Sheet 2 of 3

REV 3

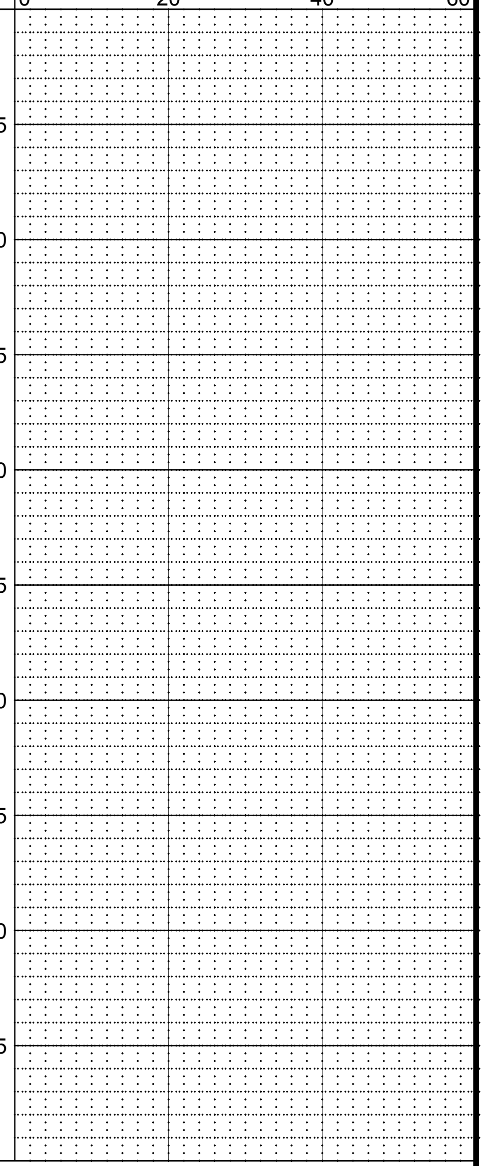
MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 9/15/17

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 140 ft. | Latitude: | ~ 47.60797° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | ~ 2223 ft. | Longitude: | ~ -103.25867° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. | Symbol | Samples | Ground Water | Depth, ft. |
|---|---|---|---|---|---|
| See Figure A-26 (continued) | | | | | 105 110 115 120 125 130 135 |
| BOTTOM OF BORING COMPLETED ON 04/24/2017 | 140.0 | | | | 140 145 |




LEGEND

* Sample Not Recovered

Inclinometer and Piezometer

Piezometer

Bentonite-Cement Grout

Slough

Inclinometer and SONDEX

NOTES

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

US-85 - I-94 to Watford City Bypass Addendum
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Billings, McKenzie, and Stark Counties, ND

## LOG OF BORING RP-127-01A

September 2017 23-1-01453-230

**SHANNON & WILSON, INC.**
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**FIG. D-2**
Sheet 3 of 3

*REV 3*

MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 9/15/17

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 150 ft. | Latitude: | 47.60485° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2154.0 ft. | Longitude: | -103.2575° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

**SOIL DESCRIPTION**

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

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

**PENETRATION RESISTANCE** (blows/foot)
▲ Hammer Wt. & Drop: 140 lbs / 30 inches

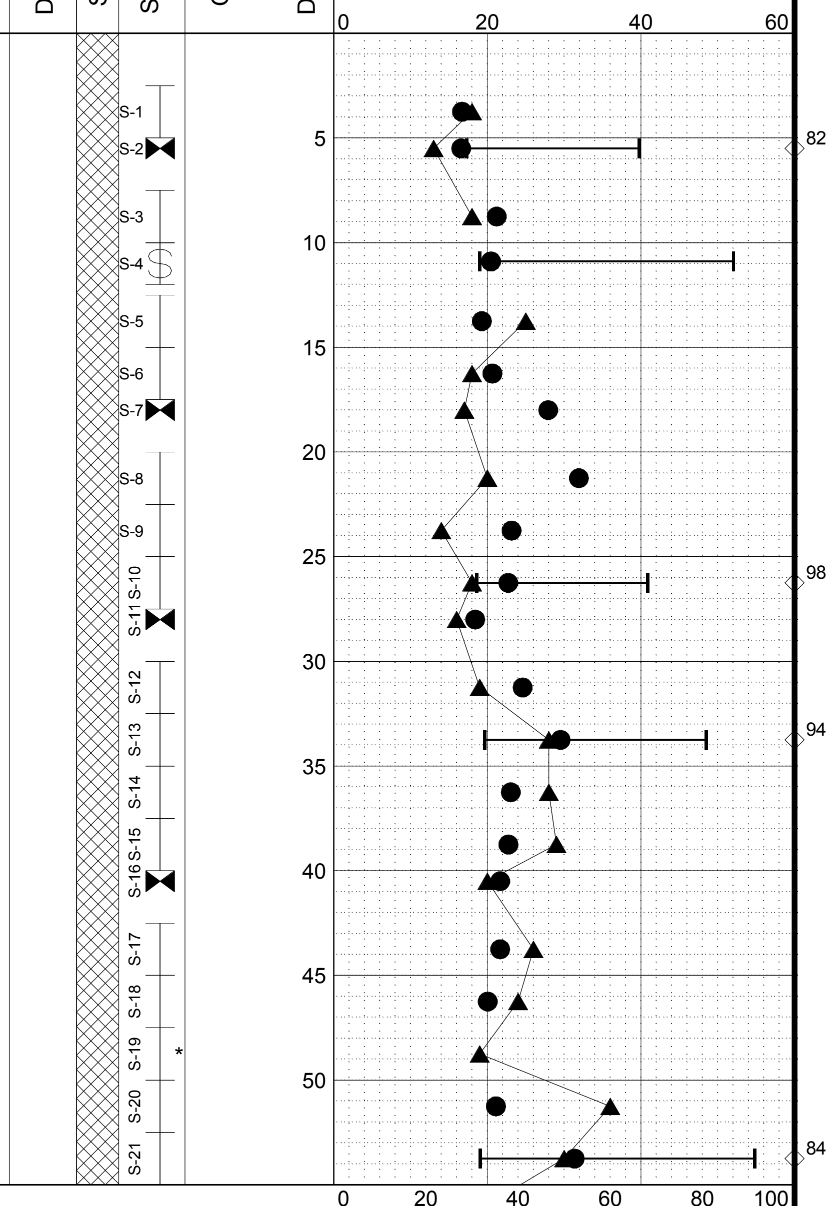
Stiff to hard, brown, dark brown, gray, and green-gray, *Lean Clay (CL)* to *Fat Clay (CH);* moist; thin to medium spaced silt and sand interbed; trace carbonaceous fragments; trace sand.
Fill

- Trace gravel at 17.5 feet.

- Red gravel layer at 25 feet.

- Little carbonaceous fragments from 32.5 to 35 feet.

- Sand and trace gravel from 42.5 to 47.5 feet.




CONTINUED NEXT SHEET

LEGEND

* Sample Not Recovered
Standard Penetration Test
Modified California Sampler
3" O.D. Thin-Walled Tube

RQD (%) Recovery (%)
◇ % Fines (<0.075mm)
● % Water Content (use scale at top)
Plastic Limit —●— Liquid Limit

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

**LOG OF BORING RP-127-02**

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-3**
Sheet 1 of 3

REV 3

MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 10/12/16

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 150 ft. | Latitude: | 47.60485° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2154.0 ft. | Longitude: | -103.2575° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

**SOIL DESCRIPTION**

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

Fill (continued)

65.0

DISPLACED CLAYSTONE: very low strength, brown to gray; thinly bedded to thickly laminated; highly to moderately weathered (Landslide Debris/Sentinel Butte Formation).

Very stiff to hard, brown to gray, *Fat Clay (CH)*; moist.

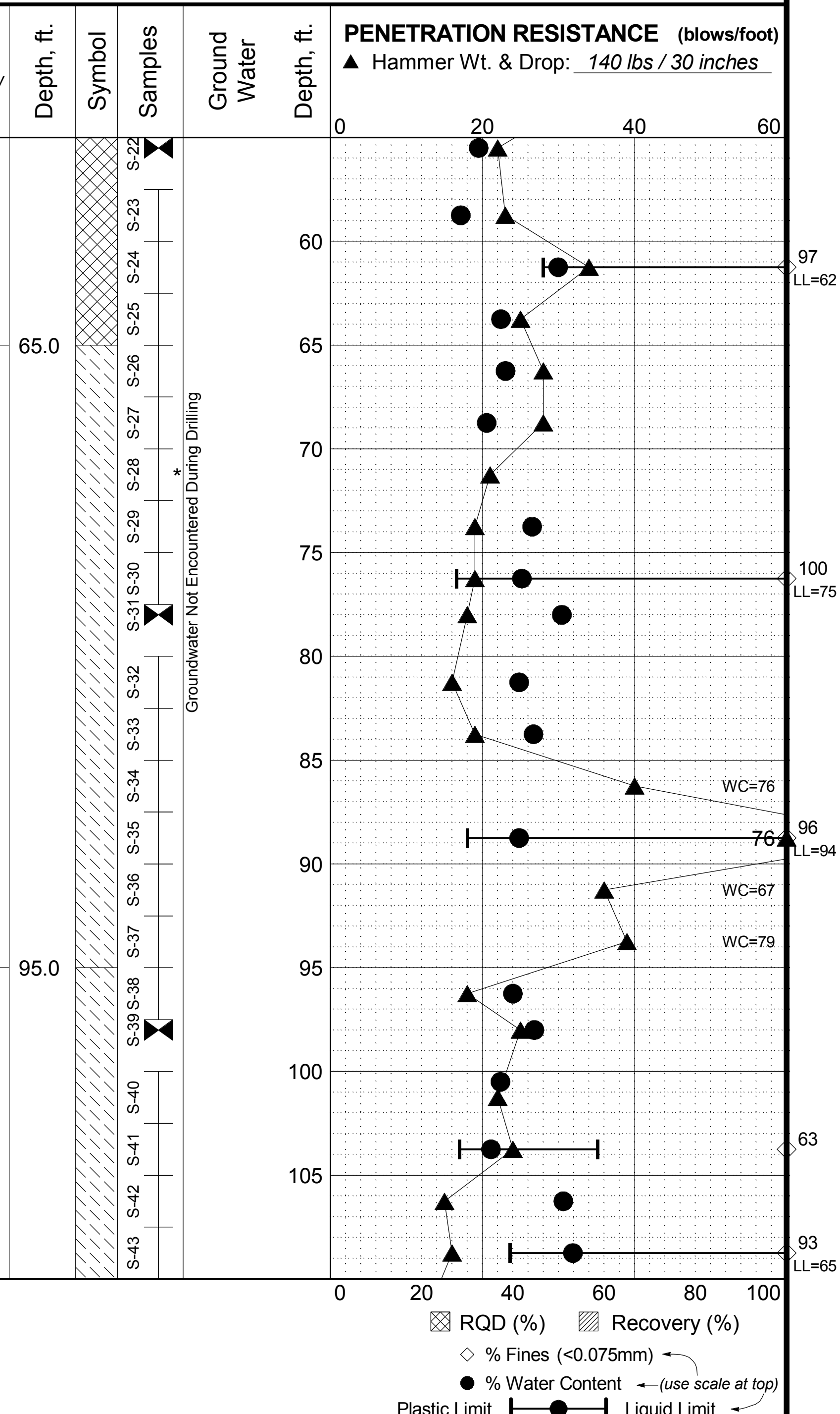
- Iron stained joints dipping approximately 90 degrees.
- Slickenside dipping approximately 60 degrees.
- Bedding dipping approximately 90 degrees from 67.5 to 70 feet.
- Coal from 84.8 to 85.3 feet.
- Coal from 89.5 to 91.5 feet.

95.0

DISPLACED CLAYSTONE: very low strength, gray to brown; thin bedded to thickly laminated; highly weathered; trace to few carbonaceous fragments (Landslide Debris/Sentinel Butte Formation).

[Stiff to very stiff, *Fat Clay (CH);* moist.]
- Sandy lean clay from 102 to 105 feet.

CONTINUED NEXT SHEET




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- 3" O.D. Thin-Walled Tube

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

**LOG OF BORING RP-127-02**

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-3**
Sheet 2 of 3

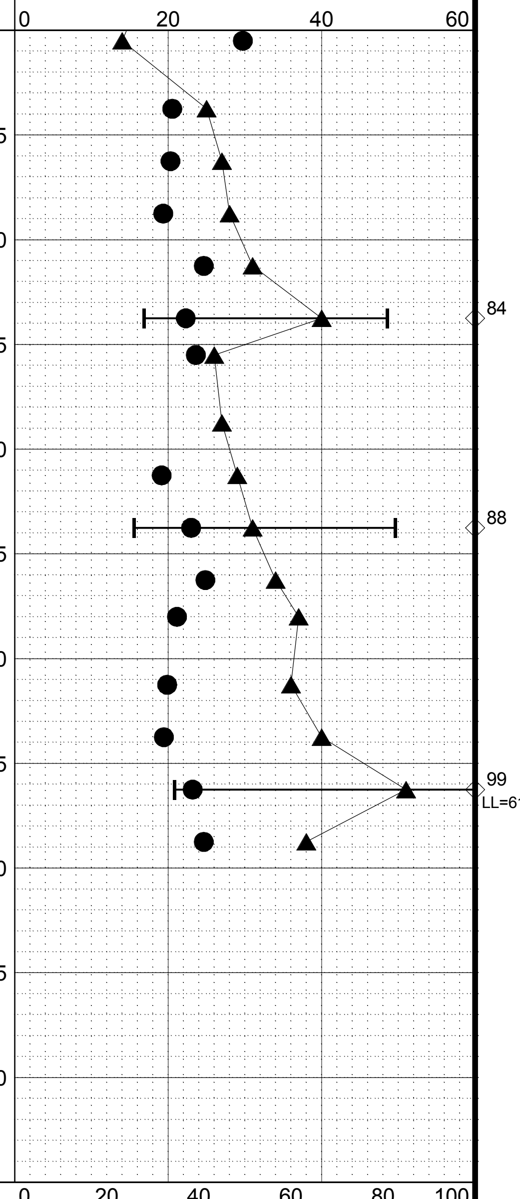
REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 150 ft. | Latitude: | 47.60485° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2154.0 ft. | Longitude: | -103.2575° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

| SOIL DESCRIPTION | Depth, ft. | Symbol | Samples | Ground Water | Depth, ft. |
|---|---|---|---|---|---|
| DISPLACED CLAYSTONE (continued) | | | S-44 | | |
| DISPLACED CLAYSTONE: very low strength, gray to brown to greenish gray; thin bedded to thickly laminated; moderately to highly weathered; trace to little carbonaceous fragments (Landslide Debris/Sentinel Butte Formation).<br><br>[Very stiff to hard, *Fat Clay (CH)* to Lean Clay (CL)*; moist.]*<br><br>- Bedding dipping approximately 50 to 70 degrees from 130 to 137.5 feet.<br><br>- Highly weathered two-inch-thick coal layer. | 112.0 | | S-45, S-46, S-47, S-48, S-49, S-50, S-51 *, S-52, S-53, S-54, S-55 | | 115, 120, 125, 130, 135, 140 |
| DISPLACED CLAYSTONE: very low strength, brown to gray; thickly laminated to thin bedded, bedding tilted at 30 to 60 degrees; highly to moderately weathered (Landslide Debris/Sentinel Butte Formation).<br><br>[Hard, *Fat Clay (CH);* moist.] | 142.5 | | S-56, S-57, S-58, S-59 | | 145 |
| BOTTOM OF BORING<br>COMPLETED ON 7/21/2016 | 150.0 | | | | 150, 155, 160 |

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

**PENETRATION RESISTANCE** (blows/foot)
▲ Hammer Wt. & Drop: *140 lbs / 30 inches*




RQD (%) Recovery (%)
◇ % Fines (<0.075mm)
● % Water Content *(use scale at top)*
Plastic Limit Liquid Limit

LEGEND

* Sample Not Recovered
Standard Penetration Test
Modified California Sampler
3" O.D. Thin-Walled Tube

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

**LOG OF BORING RP-127-02**

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-3**
Sheet 3 of 3

*REV 3*

MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 10/12/16

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 175.5 ft. | Latitude: | 47.60457° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2102.0 ft. | Longitude: | -103.25806° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

**SOIL DESCRIPTION**

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

Depth, ft.

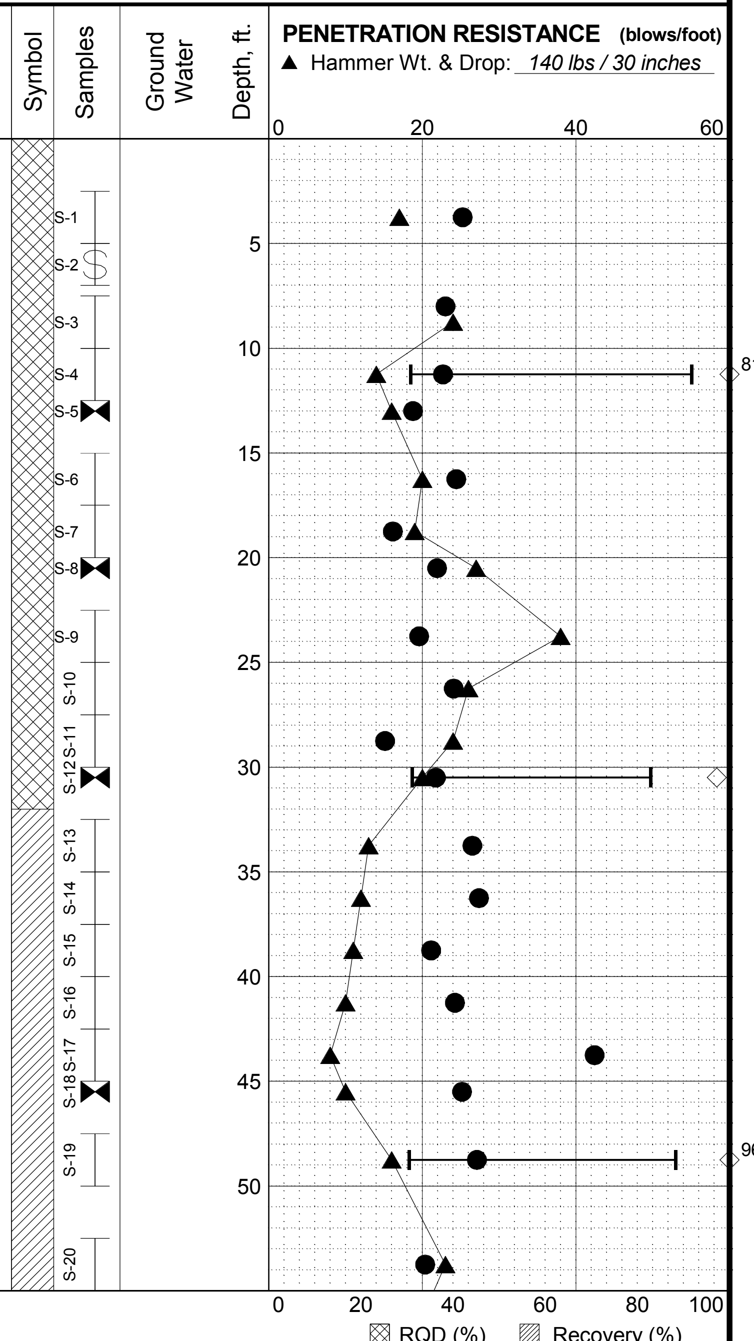
Stiff to hard, gray to brown, *Fat Clay (CH)*; moist; few to little carbonaceous fragments; few bedrock fragments.
Fill

32.0

Medium stiff to very stiff, brown, *Lean Clay (CL)* to *Fat Clay (CH);* moist; trace to few carbonaceous fragments.
Landslide Debris

- Little carbonaceous fragments from 32 to 35 feet.
- Iron stains from 37 to 40 feet.
- Little carbonaceous fragments from 42 to 45 feet.

CONTINUED NEXT SHEET




RQD (%) Recovery (%)

◇ % Fines (<0.075mm)

● % Water Content (use scale at top)

Plastic Limit ├──●──┤ Liquid Limit

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

## LOG OF BORING RP-127-03

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-4**
Sheet 1 of 4

REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 175.5 ft. | Latitude: | 47.60457° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2102.0 ft. | Longitude: | -103.25806° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

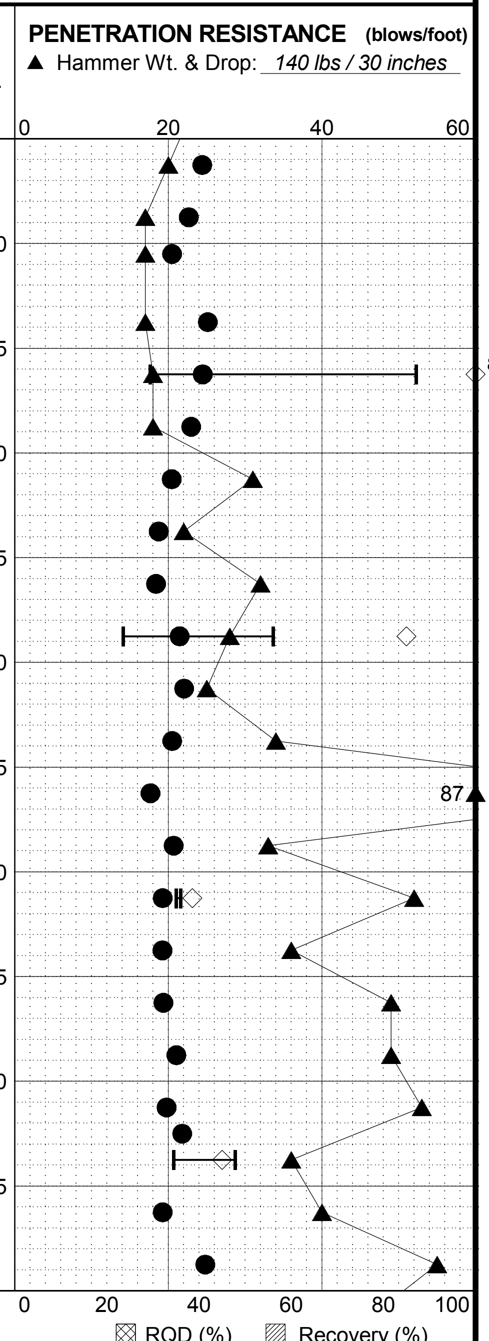
**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. | Samples |
|---|---|---|
| Landslide Debris (continued)<br>- Iron stains from 55 to 65 feet. | | S-21, S-22, S-23, S-24 |
| Very stiff to hard, brown, *Fat Clay (CH);* moist; few sand; iron stains; thin spaced SC to SM layers; bedding dipping approximately 30 to 45 degrees.<br>Landslide Debris<br>- Few gravel from 67 to 70 feet. | 65.0 | S-25, S-26, S-27, S-28, S-29 |
| Dense to very dense, brown to gray to blue-gray, *Clayey Sand (SC)* to *Silty Sand (SM)*; moist; bedding tilted from 35 degrees to near vertical; trace to few carbonaceous fragments; thin to medium spaced clayey sand zones.<br>Landslide Debris<br>- Trace carbonaceous fragments from 92 to 100 feet.<br>- Little to some carbonaceous fragments from 105 to 110 feet. | 77.0 | S-30, S-31, S-32, S-33, S-34, S-35, S-36, S-37, S-38, S-39, S-40, S-41, S-42 |

Ground Water: Groundwater Not Encountered During Drilling

CONTINUED NEXT SHEET




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

## LOG OF BORING RP-127-03

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-4**
Sheet 2 of 4

REV 3

| | | | | | |
|---|---|---|---|---|---|
| Total Depth: | 175.5 ft. | Latitude: | 47.60457° | Drilling Method: | HSA/Mud Rotary |
| Top Elevation: | 2102.0 ft. | Longitude: | -103.25806° | Drilling Company: | Interstate Drilling Service |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig |
| Horiz. Datum: | | Offset: | - | Other Comments: | |

| | |
|---|---|
| Hole Diam.: | 8 in. |
| Rod Type.: | AWJ |
| Hammer Type: | Automatic |

**SOIL DESCRIPTION**

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

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

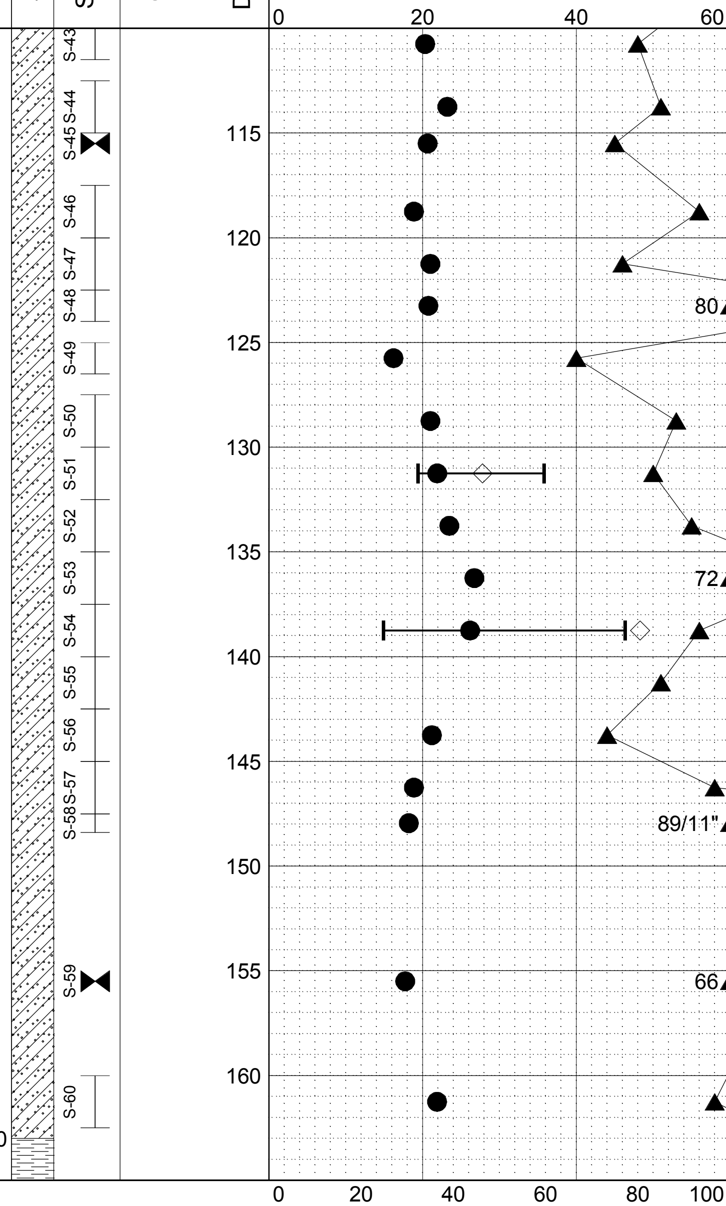
**PENETRATION RESISTANCE** (blows/foot)

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

Landslide Debris (continued)

- Slickensided joint, near vertical bedding from 135 to 137.5 feet.

163.0




CONTINUED NEXT SHEET

☒ RQD (%) ▨ Recovery (%)

◇ % Fines (<0.075mm)

● % Water Content *(use scale at top)*

Plastic Limit ├─●─┤ Liquid Limit

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

**LOG OF BORING RP-127-03**

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-4**
Sheet 3 of 4

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 175.5 ft. | Latitude: | 47.60457° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2102.0 ft. | Longitude: | -103.25806° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

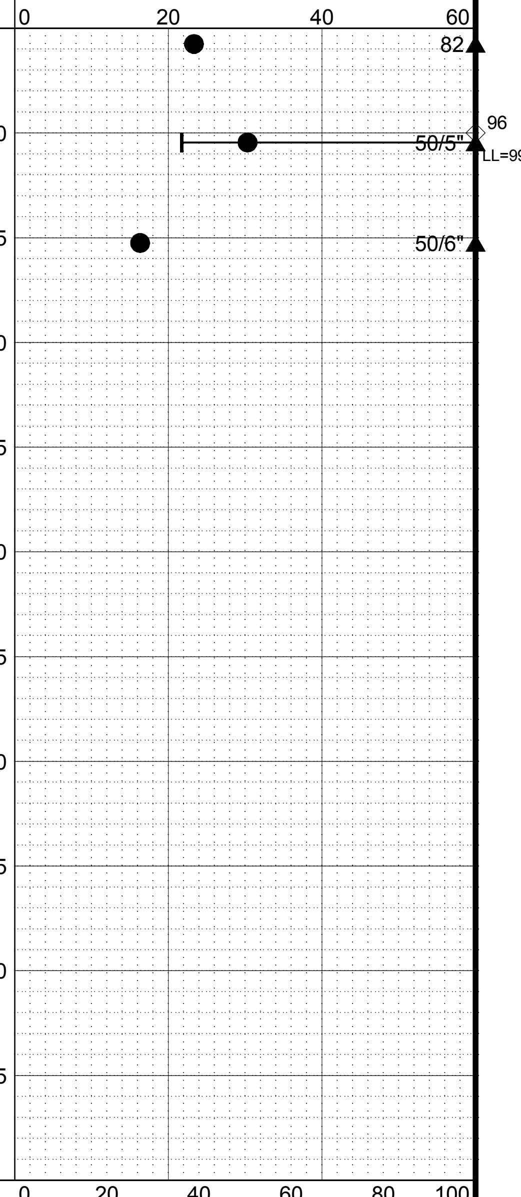
**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. | Samples |
|---|---|---|
| SILTSTONE to SANDSTONE: very low strength, gray; thin bedding; fresh (Sentinel Butte Formation). [Very dense, *Silty Sand (SM);* moist.] | 168.0 | S-61 |
| CLAYSTONE: very low strength, gray; thin bedded; fresh (Sentinel Butte Formation). [Hard, *Fat Clay (CH);* moist.] | 175.5 | S-62, S-63 |

BOTTOM OF BORING
COMPLETED ON 7/28/2016

**PENETRATION RESISTANCE (blows/foot)**
▲ Hammer Wt. & Drop: 140 lbs / 30 inches




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

## LOG OF BORING RP-127-03

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-4**


REV 3

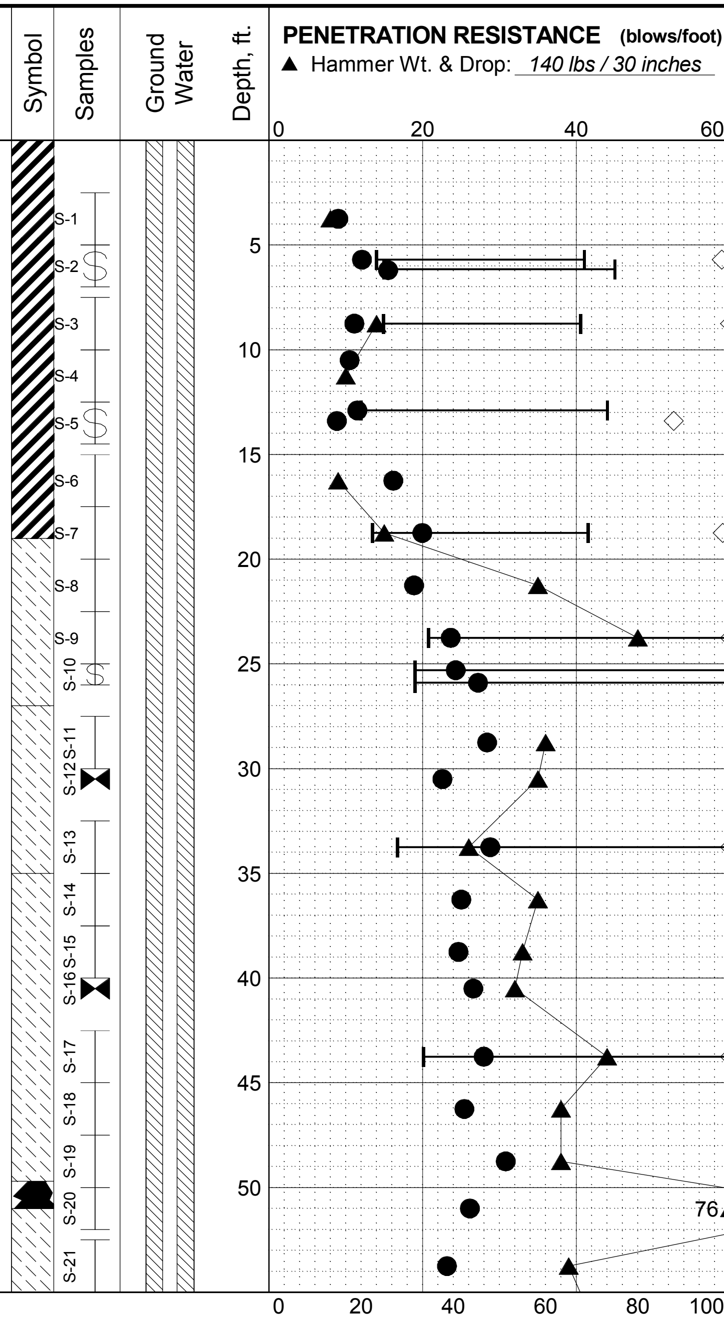
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 140 ft. | Latitude: | 47.60283° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2077.0 ft. | Longitude: | -103.25881° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. |
|---|---|
| Medium stiff to stiff, brown, *Lean Clay with Sand (CL)* to *Sandy Lean Clay (CL)*; moist; interbedded thin to medium spaced silt to fine sand layers; trace roots. Landslide Debris<br><br>- Calcite veins from 0 to 5 feet.<br><br>- Sand layer from 15 to 19 feet. | 19.0 |
| DISPLACED CLAYSTONE: very low strength, brown to dark brown to gray; thinly to thickly laminated, laminations dipping approximately 10 to 40 degrees, iron stains; moderately weathered (Landslide Debris/Sentinel Butte Formation).<br>[Hard, *Fat Clay (CH); moist.*] | 27.0 |
| DISPLACED CLAYSTONE: very low strength, green to green-gray; thin bedded to thinly laminated; fresh; trace carbonaceous fragments (Landslide Debris/Sentinel Butte Formation).<br>[Very stiff to hard, *Fat Clay (CH); moist.*] | 35.0 |
| DISPLACED CLAYSTONE: very low strength, gray; thinly laminated to thickly laminated; fresh; trace carbonaceous fragments (Landslide Debris/Sentinel Butte Formation).<br>[Hard, *Fat Clay (CH)*; moist.] | 49.7 |
| DISPLACED COAL: very low strength, black (Landslide Debris/Sentinel Butte Formation). | 51.0 |

CONTINUED NEXT SHEET




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

## LOG OF BORING RP-127-04

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-5**
Sheet 1 of 3

REV 3

MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 10/12/16

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 140 ft. | Latitude: | 47.60283° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2077.0 ft. | Longitude: | -103.25881° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. | Samples |
|---|---|---|
| DISPLACED CLAYSTONE: very low strength, green-gray; medium bedded to thickly laminated; fresh; trace carbonaceous fragments; Slickensided joint dipping approximately 70 degrees (Landslide Debris/Sentinel Butte Formation). [Hard, *Fat Clay (CH);* moist.] | 56.0 | S-22, S-23, S-24, S-25 |
| DISPLACED CLAYSTONE: very low strength, gray; thickly to thinly laminated; fresh; thinly interbedded siltstone (Landslide Debris/Sentinel Butte Formation). [Hard, *Fat Clay (CH);* moist.] | 65.0 | S-26 |
| DISPLACED COAL: very low strength, black; bedding dipping approximately 20 to 30 degrees (Landslide Debris/Sentinel Butte Formation). | 67.0 | S-27, S-28, S-29, S-30, S-31 |
| DISPLACED CLAYSTONE: very low strength, gray; thin bedded to thickly laminated, bedding dipping approximately 20 to 80 degrees; fresh; few joints dipping approximately 90 degrees (Landslide Debris/Sentinel Butte Formation).. [Very stiff to hard, *Fat Clay (CH);* moist.] - Green-gray and thin bedded from 67 to 70 feet. - Green-gray and thin bedded from 82.5 to 85 feet. - Thinly to thickly laminated from 95 to 99 feet. - Trace to few carbonaceous fragments from 99 to 116 feet. - Green-gray from 100 to 101.5 feet. - Coal from 101.7 to 102.2 feet and tilted. - Slickensided joint dipping approximately 60 degrees at 104 feet. - Coal from 107.2 to 107.5 feet. | | S-32 through S-43 |

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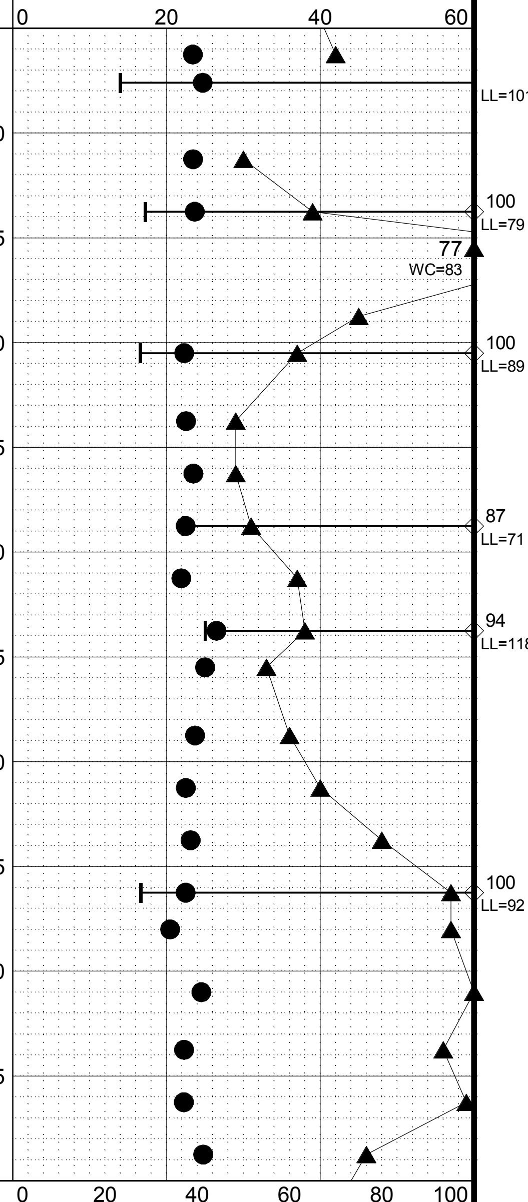
Groundwater Not Encountered During Drilling




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

# LOG OF BORING RP-127-04

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-5**
Sheet 2 of 3

REV 3

MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 10/12/16

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 140 ft. | Latitude: | 47.60283° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2077.0 ft. | Longitude: | -103.25881° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

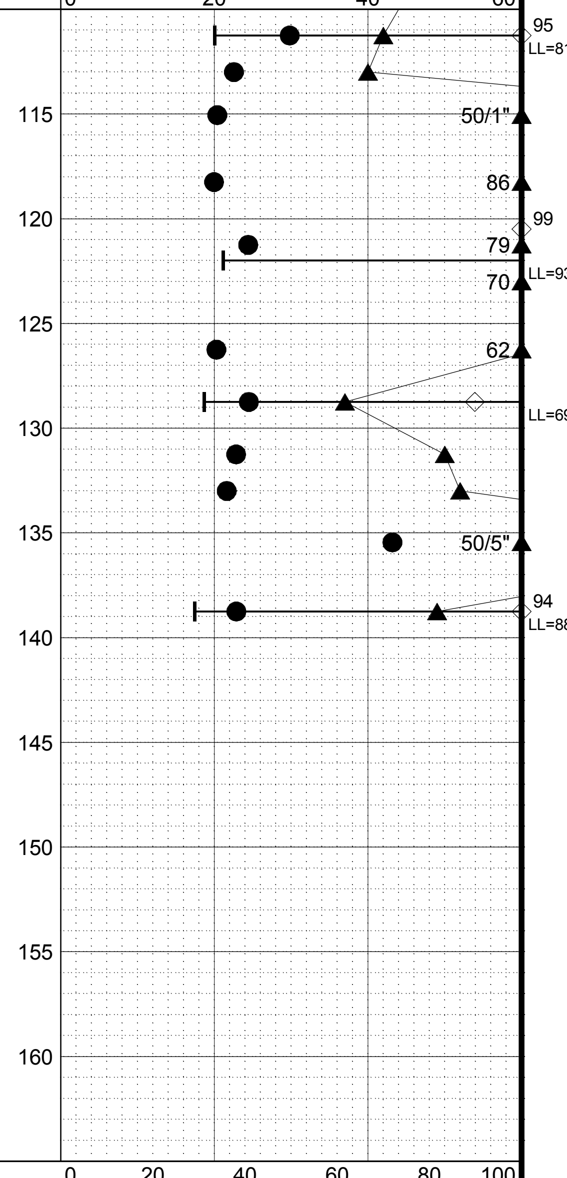
**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. | Samples |
|---|---|---|
| DISPLACED CLAYSTONE (continued) | | S-44, S-45 |
| DISPLACED CLAYSTONE: very low strength, gray; thin bedded to thickly laminated; fresh; 20 degree bedding (Landslide Debris/Sentinel Butte Formation). [Hard, *Fat Clay (CH);* moist.] - Green-gray from 124 to 127.5 feet. - Sandy fat clay from 127.5 to 135.5 feet. | 114.0 | S-46, S-47, S-48, S-49, S-50, S-51, S-52, S-53 |
| DISPLACED COAL: very low strength, black (Landslide Debris/Sentinel Butte Formation). | 135.5 | S-54 |
| DISPLACED CLAYSTONE: very low strength, green-gray; thin bedded to thickly laminated; fresh; few carbonaceous fragments; bedding dipping 20 to 40 degrees (Landslide Debris/Sentinel Butte Formation). [Hard, *Fat Clay (CH);* moist.] | 136.5 | S-55 |
| BOTTOM OF BORING COMPLETED ON 7/13/2016 | 140.0 | |

**PENETRATION RESISTANCE** (blows/foot)

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




⊠ RQD (%) ▨ Recovery (%)

◇ % Fines (<0.075mm)

● % Water Content (use scale at top)

Plastic Limit ├──●──┤ Liquid Limit

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

# LOG OF BORING RP-127-04

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-5**


REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 170 ft. | Latitude: | 47.60812° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2192.0 ft. | Longitude: | -103.26101° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

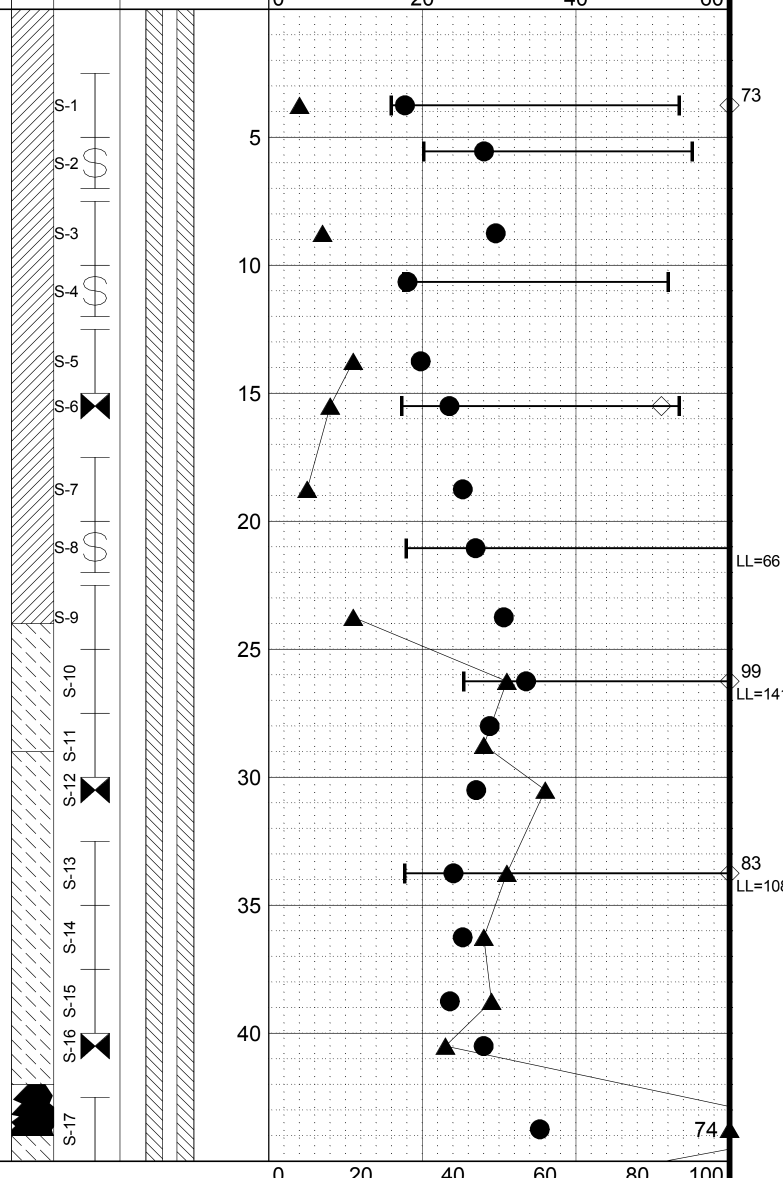
**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. | Samples |
|---|---|---|
| Soft to medium stiff, brown to gray, *Fat Clay (CH);* moist; trace roots; calcite veins; trace to some carbonaceous fragments and bedrock fragments.<br>Landslide Debris<br>- Iron oxide stains and 70 degree bedding from 10 to 18.5 feet.<br>- Clayey sand from 14 to 17 feet.<br>- Blocky from 18.5 to 24.0 feet. | | S-1, S-2, S-3, S-4, S-5, S-6, S-7, S-8, S-9 |
| DISPLACED CLAYSTONE: very low strength, green-gray; thinly bedded, slickensided joints; fresh to moderately weathered (Landslide Debris/Sentinel Butte Formation). | 24.0 | S-10, S-11 |
| [Stiff to very stiff, *Fat Clay (CH);* moist.]<br>- Coal seam from 25 to 25.3 feet.<br>- Coal seam from 27.1 to 27.5 feet.<br>CLAYSTONE: very low strength, gray; thin to thickly laminated; fresh; few carbonaceous fragments; few sand (Sentinel Butte Formation).<br>[Very stiff to hard, *Fat Clay (CH); moist.]* | 29.0 | S-12, S-13, S-14, S-15, S-16 |
| COAL: very low strength, black (Sentinel Butte Formation). | 42.0 | S-17 |
| | 44.0 | |

CONTINUED NEXT SHEET

**PENETRATION RESISTANCE** (blows/foot)
▲ Hammer Wt. & Drop: 140 lbs / 30 inches




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

# LOG OF BORING RP-127-05

October 2016 — 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-6**
Sheet 1 of 4

REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 170 ft. | Latitude: | 47.60812° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2192.0 ft. | Longitude: | -103.26101° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

**SOIL DESCRIPTION**

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

CLAYSTONE: very low strength, gray; thin to very thinly bedded; fresh (Sentinel Butte Formation).

[Hard, *Fat Clay (CH);* moist.]

- Few to trace carbonaceous fragments from 44 to 47.5 feet.

80.0

CLAYSTONE: very low strength, green-gray; slightly blocky; fresh (Sentinel Butte Formation).

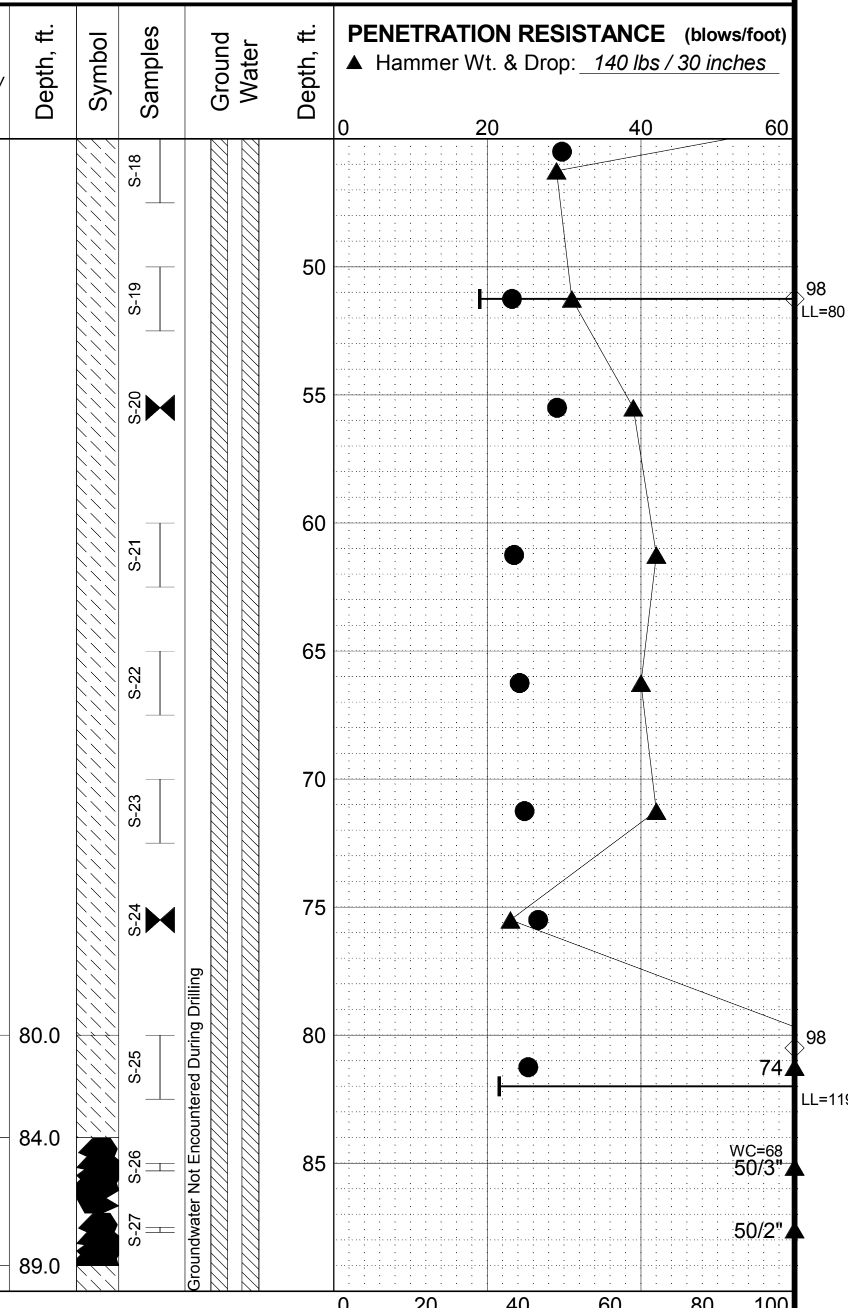
84.0

[Hard, *Fat Clay (CH)*; moist.]
- Coal seam from 80.8 to 81.1 feet.

COAL: very low strength, black (Sentinel Butte Formation).

89.0

CONTINUED NEXT SHEET




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough

RQD (%) Recovery (%)
◇ % Fines (<0.075mm)
● % Water Content (use scale at top)
Plastic Limit ├─●─┤ Liquid Limit

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

## LOG OF BORING RP-127-05

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-6**
Sheet 2 of 4

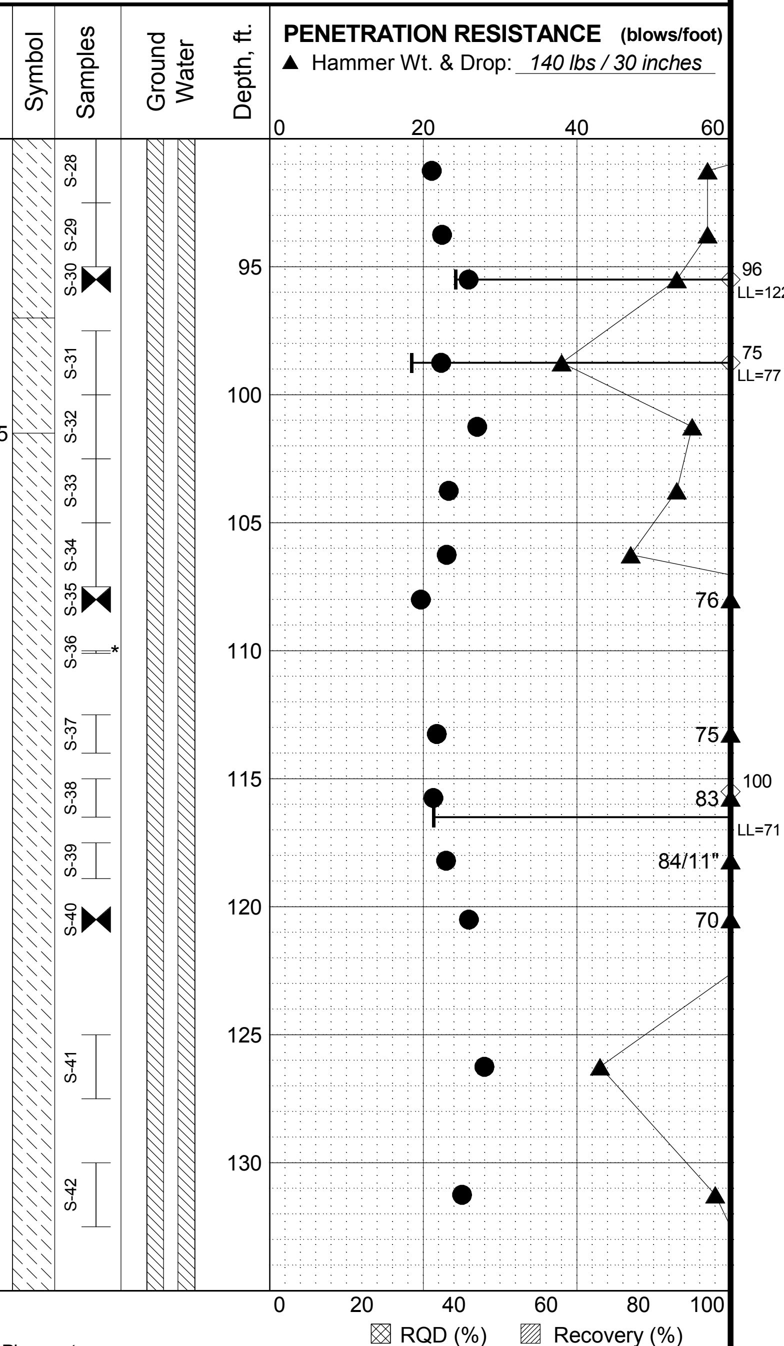
REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 170 ft. | Latitude: | 47.60812° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | 2192.0 ft. | Longitude: | -103.26101° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | - | Other Comments: | | | |

**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. |
|---|---|
| CLAYSTONE: very low strength, gray; very thin to thinly bedded; fresh; trace carbonaceous fragments (Sentinel Butte Formation).<br><br>[Hard, *Fat Clay (CH)* to *Fat Clay with Sand (CH)*; moist.] | 97.0 |
| CLAYSTONE: very low strength, green-gray; thickly laminated; fresh (Sentinel Butte Formation).<br><br>[Hard, *Fat Clay (CH)*; moist.] | 101.5 |
| CLAYSTONE: very low strength, gray; very thin bedded; fresh; trace carbonaceous fragments (Sentinel Butte Formation).<br><br>[Hard, *Fat Clay (CH)* to *Fat Clay with Sand (CH)*; moist.]<br>- Thickly to thinly laminated from 101.5 to 158 feet.<br>- Concretion inferred from drill action from 110 to 112 feet.<br><br>- Green-gray, very thin to thin bedded from 120.5 to 123 feet.<br>- Trace to few carbonaceous fragments from 123 to 143 feet. | |




CONTINUED NEXT SHEET

LEGEND

| | |
|---|---|
| * Sample Not Recovered | Inclinometer and Piezometer |
| Standard Penetration Test | Piezometer |
| 3" O.D. Thin-Walled Tube | Bentonite-Cement Grout |
| Modified California Sampler | Slough |

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

## LOG OF BORING RP-127-05

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-6**
Sheet 3 of 4

REV 3

Total Depth: 170 ft. Latitude: 47.60812° Drilling Method: HSA/Mud Rotary Hole Diam.: 8 in.
Top Elevation: 2192.0 ft. Longitude: -103.26101° Drilling Company: Interstate Drilling Service Rod Type.: AWJ
Vert. Datum: Station: Drill Rig Equipment: CME 55 Track Rig Hammer Type: Automatic
Horiz. Datum: Offset: - Other Comments:

**SOIL DESCRIPTION**

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

CLAYSTONE (continued)

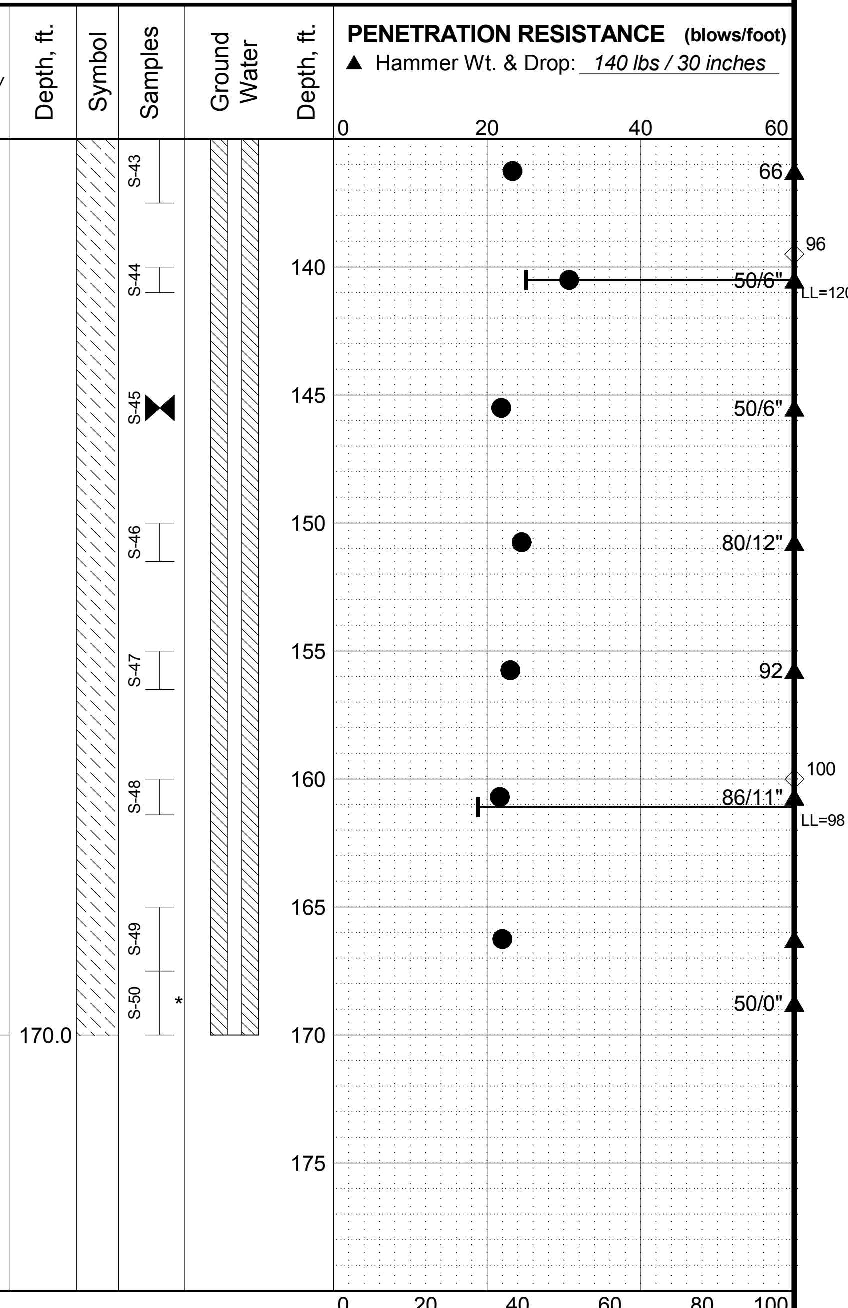
- Slickensided joint dipping approximately 45 degrees at 140.5 feet.

- Green-gray, very thin to thin bedded from 158 to 161 feet.

- Concretion inferred from drill action from 169 to 170 feet.

170.0

BOTTOM OF BORING
COMPLETED ON 7/19/2016




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

**LOG OF BORING RP-127-05**

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-6**


REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 202.5 ft. | Latitude: | ~ 47.611° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | ~ 2491 ft. | Longitude: | ~ -103.25861° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

**SOIL DESCRIPTION**

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

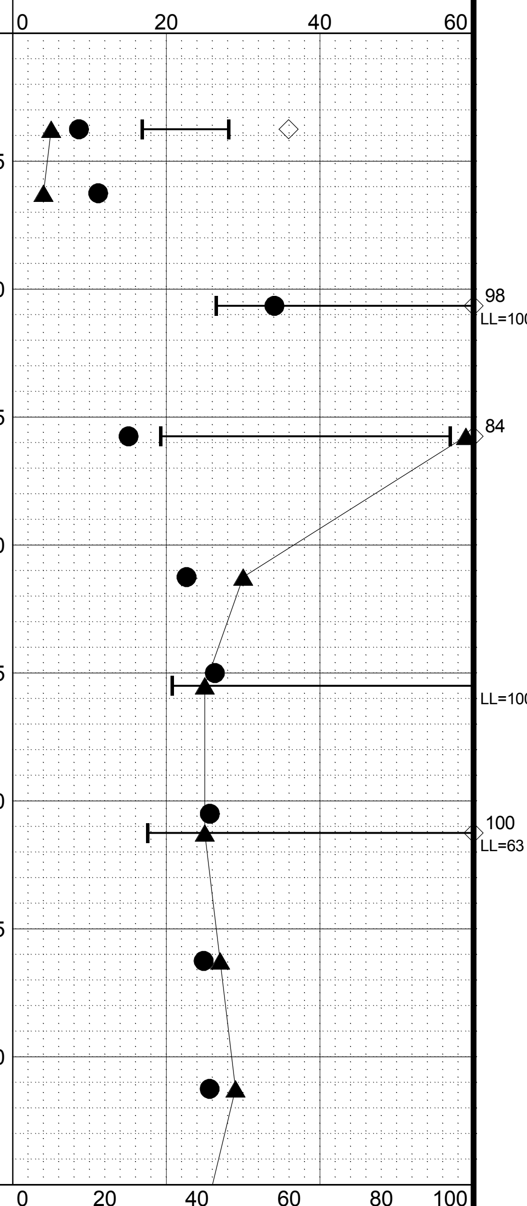
| Soil Description | Depth, ft. | Samples |
|---|---|---|
| SANDSTONE: very low strength, brown; thinly to thickly laminated; highly to completely weathered; gypsiferous lenses; calcite veins (Sentinel Butte Formation).<br><br>[Loose, *Clayey Sand (SC)* to *Sandy Lean Clay (CL)*; moist.<br><br>- Two-inch-thick sandy iron stained zone at 11.5 feet. | 13.5 | S-1, S-2, S-3 |
| CLAYSTONE: very low strength, brown; thinly laminated to thin bedding; moderately weathered; several 90 degree joints with iron oxide stains (Sentinel Butte Formation).<br><br>[Very stiff to hard, *Fat Clay (CH)*; moist].<br>- Fat clay with sand from 13.5 to 18.0 feet.<br><br>- Joint dipping approximately 70 degrees at 25.9 feet.<br><br>- Gray; thickly to thinly laminated; slightly weathered to fresh; trace carbonaceous fragments from 28 to 43.5 feet. | 44.0 | S-4, S-5, S-6, S-7, S-8, S-9 |

CONTINUED NEXT SHEET

Symbol | Samples | Ground Water | Depth, ft.

**PENETRATION RESISTANCE** (blows/foot)

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




RQD (%) Recovery (%)

◇ % Fines (<0.075mm)

● % Water Content (use scale at top)

Plastic Limit ├─●─┤ Liquid Limit

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

# LOG OF BORING RP-127-06

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-7**
Sheet 1 of 5

REV 3

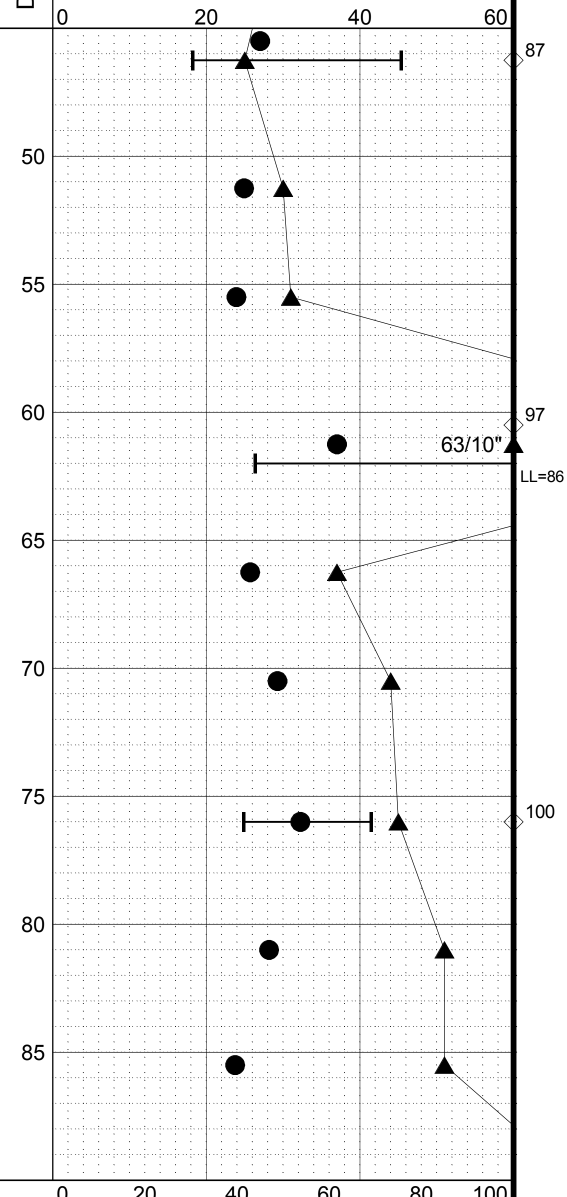
MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 10/12/16

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 202.5 ft. | Latitude: | ~ 47.611° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | ~ 2491 ft. | Longitude: | ~ -103.25861° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

| SOIL DESCRIPTION<br>*Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.* | Depth, ft. | Symbol | Samples | Ground Water |
|---|---|---|---|---|
| CLAYSTONE: very low strength, gray; thickly to thinly laminated; fresh (Sentinel Butte Formation).<br>[Very stiff to hard, *Lean Clay (CL)* to *Fat Clay (CH)*; moist].<br>- Slickensided joint dipping approximately 60 degrees at 60.2 feet. | | | S-10, S-11, S-12, S-13 | |
| COAL: very low strength, black (Sentinel Butte Formation). | 62.5 | | | |
| CLAYSTONE: very low strength, gray; thinly laminated; fresh; trace to few carbonaceous fragments (Sentinel Butte Formation).<br>[Hard, *Fat Clay (CH)*; moist]. | 64.0 | | S-14 | |
| COAL: very low strength, black (Sentinel Butte Formation).<br>- Dark brown, kerogen rich from 69 to 70.8 feet. | 67.5 | | S-15 | |
| CLAYSTONE: very low strength, gray; thin bedded to thinly laminated; fresh; thin to medium spaced sandstone and siltstone layers (Sentinel Butte Formation).<br>[Hard, *Lean Clay (CL)*; moist]. | 70.8 | | S-16, S-17, S-18 | |
| | 88.0 | | | |

CONTINUED NEXT SHEET

**PENETRATION RESISTANCE** (blows/foot)
▲ Hammer Wt. & Drop: 140 lbs / 30 inches




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler

RQD (%) Recovery (%)
◇ % Fines (<0.075mm)
● % Water Content (use scale at top)
Plastic Limit ●— Liquid Limit

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

## LOG OF BORING RP-127-06

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-7**
Sheet 2 of 5

REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 202.5 ft. | Latitude: | ~ 47.611° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | ~ 2491 ft. | Longitude: | ~ -103.25861° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

**SOIL DESCRIPTION**

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

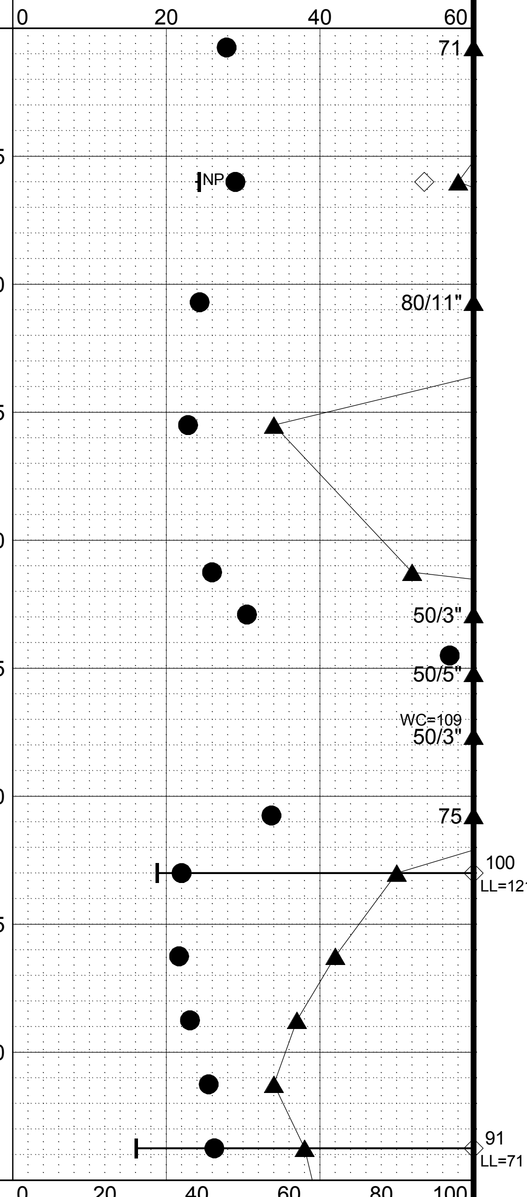
| Soil Description | Depth, ft. | Samples |
|---|---|---|
| SILTSTONE: very low strenght, gray; thin bedded to thinly laminated; fresh; thin to medium spaced claystone layers (Sentinel Butte Formation). [Medium dense to very dense, *Sandy Silt (ML)*; moist]. - Dark brown and kerogen rich from 111.5 to 113 feet. - Slickensided joint dipping approximately 30 to 40 degrees at 112 feet. | 113.0 | S-19, S-20, S-21, S-22, S-23, S-24 |
| COAL: very low strength, black (Sentinel Butte Formation). | 115.3 | S-25 |
| CLAYSTONE inferred from drilling. | 117.5 | S-26 |
| COAL: very low strength, black (Sentinel Butte Formation). | 118.5 | |
| CLAYSTONE: very low strength, gray; thin bedded to thinly laminated; fresh (Sentinel Butte Formation). [Hard, *Fat Clay (CH)*; moist]. | 120.0 | S-27, S-28 |
| CLAYSTONE: very low strength, green-gray; thin bedded to thinly laminated; fresh; trace carbonaceous fragments (Sentinel Butte Formation). [Hard, *Fat Clay (CH)*; moist]. | 125.5 | S-29, S-30, S-31, S-32 |

Ground Water: Groundwater Not Encountered During Drilling

CONTINUED NEXT SHEET

**PENETRATION RESISTANCE** (blows/foot)

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




LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler

NOTES

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

US-85 - I-94 to Watford City Bypass
Project No. 9-085(085)075, PCN 20046
Billings, McKenzie, and Stark Counties, ND

## LOG OF BORING RP-127-06

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-7**
Sheet 3 of 5

REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 202.5 ft. | Latitude: | ~ 47.611° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | ~ 2491 ft. | Longitude: | ~ -103.25861° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

**SOIL DESCRIPTION**

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

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

**PENETRATION RESISTANCE** (blows/foot)

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

CLAYSTONE: very low strength, gray; very thin to medium spaced bedding; fresh (Sentinel Butte Formation).
[Hard, *Fat Clay (CH)*; moist].

- Thinly laminated from 125.5 to 132.5 feet.

143.0

CLAYSTONE: very low strength, gray; thinly to thickly laminated; fresh; trace carbonaceous fragments (Sentinel Butte Formation).
[Hard, *Fat Clay (CH)*; moist].

- Brown, kerogen rich from 143 to 144 feet.
- Greenish gray, trace to few carbonaceous fragments from 144 to 146 feet.

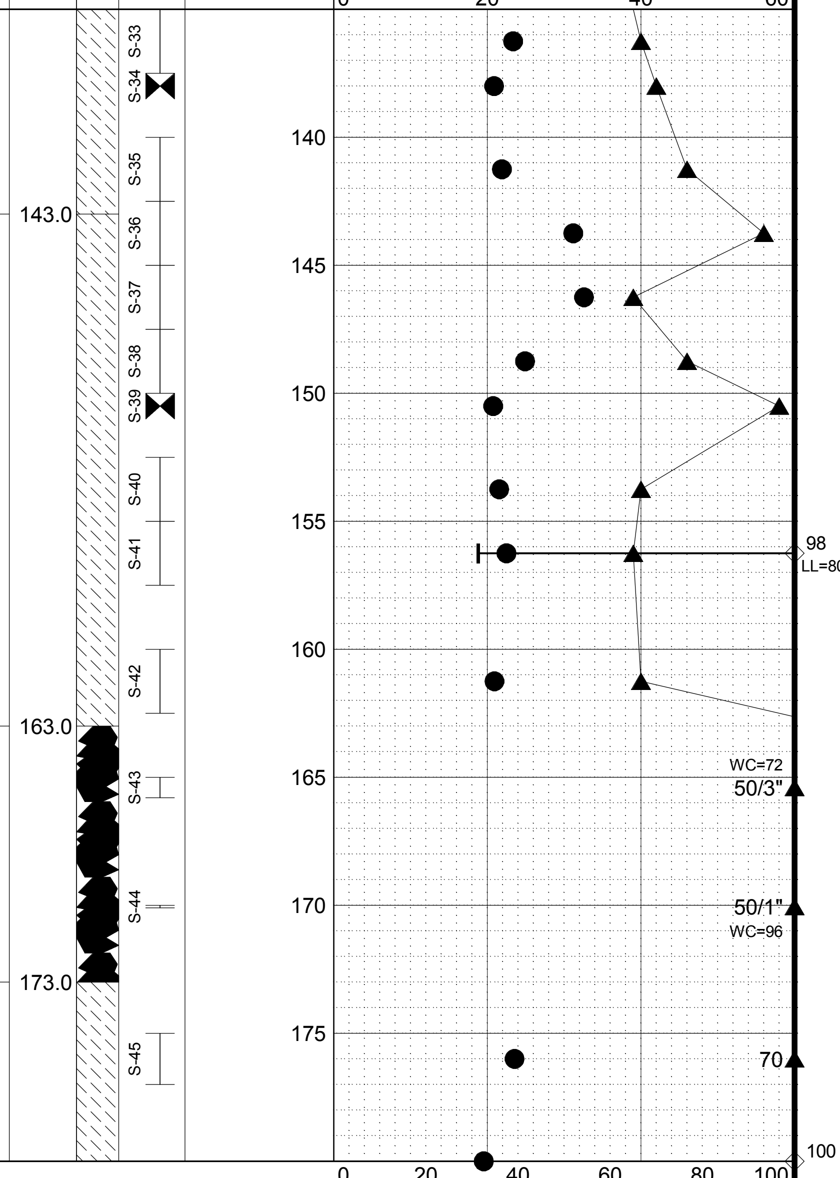
163.0

COAL: very low strength, black (Sentinel Butte Formation).

173.0

CLAYSTONE: very low strength, gray; thinly to thickly laminated; fresh; trace carbonaceous fragments (Sentinel Butte Formation).
[Hard, *Fat Clay (CH)*; moist].

CONTINUED NEXT SHEET




⊠ RQD (%) ▨ Recovery (%)

◇ % Fines (<0.075mm)

● % Water Content (use scale at top)

Plastic Limit ├─●─┤ Liquid Limit

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler

NOTES

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

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Project No. 9-085(085)075, PCN 20046
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**LOG OF BORING RP-127-06**

October 2016 23-1-01453-230

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. D-7**
Sheet 4 of 5

REV 3

MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 10/12/16

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 202.5 ft. | Latitude: | ~ 47.611° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | 8 in. |
| Top Elevation: | ~ 2491 ft. | Longitude: | ~ -103.25861° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | CME 55 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

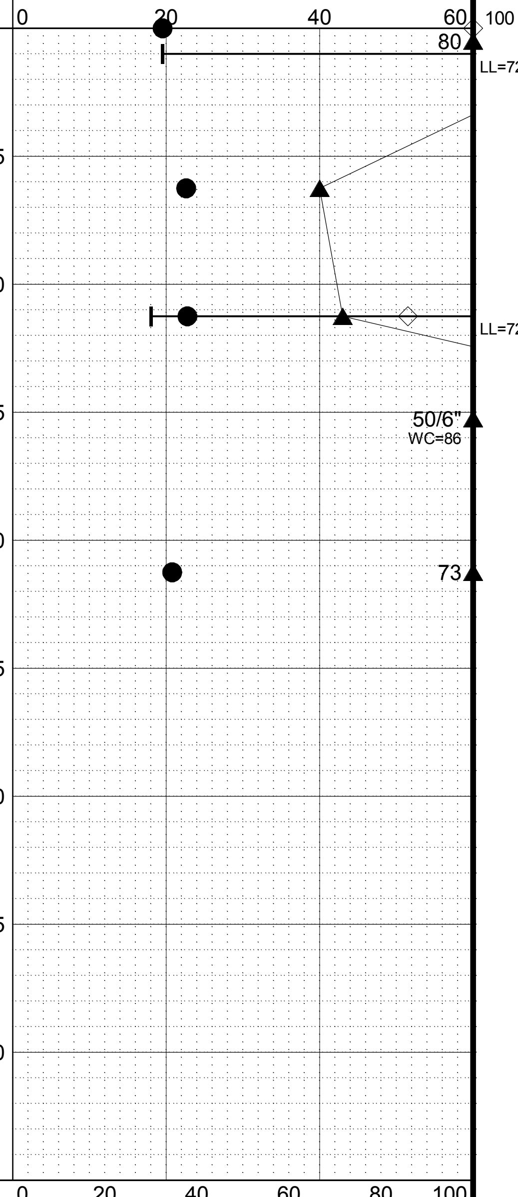
**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. | Samples |
|---|---|---|
| CLAYSTONE (continued) | | S-46 |
| - One-inch-thick, brittle, cemented zones at 185.2 and 186 feet. | | S-47 |
| SANDSTONE: very low strength, gray; thin bedded; fresh (Sentinel Butte Formation). [Very dense, *Clayey Sand (SC)* to *Sandy Fat Clay (CH)*; moist]. | 188.0 | S-48 |
| COAL: very low strength, black (Sentinel Butte Formation). | 194.0 | S-49 |
| CLAYSTONE: very low strength, gray; thinly to thickly laminated; fresh (Sentinel Butte Formation). [Hard, *Fat Clay (CH)*; moist]. | 197.0 | S-50 |
| | 202.0 | |

BOTTOM OF BORING
COMPLETED ON 8/4/2016

**PENETRATION RESISTANCE** (blows/foot)
▲ Hammer Wt. & Drop: 140 lbs / 30 inches




⊠ RQD (%) ▨ Recovery (%)
◇ % Fines (<0.075mm)
● % Water Content (use scale at top)
Plastic Limit ├──●──┤ Liquid Limit

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- 3" O.D. Thin-Walled Tube
- Modified California Sampler

NOTES

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

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# LOG OF BORING RP-127-06

October 2016 23-1-01453-230

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**FIG. D-7**
Sheet 5 of 5

REV 3

| | | | | | |
|---|---|---|---|---|---|
| Total Depth: 131.5 ft. | Latitude: ~ 47.60874° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | |
| Top Elevation: ~ 2250 ft. | Longitude: ~ -103.25886° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | Station: ~ | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | Offset: ~ | Other Comments: | | | |

**SOIL DESCRIPTION**

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

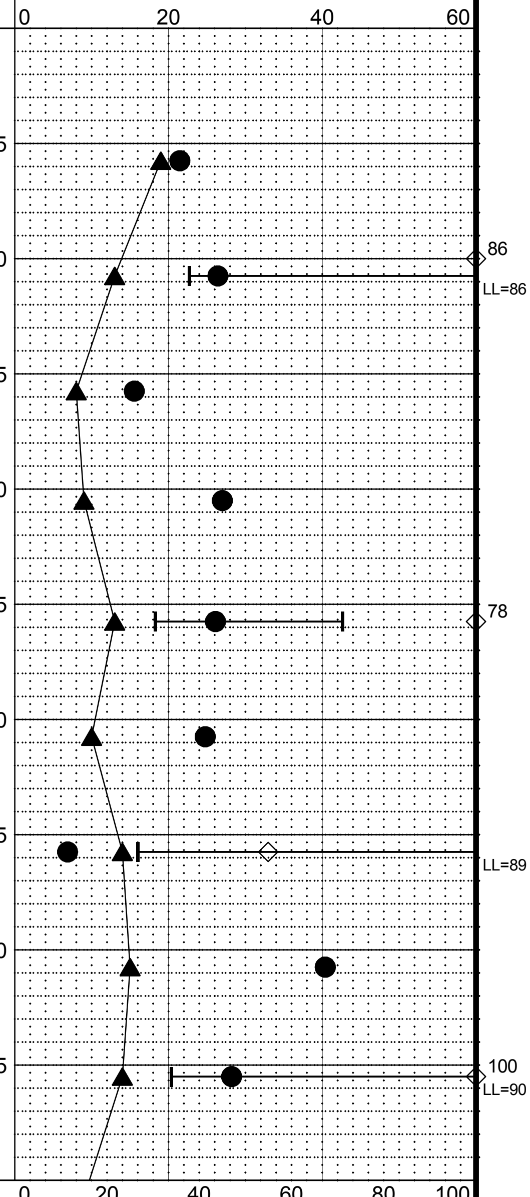
| Soil Description | Depth, ft. | Samples |
|---|---|---|
| Very stiff to medium stiff, brown to gray, *Fat Clay (CH)* to *Lean Clay (CL)*; moist; trace to few carbonaceous fragments; few to little sand and gravel. Fill | | S-1, S-2, S-3, S-4, S-5, S-6 |
| Medium dense, brown, *Clayey Sand (SC)*; moist. Landslide Debris | 33.0 | S-7 |
| DISPLACED CLAYSTONE: very low strength, gray; blocky; moderately to slightly weathered; bedding dipping approximately 40 to 50 degrees (Landslide Debris/Sentinel Butte Formation). [Stiff, *Fat Clay (CH)*; moist]. - Few to little carbonaceous fragments from 40.5 to 41.5 feet. | 38.0 | S-8, S-9 |

CONTINUED NEXT SHEET

Ground Water: 5/9/2017

**PENETRATION RESISTANCE** (blows/foot)

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




RQD (%) Recovery (%)

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough
- Inclinometer and SONDEX
- Ground Water Level in VWP
- Ground Water Level ATD
- ◇ % Fines (<0.075mm)
- ● % Water Content ←(use scale at top)
- Plastic Limit ⊢●⊣ Liquid Limit

NOTES

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

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# LOG OF BORING RP-127-07

September 2017 23-1-01453-230

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**FIG. D-8**
Sheet 1 of 3

REV 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 131.5 ft. | Latitude: | ~ 47.60874° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | |
| Top Elevation: | ~ 2250 ft. | Longitude: | ~ -103.25886° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

**SOIL DESCRIPTION**

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

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

**PENETRATION RESISTANCE** (blows/foot)

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

DISPLACED CLAYSTONE (continued)

53.0

DISPLACED SANDSTONE: very low strength, gray; slightly weathered; disturbed laminations (Landslide Debris/Sentinel Butte Formation). [Medium dense, *Silty Sand (SM)*; moist].

58.0

CLAYSTONE: very low strength, gray; very thin bedded to laminated; slightly weathered (Sentinel Butte Formation). [Hard, *Fat Clay (CH)*; moist].

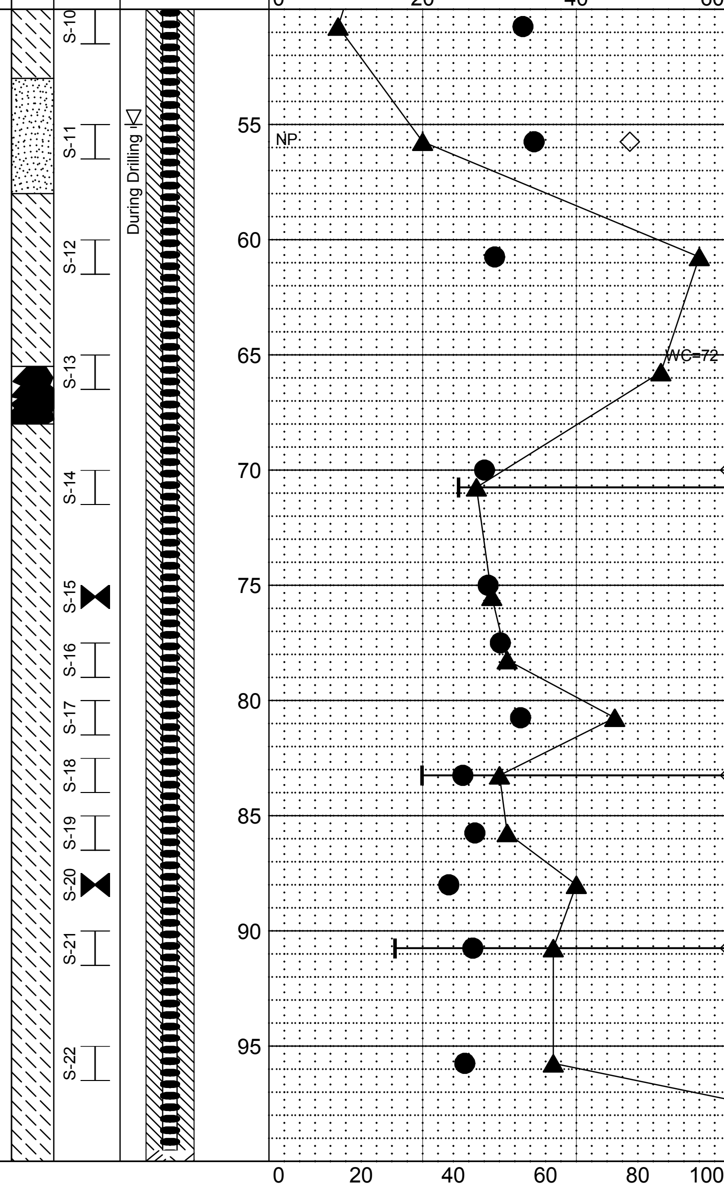
65.5

COAL: very low strength, black (Sentinel Butte Formation).

68.0

CLAYSTONE: very low strength, gray; very thin bedded to laminated; slightly weathered to fresh (Sentinel Butte Formation). [Very stiff to hard, *Fat Clay (CH)*; moist; trace carbonaceous fragments].

- Brown, kerogen rich from 78.0 to 78.5 feet
- Greenish gray from 78.5 to 79.0 feet.




CONTINUED NEXT SHEET

RQD (%) Recovery (%)

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough
- Inclinometer and SONDEX
- Ground Water Level in VWP
- Ground Water Level ATD
- ◇ % Fines (<0.075mm)
- ● % Water Content ←(use scale at top)
- Plastic Limit ├─●─┤ Liquid Limit

NOTES

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

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# LOG OF BORING RP-127-07

September 2017 23-1-01453-230

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**FIG. D-8**
Sheet 2 of 3

REV 3

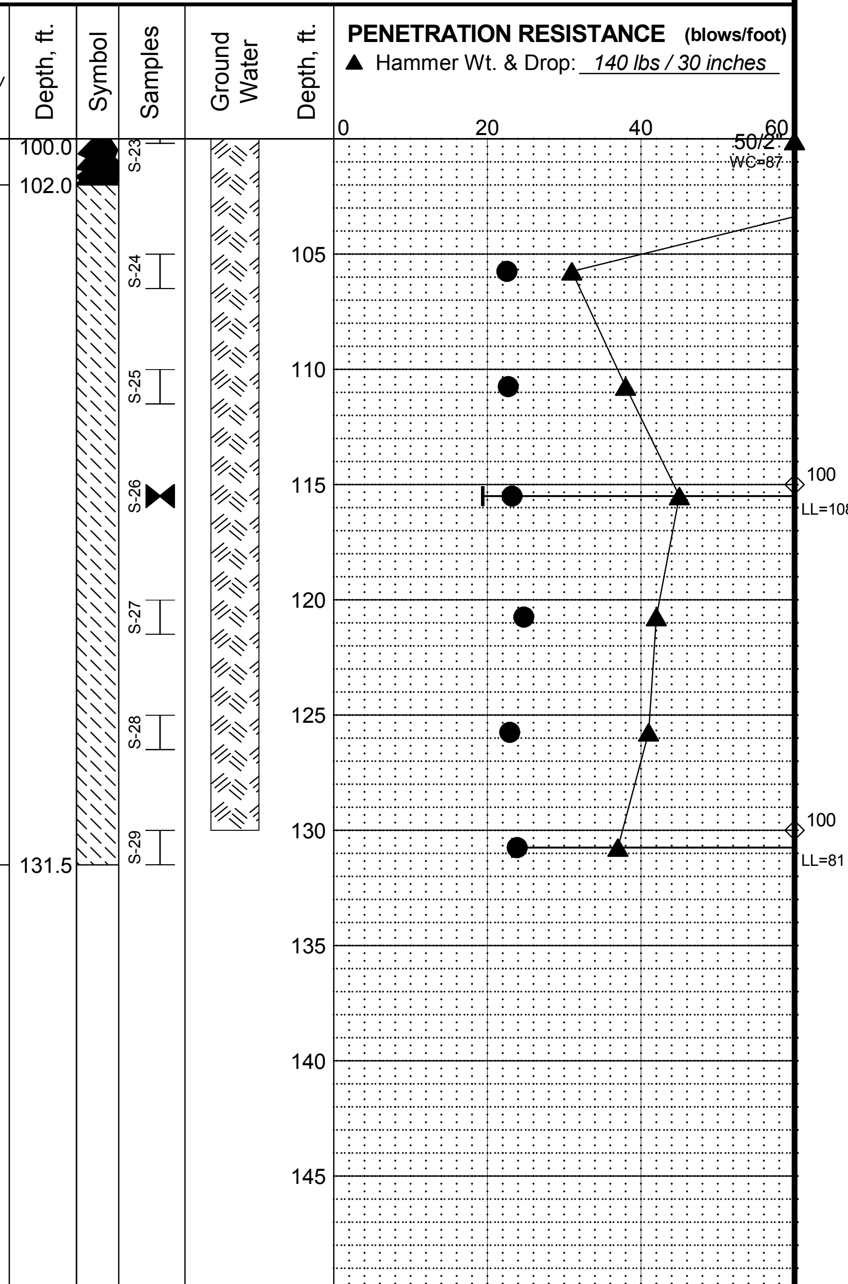
MASTER_LOG_E_POCKETPEN_LAT&LONG 23-1-01453 US-85.GPJ 9/15/17

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total Depth: | 131.5 ft. | Latitude: | ~ 47.60874° | Drilling Method: | HSA/Mud Rotary | Hole Diam.: | |
| Top Elevation: | ~ 2250 ft. | Longitude: | ~ -103.25886° | Drilling Company: | Interstate Drilling Service | Rod Type.: | AWJ |
| Vert. Datum: | | Station: | ~ | Drill Rig Equipment: | Diedrich D-50 Track Rig | Hammer Type: | Automatic |
| Horiz. Datum: | | Offset: | ~ | Other Comments: | | | |

**SOIL DESCRIPTION**

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

| Soil Description | Depth, ft. |
|---|---|
| COAL: very low strength, black (Sentinel Butte Formation). | 100.0 |
| CLAYSTONE: very low strength, gray; very thin bedded to laminated; fresh (Sentinel Butte Formation). [Hard, *Fat Clay (CH)*; moist; trace carbonaceous fragments]. | 102.0 |
| BOTTOM OF BORING COMPLETED ON 4/28/17 | 131.5 |




⊠ RQD (%) ▨ Recovery (%)

◇ % Fines (<0.075mm)

● % Water Content (use scale at top)

Plastic Limit ├─●─┤ Liquid Limit

LEGEND

- * Sample Not Recovered
- Standard Penetration Test
- Modified California Sampler
- Inclinometer and Piezometer
- Piezometer
- Bentonite-Cement Grout
- Slough
- Inclinometer and SONDEX
- Ground Water Level in VWP
- Ground Water Level ATD

NOTES

1. Refer to Figures A-1 and A-2 for explanation of symbols, codes, abbreviations and definitions.
2. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
3. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
4. Groundwater level, if indicated above, is for the date specified and may vary.
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**LOG OF BORING RP-127-07**

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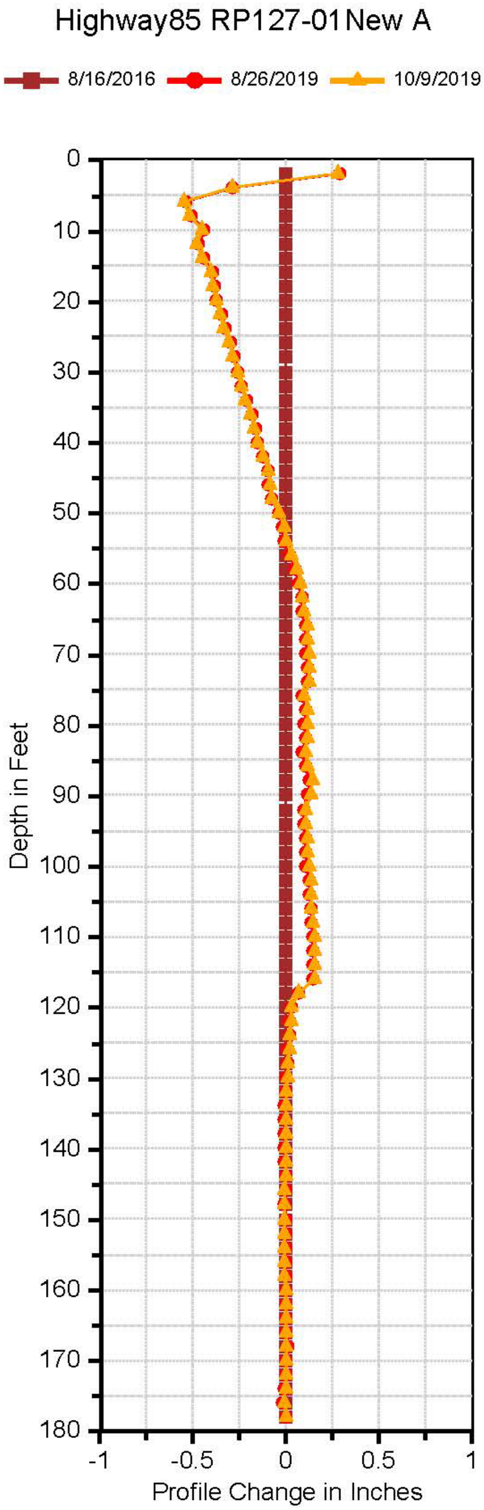
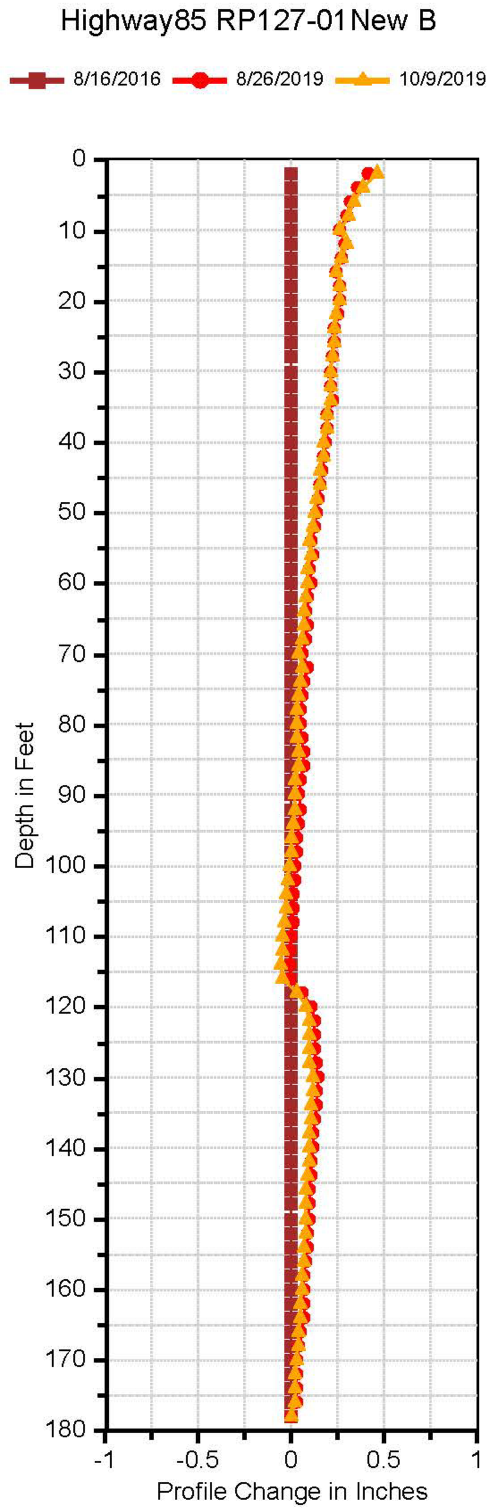
**FIG. D-8**
Sheet 3 of 3

REV 3




Horseshoe Bend Landslide Repair
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**INCLINOMETER CUMULATIVE DISPLACEMENT, BORING RP-127-01**

January 2020 | 102116-200

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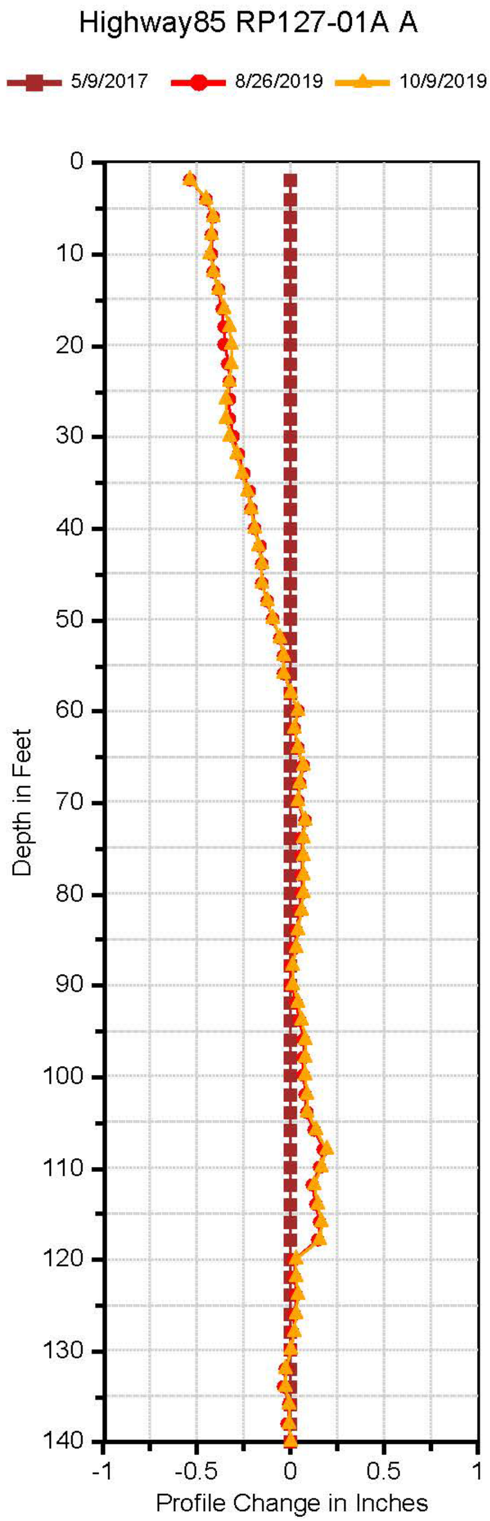
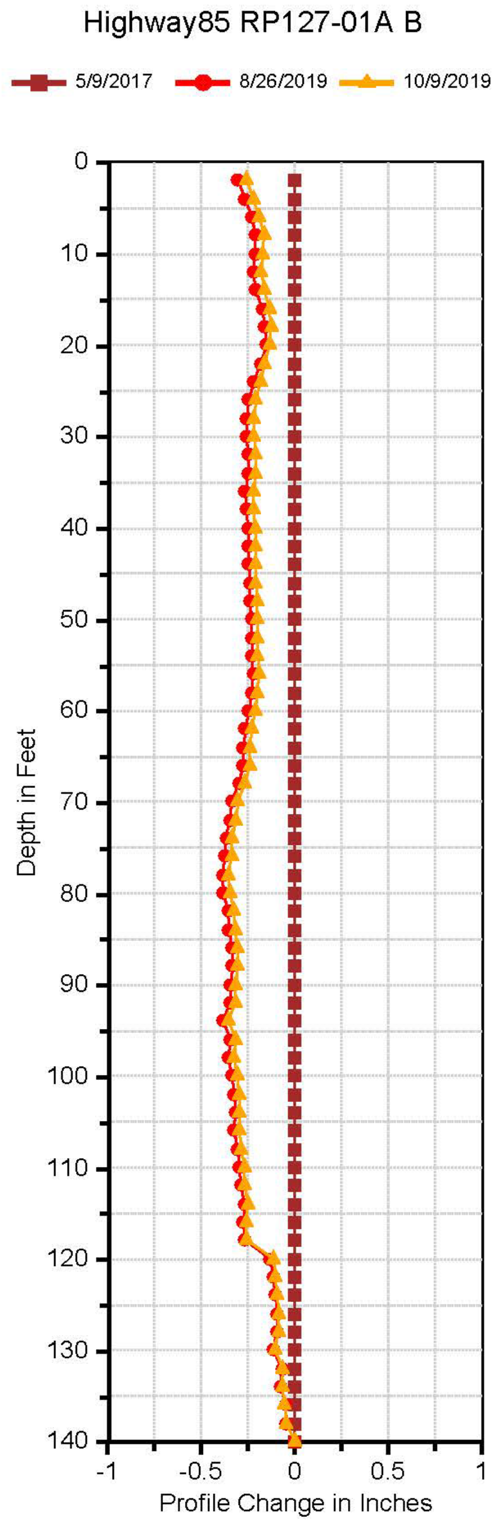
**FIG. D-9**

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**INCLINOMETER CUMULATIVE DISPLACEMENT, BORING RP-127-01A**

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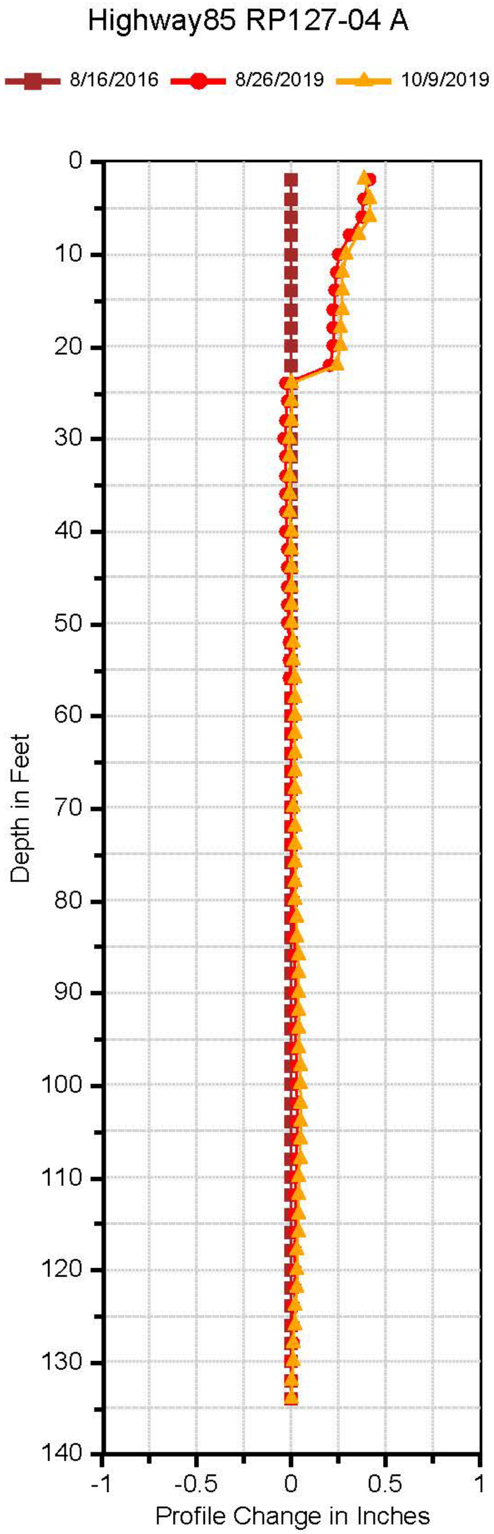
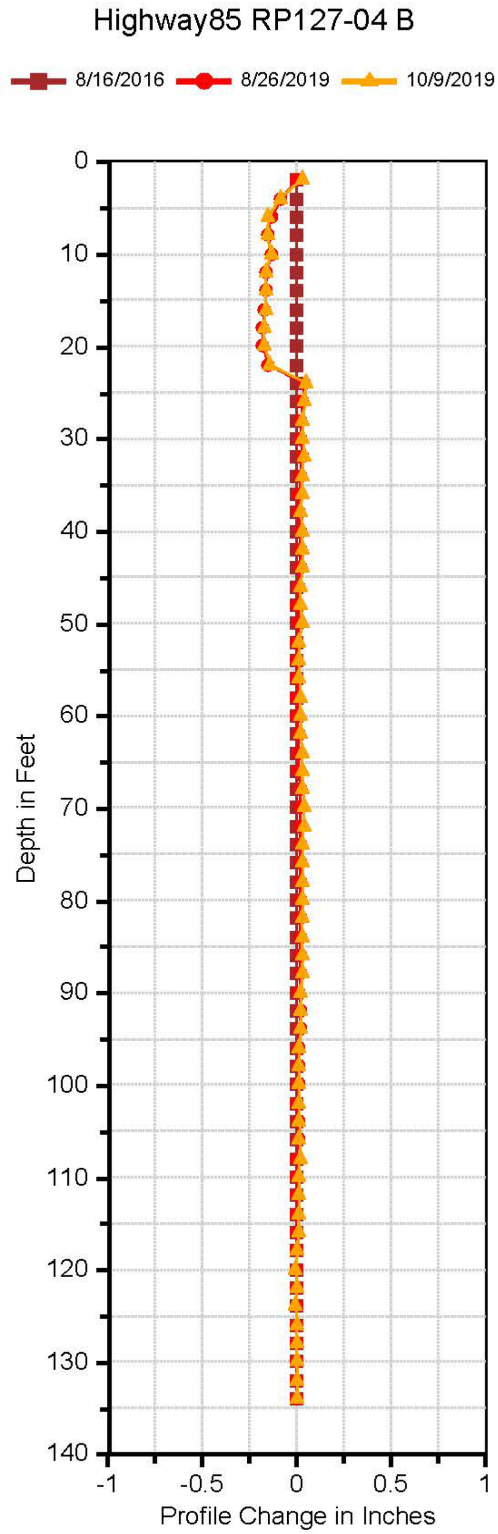
**FIG. D-10**

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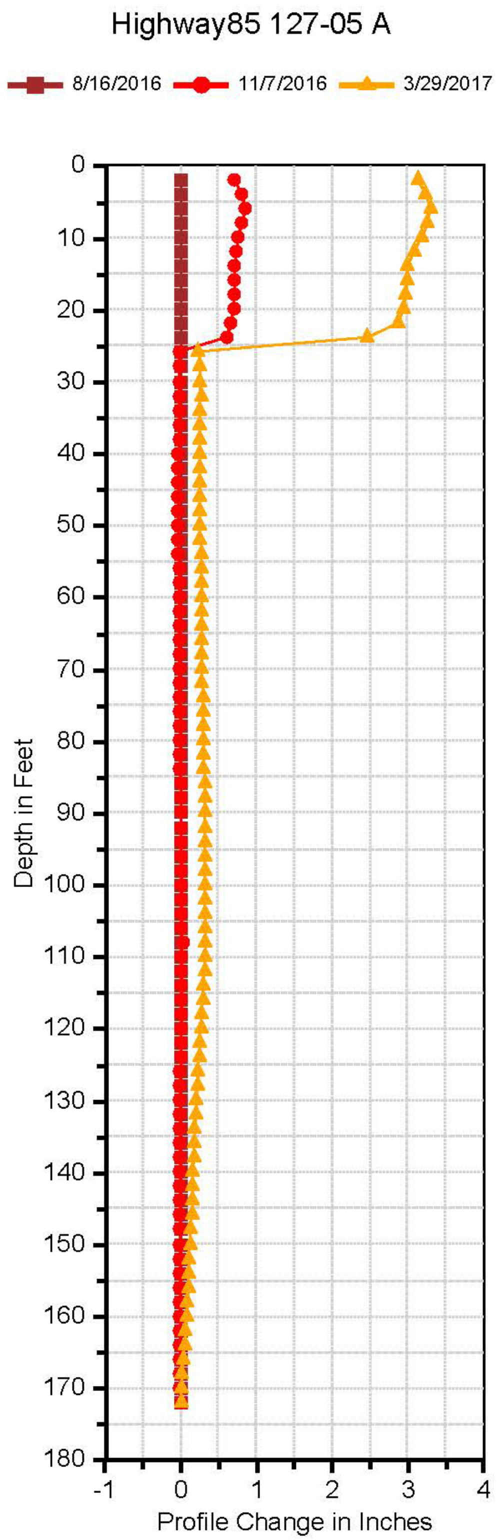
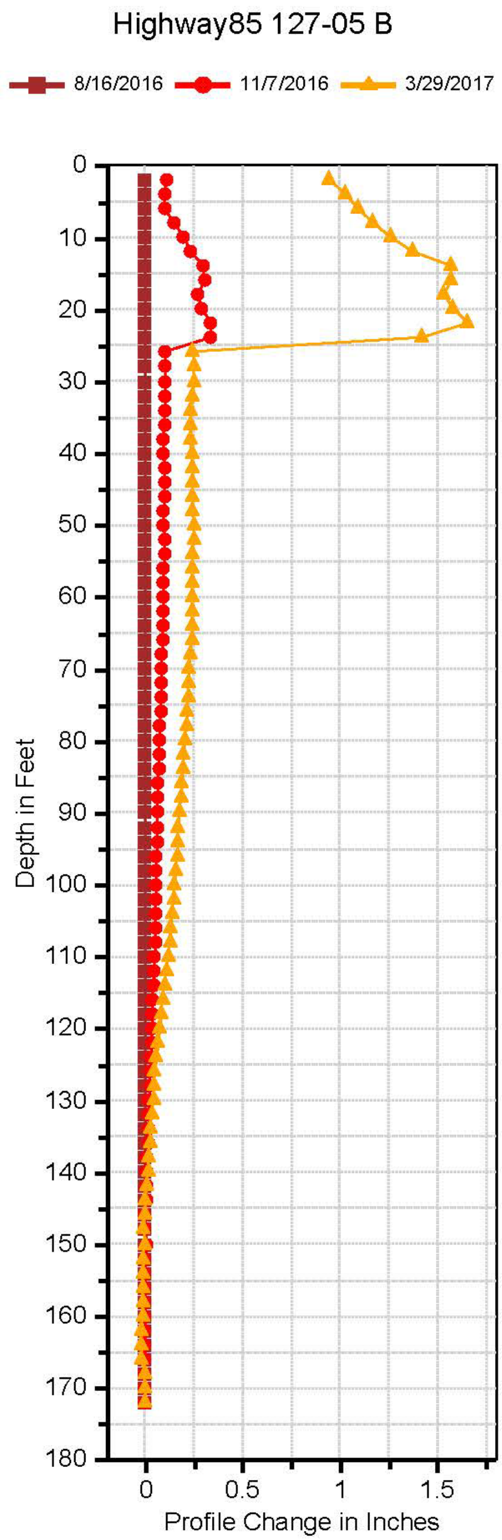
| January 2020    102116-200 |

| | |
|---|---|
| **SHANNON & WILSON, INC.**<br>Geotechnical and Environmental Consultants | **FIG. D-11** |

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**INCLINOMETER CUMULATIVE DISPLACEMENT, BORING RP-127-05**

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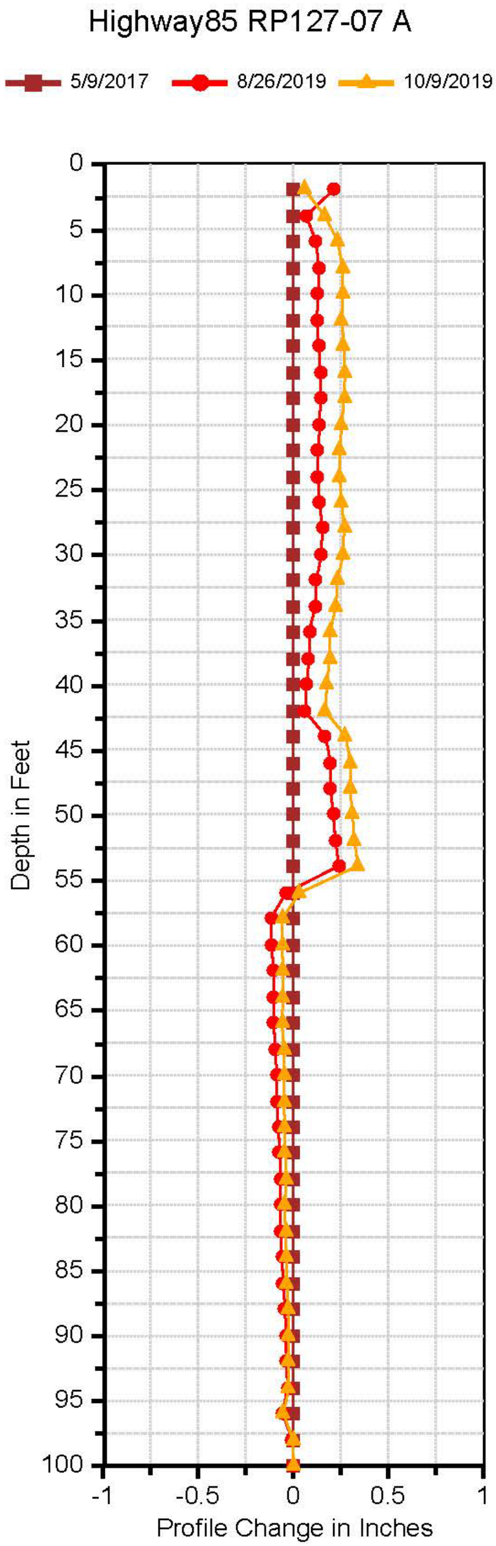
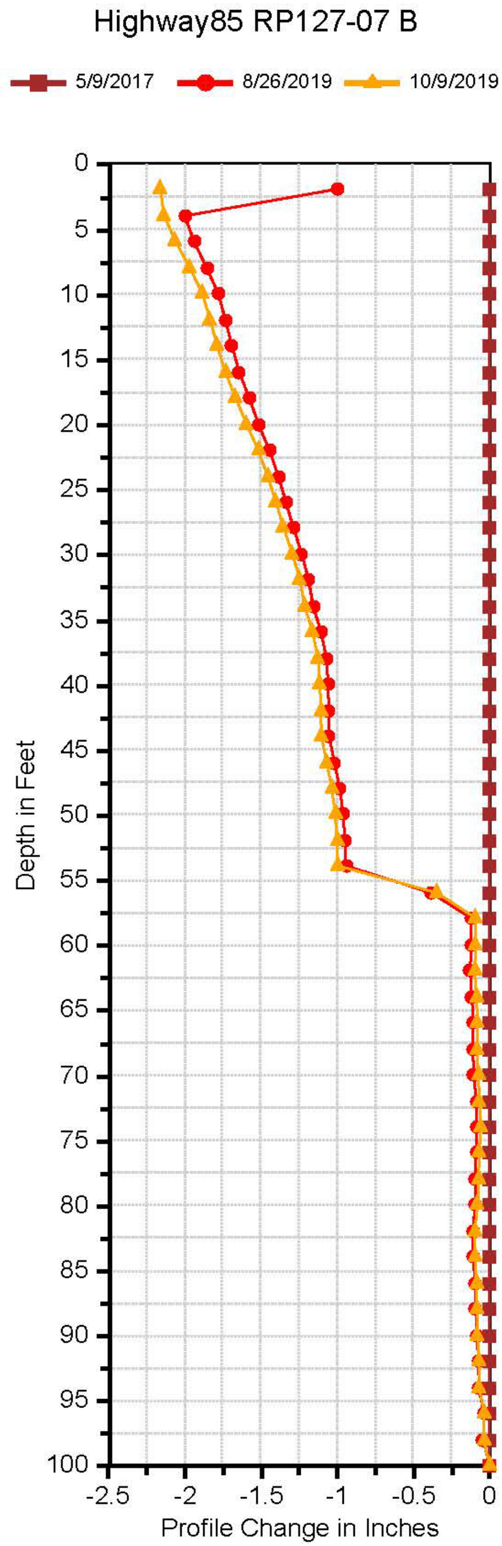
**FIG. D-12**

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|---|
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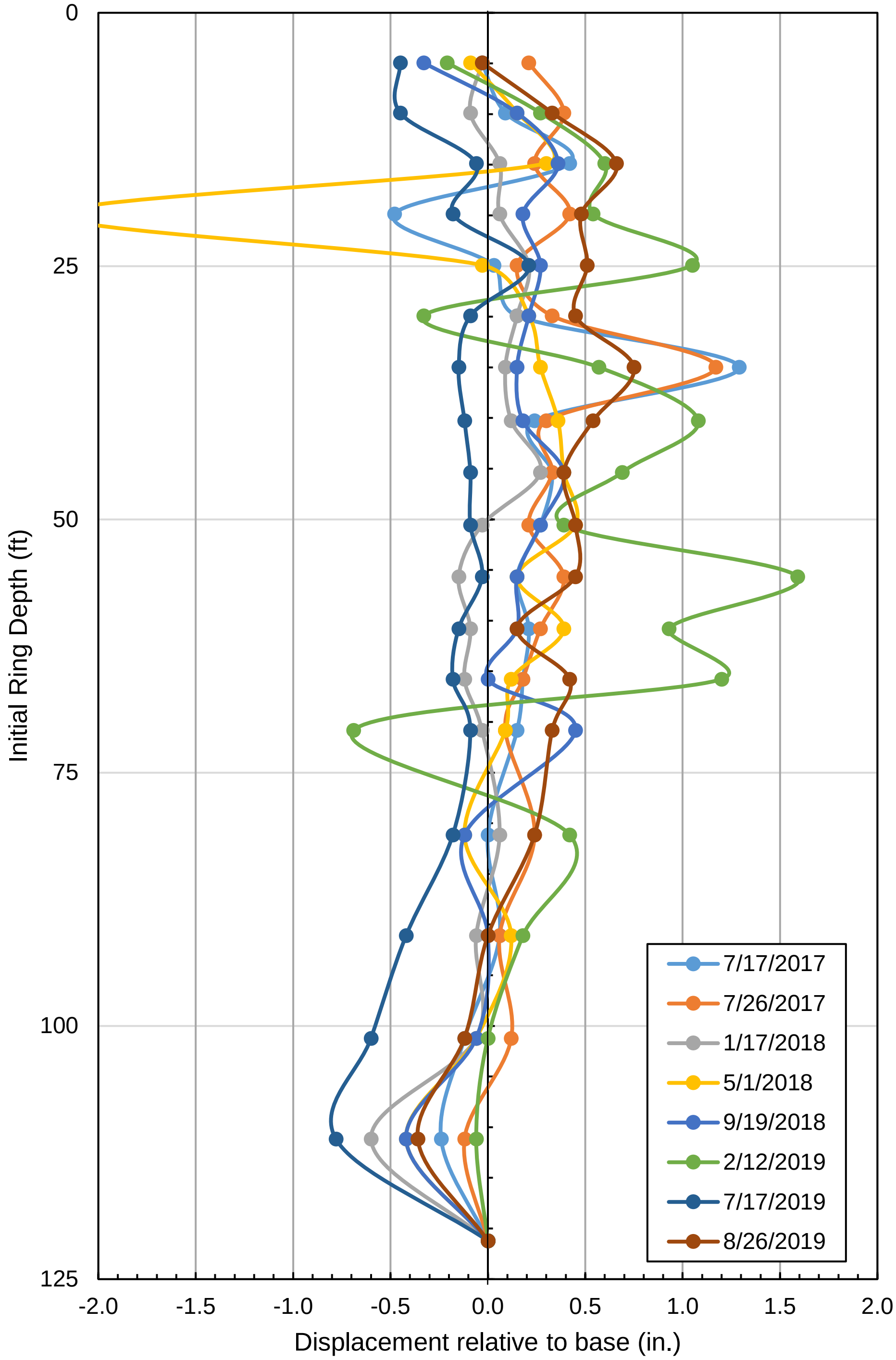
| **INCLINOMETER CUMULATIVE DISPLACEMENT, BORING RP-127-07** |
| January 2020 102116-200 |
| **SHANNON & WILSON, INC.** Geotechnical and Environmental Consultants — **FIG. D-13** |




**NOTES**

1. Cumulative displacement values are referenced from baseline reading completed on May 9, 2017.

Horseshoe Bend Landslide Repair
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McKenzie County, North Dakota

**SONDEX EXTENSOMETER DISPLACEMENT, BORING RP-127-01A**

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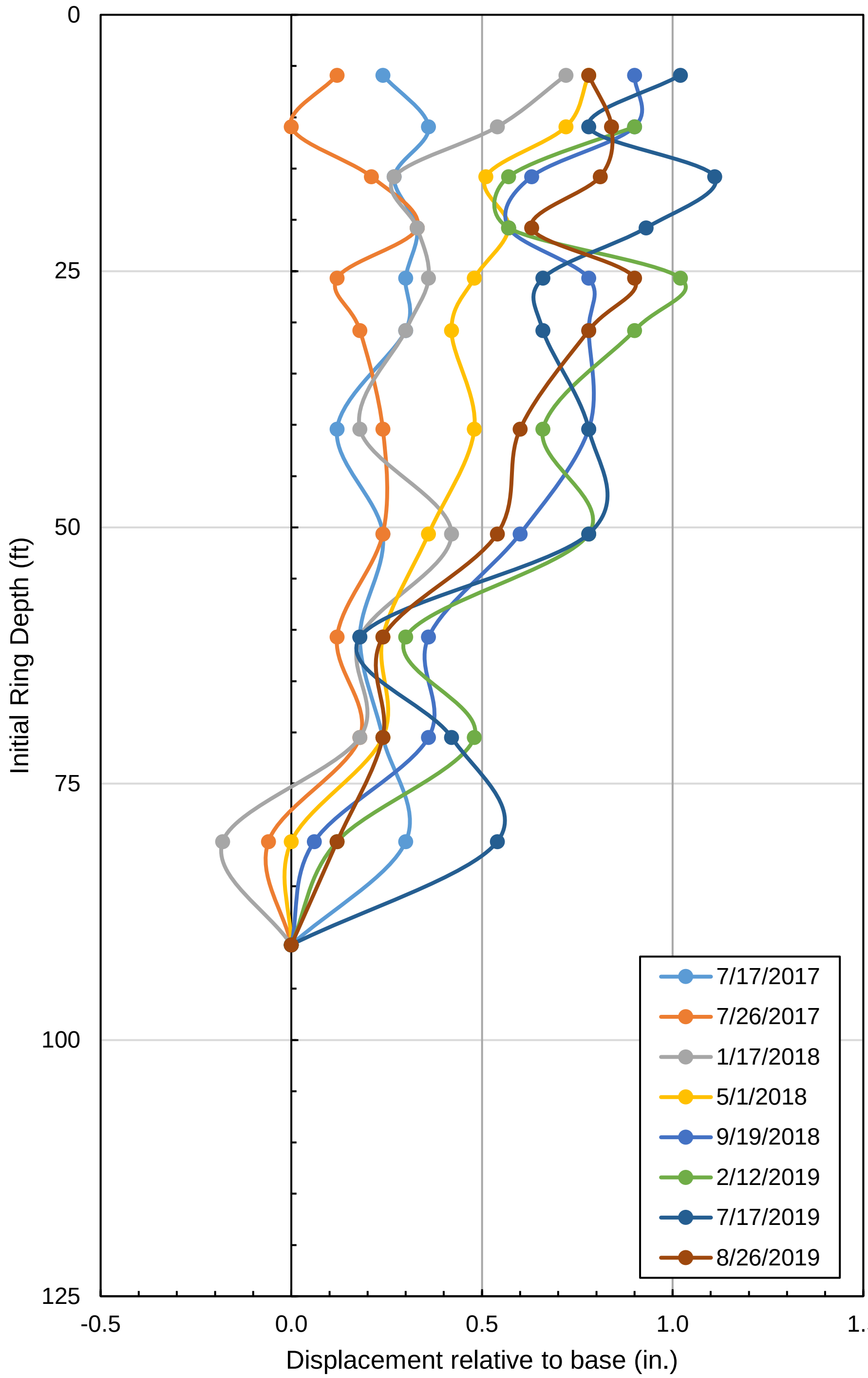
**FIG. D-14**




**NOTES**

1. Cumulative displacement values are referenced from baseline reading completed on May 9, 2017.

| | |
|---|---|
| Horseshoe Bend Landslide Repair<br>7-085(110)127, PCN 22304<br>McKenzie County, North Dakota | |
| **SONDEX EXTENSOMETER DISPLACEMENT, BORING RP-127-07** | |
| January 2020 | 102116 |
| **SHANNON & WILSON, INC.**<br>Geotechnical and Environmental Consultants | **FIG. D-15** |

APPENDIX E: INSAR STUDY

## Appendix E
# InSAR Study

## Attachments

Exhibit E-1: Historical A-DInSAR Analysis of the Horseshoe Bend Landslide (North Dakota, USA)

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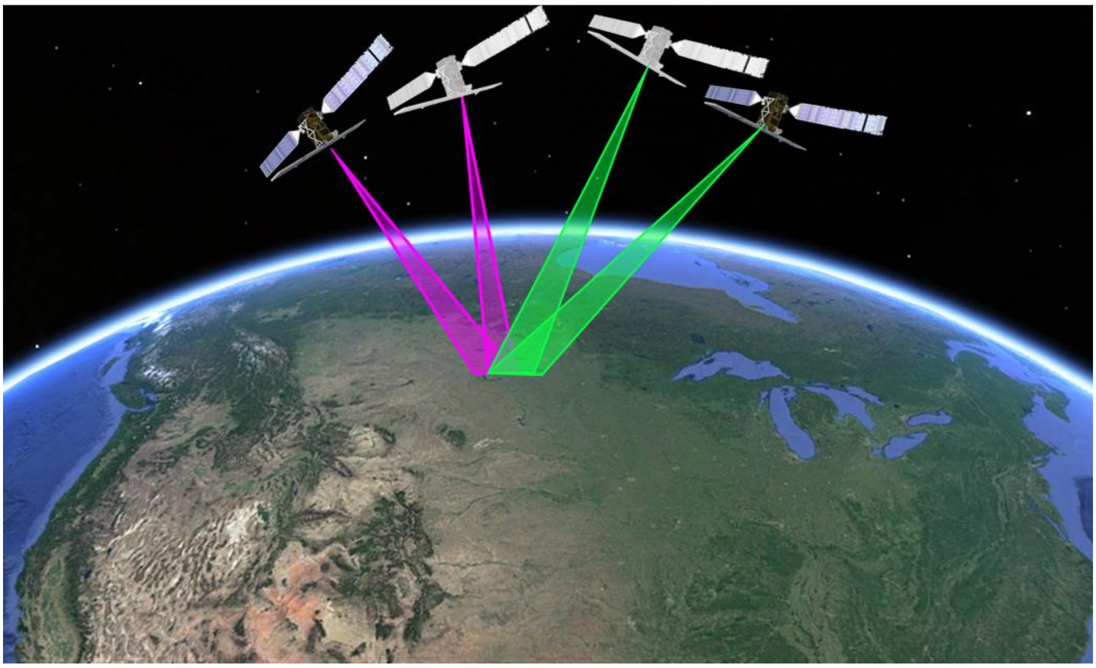
# HISTORICAL A-DInSAR ANALYSIS OF THE HORSESHOE BEND LANDSLIDE (NORTH DAKOTA, USA)

## *Technical report*

**CLIENT: Shannon & Wilson Inc.**

**TO THE ATTENTION OF: Joey Goode**

**REF. ORDER: NZ0029-U_170119 (accepted on May 29th, 2019)**



**Edited by: Dr. S. Scancella - Dr. L. Rocca - A. Rocca, PhD**

**Reviewed by: Prof. P. Mazzanti - Dr. A. Brunetti**

**Date of issue: 12th of July, 2019**

**Prot. N°: NZ0423-U_120719**

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# GLOSSARY

**A-DInSAR**

A-DInSAR is an acronym for “Advanced Differential Interferometric Synthetic Aperture Radar”. This term groups several processing techniques based on multi-temporal stacks (see “Stack”) of satellite SAR images.

**LOS**

Line of sight of the satellite (measured along the sensor-target line).

**Master**

It is called “master” image, the SAR image in a stack of data is the one used as a reference for other images (so called, slaves). All images are thus referred to the master for the coregistration stage and also for other steps in the processing chain (e.g. for the computation of interferograms).

**Orbital geometry**

Satellites equipped with SAR sensors fly around the Earth along approximately N-S orbits. Therefore, satellites fly over the same area both during the ascending (South to North) and descending (North to South) orbits. Due to the inclination of the line of sight (LOS) with respect to the nadir, the satellite is able to look the same area from two different points of view, during the data acquisition.

Most of the satellites use a right-looking configuration (they look to the right), so in ascending geometry the images are acquired from the West (LOS directed to the East), while in descending geometry images are acquired from East (LOS directed to the West).

**Persistent Scatterers (PS)**

One of the most consolidated methodologies of A-DInSAR analysis is the Persistent Scatterers Interferometry (PSI) technique. It is based on the analysis of objects (targets) on the Earth’s surface characterized by a high stability over time of the electromagnetic signal backscattered toward the sensor. The typical results of the PSI technique are

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maps of geocoded measuring points (PMs), and usually colored basing on the detected velocity of displacement (mm/year).

**RADAR**

RADAR is an acronym for “*RAdio Detection And Ranging*”: it is an object-detection system that uses electromagnetic waves to define the range, angle, or velocity of objects. A RADAR system for SAR applications consists of a transmitter emitting a microwave signal and of a receiving antenna that acquires the backscattered signal.
The system is based on the measure of the Time of Flight (TOF), namely the time required by the signal to travel from the sensor to the target.

**SAR**

SAR is an acronym for “*Synthetic Aperture Radar*”. It is a specific kind of RADAR which takes advantage of its movement along its default trajectory (e.g. satellite orbit) to synthetize a large antenna, allowing to get better ground resolution.

**Stack**

Multi-temporal dataset of SAR images acquired with the same features (resolution, orbit geometry, incidence angle, etc.) on the same area in a given time interval. It represents the input raw data for analysis with the A-DInSAR approach.

# 1. Introduction

In the frame of the collaboration formalized on May 29th, 2019 (ref. technical offer prot. NZ0029-U_170119) from Shannon & Wilson Inc., NHAZCA S.r.l. performed the A-DInSAR analysis of the area affected by the "Horseshoe Bend Landslide" (North Dakota, USA). The aim of the study was to characterize ground and infrastructures (e.g. CanAm Highway) deformation processes in the area indicated by the client, that is about 1.25 $km^2$ wide. Nevertheless, for a suitable characterization of the landslide process, the A-DInSAR analysis has been performed on a wider area, that is about 5 $km^2$ wide (Figure 1).

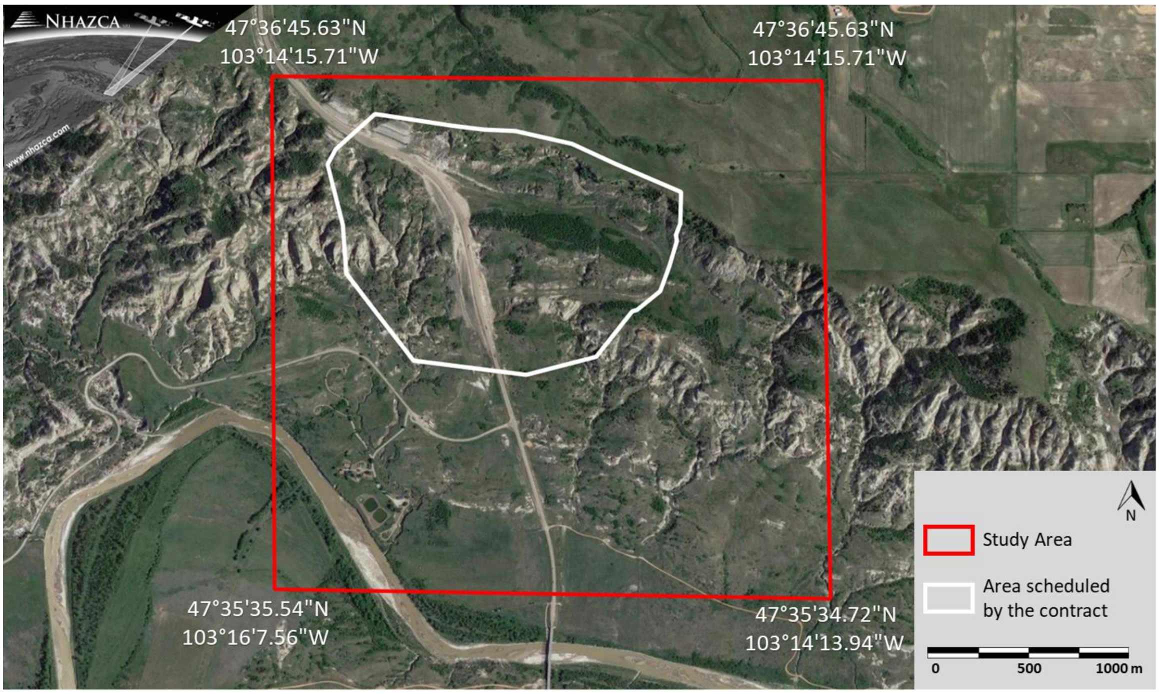


**Figure 1: identification of the study area on satellite optical image.**

The performed activities have been calibrated based on the results achieved by the preliminary feasibility study (ref. report prot. NZ0209-U_050419), already delivered to the Client.

The A-DInSAR analysis has been performed by the available archive SAR (*Synthetic Aperture Radar*) images collected by the **Sentinel-1 satellite constellation** (European Space Agency) over the study area**.** Specifically, a stack of 103 SAR scenes in ascending orbital geometry and of 46 SAR scenes in descending orbital geometry have

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been analyzed, respectively in the period **29th January 2015 – 26th May 2019** and **10th October 2016 – 01st August 2018**.

The **A-DInSAR (*Advanced Differential Interferometric SAR*) analysis** has been performed aiming to provide widespread and detailed information for all the good natural targets identified in the study area.

In the following sections, after a short introduction about the adopted techniques and the performed activities, the achieved results are reported and discussed.

Thereafter, some calibrated conventional **DInSAR** analyses have been also performed in the study area.

The results of the A-DInSAR analysis will be also provided by the ***NHAZCA InSAR Visualization Tool*** web portal for an interactive visualization of data. The login data will be provided separately.

## 2. Satellite SAR Interferometry

InSAR (*Interferometric Synthetic Aperture Radar*) (Massonnet et al., 1998; Hanssen, 2001) can be considered the main satellite remote sensing technique used for the measurement of displacements of the Earth's surface. It is based on the comparison between different RADAR images acquired in different times over the same area. The basic principle of Multi-Image InSAR or Advanced DInSAR methodologies (A-DInSAR) consists of the combination of information from a large number of SAR images, allowing to derive the temporal evolution of displacements of objects on the ground during the period of analysis. For such analysis, the quality of the results depends on the number of available images.

A-DInSAR techniques allow to detect deformation processes, both in the past (historical analysis) and/or in progress, and to estimate their evolution in time and space.

Hereunder, InSAR satellite systems and *Persistent Scatterers technique* (PS) are described more in detail.

### 2.1. General information on SAR (*Synthetic Aperture Radar*) systems

RADAR (***RAdio Detection And Ranging***) are systems able to emit an electromagnetic pulse in the domain of microwaves and to register the return signal (**echoes**)

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backscattered by the objects in the instrumental field of view (**targets**). For this reason, RADARs are considered **active** remote sensing systems, since they don't need an external source of energy (like solar lighting), but they make use of energy (pulse) generated by the sensor. So, for example, they are able to "*see*" through clouds (in case of satellite or aerial based radar platforms).

By RADAR systems, it is possible to detect objects and to measure their distances from the sensor. For this reason, the backscattering characteristics of the targets in the field of view are very important, as well as their **dielectric** properties.

**SAR (*Synthetic Aperture Radar*)** is a specific kind of RADAR system: the main characteristic of SAR systems is to take advantage of the motion of the sensor along a pre-defined trajectory (e.g. the orbit of a satellite equipped with the SAR sensor) in order to observe the same area from different points of view, thus simulating a large antenna able to get high resolution on the ground. This specific geometry of acquisition is sketched in Figure 2.

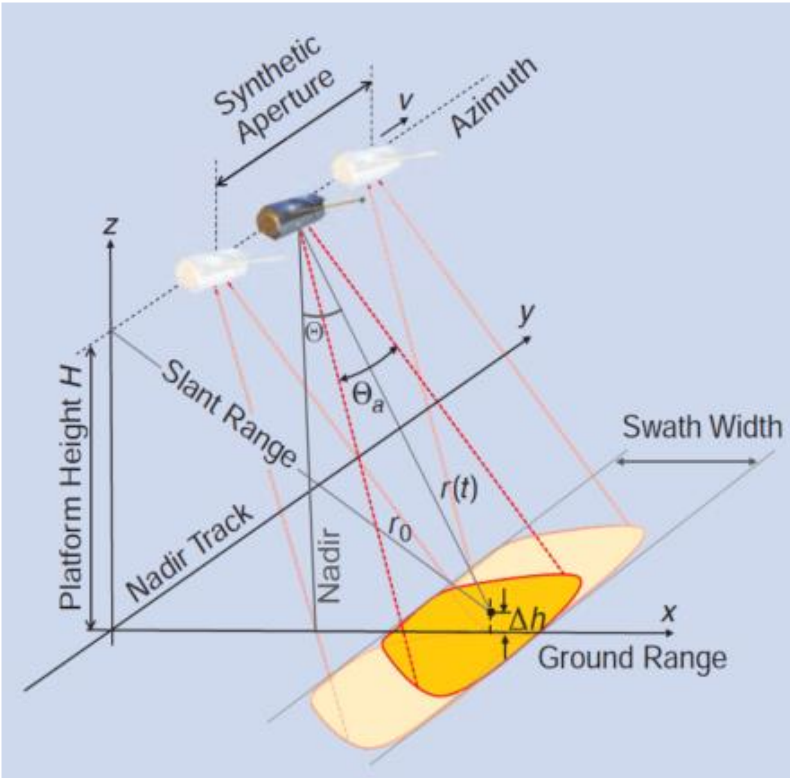


**Figure 2: SAR acquisition geometry.**

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SAR images are characterized by a ***Slant Range*** and ***Azimuth*** resolution. The first one (*Slant Range*) refers to the resolution along the direction of propagation of the RADAR signal, orthogonal to the satellite orbit, which is inclined with an *off-nadir* angle θ specific for each satellite. The second one (*Azimuth*) refers to the resolution along the flight direction that, in case of satellite, corresponds to the orbit that can be approximately considered North-South.

## 2.2. SAR satellite images

A satellite SAR image is made up by a matrix of pixels arranged along the directions of azimuth (parallel to the movement of the satellite) and slant range (orthogonal with respect to the flight direction).

Each pixel contains information about amplitude and phase of the signal backscattered from the observed objects. Amplitude represents the energy of the signal reflected to the sensor, while the phase contains the most important information for interferometric purposes: the distance between the sensor and the backscattering target on the ground.

Satellites can collect data into two different orbital geometries: the satellite revisits the same area following both a path approximately from North to South (descending geometry) and a path from South to North (ascending geometry) (Figure 3). So, the same area is detected by two different angles of view.

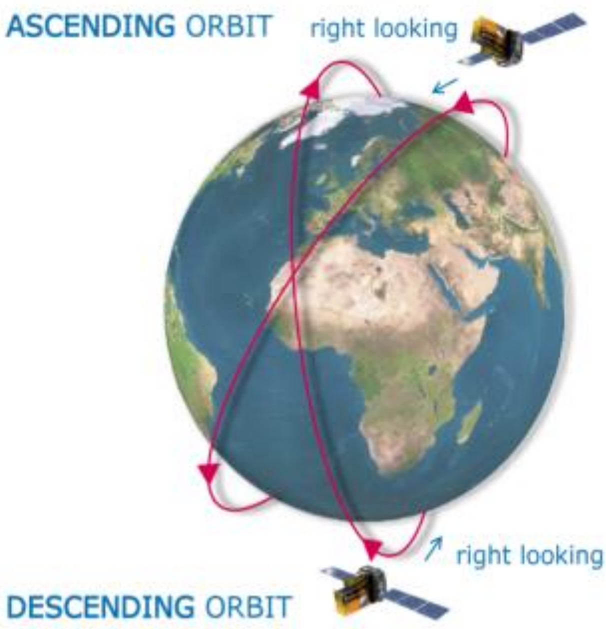


**Figure 3: acquisition geometries of SAR images.**

The acquisition geometry, according to the orbits of the SAR sensors, can introduce some uncertainties in the detection of deformation processes characterized by some specific features. For example, areas characterized by steep slopes may appear distorted (i.e. *foreshortening* effect) or even be in shadow (*shadowing*). In these cases, the analysis of the data can be complex and inaccurate (Figure 4).

Moreover, movements with a strong N-S horizontal component cannot be properly analyzed and the displacement values can be underestimated.

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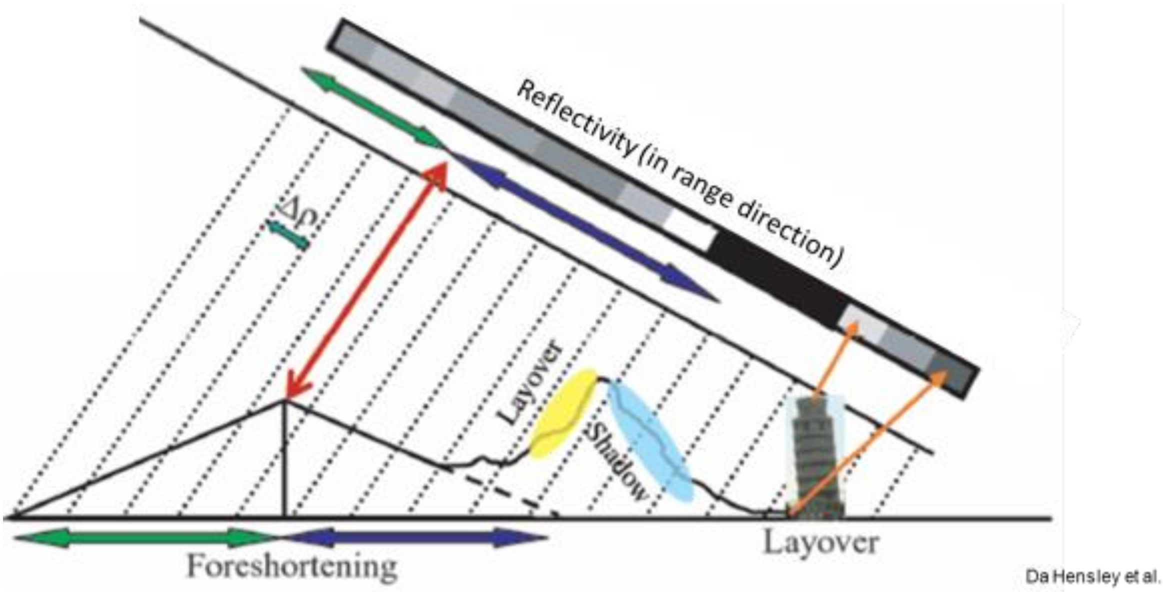


**Figure 4: main geometric distortions.**

## 2.3. Sentinel-1 constellation by the European Space Agency (ESA)

Sentinel-1 mission is part of the Copernicus program, with a partnership between ESA (European Space Agency) and European Commission, representing a revolution in the Earth Observation scientific world.

Sentinel-1 is a two-satellite constellation with the prime objectives of Land and Ocean monitoring. The goal of the mission is to provide C-band SAR data continuity following the retirement of ERS-2 and the end of the Envisat mission. The first satellite (Sentinel-1A) launch occurred on 03 April 2014, meanwhile the second one (Sentinel-1B) was launched two years later.

Both satellites carry onboard a C-band SAR sensor (5,40 GHz frequency and about 5,55 cm wavelength), able to acquire SAR images with extremely variable resolution and coverage (up to 400 km of swath). Specifically, the standard acquisition mode is the Interferometric Wide Swath (IW), characterized by 250 km wide images and resolution comparable to the first-generation ESA satellites (ERS and Envisat).

Such effective performances are possible thanks to an innovative acquisition mode, called TOPS (Terrain Observation with Progressive Scans SAR).

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One of the main advantages of Sentinel-1 is the short revisit time, that is 12 days (or 6 days with the acquisition of both satellites over the same area for specific regions of the planet).
*[information from earth.esa.int]*

### 2.4. Basic Principles of differential SAR interferometry (DInSAR)

DInSAR (Differential Interferometric SAR) is the traditional technique used for the detection of displacements from SAR Interferometry. It is based on the analysis of the variation of the phase signal between pairs of images collected at different times over the same area, thus allowing to measure the displacements on the Earth's surface.
Information about the phase difference is derived from the **Interferogram** which represents the basic element of this methodology.
In particular, the phase of each pixel given by the sum of two terms:

$$\boxed{\varphi = \varphi_s + \varphi_r} \quad (1)$$

The first ($\varphi_s$) is related to the scatterers within the scene; the second ($\varphi_r$) depends on the double path satellite-target and on the wavelength of the electromagnetic pulse emitted and then recorded by the sensor:

$$\boxed{\varphi_r = \frac{4 \cdot \pi \cdot r}{\lambda}} \quad (2)$$

*r* is the distance between the satellite and the target on the ground along the range direction and $\lambda$ is the wavelength. However, the phase of a single SAR image cannot be used because:

• $\varphi_s$ is random;

• $\varphi_r$ depends on *r*, that is in the order of hundreds of kilometers and on λ that, on the contrary, is in the order of few centimeters.

In fact, the electromagnetic wave, for each pixel, is sent from the SAR antenna to the Earth’s surface; during the satellite-ground path, the sinusoidal signal performs millions

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of cycles, hits the targets with a particular phase value and it's randomly backscattered (multiple reflections, $\varphi_s$). Finally, part of the signal returns to the satellite, that records the information.

By considering the phase difference between two SAR images, $\varphi_s$ of the same target is deleted and the **interferometric phase** $\Delta\phi$ is given by:

$$\boxed{\Delta\phi = \frac{4\cdot\pi}{\lambda}\cdot\Delta R} \quad (3)$$

$\Delta\phi$ is characterized by the following main contributions:

$$\boxed{\Delta\phi = \Delta\phi_f + \Delta\phi_{topo} + \Delta\phi_{displ} + \Delta\phi_{atm} + \Delta\phi_{err}} (4)$$

$\Delta\phi_f$ is called "flat earth phase" and is due to the different angles of view of the satellites during the acquisition of the image. It is a contribution easy to remove.

$\Delta\phi_{topo}$ is the phase component containing the topographical information, that is the relation between phase and heights. This phase contribution can be estimated by using a *DEM* (Digital Elevation Model).

$\Delta\phi_{atm}$ represents a random element caused by the different weather conditions during the acquisition of SAR images over time.

$\Delta\phi_{displ}$ is the contribution to the interferometric phase due to the earth's surface displacements.

$\Delta\phi_{err}$ is a residual noise not directly determinable.

The differential interferogram is obtained from (4). The flat earth contribution and the topographic phase can be easily removed by the use of a DEM. So, in order to detect the displacement information, $\Delta\phi_{atm}$ and $\Delta\phi_{err}$ have to be estimated. The acquisition system of the interferometric pairs of SAR images is characterized by the geometric baseline (also called normal or perpendicular baseline) (Figure 5) and by the temporal baseline (i.e. the time interval between two consecutive acquisitions), which can influence the quality of the results obtained with the DInSAR analysis. The normal baseline is related to the different orbital positions of the satellite during the acquisition of SAR images on the same area over time. Orbits, in fact, can slightly deviate respect to the nominal

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trajectory (in the order of some hundreds of meters) and the same area is looked at with slight different angles.

The temporal baseline, on the other hand, introduces artifacts known as "temporal decorrelation" which become more and more remarkable with the increasing of the time elapsed between the acquisition of two subsequent SAR images. Such degradation of the quality is due to the variation of conditions like changes in vegetation cover, frosts, thaws, building works etc.

The interpretation of interferometric data can be further complicated due to changes of the weather conditions during the two acquisitions. The atmospheric artifacts (also known as "*Atmospheric Phase Screen*") are among the main limitations for these techniques; that is the reason why a large number of interferograms are necessary in order to estimate and remove it.

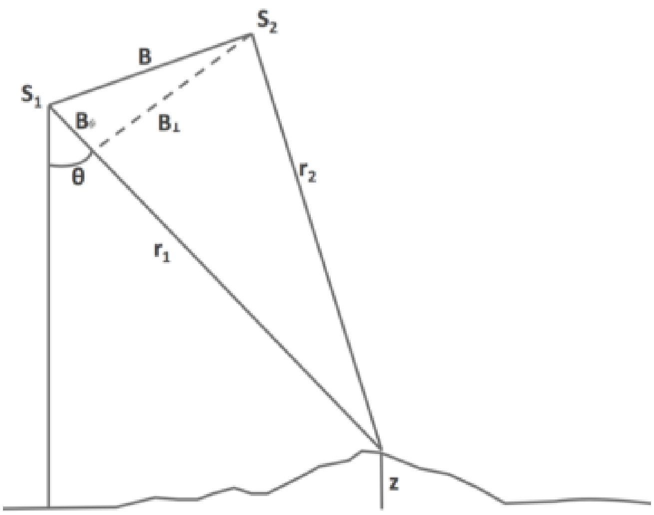


**Figure 5: geometric baseline. Acquisition geometry of two SAR images. S1 and S2 represent the position of the satellites at different times; *θ* is the nadir-off angle; $r_1$ and $r_2$ are the satellite-target distances for two acquisitions; *B* schematically represents the geometric baseline; *z* is the measured topographic height.**

### 2.5. Advanced DInSAR: Persistent Scatterers Interferometry (PSI)

The development of interferometric multi-image techniques (or Advanced DInSAR), represented a significant step forward in the analysis of Earth's surface deformation using satellite SAR images. First of all, the use of datasets made of many SAR images allows the estimation and the removal of the atmospheric contribution. By such

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methodologies, the multi-temporal analysis of deformation processes can be performed, and time series of displacement can be estimated for a very large number of measurement points (MP) on the observed scene.

A-DInSAR techniques are based on the analysis of objects characterized by strong stability over time in terms of reflectivity: the so called "**Persistent Scatterers (PS)**". So, the PS are favored "**measurement points**", having specific properties allowing to perform accurate measurements of displacement (in the order of a few millimeters). Good reflectors are, for example: buildings, transportation routes (roads, railways), pylons, dams, bridges etc. Under specific conditions, also outcropping rocks are good reflectors. This dense *natural* network of "measurement points" allows to detect both local scale deformation processes (e.g. those affecting a single building or structure) and large-scale deformation processes (e.g. landslides, subsidence, faults, etc.).

It is worth noting that the displacement of the measurement points is detected **along the instrumental line of sight (LOS)**. This implies that the measured displacement is the projection of the real displacement vector along the **sensor-target line**. For vertical movements (e.g. subsidence), the actual displacement can be easily retrieved by basic trigonometric functions; if the target is affected also by horizontal displacements, the achieved measurement is the result of the projection of all the components on the LOS. By the use of SAR images collected by different orbital geometries (ascending and descending) it is possible to perform more complex post-processing analysis in order to estimate the horizontal and the vertical components of the actual displacement vector.

In addition, it is worth noting that the displacement measurements are relative with respect to the time and the space. In fact, one of the first steps of A-DInSAR analysis includes the identification of a **master SAR image**: all other images, will be connected to the master one, and therefore defined "**slaves images**". The master image is properly selected in order to minimize the dispersion of temporal and/or normal baseline.

Moreover, the measurements of velocity are also differential: they do not express an absolute value of displacement over time, but a relative displacement with respect to a reference point, i.e. a point within the investigated area that is assumed as stable (not affected by movement).

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Each measurement point is characterized by a **temporal coherence** value, that is a measure of the fitting between the measured data and the deformational model used in the analysis.

If the characteristics of the backscattering targets change over time, the interferometric phase contains a random noise that shall affect the reliability of the results obtained, and the temporal coherence value decreases. Interferometric coherence ranges between 0 (no correlation between corresponding pixels of the two SAR images) to 1 (full correlation).

Thanks to the PSI technique we can retrieve for each measurement point:

- the position (i.e. its geographic coordinates: latitude and longitude);
- the average velocity of displacement (along the line sensor-target, LOS) in mm/year, with an accuracy depending on the number of available images and the sensor used (up to a few millimeters);
- the time series of displacement, starting from the first available image, with an accuracy of few millimeters on the single measure for the most reliable measurement points.

The main advantages introduced by the PSI technique are:

- the measurement points generate a "natural geodetic network": they, in fact, are already on the ground, such as buildings, roads, railways, anthropic elements, outcropping rocks. For each of them (if archive images are available) it is possible to obtain displacement measurements since 1992;
- the aerial extension of SAR images makes it possible to analyze large areas in a short time;
- the measuring accuracy is very high, thus allowing the detection of slow phenomena over large areas otherwise not detectable;
- the achieved results can be easily imported and visualized into geographic information systems (GIS) allowing rapid integration with other available data;
- the dual acquisition geometry (ascending and descending) improves the quality of the information about the analyzed phenomenon: in fact, by decomposing

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the velocity vectors and combining the two geometries, it is possible to retrieve the displacement vector component on the horizontal plane (E-W) and on the vertical axis. The horizontal component along the N-S direction cannot be measured because the orbits of operating satellites follow approximately meridian orbits.

Finally, as regards the PSI technique, it is worth noting also that:

- the presence of good targets is required as well as a suitable density of measurement points. For example, in areas completely vegetated or not visible from the satellite (e.g. shadowing), it is not possible to get information. On the other hand, areas densely urbanized are usually characterized by a very large number of measurement points, allowing to perform accurate analysis;
- the analysis of deformation processes characterized by quick evolution is quite difficult to be performed by PS technique and, in some cases, only qualitative information can be retrieved by a priori assumptions. Also, impulsive phenomena cannot be monitored by this technique, especially when centimeter scale displacements occur in a short time and in extremely localized areas.

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# 3. Performed activities

In what follows, the performed activities are described. Specifically, the following work packages have been developed:

- Acquisition of the dataset (sect. 3.1)
- Processing and analysis of satellite SAR images by A-DInSAR techniques based on the *Persistent Scatterers Interferometry (PSI)* approach for the study area (Sect. 3.2);
- Post-processing and validation (Sect. 3.3);
- Processing and analysis of satellite SAR images by DInSAR technique (Sect. 3.4)
- Presentation and discussion about the achieved results (Sect. 4)

## 3.1. Acquisition of the dataset

A dataset (stack) made of 103 Sentinel-1 SAR scenes in ascending orbital geometry and 46 scenes in descending orbital geometry covering the study area has been acquired by the ESA archives.

In what follows, the acquisition calendar of the analyzed SAR images is reported (Figure 6, Table 1 and Table 2).

The ascending stack covers a period of about 4.5 years, while the descending one covers a period of about 2 years. More in detail, the distribution of the collected images over time is optimal for the ascending stack (2015-to date) and fairly good for the descending one (2016-2018).

The footprints of the analyzed stacks (ascending and descending) are reported in Figure 7. The magenta polygons identify the footprints of the ascending dataset, while the green polygons identify the footprints of the descending one.

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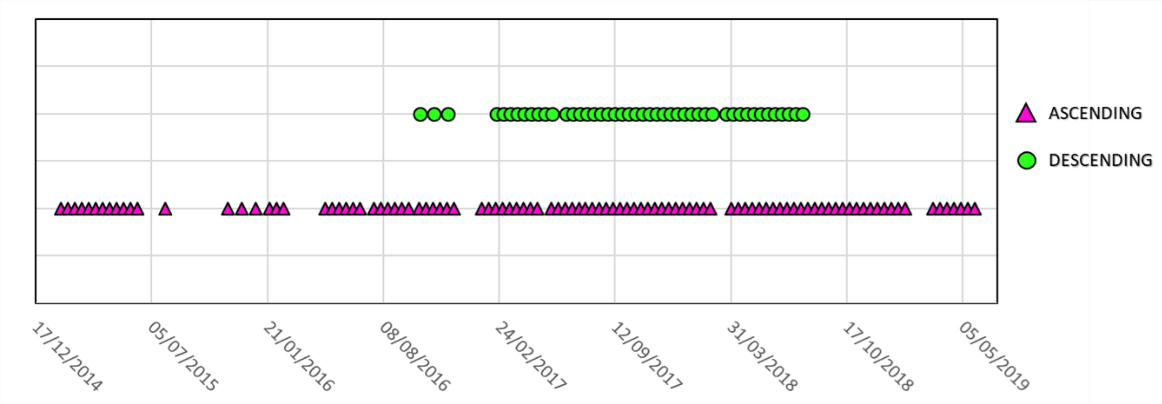


**Figure 6: temporal distribution of the analyzed SAR images.**

| Ascending | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ID | Date | ID | Date | ID | Date | ID | Date | ID | Date |
| 1 | 29/01/2015 | 26 | 22/07/2016 | 51 | 11/07/2017 | 76 | 31/05/2018 | 101 | 02/05/2019 |
| 2 | 10/02/2015 | 27 | 03/08/2016 | 52 | 23/07/2017 | 77 | 12/06/2018 | 102 | 14/05/2019 |
| 3 | 22/02/2015 | 28 | 15/08/2016 | 53 | 04/08/2017 | 78 | 24/06/2018 | 103 | 26/05/2019 |
| 4 | 06/03/2015 | 29 | 27/08/2016 | 54 | 16/08/2017 | 79 | 06/07/2018 | | |
| 5 | 18/03/2015 | 30 | 08/09/2016 | 55 | 28/08/2017 | 80 | 18/07/2018 | | |
| 6 | 30/03/2015 | 31 | 20/09/2016 | 56 | 09/09/2017 | 81 | 30/07/2018 | | |
| 7 | 11/04/2015 | 32 | 08/10/2016 | 57 | 21/09/2017 | 82 | 11/08/2018 | | |
| 8 | 23/04/2015 | 33 | 20/10/2016 | 58 | 03/10/2017 | 83 | 23/08/2018 | | |
| 9 | 05/05/2015 | 34 | 01/11/2016 | 59 | 15/10/2017 | 84 | 04/09/2018 | | |
| 10 | 17/05/2015 | 35 | 13/11/2016 | 60 | 27/10/2017 | 85 | 16/09/2018 | | |
| 11 | 29/05/2015 | 36 | 25/11/2016 | 61 | 08/11/2017 | 86 | 28/09/2018 | | |
| 12 | 10/06/2015 | 37 | 07/12/2016 | 62 | 20/11/2017 | 87 | 10/10/2018 | | |
| 13 | 28/07/2015 | 38 | 24/01/2017 | 63 | 02/12/2017 | 88 | 22/10/2018 | | |
| 14 | 13/11/2015 | 39 | 05/02/2017 | 64 | 14/12/2017 | 89 | 03/11/2018 | | |
| 15 | 07/12/2015 | 40 | 17/02/2017 | 65 | 26/12/2017 | 90 | 15/11/2018 | | |
| 16 | 31/12/2015 | 41 | 01/03/2017 | 66 | 07/01/2018 | 91 | 27/11/2018 | | |
| 17 | 24/01/2016 | 42 | 13/03/2017 | 67 | 19/01/2018 | 92 | 09/12/2018 | | |
| 18 | 05/02/2016 | 43 | 25/03/2017 | 68 | 31/01/2018 | 93 | 21/12/2018 | | |
| 19 | 17/02/2016 | 44 | 06/04/2017 | 69 | 12/02/2018 | 94 | 02/01/2019 | | |
| 20 | 29/04/2016 | 45 | 18/04/2017 | 70 | 24/02/2018 | 95 | 14/01/2019 | | |
| 21 | 11/05/2016 | 46 | 30/04/2017 | 71 | 01/04/2018 | 96 | 26/01/2019 | | |
| 22 | 23/05/2016 | 47 | 24/05/2017 | 72 | 13/04/2018 | 97 | 15/03/2019 | | |
| 23 | 04/06/2016 | 48 | 05/06/2017 | 73 | 25/04/2018 | 98 | 27/03/2019 | | |
| 24 | 16/06/2016 | 49 | 17/06/2017 | 74 | 07/05/2018 | 99 | 08/04/2019 | | |
| 25 | 28/06/2016 | 50 | 29/06/2017 | 75 | 19/05/2018 | 100 | 20/04/2019 | | |

**Table 1: acquisition dates (dd/mm/yyyy) of the analyzed SAR images for ascending stack.**

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| Descending | | | |
|---|---|---|---|
| ID | Date | ID | Date |
| 1 | 10/10/2016 | 24 | 29/10/2017 |
| 2 | 03/11/2016 | 25 | 10/11/2017 |
| 3 | 27/11/2016 | 26 | 22/11/2017 |
| 4 | 19/02/2017 | 27 | 04/12/2017 |
| 5 | 03/03/2017 | 28 | 16/12/2017 |
| 6 | 15/03/2017 | 29 | 28/12/2017 |
| 7 | 27/03/2017 | 30 | 09/01/2018 |
| 8 | 08/04/2017 | 31 | 21/01/2018 |
| 9 | 20/04/2017 | 32 | 02/02/2018 |
| 10 | 02/05/2017 | 33 | 14/02/2018 |
| 11 | 14/05/2017 | 34 | 26/02/2018 |
| 12 | 26/05/2017 | 35 | 22/03/2018 |
| 13 | 19/06/2017 | 36 | 03/04/2018 |
| 14 | 01/07/2017 | 37 | 15/04/2018 |
| 15 | 13/07/2017 | 38 | 27/04/2018 |
| 16 | 25/07/2017 | 39 | 09/05/2018 |
| 17 | 06/08/2017 | 40 | 21/05/2018 |
| 18 | 18/08/2017 | 41 | 02/06/2018 |
| 19 | 30/08/2017 | 42 | 14/06/2018 |
| 20 | 11/09/2017 | 43 | 26/06/2018 |
| 21 | 23/09/2017 | 44 | 08/07/2018 |
| 22 | 05/10/2017 | 45 | 20/07/2018 |
| 23 | 17/10/2017 | 46 | 01/08/2018 |

**Table 2: acquisition dates (dd/mm/yyyy) of the analyzed SAR images for descending stack.**

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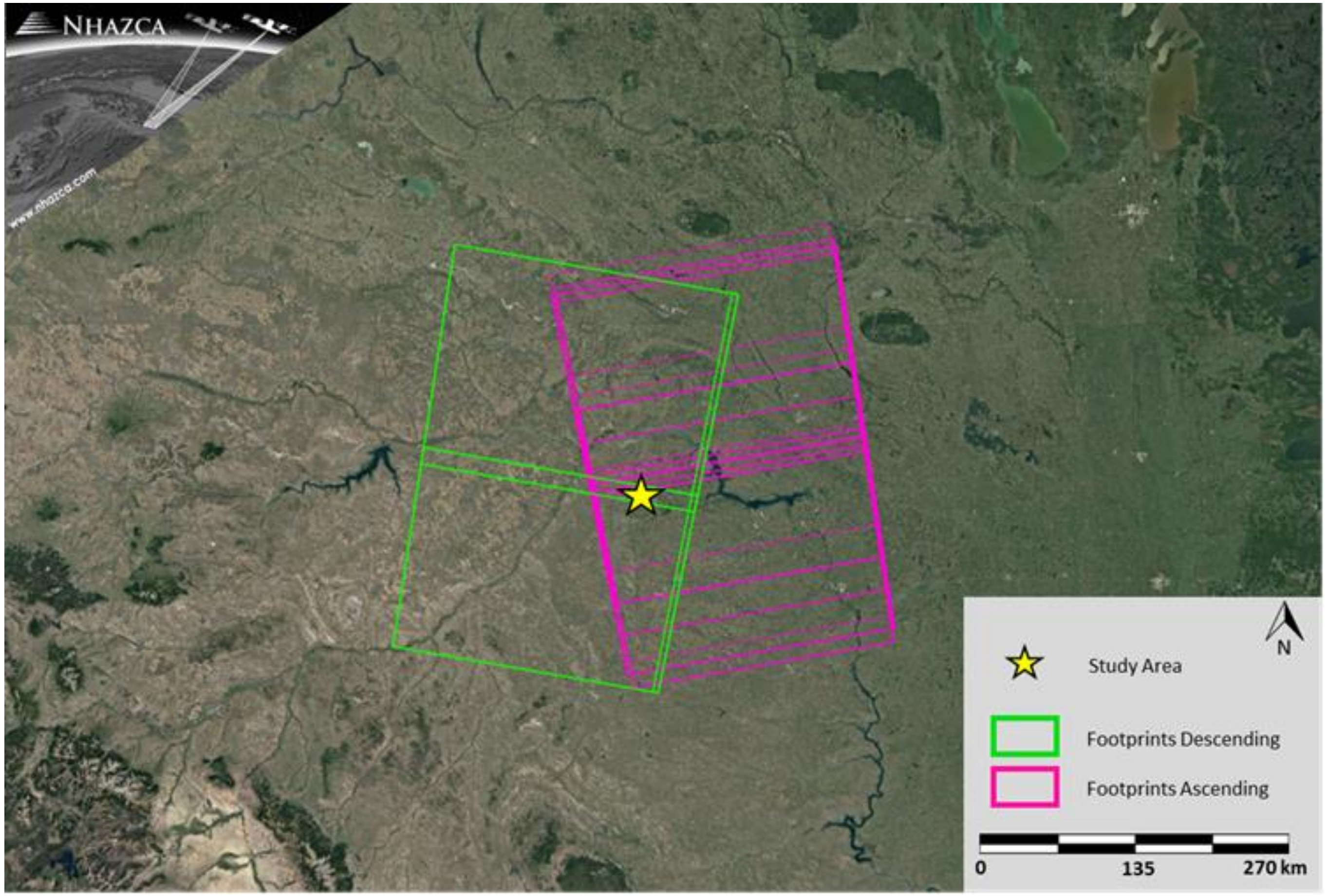


**Figure 7: identification of the study area (yellow star) on satellite optical image and footprint of the analyzed ascending (magenta) and descending dataset (green).**

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### 3.2. Processing and analysis of SAR images by A-DInSAR techniques

The *Persistent Scatterers Interferometry (PSI)* approach has been adopted for the A-DInSAR analysis on the whole study area, by commercial software and proprietary algorithms from NHAZCA S.r.l. For the basic geographic information and geocoding of results, a *Digital Elevation Model* (DEM) with 30 m cell resolution has been adopted (data by *SRTM, Shuttle Radar Topography Mission*).

Moreover, the master images have been selected thus optimizing the temporal and the normal baselines: all other SAR images have been referred to the masters for the phase difference computations.

The selection of the PS *Candidates* (PSC), i.e. points characterized by good radar quality parameters making them suitable for displacement analysis, has been performed based on the analysis of the following maps:

i) **Reflectivity Map** (amplitude mean values of radar images. It represents the mean reflectivity of pixels over time).

ii) **Amplitude Stability Index Map** (stability of reflectivity over time).

iii) **Spatial Coherence Map** (mean coherence of the generated interferograms).

Once selected the measurement points, it has been possible to estimate the phase component due to the atmospheric noise (Atmospheric Phase Screen, APS) for each image of both datasets and to remove its contribution from the interferometric phase in order to estimate high precision displacement trends for all the selected points.

The results of the analysis are reported through maps on orthophotographic basemaps that show the velocity (mm/year) of the measurement points (MP). A color scale has been adopted to represent the direction of the movement along the LOS: colors from yellow to red for MPs moving away from the sensor and colors from cyan to blue for MPs approaching the sensor; the green color indicates MPs with displacement rates in the range of the instrumental accuracy (estimated to be approximately ±2.5 mm/year).

### 3.3. Post-processing and validation

Starting from the results achieved by the above described A-DInSAR analysis, a post-processing and validation process has been performed. Specifically, semi-automatic validation routines based on statistical algorithms and proprietary software tools have

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been applied, allowing for a point-to-point multi-parameter control of all the available measurement points aiming at analyzing the spatial and temporal deformational behaviors and to identify and remove unreliable outliers. The analysis was performed based on some relevant parameters such as the Temporal Coherence, the Amplitude Stability Index, the estimated velocity, the deformational trends and the estimated residual heights.

The validation procedures allowed to get about 4.300 reliable measurement points in the whole study area.

The post-processing activity, performed by qualified staff through the guided application of proprietary algorithms, allowed moreover to provide ***outputs tuned for the specific site*** and to extract the most useful information in terms of displacements, involved areas and local anomalies for the effective comprehension and characterization of the detected phenomena.

### 3.4. Processing and analysis of satellite SAR images by DInSAR technique

In order to identify deformation phenomena with markedly impulsive and/or intermittent behavior (possibly related to the occurrence of precipitation), a specific analysis has been performed by standard DInSAR technique (Differential SAR Interferometry).

DInSAR technique is based on the analysis of the phase variations (between -π e + π) between couples of SAR images collected at different times (namely “interferograms”), thus allowing the identification of local phase anomalies, potentially related to deformation processes.

Redundant interferograms between couples of images spanning for entire monitoring period have been analyzed both in ascending and descending geometry.

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# 4. ACHIEVED RESULTS

Following the processing steps above described, the results of the performed A-DInSAR analysis have been achieved. Specifically, the velocity maps of measurement points (MP) along the instrumental LOS have been generated for each stack (i.e. ascending and descending orbital geometry) and for the about 5 $km^2$ wide study area. The results (Figure 8, Figure 9 and Figure 10) are reported for an area larger than the AOI scheduled by the contract, for an exhaustive characterization of the site.

About **2600 MP** have been achieved, in the full study area, **for the ascending stack** and about **1700 for the descending stack**.

In what follows are reported:

i) The map of all MP for the ascending and the descending stack (Figure 8, Figure 9 and Figure 10), some 3D views of the results from different points of view are also reported for a more exhaustive visualization (Figure 11 and Figure 12);

ii) Combination of results from ascending and descending stacks – assessment of the direction of displacements (Figure 13 and Figure 14). Specifically, by the application of proprietary algorithms, it was possible to estimate the velocity along the vertical and horizontal directions in different sectors of the landslide;

iii) The map of MP – Ascending stack (Figure 15) in which are highlighted the MP whose times series of displacement are reported in Figure 16, Figure 17 and Figure 18.

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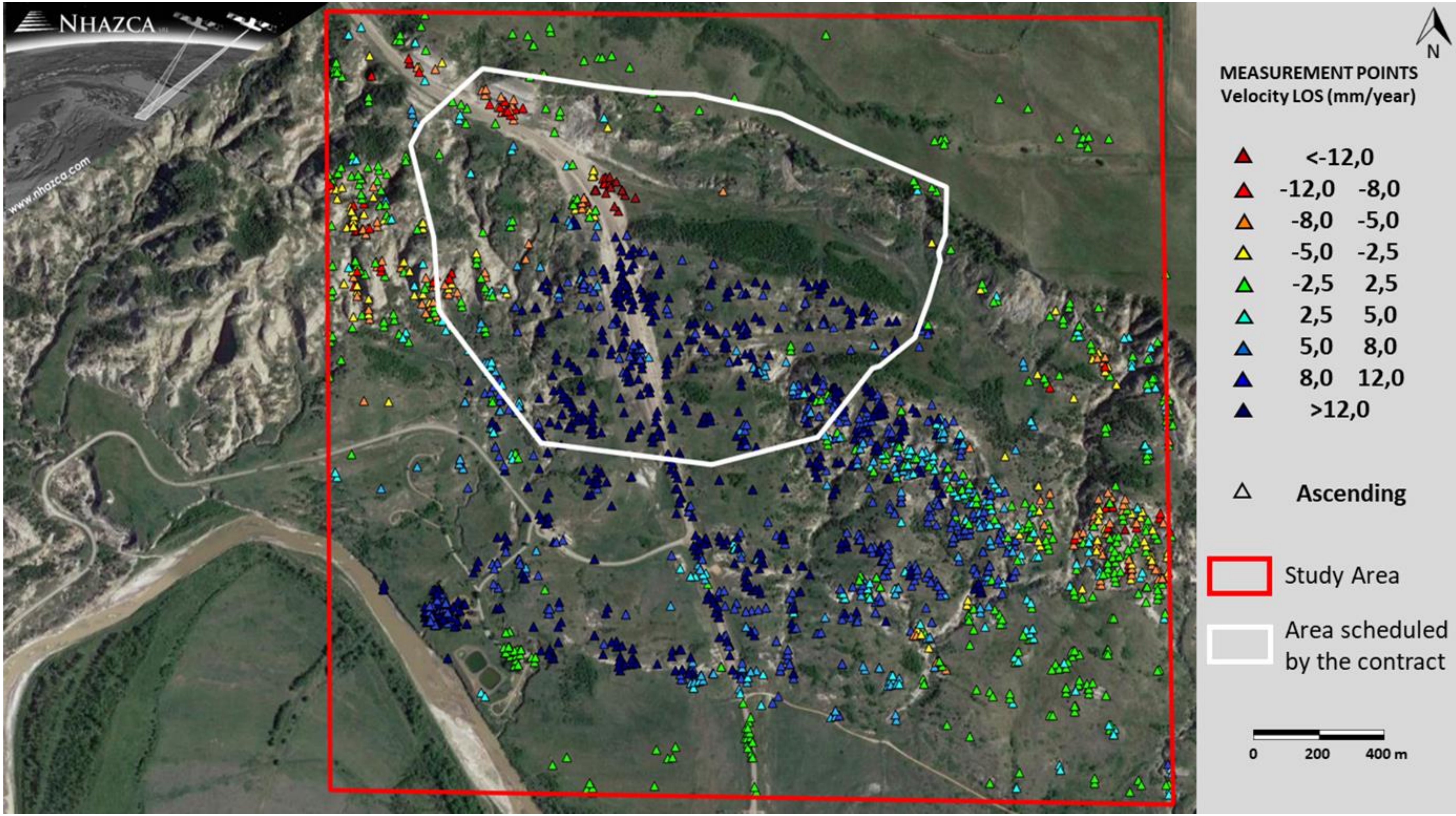


**Figure 8: velocity of MP resulting from A-DInSAR analysis in the study area (29th January 2015 – 26th May 2019) – Ascending stack. The study area is identified in red.**

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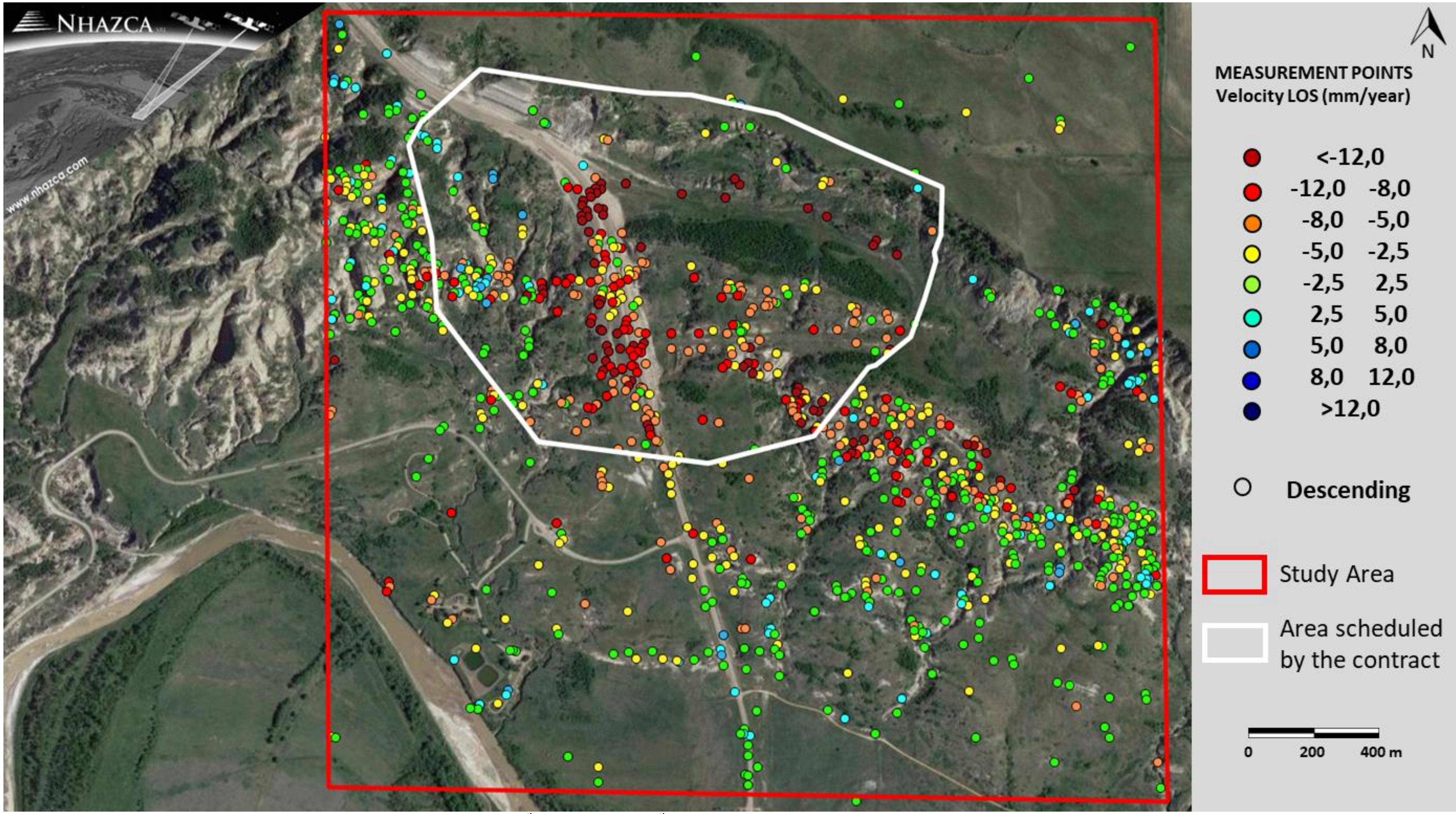


**Figure 9: velocity of MP resulting from A-DInSAR analysis in the study area (10th October 2016 – 01th August 2018) – Descending stack. The study area is identified in red.**

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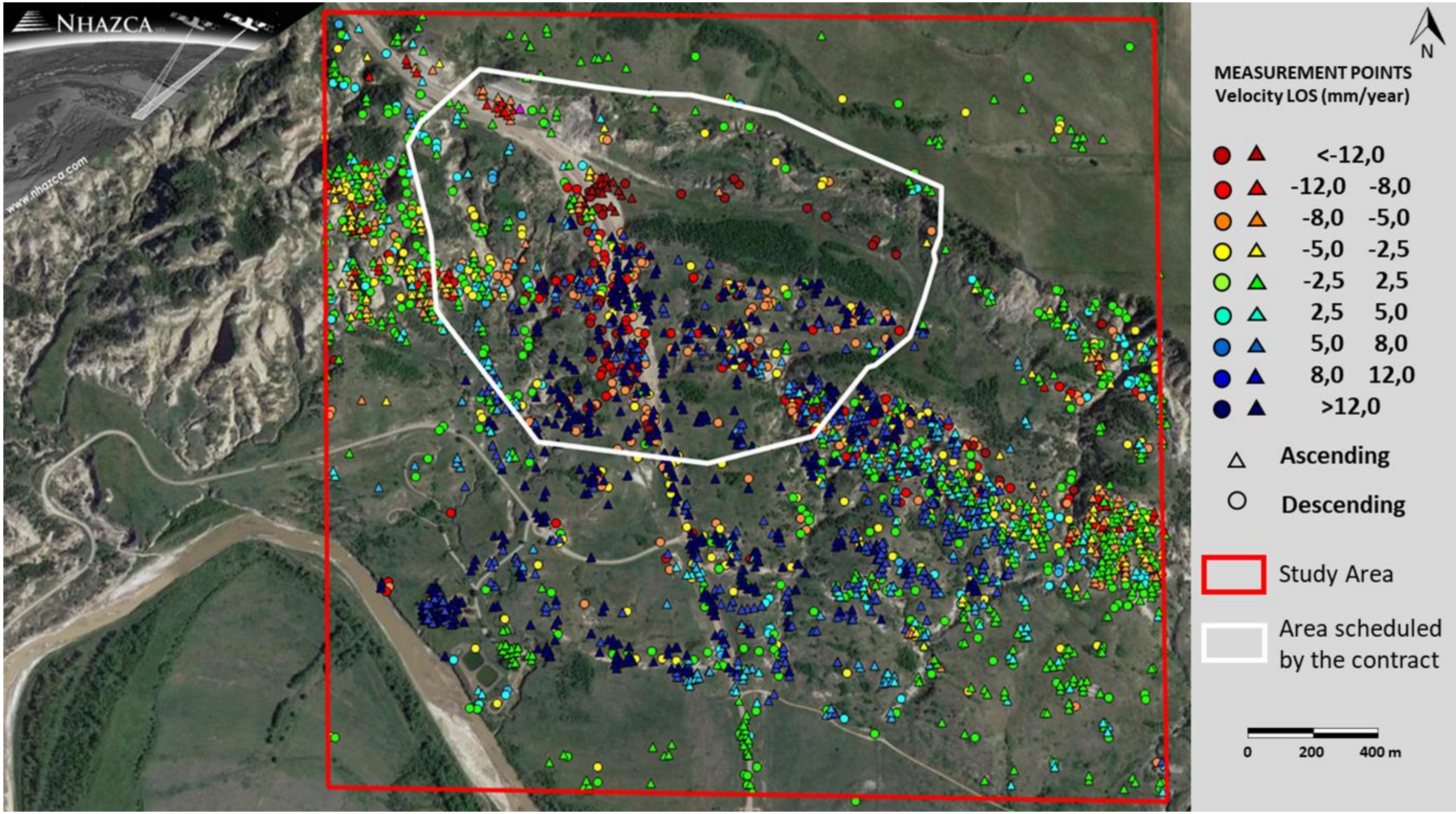


**Figure 10: velocity of MP resulting from A-DInSAR analysis in the study area – Asending and Descending stack. The study area is identified in red.**

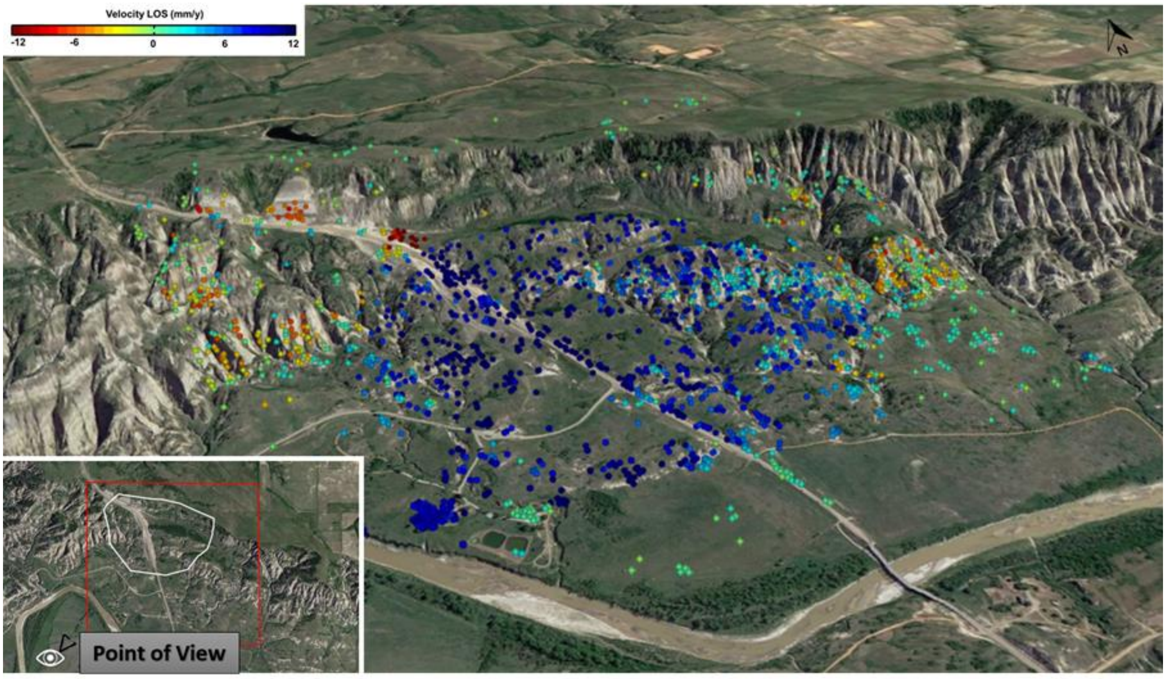


**Figure 11: 3D view of the MP in the study area achieved by the ascending stack, front view.**

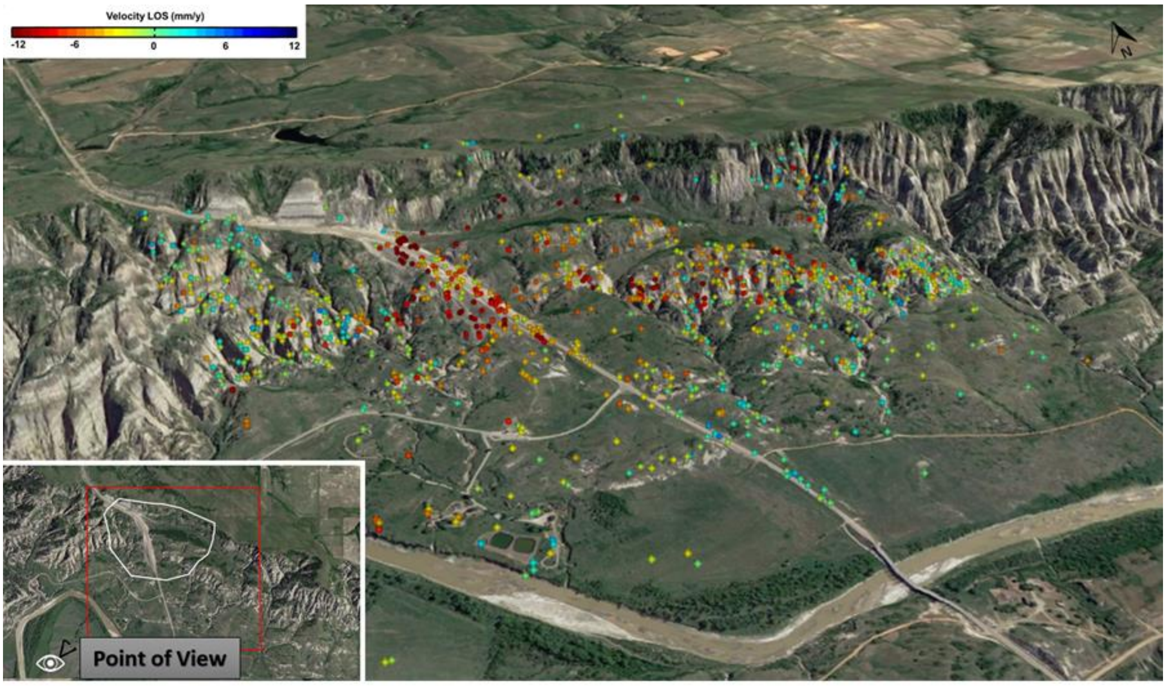


**Figure 12: 3D view of the MP in the study area achieved by the descending stack, front view.**

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By the analysis of the MPs velocity maps (both in ascending and descending orbital geometry), remarkable displacements are detected in some sectors of the study area. In particular, it is highlighted a widespread sector (about 2.4 $km^2$ wide) in the central portion of the study area, with velocity rates along the LOS up to about 25 mm/y.

As it can be noticed by the above images, most of reliable MP are located in areas with sparse or no vegetation (mainly outcropping rocks, debris and clayey sectors), where the reflectivity and coherence values are higher. Some groups or isolated MPs, characterized by velocity rates up to about 13 mm/y, have been also identified in other sectors of the study area, due to the heterogeneous nature of the backscattering material.

Lastly, some sparse isolated MPs with velocities exceeding the instrumental error (about ± 2.5 mm/year) have been achieved in other areas of the study area.

By exploiting the availability of the dual orbital geometry, NHAZCA S.r.l. applied proprietary algorithms allowing for the estimation of the actual direction of movements in different sectors of the landslide. Specifically, the area was discretized in hexagonal cells on a regular grid; the results showed in Figure 13 and Figure 14 (respectively, vertical and horizontal velocity rates) are achieved for the only cells containing at least one MP from the ascending stack and one MP from the descending one. As it can be noticed, in the central sector of the study area (corresponding to a widespread portion of the main body of the landslide), horizontal displacements (toward west) are dominant. The upper sector of the landslide, due to lack of an adequate number of MP, shows only clues of deformation in vertical direction. It is worth noting that the horizontal component along the N-S direction cannot be measured because the satellites orbits are approximately meridian.

The MP whose time series of displacement are reported in Figure 16 and Figure 17, whose location is highlighted in Figure 15.

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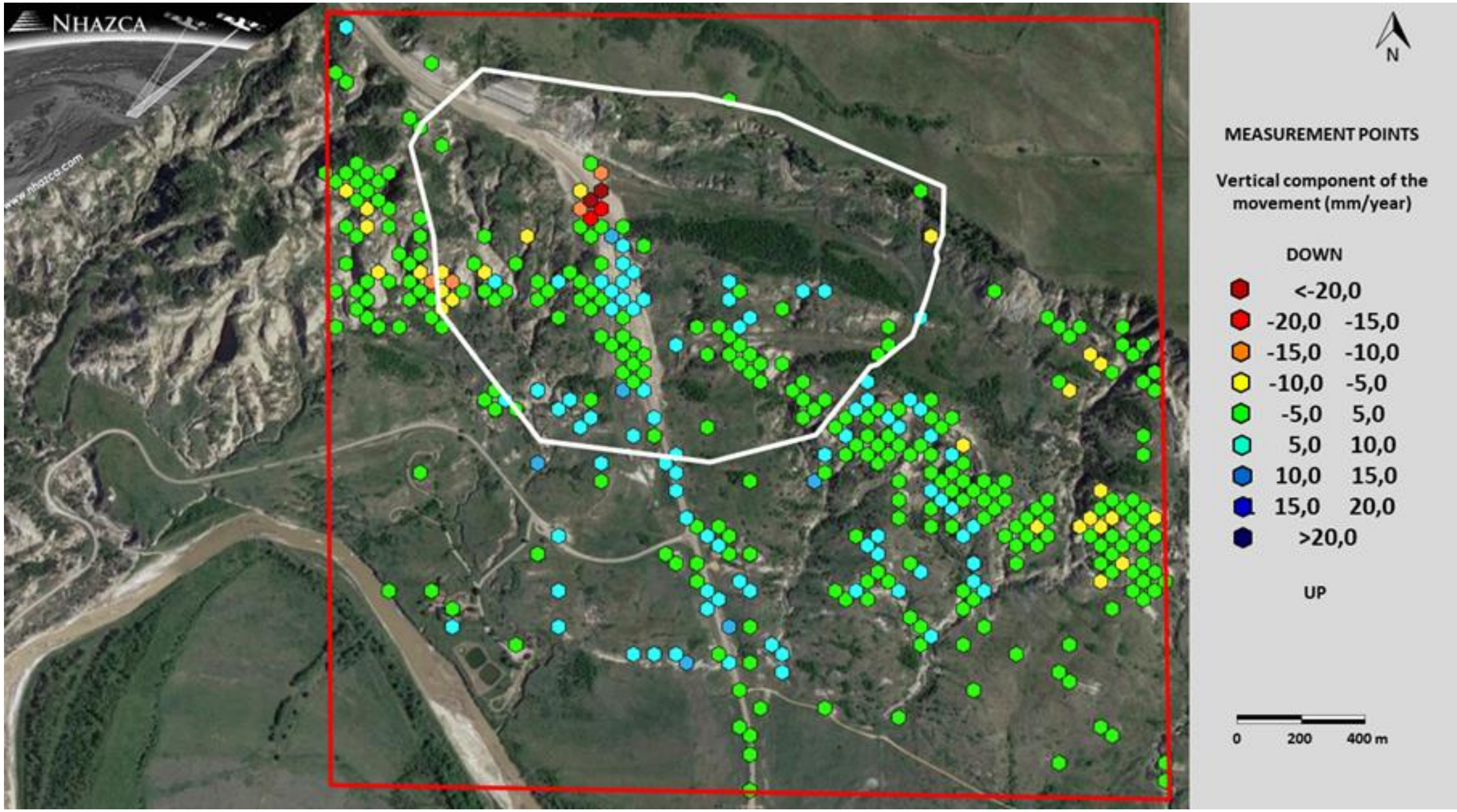


**Figure 13: velocity in the vertical direction. Positive values = up; negative values = down.**

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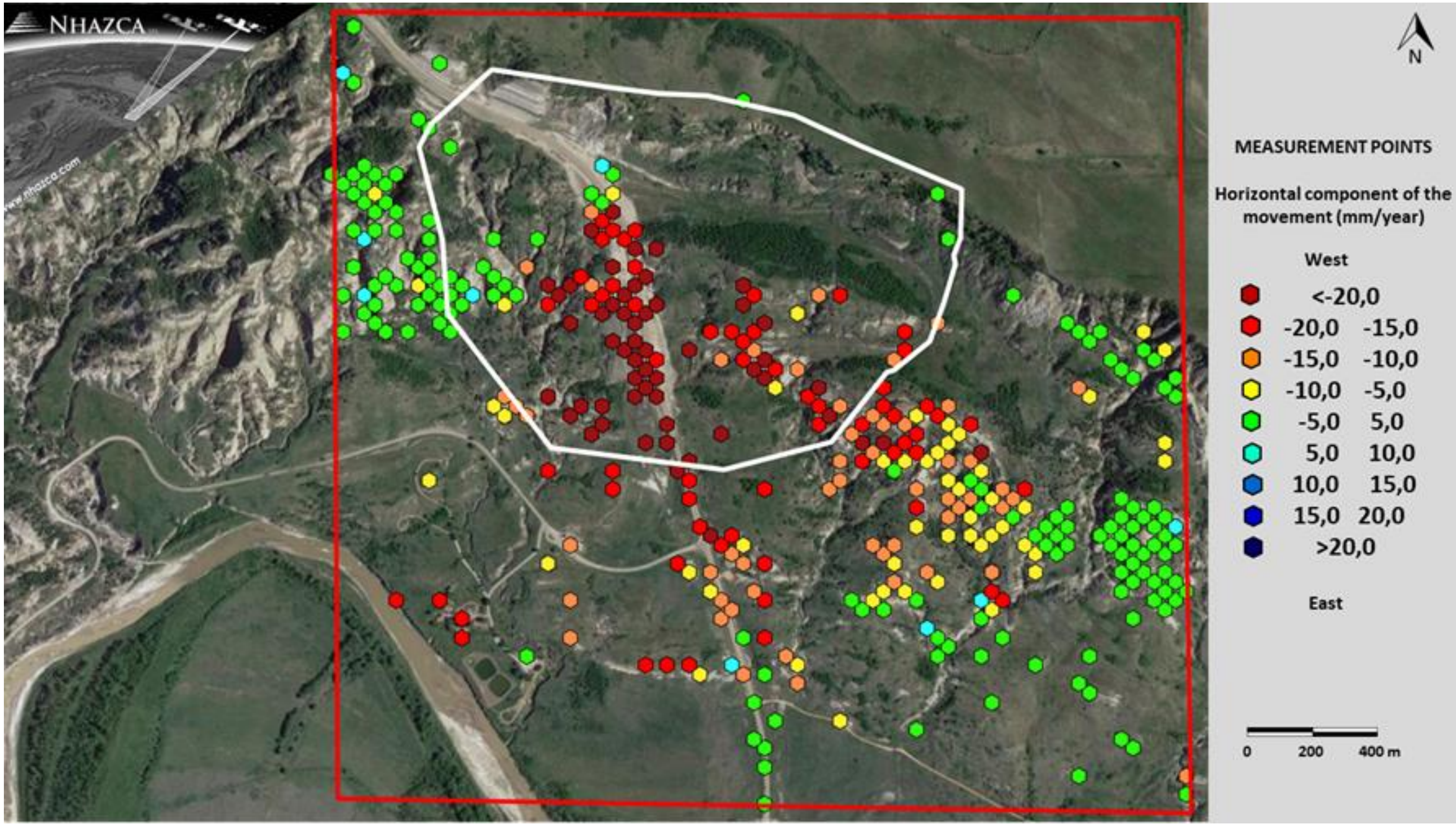


**Figure 14: velocity in the horizontal direction. Positive values = East; negative values = West.**

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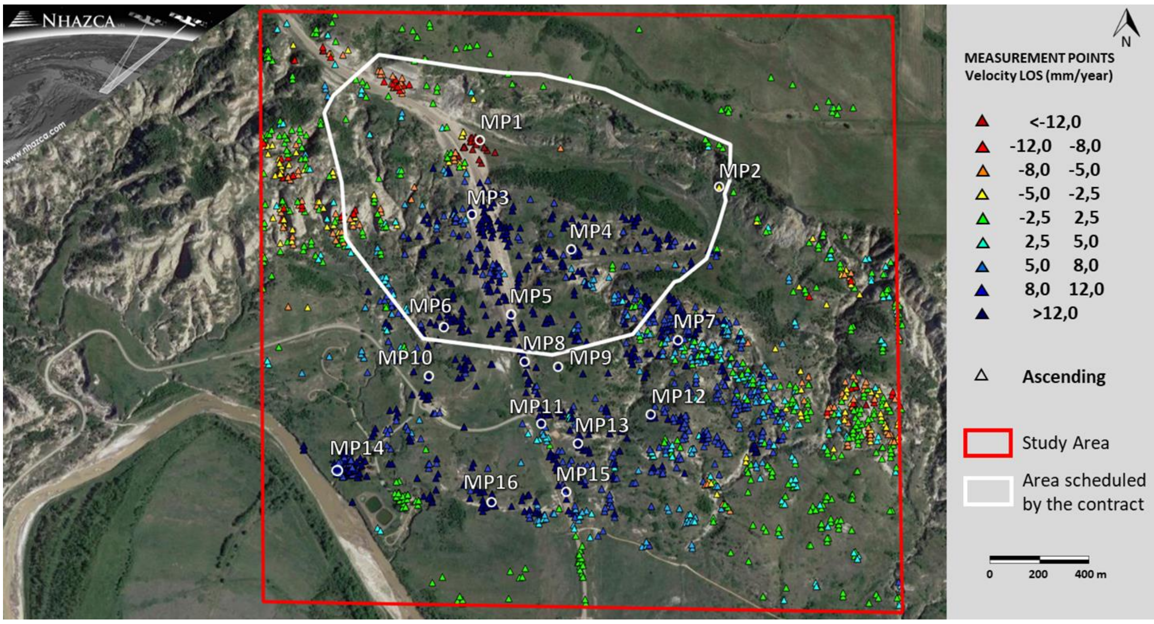


**Figure 15: velocity of MP resulting from A-DInSAR analysis in the study area (29th January 2015 – 26th May 2019) – Ascending stack. In white are highlighted the MP whose times series of displacement are reported in Figure 16 and Figure 17.**

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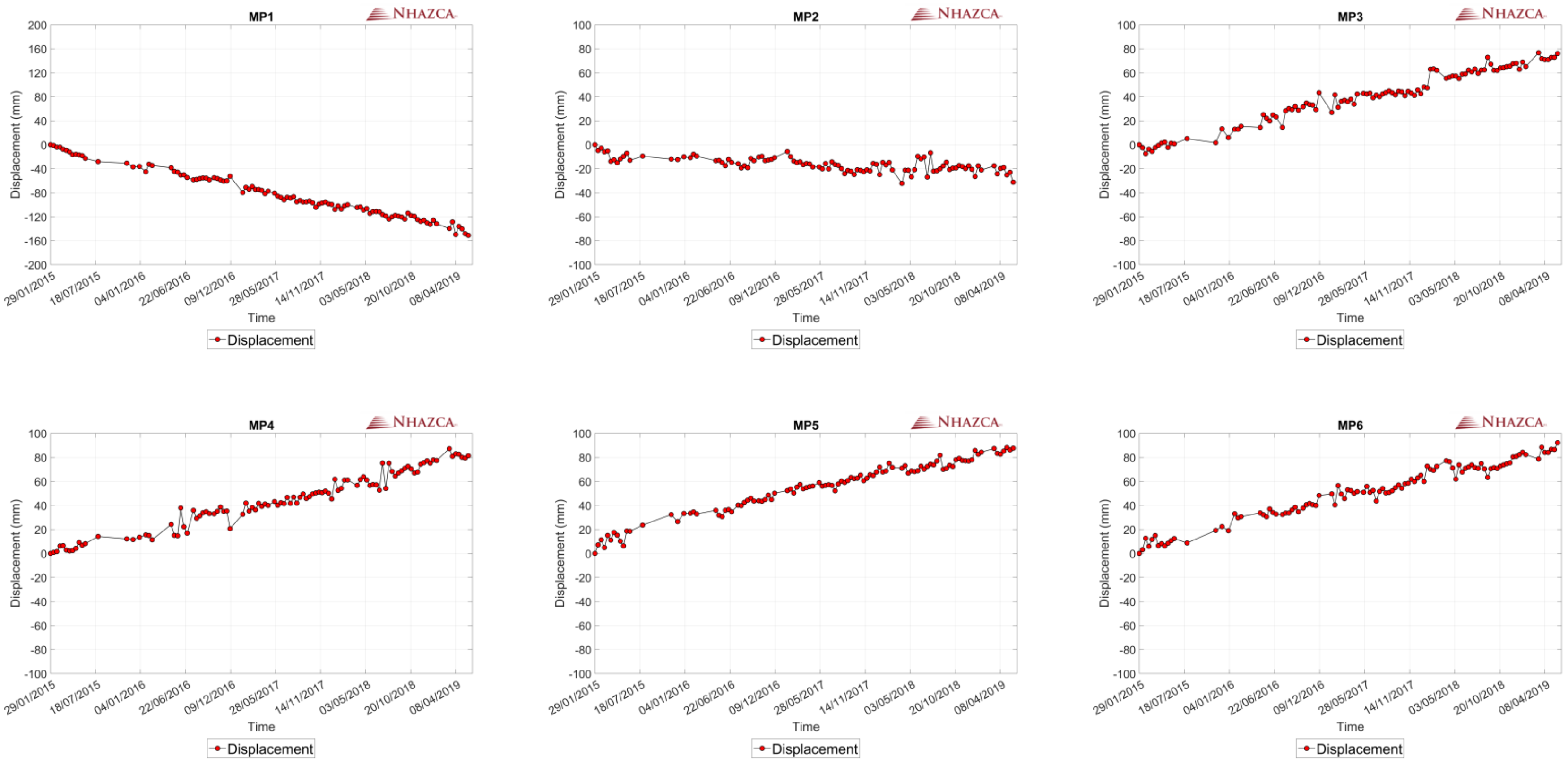


**Figure 16: time series of displacement of some key MP. The location of the plotted MP is reported in Figure 15.**

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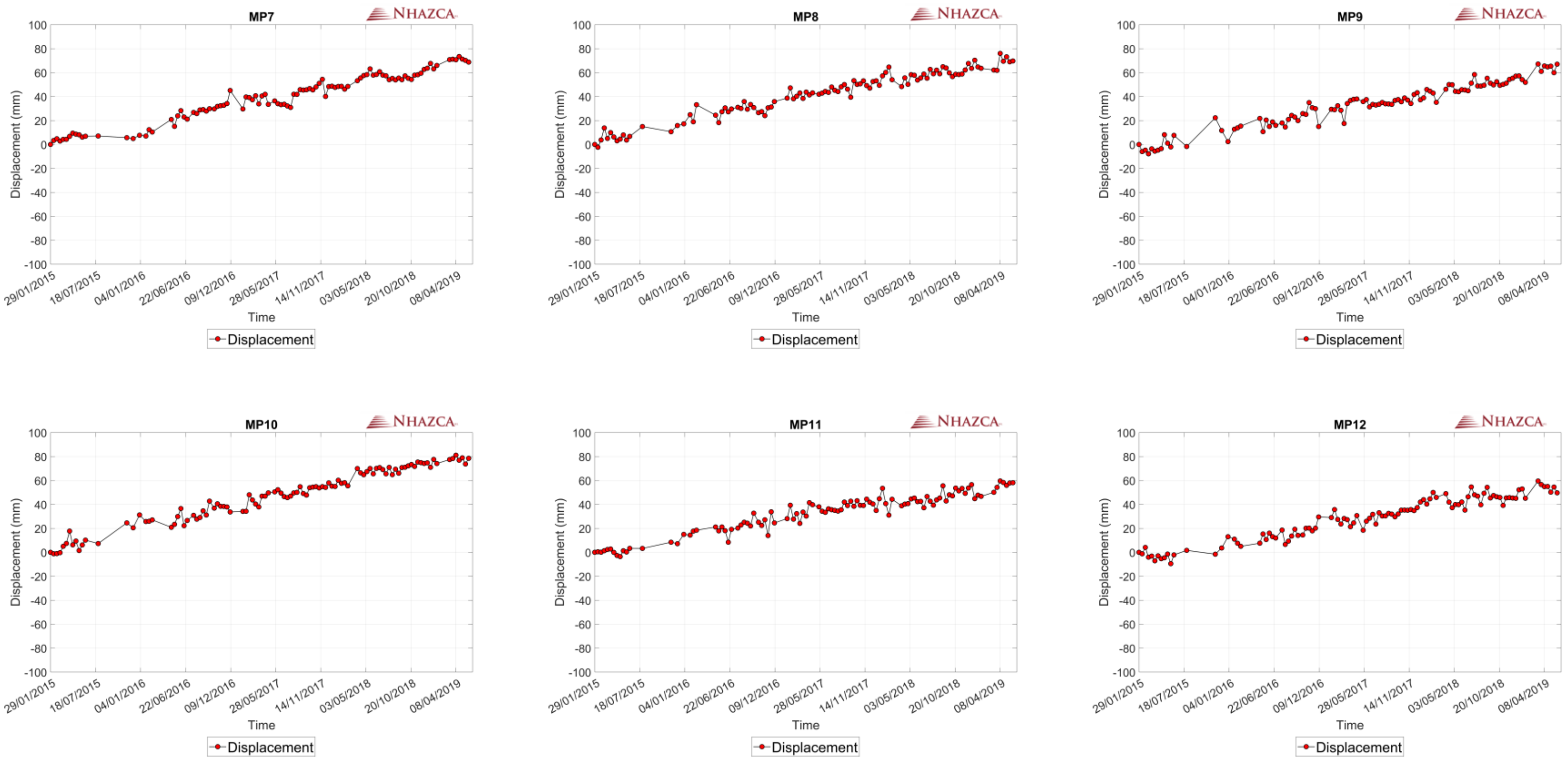


**Figure 17: time series of displacement of some key MP. The location of the plotted MP is reported in Figure 15.**

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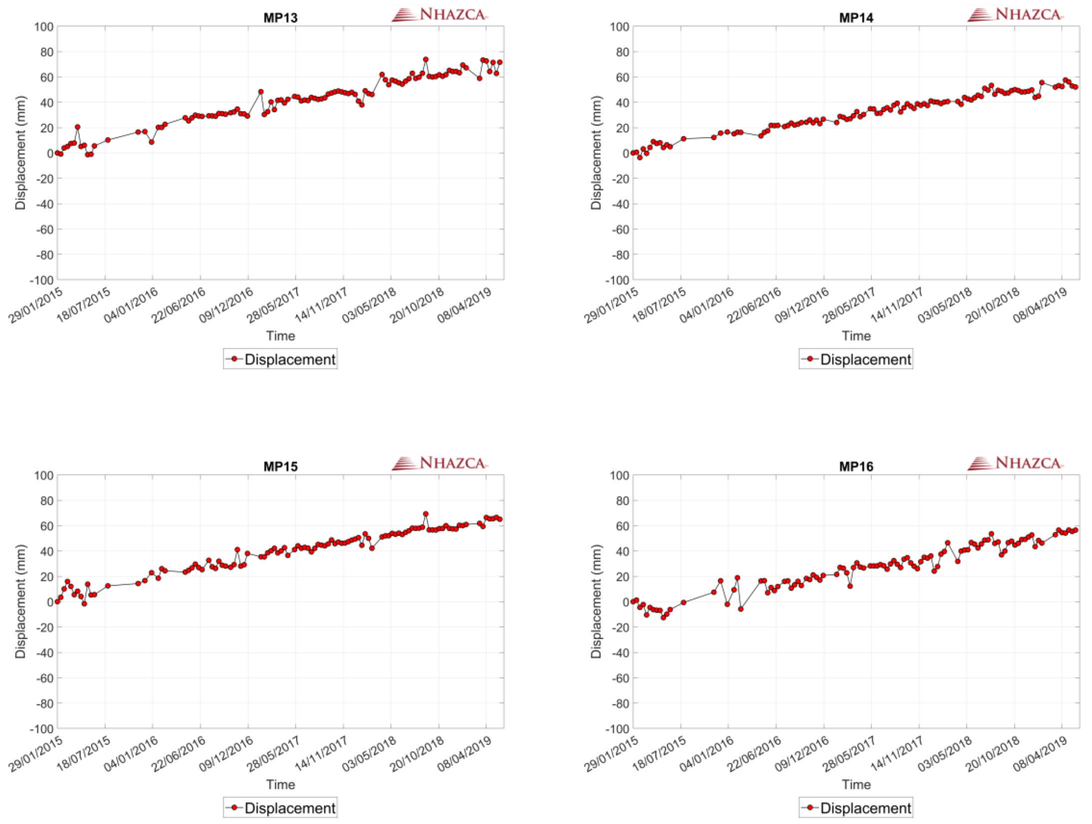


**Figure 18: time series of displacement of some key MP. The location of the plotted MP is reported in Figure 15.**

As regards the DInSAR analysis, relevant interferometric anomalies that justify slope instability processes have been identified by the ascending stacks.

By the analysis of the interferometric anomalies (both in ascending and in descending orbital geometry), it is possible to preliminary identify the most active sector in the study area (an example is reported in Figure 19), whose extension allows to clearly identify the landslide body.

No other relevant interferometric anomalies have been detected in the other sectors of the study area.

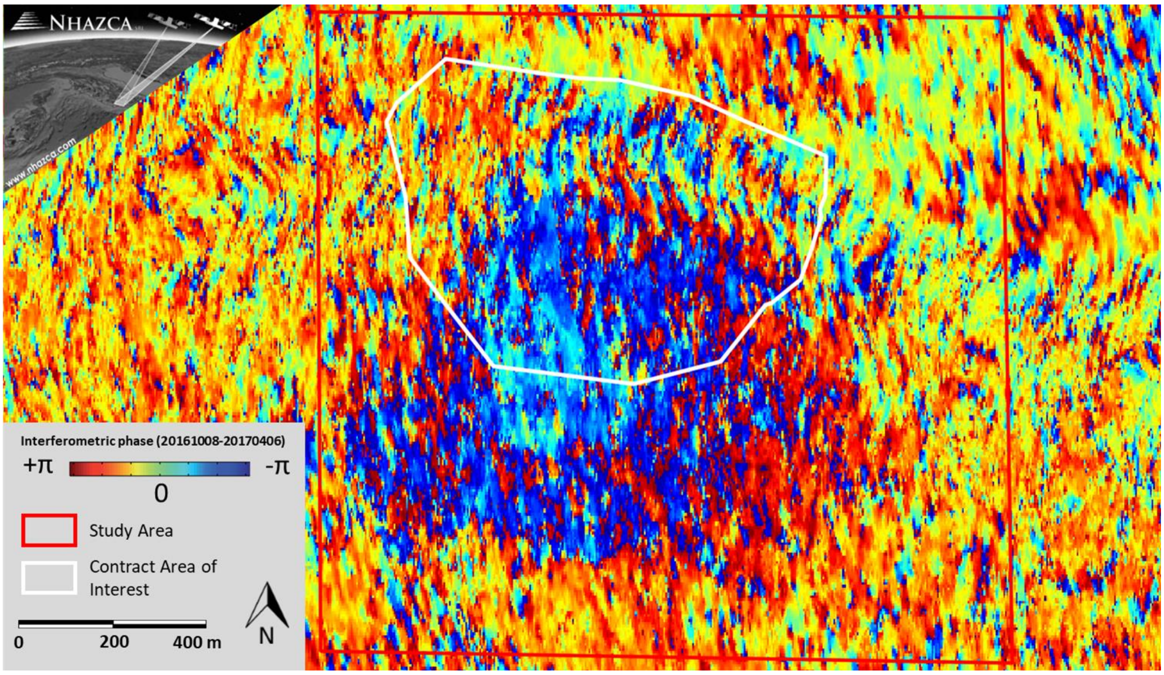


**Figure 19: interferogram generated by the couple of images (in ascending orbital geometry) collected on 08th October 2016 and 06th April 2017.**

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# 5. FINAL REMARKS AND OUTLOOKS

The A-DInSAR analysis performed in the frame of the present work and, especially, the results achieved by the post-processing analyses, allowed the adequate characterization of the Horseshoe Bend study area (that is about 5 km$^2$ wide) and the identification of the main areas of attention for potential interferences with the CanAm Highway. Specifically, the most relevant information have been achieved by the ascending stack, considered more suitable based on the amount and temporal distribution of the available images.

Thanks to the high density and accuracy of information (about 4000 MP with accuracy values up to 2.5 mm/y) the achieved results are considered reliable and useful to support the site-characterization in terms of ground deformation, allowing to reach the following targets:

i) the identification and mapping of the sectors of the area affected by displacement in the investigated period;

ii) the identification of the key-sectors of the area to be monitored, also by the installation of on-site monitoring systems;

iii) providing useful information to evaluate the design of future monitoring activities integrating satellite InSAR with on-site systems;

The most active area has been identified in the central sector of the area, corresponding to a landslide with velocity rates up to about 25 mm/y approaching the sensor along the instrumental LOS, in the ascending stack (Figure 8 and Figure 10), also shown by the time series of displacement of MPs (Figure 16, Figure 17 and Figure 18). Such process has a direct interference with the CanHam Highway and other structures in the area.

By exploiting the availability of the dual orbital geometry, horizontal (E-W) and vertical displacement rates have been derived, showing horizontal displacements (toward west) dominant with respect to vertical one, in the central sector of the study area (Figure 13 and Figure 14).

The main body of the landslide is characterized by an almost constant and spatially homogeneous displacement trends, without showing evident phases of acceleration/deceleration, in the horizontal direction.

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As regards the upper sector of the landslide, due to lack of an adequate number of MP, only clues of deformation are detected, showing deformation mainly in the vertical direction (e.g. time series of MP 1 and Figure 13).
<u>On-site additional investigations are suggested for the characterization of the processes.</u>

Some groups or isolated MPs, characterized by velocity rates up to about 13 mm/y, have been also identified in other sectors of the study area, with no direct interference with the CanAm Highway, due to the heterogeneous nature of the backscattering material.
Finally, standard DInSAR techniques have been applied. Also in this case, information about ground deformation have been achieved in the central sector of the area (Figure 19), affected by a landslide.

Combining the results achieved by A-DInSAR and standard DInSAR analyses, a hypothesis of landslide perimeter is achievable, whose boundaries are based on interferometric results supported by preliminary geomorphologic interpretation (Figure 20).

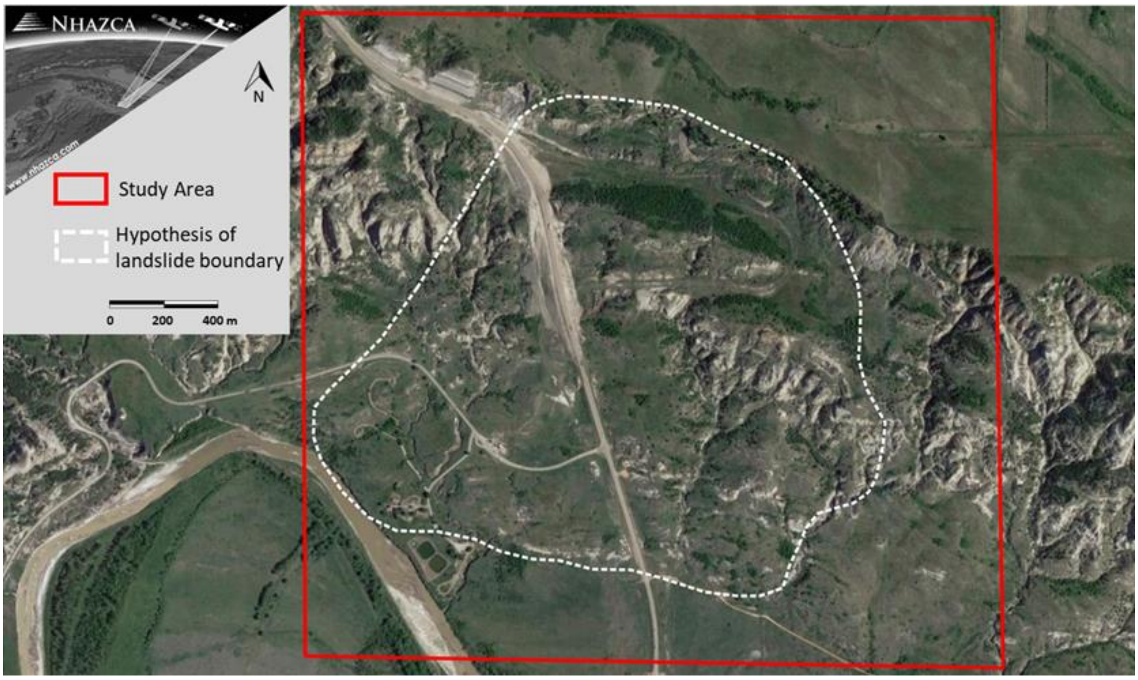


**Figure 20: hypothesis of landslide boundary based on interferometric results supported by preliminary geomorphologic interpretation.**

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In order to improve the A-DInSAR results during a potential monitoring stage, the sectors of the slope not covered by MP could be analyzed through the installation of artificial corner reflectors (Figure 21). The design and installation of a network of such artificial targets will allow to increase spatial coverage of MP, in order to get displacements information, starting from the installation date, with very high accuracy and to characterize a larger portion of the slope.

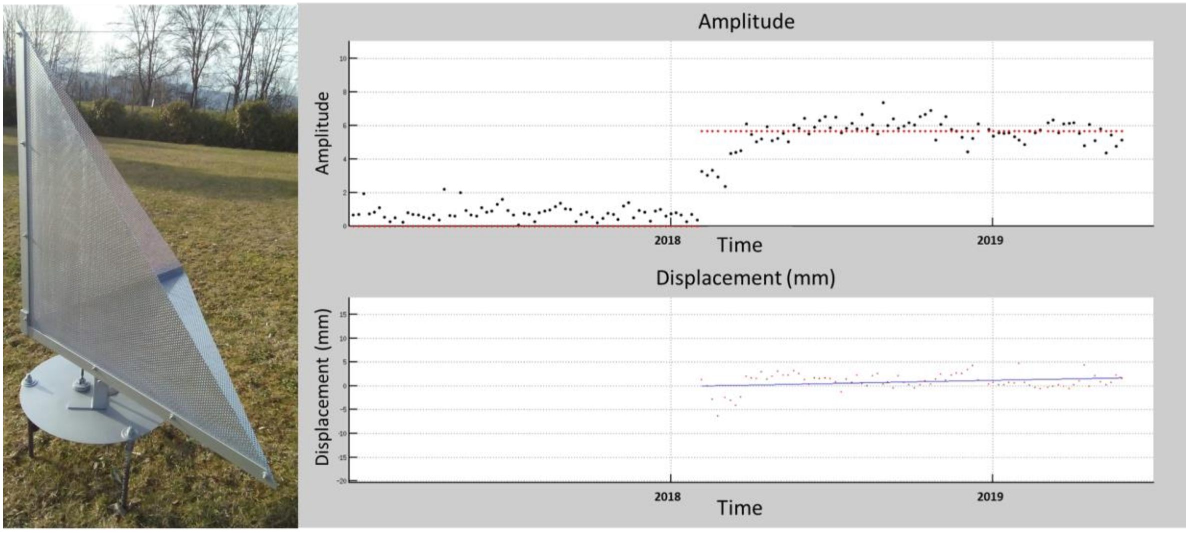


**Figure 21: example of a corner reflector designed and assembled by NHAZCA S.r.l. in a vegetated area with no suitable radar targets. The example on the right show the "birth" of a new measurement point starting from the installation of a corner reflector, allowing to detect displacements in a sector previously lacking MP.**

In this regard, we propose a preliminary selection of possible locations for corner reflectors, which would allow a more comprehensive investigation of the phenomenon, adding measurement points in areas currently lacking (Figure 22).

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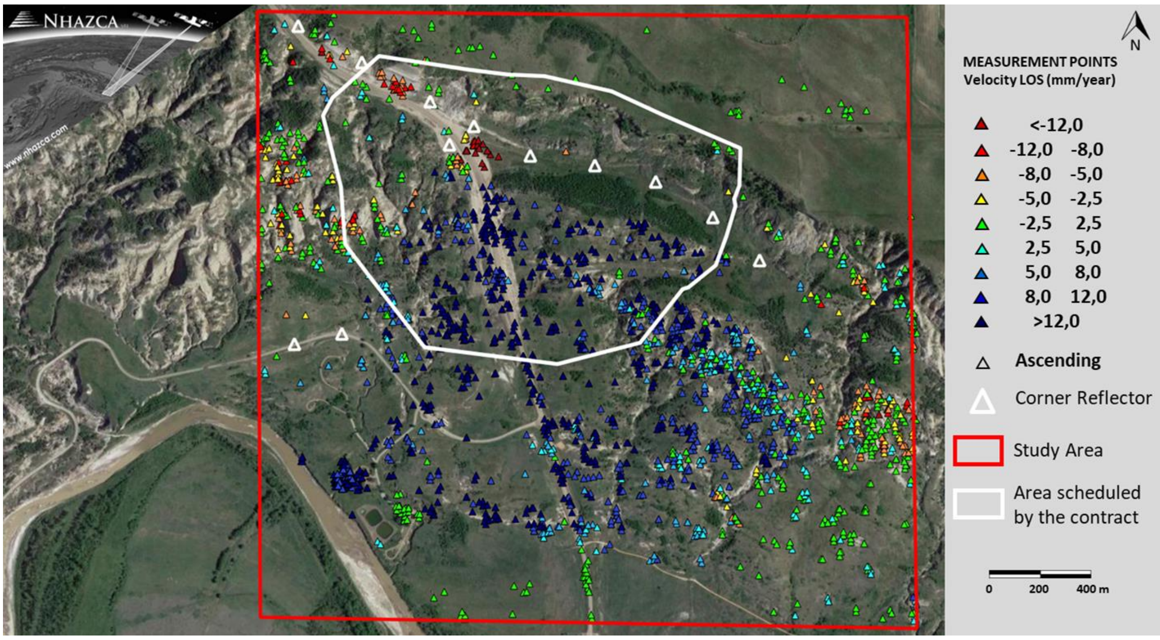


**Figure 22: proposal for the location of Corner Reflectors.**

Alternatively, given the extent of the deformations involving the highway, monitoring could be integrated by the installation of a TInSAR (Terrestrial SAR Interferometer, Figure 23) system, which would guarantee continuous monitoring with much higher acquisition frequencies (in the order of a few minutes), allowing the setting of a real-time alert system (Figure 24).

Considering the prevalent deformation in the horizontal direction (Figure 14), this kind of solution allows to detect displacements from an ideal line of sight. In addition, an installation of artificial reflector is not needed, although is advisable.

The exact location of the monitoring station could only be defined after an appropriate technical inspection, considering the site-specific characteristics, in consideration of the presence of vegetation and the expected prevailing direction of movement.

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**Figure 23: example of a Terrestrial SAR Interferometer installed by NHAZCA S.r.l.**

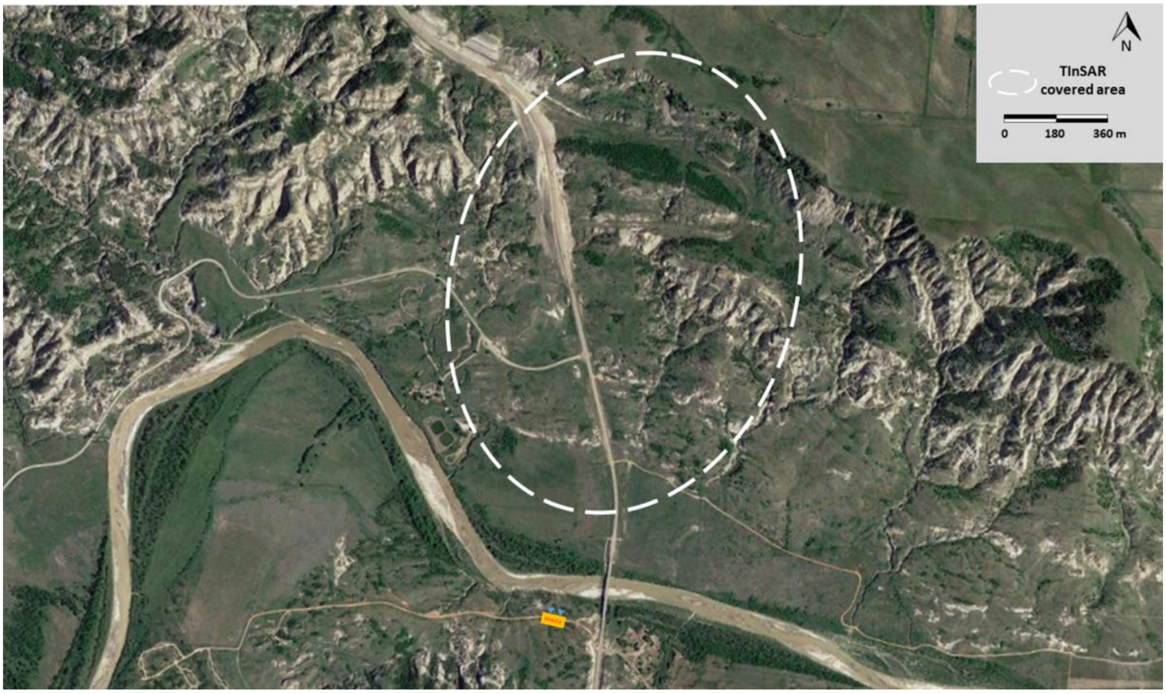


**Figure 24: preliminary hypothesis of location of TInSAR.**

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# 6. BIBLIOGRAPHY

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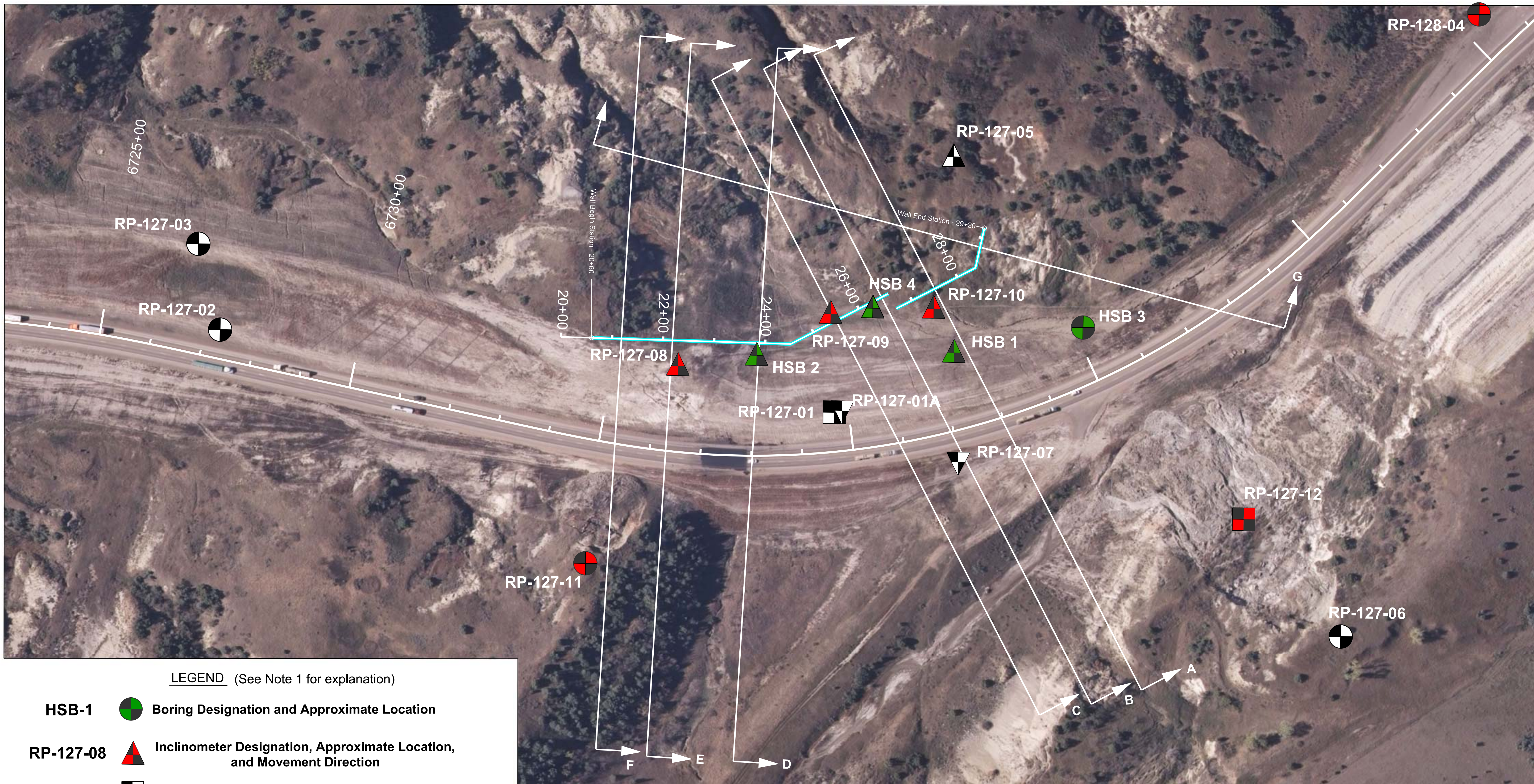
Massonnet, D.; Feigl, K. L. (1998), "Radar interferometry and its application to changes in the earth’s surface", Rev. Geophys.36(4): 441–500, Bibcode: 1998 RvGeo. 36.441M, doi: 10.1029/97RG03139.

APPENDIX F: GLOBAL STABILITY ANALYSIS

Appendix F
# Global Stability Analysis

## Figures


| | |
|---|---|
| Figure F-1: | Global Stability Analysis, Plan View |
| Figures F-2 through F-6: | Global Stability Analysis, Section A |
| Figures F-7 through F-11: | Global Stability Analysis, Section B |
| Figures F-12 through F-16: | Global Stability Analysis, Section C |
| Figures F-17 through F-20: | Global Stability Analysis, Section D |
| Figures F-21 through F-24: | Global Stability Analysis, Section E |
| Figures F-25 through F-28: | Global Stability Analysis, Section F |
| Figures F-29 through F-32: | Global Stability Analysis, Section G |




LEGEND (See Note 1 for explanation)

| | |
|---|---|
| HSB-1 | Boring Designation and Approximate Location |
| RP-127-08 | Inclinometer Designation, Approximate Location, and Movement Direction |
| RP-127-01 | Nested Inclinometer/VWP Designation and Approximate Location |
| RP-127-07 | Nested Inclinometer/Sondex Designation and Approximate Location |
| B | Global Stabitliy Analysis Section |
| | Wall Location |

NOTES

1) Boring and instrument designations shown in red were completed as part of this report, borings and instrument designations shown in green were completed by the NDDOT, and designations shown in white were previously drilled and/or installed by Shannon & Wilson.

2) Figure developed from KLJ files Photo_North_NDDOTPrelim_McKenzie.dgn and control_mckenzie.dgn.

0 200 400

Scale in Feet

N

Horseshoe Bend Landslide
7-085(110)127, PCN 22304
McKenzie County, North Dakota

**GLOBAL STABILITY ANALYSES, PLAN VIEW**

February 2020 102116-200

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

**FIG. F-1**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section A.gsz
Name: 01 Back-analysis
Lower

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

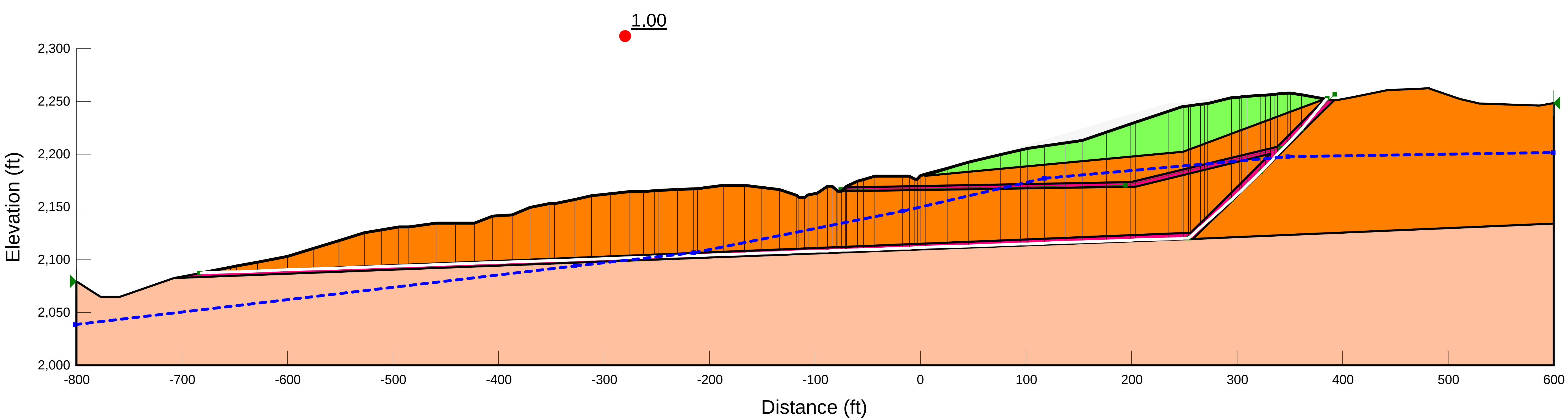



**Fig. F-2**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section A.gsz
Name: 01 Back-analysis
Upper

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

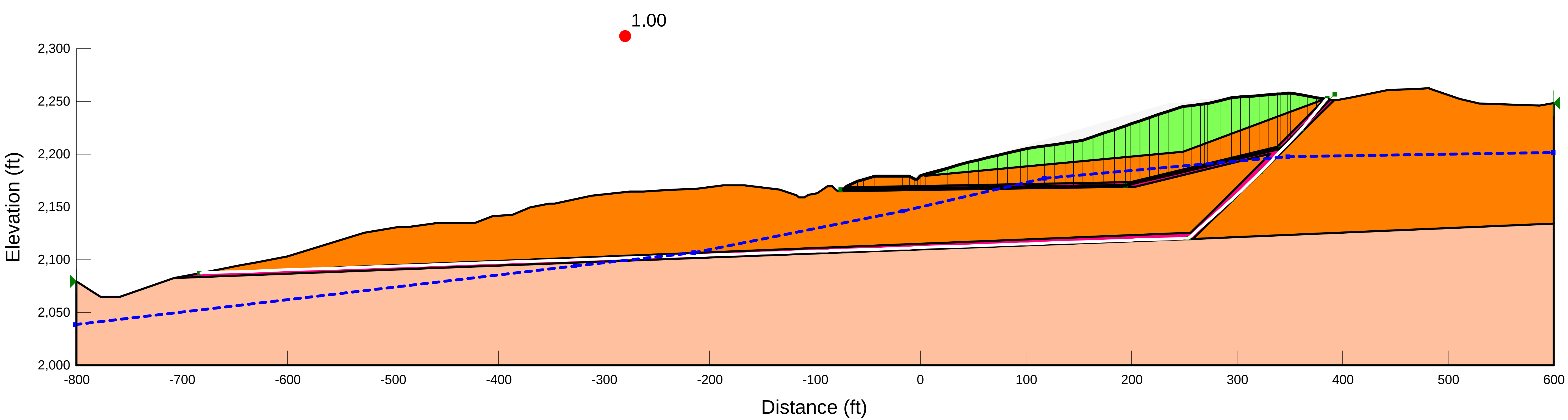



Fig. F-3

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section A.gsz
Name: 02 Construction

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
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| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
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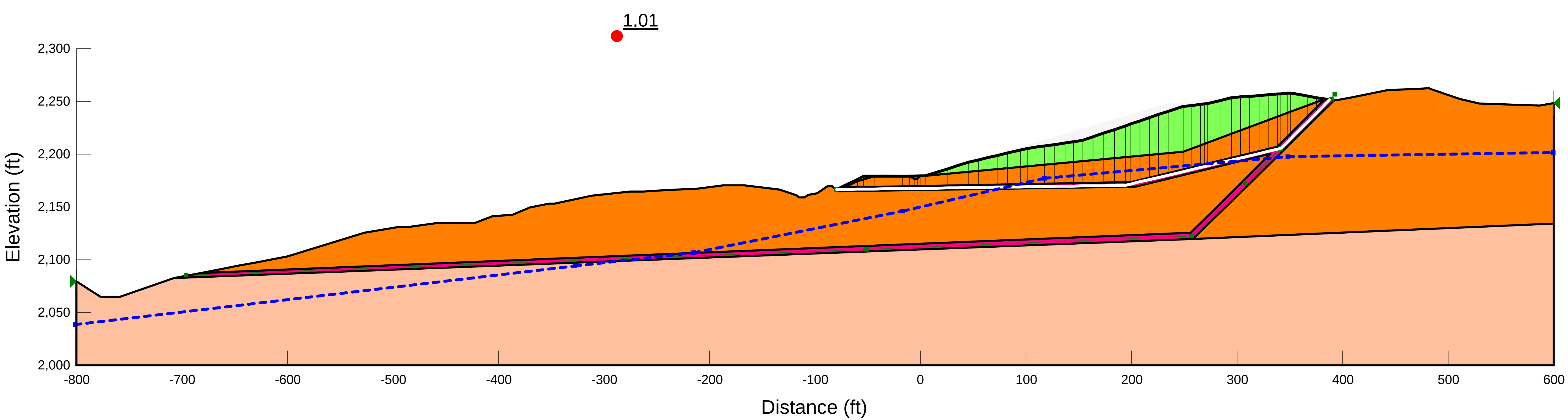


Fig. F-4

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section A.gsz
Name: 03 Shafts and Anchors

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

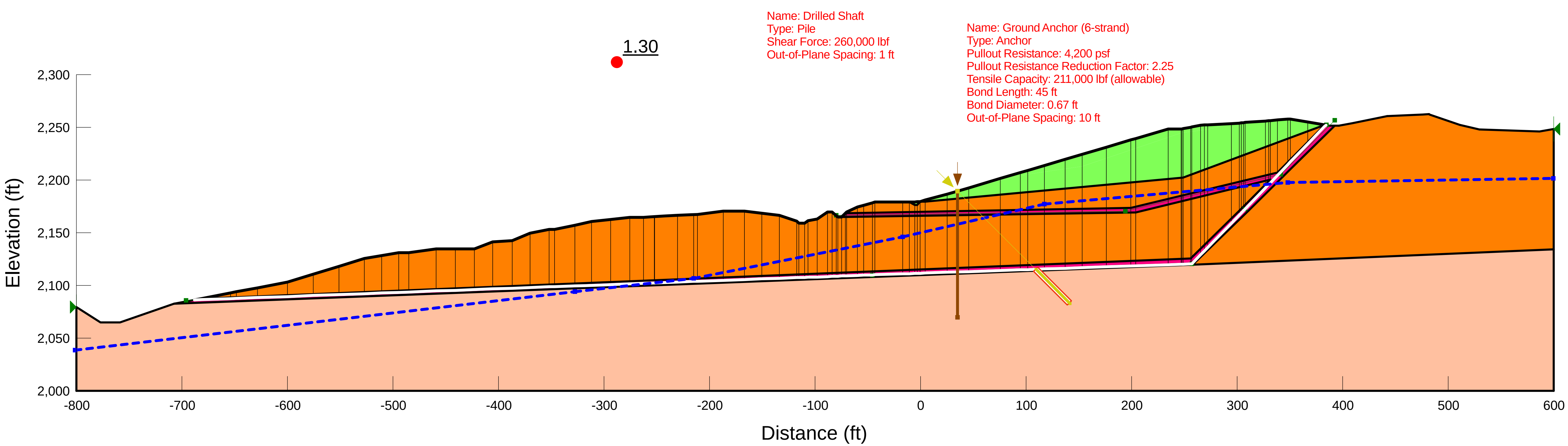


**Fig. F-5**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section A.gsz
Name: 04 Overtopping

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
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| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

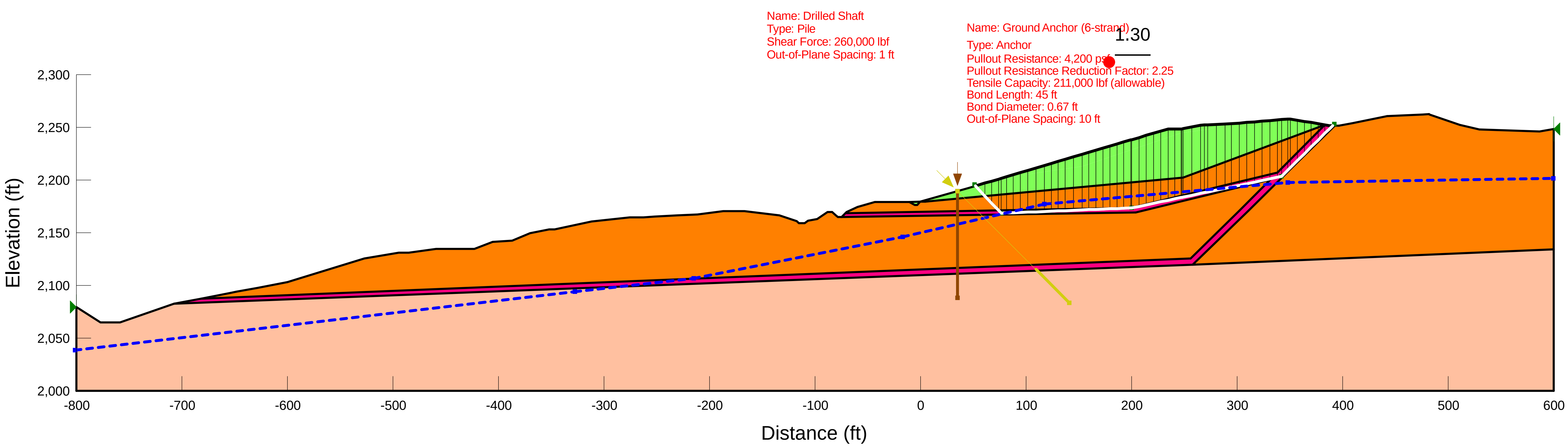


**Fig. F-6**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section B.gsz
Name: 01 Back-analysis
Lower

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Lower_Residual | Shear/Normal Fn. | 125 | Resid_LL=90,25<CF<45 | | | 0 | 1 |
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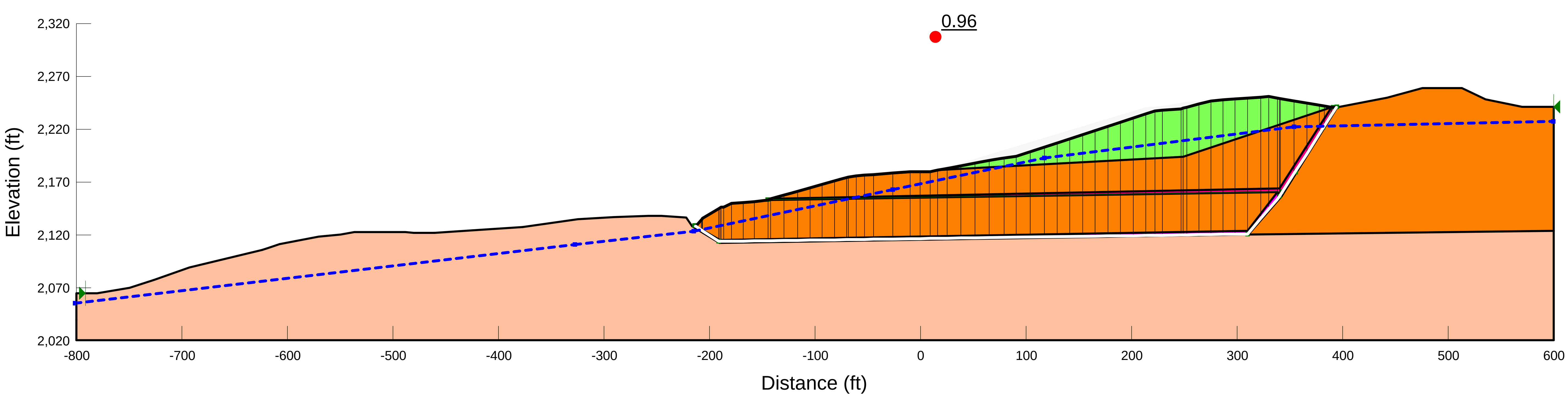



**Fig. F-7**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section B.gsz
Name: 01 Back-analysis Upper

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Lower_Residual | Shear/Normal Fn. | 125 | Resid_LL=90,25<CF<45 | | | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=110,25<CF<45 | | | 0 | 1 |

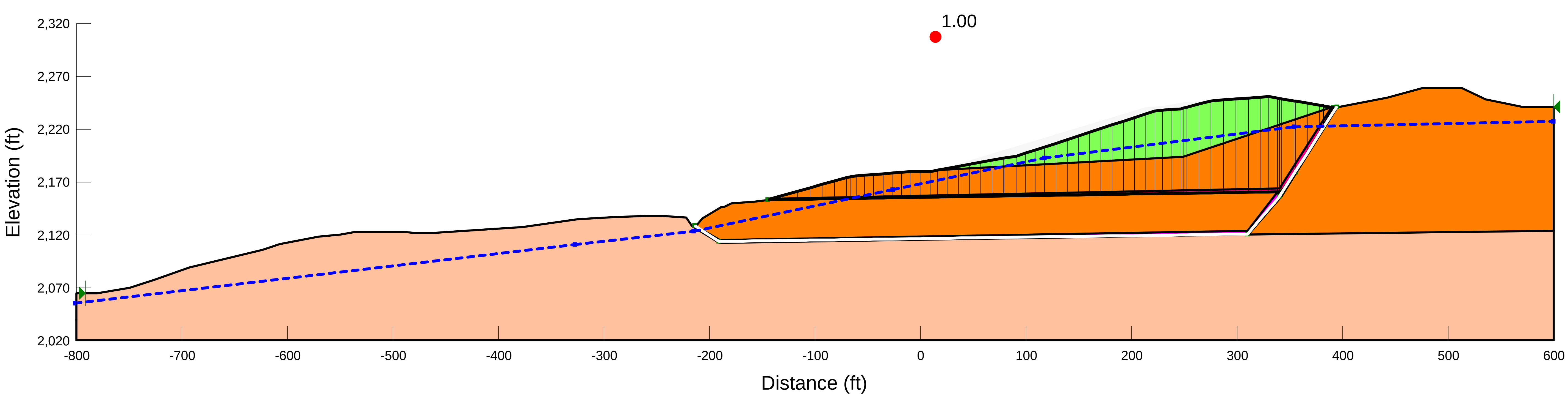



**Fig. F-8**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section B.gsz
Name: 02 Construction

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Lower_Residual | Shear/Normal Fn. | 125 | Resid_LL=90,25<CF<45 | | | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=110,25<CF<45 | | | 0 | 1 |

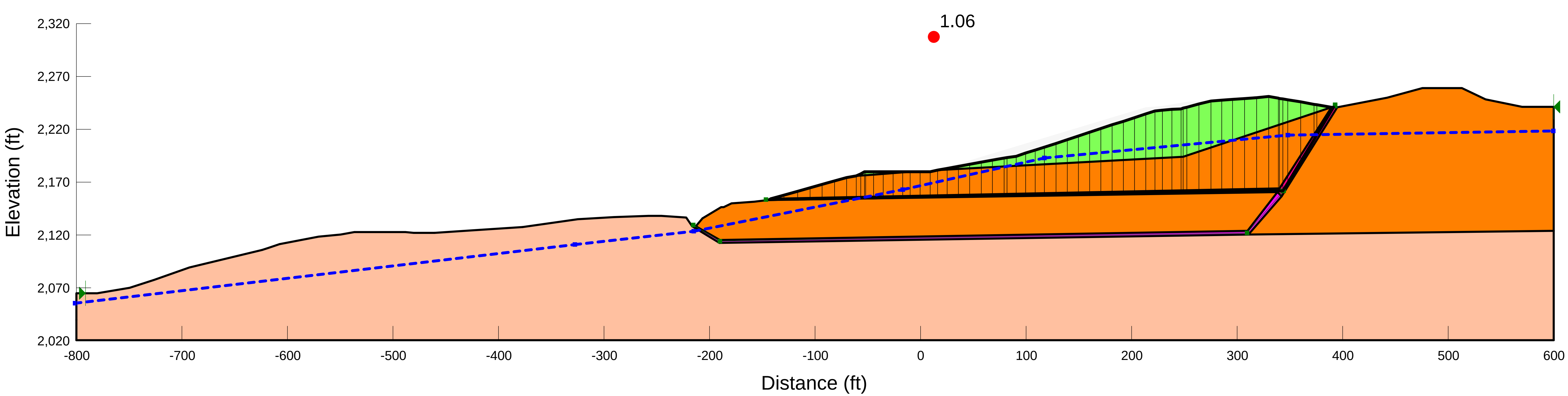



Fig. F-9

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section B.gsz
Name: 03 Anchored Shafts

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Lower_Residual | Shear/Normal Fn. | 125 | Resid_LL=90,25<CF<45 | | | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=110,25<CF<45 | | | 0 | 1 |

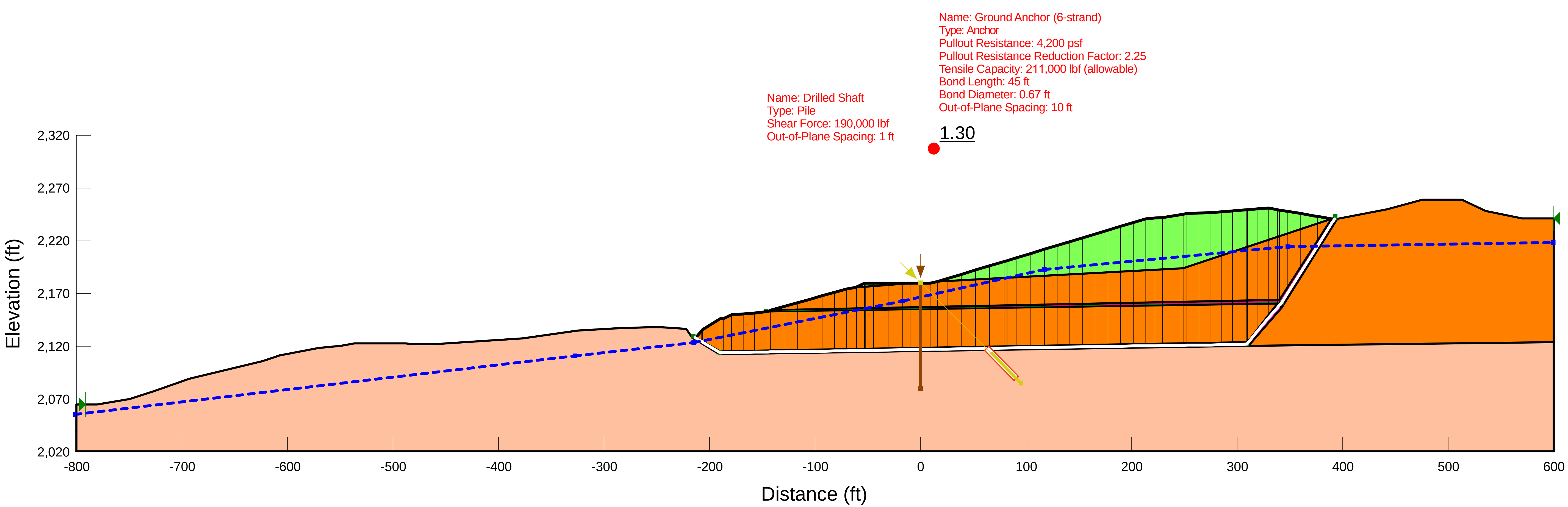



**Fig. F-10**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section B.gsz
Name: 04 Overtopping

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Lower_Residual | Shear/Normal Fn. | 125 | Resid_LL=90,25<CF<45 | | | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=110,25<CF<45 | | | 0 | 1 |

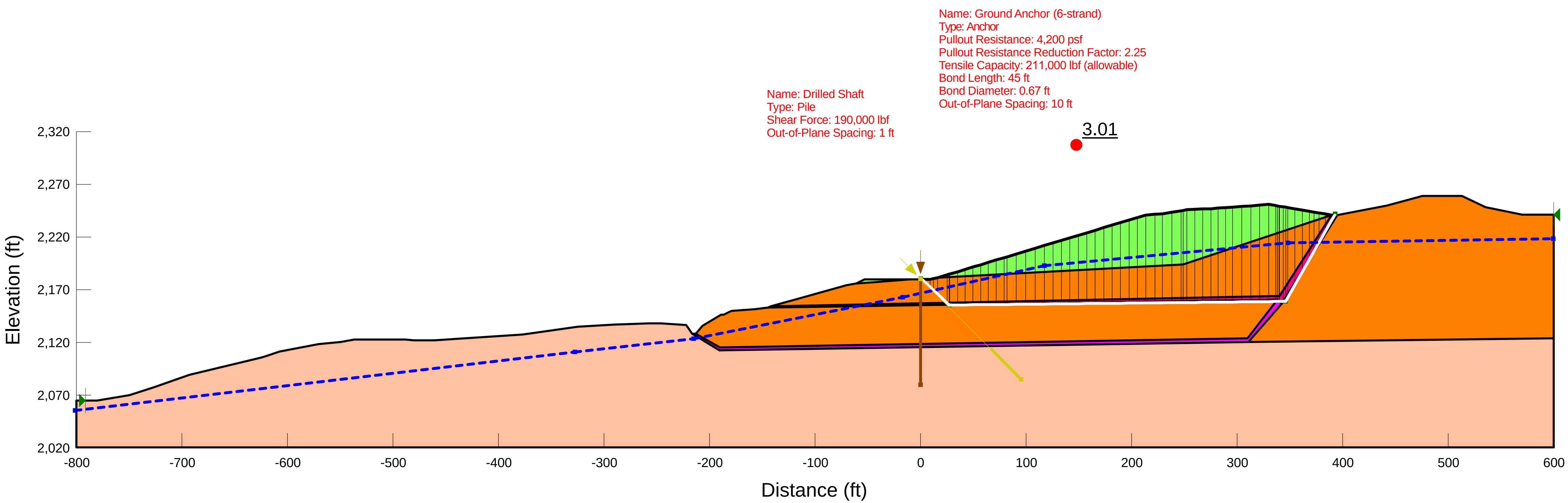



**Fig. F-11**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section C.gsz
Name: 01 Back-analysis
Lower

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Lower_Residual | Shear/Normal Fn. | 125 | Resid_LL=90,25<CF<45 | | | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

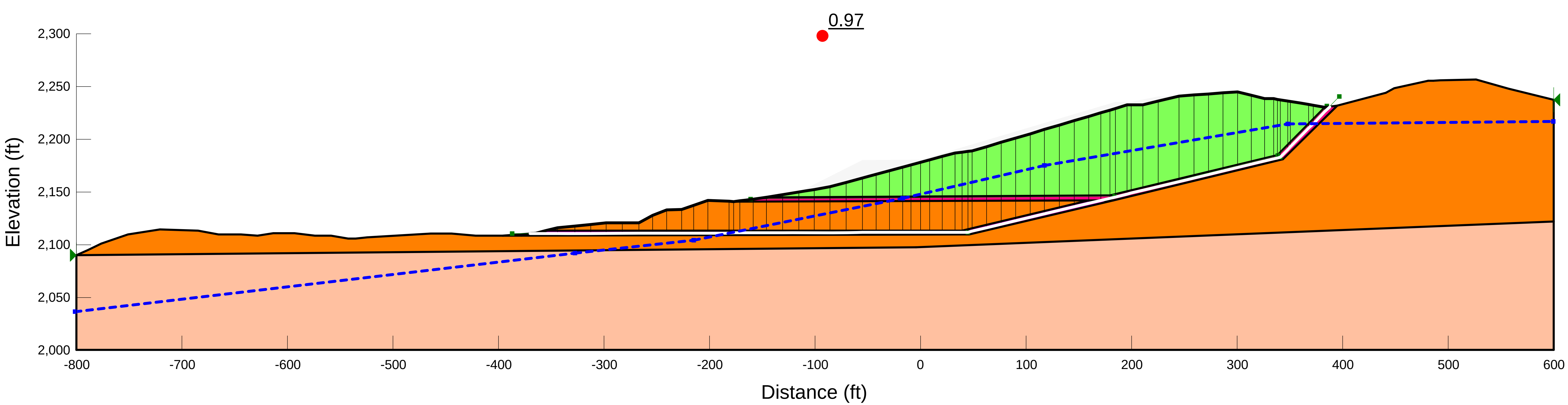



Fig. F-12

**Horseshoe Bend Landslide**
**102116**

SHANNON & WILSON, INC.

Date: 02/10/2020
File Name: Section C.gsz
Name: 01 Back-analysis
Upper

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Lower_Residual | Shear/Normal Fn. | 125 | Resid_LL=90,25<CF<45 | | | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

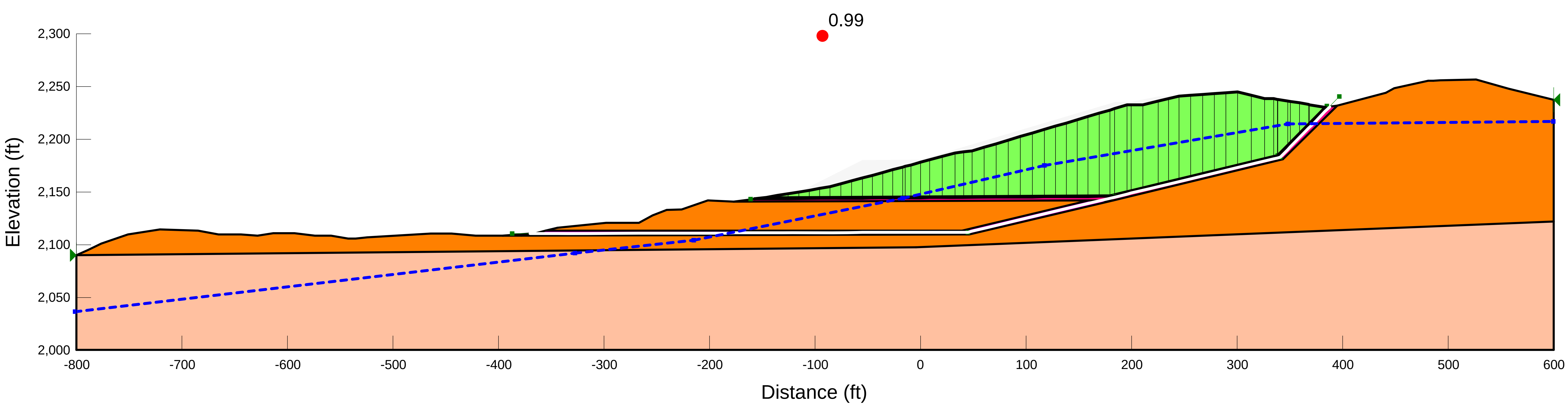



Fig. F-13

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/10/2020
File Name: Section C.gsz
Name: 02 Construction

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Lower_Residual | Shear/Normal Fn. | 125 | Resid_LL=90,25<CF<45 | | | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

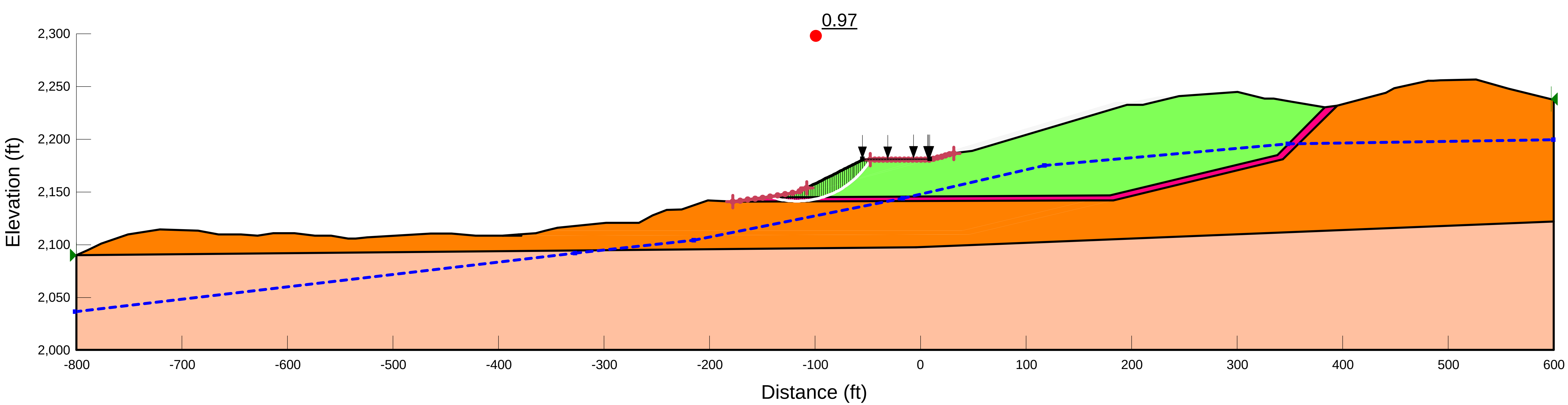



**Fig. F-14**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section C.gsz
Name: 03 Shafts and Anchors

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Lower_Residual | Shear/Normal Fn. | 125 | Resid_LL=90,25<CF<45 | | | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

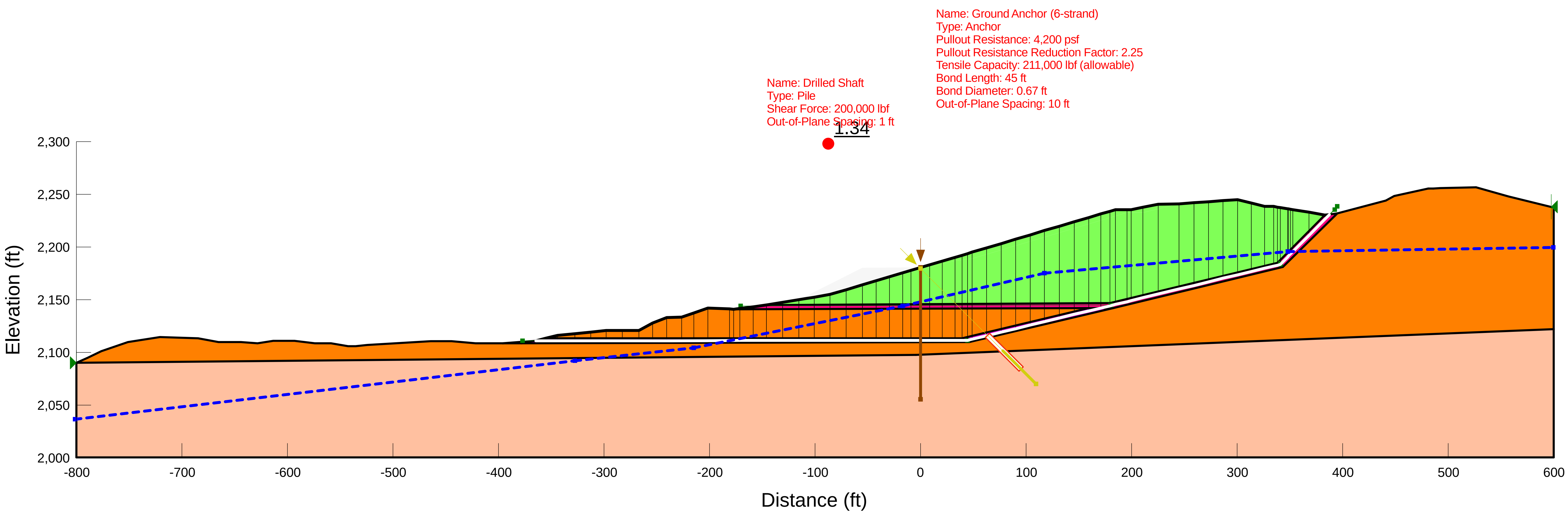



**Fig. F-15**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section C.gsz
Name: 04 Overtopping

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Lower_Residual | Shear/Normal Fn. | 125 | Resid_LL=90,25<CF<45 | | | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

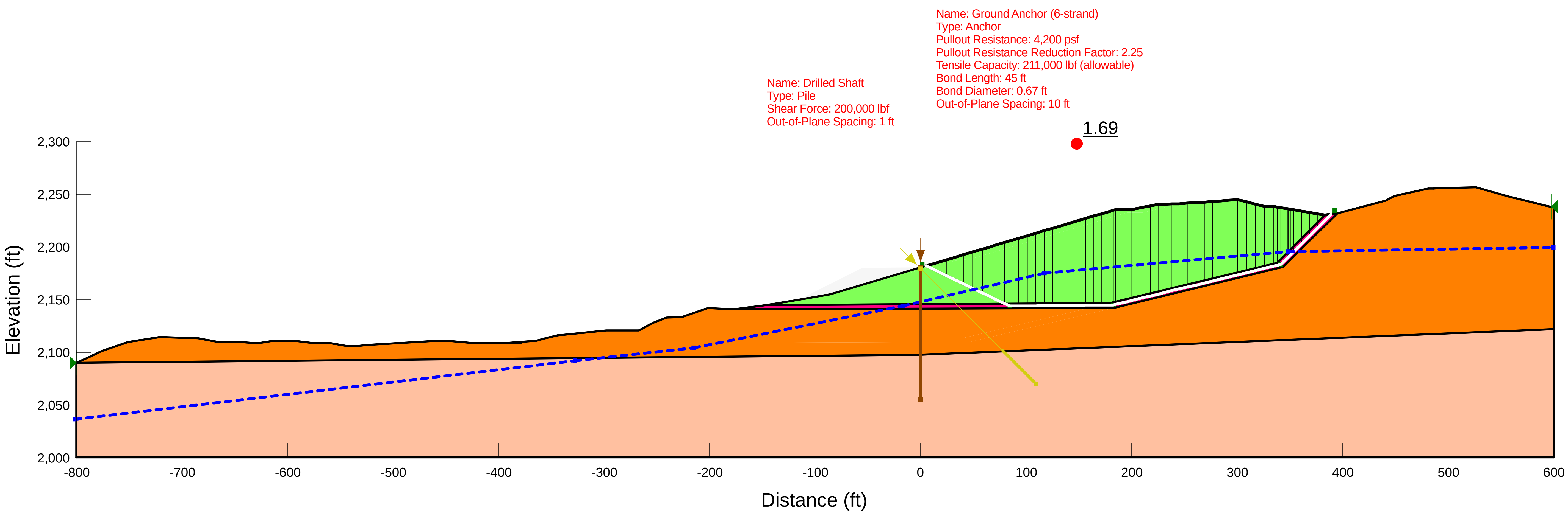



**Fig. F-16**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section D.gsz
Name: 01 Back Analysis

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

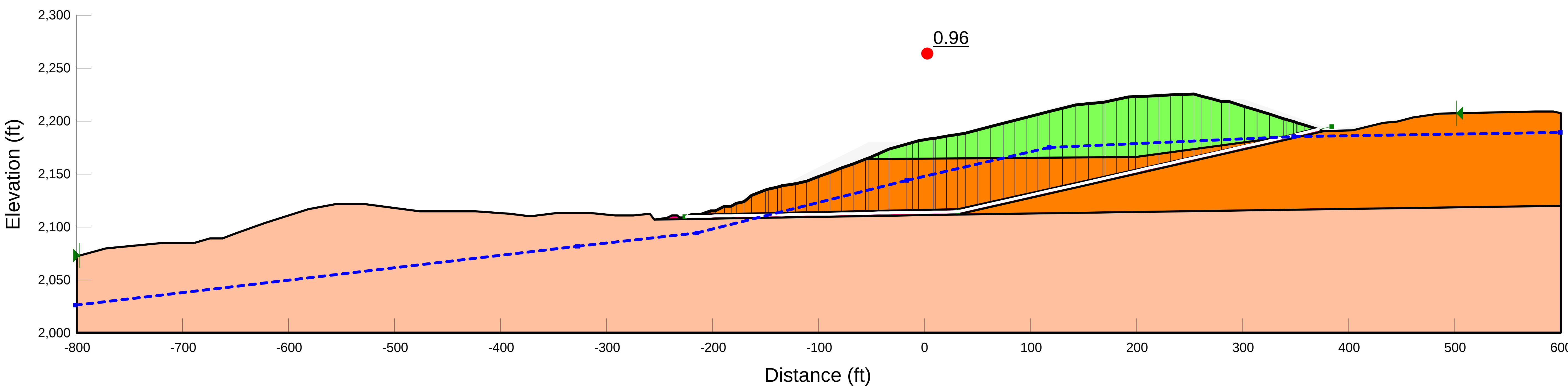



Fig. F-17

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section D.gsz
Name: 02 Construction

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

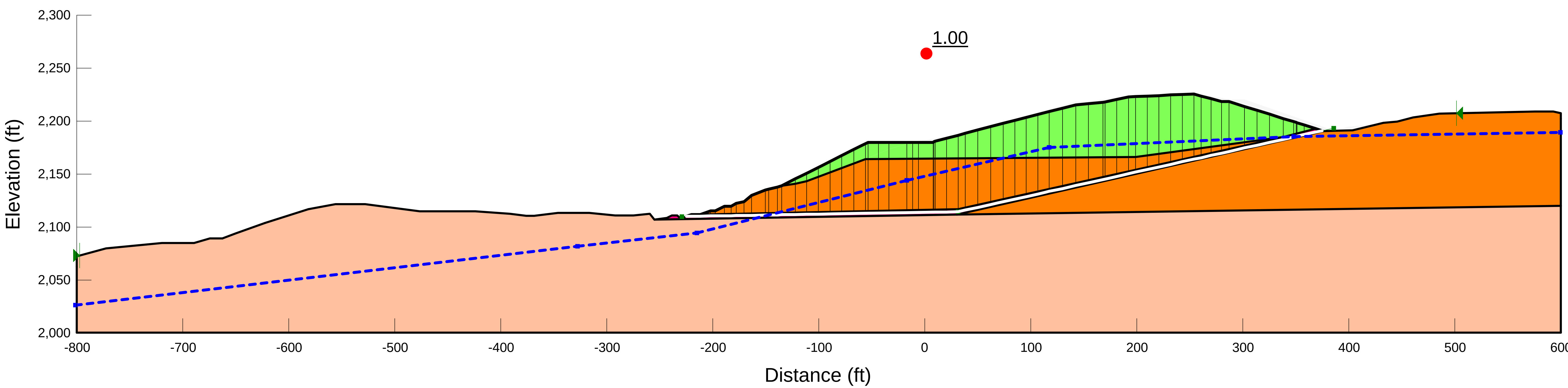



Fig. F-18

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section D.gsz
Name: 03 Anchored Shafts

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

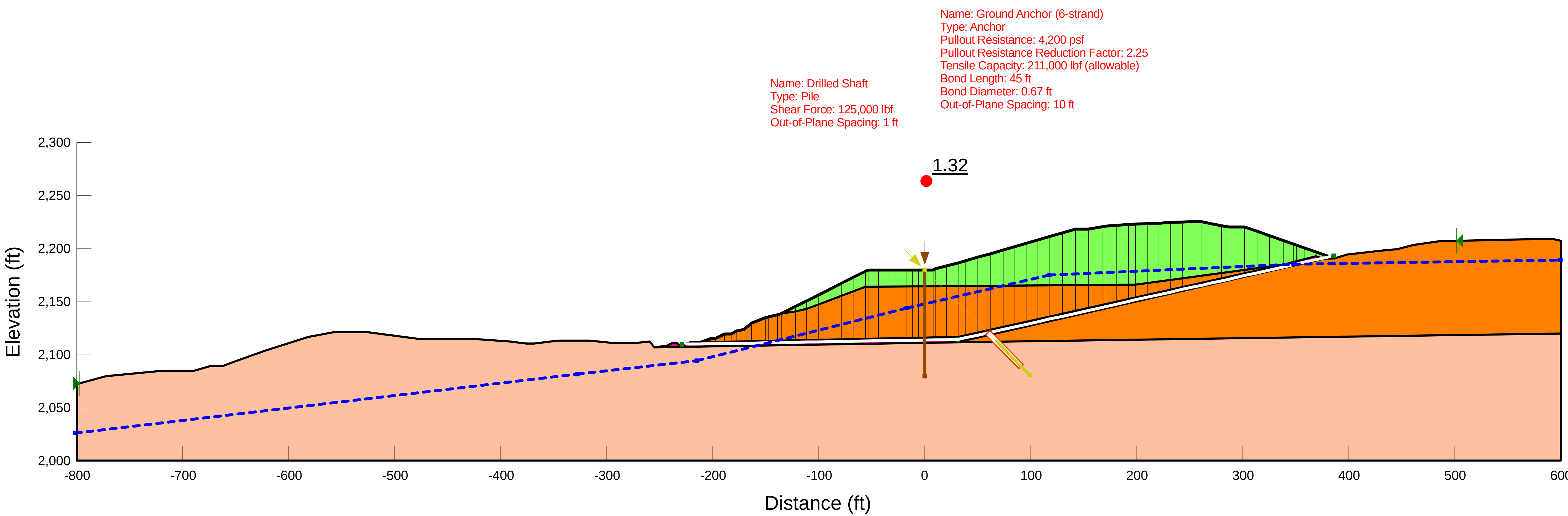



Fig. F-19

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section D.gsz
Name: 04 Overtopping

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

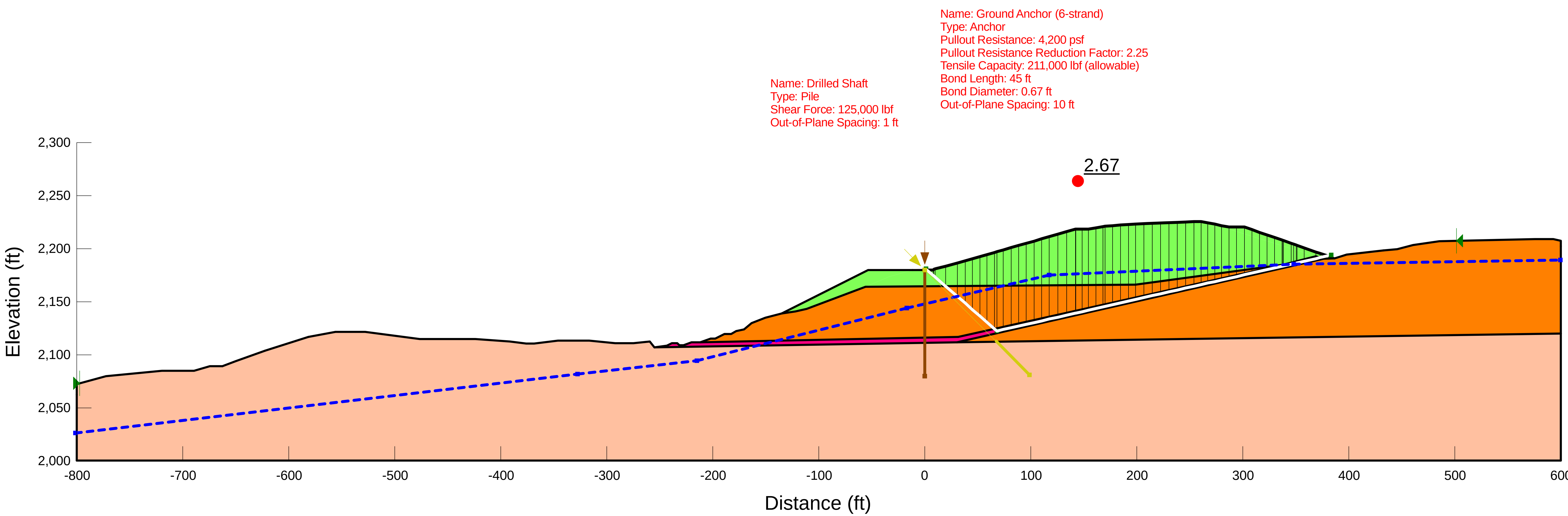


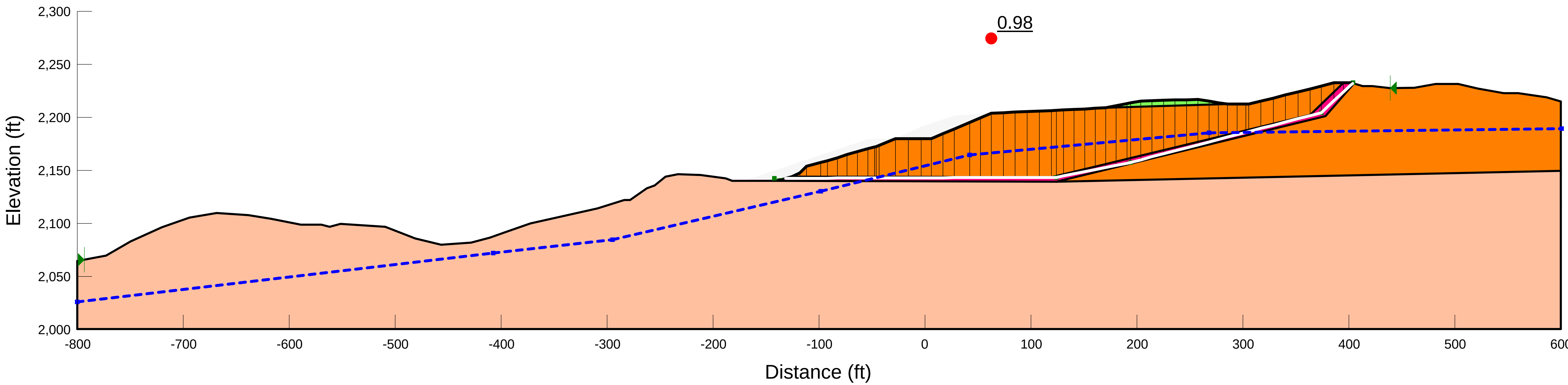

**Fig. F-20**

**Horseshoe Bend Landslide**
**102116**



Date: 02/11/2020
File Name: Section E.gsz
Name: 01 Back-analysis

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=100, CF>50 | | | 0 | 1 |



**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section E.gsz
Name: 02 Construction

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=100, CF>50 | | | 0 | 1 |

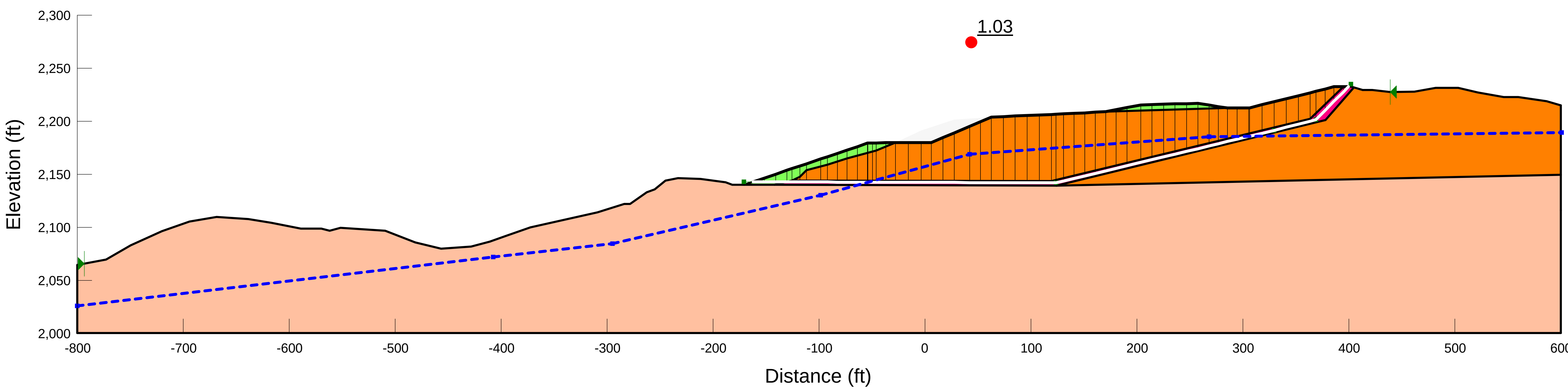



Fig. F-22

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section E.gsz
Name: 03 Anchored Shafts

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=100, CF>50 | | | 0 | 1 |

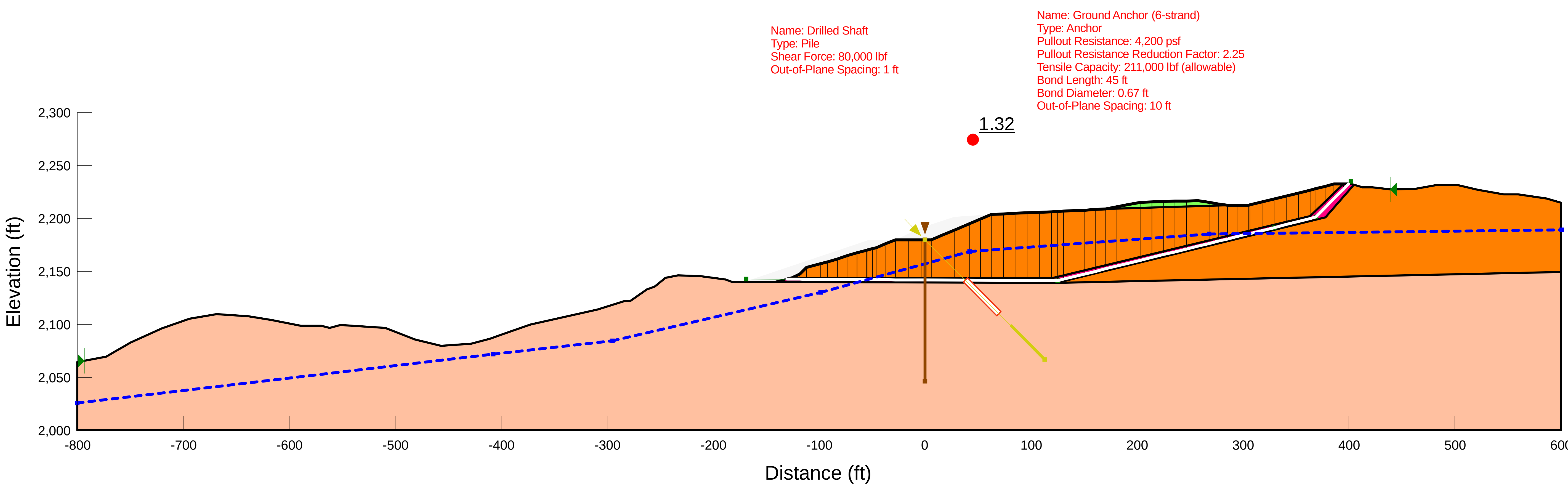



Fig. F-23

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section E.gsz
Name: 04 Overtopping

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=100, CF>50 | | | 0 | 1 |

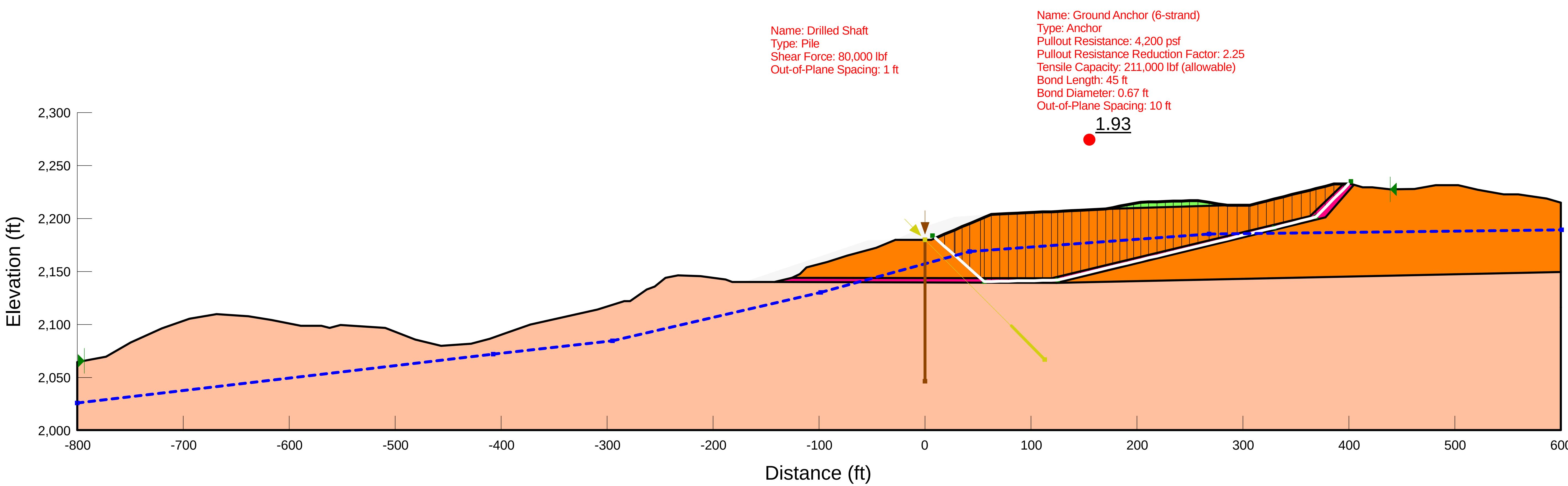



Fig. F-24

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section F.gsz
Name: 01 Back-analysis

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=110, CF>50 | | | 0 | 1 |

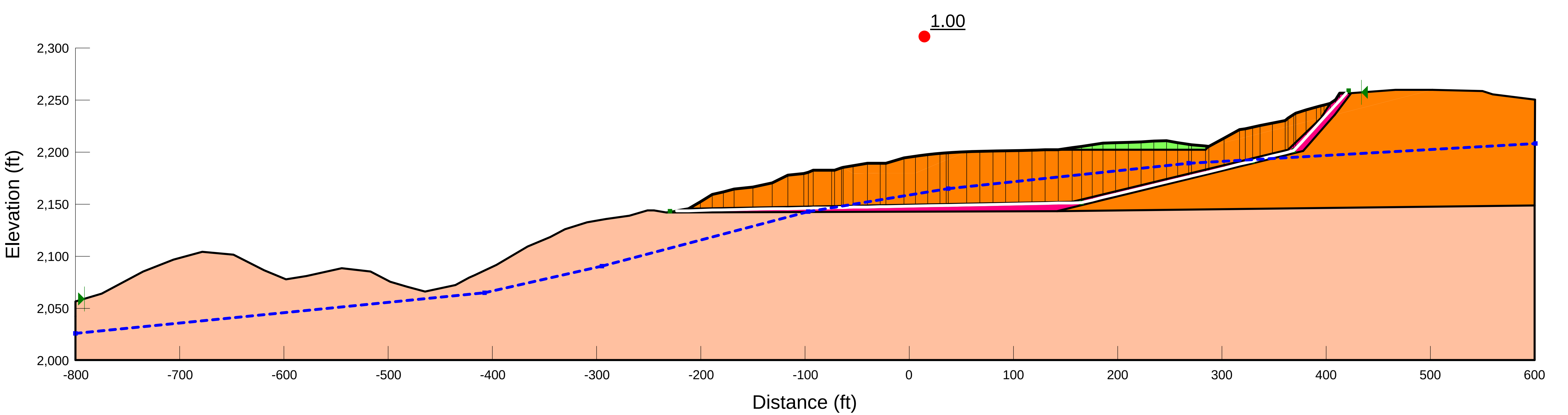



**Fig. F-25**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section F.gsz
Name: 02 Construction

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=110, CF>50 | | | 0 | 1 |

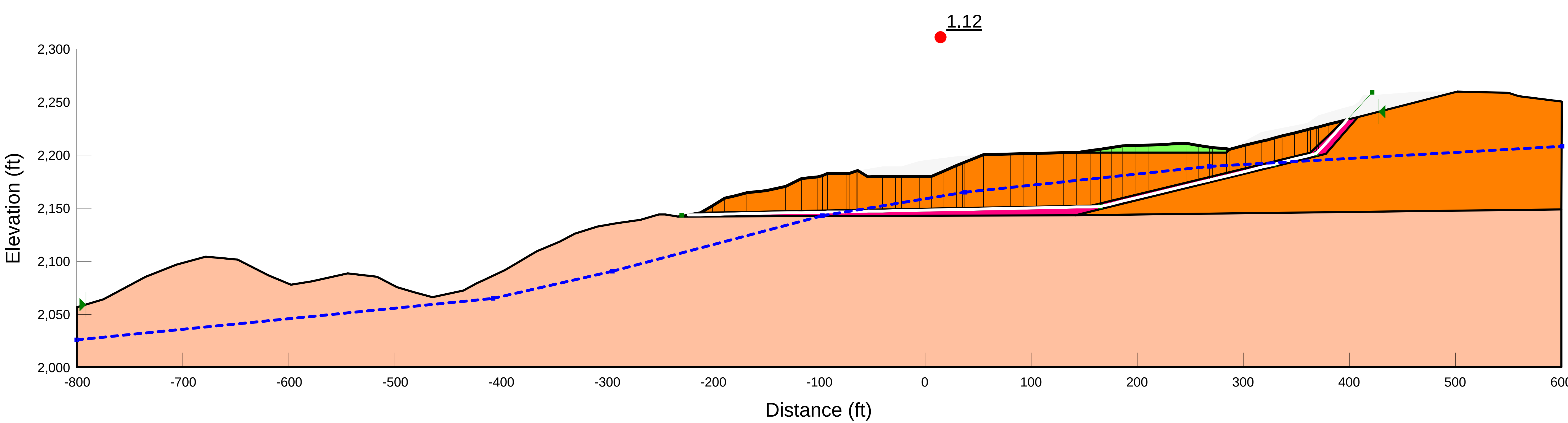



**Fig. F-26**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section F.gsz
Name: 03 Anchored Shafts

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=110, CF>50 | | | 0 | 1 |

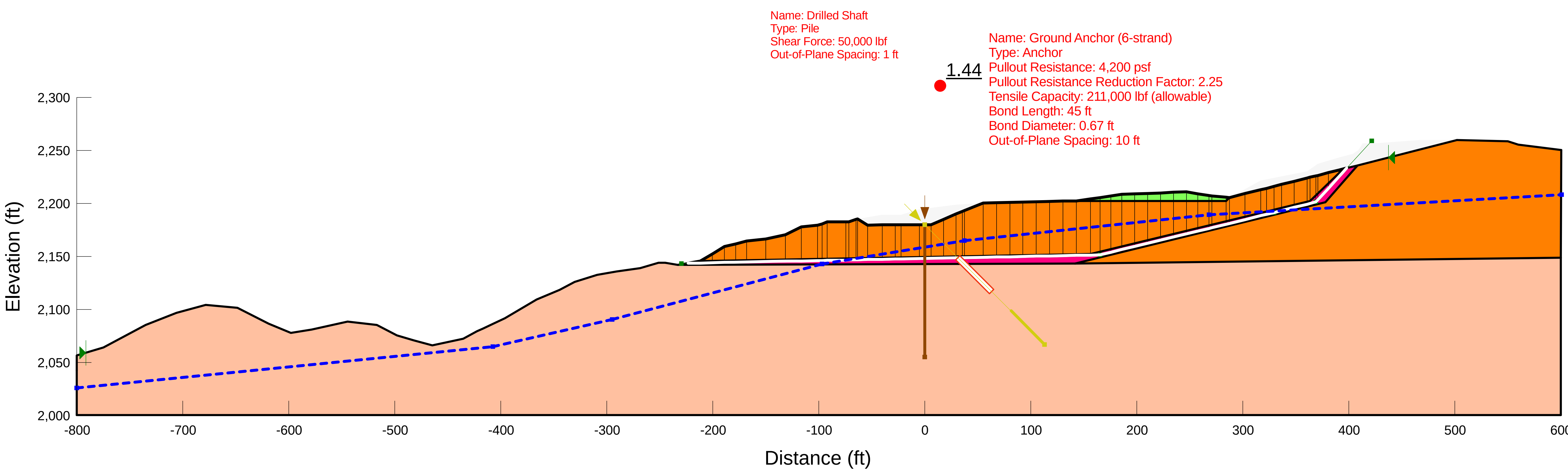



**Fig. F-27**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section F.gsz
Name: 04 Overtopping

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=110, CF>50 | | | 0 | 1 |

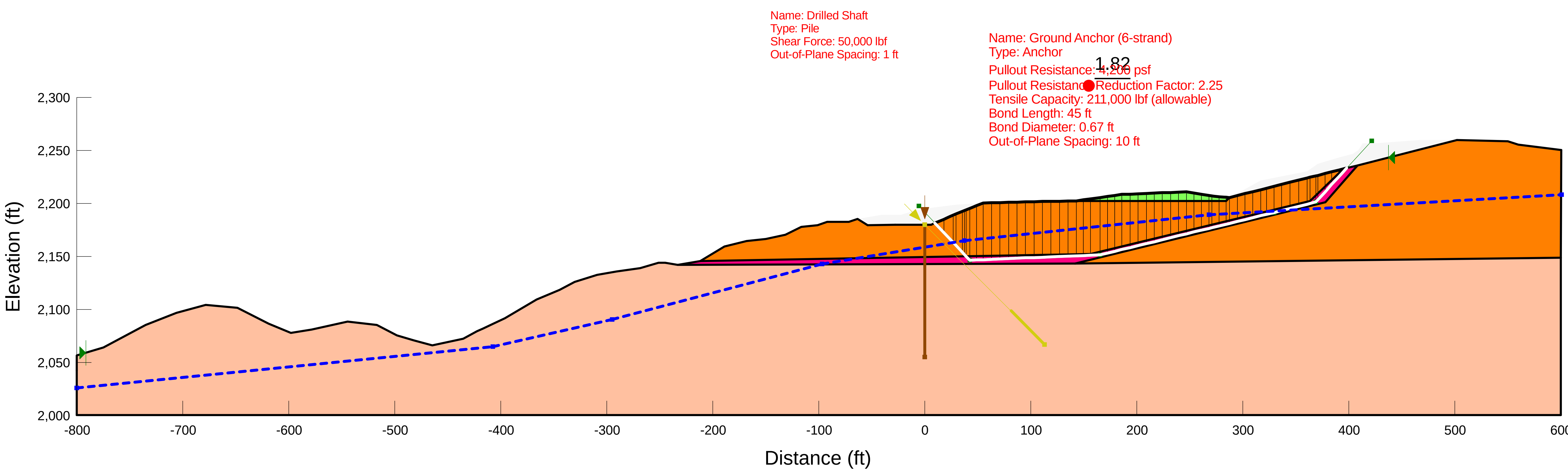



**Fig. F-28**

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section G.gsz
Name: 01 Back-analysis

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

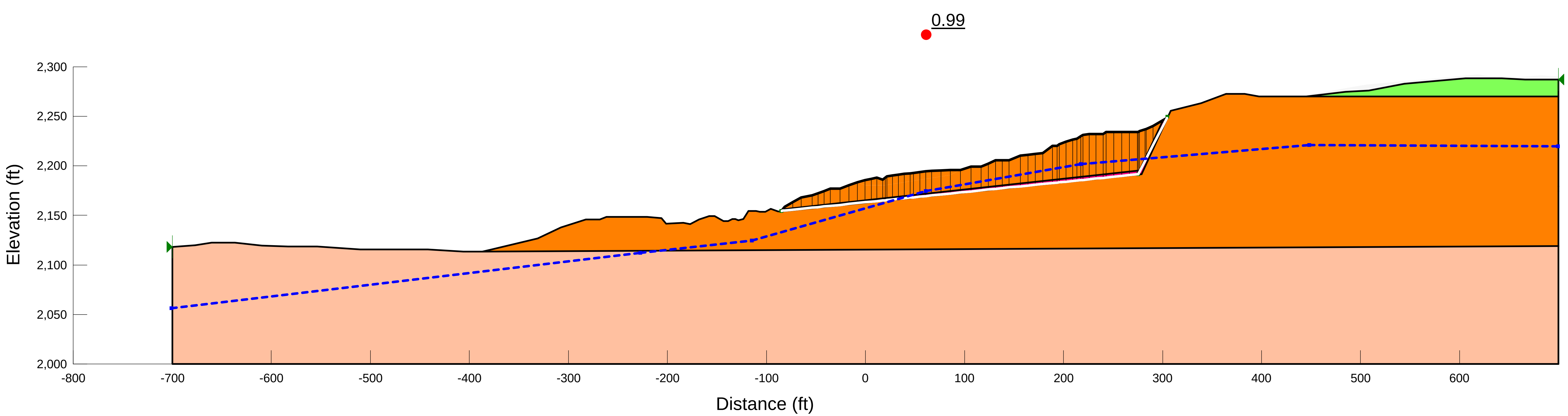



Fig. F-29

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section G.gsz
Name: 02 Construction

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

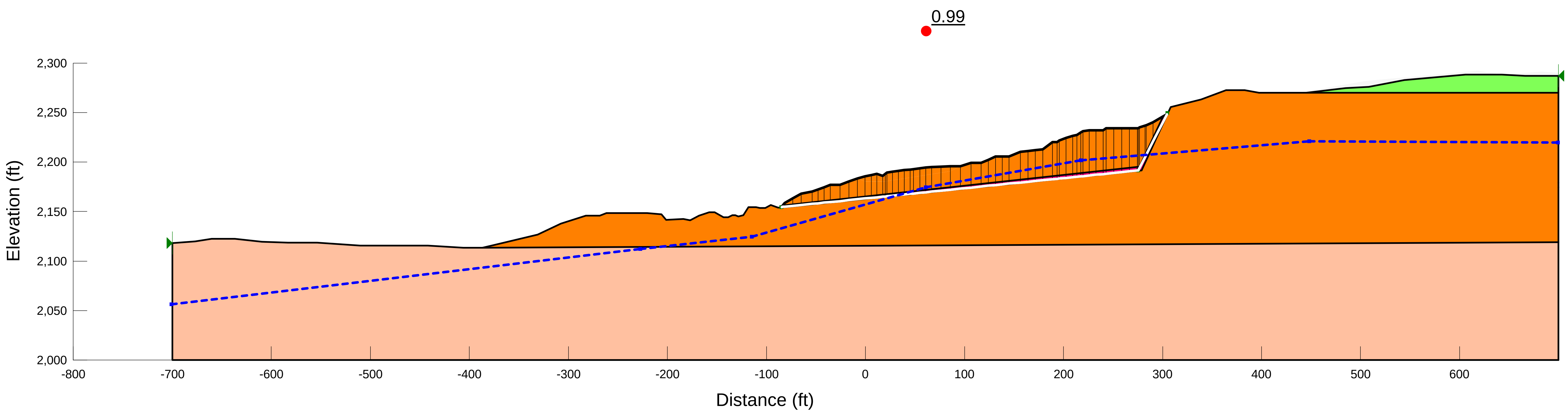



Fig. F-30

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section G.gsz
Name: 03 Anchors

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

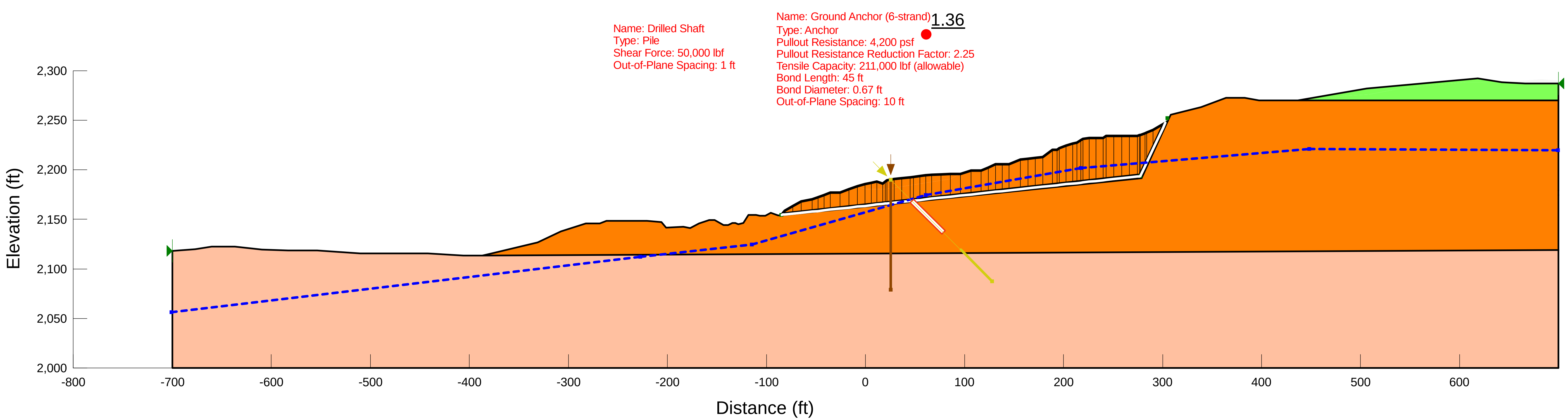



Fig. F-31

**Horseshoe Bend Landslide**
**102116**

**SHANNON & WILSON, INC.**

Date: 02/11/2020
File Name: Section G.gsz
Name: 04 Overtopping

| Color | Name | Model | Unit Weight (pcf) | Strength Function | Cohesion' (psf) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Bedrock | Mohr-Coulomb | 125 | | 200 | 24 | 0 | 1 |
| | Fill | Mohr-Coulomb | 125 | | 50 | 25 | 0 | 1 |
| | Landslide Debris | Mohr-Coulomb | 120 | | 50 | 25 | 0 | 1 |
| | Landslide Debris Upper_Residual | Shear/Normal Fn. | 125 | Resid_LL=105,25<CF<45 | | | 0 | 1 |

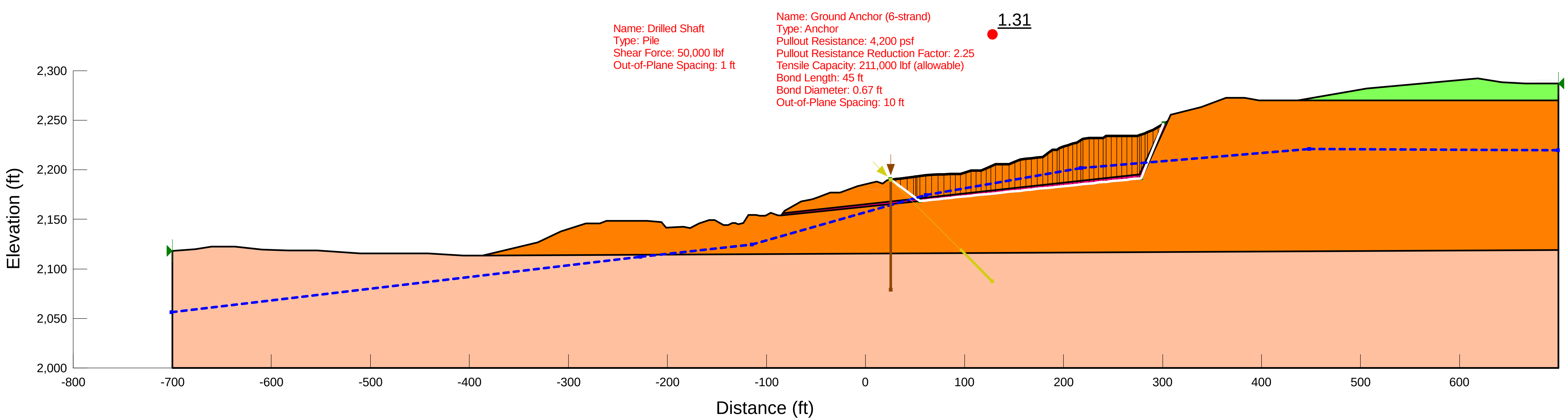



**Fig. F-32**

IMPORTANT INFORMATION

# Important Information

## About Your Geotechnical Report

IMPORTANT INFORMATION

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

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

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

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

## SUBSURFACE CONDITIONS CAN CHANGE.

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

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

## MOST RECOMMENDATIONS ARE PROFESSIONAL JUDGMENTS.

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

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

## A REPORT'S CONCLUSIONS ARE PRELIMINARY.

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

## THE CONSULTANT'S REPORT IS SUBJECT TO MISINTERPRETATION.

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

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

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

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

IMPORTANT INFORMATION

## READ RESPONSIBILITY CLAUSES CLOSELY.

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

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