GEOTECHNICAL
CONSULTANTS INC.

**GCI PROJECT No.: 21-G-25314**

# Structure Foundation Exploration Report

MOE-CR28-00.56 Bridge Replacement, PID 109262
Bondi Ridge Road over Cranenest Fork

Green Township, Monroe County, Ohio

**Prepared for:**
ADR & Associates, Ltd.

August 22, 2021

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August 22, 2021

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**Reference: Structure Foundation Exploration Report**
**MOE-CR28-00.56 Bridge Replacement**
**Bondi Ridge Road over Cranenest Fork**
**Green Township, Monroe County, Ohio**
**GCI Project No. 21-G-25314**

Dear Mr. Hartfield:

As authorized, Geotechnical Consultants, Inc. (GCI) has performed a subsurface exploration and prepared this structure foundation exploration report for the referenced project. After you have reviewed the report, feel free to contact GCI with any questions you may have. GCI appreciates the opportunity to provide our services for this project, and we hope to continue service through construction.

Sincerely,
**Geotechnical Consultants, Inc.**

STATE OF OHIO
JEFFREY M. HOLKO
E-82689
REGISTERED
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**Distribution:** Mr. Justin Hartfield @ ADR & Associates, Ltd – 1 pdf via e-mail
GCI File – 1 copy

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## 1.0 EXECUTIVE SUMMARY

The project involves removal and replacement of the existing bridge carrying Bondi Ridge Road over Cranenest Fork. We performed geotechnical borings to aid in assessing subsurface conditions and making recommendations for foundations of the proposed bridge. The borings found natural deposits of fine- and coarse-grained soils overlying shale bedrock. We have recommended the new bridge be founded on a deep foundation system consisting of drilled shafts end-bearing in bedrock.

## 2.0 INTRODUCTION

As requested by Mr. Justin Hartfield, P.E., representing ADR & Associates, Ltd. (ADR), Geotechnical Consultants, Inc. (GCI) performed a subsurface exploration for the proposed bridge replacement project (MOE-CR28-00.56, PID 109262) for Bondi Ridge Road over Cranenest Fork in Green Township, Monroe County, Ohio. Our study consisted of two standard penetration test borings (one behind each of the existing abutments), laboratory soil testing, and walk-over site observations. A boring location plan and copies of the boring logs are included in the appendix.

The intent of this exploration was to evaluate subsurface conditions and offer recommendations relative to foundations for the proposed bridge replacement. This report has been prepared for the exclusive use of ADR and their consultants for specific application to the referenced bridge replacement project in accordance with generally accepted soil and foundation engineering practices. No warranty, expressed or implied, is made.

## 3.0 GEOLOGY AND OBSERVATIONS OF THE PROJECT

The existing bridge spans Cranenest Fork. A site aerial below shows the existing bridge location and immediate surrounding area.


**Aerial courtesy of Google Earth (Image dated October 2015)**

The existing bridge consists of a steel superstructure supported by two abutments. The underside of the structure contains a network of beams and girders, with a truss system above the deck. The bridge deck was built with corrugated metal decking filled with asphalt. The abutments consist of cut stone blocks with mortar. The bridge span was measured at 71' and the deck width at about 16.5'. Please see the images on the following page.

Facing North

Facing South

Facing North Abutment

Facing South Abutment

The bridge spans Cranenest Fork, which generally flows from the east to the west at the bridge area. GCI reviewed topographic information from the United States Geological Survey (USGS), which shows the stream and bank at an elevation range of 860' – 870'. Grades rise sharply to the south and north (i.e., outside of the Cranenest Fork valley) to elevations exceeding 1,100'.

The creek bed was measured at about 12.5' below the top of bridge deck. On the day of our site visit (June 16, 2021), the creek was about 1.5' – 2' deep. Cranenest Fork has a slight bend as it approaches the bridge from the east. This bend had a considerable amount of debris stacked along its bank. Beyond this bank, grades rise sharply up the mountain to the south. The bank northeast of the bridge was about 2' – 3' in height and vegetated and flat; about 200' to the north, grades rise sharply. See the photos below.


**Bank Southeast of Bridge (Debris at Bend)** **Bank Northeast of Bridge**

Downstream of the bridge (to the west), both banks were vegetated. The northwest bank was about 7' – 8' in height and flat beyond for about 200', where grades then rise sharply. Some erosion was noted along the northwest bank. The southwest bank was about 5' – 6' in height with a vegetated flat area on top. About 100' south of the southwest bank, grades rise sharply to the south. See the photos below.


**Bank Northwest of Bridge** **Cranenest Fork Downstream (to the west)**

GCI researched and attained available geotechnical information using the following sources:

- *Physiographic Regions of Ohio* produced by the Ohio Department of Natural Resources (ODNR) – Division of Geological Survey:

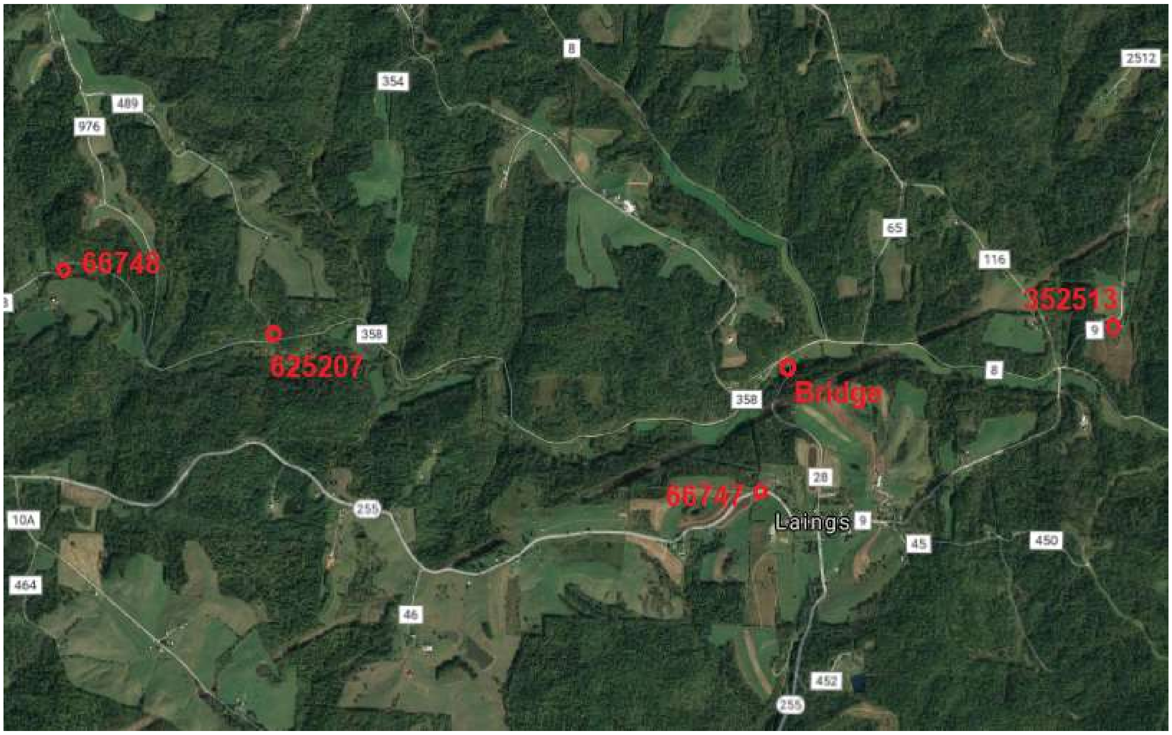
  The map notes the site to be within the far eastern extent of the Marietta Plateau. The map characterizes this plateau to have high relief (generally 350’, and up to 600’ near the Ohio River), fine-grained rocks, and red shales. Landslides are common in this region.

- *Bedrock Geology Map of Ohio* produced by the ODNR – Division of Geological Survey:

  The map shows bedrock to consist of lower Pennsylvanian age – sedimentary rocks: mainly shale, sandstone, siltstone, mudstone, and some coal.

- Well boring information from the Ohio Department of Natural Resources (ODNR) – Division of Water Resources, Water Wells Map:

  Utilizing the ODNR Water Wells Map, logs from four wells were reviewed (see diagram below). Well 66748 recorded limestone at a depth of 13 feet, well 625207 recorded sandstone at a depth of 3 feet, well 66747 recorded shale at a depth of 19 feet, and well 352513 recorded shale at a depth of 14 feet. Note that wells 66747 and 352513 are outside of the Cranenest Fork valley.




## 4.0 EXPLORATION

### 4.1 Historic Borings Review

GCI researched available geotechnical information using the ODOT Transportation Information and Mapping System (TIMS) program. The nearest project was about 1.5 to the south. This project contained PID 99390 and was for culvert preservation. Due to the distance and the project being in a different valley, and likely different geological conditions, we do not consider is as a reliable comparison. We consider the nearby water well logs (mentioned in the prior section) as the most reliable source as a comparison of similar geological conditions.

### 4.2 Project Exploration

After performing research on the site geological conditions (as discussed in Section 3.0 and Subsection 4.1), GCI visited the project site. At the project site, we were able to determine the depth from road surface to stream bed; knowing this depth aided us in shaping our exploration program. After review of the ODOT Specifications for Geotechnical Exploration (SGE), GCI created the following boring sequence prior to site mobilization:

- 2.5' interval spacing from the road surface to stream bed;
- Continuous sampling from the stream bed to 6' below the stream bed (scour sampling zone);
- Since we expected the bottom of footing / pile cap to be near the stream bed elevation, we would drill at 2.5' intervals for about 14' beyond the scour sampling zone;
- 5' sampling intervals to a depth of 40'.

GCI mobilized a truck-mounted rotary drill rig with automatic sampling hammer (calibrated energy rating of 82%) to the site on July 12, 2021. We drilled two borings (B-001-0-21 & B-002-0-21) within the roadway, behind the existing bridge abutments. Both borings were drilled to a depth of 23 feet below existing pavement, where auger refusal was encountered on bedrock.

Our $N_{60}$-values were determined by using the following equation:

$N_{60} = N_m \times (ER/60)$

where: $N_m$ = the field blow counts from the 2nd and 3rd 6-inch intervals

ER = the drill rod energy ratio (82 for the CME 45B used on this project)

Our subsurface findings were generally consistent with the previously noted well boring logs and published geologic data. Our boring findings are described in Section 5.0.

### 4.3 Laboratory Testing Program

GCI performed a laboratory testing program consisting of natural moisture content, Atterberg Limits, grain size analysis, and hydrometer analysis. Results of the laboratory soil testing have been incorporated into the text of this report and attached boring logs; results are attached in the Appendix. Note the sample from the 15.5' – 16.5' depth interval in boring B-001-0-21 did not contain enough recovery to perform laboratory testing. The listed strata was based on driller observations and the minimal sample recovery.

## 5.0 FINDINGS

The upper level soils (above stream level) consisted of fine- and coarse-grained fill soils of variable stiffness / density. Upon reaching stream level (i.e., about 12.5 feet below top of pavement), interspersed natural coarse-grained (A-1b, A-2-4, A-3a) and fine-grained (A-4a and A-6a) materials were encountered. Standard penetration test $N_{60}$-values increased with depth. Shale bedrock was encountered below the natural soil deposits. We summarize our findings below; please refer to the boring logs for specific information at the boring locations.

B-001-0-19 (drilled behind south abutment of existing bridge):

- 0' – 0.75': asphalt (6") over aggregate base (3");
- 0.75' – 10.5': soft to stiff brown SILT AND CLAY (A-6a), fill, damp; interspersed layers of coal, gravel, and sand;
- 10.5' – 12.5': loose dark gray and black STONE FRAGMENTS WITH SAND (A-1-b), fill, damp;
- 12.5' – 14.0': medium dense brown STONE FRAGMENTS WITH SAND (A-1-b), wet;
- 14.0' – 15.0': stiff brown SANDY SILT (A-4a), damp;
- 15.0' – 15.5': stiff gray SILT AND CLAY (A-6a), damp;
- 15.5' – 16.5': very dense brown STONE FRAGMENTS WITH SAND (A-1-b), wet;
- 16.5' – 18.5': gray highly weathered SHALE, fissile;

- 18.5’ – 23.0’: gray moderately weathered SHALE;
- groundwater seepage was encountered at a depth of 12’ during drilling;
- auger refusal at 23’.

B-002-0-19 (drilled behind north abutment of existing bridge):

- 0’ – 0.83’: asphalt (8”) over aggregate base (2”);
- 0.83’ – 3.0’: medium dense light gray and yellowish brown STONE FRAGMENTS WITH SAND AND SILT (A-2-4), fill, damp;
- 3.0’ – 5.5’: loose dark gray and black STONE FRAGMENTS WITH SAND (A-1-b), fill damp; gray clay layer near 5.5’;
- 5.5’ – 8.0’: medium stiff gray SANDY SILT (A-4a), fill, damp; sand and stone fragment layers near 8’;
- 8.0’ – 12.5’: medium stiff brown SILT AND CLAY (A-6a), fill, moist; sand and stone fragment layers near 11’;
- 12.5’ – 14.0’: medium stiff dark brown SANDY SILT (A-4a), moist;
- 14.0’ – 15.5’: loose gray GRAVEL WITH SAND (A-1-b), wet;
- 15.5’ – 17.0’: loose gray and brown SANDY SILT (A-4a), wet;
- 17.0’ – 18.5’: medium dense gray and brown STONE FRAGMENTS WITH SAND AND SILT (A-2-4), wet;
- 18.5’ – 20.0’: dense gray and brown COARSE AND FINE SAND (A-3a), wet;
- 20.0’ – 23.0’: gray highly to moderately weathered SHALE;
- groundwater seepage was encountered at a depth of 14’ during drilling;
- auger refusal at 23’.

## 6.0 ANALYSES AND RECOMMENDATIONS

### 6.1 Foundations

GCI reviewed three foundation types for the new bridge abutments; our analyses assumed a bottom of pile cap elevation of 10 feet below existing pavement based on information provided by ADR:

- <u>Driven Piles</u>: Driven piles would be driven to end bear in shale bedrock. Section 305.3.5.7 of the 2021 ODOT Bridge Design Manual (BDM) requires that piles attain a minimum 5-foot embedment into bedrock if the soil embedment length is below 10 feet (as would likely be the case for the south abutment). The shale transitions from a highly to moderately weathered shale within a few feet of the soil / bedrock interface. It is possible that pile refusal may occur less than 5 feet into the shale. Therefore, we deemed driven piles as not feasible.

- <u>Spread Footings</u>: Spread footings would bear on shale bedrock. The depth to reach bedrock would be ± 7.5 feet below stream level at the north abutment (boring B-002-0-21). Excavating and dewatering costs would likely make this option less economically viable than a deep foundation option. Therefore, we determined that spread footings would not be feasible.

- <u>Drilled Shafts</u>: BDM Section C305.4 states that drilled shafts should be considered when driven pile depth requirements cannot be met and spread footings are not feasible due to depth. In our opinion, drilled shafts bearing within the shale bedrock are the most feasible foundation option for this project.

Drilled shaft foundations would bear in moderately weathered shale bedrock. The shafts would attain a majority of their resistance from end bearing, and a smaller amount from side resistance. Note that GCI does not recommend accounting for side resistance within the soil layers or highly weathered shale.

Our analysis for side resistance (skin friction) began using AASHTO LRFD Equation 10.8.3.5.4b-1:

$$q_s = 0.65 \bullet \alpha_E \bullet p_a (q_u/p_a)^{0.5} \quad \text{where } q_s < 7.8 \bullet p_a (f_c'/p_a)^{0.5}$$

assume: $f_c'$ = 3 kips per square inch (ksi)

$p_a$ = 2.12 ksf

$\alpha_E$ = 0.45 (see Analysis and Calculations section in the Appendix)

Next, we evaluated the unconfined compressive strength ($q_u$) of the shale bedrock using the document "Modified Standard Penetration Test-Based Drilled Shalt Design Method for Weak Rocks" (research report no. FHWA-ICT-17-018*,* dated December 2017). Resistance factors attained from AASHTO LRFD Table 10.5.5.2.4-1 were used for side and tip resistance values. Our analyses are shown in the Appendix of this report (see sheets 2 and 3 of the Analyses and Calculations section). GCI recommends the following parameters for drilled shafts:

- Side resistance ($q_s$) = 0.90 kips per square foot (ksf) *

  *This side resistance value is for "moderately weathered" shale bedrock; for the purposes of this report, "moderately weathered" shale bedrock is shale with an SPT penetration value of 3 inches or less over 50 blow counts. On-site observation of drilling activities by a geotechnical engineer, or their representative, would need to be performed to confirm "moderately weathered" bedrock.

- Tip resistance ($q_{tip}$) = 20 ksf **

  *This tip resistance value is for shale bedrock with an SPT penetration value of 1 inch or less over 50 blow counts. Based on our borings, GCI anticipates shale bedrock of this tip resistance to be attained at a depth of 21' below top of pavement at both abutments; on-site observation of drilling activities by a geotechnical engineer, or their representative, would need to be performed to confirm suitable end bearing conditions.

## 6.2 Scour

A scour study was beyond the scope of our services for the project. As a minimum for scour mitigation, we recommend the placement of Rock Channel Protection along the entire length of abutments and wing walls. As stated in the Federal Highways Administration (FHWA) “Hydraulic Engineering Circular No. 18” (HEC-18), rip-rap is not a permanent countermeasure against scour, nor does it eliminate the potential for scour. Therefore, we recommend that the bridge be periodically inspected, particularly after major storm events, to ensure the rip-rap blanket is properly preserved. $D_{50}$ values from our borings are presented below.

| Boring | Sample | Depth | $D_{50}$ values | Boring | Sample | Depth | $D_{50}$ values |
|---|---|---|---|---|---|---|---|
| B-001-0-21 | SS-1 | 1’ – 2.5’ | 0.2373 mm | B-002-0-21 | SS-1 | 1’ – 2.5’ | 0.8304 mm |
| B-001-0-21 | SS-2 | 3.5’ – 5’ | 0.4293 mm | B-002-0-21 | SS-2 | 3.5’ – 5’ | 1.4261 mm |
| B-001-0-21 | SS-4 | 8.5’ – 10’ | 0.0622 mm | B-002-0-21 | SS-3 | 6’ – 7.5’ | 0.15 mm |
| B-001-0-21 | SS-5 | 11’ – 12.5’ | 1.1521 mm | B-002-0-21 | SS-6 | 11’ – 12.5’ | 0.0206 mm |
| B-001-0-21 | SS-6 | 12.5’ – 14’ | 0.6996 mm | B-002-0-21 | SS-7 | 12.5’ – 14’ | 0.0557 mm |
| B-001-0-21 | SS-7a | 14’ – 15’ | 0.0948 mm | B-002-0-21 | SS-8 | 14’ – 15.5’ | 2.4073 mm |
| B-001-0-21 | SS-7b | 15’ – 15.5’ | 0.2832 mm | B-002-0-21 | SS-9 | 15.5’ – 17’ | 0.1532 mm |
| | | | | B-002-0-21 | SS-10 | 17’ – 18.5’ | 0.3737 mm |
| | | | | B-002-0-21 | SS-11 | 18.5’ – 20’ | 0.3169 mm |

## 7.0 CONSTRUCTION MATERIALS ENGINEERING AND TESTING

GCI provides construction materials engineering and testing services. For project continuity throughout construction, we recommend GCI be retained to observe, test, and document:

- earthwork procedures,
- drilled shaft installation observations,
- reinforcing steel and concrete observation and testing, and
- structural steel (welds, bolts, etc.).

The purpose of this work is to assess that our recommendations are being followed and to make timely changes to our recommendations (as needed) in the event site conditions vary from those encountered in our borings. Please contact our field department to initiate these services.

## 8.0 FINAL

In the event that changes to the nature, design, or location of the proposed bridge are planned, the conclusions and recommendations contained in this report shall not be considered valid, unless the changes are reviewed and conclusions of this report are modified or verified by Geotechnical Consultants, Inc. This report is for design purposes only and is not sufficient to prepare an accurate bid. GCI appreciates the opportunity to work with you on this project. If you have any questions or the need for additional service, please call.

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# APPENDIX – MOE-CR28-00.56 Bridge Replacement – Monroe County, Ohio

# APPENDIX A.1 - ODOT Quick Reference for Visual Description of Soils

**1) STRENGTH OF SOIL:**

Non-Cohesive (granular) Soils - Compactness

| Description | Blows Per Ft. |
|---|---|
| **Very Loose** | ≤ 4 |
| **Loose** | 5 – 10 |
| **Medium Dense** | 11 – 30 |
| **Dense** | 31 – 50 |
| **Very Dense** | > 50 |

Cohesive (fine grained) Soils - Consistency

| Description | Qu (TSF) | Blows Per Ft. | Hand Manipulation |
|---|---|---|---|
| **Very Soft** | <0.25 | <2 | Easily penetrates 2" by fist |
| **Soft** | 0.25-0.5 | 2 - 4 | Easily penetrates 2" by thumb |
| **Medium Stiff** | 0.5-1.0 | 5 - 8 | Penetrates by thumb with moderate effort |
| **Stiff** | 1.0-2.0 | 9 - 15 | Readily indents by thumb, but not penetrate |
| **Very Stiff** | 2.0-4.0 | 16 - 30 | Readily indents by thumbnail |
| **Hard** | >4.0 | >30 | Indent with difficulty by thumbnail |

**2) COLOR :**

If a color is a uniform color throughout, the term is single, modified by an adjective such as light or dark. If the predominate color is shaded by a secondary color, the secondary color procedes the primary color. If two major and distinct colors are swirled throughout the soil, the colors are modified by the term "mottled"

**3) PRIMARY COMPONENT**

Use **DESCRIPTION** from ODOT Soil Classification Chart on Back

**4) COMPONENT MODIFIERS:**

| Description | Percentage By Weight |
|---|---|
| **Trace** | 0% - 10% |
| **Little** | 10% - 20% |
| **Some** | 20% - 35% |
| **"And"** | 35% -50% |

**5) Soil Organic Content**

| Description | % by Weight |
|---|---|
| **Slightly Organic** | 2% - 4% |
| **Moderately Organic** | 4% - 10% |
| **Highly Organic** | > 10% |

**6) Relative Visual Moisture**

| Description | Criteria | |
|---|---|---|
| | **Cohesive Soil** | **Non-cohesive Soils** |
| **Dry** | Powdery;<br>Cannot be rolled;<br>Water content well below the plastic limit | No moisture present |
| **Damp** | Leaves very little moisture when pressed between fingers;<br>Crumbles at or before rolled to $^1/_8$";<br>Water content below plastic limit | Internal moisture, but no to little surface moisture |
| **Moist** | Leaves small amounts of moisture when pressed between fingers;<br>Rolled to $^1/_8$" or smaller before crumbling;<br>Water content above plastic limit to -3% of the liquid limit | Free water on surface, moist (shiny) appearance |
| **Wet** | Very mushy;<br>Rolled multiple times to $^1/_8$" or smaller before crumbles;<br>Near or above the liquid limit | Voids filled with free water, can be poured from split spoon. |

# CLASSIFICATION OF SOILS

Ohio Department of Transportation

(The classification of a soil is found by proceeding from top to bottom of the chart. The first classification that the test data fits is the correct classification.)

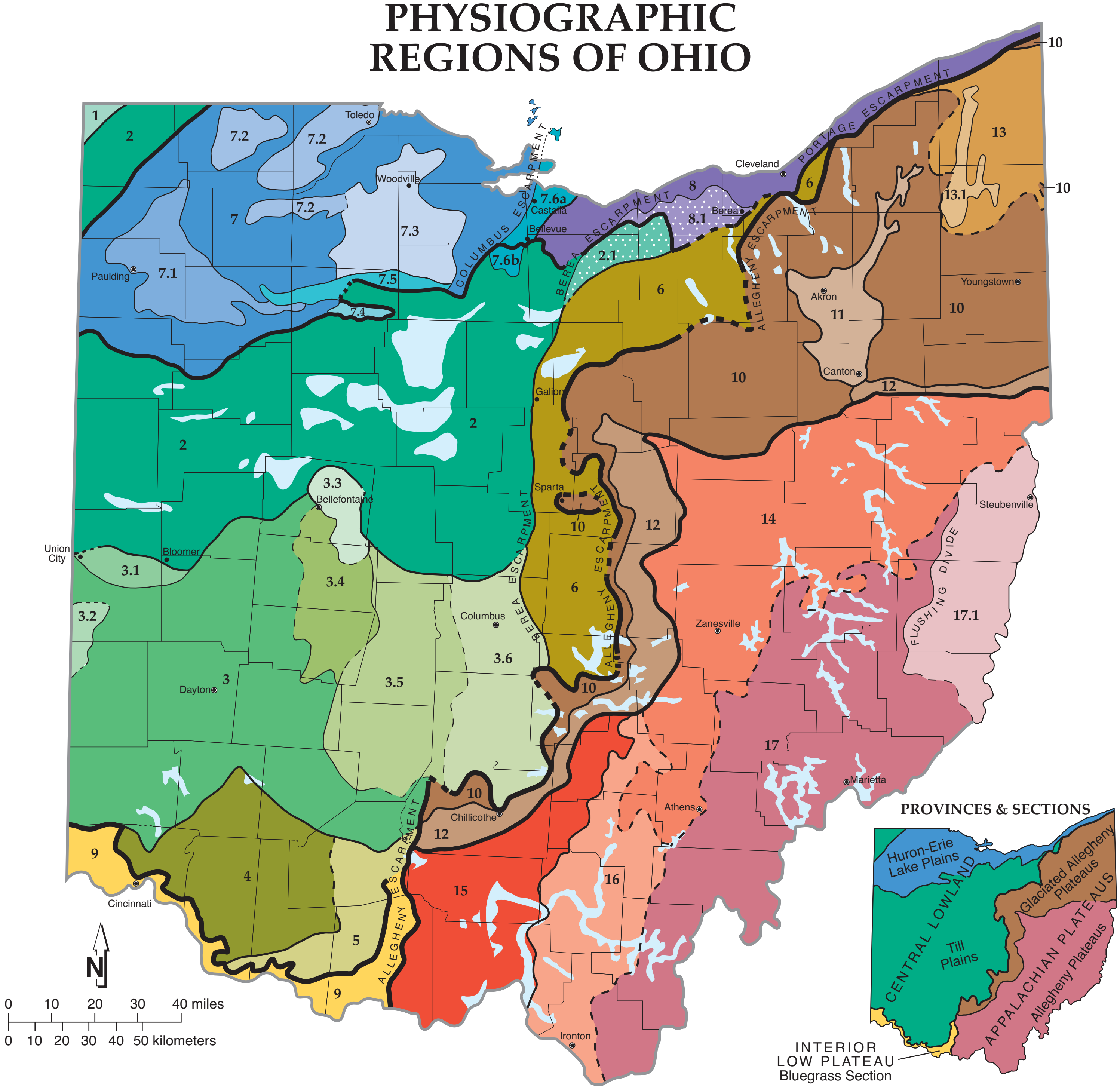
| SYMBOL | DESCRIPTION | Classifcation AASHTO | Classifcation OHIO | $LL_O/LL$ x 100* | % Pass #40 | % Pass #200 | Liquid Limit (LL) | Plastic Index (PI) | Group Index Max. | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| | Gravel and/or Stone Fragments | A-1-a | | | 30 Max. | 15 Max. | | 6 Max. | 0 | Min. of 50% combined gravel, cobble and boulder sizes |
| | Gravel and/or Stone Fragments with Sand | A-1-b | | | 50 Max. | 25 Max. | | 6 Max. | 0 | |
| F S | Fine Sand | A-3 | | | 51 Min. | 10 Max. | NON-PLASTIC | | 0 | |
| | Coarse and Fine Sand | -- | A-3a | | | 35 Max. | | 6 Max. | 0 | Min. of 50% combined coarse and fine sand sizes |
| | Gravel and/or Stone Fragments with Sand and Silt | A-2-4<br>A-2-5 | | | | 35 Max. | 40 Max.<br>41 Min. | 10 Max. | 0 | |
| | Gravel and/or Stone Fragments with Sand, Silt and Clay | A-2-6<br>A-2-7 | | | | 35 Max. | 40 Max.<br>41 Min. | 11 Min. | 4 | |
| | Sandy Silt | A-4 | A-4a | 76 Min. | | 36 Min. | 40 Max. | 10 Max. | 8 | Less than 50% silt sizes |
| | Silt | A-4 | A-4b | 76 Min. | | 50 Min. | 40 Max. | 10 Max. | 8 | 50% or more silt sizes |
| | Elastic Silt and Clay | A-5 | | 76 Min. | | 36 Min. | 41 Min. | 10 Max. | 12 | |
| | Silt and Clay | A-6 | A-6a | 76 Min. | | 36 Min. | 40 Max. | 11 - 15 | 10 | |
| | Silty Clay | A-6 | A-6b | 76 Min. | | 36 Min. | 40 Max. | 16 Min. | 16 | |
| | Elastic Clay | A-7-5 | | 76 Min. | | 36 Min. | 41 Min. | ≦LL-30 | 20 | |
| | Clay | A-7-6 | | 76 Min. | | 36 Min. | 41 Min. | >LL-30 | 20 | |
| | Organic Silt | A-8 | A-8a | 75 Max. | | 36 Min. | | | | W/o organics would classify as A-4a or A-4b |
| | Organic Clay | A-8 | A-8b | 75 Max. | | 36 Min. | | | | W/o organics would classify as A-5, A-6a, A-6b, A-7-5 or A-7-6 |

MATERIAL CLASSIFIED BY VISUAL INSPECTION

- Sod and Topsoil
- Pavement or Base
- Uncontrolled Fill (Describe)
- Bouldery Zone
- Peat, S-Sedimentary W-Woody F-Fibrous L-Loamy & etc

* Only perform the oven-dried liquid limit test and this calculation if organic material is present in the sample.

# PHYSIOGRAPHIC REGIONS OF OHIO




Transitional boundary

Lake basin/deposits outside Huron-Erie Lake Plains

**Till Plains**

1. Steuben Till Plain
2. Central Ohio Clayey Till Plain
   - 2.1. Berea Headlands of the Till Plain
3. Southern Ohio Loamy Till Plain
   - 3.1. Union City-Bloomer Transitional Terrain
   - 3.2. Whitewater Interlobate Plain
   - 3.3. Bellefontaine Upland
   - 3.4. Mad River Interlobate Plain
   - 3.5. Darby Plain
   - 3.6. Columbus Lowland
4. Illinoian Till Plain
5. Dissected Illinoian Till Plain
6. Galion Glaciated Low Plateau

**Huron-Erie Lake Plains**

7. Maumee Lake Plains
   - 7.1. Paulding Clay Basin
   - 7.2. Maumee Sand Plains
   - 7.3. Woodville Lake-Plain Reefs
   - 7.4. Findlay Embayment
   - 7.5. Fostoria Lake-Plain Shoals
   - 7.6a and 7.6b. Bellevue-Castalia Karst Plain
8. Erie Lake Plain
   - 8.1. Berea Headlands of the Erie Lake Plain

**Bluegrass Section**

9. Outer Bluegrass Region

**Glaciated Allegheny Plateaus**

10. Killbuck-Glaciated Pittsburgh Plateau
11. Akron-Canton Interlobate Plateau
12. Illinoian Glaciated Allegheny Plateau
13. Grand River Low Plateau
    - 13.1 Grand River Finger-Lake Plain

**Allegheny Plateaus**

14. Muskingum-Pittsburgh Plateau
15. Shawnee-Mississippian Plateau
16. Ironton Plateau
17. Marietta Plateau
    - 17.1. Little Switzerland Plateau

4/98

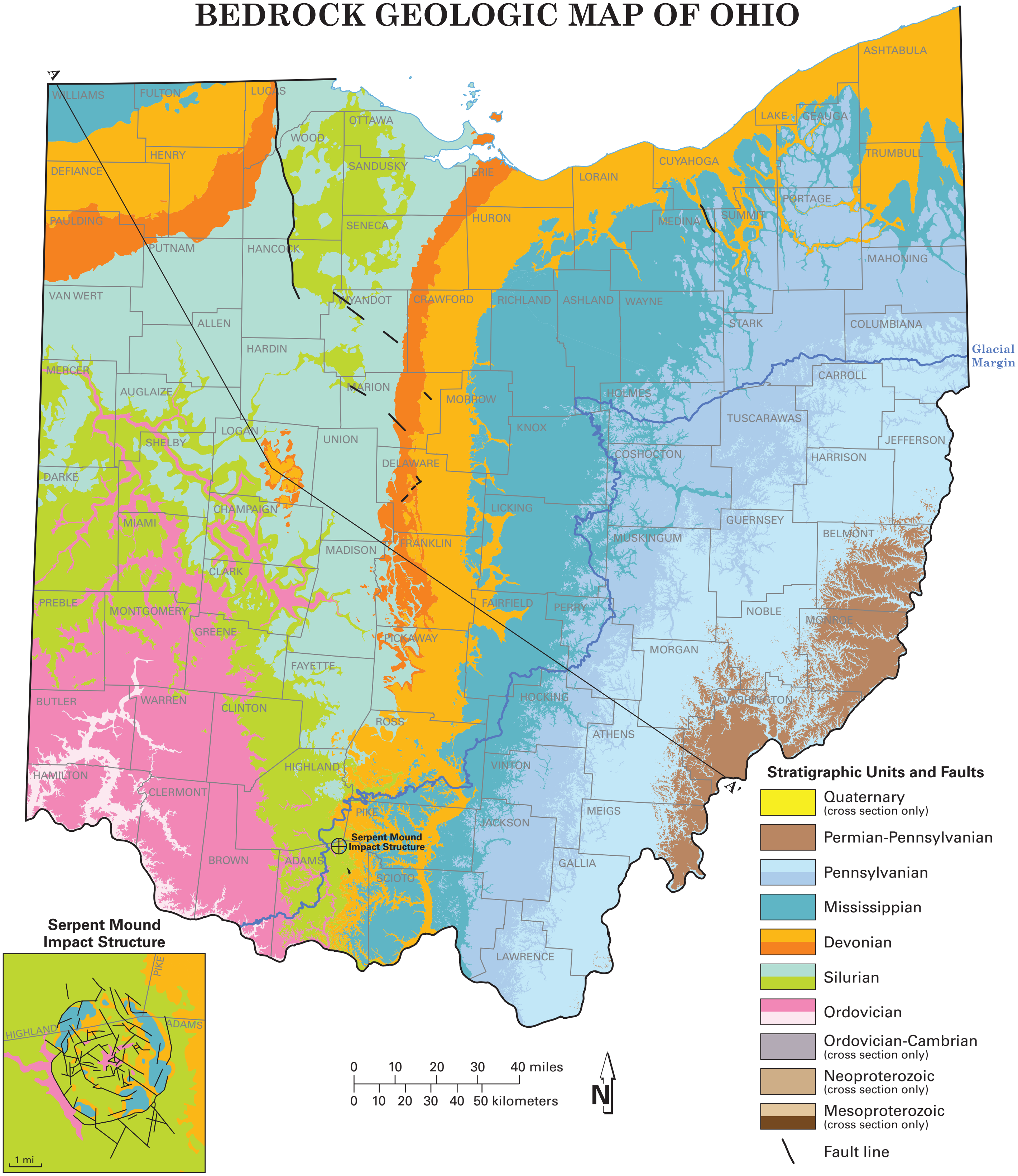
**Recommended citation:** Ohio Division of Geological Survey, 1998, Physiographic regions of Ohio: Ohio Department of Natural Resources, Division of Geological Survey, page-size map with text, 2 p., scale 1:2,100,00.

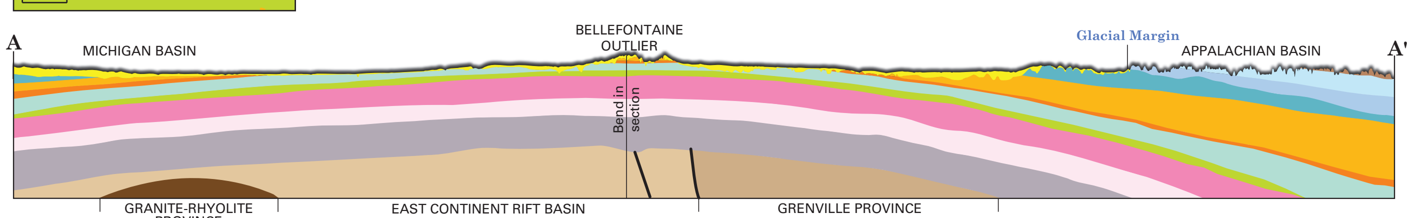
# PHYSIOGRAPHIC REGIONS OF OHIO

| Major Divisions | Provinces | Sections * | DISTINGUISHING CHARACTERISTICS OF REGIONS & DISTRICTS | GEOLOGY | BOUNDARIES |
|---|---|---|---|---|---|
| INTERIOR PLAINS | CENTRAL LOWLAND | Till Plains | **1. Steuben Till Plain.** Hummocky terrain with rolling hills, interspersed flats and closed depressions; wetlands, few streams, deranged drainage; only a small part of the region is in Ohio; elevation 950'-1100', moderately low relief (60') | Wisconsinan-age (latest Ice-Age) loamy till from a northern source (Saginaw glacial lobe) over Mississippian-age Coldwater Shale | Southeast: edge of Wabash Moraine |
| | | | **2. Central Ohio Clayey Till Plain.** Surface of clayey till; well-defined moraines with intervening flat-lying ground moraine and intermorainal lake basins; no boulder belts; about a dozen silt-, clay- and till-filled lake basins range in area from a few to 200 square miles; few large streams; limited sand & gravel outwash; elevation 700'-1150', moderate relief (100') | Clayey, high-lime Wisconsinan-age till from a northeastern source (Erie glacial lobe) and lacustrine materials over Lower Paleozoic-age carbonate rocks and, in the east, shales; loess thin to absent | North: Lake Plain; northeast: limit of Berea Sandstone; east: Berea Escarpment; south: Powell and Union City/Bloomer Moraines; northern segment boundaries: Wabash Moraine and lake plain |
| | | | **2.1. Berea Headlands of the Till Plain.** Gently rolling to flat terrain of thin drift descending to Lake Erie; punctuated by more than 20 streamlined "whalebacks" of Berea Sandstone, 0.5 to 2.5 miles long, 30'-60' high; somewhat poorly drained; elevation 800'-1000', low relief (20') | Thin, clayey, medium-lime Wisconsinan-age till over resistant Mississippian-age Berea Sandstone | South: limit of Berea Sandstone; elsewhere: Berea Escarpment and/or margin of highest Pleistocene lake |
| | | | **3. Southern Ohio Loamy Till Plain.** Surface of loamy till; end and recessional moraines, commonly associated with boulder belts, between relatively flat-lying ground moraine, cut by steep-valleyed large streams; stream valleys filled with outwash and alternate between broad floodplains and narrows; buried valleys common; elevation 530'-1150', moderate relief (200') | Loamy, high-lime Wisconsinan-age till, outwash, and loess over Lower Paleozoic-age carbonate rocks and, in the east, shales | East: Berea and Allegheny Escarpments; north: Powell and Union City/Bloomer Moraines; south: limit of Wisconsinan-age till |
| | | | **3.1. Union City-Bloomer Transitional Terrain.** Well-defined moraines with low-relief, hummocky ground moraine like the Central Ohio Clayey Till Plain to the north; loamy till with loess cap like Southern Ohio Loamy Till Plain to the south; elevation 920'-1075', moderately low relief (30') | Loamy, high-lime Wisconsinan-age till with thin loess cap over Silurian-age dolomites | North: Bloomer Moraine and limit of loamy till; south: Union City Moraine |
| | | | **3.2. Whitewater Interlobate Plain.** An upland between two converging glacial lobes with hummocky moraines, moraine complexes, kames, boulder belts, and broad outwash trains/plains; contains highest elevations in Indiana (1257') and in adjacent Ohio counties (1240'); elevation in Ohio 980'-1240', moderate relief (150') | Loamy, high-lime Wisconsinan-age till and sand and gravel outwash over resistant Silurian-age carbonate rocks (north) and less resistant Ordovician-age shales and limestones (south) | North: limit of Knightstown/Farmersville Moraines and kame fields; east: high, dissected hills draining to Whitewater River |
| | | | **3.3. Bellefontaine Upland.** Moderately high relief (250') dissected topography with moraine complexes, boulder belts, high-gradient major streams, caves and sinkholes; few glacial depressions/kettles compared to surrounding areas; elevation 1100'-1549', includes highest elevation in Ohio (Campbell Hill, 1549') | Loamy, high-lime Wisconsinan-age till over generally deeply buried Silurian- to Devonian-age carbonate rocks and Ohio Shale | North: areas with hilltops above 1200'; elsewhere: hilltops above about 1300' |
| | | | **3.4. Mad River Interlobate Plain.** Area between two major converging glacial lobes with extensive outwash, outwash terraces, and bordering moraines; springs and cool, ground-water-fed surface waters; elevation 800'-1350', moderate relief (200') | Loamy, high-lime Wisconsinan-age till and sand and gravel outwash over Silurian- to Devonian-age carbonate rocks and Ohio Shale | East and north: rear edge of Cable Moraine Complex; south: outwash to Clifton Gorge; west: western edge of Mad River Outwash |
| | | | **3.5. Darby Plain.** Moderately low relief (25'), broadly hummocky ground moraine with several broad, indistinct recessional moraines; between hummocks are broad, poorly drained swales which held wet prairies/meadows in pioneer days; few large streams; elevation 750'-1100' | Loamy, high-lime Wisconsinan-age till and sparse outwash over Silurian- and Devonian-age carbonate rocks and Ohio Shale in the southeast | South and west: front of Reesville and rear of Cable Moraines; north: Powell Moraine; east: increasing eastward slope (see 3.6) |
| | | | **3.6. Columbus Lowland.** Lowland surrounded in all directions by relative uplands, having a broad regional slope toward the Scioto Valley; many larger streams; elevation 600'-850' (950' near Powell Moraine), moderately low relief (25') | Loamy, high-lime (west) to medium-lime (east) Wisconsinan-age till and extensive outwash in Scioto Valley over deep Devonian- to Mississippian-age carbonate rocks, shales, and siltstones | North: Powell Moraine; east and south: Berea and/or Allegheny Escarpments; west: flatter and higher Darby Plain |
| | | | **4. Illinoian Till Plain.** Rolling ground moraine of older till generally lacking ice-constructional features such as moraines, kames, and eskers; many buried valleys; modern valleys alternating between broad floodplains and bedrock gorges; elevation 600'-1100', moderately low relief (50') | Silt-loam, high-lime, Illinoian-age till with loess cap; soils leached several feet; underlain by Ordovician- and Silurian-age carbonate rocks and calcareous shales | North: Wisconsinan glacial margin (Cuba and Hartwell Moraines); elsewhere: limit of common till-covered hillslopes |
| | | | **5. Dissected Illinoian Till Plain.** Hilly former till plain in which glacial deposits have been eroded from many valley sides; relatively high stream density; elevation 600'-1340', moderate relief (200') | Hilltops of high-lime Illinoian-age till with loess cap; slopes of bedrock- and till-derived colluvium and Ordovician- and Silurian-age carbonate rocks and calcareous shales | East: maximum glacial margin; elsewhere: limit of general absence of till on hillslopes |
| | | | **6. Galion Glaciated Low Plateau.** Rolling upland transitional between the gently rolling Till Plain and the hilly Glaciated Allegheny Plateau; mantled with thin to thick drift; elevation 800'-1400', moderate relief (100') | Medium- to low-lime Wisconsinan-age till over Mississippian-age shales and sandstones | North: limit of Berea Sandstone; west: Berea Escarpment; south and east: Allegheny Escarpment |
| | | Huron-Erie Lake Plains | **7. Maumee Lake Plains.** Flat-lying Ice-Age lake basin with beach ridges, bars, dunes, deltas, and clay flats; contained the former Black Swamp; slightly dissected by modern streams; elevation 570'-800', very low relief (5') | Pleistocene-age silt, clay, and wave-planed clayey till over Silurian- and Devonian-age carbonate rocks and shales | Northeast: Lake Erie; elsewhere: margin of highest Pleistocene lake |
| | | | **7.1. Paulding Clay Basin.** Nearly flat lacustrine plain; most clayey of all Lake Plain subregions; low-gradient, highly meandering streams; easily ponded soils; elevation 700'-725', extremely low relief (less than 5') | Pleistocene-age lacustrine clay over clay till and Silurian-age dolomites | Northeast: subdued ("drowned") remnant of Defiance Moraine; elsewhere: limit of lacustrine clay |
| | | | **7.2. Maumee Sand Plains.** Lacustrine plain mantled by sand; includes low dunes, inter-dunal pans, beach ridges, and sand sheets of glacial lakeshores; well to poorly drained; elevation 600'-800', very low relief (10') | Late Wisconsinan-age sand over clay till and lacustrine deposits; Silurian- and Devonian-age carbonate rocks and shales buried deeply. | Limit of sandy deposits and/or low dunes |
| | | | **7.3. Woodville Lake-Plain Reefs.** Very low relief (10') lacustrine plain with low dunes and lake-margin features, punctuated by more than 75 ancient bedrock reefs rising 10' to 40' above the level of the plain and ranging in area from 0.1 to 3.0 square miles; the oblong reefs are thinly draped with drift; elevation 600'-775' | Thin to absent Wisconsinan-age wave-planed clay till, lacustrine deposits, and sand over Silurian-age reefal Lockport Dolomite | Limit of thinly mantled Lockport Dolomite (Bowling Green Fault to the west and the Defiance Moraine to the south) |
| | | | **7.4. Findlay Embayment.** Very low relief (10'), broadly rolling lacustrine plain; embayment of ancestral Lake Erie in which relatively coarse lacustrine sediments collected; elevation 775'-800' | Silty to gravelly Wisconsinan-age lacustrine deposits and wave-planed clayey till over Silurian-age Lockport Dolomite | West: 775' beach ridge; north: Defiance Moraine; south: margin of highest Pleistocene lake level |
| | | | **7.5. Fostoria Lake-Plain Shoals.** Portion of the Defiance Moraine lightly eroded by shallow Lake Maumee with low north-south trending hillocks and shallow, closed depressions; many sandy areas; elevation 750'-825', low relief, decreasing westward (10'-15') | Silty to gravelly Wisconsinan-age lacustrine deposits and wave-planed clay till over deeply covered Silurian-age dolomite | South and east: unmodified Defiance Moraine; elsewhere: very low-relief lake plain |
| | | | **7.6a and 7.6b. Bellevue-Castalia Karst Plain.** Hummocky plain of rock knobs and numerous sinkholes, large solution features, and caves; large springs; thinly mantled by drift; region straddles both Lake Plain (7.6a) and Till Plain (7.6b); 7.6a has greatest relief of any Lake Plain region (25'); elevation 570'-825' | Columbus and Delaware Limestones overlain by thin clay till in 7.6b, and thin silty and sandy Wisconsinan-age lacustrine deposits and wave-planed clay till in 7.6a | Limit of thinly mantled Columbus and Delaware Limestones, which is marked in the west by the Columbus Escarpment |
| | | | **8. Erie Lake Plain.** Edge of very low-relief (10') Ice-Age lake basin separated from modern Lake Erie by shoreline cliffs; major streams in deep gorges; elevation 570'-800' | Pleistocene-age lacustrine sand, silt, clay, and wave-planed till over Devonian- and Mississippian-age shales and sandstones | North: Lake Erie; south: margin of highest Pleistocene lake |
| | | | **8.1 Berea Headlands of the Erie Lake Plain.** Portion of the Erie Lake Plain underlain by resistant Berea Sandstone; several large sandstone headlands jut into the Ice-Age lake basin; contains several streamlined "whalebacks" of Berea Sandstone, 0.5 to 2.0 miles long, 20'-35' high; poorly drained; elevation 670'-800', very low relief (10') | Thin lacustrine deposits over thin, wave-planed, clayey, medium-lime Wisconsinan-age till; underlain by resistant Berea Sandstone | North: portion of Lake Plain underlain by soft shales; south: margin of highest Pleistocene lake |
| | INT. LOW PLATEAUS | Bluegrass Section | **9. Outer Bluegrass Region.** Moderately high relief (300') dissected plateau of carbonate rocks; in east, caves and other karst features relatively common; in west, thin, early drift caps narrow ridges; elevation 455'-1120' | Ordovician- and Silurian-age dolomites, limestones, and calcareous shales; thin pre-Wisconsinan drift on ridges in west; silt-loam colluvium | Eastern segment: maximum glacial margin and high eastern ridges capped by noncarbonate rocks; connected by Ohio River bluffs to western segment which is bounded by nondissected till plain |
| APPALACHIAN HIGHLANDS | APPALACHIAN PLATEAUS | Glaciated Allegheny (Southern New York) Plateaus | **10. Killbuck-Glaciated Pittsburgh Plateau.** Ridges and flat uplands generally above 1200', covered with thin drift and dissected by steep valleys; valley segments alternate between broad drift-filled and narrow rock-walled reaches; elevation 600'-1505', moderate relief (200') | Thin to thick Wisconsinan-age clay to loam till over Mississippian- and Pennsylvanian-age shales, sandstones, conglomerates and coals | West and north: resistant sandstones of the Allegheny and Portage Escarpments; south and east: Wisconsinan glacial margin |
| | | | **11. Akron-Canton Interlobate Plateau.** Hummocky area between two converging glacial lobes dominated by kames, kame terraces, eskers, kettles, kettle lakes, and bogs/fens; deranged drainage with many natural lakes; elevation 900'-1200', moderate relief (200') | Sandy Wisconsinan-age and older drift over Devonian- to Pennsylvanian-age sandstones, conglomerates and shales | Limit of common, sandy ice-contact features and deposits |
| | | | **12. Illinoian Glaciated Allegheny Plateau.** Dissected, rugged hills; loess and older drift on ridgetops, but absent on bedrock slopes; dissection similar to unglaciated regions of the Allegheny Plateau; elevation 600'-1400', moderate relief (200') | Colluvium and Illinoian-age till over Devonian- to Pennsylvanian-age shales, siltstones and sandstones | North and west: Wisconsinan glacial margin; south and east: Illinoian (maximum) glacial margin |
| | | | **13. Grand River Low Plateau.** Gently rolling ground and end moraine having thin to thick drift; poorly drained areas and wetlands relatively common; elevation 760'-1200', low relief (20') except near Grand River Valley (200') | Clayey, low-lime Wisconsinan-age till over deeply buried, soft Devonian-age shales and near-surface Mississippian-age sandstones and shales | North: Portage Escarpment; south and west: Defiance Moraine; southeast: increasing relief from proximity of buried Pennsylvanian-age sandstones |
| | | | **13.1. Grand River Finger-Lake Plain.** Very low relief (10') lake deposits in steep-sided troughs (200' relief) within the Grand River Low Plateau; cut by glacial and stream erosion; extensive wetlands; elevation 800'-900' | Surficial lacustrine clay and drift over deeply buried, soft Devonian-age shales | Margins of steeply sloping troughs containing the Grand River and parts of Rock and Mosquito Creeks |
| | | Allegheny (Kanawha) Plateaus | **14. Muskingum-Pittsburgh Plateau.** Moderately high to high relief (300'-600') dissected plateau having broad major valleys that contain outwash terraces, and tributaries with lacustrine terraces; medium-grained bedrock sequences coarser than those in Marietta Plateau (17) but finer than those in Ironton Plateau (16); remnants of ancient Teays-age drainage system uncommon; elevation 650'-1400' | Mississippian and Pennsylvanian-age siltstones, shales, sandstones and economically important coals and claystones; Wisconsinan-age sand, gravel, and lacustrine silt; silt-loam colluvium | North and west: maximum glacial margin; southeast: transition to finer grained bedrock; southwest: transition to coarser grained bedrock |
| | | | **15. Shawnee-Mississippian Plateau.** High relief (400'-800'), highly dissected plateau of coarse and fine grained rock sequences; most rugged area in Ohio; remnants of ancient lacustrine clay-filled Teays drainage system are extensive in lowlands, absent in uplands; elevation 490'-1340' | Devonian- and Mississippian-age shales, siltstones, and locally thick sandstones; Pleistocene-age sandy outwash in Scioto River; Teays-age Minford Clay; silt-loam and channery colluvium | North: Maximum glacial margin; west:: carbonate bedrock; east: limit of Mississippian-age bedrock |
| | | | **16. Ironton Plateau.** Moderately high relief (300') dissected plateau; coarser grained coal-bearing rock sequences more common than in other regions of the Allegheny Plateau; common lacustrine clay-filled Teays Valley remnants; elevation 515'-1060' | Pennsylvanian-age (Pottsville, Allegheny and Conemaugh Groups) cycles of sandstones, siltstones, shales and economically important coals; Pleistocene (Teays)-age Minford Clay; silt-loam and channery colluvium | West: limit of common Pennsylvanian-age bedrock; north and east: gradation to finer rock sequences |
| | | | **17. Marietta Plateau.** Dissected, high-relief (generally 350', to 600' near Ohio River) plateau; mostly fine-grained rocks; red shales and red soils relatively common; landslides common; remnants of ancient lacustrine clay-filled Teays drainage system common; elevation 515'-1400' | Pennsylvanian-age Upper Conemaugh Group through Permian-age Dunkard Group cyclic sequences of red and gray shales, and siltstones, sandstones, limestones and coals; Pleistocene (Teays)-age Minford Clay; red and brown silty-clay loam colluvium; landslide deposits | North and west: transition to medium-grained Lower Conemaugh rocks; east: Flushing Divide |
| | | | **17.1. Little Switzerland Plateau.** Highly dissected, high-relief (generally 450', to 750' along Ohio River) plateau; mostly fine-grained rocks; red shales and red soils relatively common; landslides common; high-gradient shale-bottomed streams subject to flash flooding; no remnants of ancient Teays drainage system; elevation 540'-1400' | Similar to Marietta Plateau but lacking Pleistocene (Teays)-age Minford Clay | North: transition to medium-grained rocks; west and south: Flushing Divide; east: Ohio River |

* Section names modified from Fenneman (1938, 1946).

# BEDROCK GEOLOGIC MAP OF OHIO




**Recommended citation:** Ohio Division of Geological Survey, 2006, Bedrock geologic map of Ohio: Ohio Department of Natural Resources, Division of Geological Survey Map BG-1, generalized page-size version with text, 2 p., scale 1:2,000,000. [Revised 2017.]

This map is a generalization of the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006)—the first statewide 1:500,000-scale bedrock-geology map compiled by the ODNR Division of Geological Survey since 1920 and the first to properly portray the bedrock geology that exists beneath the extensive deposits of Quaternary sediments that cover much of the bedrock in the state[1]. Overall, the bedrock geology of Ohio consists of flat-lying to gently dipping carbonate, siliciclastic, evaporite, and organoclastic strata of sedimentary origin that range in age from Upper Ordovician to Upper Carboniferous-Lower Permian. As illustrated in the cross section, older sedimentary, igneous, and metamorphic rocks occur at depth and range from Lower Ordovician to Mesoproterozoic in age. At the surface, an irregular veneer of mainly unconsolidated Quaternary sediments conceal most bedrock units occurring northward and westward of the glacial margin.

Strata of the Ordovician System are the oldest exposed rocks in Ohio and consist mainly of alternating shale and limestone sequences. Silurian System strata are mostly dolomites with lesser amounts of shale. Rocks of the Devonian System consist of two contrasting types. Lower and Middle Devonian-age strata are mainly carbonate rocks, whereas Upper Devonian-age rocks consist mostly of clastic rocks. In Champaign and Logan Counties, Devonian-age rocks occur on a small erosional remnant referred to by geologists as the Bellefontaine Outlier. Coincidentally, the highest topographic point in Ohio (Campbell Hill at 1,549 feet above sea level) occurs also in this area.

The Carboniferous System is divided into two Subsystems, the Mississippian and Pennsylvanian. Mississippian-age strata are mostly shales and sandstones that occur locally in various proportions. Pennsylvanian-age strata consist mainly of a diverse array of alternating sandstones, siltstones, shales, mudstones, limestones, and underclays; economic coal beds occur also in portions of this sequence. The youngest interval of sedimentary rocks in Ohio, the Dunkard Group, occurs only in southeastern Ohio and consists of strata similar in composition to the underlying Upper Pennsylvanian-age rocks; however, the age of the Dunkard Group has been debated since the late 1800s. Dunkard strata contain a well-studied late Pennsylvanian-age assemblage of plant fossils with infrequent early Permian-age forms. Yet, fossil plant spores found in coal beds in the interval only support a late, but not latest Pennsylvanian age. Thus until more definitive fossils are found, geologists are unable to determine the exact age of the Dunkard Group beyond a combined Permian-Pennsylvanian age assignment.

In west-central Ohio, the ancient Teays River system extended across much of Ohio during the late Neogene to early Quaternary Periods and sculptured an extensive network of deeply dissected valleys into the bedrock surface. The spatial configuration of many geologic units on this map clearly reflects the major channel networks of these former drainage systems. Also, four major regional structural geology elements affect the spatial distribution of rocks in Ohio: the Appalachian and Michigan Basins and the Cincinnati and Findlay Arches, which occur between the two basins. Locally, several high-angle normal faults displace rocks in the state.

The Serpent Mound Impact Structure in southern Ohio is a circular area of deformed and broken rocks that is approximately nine miles in diameter. Recent investigations indicate the feature is the result of a meteorite or comet impact believed to have occurred between 256 and 330 million years ago.

Cross section A–A' traverses Ohio from the northwest to the southeast and intersects the southern portion of the Michigan Basin, the area between the Cincinnati and Findlay Arches, and the western Appalachian Basin, respectively. The stratigraphic units shown in this profile illustrate the broad, arching geometric distortion to the bedrock in Ohio, created mainly by periods of tectonic subsidence within these regional structural basins. For specific details on the various rock units, economic commodities, and geologic hazards within Ohio, see the large-format *Bedrock Geologic Map of Ohio* (Slucher and others, 2006), available for purchase by contacting the ODNR Geologic Records Center at 614-265-6576 or geo.survey@dnr.state.oh.us.

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1 Slucher, E.R., Swinford, E.M., Larsen, G.E., Schumacher, G.A., Shrake, D.L., Rice, C.L., Caudill, M.R., and Rea, R.G., 2006, Bedrock geologic map of Ohio: Ohio Department of Natural Resources, Division of Geological Survey Map BG-1, Version 6.0, scale 1:500,000.

**Quaternary** (about 1.8 million years ago to present). Unconsolidated sediments: till, gravel, sand, silt, clay, and organic debris. Continental origin. (Shown in cross section only)

*Period of widespread erosion*

**Permian and Pennsylvanian** (about 298 to 302 million years ago). Sedimentary rocks: mainly shale, sandstone, siltstone, mudstone, and minor coal. Continental origin.

**Pennsylvanian** (about 302 to 307 million years ago). Sedimentary rocks: mainly shale, sandstone, siltstone, mudstone, limestone, and some coal. Continental and marine origin.

**Pennsylvanian** (about 307 to 318 million years ago). Sedimentary rocks: mainly sandstone, siltstone, shale, and conglomerate, with some coal and limestone. Deltaic and marine origin.

*Period of widespread erosion*

**Mississippian** (about 322 to 359 million years ago). Sedimentary rocks: sandstone, shale, siltstone, conglomerate, and minor limestone. Marine to marginal marine origin.

**Devonian** (about 359 to 385 million years ago). Sedimentary rocks: mainly shale and siltstone with some sandstone. Marine to marginal marine origin.

**Devonian** (about 385 to 407 million years ago). Sedimentary rocks: mainly limestone and dolomite with some shale, and minor sandstone. Marine and eolian origin.

*Period of widespread erosion*

**Silurian** (about 416 to 423 million years ago). Sedimentary rocks: dolomite, anhydrite, gypsum, salt, and shale. Marine and restricted marine origin.

**Silurian** (about 423 to 435 million years ago). Sedimentary rocks: dolomite and shale with some limestone. Marine origin.

*Period of widespread erosion*

**Ordovician** (about 446 to 450 million years ago). Sedimentary rocks: shale and limestone. Marine origin.

**Ordovician** (about 450 to 460 million years ago). Sedimentary rocks: limestone and shale. Marine origin.

*Period of widespread erosion*

**Ordovician and Cambrian** (about 486 to 510 million years ago). Sedimentary rocks: mainly dolomite, sandstone, shale, with minor limestone. Marine origin. (Shown in cross section only.)

*Period of widespread erosion*

**Neoproterozoic** (between 900 million and 1 billion years ago). Metamorphic rocks: gneiss, schist, amphibolite, and marble; and igneous rocks: granite. Form during collision of tectonic plates. (Shown in cross section only.)

**Mesoproterozoic** (between 1.0 and 1.2 billion years ago). Sedimentary rocks: sandstone and siltstone; and igneous rocks: basalt and rhyolite. Form during rifting of continental landmass. (Shown in cross section only.)

*Period of widespread erosion*

**Mesoproterozoic** (between 1.45 and 1.52 billion years ago). Igneous rocks: granite and rhyolite. Formed during crustal evolution and differentiation. (Shown in cross section only.)


● **Boring Location**

**B-001-0-21 shown in upper photo; B-002-0-21 in lower photo**

| **BORING LOCATION PLAN** |
|---|
| **MOE-CR28-00.56 (Bondi Ridge Road) Bridge Replacement** |
| **Green Township, Monroe County, Ohio** |
| **Aerial obtained from Google Earth, dated October 2015** |
| **Project No.: 21-G-25314** |
| **Date: 08/22/2021 Drawn By: Jeffrey Holko** |
| **Scale: Not to Scale** |

| PROJECT: MOE-CR28-00.56 | DRILLING FIRM / OPERATOR: GCI / JAMES PODVIN | DRILL RIG: CME 45B(RIG 1-325744) | STATION / OFFSET: - | EXPLORATION ID B-001-0-21 |
|---|---|---|---|---|
| TYPE: BRIDGE REPLACEMENT | SAMPLING FIRM / LOGGER: GCI / JAMES PODVIN | HAMMER: CME AUTOMATIC | ALIGNMENT: - | |
| PID: 109262 BR ID: - | DRILLING METHOD: 3.5" SSA | CALIBRATION DATE: 12/18/20 | ELEVATION: - EOB: 23.0 ft. | PAGE 1 OF 1 |
| START: 7/12/21 END: 7/12/21 | SAMPLING METHOD: SPT | ENERGY RATIO (%): 82 | LAT / LONG: 39.723891, -81.013556 | |

| ***MATERIAL DESCRIPTION AND NOTES*** | ELEV. | DEPTHS | SPT/ RQD | $N_{60}$ | REC (%) | SAMPLE ID | HP (tsf) | GRADATION (%) GR | CS | FS | SI | CL | ATTERBERG LL | PL | PI | WC | ODOT CLASS (GI) | BACK FILL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Asphalt (6") over Aggregate Base (3") | | | | | | | | | | | | | | | | | | |
| STIFF, LIGHT BROWN AND GRAY, **SILT AND CLAY**, SOME STONE FRAGMENTS, SOME SAND, FILL, DAMP<br>interspersed coal fragments | | 1 – 2.5 | 4 4 3 | 10 | 78 | SS-1 | 0.75-1.75 | 31 | 14 | 13 | 16 | 26 | 36 | 22 | 14 | 18 | A-6a (2) | |
| MEDIUM STIFF | | 3.5 – 5 | 2 2 2 | 5 | 50 | SS-2 | 1.75-3.75 | 36 | 14 | 12 | 16 | 22 | 37 | 23 | 14 | 17 | A-6a (2) | |
| interspersed gravel from 3' - 8' | | 6 – 7.5 (▽ 7) | 2 3 3 | 8 | 44 | SS-3 | 0.5-1.25 | - | - | - | - | - | - | - | - | 16 | A-6a (V) | |
| SOFT<br>interspersed sand layers | | 8.5 – 10 | 2 1 1 | 3 | 56 | SS-4 | 0.75 | 29 | 10 | 9 | 26 | 26 | 34 | 21 | 13 | 12 | A-6a (5) | |
| LOOSE, DARK GRAY AND BLACK, **STONE FRAGMENTS WITH SAND**, SOME SILT, FILL, DAMP | | 11 – 12.5 (W 12) | 2 2 2 | 5 | 39 | SS-5 | | 40 | 25 | 15 | - 20 - | | NP | NP | NP | 8 | A-1-b (0) | |
| MEDIUM DENSE, BROWN, **STONE FRAGMENTS WITH SAND**, LITTLE SILT, WET<br>brown sandstone fragments | | 12.5 – 14 | 3 4 5 | 12 | 56 | SS-6 | | 40 | 20 | 24 | 7 | 9 | NP | NP | NP | 18 | A-1-b (0) | |
| STIFF, BROWN, **SANDY SILT**, SOME SAND, SOME STONE FRAGMENTS, DAMP | | 14 – 15.5 | 6 5 6 | 15 | 56 | SS-7a | | 21 | 9 | 22 | 33 | 15 | 25 | 18 | 7 | 13 | A-4a (3) | |
| STIFF, GRAY, **SILT AND CLAY**, SOME SAND, SOME STONE FRAGMENTS, DAMP | | | | | | SS-7b | | 28 | 17 | 15 | 21 | 19 | 29 | 17 | 12 | 15 | A-6a (2) | |
| VERY DENSE, BROWN, **STONE FRAGMENTS WITH SAND**, LITTLE SILT, WET | | 15.5 – 17 (TR 16) | 12 17 21 | 52 | 33 | SS-8 | | - | - | - | - | - | - | - | - | - | A-1-b (V) | |
| **SHALE**, GRAY, HIGHLY WEATHERED, FISSILE. | | | | | | | | - | - | - | - | - | - | - | - | - | Rock (V) | |
| | | 17 – 17.9 | 18 50/5" | - | 64 | SS-9 | | - | - | - | - | - | - | - | - | - | Rock (V) | |
| **SHALE**, GRAY, MODERATELY WEATHERED, @ 18.5' | | 18.5 | 50/3" | - | 100 | SS-10 | | - | - | - | - | - | - | - | - | - | Rock (V) | |
| | | 21 | 50/0" | - | | SS-11 | | - | - | - | - | - | - | - | - | - | | |
| Auger refusal at 23' | | EOB 23 | | | | | | | | | | | | | | | | |

NOTES: NONE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED ASPHALT PATCH; BACKFILLED WITH AUGER CUTTINGS

GCI Job No: 21-G-25314

| | | | |
|---|---|---|---|
| PROJECT: MOE-CR28-00.56 | DRILLING FIRM / OPERATOR: GCI / JAMES PODVIN | DRILL RIG: CME 45B(RIG 1-325744) | STATION / OFFSET: - |
| TYPE: BRIDGE REPLACEMENT | SAMPLING FIRM / LOGGER: GCI / JAMES PODVIN | HAMMER: CME AUTOMATIC | ALIGNMENT: - |
| PID: 109262 BR ID: - | DRILLING METHOD: 3.5" SSA | CALIBRATION DATE: 12/18/20 | ELEVATION: - EOB: 23.0 ft. |
| START: 7/12/21 END: 7/12/21 | SAMPLING METHOD: SPT | ENERGY RATIO (%): 82 | LAT / LONG: 39.724041, -81.013610 |

EXPLORATION ID B-002-0-21



| ***MATERIAL DESCRIPTION AND NOTES*** | ELEV. | DEPTHS | SPT/ RQD | N60 | REC (%) | SAMPLE ID | HP (tsf) | GRADATION (%) GR | CS | FS | SI | CL | ATTERBERG LL | PL | PI | WC | ODOT CLASS (GI) | BACK FILL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Asphalt (8") over Aggregate Base (2") | | 0 - 0.8 | | | | | | | | | | | | | | | | |
| MEDIUM DENSE, LIGHT GRAY AND YELLOWISH BROWN, **STONE FRAGMENTS WITH SAND AND SILT**, FILL, DAMP | | 1 - 2.5 | 3-4-6 | 14 | 72 | SS-1 | | 40 | 16 | 11 | 11 | 22 | NP | NP | NP | 15 | A-2-4 (0) | |
| LOOSE, DARK GRAY AND BLACK, **STONE FRAGMENTS WITH SAND**, LITTLE SILT, FILL, DAMP; gray clay layer | | 3.5 - 5 | 3-3-2 | 7 | 78 | SS-2 | | 46 | 19 | 11 | 7 | 17 | NP | NP | NP | 21 | A-1-b (0) | |
| MEDIUM STIFF, GRAY, **SANDY SILT**, SOME SAND, LITTLE STONE FRAGMENTS, FILL, DAMP; sand and stone fragment layers | | 6 - 7.5 | 3-2-2 | 5 | 56 | SS-3 | 0.5 | 13 | 23 | 18 | 30 | 16 | NP | NP | NP | 18 | A-4a (2) | |
| MEDIUM STIFF, BROWN, **SILT AND CLAY**, AND SAND, FILL, MOIST | | 8.5 - 10 | 2-2-2 | 5 | 67 | SS-4 | 0.5 | - | - | - | - | - | - | - | - | 24 | A-6a (V) | |
| sand and stone fragment layers | | 11 - 12.5 | 2-2-2 | 5 | 56 | SS-5 | 0.25-1.5 | 0 | 14 | 25 | 30 | 31 | 34 | 23 | 11 | 26 | A-6a (6) | |
| MEDIUM STIFF, DARK BROWN, **SANDY SILT**, TRACE WOOD, MOIST | | 12.5 - 14 | 2-3-2 | 7 | 67 | SS-6 | 1.0-3.0 | 0 | 17 | 27 | 42 | 14 | 35 | 26 | 9 | 30 | A-4a (4) | |
| LOOSE, GRAY, **GRAVEL WITH SAND**, WET | | 14 - 15.5 | 2-2-2 | 5 | 33 | SS-7 | | 53 | 20 | 11 | - 16 | - | NP | NP | NP | 15 | A-1-b (0) | |
| LOOSE, GRAY AND BROWN, **SANDY SILT**, NON-PLASTIC, WET | | 15.5 - 17 | 3-3-2 | 7 | 39 | SS-8 | | 0 | 25 | 36 | 39 | 0 | NP | NP | NP | 17 | A-4a (1) | |
| MEDIUM DENSE, GRAY AND BROWN, **STONE FRAGMENTS WITH SAND AND SILT**, WET | | 17 - 18.5 | 7-9-10 | 26 | 50 | SS-9 | | 32 | 15 | 29 | 14 | 10 | NP | NP | NP | 14 | A-2-4 (0) | |
| DENSE, GRAY AND BROWN, **COARSE AND FINE SAND**, WET | | 18.5 - 20 (TR) | 8-10-13 | 31 | 67 | SS-10 | | 21 | 22 | 32 | 13 | 12 | NP | NP | NP | 13 | A-3a (0) | |
| **SHALE**, GRAY, HIGHLY TO MODERATELY WEATHERED | | 20 - 23 (EOB) | 50/0" | - | | SS-11 | | - | - | - | - | - | - | - | - | - | Rock (V) | |

Depths column markings: ▽ at 7; W at 14; TR at 20; EOB at 23.

Auger refusal at 23'

NOTES: NONE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED ASPHALT PATCH; BACKFILLED WITH AUGER CUTTINGS

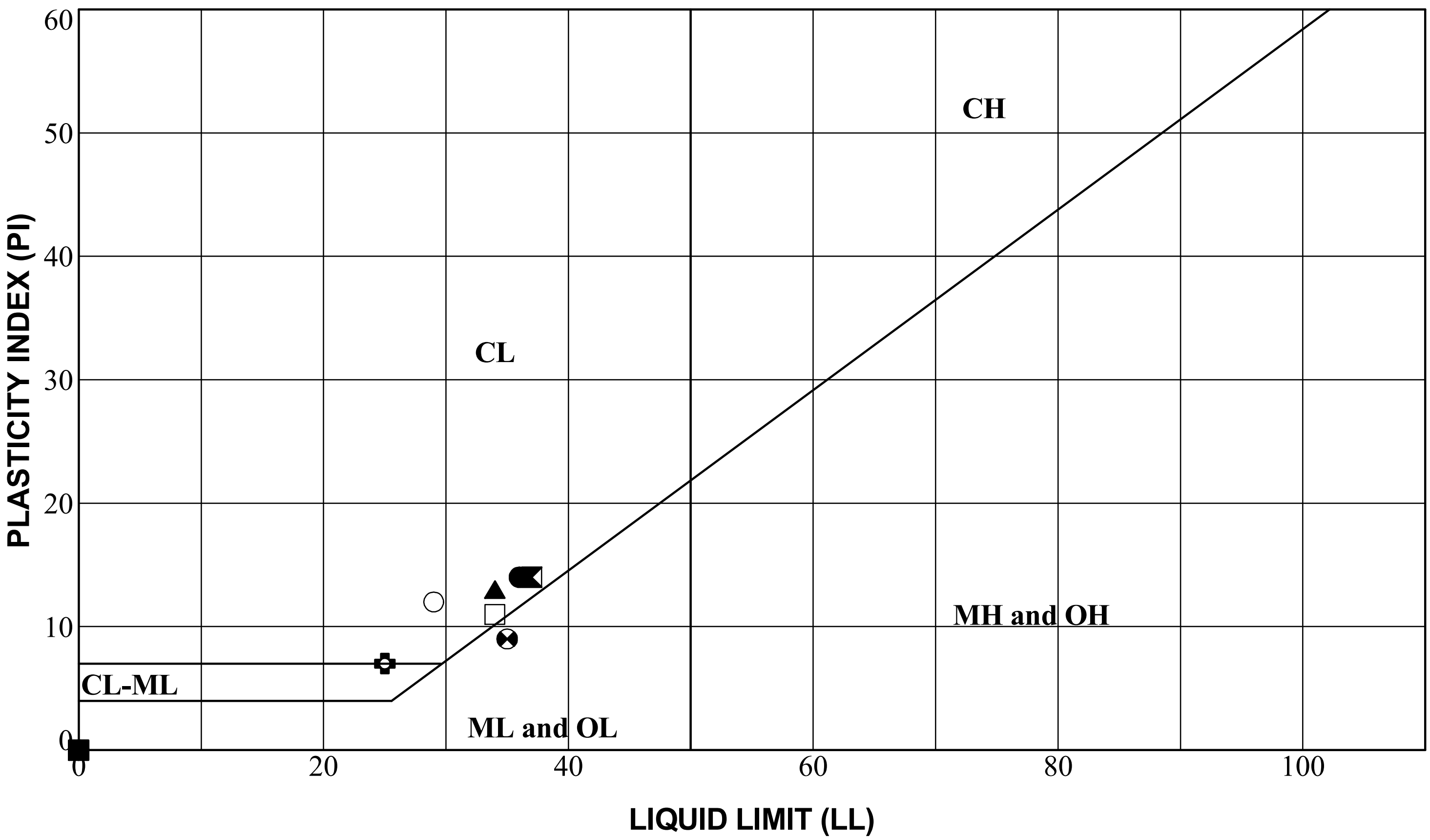
GCI Job No: 21-G-25314

# Summary of Laboratory Results

MOE-CR28-00.56 Bridge Replacement
Green Township, Monroe County, Ohio
GCI Job Number: 21-G-25314

| Test Hole | Depth | Water Content (%) | Liquid Limit | Plastic Limit | Plasticity Index | % Fines (< #200 Sieve) | % Clay (< 0.005 mm) | ODOT Class-ification | ODOT Group Index |
|---|---|---|---|---|---|---|---|---|---|
| B-001-0-21 | 1.0 | 17.9 | 36 | 22 | 14 | 42.2 | 26 | A-6a | 2 |
| B-001-0-21 | 3.5 | 16.8 | 37 | 23 | 14 | 38.1 | 22 | A-6a | 2 |
| B-001-0-21 | 6.0 | 16.2 | | | | | | | |
| B-001-0-21 | 8.5 | 12.4 | 34 | 21 | 13 | 51.5 | 26 | A-6a | 5 |
| B-001-0-21 | 11.0 | 8.1 | NP | NP | NP | 20.4 | | A-1-b | 0 |
| B-001-0-21 | 12.5 | 17.8 | NP | NP | NP | 15.9 | 9 | A-1-b | 0 |
| B-001-0-21 | 14.0 | 12.7 | 25 | 18 | 7 | 47.8 | 15 | A-4a | 3 |
| B-001-0-21 | 15.0 | 14.9 | 29 | 17 | 12 | 40.0 | 19 | A-6a | 2 |
| B-002-0-21 | 1.0 | 14.7 | NP | NP | NP | 33.4 | 22 | A-2-4 | 0 |
| B-002-0-21 | 3.5 | 21.2 | NP | NP | NP | 24.4 | 17 | A-1-b | 0 |
| B-002-0-21 | 6.0 | 18.4 | NP | NP | NP | 45.7 | 16 | A-4a | 0 |
| B-002-0-21 | 8.5 | 23.5 | | | | | | | |
| B-002-0-21 | 11.0 | 26.4 | 34 | 23 | 11 | 61.2 | 31 | A-6a | 6 |
| B-002-0-21 | 12.5 | 30.2 | 35 | 26 | 9 | 55.8 | 14 | A-4a | 4 |
| B-002-0-21 | 14.0 | 14.5 | NP | NP | NP | 15.8 | | A-1-b | 0 |
| B-002-0-21 | 15.5 | 16.6 | NP | NP | NP | 38.7 | | A-4a | 0 |
| B-002-0-21 | 17.0 | 13.5 | NP | NP | NP | 23.5 | 10 | A-2-4 | 0 |
| B-002-0-21 | 18.5 | 13.0 | NP | NP | NP | 24.9 | 12 | A-3a | 0 |

August 2021




*LEGEND:*

| TEST HOLE | DEPTH | $w_n$ | LL | PL | PI | ODOT CLASS-IFICATION | ODOT GROUP INDEX |
|---|---|---|---|---|---|---|---|
| ● B-001-0-21 | 1.0 | 17.9 | 36 | 22 | 14 | A-6a | 2 |
| ⧗ B-001-0-21 | 3.5 | 16.8 | 37 | 23 | 14 | A-6a | 2 |
| ▲ B-001-0-21 | 8.5 | 12.4 | 34 | 21 | 13 | A-6a | 5 |
| ★ B-001-0-21 | 11.0 | 8.1 | NP | NP | NP | A-1-b | 0 |
| ⊙ B-001-0-21 | 12.5 | 17.8 | NP | NP | NP | A-1-b | 0 |
| ✿ B-001-0-21 | 14.0 | 12.7 | 25 | 18 | 7 | A-4a | 3 |
| ○ B-001-0-21 | 15.0 | 14.9 | 29 | 17 | 12 | A-6a | 2 |
| △ B-002-0-21 | 1.0 | 14.7 | NP | NP | NP | A-2-4 | 0 |
| ⊗ B-002-0-21 | 3.5 | 21.2 | NP | NP | NP | A-1-b | 0 |
| ⊕ B-002-0-21 | 6.0 | 18.4 | NP | NP | NP | A-4a | 2 |
| □ B-002-0-21 | 11.0 | 26.4 | 34 | 23 | 11 | A-6a | 6 |
| ⊗ B-002-0-21 | 12.5 | 30.2 | 35 | 26 | 9 | A-4a | 4 |
| ◑ B-002-0-21 | 14.0 | 14.5 | NP | NP | NP | A-1-b | 0 |
| ☆ B-002-0-21 | 15.5 | 16.6 | NP | NP | NP | A-4a | 1 |
| ✤ B-002-0-21 | 17.0 | 13.5 | NP | NP | NP | A-2-4 | 0 |
| ■ B-002-0-21 | 18.5 | 13.0 | NP | NP | NP | A-3a | 0 |

**Job No:** *21-G-25314*

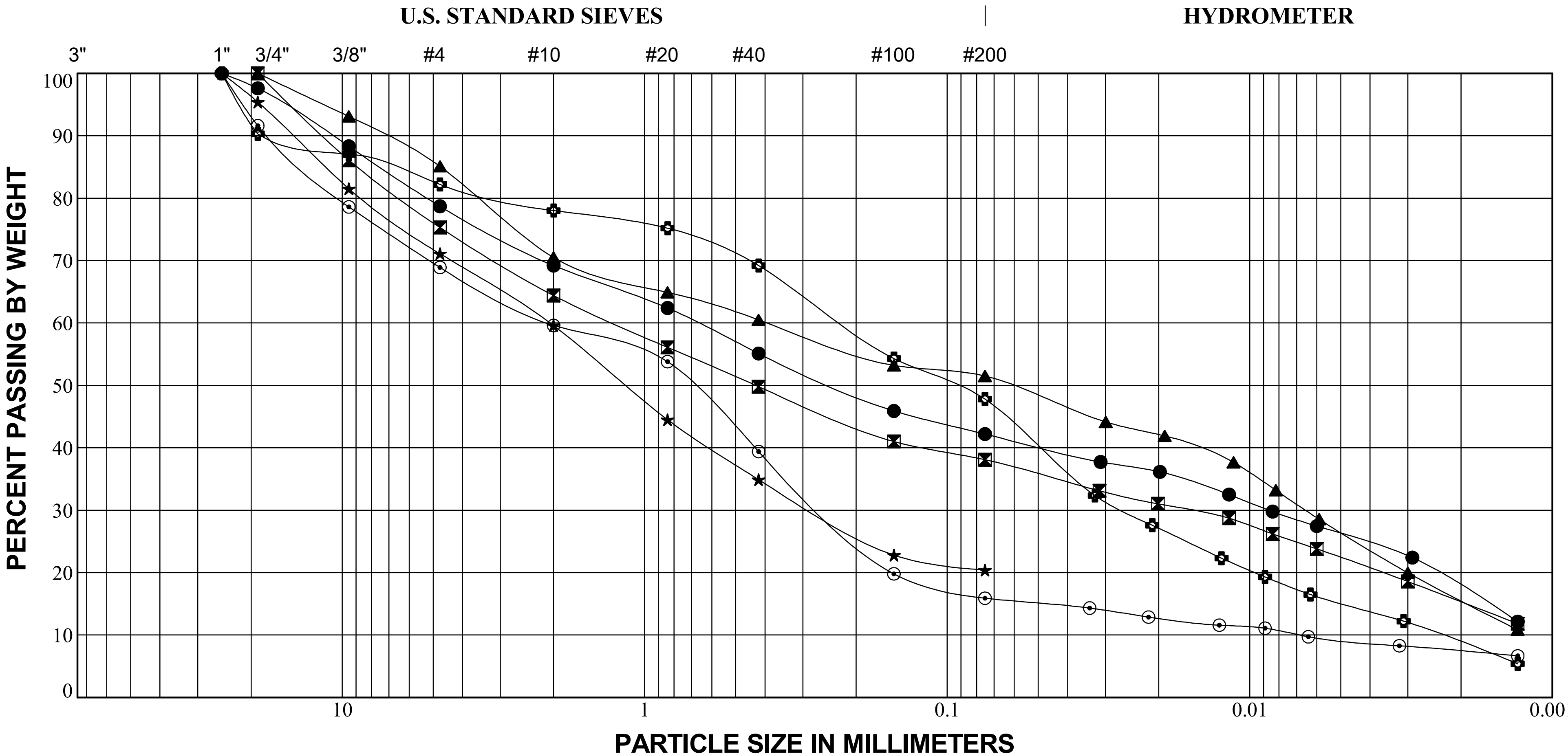
**Method:** *ASTM D4318*

**Date:** *August 2021*

# ATTERBERG LIMITS TEST RESULTS

*MOE-CR28-00.56 Bridge Replacement*
*Green Township, Monroe County, Ohio*

Geotechnical Consultants, Inc. - Westerville, Ohio 43081




| GRAVEL | | SAND | | SILT | CLAY |
|---|---|---|---|---|---|
| coarse | fine | coarse | fine | | |

***LEGEND:***

| | TEST HOLE | DEPTH | LL | $w_n$ | PL | ODOT CLASSIFI-CATION | ODOT GROUP INDEX | C.B.R. |
|---|---|---|---|---|---|---|---|---|
| ● | B-001-0-21 | 1.0 | 36 | 17.9 | 22 | A-6a | 2 | --- |
| ⧗ | B-001-0-21 | 3.5 | 37 | 16.8 | 23 | A-6a | 2 | --- |
| ▲ | B-001-0-21 | 8.5 | 34 | 12.4 | 21 | A-6a | 5 | --- |
| ★ | B-001-0-21 | 11.0 | NP | 8.1 | NP | A-1-b | 0 | --- |
| ⊙ | B-001-0-21 | 12.5 | NP | 17.8 | NP | A-1-b | 0 | --- |
| ✿ | B-001-0-21 | 14.0 | 25 | 12.7 | 18 | A-4a | 3 | --- |

**Job No:** *21-G-25314*

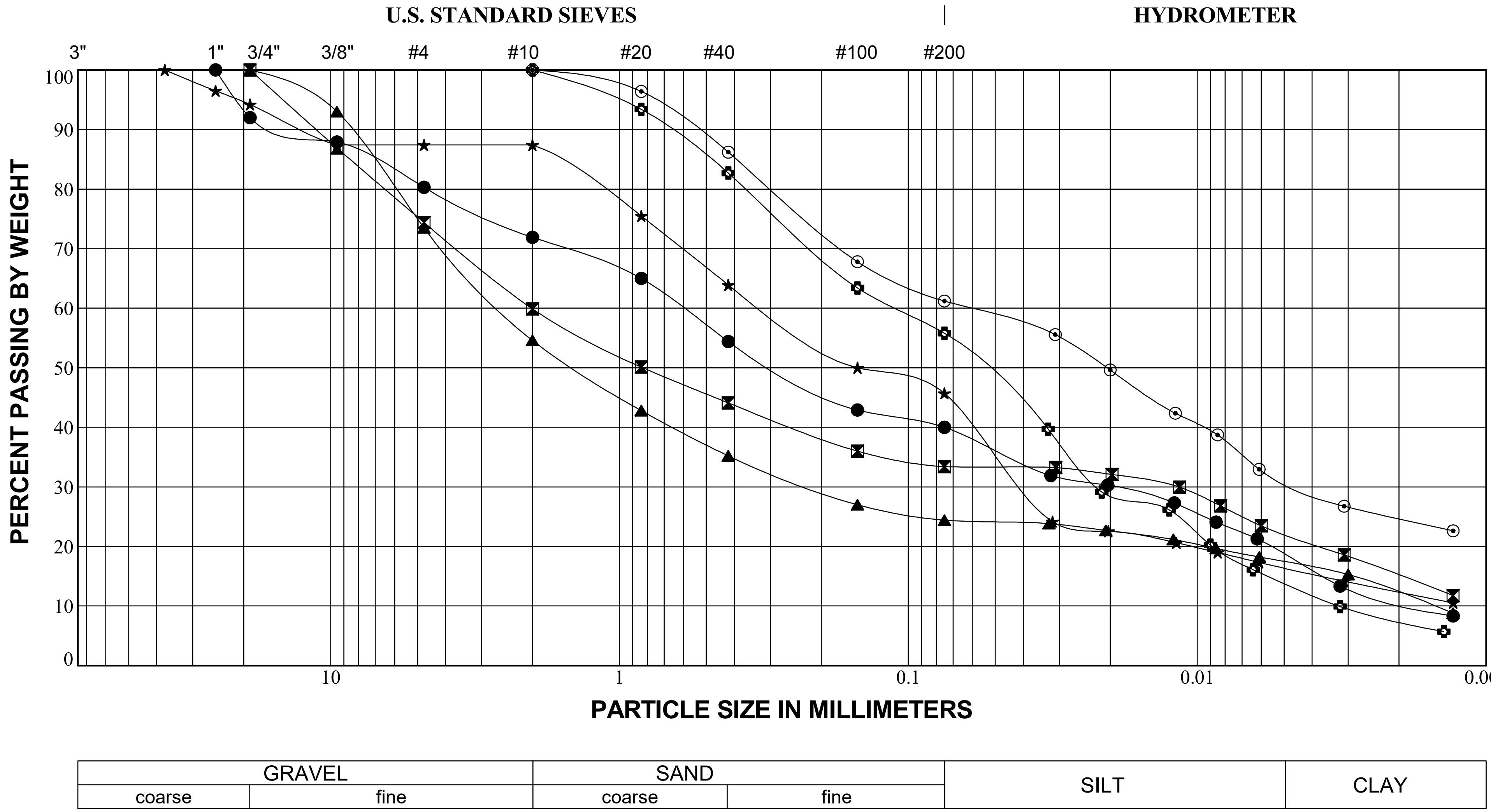
**Method:** *ASTM D421 D422*

**Date:** *August 2021*

# COMBINED PARTICLE SIZE DISTRIBUTION

*MOE-CR28-00.56 Bridge Replacement - Green Township, Monroe County, Ohio*

Geotechnical Consultants, Inc. - Westerville, Ohio 43081




**LEGEND:**

| | TEST HOLE | DEPTH | LL | $w_n$ | PL | ODOT CLASSIFICATION | ODOT GROUP INDEX | C.B.R. |
|---|---|---|---|---|---|---|---|---|
| ● | B-001-0-21 | 15.0 | 29 | 14.9 | 17 | A-6a | 2 | --- |
| ⧗ | B-002-0-21 | 1.0 | NP | 14.7 | NP | A-2-4 | 0 | --- |
| ▲ | B-002-0-21 | 3.5 | NP | 21.2 | NP | A-1-b | 0 | --- |
| ★ | B-002-0-21 | 6.0 | NP | 18.4 | NP | A-4a | 2 | --- |
| ⊙ | B-002-0-21 | 11.0 | 34 | 26.4 | 23 | A-6a | 6 | --- |
| ✚ | B-002-0-21 | 12.5 | 35 | 30.2 | 26 | A-4a | 4 | --- |

**Job No:** 21-G-25314

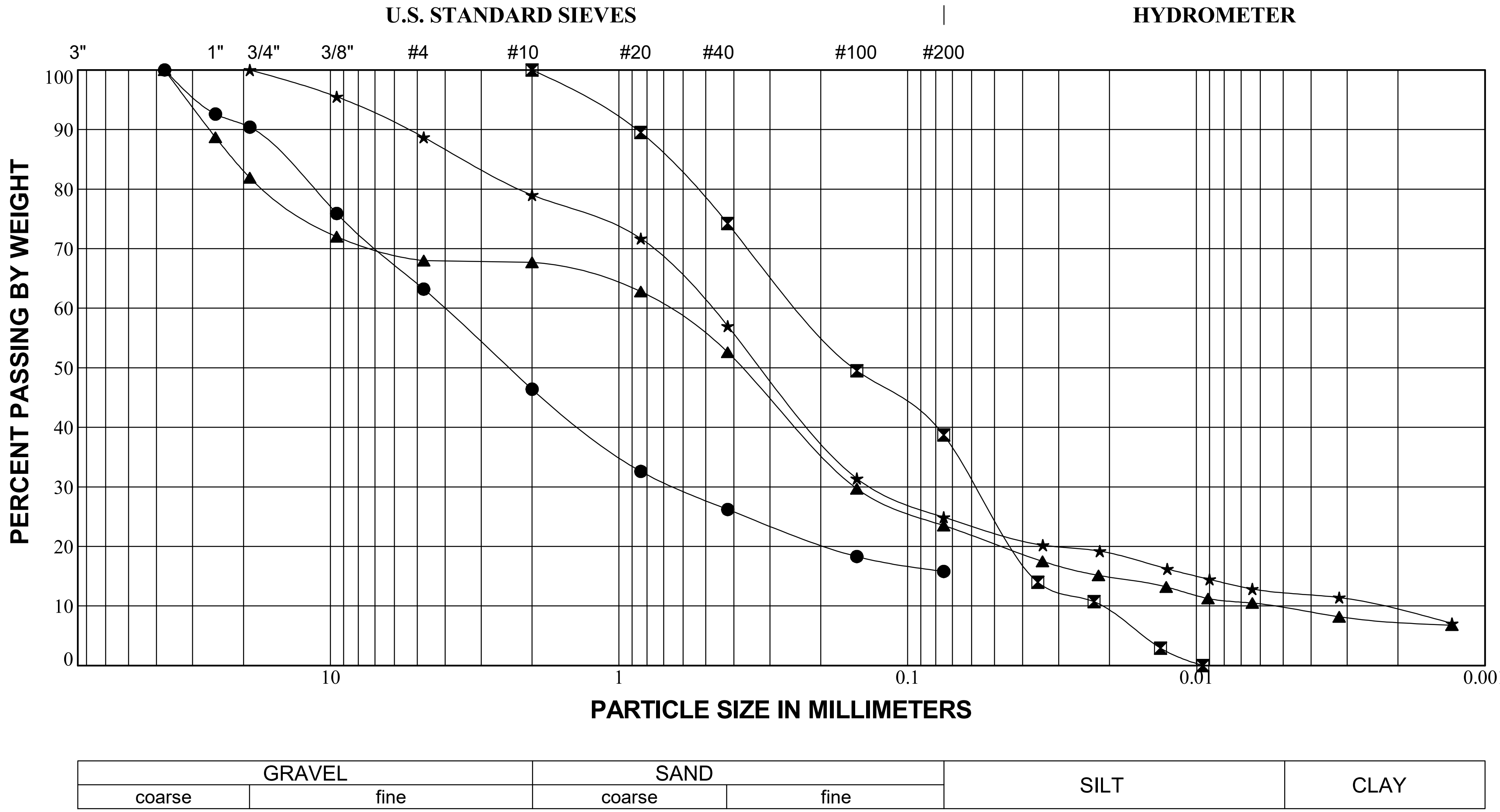
**Method:** ASTM D421 D422

**Date:** August 2021

# COMBINED PARTICLE SIZE DISTRIBUTION

*MOE-CR28-00.56 Bridge Replacement - Green Township, Monroe County, Ohio*

Geotechnical Consultants, Inc. - Westerville, Ohio 43081




***LEGEND:***

| TEST HOLE | DEPTH | LL | $w_n$ | PL | ODOT CLASSIFI-CATION | ODOT GROUP INDEX | C.B.R. |
|---|---|---|---|---|---|---|---|
| ● B-002-0-21 | 14.0 | NP | 14.5 | NP | A-1-b | 0 | --- |
| ⊠ B-002-0-21 | 15.5 | NP | 16.6 | NP | A-4a | 1 | --- |
| ▲ B-002-0-21 | 17.0 | NP | 13.5 | NP | A-2-4 | 0 | --- |
| ★ B-002-0-21 | 18.5 | NP | 13.0 | NP | A-3a | 0 | --- |

**Job No:** *21-G-25314*

**Method:** *ASTM D421 D422*

**Date:** *August 2021*

# COMBINED PARTICLE SIZE DISTRIBUTION

*MOE-CR28-00.56 Bridge Replacement - Green Township, Monroe County, Ohio*

Geotechnical Consultants, Inc. - Westerville, Ohio 43081

GEOTECHNICAL CONSULTANTS INC.

JOB MOE-CR28-00.56

SHEET NO. 1 OF 3

CALCULATED BY JHolko DATE 8/10/21

CHECKED BY DATE

SCALE

## FOUNDATION SELECTION AND PARAMETERS

1) Consider the following foundation types:

a) Driven Piles → Per the ODOT BDM Article 305.3.5.7, if the in-situ soil depth is ≤ 10 feet, the pile should be extended 5 ft into rock. We estimate a bottom of pile cap elevation at 10 ft below the existing roadway based on the site conditions. Shale bedrock was encountered at a depth of 16.5 ft in boring B-001-0-21. The bedrock is moderately weathered at 18.5 ft. In our opinion, it is possible that the 5 ft rock embedment will not be attained. Therefore, driven piles are likely not feasible for this structure.

b) Spread Footings → If spread footings are used, they should bear on the shale bedrock. Bedrock is at a depth of 16.5 ft in boring B-001-0-21 (south abutment) and 20 ft in boring B-002-0-21 (north abutment). While spread footings are possible, it is likely not feasible in consideration of the excavation depth on the north abutment (> 10 ft).

c) Drilled Shafts → Per ODOM BDM Article C305.4, drilled shafts should be considered when driven piles will not reach required embedment and spread footings are not feasible. Drilled shafts would bear within the shale bedrock.

GCI will recommend a deep foundation system consisting of drilled shafts.

2) Drilled Shaft Design Parameters:

a) Determine parameters using AASHTO LRFD Article 10.8.3.5.4

- Side Resistance → reference Article 10.8.3.5.4b

$$q_s = 0.65\,\alpha_E\,p_a\left(\frac{q_u}{p_a}\right)^{0.5} < 7.8\,p_a\left(\frac{f_c'}{p_a}\right)^{0.5} \quad \text{(Eq. 10.8.3.5.4b-1)}$$

$p_a = 2.12$ ksf    $f_c'$ = concrete compressive strength ⇒ assume 3 ksi or 4??

GEOTECHNICAL CONSULTANTS INC.

JOB MOE-CR28-00.56

SHEET NO. 2 OF 3

CALCULATED BY JHolko DATE 8/10/21

CHECKED BY DATE

SCALE

$\alpha_E$ → determined from AASHTO LRFD Table 10.8.3.5.4b-1

The Em/Ei value obtained from Table 10.3.5.4b-1 can be obtained from Table 10.4.6.5-1. Using Table 10.4.6.5-1, an estimate of 20% RQD will be made for the shale along the shaft walls. This will give an Em/Ei value of 0.05. An Em/Ei value of 0.05 will give a $\alpha_E$ value of 0.45.

$q_u$ → uniaxial compressive strength of rock

We will use the Modified Standard Penetration Test (MSPT) presented in "Modified Standard Penetration Test - Based Drilled Shaft Design Method for Weak Rocks" from the Illinois Center for Transportation, December 2017. Article 2.4 presents the following equation:

$$(N_{rate})_{90} = \frac{N_{rate} \times E_m \times C_B \times C_S \times C_R}{90}$$

$E_M = 82$ (from our drill rig)
$C_B = 1.0$ (Table Q.1 from MSPT Article)
$C_S = 1.0$ (" ")
$C_R = 0.85$ (from " " with 13'-20' rod length)

In boring B-001-0-21, highly weathered shale is encountered at 16.5'. This material material exhibited low blow counts and should not be considered for the side resistance.

Moderately weathered shale was encountered at 18.5' with a blow count of 50 blows/3" of penetration. We will use the following as our $N_{rate}$ value:

$$N_{rate} = \frac{50}{(0.25\ ft)} = 200\ \frac{blows}{ft}$$

$$(N_{rate})_{90} = \frac{(200)(82)(1.0)(1.0)(0.85)}{90} = 155\ blows/ft$$

Eq. 2.2 in the MSPT publication gives → $q_u = 0.092 \times (N_{rate})_{90} = 14.26\ ksf \rightarrow 14\ ksf$

GEOTECHNICAL CONSULTANTS INC.

JOB MOE-CR28-00.56

SHEET NO. 3 OF 3

CALCULATED BY JHolko DATE 8/10/21

CHECKED BY ______ DATE ______

SCALE ______

$$q_s = 0.65\,\alpha_E\, p_a \left(\frac{q_u}{p_a}\right)^{0.5} = (0.65)(0.45)(2.12\ ksf)\left(\frac{14\ ksf}{2.12\ ksf}\right)^{0.5} = 1.59\ ksf$$

*check $7.8\, p_a\left(\frac{f_c'}{p_a}\right)^{0.5} = 19.7$

(greater than 1.5) ✓

From AASHTO LRFD Table 10.5.5.2.4-1 (or ODOT BDM Table 305-1; same table) a resistance factor of 0.60 will be used for side resistance. The shale will be considered an Intermediate Geo Material (IGM).

$$q_{side} = (0.60)(1.59\ ksf) = 0.954\ ksf \rightarrow \text{use } 0.90\ ksf$$

- Tip Resistance → SPT blow counts were at 50 blows/0 inches at 21 ft in both borings. As such, we will evaluate our tip resistance using these values since it will be the bearing surface. We will use 1 inch as the penetration distance.

$$N_{rate} = \frac{50}{\left(\frac{1}{12}\ ft\right)} = 600\ blows/ft$$

$$(N_{rate})_{90} = \frac{(600)(82)(1.0)(1.0)(0.85)}{90} = 465\ blows/ft$$

$$q_u = 0.092 \times (N_{rate})_{90} = 42.8\ ksf$$

From AASHTO LRFD Table 10.5.5.2.4-1, a tip resistance of 0.55 will be use for this IGM.

$$q_{tip} = (0.55)(42\ ksf) = 23.54\ ksf \rightarrow \text{use } 20\ ksf$$

CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 17-024
UILU-ENG-2017-2024
ISSN: 0197-9191

# MODIFIED STANDARD PENETRATION TEST–BASED DRILLED SHAFT DESIGN METHOD FOR WEAK ROCKS

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Southern Illinois University at Edwardsville

Research Report No. FHWA-ICT-17-018

A report of the findings of

**ICT PROJECT R27-145**
**Modified Standard Penetration Test–based Drilled Shaft Design Method for Weak Rocks (Phase 2 Study)**

https://doi.org/10.36501/0197-9191/17-024

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**Illinois Center for Transportation**

**December 2017**

## 2.4 MODIFIED STANDARD PENETRATION TEST (MSPT)

The standard penetration test (SPT) has been used to estimate strength parameters for soils and weak rock when it is difficult to obtain high-quality/undisturbed samples for laboratory testing (Peck et al., 1974). SPTs require 18-in.-penetration of the split-spoon sampler, which can be difficult to impossible to obtain in weak rocks or shales. In Phase 1 of this study, the procedure for conducting and interpreting the standard penetration test was modified to provide results in penetration per 10 blows increments where the penetration is less than 18 in. in weak shales. This new procedure is termed the modified standard penetration test (MSPT) and utilizes the concept of the split-spoon sampler penetration rate ($N_{Rate}$), not the sum of the penetration blow counts, to estimate the undrained strength parameters of weak shales. The penetration rate is the inverse of the linear slope of the penetration depth versus cumulative blow count relationship. This proposed test and recommended test procedure are discussed in detail in Appendix Q.

During this phase of the study, 16 IDOT bridge sites where weak shales are present were investigated. Modified standard penetration tests were conducted, and penetration rates were determined at various depths in weak shales in accordance with the MSPT procedure and recommendations developed herein and outlined in Appendix Q. MSPT results from the 16 sites investigated herein are presented in Appendices A through P. The results of the MSPT penetration rates (NRate), together with the laboratory-measured unconfined compressive strength for weak shales tested during both phases of the study were used to develop a useable empirical correlation between $N_{Rate}$ and UCS (see Section 2.5.1).

## 2.5 SPT HAMMER ENERGY MEASUREMENTS

The SPT hammer energy used to measure penetration rate can vary from 40 to 100% of the maximum theoretical energy of a 140-lb weight falling 30 in. The wide variation in the transferred energy can cause inconsistent measurements of the MSPT penetration rate, which can undermine the targeted correlation. This inconsistency can lead to inaccurate values of UCS. Therefore, an energy correction must be developed and applied to the MSPT penetration rate to improve the reliability of the correlation, as is done for blow counts in soils where they are corrected to 60% of the maximum theoretical energy. In general, a higher energy results in a lower MSPT penetration rate, a lower UCS, and thus a more conservative drilled shaft design. Thus, it was important that the energy used to measure penetration rate be measured and/or obtained for each drill rig used in this study, to develop this energy-based correlation between UCS and penetration rate so designers can enter the correlation with a similar magnitude of MSPT energy to obtain an accurate estimate of UCS.

The research team measured the SPT hammer energy for all IDOT drill rigs used in this study. The tests were performed using an instrumented AW-J rod and a dynamic pile analyzer. Dynamic measurements were obtained using pairs of strain transducers and accelerometers mounted about 1 ft from the top of the drill rod. Measurements from the gauges were processed using the pile-driving analyzer (PDA), manufactured by Pile Dynamics, Inc. Table 2.2 summarizes the SPT hammer energy efficiencies for all of the operational IDOT drill rigs, together with the reported energies of the private drilling companies' drill rigs used in this study. Detailed SPT hammer energy measurements and results for all of the IDOT drill rigs are presented in Appendix S.

**Table 2.2 Summary of the SPT Hammer Energies for all Drill Rigs Used in this Study**

| IDOT District/Drilling Company | Drill Rig | Hammer Energy Efficiency (%) |
|---|---|---|
| District 3 | CME-75 | 93.2 |
| | CME-45c | 85.8 |
| District 5 | CME-75 | 91.3 |
| District 6 | CME-75 | 96.4 |
| | CME-550x | 80.4 |
| District 7 | CME-55 | 97.5 |
| Wang Engineering | Mobile B-57 | 100 |
| | D-50 TMR | 78 |
| Bulldog Drilling | CME-550x | 94 |
| Geocon | D-120 | 77 |
| TSi Engineering | CME-550x | 92 |

The results from this study indicate that 75 to 100% of the theoretical maximum hammer energy was delivered to the drill rod by the automatic hammers used herein. Because automatic hammers are now being widely used, an energy ratio of 90% shall be used to correct $N_{Rate}$ for all of the drill rigs used during this study. In short, all of the drill rigs used during this study utilized an automatic trip hammer that imparted an average of 90% of the theoretical maximum hammer energy. Thus, MSPT $N_{Rate}$ values obtained using an automatic trip hammer, which is the hammer most commonly used by IDOT, do not require significant corrections, in comparison to the previously suggested energy correction factor for soils, i.e., 60% of the theoretical maximum hammer energy, which is primarily based on a rope-and-pulley system. A normalized penetration rate, $(N_{Rate})_{90}$, was developed herein and is defined as follows for hammers that deliver 90% of theoretical maximum energy:

$$(N_{rate})_{90} = \frac{N_{rate} \times E_M \times C_B \times C_S \times C_R}{90}$$

where:

$(N_{Rate})_{90}$ = Nrate corrected for 90% of the theoretical energy and various field procedures

$E_M$ = hammer efficiency, %

$C_B$ = borehole diameter correction

$C_S$ = sampler correction

$C_R$ = rod length correction, and

$N_{Rate}$ = measured penetration rate, bpf

Table Q.1 in appendix Q shows the recommended borehole diameter, rod length, and sampler correction factors from Skempton (1986). If the hammer does not yield 90% of the theoretical maximum hammer energy, the measured hammer energy should be inserted for $E_M$ in the equation above to normalize the measured $N_{Rate}$ to 90% of the theoretical maximum hammer energy. The sampler correction assumes that liners will be installed in the split-spoon sampler to be consistent with Skempton (1986) even though the practice now is to not use liners.

### *2.5.1 Proposed Correlation*

The MSPT provides a convenient means for estimating the in situ strength properties of weak, fine-grained rocks, e.g., weak shales. Figure 2.4 presented the refined and calibrated correlation of MSPT penetration rate, corrected for 90% of the theoretical energy and various field procedures $(N_{Rate})_{90}$, and UCS of the weak shales tested herein. Figure 2.4 shows a linear relationship between $(N_{Rate})_{90}$ and the UCS of weak shales that can be used for future drilled shaft design. This correlation for estimating the UCS of weak rocks reduces or eliminates the need for rock coring and subsequent laboratory testing that may be expensive, time-consuming, and problematic because of the fractured nature of weak rocks or shales.

Figure 2.4 shows the current line of best fit of the MSPT penetration rate and UCS data for the of Illinois weak shales tested herein. The following equation is recommended to estimate the UCS of weak shales, using the normalized MSPT penetration rate:

$$\text{UCS (ksf)} = 0.092 * (N_{rate})_{90} \qquad (2.2)$$

where

UCS = Unconfined compressive strength, ksf

$(N_{Rate})_{90}$ = MSPT penetration rate corrected for 90% of the theoretical energy and various field procedures, bpf. (see appendix Q)

Figure 2.4 also presents upper and lower bounds of the empirical correlation, which can be used to investigate the range of UCS and thus drilled shaft design. For less critical structures, it may be possible to use the upper bound; while for vital structures, the lower bound may be relevant. This correlation should only be used to estimate the UCS values for geomaterials that have a UCS of 10 to 100 ksf. For fine-grained soils with UCS values lower than 10 ksf, previously published correlations (e.g. Stroud 1974) should be used. Differences in the compressive strength of the geomaterials and the procedures used to measure the blow count or penetration rate ($N_{spt}$ and $N_{rate}$) are the reasons for the significant difference between previous correlations (e.g., Stroud 1974) and the correlation presented herein to estimate the UCS.

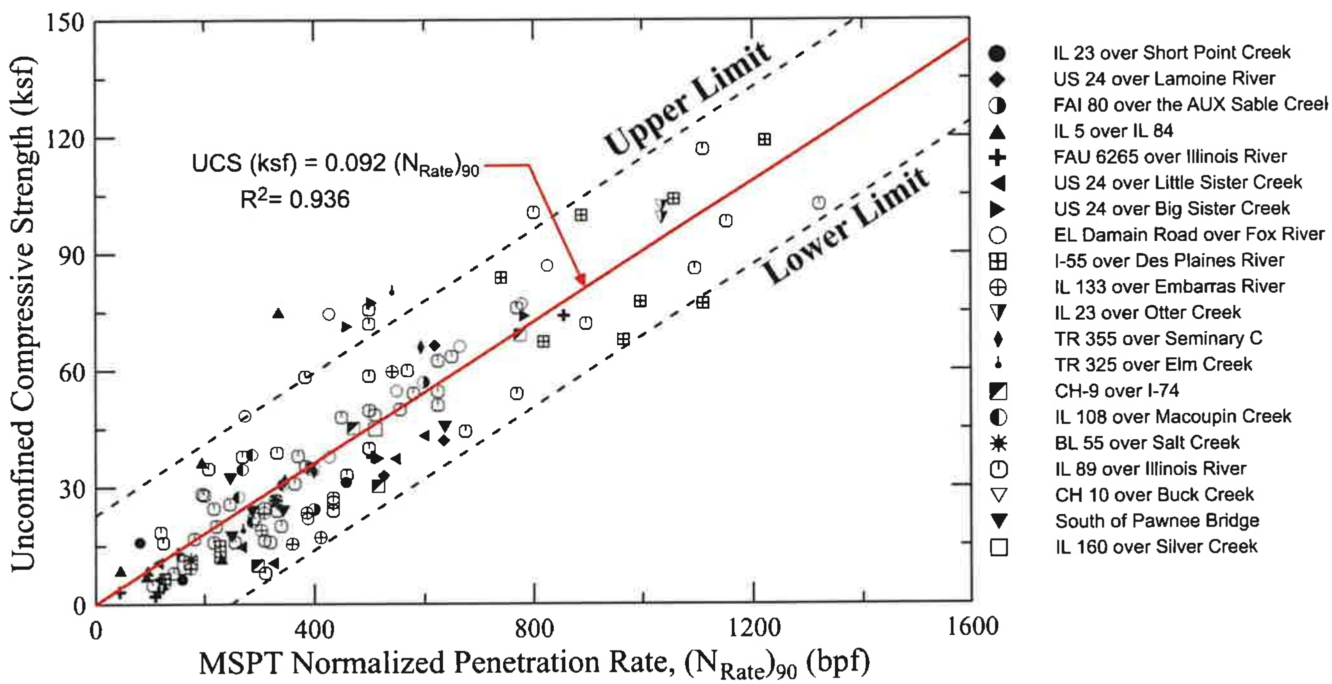


**Figure 2.4. Relationship between UCS and $(N_{Rate})_{90}$ from MSPTs at 21 IDOT bridge sites.**

## 2.6 SUMMARY

Field exploration was conducted at 16 additional IDOT bridge sites where weak shales are present. The main objective of this exploration was to develop and validate the MSPT penetration rate versus the unconfined compressive strength of weak shales relationship proposed in Phase 1 of this study and to investigate the strength and compressibility properties of weak shale in Illinois. The following is a summary of the major findings:

- Undrained Young's modulus was correlated with the in situ water content and the unconfined compressive strength of weak shales. These correlations can be used for estimating the modulus of shales for preliminary settlement analysis of bridge piers when site-specific data are not available or to evaluate site-specific data and laboratory testing.

- SPT hammer energy measurements for all operational IDOT drill rigs and the ones used for MSPT penetration rate measurements imparted an average of 90% of the theoretical maximum hammer energy. As a result, a normalized penetration rate, $(N_{Rate})_{90}$, was developed herein to improve the reliability and consistency of the proposed correlation between unconfined compressive strength and MSPT penetration rates.
- An energy-based correlation between unconfined compressive strength and normalized MSPT penetration rate was developed and validated herein for Illinois weak shales. This correlation can be used with MSPT penetration rates for drilled shaft design, especially when obtaining high-quality shale samples for triaxial compression testing is difficult or impossible. The use of MSPT penetration rates for drilled shaft design should reduce the design time and costs by reducing or eliminating shale coring and laboratory triaxial compression testing by IDOT.

of 90% of the theoretical maximum hammer energy. Thus, MSPT $N_{rate}$ values obtained using an automatic trip hammer, which is the most commonly used hammer by IDOT, do not require significant corrections in comparison to the previously suggested energy correction factor for soils, i.e., 60% of the theoretical maximum hammer energy. A normalized penetration rate, $(N_{rate})_{90}$, was developed herein and is defined as follows for hammers that deliver 90% of theoretical maximum energy:

$$(N_{rate})_{90} = \frac{N_{rate} \times E_M \times C_B \times C_S \times C_R}{90}$$

where:

$(N_{rate})_{90}$ = $N_{rate}$ corrected for 90% of the theoretical energy and various field procedures

$E_M$ = hammer efficiency (i.e. average energy transfer ratio), %

$C_B$ = borehole diameter correction

$C_S$ = sampler correction

$C_R$ = rod length correction, and

$N_{rate}$ = measured penetration rate, bpf

Table Q.1 shows the recommended borehole diameter, rod length, and sampler correction factors from Skempton (1986). If the hammer does not yield 90% of the theoretical maximum hammer energy, the measured hammer energy should be inserted for $E_M$ in the equation above to normalize the measured $N_{rate}$ to 90% of the theoretical maximum hammer energy. The sampler correction assumes that liners will be installed in the split-spoon sampler to be consistent with Skempton (1986) even though the practice now is to not use liners.

Table Q.1: $N_{rate}$ Correction factors after Skempton (1986)

| Effect | Variable | Term | Value |
|---|---|---|---|
| Borehole diameter | 2.5 – 4.5 inches<br>6 inches<br>8 inches | $C_B$ | 1.00<br>1.05<br>1.15 |
| Sampling Spoon | Smooth sampler (or with liners)<br>Sampler without liners | $C_S$ | 1.0<br>1.2 |
| Rod Length | 30 – 100 ft<br>20 – 30 ft<br>13 – 20 ft<br>10 – 13 ft | $C_R$ | 1.0<br>0.95<br>0.85<br>0.75 |

**MSPT Data Sheets**

Drilling information and MSPT data obtained at each borehole shall be recorded in the field and include the following:

1. Date,
2. Name of the Drilling Crew,
3. Type and Make of the drill rig,
4. SPT Hammer Efficiency,
5. Project/Bridge Location,
6. Boring Number and location (station and coordinates),
7. Ground Surface Elevation,
8. Ground water surface Elevation,
9. MSPT elevations and depths,
10. Description of recovered weak rock or shale, and
11. Measured penetration depth every 10 blows to the nearest 0.1 inches (2.5 mm).