Slide Location
Timeline

• Grade Raise and Realignment completed in 2000

• 2001 North Inslope begins to show distress
Timeline

- Grade Raise and Realignment completed in 2000
- 2001 North Inslope begins to show distress
Timeline

- Grade Raise and Realignment completed in 2000
- 2001 North Inslope begins to fail
- 2001 400 feet of sheet piling and longitudinal drain installed
Timeline

• 2007 Road Shoulder has dropped noticeably, and sheet piling is deflecting
Timeline

- 2014 Shoulder has continued to drop and pull away from driving lane. New shoulder area further west has noticeably dropped and pulled away.
Timeline

• 2014 Shoulder has continued to drop and pull away from driving lane. New shoulder area further west has noticeably dropped and pulled away.
• Become concerned about larger failure
Timeline

- 2016 Inclinometers installed through the area of distress North, South and in the Median of the Interstate
Inclinometers

• Inclinometers are plastic tubes with internal grooves that guide a probe along the length of the tube.
• The inclinometers are placed in a borehole and grouted in place.
• The inclinometers move with the surrounding soil and can be read using a portable probe.
• Inclinometers can show depth, direction, and rate of movement over time.
Inclinometer Locations
<table>
<thead>
<tr>
<th>ELEVATION (FT)</th>
<th>MATERIAL DESCRIPTION</th>
<th>FPN-FEET</th>
<th>UNM</th>
<th>SPN &amp; NUMBER</th>
<th>MATERIAL FRACT. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1273.7</td>
<td>Lower Most Clayey Sand Fill since 2006</td>
<td>8.34</td>
<td>50</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>1227.3</td>
<td>Medium Silt to Silt Most Brown/Black/Cracked Gravel with Gravel Fill since 2006</td>
<td>0.36</td>
<td>50</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>1205.0</td>
<td>Medium Silt to Silt Most Brown/Black/Cracked Gravel with Gravel Fill since 1989</td>
<td>11.0</td>
<td>50</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>1200.0</td>
<td>Medium Silt to Silt Most Brown/Black/Cracked Gravel with Gravel Fill since 2006</td>
<td>29.0</td>
<td>50</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>1204.0</td>
<td>Coarse Sand</td>
<td>39.0</td>
<td>50</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>1218.0</td>
<td>Very Silt to Silt Most Brown/Black/Cracked Gravel with Gravel Fill since 1990</td>
<td>82.0</td>
<td>50</td>
<td>85</td>
<td></td>
</tr>
</tbody>
</table>

Bottom of borehole at 80.5 ft.
### LOG OF BORING SB - 5

**ENGINEER**
Middle North Slope

<table>
<thead>
<tr>
<th>ELEVATION (ft)</th>
<th>MATERIAL DESCRIPTION</th>
<th>GRAPHIC LOG</th>
<th>UNS</th>
<th>SAMPLE TYPE &amp; NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1195.0 ft</td>
<td>Topsoil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1194.0 ft</td>
<td>Topsoil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1200.0 ft</td>
<td>Medium Medium Gravel/Black/Dark Grey Fat Clay and Gravel fill circa 2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1200.0 ft</td>
<td>Very Strong Medium Brown/Black/Dark Grey Fat Clay and Gravel fill circa 1988</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1220.0 ft</td>
<td>Coarse Sand</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1223.7 ft</td>
<td>Topsoil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1230.0 ft</td>
<td>Medium Strong Medium Brown/Black/Dark Grey Fat Clay and Gravel fill circa 2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1230.0 ft</td>
<td>Medium Strong Medium Brown/Black/Dark Grey Fat Clay and Gravel fill circa 1988</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1240.0 ft</td>
<td>Medium Strong Medium Brown/Black/Dark Grey Fat Clay and Gravel fill circa 2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1240.0 ft</td>
<td>Medium Strong Medium Brown/Black/Dark Grey Fat Clay and Gravel fill circa 1988</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTES**

- Bottom of borehole at 805.5 ft
Timeline

• 2017 Shannon and Wilson Hired to Peer Review Design Process
• 2017 Distress moves into the driving lane pavement and a project is triggered and design begins
Peer Review Process

• NDDOT has no experience with structural landslide mitigation alternatives
• NDDOT has had consultants provide structural landslide mitigation alternatives in the past couple years
• Due to project constraints it was likely that this project would require a structural alternative
• RFP process was relatively quick and painless
• Consultant was chosen based on phone interviews and short presentation
• Allowed the NDDOT to rely on Shannon and Wilson’s experience designing and constructing structural solutions during the design process
Options and Design Issues

- 1st choice mitigation alternative was a buttress
- Drainage at toe of slope must be accounted for both during construction and permanently
- Buttress option would require an 11’ x 9’ approximately 1000’ long box culvert
Options and Design Issues

- Excavation required for box culvert option results in very questionable temporary stability
- Buttress option is abandoned, and Ground Anchor Option is pursued
Ground Anchors

• Ground Anchors are grouted, prestressed structural elements installed in soil or rock that are used to transmit a tensile load into the ground.

• Ground Anchors consist of a bond zone, anchorage, and unbonded zone.
Ground Anchors

- The bond zone is a length of prestressed steel that is bonded to the grout and the soil.
- The anchorage transmits the force from the prestressing steel to the ground.
- The unbonded zone is a portion of the prestressed steel that is not directly exposed to grout allowing it to elongate elastically and transfer the force from the bond length to the anchorage.
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Options and Design Issues

- Access to Drill Ground Anchors is evaluated
- Cannot avoid impacting the drainage at the toe of the slope
- Requires a 48” diameter Temporary pipe to maintain drainage and temporary grading to provide a construction platform
Final Design

- Satisfactory Ground Anchor Option is achieved
- 1-3 rows
- 5 strand 193.1 kip Design Load
- 125-140’ Long
Timeline

- 2018 SAA installed
- 2018 Construction Begins
Timeline

- 2018 SAA installed
- 2018 Construction Begins

Velocity increased from .0175 in/day to .278 in/day
1500% increase
Construction

- Project Engineering Staff
- Construction Phasing
- Major Project Issues
Project Engineering Staff

- NDDOT
  - Project Engineer
  - Geotechnical Engineers (M & R)

- KLJ
  - Project Inspectors
  - Materials Tester
  - Surveyor

- Shannon and Wilson
  - Geotechnical Inspector
  - Geotechnical Engineer
Construction Phasing

- Two Year Project
  - Year 1 – 2018
  - Year 2 - 2019
Year 1 - 2018

- Place and Remove Temporary Drainage Pipe
Year 1 - 2018

- Place and Remove Temporary Drainage Pipe
- Grading
- Precast and Install Concrete Anchor Blocks
- Drill and Install Ground Anchors
Phase 1 Construction - Install Top Row Ground Anchors Sta 113+44.70 to 116+30.20 (WB I-94)

Phase 2 Construction - Install Middle Row Ground Anchors Sta 108+46.50 to 112+54.60 (WB I-94)

Phase 3 Construction - Install Bottom Row Ground Anchors Sta 103+54.00 to 110+63.00 (WB I-94)

Varies - 24' min

Install Top Row Ground Anchors

Install Middle Row Ground Anchors Installed in Phase 1

Install Bottom Row Ground Anchors

Pipe Conduit 48BN - Approach

Embarkment for temporary work platform

Common Excavation Type B

Middle Row Ground Anchors

Top Row Ground Anchors Sta 113+44.70 to 116+30.20 (WB I-94) Installed in Phase 1

Top Row Ground Anchors Sta 113+44.70 to 116+30.20 (WB I-94)

Varies - 24' min

This document was originally issued and sealed by Jeffrey R. Roach, Registration Number PE-8211, on 4/1/18 and the original document is stored at the North Dakota Department of Transportation.
NOTES:

1. The Contractor is to determine the size and thickness of the bearing plates, trumpet, anchor head and end cap. Provide a steel bearing plate and trumpet with a minimum yield strength of 60 ksi. Provide a bearing plate with minimum plan dimensions of 10" x 16".

2. Provide a SCH 40 steel pipe meeting ASTM A53 with a minimum yield strength of 30 ksi. Extend the pipe for the full depth of the concrete anchor block. Indicate the cost of furnishing and placing the steel pipe in the price bid for Class AAE-3 concrete.

3. Achieve a minimum 28-day concrete compressive strength of 4,000 psi in the anchor block before the ground anchor is stressed.

4. Install the anchor block so that its base is in full contact with the soil prior to the application of tension during installation. No voids between the anchor block and soil are permitted.
Year 1 - 2018

- Place and Remove Temporary Drainage Pipe
- Grading
- Precast and Install Concrete Anchor Blocks
- Drill and Install Ground Anchors
- Jack and Bore Pipe Conduit
- Pipe Extensions
Year 1 - 2018

- Place and Remove Temporary Drainage Pipe
- Grading
- Precast and Install Concrete Anchor Blocks
- Drill and Install Ground Anchors
- Jack and Bore Pipe Conduit
- Pipe Extensions
- Drill and Install Inclinometers
Year 1 - 2018

- Place and Remove Temporary Drainage Pipe
- Grading
- Precast and Install Concrete Anchor Blocks
- Drill and Install Ground Anchors
- Jack and Bore Pipe Conduit
- Pipe Extensions
- Drill and Install Inclinometers
- Topsoil, Seeding, & Permanent Erosion Control
Year 2 - 2018

- Removal of Pavement
- Grading
- PCC Pavement
- Permanent Erosion Control
Major Project Issues

- Jack and Bore Pipe Conduit
- Erosion Control
Jack and Bored Pipe

- Reconstruction of the pavement section triggered a hydraulic study
- Hydraulic study called for an additional 30” diameter pipe to be jack and bored through the slide area
- Original schedule called for this to take 21 days
- Work began on October 28th, 2018
- October 30th pipe contractor encountered boulders (approx. 140’ in)
- No boulders were encountered during geotechnical investigation
- Boulders required microblasting and manual removal for the rest of the 170’ of pipe
- 36 ground anchors could not be installed in 2018 due to the bore pit
- Construction completed on May 22nd, 161 total days to complete this work
- Contract revision due to differing site conditions
Jack and Bored Pipe

- All labor, equipment, & material was tracked and accounted for
- Re-Mobilization to finish the ground anchor work
Erosion Control

- The Original Design was to install seeding class II or Wetland Seed with Turf Reinforcement Mats
- In the Spring of 2019, the ditch experienced high turbulent flows
- The NDDOT and the Contractor evaluated the ditch and noticed excessive amounts of erosion
Erosion Control

- The Original Design was to install seeding class II or Wetland Seed with Turf Reinforcement Mats
- In the Spring of 2019, the ditch experienced high turbulent flows
- The NDDOT and the Contractor evaluated the ditch and noticed excessive amounts of erosion
- A contract revision was made to line the ditch with Grade II RIP RAP to prevent future erosion from occurring.
Consultant Role - Review

- Subsurface Information
  - Exploration and instrumentation by NDDOT
  - Review NDDOT landslide characterization

- Proposed Alternatives
  - Preliminary analyses
  - Comparison and selection of stabilization approach

- Design of Selected Alternative
  - Review of NDDOT analyses and Independent analyses

- Plans and Specifications
  - Review and support
Consultant Role - Review

- Independent Analyses
  - Limit Equilibrium
    - Preliminary evaluation of various alternatives
    - Check of NDDOT final design and evaluation of several construction cases (e.g. installation of access benches, culvert)
- Stress Distribution
- Specialized Analyses
  - FLAC to evaluate A-Frame micropile structure
Review Schedule

- 2 Weeks of Receiving Deliverable
- Concept – Engagement throughout Design Process to Expedite Review Process
- Coordinated effort to find and evaluate potential fatal flaws
  - Construction access and stability of slide
  - Anchor bond strength
Add-Ons

- Ground Anchor Specifications
- Instrumentation for stability monitoring
  - Shape Accel Array
  - Real-time remote monitoring with alerts
  - Setting monitoring thresholds and dealing with triggers
Construction

- Full-time representative during anchor installation
- Review of verification and proof test results
- Stability monitoring and review of SAA data
- Problems during construction?
Submittal Review

- Anchor Contractor
- Anchor Working Drawing
- Instrumentation Plan
- Sacrificial Tests
- Work Plan to Remove Obstruction
Inspector

- Interpret and verify the Contractors compliance
- Perform visual field verification of excavated soil/rock material for comparison to the projects boring logs
- Perform required reporting
- Perform inspection of instrumentation installation for compliance to plans and manufacturer recommendations
## Instrumented Anchors

### Anchor A-19

<table>
<thead>
<tr>
<th>Strain Gauge</th>
<th>Test Load at 193 kips</th>
<th>18 Days after Lock-off</th>
<th>Readings taken 7/3/19</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 (10' in bond zone)</td>
<td>Not Functioning</td>
<td>67.8 kips</td>
<td>72.7 kips</td>
</tr>
<tr>
<td>S2 (25' in bond zone)</td>
<td>31.2 kips</td>
<td>23.4 kips</td>
<td>27.6 kips</td>
</tr>
<tr>
<td>S3 (40' in free length)</td>
<td>151.8 kips</td>
<td>109.8 kips</td>
<td>91.8 kips</td>
</tr>
</tbody>
</table>

### Anchor C-37

<table>
<thead>
<tr>
<th>Strain Gauge</th>
<th>Lock-off at 193 kips</th>
<th>2 Days after Lock-off</th>
<th>7 Days after Lock-off</th>
<th>Readings taken 7/3/19</th>
</tr>
</thead>
<tbody>
<tr>
<td>S7 (10' in bond zone)</td>
<td>88.8 kips</td>
<td>90.6 kips</td>
<td>93.0 kips</td>
<td>97.8 kips</td>
</tr>
<tr>
<td>S8 (25' in bond zone)</td>
<td>28.2 kips</td>
<td>31.2 kips</td>
<td>31.2 kips</td>
<td>30 kips</td>
</tr>
<tr>
<td>S9 (40' in free length)</td>
<td>139.2 kips</td>
<td>132 kips</td>
<td>126 kips</td>
<td>140.4 kips</td>
</tr>
</tbody>
</table>
Summary

- Consultant Review Role Successful
- Useful when Considering New Technology or New Design Approaches without In-House Experience
- Previous Working Relationship Helpful
- Ground Anchor Stabilization Successful
- Don’t Forget about the Other Features of a Project