Technical Memorandum

To: Project File and Appendix F to Sediment Remedial Investigation Report
From: Sara L. Leow, PE
Subject: Geotechnical Investigation and Results Summary
Date: February 2013
Project: U.S. Steel Spirit Lake Sediment Investigation

Overview

A geotechnical investigation was performed in conjunction with the remedial investigation for the U.S. Steel (USS) Spirit Lake Sediment Investigation project during the summer and fall of 2011. The geotechnical investigation served to document general geotechnical soil characteristics across the site by means of field and laboratory testing. This memo presents a summary of the geotechnical field and laboratory testing data collected during the investigation. This memo is to accompany the associated Sediment Remedial Investigation Report (RI Report). Please refer to the RI report for complete project description, background information, site figures, and environmental data.

Field Testing

The geotechnical field investigation consisted of soil borings, standard penetration tests (SPT), cone penetration test (CPT) soundings, pore-pressure dissipation (PPD) testing, flat plate dilatometer (DMT) testing, and vane shear testing (VST). The locations of the Fall 2011 geotechnical borings are presented on Figure F-1. Boring logs, CPT logs, pore-water dissipation plots, DMT data, and lab testing data are included in this memo as attachments F-1 through F-4. Each of the field tests is described below, and results of field data are shown in the attached Table F-1 or in attached report sheets, as applicable.

Soil Borings

Soil borings were completed at several locations within the Unnamed Creek (UC) and Wire Mill areas. Soil borings were initially denoted with a solely numerical label, and subsequently renamed to include a UC or WM to designate of the area where the test boring was performed. The old boring number is provided in parentheses next to the new denotation in this document.

Soil borings were performed at six locations at the site, including three in the Unnamed Creek area: UC-94 (304), UC-96 (305), and UC-97 (309); as well as three in the Wire Mill area: WM-100 (311), WM-101 (314), and WM-102 (315) (Figure F-1). Each test boring was performed in general accordance with ASTM D1586 from a balloon-tired drill rig mounted on a barge, and were extended to a depth of 20
to 36.5 feet below the riverbed. The borings were advanced using hollow stem auger. Continuous sampling was performed with a standard split spoon for two test borings, UC-94 (304) and WM-100, and with a modified California sampler for the remaining four test borings. Shelby (thinwall) tube samples were collected at select intervals per ASTM D1597, with the majority collected in offset borings.

USCS soil classifications are shown on the geotechnical test boring logs, provided as attachments. In general, the subsurface conditions consist of organic silt or peat underlain by layers of lean clay, sandy clay, silt, sandy silt, sand, and silty sand. In some cases, multiple layers of peat were encountered, separated by layers of clay, silt, and/or sand. Due to the complex depositional environment at the site, soils with the same USCS symbols may have different geotechnical properties. Soil types and properties should be further assessed at specific locations and depths for design as part of future project phase(s).

**Standard Penetration Tests**

Blow counts were recorded per each 6-inch drive of a standard split spoon over a two-foot interval for SPT performed at two soil borings, UC-94 (304) and WM-100 (311) (see Figure F-1). The SPT N-value is calculated as the sum of the blow counts for the second and third 6-inch drives. The uncorrected SPT N-values are shown on the boring logs. N-values ranged from less than 1 to 16, with the majority between less than 1 and 7.

It should be noted that although blow counts were recorded while sampling with the modified California sampler, those blow counts were not considered viable for future geotechnical design since a correlation cannot reliably be made between SPT N-values and blow counts recorded while driving a modified California sampler.

**Cone Penetration Test Soundings**

CPT soundings were performed at twelve locations from equipment mounted to a barge in general accordance with ASTM D5778, each to a depth of 50 feet below the riverbed. The associated test boring is designated in parentheses after the CPT number. Seven CPT soundings, CPT-301 (UC-94), CPT-303 (UC-93), CPT-304 (UC-92), CPT-305 (UC-96), CPT-306 (UC-95), CPT-307 (UC-98), and CPT-309 (UC-97) were performed in the Unnamed Creek area, and five CPT soundings, CPT-310 (WM-99), CPT-311 (WM-100), CPT-314 (WM-101), CPT-315 (WM-102), and CPT-316 (WM-103) were performed in the Wire Mill area (Figure F-1).

CPT logs are attached. Similar to the conditions encountered in the soil borings, the CPT soundings indicate subsurface conditions consisting of layers of clay, silt, and sand. Based on the CPT results, the undrained shear strengths of cohesive soils (clays) range from approximately 150 to greater than 2,000 pounds per square foot (psf). For non-cohesive soils (sand and silt), the angle of internal friction ranges from approximately 28 degrees to greater than 40 degrees based on the CPT results. Attached Figures F-2 and F-3 graphically depict the undrained shear strength and angle of internal friction ranges.
Pore Pressure Dissipation Tests

PPD was also performed at select intervals during CPT testing per ASTM D5778. PPD test data is available from CPT-303 (UC-93), CPT-304 (UC-92), CPT-314 (WM-101), and CPT-316 (WM-103) at approximate depths of 4.6, 4.6, 31.8, and 4.8 feet below the riverbed, respectively (Figure F-1). Soil coefficients of permeability from the PPD tests range from $5 \times 10^{-8}$ to $2 \times 10^{-5}$ centimeters per second (cm/s). The time duration to reach 50% dissipation ($t_{50}$) mainly varied between 0.33 and 0.67 minutes, although a $t_{50}$ of 3.92 minutes was calculated for the dissipation test performed at CPT-303 (UC-93). PPD plots are attached to this memo.

Flat Plate Dilatometer Testing

DMT testing was performed to document soil characteristics to, in conjunction with consolidation lab testing, aid in settlement assessment during future project phases. DMT was performed in general accordance with ASTM D6635 at locations offset from four CPT soundings, CPT-301 (UC-94), CPT-306 (UC-95), CPT-305 (UC-96), and CPT-311 (WM-100) (Figure F-1). DMT testing was performed at select intervals to termination depths of approximately 15 to 37 feet below the sediment surface. DMT data is attached.

In-Situ Vane Shear Testing

Vane shear testing was performed to document shear strength of soft soils at various depths in general accordance with ASTM D2573. Vane shear testing of near-riverbed surface soils was initially attempted through the ice in March 2011; however, the strength of the surficial sediments did not provide the resistance necessary to record readings with the field equipment available at the time. A more sensitive vane shear tool was obtained, and vane shear testing was performed at depths below the riverbed of 5 feet and shallower in June 2011. The results of shallow vane shear testing near the riverbed performed in June 2011 indicate peak undrained shear strengths between approximately 37 and 1,600 psf; a summary of the results is provided in Table F-1. The strength values attained from this testing period are considered preliminary. Factors such as performing the test from a moving platform affixed to a small boat and approximations of test depths relative to variable water surface elevations may have affected the data. The recorded shear strength for some intervals may also be arbitrarily high due to the presence of debris in some near-surface soil layers. Additional vane shear testing should be performed to further document strengths for near-riverbed surface soils for design.

Additional vane shear testing was performed at depths below the riverbed generally greater than 5 feet in November 2011. A summary of the results from the vane shear testing is presented in Table F-1. Results of vane shear tests performed at greater depths in November 2011 indicate that peak undrained shear strengths range between 32 and 990 psf, while remolded shear strengths range between 32 and 301 psf.
Laboratory Testing

Laboratory testing was performed on select samples to further document soil properties. The laboratory testing performed and associated methods are listed below, followed by a description of each test and summary of test results. Test results are also presented in the attached Table F-1, as well as in attached laboratory test reports.

- Unit Weight tests per ASTM D7263, “Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens”.
- Grain Size and Hydrometer Analyses per ASTM D422, “Standard Test Method for Particle-Size Analysis of Soils”.

In addition to the samples discussed below, laboratory testing consisting of moisture content, unit weight, Atterberg Limits, organic content, and consolidated undrained (CU) triaxial testing were performed on a Shelby tube sample collected between the depths of 17.5 to 20 feet below riverbed at test boring UC-96 (305). Further review of this information indicated significantly different laboratory test results than anticipated based on similar materials encountered at the site. As such, it is recommended that the lab test data from the 17.5 to 20 foot Shelby tube sample from test boring UC-96 (305) should not be used for analyses.
Moisture Content Tests
Moisture content tests were performed on eight Shelby (thinwall) tube samples collected from borings UC-94 (304), UC-96 (305), WM-100 (311), and WM-101 (314) (Figure F-1). Results of tests on these samples indicate a moisture content range of approximately 24 to 97 percent, with the higher moisture contents generally associated with soils containing organics (peat, organic silt, or organic clay).

Unit Weight Tests
Unit weight tests were also performed on eight Shelby tube samples collected from borings UC-94 (304), UC-96 (305), WM-100 (311), and WM-101 (314) (Figure F-1). The dry unit weights of these samples range from 48 to 104 pounds per cubic foot (pcf), and the moist unit weights vary from 95 to 128 pcf. The lower densities are generally associated with materials containing organics.

Grain Size Analyses
Grain size analysis tests, including both sieve and hydrometer tests, were performed on several near-surface (shallow than approximately 5 feet) soil samples collected via vibracore methods at UC-11, UC-23, UC-29, WM-3, WM-10, WM-18, WM-21, WM-30, and WM-32. Vibracore samples were collected mainly for the intention of environmental analyses. Gradation tests were also performed on three Shelby tube samples from test borings UC-96 (305), WM-100 (311), and WM-101 (314) (Figure F-1). Test results indicate that near-surface soil samples contain gravel, sand, silt, and clay ranges of 0 to 3.8 percent, 0.8 to 97.4 percent, 1.6 to 89.1 percent, and 1 to 28.5 percent, respectively. Gradation results for the Shelby tube samples indicate soils containing gravel, sand, silt, and clay ranges of zero percent, 0.1 to 13.5 percent, 72.5 to 91.3, and 6.1 to 14 percent, respectively.

Atterberg Limits Tests
Atterberg Limits tests were performed on several near-surface vibracore soil samples from locations UC-11, UC-23, UC-29, WM-3, WM-10, WM-18, WM-21, WM-30, and WM-32 (Figure F-1). Atterberg limits tests were also performed on the eight Shelby tube samples collected from borings UC-94 (304), UC-96 (305), WM-100 (311), and WM-101 (314) (Figure F-1). Test results indicate the liquid limit ranges from 23 to 123 percent, the plastic limit ranges from 19 to 52 percent, and the plasticity index ranges from 1 to 73 percent. Atterberg limits results of the tested samples indicate near-surface soils (shallow than approximately 5 feet) consist of fat clay (CH), high plasticity silt/high plasticity organic silt (MH/OH), low plasticity silt/low plasticity organic silt (ML/OL), and low plasticity clay/low plasticity organic clay (CL/OL). Atterberg limits tests on deeper soils indicate silt (ML), lean clay (CL), and silty clay (CL-ML) soils.

Permeability Tests
Permeability tests were performed on three Shelby tube samples collected from UC-96 (305), WM-100 (311), and WM-101 (314) (Figure F-1). The tests indicate coefficients of permeability between approximately 3.0x10^{-7} to 2.0x10^{-6} cm/s.
Consolidation Tests

Consolidation testing was performed on two Shelby tube samples collected from test borings UC-94 (304) and UC-96 (305) (Figure F-1). The testing indicates coefficients of consolidation between 0.13 to 0.73, and coefficients of recompression from 0.01 to 0.03. This data will be used in conjunction with DMT testing data to aid in settlement evaluation for future project phases.

Consolidated Undrained (CU) Triaxial Tests

CU triaxial tests were performed on two Shelby tube samples collected from test borings UC-94 (304) and WM-100 (311) (Figure F-1) to document strength characteristics. Test results indicate drained angles of internal friction between approximately 34 and 36 with an associated drained cohesion value of 0 psf.

Closing

This memo has presented a summary of the geotechnical investigation performed as part of the USS Spirit Lake Sediment Investigation. Soil characteristics discussed in this memo will be further evaluated and employed as applicable to designs for environmental remediation efforts developed during future project phases.

Attachments:

Table F-1  Geotechnical Field and Laboratory Data Summary

Figure F-1  Fall 2011 Geotechnical Boring Locations
Figure F-2  Graph, Undrained Shear Strength from CPT vs. Depth
Figure F-3  Graph, Friction Angle vs. Depth

Attachment F-1 Boring Logs
Attachment F-2 CPT Logs
Attachment F-3 Pore Pressure Dissipation Plots
Attachment F-4 DMT Data
Attachment F-5 Laboratory Testing Data
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--- End of Table F-3: Geotechnical Field and Lab Data Summary (cont.) ---
Approximate U. S. Steel Operations Area

Figure F-1

FALL 2011

GEO TECHNICAL BORING LOCATIONS

Spirit Lake Sediment Site -
Former U. S. Steel Duluth Works
Saint Louis River
Duluth, Minnesota
Figure F-2. Undrained Shear Strength from CPT vs. Depth ($N_{kt}=16$)
Figure F-3. Friction Angle vs. Depth
(Robertson & Campanella, 1983)
Attachment F-1

Soil Boring Logs
LOG OF BORING UC-94 (304)

MATERIAL DESCRIPTION

Surface Elevation: 595.9 ft

- ORGANIC SILT (OL): very dark brown; wet.
- PEAT (PT): very dark brown; wet.
- CLAYEY SAND (SC): very dark brown; wet.
- SAND (SP): fine grained; very dark brown; wet.
- SANDY CLAY (CL): very dark gray; moist; very soft.
- SILT (ML): very dark gray; wet.
- LEAN CLAY (CL): very dark gray; moist.
- SAND (SP): fine to medium grained; very dark gray; wet.
- CLAYEY SAND (SC): very dark gray; moist; very soft.
- SANDY CLAY (CL): brown; moist; medium stiff.
- LEAN CLAY (CL): very dark gray; wet.
- SANDY CLAY (CL): brown; moist to wet; medium stiff.
- SANDY CLAY (CL): brown; moist.
- SILTY SAND (SM): brown; wet; very loose.

Water Levels (ft)

Surface Elev.: 595.9 ft

- 595.0 ft
- 594.5 ft
- 594.3 ft
- 594.1 ft
- 593.9 ft
- 591.5 ft
- 591.1 ft
- 588.7 ft
- 587.9 ft
- 587.6 ft
- 586.5 ft
- 585.5 ft
- 585.1 ft
- 584.3 ft
- 583.9 ft
- 581.1 ft
- 578.5 ft
- 577.5 ft
- 575.9 ft

Date Boring Started: 11/8/11
Date Boring Completed: 11/8/11
Logged By: IGM
Drilling Contractor: EPC
Drill Rig:

Remarks: Vane shear testing performed and Shelby tubes were collected in boring offset 12 feet.

Weather:
LOG OF BORING UC-94 (304)

Project: Spirit Lake Sediment Site
Job No.: 23/69-1125.03-100-002
Location: Duluth, MN
Coordinates: N 399,372.2 ft E 2,851,039.7 ft
Datum: 

Surface Elevation: 595.9 ft
Drilling Method: 3.25" HSA
Sampling Method: SS
Completion Depth: 30.0 ft

Remarks: Vane shear testing performed and Shelby tubes were collected in boring offset 12 feet.

Weather:

Date Boring Started: 11/8/11
Date Boring Completed: 11/8/11
Logged By: IGM
Drilling Contractor: EPC

Elevation, feet

Depth, feet

MATERIAL DESCRIPTION

575.0
572.5
570.0
567.5
565.0
562.5
560.0
557.5
555.0
552.5
550.0
547.5
545.0
542.5
540.0
537.5
535.0
532.5
530.0
527.5
525.0
522.5
520.0
517.5
515.0
512.5
510.0
507.5
505.0
502.5
500.0

SAND (SP): brown; wet.

LEAN CLAY (CL): brown; moist.

SAND (SP): fine to medium grained; dark yellowish brown; wet; very loose to loose.

SANDY CLAY (CL): dark yellowish brown; moist to wet.

SAND (SP): fine to medium grained; dark yellowish brown; wet; very loose.

Bottom of Boring at 30.0 feet

Graphic Log

Depth, feet

STRENGTH, psf

TEST DATA | N in blows/ft

10 20 30 40

STANDARD PENETRATION

SPT, N value or RQD %

% Recovery

Sample No.

Samples

RQD %

20 40 60 80
LOG OF BORING UC-96 (305)

MATERIAL DESCRIPTION

Surface Elevation: 599.0 ft

591.5 ft

SANDY SILT (ML): black; wet; with weakly cemented sandy material, trace shell fragments, apparent black staining from contaminants.

3.5': Vane shear test.

5.0-7.5': Shelby tube, 21 inches recovery.

591.5 ft

ORGANIC SILT (OL): very dark brown; wet. 7.5 ft

8.0': Vane shear test.

590.0 ft

SAND (SP): fine to medium grained; very dark grayish brown; wet. 9.5 ft

PEAT (PT): very dark brown; wet. 10.0 ft

LEAN CLAY (CL): dark gray; wet. 10.3 ft

588.7 ft

SAND (SP): fine to coarse grained; dark gray; wet. 12.5 ft

587.5 ft

LEAN CLAY (CL): brown; moist to wet; lens of peat at 20.5 feet. 17.0 ft

Date Boring Started: 10/31/11

Date Boring Completed: 10/31/11

Logged By: IGM

Drilling Contractor: EPC

Drill Rig:

Water Levels (ft)

Remarks: Shallow vane shear tests performed and Shelby tubes collected in offset boring.

Weather:
MATERIAL DESCRIPTION

LEAN CLAY (CL): brown; moist to wet; lens of peat at 20.5 feet. 

(LContinued)
MATERIAL DESCRIPTION

Surface Elevation:

No samples collected - see UC-96 (305).

SILTY SAND (SM): black; wet; trace shell fragments and peat.

ORGANIC SILT (OL): black; wet; trace clay.

SAND (SP): fine to medium grained; dark grayish brown; wet.

SILTY CLAY (CL-ML): dark brown.

SAND (SP): fine to coarse grained; dark grayish brown.

LEAN CLAY (CL): brown.

Remarks: Boring offset 5 feet from UC-96 (305).
Project: Spirit Lake Sediment Site
Job No.: 23/69-1125.03-100-002
Location: Duluth, MN
Coordinates: 
Datum: 

Surface Elevation: 
Drilling Method: 3.25" HSA
Sampling Method: MC
Completion Depth: 25.0 ft

Elevation, feet
Depth, feet

MATERIAL DESCRIPTION

LEAN CLAY (CL): brown. (Continued)

Vane Shear test performed at 22 feet.

Bottom of Boring at 25.0 feet

Weather:

Date Boring Started: 11/1/11
Date Boring Completed: 11/1/11
Logged By: JD (EPC)
Drilling Contractor: EPC

Remarks: Boring offset 5 feet from UC-96 (305).
LOG OF BORING UC-97 (309)

MATERIAL DESCRIPTION

Surface Elevation: 599.7 ft

SAND (SP): fine grained; black; wet.
599.2 ft

SANDY SILT (ML): bluish black; moist; weakly cemented, laminations of white crystal pieces.
598.7 ft

SILT (ML): very dark brown and black; moist; laminated, weakly cemented. 5.0 ft

Trace greenish, weakly cemented sandy material between approximately 6.5 and 7 feet.

PEAT (PT): very dark brown; moist; fibrous.

PEAT (PT): very dark brown; moist to wet; fibrous.

SANDY SILT (ML): fine grained; dark grayish brown; moist to wet. 13.5 ft

Apparent milled wood pieces between approximately 13.5 and 13.75 feet.

Date Boring Started: 11/1/11
Date Boring Completed: 11/1/11
Logged By: IGM
Drilling Contractor: EPC
Drill Rig:
**LOG OF BORING UC-97 (309)**

**Project:** Spirit Lake Sediment Site  
**Job No.:** 23/69-1125.03-100-002  
**Location:** Duluth, MN  
**Coordinates:** N 398,009.7 ft E 2,850,626.7 ft  
**Datum:**  

**Surface Elevation:** 599.7 ft  
**Drilling Method:** 3.25" HSA  
**Sampling Method:** MC  
**Completion Depth:** 20.0 ft

**MATERIAL DESCRIPTION**

- **Elevation, feet**  
  - 583.7 ft  
  - 581.2 ft  
  - 581.0 ft  
  - 579.7 ft  

- **Depth, feet**  
  - 16.0 ft  
  - 18.5 ft  
  - 18.7 ft  
  - 20.0 ft

**Remarks:**  
- Bottom of Boring at 20.0 feet

**Date Boring Started:** 11/1/11  
**Date Boring Completed:** 11/1/11  
**Logged By:** IGM  
**Drilling Contractor:** EPC  
**Drill Rig:**  
**Water Levels (ft):**  
**Remarks:**  
**Weather:**
LOG OF BORING WM-100 (311)

MATERIAL DESCRIPTION

Elevation, feet

Depth, feet

Surface Elevation: 598.7 ft

ORGANIC SILT (OL): very dark brown; wet; with sand, apparent black staining from contaminants below approximately 1 foot.

597.3 ft

SILTY SAND (SM): brown; wet; trace peat.

1.4 ft

SILTY CLAY (CL-ML): brown; wet; very soft; with sand.

3.0-5.5': Shelby tube, 17.5 inches recovery.

With peat between approximately 8 to 10 feet.

588.7 ft

SANDY SILT (ML): brown; wet.

10.0': Vane shear test.

Apparent milled wood pieces between 10.4 and 10.6 feet.

11.5': Vane shear test.

12.0-14.5': Shelby tube, 14 inches recovery.

584.7 ft

SILTY SAND (SM): yellowish brown; wet; medium dense.

14.0 ft

Gravel between approximately 15.6 and 15.8 feet.

581.5 ft

LEAN TO FAT CLAY (CL/CH): reddish brown; moist; lamination of sand at approximately 17.8 feet.

17.2 ft

SAND (SP): fine grained; greenish gray; wet; loose to medium dense; lamination of sand at approximately 19.4 feet.

18.0 ft

Remarks: Vane shear testing performed and Shelby tubes (excluding 34-36.5' Shelby tube) collected in an offset boring.

Date Boring Started: 11/9/11
Date Boring Completed: 11/9/11
Logged By: JD (EPC)
Drilling Contractor: EPC
Drill Rig:
MATERIAL DESCRIPTION

SAND (SP): fine grained; greenish gray; wet; loose to medium dense; lamination of sand at approximately 19.4 feet. (Continued)

LEAN CLAY (CL): reddish brown; moist; lamination of sand.

LEAN CLAY (CL): reddish brown; moist.

SILTY CLAY (CL-ML): reddish brown; moist.

LEAN CLAY (CL): reddish brown; moist; soft.

34.0-36.5': Shelby tube, 18 inches recovery.

Bottom of Boring at 30.0 feet

562.2 ft

Surface Elevation: 598.7 ft
Drilling Method: 3.25" HSA
Sampling Method: SS
Completion Depth: 30.0 ft

Remarks: Vane shear testing performed and Shelby tubes (excluding 34-36.5' Shelby tube) collected in an offset boring.

Weather:
MATERIAL DESCRIPTION

Surface Elev.: 597.1 ft

ORGANIC SILT (OL): black; wet.

595.6 ft

PEAT (PT): very dark brown; wet; fibrous and silty.

595.1 ft

SILT (ML): dark grayish brown; moist; trace to with sand.

5.0': Vane shear test.

Lenses of sand at approximately 9 and 9.8 feet.

Sandy at approximately 9.5 feet.

10.0-12.5': Shelby tube, no recovery.

15.5': Vane shear test.

Remarks: Vane shear testing performed and Shelby tubes (excluding 27.5-30.0' Shelby tube) were collected in an offset boring.

Weather:
MATERIAL DESCRIPTION

SILT (ML): dark grayish brown; moist; trace to with sand. (Continued)

Trace to with clay between approximately 22 and 25 feet.

27.5-30.0': Shelby tube, 18 inches recovery.

Bottom of Boring at 30.0 feet

Date Boring Started: 11/10/11
Date Boring Completed: 11/10/11
Logged By: JD (EPC)
Drilling Contractor: EPC

Surface Elevation: 597.1 ft
Drilling Method: 3.25" HSA
Sampling Method: MC
Completion Depth: 30.0 ft

Remarks: Vane shear testing performed and Shelby tubes (excluding 27.5-30.0' Shelby tube) were collected in an offset boring.

Weather:
**LOG OF BORING WM-102 (315)**

**Project:** Spirit Lake Sediment Site  
**Job No.:** 23/69-1125.03-100-002  
**Location:** Duluth, MN  
**Coordinates:** N 394,638.3 ft E 2,851,561.0 ft  
**Datum:**

---

**MATERIAL DESCRIPTION**

**Surface Elev.:** 597.8 ft

**ORGANIC SILT (OL):** very dark brown; wet; apparent black staining from contaminants.

**LEAN CLAY (CL):** very dark brown; wet.

**SAND (SP):** fine grained; very dark brown; wet.

**Fine to medium grained below approximately 6.5 feet.**

**SAND (SP):** fine grained; very dark brown; wet; laminations of silt.

**SANDY SILT (ML):** fine grained; very dark brown; wet.

**Fine to medium grained; very dark brown; wet; trace to with silt.**

**SILT (ML):** very dark brown; wet; trace to with sand.

**SAND (SP):** fine to medium grained; very dark brown; wet; laminations of silt.

**SILT (ML):** very dark brown; wet; with sand to sandy; trace to with clay below approximately 19.5 feet.

---

**Remarks:**

**Weather:**

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**Date Boring Started:** 11/11/11  
**Date Boring Completed:** 11/11/11  
**Logged By:** JD (EPC)  
**Drilling Contractor:** EPC  
**Water Levels (ft):**

---

**Continued Next Page**
MATERIAL DESCRIPTION

577.5 ft
SILT (ML): very dark brown; wet; with sand to sandy.

573.3 ft
SAND (SP): fine grained; very dark brown; wet.

572.3 ft
SILTY SAND (SM): fine to medium grained; very dark brown; wet; lenses of wood chips.

570.3 ft
SAND (SP): fine to medium grained; very dark brown; wet.

567.8 ft
Bottom of Boring at 30.0 feet

Surface Elevation: 597.8 ft
Drilling Method: 3.25" HSA
Sampling Method: MC
Completion Depth: 30.0 ft

Remarks:
Weather:
Attachment F-2

Cone Penetration Test (CPT) Logs
EPC Engineering

Job No: 11-411
Date: 10:25:11 11:48
Site: SPIRIT LAKE SEDIMENT STUDY
Sounding: CPT-303
Cone: 155:T1500F15U500

Max Depth: 15.250 m / 50.03 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 11-411CP303.COR
Unit Wt: SBT Chart Soil Zones

SBT: Lunne, Robertson and Powell, 1997
Coords: Lat: 46.693000 Long: -92.196210
○ Equilibrium Pore Pressure from Dissipation
Job No: 11-411  
Sounding: CPT-305A  
Date: 10:26:11 13:27  
Site: SPIRIT LAKE SEDIMENT STUDY  

Max Depth: 3.050 m / 10.01 ft  
Depth Inc: 0.050 m / 0.164 ft  
Avg Int: 0.150 m  

Equilibrium Pore Pressure from Dissipation  

SBT: Lunne, Robertson and Powell, 1997  
Coords: Lat: 46.690250 Long: -92.202430
Max Depth: 14.950 m / 49.05 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 11-411CP305.COR
Unit Wt: SBT Chart Soil Zones

SBT: Lunne, Robertson and Powell, 1997
Coords: Lat: 46.690270 Long: -92.202480

Equilibrium Pore Pressure from Dissipation
EPC Engineering

Job No: 11-411
Date: 10:26:11 08:22
Site: SPIRIT LAKE SEDIMENT STUDY

Sounding: CPT-306
Cone: 155:T1500F15U500

Max Depth: 15.250 m / 50.03 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 11-411CP306.COR
Unit Wt: SBT Chart Soil Zones

SBT: Lunne, Robertson and Powell, 1997
Coords: Lat: 46.690700 Long: -92.200290

Equilibrium Pore Pressure from Dissipation
Max Depth: 13.550 m / 44.45 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 11-411CP307.COR
Unit Wt: SBT Chart Soil Zones

SBT: Lunne, Robertson and Powell, 1997
Coords: Lat: 46.689500 Long: -92.197000
Equilibrium Pore Pressure from Dissipation
Max Depth: 15.250 m / 50.03 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 11-411CP310.COR
Unit Wt: SBT Chart Soil Zones

SBT: Lunne, Robertson and Powell, 1997
Coords: Lat: 46.683980  Long: -92.200200
● Equilibrium Pore Pressure from Dissipation
Job No: 11-411
Date: 10:27:11 14:41
Site: SPIRIT LAKE SEDIMENT STUDY

Sounding: CPT-311
Cone: 155:T1500F15U500

Max Depth: 15.850 m / 52.00 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 11-411CP311.COR
Unit Wt: SBT Chart Soil Zones

SBT: Lunne, Robertson and Powell, 1997
Coords: Lat: 46.682300  Long: -92.203270

- Equilibrium Pore Pressure from Dissipation
Max Depth: 15.250 m / 50.03 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 11-411CP314.COR
Unit Wt: SBT Chart Soil Zones

SBT: Lunne, Robertson and Powell, 1997
Coords: Lat: 46.677880  Long: -92.199360
Equilibrium Pore Pressure from Dissipation
Job No: 11-411
Date: 10:28:11 11:06
Site: SPIRIT LAKE SEDIMENT STUDY

Max Depth: 15.250 m / 50.03 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 11-411CP315.COR
Unit Wt: SBT Chart Soil Zones

SBT: Lunne, Robertson and Powell, 1997
Coords: Lat: 46.678830 Long: -92.196260

Equilibrium Pore Pressure from Dissipation
Max Depth: 15.250 m / 50.03 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 11-411CP316.COR
Unit Wt: SBT Chart Soil Zones

SBT: Lunne, Robertson and Powell, 1997
Coords: Lat: 46.678390  Long: -92.192190
- Equilibrium Pore Pressure from Dissipation
Attachment F-3

Pore Pressure Dissipation (PPD) Plots
Trace Summary:

Filename: 11-411CP303.PPD
Depth: 1.800 m / 5.905 ft
Duration: 2000.0 s

U Min: 6.1 ft
U Max: 28.3 ft
Ueq: 13.8 ft
WT: -2.393 m / -7.851 ft
Trace Summary:
Filename: 11-411CP304.PPD
Depth: 1.400 m / 4.593 ft
Duration: 500.0 s

U Min: -3.3 ft
U Max: 20.2 ft
WT: -2.742 m / -8.996 ft
Ueq: 13.6 ft

© 2011 ConeTec Investigations Ltd.
Trace Summary:
Filename: 11-411CP316.PPD  U Min: 8.5 ft  WT: -1.961 m / -6.434 ft
Depth: 1.450 m / 4.757 ft  U Max: 19.0 ft  Ueq: 11.2 ft
Duration: 400.0 s
Attachment F-4

Flat Plate Dilatometer (DMT) Data
| Depth (ft) | A  | B  | po | p1 | ωo | sωo | Eo | κo | κc | OCR1 | OCR2 | φ4 | φ5 | Rd | s6 | s7 | M |
|-----------|----|----|----|----|----|-----|----|----|----|------|------|-----|-----|----|----|----|
| 3.0       | 0.55 | 1.15 | 0.69 | 0.9 | 478 | 591 | 113 | 0.46 | 8.5 | 7  | 1.7 | 4.3 | 9.6 | 2.3 | 15 | 152 | 96 | 36 |
| 4.0       | 0.85 | 1.35 | 1.00 | 1.1 | 540 | 691 | 150 | 0.14 | 10.2 | 4  | 1.9 | 5.2 | 12.7 | 2.5 | 8  | 254 | 154 | 19 |
| 5.0       | 0.8  | 1.7  | 0.93 | 1.45 | 603 | 791 | 188 | 0.82 | 7.1 | 18 | 1.5 | 3.6 | 7.2 | 2.1 | 38 | 200 | 133 | 83 |
| 6.0       | 0.95 | 1.6  | 1.09 | 1.35 | 665 | 891 | 226 | 0.34 | 7.1 | 9  | 1.5 | 3.6 | 7.2 | 2.2 | 19 | 243 | 161 | 41 |
| 7.0       | 0.95 | 1.75 | 1.08 | 1.5 | 728 | 991 | 263 | 0.57 | 5.8 | 15 | 1.3 | 3.0 | 5.3 | 1.9 | 30 | 219 | 153 | 59 |
| 12.0      | 1.25 | 3.35 | 1.32 | 3.1 | 1040| 1491| 451 | 2.18 | 3.8 | 62 | 0.9 | 35.7| 39.0| 1.6 | 129| 207|  
| 17.0      | 2.55 | 8.55 | 2.42 | 8.3 | 1352| 1991| 639 | 3.32 | 5.8 | 204| 1.3 | 37.9| 40.1| 2.0 | 426| 863|  
| 22.0      | 2.1  | 4.35 | 2.16 | 4.1 | 1664| 2491| 827 | 1.43 | 3.4 | 67 | 0.9 | 35.2| 38.7| 1.5 | 141| 206|  
| 27.0      | 2.1  | 3.7  | 2.19 | 3.45 | 2176| 2991| 1015| 1.01 | 2.6 | 44 | 0.7 | 1.3 | 1.5 | 1.1 | 91 | 304 | 260 | 104 |
| 32.0      | 2.9  | 4.05 | 3.61 | 3.8 | 2288| 3491| 1203| 0.41 | 3.3 | 27 | 0.9 | 1.7 | 2.2 | 1.4 | 57 | 500 | 400 | 78 |
| 37.0      | 3    | 5.25 | 3.06 | 5   | 2600| 3991| 1391| 1.07 | 2.7 | 67 | 0.7 | 1.4 | 1.6 | 1.2 | 141| 450 | 379 | 170 |
### DMT Spreadsheet - Data Summary

**St Louis River Duluth Works Sediment**

**23/69-1125**

**Sounding No:** UC-95  
**October 29, 2011**

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1. Depth Below Existing Ground Surface  
2. Mayne, 1995  
3. Marchetti, 1980  
4. Marchetti, 1997  
5. Campanella and Robertson, 1991  
6. Marchetti, 1980  
7. Schmertman, 1981
### St Louis River Duluth Works Sediment

**UTM, Zone 16N - NAD 83 (m)**

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**Water Depth (ft):** -1.75

**DMT Spreadsheet- Data Summary**

1. **Depth Below Existing Ground Surface**
2. Mayne, 1995
3. Marchetti, 1980
4. Marchetti, 1997
5. Campanella and Robertson, 1991
6. Marchetti, 1980
7. Schmertman, 1981

**Table: Geotechnical Evaluation**

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1. Depth Below Existing Ground Surface
2. Mayne, 1995
3. Marchetti, 1980
4. Marchetti, 1997
5. Campanella and Robertson, 1991
6. Marchetti, 1980
7. Schmertman, 1981
### Barr Engineering Company

**DMT Spreadsheet- Data Summary**

#### St Louis River Duluth Works Sediment

**23/69-1125**

**Sounding No:** WM-100  
**Easting:** 0.0  
**Northing:** 0.0  
**UTM, Zone 16N - NAD 83 (m)**  
**Water Depth (ft):** -4.75  
**Depth Below Existing Ground Surface**  
**Mayne, 1995**  
**Marchetti, 1980**  
**Marchetti, 1997**  
**Campanella and Robertson, 1991**  
**Marchetti, 1980**  
**Schmertman, 1981**

### Table: DMT Data Summary

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1. Depth Below Existing Ground Surface  
2. Mayne, 1995  
3. Marchetti, 1980  
4. Marchetti, 1997  
5. Campanella and Robertson, 1991  
6. Marchetti, 1980  
7. Schmertman, 1981
Grain Size Distribution ASTM D422

**Project:** Spirit Lake Sediment Site - Former US Steel Duluth Works

**Reported To:** Barr Engineering Company

**Report Date:** 1/31/12

**Test Date:** 1/25/12

**Location / Boring No.** | **Sample No.** | **Depth (ft)** | **Sample Type** | **Soil Classification**
---|---|---|---|---
UC-96 | (305) | 5-7.5 | 3T | Silt (ML)
WM-100 | (311) | 3-5.5 | 3T | Lean Clay (CL)
WM-101 | (314) | 27.5-30 | 3T | Silty Clay (CL-ML/CL)

**Gravel**

Coarse | Fine
---|---

**Sand**

Coarse | Medium | Fine
---|---|---

**Hydrometer Analysis**

Fines

| Mass (g) | * | * | *
---|---|---|---
2" | 92.9 | 118.5 | 144.9
1.5" | 100.0 | 100.0 | 100.0
1" | 100.0 | 100.0 | 100.0
3/4" | 100.0 | 100.0 | 100.0
3/8" | 99.4 | 100.0 | 100.0
#4 | 98.1 | 100.0 | 100.0
#10 | 97.6 | 99.0 | 100.0
#20 | 97.4 | 86.5 | 99.9
#40 | 99.9 | 100.0 | 100.0
#100 | 100.0 | 100.0 | 100.0
#200 | 100.0 | 100.0 | 100.0

**Other Tests**

| Parameter | * | * | *
---|---|---|---
Liquid Limit | 46.8 | 28.5 | 28.1
Plastic Limit | 34.5 | 19.8 | 21.4
Plasticity Index | 12.3 | 8.7 | 6.7
Water Content | | | |
Dry Density (pcf) | | | |
Specific Gravity | | | |
Porosity | | | |
Organic Content | | | |
pH | | | |
Shrinkage Limit | | | |
Penetrometer | | | |
Qu (psf) | | | |

(* = assumed)

**Remarks:**

**2401 W 66th Street**

Richfield, Minnesota 55423-2031
Hydraulic Conductivity Test Data

Project: Spirit Lake Sediment Site - Former US Steel Duluth Works
Date: 2/7/2012

Reported To: Barr Engineering Company
Job No.: 8192-A

Boring No.: UC-96 WM-100 WM-101
Sample No.: 305 311 314
Depth (ft): 5-7.5 3-5.5 27.5-30

Location:
Sample Type: 3T 3T 3T

Soil Type:
Organic Clay (OH) Lean Clay (CL) Silty Clay (CL-ML/CL)

Atterberg Limits
LL: 78.6 28.5 28.1
PL: 41.8 19.8 21.4
PI: 36.8 8.7 6.7

Permeability Test
Undisturbed Undisturbed Undisturbed

Before Test Conditions:
Saturation %:

Porosity:
Ht. (in): 1.45 2.76 2.74
Dia. (in): 2.88 2.85 2.91
Dry Density (pcf): 48.3 94.0 88.6

Water Content:
96.7% 28.3% 31.2%

Test Type: Falling Falling Falling
Max Head (ft): 5.0 5.0 5.0
Confining press. (Effective-psl): 2.0 2.0 2.0
Trial No.: 7-11 9-13 8-12
Water Temp °C: 21.0 21.0 21.0

% Compaction

% Saturation (After Test)

Coefficient of Permeability
K @ 20 °C (cm/sec) 2.0 x 10^-6 3.0 x 10^-7 1.1 x 10^-6
K @ 20 °C (ft/min) 4.0 x 10^-6 5.8 x 10^-7 2.1 x 10^-6

Notes:
**TRIAXIAL TEST ASTM: D 4767**

**Project:** Spirit Lake Sediment Site - Former US Steel Duluth Works  
**Boring #:** 304  
**Sample #:** 3T  
**Depth (ft):** 10.5-13 (Mid)  
**Soil Type:** Specimen A: Silty Sand (SM)  
Specimens B and C: Sandy Silt to Silt w/sand (ML)

### Before Consolidation

<table>
<thead>
<tr>
<th>Diameter (in)</th>
<th>Height (in)</th>
<th>Water Content (%)</th>
<th>Dry Density (pcf)</th>
<th>Void Ratio</th>
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<td>104.1</td>
<td>0.61</td>
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### After Consolidation

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<th>Diameter (in)</th>
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<th>Water Content (%)</th>
<th>Dry Density (pcf)</th>
<th>Void Ratio</th>
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### Test Results

- **Angle of internal friction, φ' = 38.9°**
- **Apparent Cohesion, c' = 0.00 (tsf)**
- **Liquid Limit:**
- **Plastic Limit:**
- **Test Date:** 1/26/12
- **Strain Rate (in/min):** 0.001369
- **Strain Rate (%/min):** 0.050
- **Spec. Gravity (Assumed):** 2.69

### Remarks

Specimens varied significantly in sand content from a Silty Sand (SM) for the 0.25 tsf specimen A to the Silt w/sand (ML) for specimens B and C.

*These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design.*

2401 W 66th Street  
Richfield, Minnesota 55423-2031
TRIAXIAL TEST ASTM: D 4767

Project: Spirit Lake Sediment Site - Former US Steel Duluth Works
Boring #: 304  
Sample #: 3T  
Depth (ft): 10.5-13 (Mid)

Soil Type: Specimen A: Silty Sand (SM)  
Specimens B and C: Sandy Silt to Silt w/sand (ML)

Failure Criterion:

- Max. Deviator Stress
- Angle of internal friction, \( \phi' = 36.2 \)°
- Apparent Cohesion, \( c' = 0.00 \) (tsf)

Test Date: 1/26/12
Test Type: CU w/pp
Strain Rate (in/min): 0.001369
Strain Rate (%/min): 0.050

Before Consolidation

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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</thead>
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<tr>
<td>Diameter (in)</td>
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<td>1.45</td>
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<tr>
<td>Height (in)</td>
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<td>Water Content (%)</td>
<td>24.6</td>
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<td>Dry Density (pcf)</td>
<td>97.3</td>
<td>96.3</td>
<td>104.1</td>
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<tr>
<td>Void Ratio</td>
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<td>0.74</td>
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<td>Ultimate Deviator Stress (tsf)</td>
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<td>Deviator Stress at Failure (tsf)</td>
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<td>Max. Pore Pressure Buildup (tsf)</td>
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<td>Pct. Axial Strain at Failure</td>
<td>8.0</td>
<td>20.0</td>
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</tbody>
</table>

"These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design"

Remarks: Specimen trimmed to given dimensions; Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.

Specimens varied significantly in sand content from a Silty Sand (SM) for the 0.25 tsf specimen A to the Silt w/sand (ML) for specimens B and C.
TRIAXIAL TEST ASTM: D 4767

Project: Spirit Lake Sediment Site - Former US Steel Duluth Works
Boring #: 304
Sample #: Type: 3T
Soil Type: Specimen A: Silty Sand (SM) Specimens B and C: Sandy Silt to Silt w/sand (ML)

Failure Criterion: Given Strain of: 15%

Angle of internal friction, \( \phi' = 36.2^\circ \)
Apparent Cohesion, \( c' = 0.00 \) (tsf)

Test Date: 1/26/12
Test Type: CU w/pp
Strain Rate (in/min): 0.001369
Strain Rate (%/min): 0.050

Before Consolidation

| Diameter (in) | 1.45 | 1.45 | 1.45 |
| Height (in)   | 2.74 | 2.99 | 2.99 |
| Water Content (%) | 24.6 | 25.8 | 21.9 |
| Dry Density (pcf) | 97.3 | 96.3 | 104.1 |
| Void Ratio    | 0.73 | 0.74 | 0.61 |

After Consolidation

| Diameter (in) | 1.45 | 1.44 | 1.44 |
| Height (in)   | 2.74 | 2.98 | 2.99 |
| Water Content (%) | 26.9 | 27.0 | 22.2 |
| Dry Density (pcf) | 97.4 | 97.3 | 105.2 |
| Void Ratio    | 0.72 | 0.73 | 0.60 |

Back Pressure (tsf): 5.8
Minor Principal Stress (tsf): 0.25
Max. Deviator Stress (tsf): 15.56
Ultimate Deviator Stress (tsf): 14.08
Deviator Stress at Failure (tsf): 13.95
Max. Pore Pressure Buildup (tsf): 0.05
Pore Pressure Parameter "B": 1.0
Pct. Axial Strain at Failure: 15.0

These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design.

Remarks: Specimen trimmed to given dimensions; Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.

Specimens varied significantly in sand content from a Silty Sand (SM) for the 0.25 tsf specimen A to the Silt w/sand (ML) for specimens B and C.
<table>
<thead>
<tr>
<th>Sample 1</th>
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**TRIAXIAL TEST ASTM: D 4767**

**Project:** Spirit Lake Sediment Site - Former US Steel Duluth Works

**Boring #:** UC-96

**Sample #:** 305

**Type:** 3T

**Soil Type:** Organic Clay (OH) **

**Spirit Lake Sediment Site - Former US Steel Duluth Works**

**Sample #:** 305

**Type:** 3T

**Date:** 2/16/12

**Test No.:** 8192-A

**Job No.:**

**Test Type:** CU w/pp

**Gage:**

**Diameter (in):** 1.45 1.45 1.45

**Height (in):** 2.99 2.99 2.74

**Water Content (%):** 133.9 115.8 122.9

**Dry Density (pcf):** 35.1 39.2 37.7

**Void Ratio:** 3.79 3.28 3.46

**Back Pressure (tsf):**

**Major Principal Stress (tsf):**

**Minor Principal Stress (tsf):**

**Max. Pore Pressure Buildup (tsf):**

**Ultimate Deviator Stress (tsf):**

**Max. Stress Ratio (tsf):**

**Apparent Cohesion, c' = 0.16 (tsf)**

**Angle of internal friction, φ = 16.8 °**

**Effective φ = 16.1 °**

**Total φ = 11.4 °**

**Spec. Gravity (Assumed):** 2.69

**Liquid Limit:**

**Plastic Limit:**

**Plasticity Index:**

**Depth (ft):** 17.5-20

**Remarks:**

"These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design."
**TRIAXIAL TEST** ASTM: D 4767

Project: Spirit Lake Sediment Site - Former US Steel Duluth Works
Boring #: UC-96
Sample #: 305
Type: 3T
Depth (ft): 17.5-20

**Failure Criterion:**
- Max. Deviator Stress
- Strain Rate (%/min): 0.00147
- Strain Rate (%/min): 0.050

**Test Details:**
- Test Date: 1/27/12
- Test Type: CU w/pp
- Liquid Limit:
- Plastic Limit:
- Spec. Gravity (Assumed): 2.69

**Before Consolidation:**
- Diameter (in): 1.45, 1.45, 1.45
- Height (in): 2.99, 2.99, 2.74
- Water Content (%): 133.9, 115.8, 122.9
- Dry Density (pcf): 35.1, 39.2, 37.7
- Void Ratio: 3.79, 3.28, 3.46

**After Consolidation:**
- Diameter (in): 1.43, 1.40, 1.40
- Height (in): 2.95, 2.86, 2.47
- Water Content (%): 134.1, 105.9, 102.8
- Dry Density (pcf): 36.4, 43.6, 44.6
- Void Ratio: 3.61, 2.85, 2.77
- Back Pressure (tsf): 5.8, 5.8, 5.8
- Minor Principal Stress (tsf): 0.25, 0.50, 1.00
- Max. Deviator Stress (tsf): 0.47, 0.52, 0.82
- Ultimate Deviator Stress (tsf): 0.46, 0.50, 0.79
- Deviator Stress at Failure (tsf): 0.47, 0.52, 0.82
- Max. Pore Pressure Buildup (tsf): 0.27, 0.39, 0.94
- Pore Pressure Parameter "B": 1.0, 1.0, 1.0
- Pct. Axial Strain at Failure: 13.6, 17.5, 13.8

*These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design*

Remarks: Radial drainage strips applied to trimmed specimen; Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.

**Material was unusual, with atterberg limits that varied greatly depending upon preparation method.**
**TRIAXIAL TEST ASTM: D 4767**

**Project:** Spirit Lake Sediment Site - Former US Steel Duluth Works

**Boring #:** UC-96  **Sample #:** 305  **Type:** 3T  **Depth (ft):** 17.5-20

**Failure Criterion:**
- **Given Strain of:** 15%
- **Angle of Internal Friction, \( \phi \):** 16.5°
- **Apparent Cohesion, \( c' \):** 0.16 (tsf)

**Test Date:** 1/27/12  **Liquid Limit:**
**Test Type:** CU w/pp  **Plastic Limit:**
**Strain Rate (in/min):** 0.00147  **Plasticity Index:**
**Strain Rate (%/min):** 0.050  **Spec. Gravity (Assumed):** 2.69

**Before Consolidation**

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (in)</td>
<td>1.45</td>
<td>1.45</td>
<td>1.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (in)</td>
<td>2.99</td>
<td>2.99</td>
<td>2.74</td>
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<td></td>
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<tr>
<td>Water Content (%)</td>
<td>133.9</td>
<td>115.8</td>
<td>122.9</td>
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<tr>
<td>Dry Density (pcf)</td>
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<td>37.7</td>
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</tr>
<tr>
<td>Void Ratio</td>
<td>3.79</td>
<td>3.28</td>
<td>3.46</td>
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**After Consolidation**

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<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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<td>Height (in)</td>
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<tr>
<td>Water Content (%)</td>
<td>134.1</td>
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**Remarks:**
- Radial drainage strips applied to trimmed specimen; Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.
- Material was unusual, with atterberg limits that varied greatly depending upon preparation method.

**These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design**
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TRIAXIAL TEST ASTM: D 4767  

Project: Spirit Lake Sediment Site - Former US Steel Duluth Works  
Boring #: 311  
Sample #: 3T  
Soil Type: Sandy Silt (ML)  

Type: 3T  
Depth (ft): 12-14.5  

Failure Criterion:  
Max. Stress Ratio  
Angle of internal friction, $\phi' = 37.9^\circ$  
Apparent Cohesion, $c' = 0.03\text{ (tsf)}$  

Test Date: 1/26/12  
Test Type: CU w/pp  
Strain Rate (in/min): 0.00137  
Strain Rate (%/min): 0.050  
Liquid Limit:  
Plastic Limit:  
Spec. Gravity (Assumed): 2.69  

Before Consolidation  

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<th>D</th>
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After Consolidation  

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"These test results are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design"  

Remarks: Radial drainage strips applied to trimmed specimen; Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.
**TRIAXIAL TEST ASTM: D 4767**

**Project:** Spirit Lake Sediment Site - Former US Steel Duluth Works  
**Boring #:** 311  
**Sample #:**  
**Type:** 3T  
**Depth (ft):** 12-14.5

---

**Failure Criterion:**

- **Angle of internal friction, \( \phi' \):** 34.8°  
- **Apparent Cohesion, \( c' \):** 0.00 (tsf)

**Test Date:** 1/26/12  
**Test Type:** CU w/pp  
**Strain Rate (in/min):** 0.00137  
**Strain Rate (%/min):** 0.050

### Before Consolidation

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### After Consolidation

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**Remarks:** Radial drainage strips applied to trimmed specimen; Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.

---

**Rupture Envelope at Failure**

\[ \alpha = 29.7^\circ \quad a = 0.0 \text{ (tsf)} \]

---

**Effective \( \phi' \):** 34.8°  
**Total \( \phi' \):** 57.1°  
**\( c' \):** 0.00 (tsf)  
**\( c \):** 0.00 (tsf)

---

**Address:** 2401 W 66th Street  
**Richfield, Minnesota 55423-2031**
**TRIAXIAL TEST ASTM: D 4767**  
**Project:** Spirit Lake Sediment Site - Former US Steel Duluth Works  
**Boring #:** 311  
**Sample #:** 3T  
**Type:** 3T  
**Depth (ft):** 12-14.5  
**Job No.:** 8192-A  
**Date:** 2/16/12

---

**Failure Criterion:**
- Given Strain of: 15%
- Angle of internal friction, \( \phi' \): 35.4°
- Apparent Cohesion, \( c' \): 0.00 (tsf)

**Test Date:** 1/26/12  
**Test Type:** CU w/pp  
**Strain Rate (in/min):** 0.00137  
**Strain Rate (%/min):** 0.050

### Before Consolidation

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**Remarks:** Radial drainage strips applied to trimmed specimen; Saturated, backpressured until "B" response was 0.95 to 1.00; Consolidated; All Drainage valves closed and immediately sheared.
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Void Ratio and % Settlement vs. Log of Pressure

Project: Spirit Lake Sediment Site - Former US Steel Duluth Works  Date: 2/17/12
Sample #: 304  Boring #: UC-94  Depth ft: 10.5-13  Job #: 8192-A
Soil Type: Sandy Silt (ML/SM)
Initial W/C (%): 23.5  Dry Density (pcf): 103.7  LL: 23.4  PL: 20.4  PI: 3.0  Gs: 2.73 (Assumed)
Organic Content (%):  Initial Height (in.): 0.746  Diameter (in.): 2.506  \( e_o \approx 0.644
Preconsolidation Pressure (Pc): 9 tsf  Compression Index (Cc): 0.13  Recompression Index (Cr): \approx 0.01
Remarks:
Square Root of Time Curves

1 TSF: \( C_v = 3.1 \times 10^{-3} \text{ (cm}^2/\text{sec)} \)

2 TSF: \( C_v = 6.7 \times 10^{-3} \text{ (cm}^2/\text{sec)} \)

4 TSF: \( C_v = 6.2 \times 10^{-3} \text{ (cm}^2/\text{sec)} \)

8 TSF: \( C_v = 5.7 \times 10^{-3} \text{ (cm}^2/\text{sec)} \)

16 TSF: \( C_v = 4.6 \times 10^{-3} \text{ (cm}^2/\text{sec)} \)

32 TSF: \( C_v = 5.6 \times 10^{-3} \text{ (cm}^2/\text{sec)} \)
Void Ratio and % Settlement vs. Log of Pressure

- Void Ratio (e)
- Settlement

Pressure (tsf)

Project: Spirit Lake Sediment Site - Former US Steel Duluth Works
Sample #: 305
Boring #: UC-96
Depth ft: 5-7.5
Job #: 8192-A

Soil Type: Organic Clay, extremely soft and wet (OL)

- Initial W/C (%): 92.7
- Dry Density (pcf): 50.3
- LL: 78.6
- PL: 41.8
- PI: 36.8
- Gs: 3.19 (Assumed)

Organic Content (%):
- Initial Height (in.): 0.747
- Diameter (in.): 2.06
- e_o = 2.957

Preconsolidation Pressure (Pc): 0.41 tsf
Compression Index (Cc): 0.73
Recompression Index (Cr): ≈ 0.03

Remarks:
Consolidation Log of Time Curves

Project: Spirit Lake Sediment Site - Former US Steel Duluth Works
Date: 1/24/12
Sample #: 305, Boring #: UC-96, Depth ft: 5-7.5, Job #: 8192-A

Deformation (10^-4 in)

Time (min)

0.1 TSF: Cv = 5.2 x 10^-3 (cm^2/sec)
0.25 TSF: Cv = 4.4 x 10^-3 (cm^2/sec)
0.5 TSF: Cv = 4.4 x 10^-3 (cm^2/sec)
1 TSF: Cv = 5.2 x 10^-3 (cm^2/sec)
2 TSF: Cv = 3.0 x 10^-3 (cm^2/sec)
4 TSF: Cv = 3.4 x 10^-3 (cm^2/sec)
8 TSF: Cv = 3.5 x 10^-3 (cm^2/sec)
16 TSF: Cv = 2.2 x 10^-3 (cm^2/sec)
# Laboratory Test Summary

**Project:** Spirit Lake Sediment Site - Former US Steel Duluth Works  
**Job:** 8192-B  
**Client:** Barr Engineering Company  
**Date:** 3/13/12

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## Organic Content (ASTM:D2974)

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