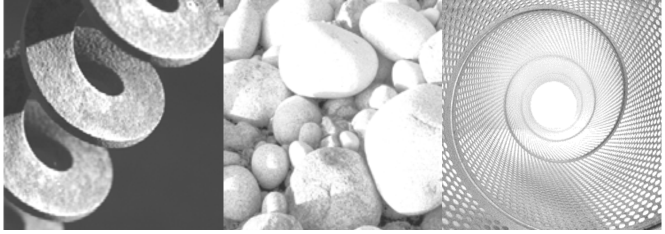

Consulting
Engineers and
Scientists

Bench Scale Testing Report

Barrier Wall Interlock Seal Systems

Former Citizens Gas Works Manufactured Gas Plant Site
Brooklyn, New York
NYSDEC Site # C224012

Submitted to:
National Grid
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August 2015
Project 093250

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STD/MDZ/JLD

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Executive Summary

GEI Consultants, Inc. (GEI) was retained by National Grid to conduct bench scale testing of barrier wall sheet pile interlock seal system for the Former Citizens Gas Works Manufactured Gas Plant (MGP) site (Site) in Brooklyn, New York. The bench scale testing was performed to measure the flow through six sheet pile interlock seal configurations using water and MGP-related dense non-aqueous phase liquids (DNAPL) collected from the Site as the permeants. This effort is, in part, a response to a requirement by the NYSDEC to demonstrate the application and effectiveness of barrier wall technologies at the Site as requested at a design status meeting with the NYSDEC on January 19, 2011.

The steel sheet pile configurations are a major design component for the proposed remediation action at the Site. The sheet piles are being designed to prevent DNAPL from passing through the barrier wall and into the Gowanus Canal.

The bench scale test program included six different steel sheet pile enclosures (chambers), each with a distinctive sealant configuration over the horizontally positioned interlocks. A standpipe was screwed atop each chamber to provide a minimum of 9 feet of permeant pressure head at the secondary interlock within the chamber. Multiple tests were performed with water and DNAPL as permeants, and all permeant discharge was collected and recorded over a 2-week period.

The results collected from this test will be incorporated into the final design of the barrier wall at the Site.

1. Introduction

1.1 Purpose

GEI Consultants, Inc., P.C. (GEI) prepared this report to present the results of a bench scale testing program that was performed at the TerraSense, LLC laboratory in Totowa, New Jersey from January 27, 2014 through March 17, 2014. The work was performed on behalf of National Grid to support remedial design efforts at the Former Citizens Gas Works Manufactured Gas Plan (MGP) site (Site) located at Smith and 5th Streets, in Brooklyn, New York. The remedial design efforts are consistent with the requirements of the "Final Remedial Design Work Plan Carroll Gardens/Public Place," dated September 14, 2007.

The purpose of the bench scale testing was to evaluate the performance of six interlock sealant system configurations for a steel sheet pile barrier wall using tap water and MGP-related dense non-aqueous phase liquids (DNAPL) collected from the Site as permeants. The interlock sealant system configurations evaluated were an unsealed interlock (as a baseline), a sealant in the interlock, and four other configurations each filled with only sealant material behind the interlock.

This Bench Scale Testing Report is an appendix to the Barrier Wall Pilot Test Program Data Summary Report.

1.2 Project Description

The former MGP property is located in a densely developed urban area of commercial, industrial, and residential land that abuts the Gowanus Canal to the east and southeast (Fig. 1). The remediation of the Site will include the construction of a bulkhead barrier wall along the Gowanus Canal to mitigate non-aqueous phase liquid (NAPL) migration into the Gowanus Canal. Additional project background is provided in the Barrier Wall Pilot Test Program Data Summary Report.

1.3 Project Participants

The table below lists the contractors, consultants, and other participants involved in the project that will be referenced throughout the text:

Company	Role
Dura-Bond Industries	Steel Fabricator (Subcontractor to Cashman)
B & B Welding, Inc.	Welding Contractor (Subcontractor to Cashman)
GEI Consultants, Inc., P.C.	Construction Administrator
Jay Cashman, Inc.	General Contractor
National Grid	Project Sponsor
TerraSense, LLC	Geotechnical Testing Laboratory (Subconsultant to GEI)

2. Test Cell Configurations

For the bench scale testing program, test cells were fabricated at the Dura-Bond Industries steel plant and assembled at the TerraSense laboratory (further discussed in Section 3).There were six bench scale test cells built (BT1 through BT6), which included:

- BT1: Sheet Pile with no interlock sealant or groutable enclosure seal.
- BT2: Sheet Pile with De Neef Swellseal WA interlock sealant.
- BT3: Sheet Pile with no interlock sealant and Steel Angle enclosure filled with CETCO Bentogrout behind the interlock.
- BT4: Sheet Pile with no interlock sealant, Steel Angle enclosure filled with CETCO Bentogrout and SKS 14 enclosure filled with AquaBlok 3070SW behind the interlock.
- BT5: Sheet Pile with no interlock sealant and Half Pipe enclosure filled with CETCO Bentogrout behind the interlock.
- BT6: Sheet Pile with no interlock sealant, Half Pipe enclosure filled with CETCO Bentogrout and SKS 14 enclosure filled with AquaBlok 3070SW behind the interlock.

The configuration of each of these test cells is depicted in Fig. 2.

2.1 General Test Cell Configurations

The exterior construction and dimensions of each test cell were similar. The interior configuration of each test cell varied depending on the type of seal system being evaluated. Each bench scale test cell configuration started with an interlocked pair of 2-foot-long AZ 26-700 sheet piles featuring Larssen-type double jaw interlocks. Each bench test cell configuration had ¼-inch-thick steel plates welded to the sides and top of the sheet pile pairs to create an enclosed cell.

In BT3 through BT6, side plates were fabricated in two sections for access to weld interior components and fill groutable enclosures. Holes were cut into the side plates for access to groutable enclosures and to fill and drain the permeant cavity.

A ¼-inch pipe nipple and coupling were welded to the bottom of each test cell near the sheet pile interlock. A pressure transducer was hooked up during the testing of BT2 to measure the pressure head on the interlock. However, the pressure transducer did not provide useful data, as the static head pressure remained constant throughout the testing period. The pressure transducer was not used on any other test cells.

A 3-inch-diameter steel standpipe was threaded into a pipe coupling welded to the top plate. The standpipe was 8.5 feet long and was filled with permeant during testing. This standpipe length allowed for the testing of up to 10 feet of head of permeant on the sheet pile interlock. A catch angle was welded beneath the sheet pile interlock to collect and direct permeant flowing through the interlock into a bucket so it could be measured. A bead of silicone caulk was placed on the outside flange parallel with and about 1 inch on either side of the interlock opening. This bead was placed on all the test cells to prevent permeant from draining out beyond the reach of the catch angle.

A schematic of the bench scale test cell set up is shown in Fig. 3. Test cells were assembled and grouted in the vertical orientation and were tested in the horizontal orientation. Test cells were initially drained form the horizontal orientation using the drainage port holes and then tipped to complete drainage.

3. Fabrication and Test Cell Construction

3.1 Test Cell Configuration Fabrication Requirements

An important consideration in the test cell fabrication was the boundary conditions for the experiment. The welds between vertical components of the barrier wall sealant systems (sheet pile, steel angles, half pipe, and SKS sheet) and the side plates of the test cells needed to be competent to prevent short circuiting of the permeant through one or more or the components of the sealant systems at that interface.

The goal of the test was to evaluate each test cell configuration by measuring the mass discharge through the interlock. However, incomplete welds could cause the permeant to short circuit the interior components and travel along the interface with the side plates, causing higher volumes of permeant discharge than what would normally be measured if permeant had to travel through sealant systems.

A fabrication sequence specific to each test cell (Appendix A) was developed with the sequence including welding and grouting procedures. The sequence of construction was important to allow for each interior component to be welded to the side plates at as many contact points as possible. The fabrication sequence also took into account filling the groutable enclosures.

3.2 Test Cell Fabrication at Dura-Bond Plant

Dura-Bond Industries, of Steelton, Pennsylvania, fabricated the components for the bench scale test cells, partially assembled them, and shipped them to TerraSense. Dura-Bond shop drawings are provided in Appendix A. Each bench scale test cell was fabricated, shipped, and assembled according to these shop drawings. An SKS 14 was substituted for an SKS 16 in BT4 and BT6. The substitution did not have an impact on the bench scale testing.

3.3 Test Cell Construction at TerraSense

Partially assembled test cells and other components arrived at TerraSense on January 24, 2014. B&B Mobile Welding (B&B) of Denville, New Jersey, constructed and finished assembling the bench scale test cells from January 27 to February 7, 2104. For all test cells, grout access ports, release valve fixtures, catch angles, and standpipes were welded or assembled at TerraSense. A GEI field engineer was on site to document the assembly of the test cells. Photographs of fabrication are provided in Appendix B.

3.4 Groutable Enclosures

3.4.1 CETCO Bentogrout

The steel angle and half pipe enclosures in BT3 through BT6 were filled with CETCO Bentogrout. Bentogrout is a high-solids grout consisting of a proprietary blend of bentonite and polymers. Bentogrout bags are mixed with tap water and pumped in a fluid state where it begins to sets up after an hour. B&B mixed and placed the grout into the enclosures and let the grout set up overnight before continuing to assemble the test cells.

3.4.2 AquaBlok 3070 SW

The SKS sheet pile enclosures in BT4 and BT6 were filled with AquaBlok 3070 SW. AquaBlok is a composite aggregate made a pea gravel coated in a powdered blend of sodium bentonite and attapulgite clay (also known as palygorskite clay). AquaBlok 3070 SW is compatible with saltwater up to 35 parts per thousand and contains about 30 percent clay by weight. There are no pre-installation preparations required for the AquaBlok. After the AquaBlok was placed into the SKS sheet pile enclosures tap water was added to the enclosure for hydration of the AquaBlok.

3.5 Leak Testing

After fabrication, B & B placed test cells in the horizontal orientation on wood dunnage, as shown in Fig. 3, with the sheet pile interlock at the bottom and the standpipe at the top. B & B placed a plastic tub or similar containment pad beneath the entire footprint of each test cell. Each test cell was filled with about 3 to 5 gallons of water to check for any unanticipated leaks around the weld joints and fixtures and begin the hydration of the sealant materials.

Leaks around the connection between the portholes and the test cells were repaired with additional welding or plumber's putty. Plumber's putty was also used to seal the connection where the standpipe screws into the test cells. No alterations were made to the sheet pile interlock or surrounding areas, except for in BT2, as will be discussed below.

Water leaking through the BT2 interlock was observed over much of its length for the first 20 minutes or so before the Swellseal WA began to hydrate and seal the interlock. However, there remained about a 3 inch length of interlock starting at the side plate and the end of the interlock that did not stop leaking. From what could be observed there was no De Neef Swellseal WA in the area where it was leaking. GEI suspects that the Swellseal WA was installed correctly, but that welding the side plate to the interlock damaged or burnt off the sealant in the interlock. B&B drilled a ¾-inch hole through the side plate to access the interlock and reestablish a sealed interlock. The interlock with additional Sweelseal WA was filled and B&B welded a capped pipe nipple over the drilled hole.

When no leaks were observed for ten minutes, the test cells were filled with water to the base of the standpipe joint (between 21 and 50 gallons depending on the permeant cavity configuration). After another 10 minutes without leaks, each cell was filled to within 6 inches of the top of the standpipe.

Water flowed through the BT1 interlock too quickly for the cell to hold a 50 gallon volume. BT1 was not filled to the top of the standpipe.

4. Bench Scale Testing

4.1 Testing Protocols

Testing protocols were developed for both tap water and site DNAPL as permeants that are provided in Appendix C. Testing protocols for BT1 were adjusted because the flow through the interlock was greater than anticipated during development of the protocols.

On average, GEI collected measurements twice a day, excluding weekends. Measurements were made of the distance from top of the standpipe to the permeant level, ambient temperature, permeant temperature, and the mass of permeant collected in the catch buckets. Temperature was measured using either a borosilicate glass immersion thermometer or an infrared digital thermometer gun.

4.2 Permeant - Tap Water

Bench scale testing was conducted using water as the permeant from February 7 to February 19, 2014 following the testing protocols. Raw data sheets are provided in Appendix D.

Discharge water from BT1 was not measured. GEI observed that the flow through BT1 was effectively instantaneous as was to be expected with an interlock without any sealant.

GEI measured the volume of water leaking through the BT2 interlock after it was channeled by the steel angle trough and collected in a graduated cylinder or catch bucket.

GEI did not observe any water collected by the steel angles troughs or catch buckets in BT3 through BT6 during the 14 days of testing.

4.3 Permeant - Site DNAPL

Bench scale testing was conducted with DNAPL as the permeant from February 24 to March 31, 2014. Raw data sheets are provided in Appendix D. GEI previously collected four 55-gallon drums of DNAPL from recovery wells on the Site and had them transported to TerraSense for use in the test program. A combination of an electric pump, a hand-crank rotary pump, and 5-gallon buckets were used to fill test BT2 through BT6 with DNAPL to the top of the standpipe.

The testing procedure for BT1 was altered for safety reasons. The rate of flow of water through the interlock was very high and GEI did not want to risk a potential DNAPL spill if we filled BT1 to the top of the standpipe and it flowed through the interlock at a similar rate. BT1 was tested with only 1.3 gallons of DNAPL. The amount of discharge and time it took for the entire quantity to be discharged were measured.

Testing in BT2, BT4, and BT5 was run for about 10 days and testing in BT6 was run for about 11 days.

The testing for BT3 ran for about 31 days. There was no discharge observed in BT3 through the first 9 days of testing. On the 10^{th} day of testing of BT3, 3.2 g of discharge fluid was recorded. In error, the DNAPL was removed from the test cell. The cell was refilled and the test restarted within 2 hours when the full head pressure was attained on the interlock. As such, GEI conducted the BT3 bench test for a longer period of time to gather more data.

All test cells were drained and DNAPL was disposed of properly upon completion of testing.

5. Results

5.1 Permeant Mass Discharge through Interlock

Tap water and DNAPL were used as the permeants for these tests. The permeant discharge was measured by weighing the mass or volume of permeant collected in the catch bucket about two times a day.

5.1.1 Water

BT1 (sheet pile with no interlock sealant) could not restrain flow of water through the test cell so the flow was not measured through the test cell. BT2 also allowed water to pass through the interlock during the testing period, which was attributed to the initial swell period of the seal and damaged seal sections that were repaired. A plot of discharge versus time for BT2 is provided in Fig. 4. GEI did not observe any measurable amount of water discharge through BT3, BT4, BT5, and BT6 during the testing period.

5.1.2 DNAPL

DNAPL discharge versus time plots for BT1 through BT5 are presented in Fig. 5. The DNAPL flowed through the BT1 non-sealed interlock too quickly to measure the permeant discharge over a several-day period. The time for about 1.3 gallons of DNAPL to pass through the interlock was measured (30 seconds). Because there are no incremental readings, there are only two points in the plot for BT1 in Fig. 5. GEI did not observe any measurable amount of DNAPL discharge through BT6 during the testing period.

Test pile installation from the field portion of the pilot test ran concurrently with the bench scale testing program. The potential sheet pile sealant configuration similar to the BT3 test cell configuration performed well in the field. Therefore, GEI decided to increase the duration of the DNAPL mass discharge testing in BT3 for an additional 21 days. The results for this longer duration test are shown in Fig. 5.

5.2 Calculation of Inverse Joint Resistance

The inverse joint resistance was calculated for test cells BT2 through BT5 to estimate the permeability through the interlocks. A well-established method for the estimation of the permeability of a steel sheet pile wall does not exist. Sheet piles are impervious and principals of porous media flow and Darcy’s Law do not apply. Flow of a permeant through a sheet pile wall only occurs through the interlocks and therefore the wall assembly, rather than the material itself, is evaluated to obtain a measure of flow.

The concept of joint resistance through a steel sheet pile wall was developed by the sheet piling industry as an assessment measure that could be compared against other types of low-permeability wall designs (such as a slurry wall). Low-permeability walls are designed to an allowable seepage criteria, typically set by regulators. Joint resistance also applies to methods for testing the effectiveness of the sealing system (interlock configuration and sealant material).

The inverse joint resistance of each test cell was calculated from the change in volume of the discharge through the interlock over a change in time using the following equation:

$$q(z) = \frac{\rho \times \Delta p(z)}{\gamma}$$

where:

$q(z)$:	the discharge per unit of the joint length at level z, [m^3/s/m]
$\Delta p(z)$:	the pressure drop at level z, [kPa]
ρ:	the inverse joint resistance, [m/s]
γ:	unit weight of permeant [kN/m^3]

A unit weight of 10.69 kN/m^3 was used for DNAPL based on chemical testing data previously performed on samples collected on the Site. Results are provided in Table 1 and calculations in Appendix E.

5.3 Calculation of Equivalent Permeability

For comparison purposes, each calculated inverse joint resistance was converted (backcalculated) to an equivalent permeability of a 1-meter-thick slurry wall. The calculation was done assuming that the discharge per unit wall area of the slurry wall was the same as an equivalent unit wall area of a tested steel sheet pile wall section. Results are provided in Table 1 and calculations in Appendix E.

Tables

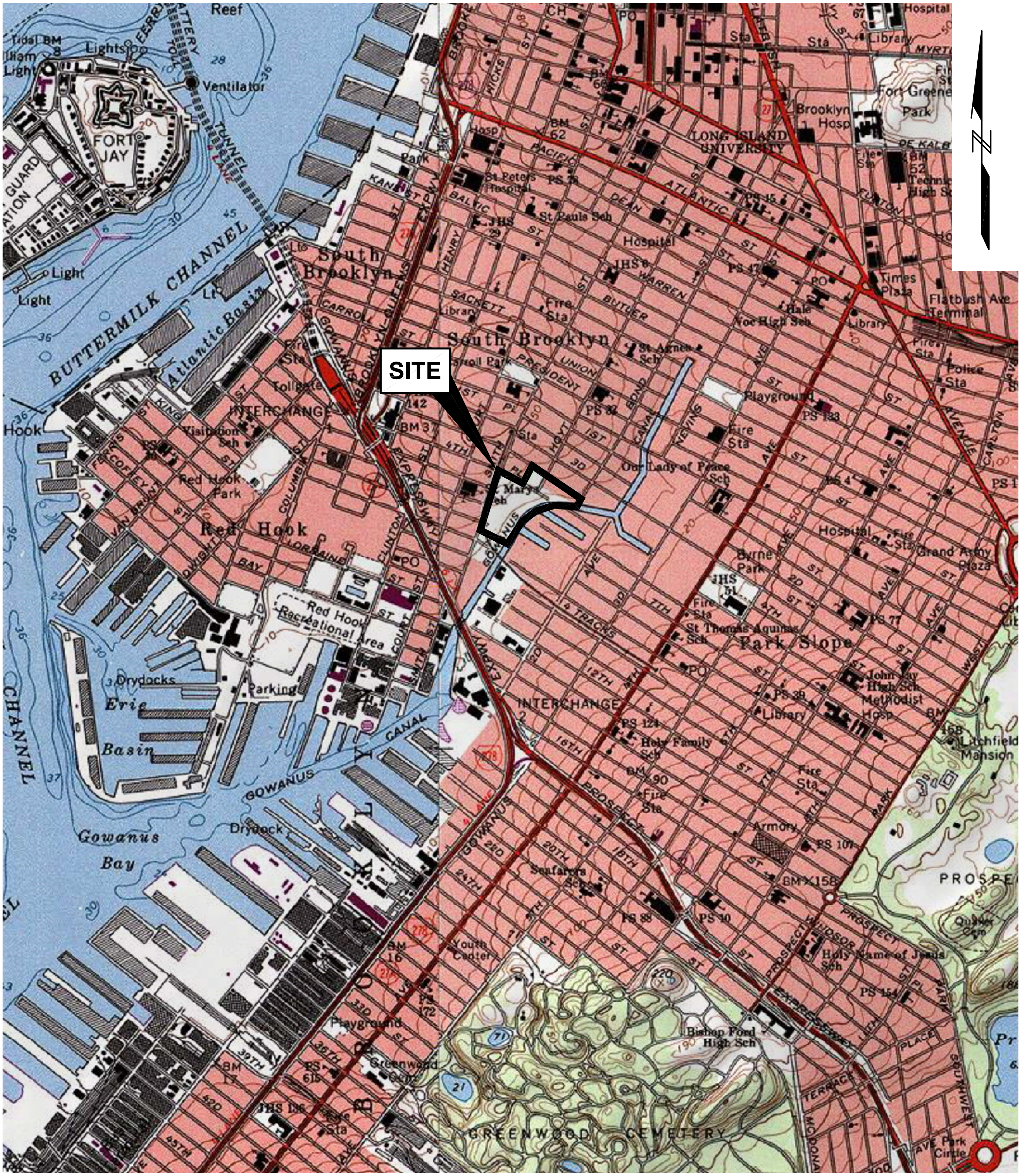
Table 1. Bench Scale Test Cell Inverse Joint Resistance and Equivalent Permeability
Barrier Wall Interlock Seal Systems Bench Scale Testing Report
Former Citizens Gas Works Manufactured Gas Plant Site
National Grid
Brooklyn, New York

Permeant	Bench Scale Test Cell[1]	Start of Test	Duration of Test, Days	Steel Sheet Pile Inverse Joint Resistance, cm/s	Equivalent Permeability[2], cm/s	Comment
Tap Water	BT1: No Seals	2/4/2014	0	-	-	Observed flow through test cell effectively instantaneous.
	BT2: Interlock Sealant	2/7/2014	11	8.55×10^{-7}	6.11×10^{-7}	
	BT3: Steel Angle Sealant	2/4/2014	14	-	-	No measurable flow through test cell observed.
	BT4: Steel Angle Sealant & Sheet Pile Sealant	2/4/2014	14	-	-	No measurable flow through test cell observed.
	BT5: Half Pipe Sealant	2/4/2014	14	-	-	No measurable flow through test cell observed.
	BT6: Half Pipe Sealant & Sheet Pile Sealant	2/4/2014	14	-	-	No measurable flow through test cell observed.
DNAPL	BT1: No Seals	3/3/2014	0	8.43×10^{-3}	6.02×10^{-3}	Discharge too large to test at full pressure head; used 1.3 gallons of DNAPL and timed throughput.
	BT2: Interlock Sealant	2/28/2014	10	8.45×10^{-9}	6.04×10^{-9}	
	BT3: Steel Angle Sealant	2/28/2014	31[3]	2.94×10^{-9}	2.10×10^{-9}	
	BT4: Steel Angle Sealant & Sheet Pile Sealant	2/25/2014	10	4.11×10^{-8}	2.94×10^{-8}	
	BT5: Half Pipe Sealant	2/28/2014	10	4.32×10^{-10}	3.08×10^{-10}	
	BT6: Half Pipe Sealant & Sheet Pile Sealant	2/24/2014	11	-	-	Limited or no flow through test cell observed.

Footnotes:

1. Interlock Sealant = DeNeef Swellseal WA
   Steel Angle and Half Pipe Sealant = CETCO Bentogrout
   Sheet Pile Sealant = AquaBlok 3070SW.
2. Calculated equivalent permeability of a 1-meter-thick slurry wall assuming that the discharge per unit wall area is the same for a steel sheet pile wall.
3. The testing for BT3 cummulatively ran for about 31 days. DNAPL was removed from the test cell in error on the 10th day and refilled to resume testing for an additional 21 days.

Figures



NOTES:

MAP CREATED WITH TOPO! ® ©2001 NATIONAL GEOGRAPHIC (www.nationalgeographic.com/topo)

0 2000 4000

SCALE, FEET

FORMER CITIZENS GAS WORKS CARROLL GARDENS/PUBLIC PLACE BOROUGH OF BROOKLYN, NEW YORK	GEI Consultants	**PROJECT LOCATION**
nationalgrid	Project 093250-1-1117	August 2015 Fig. 1

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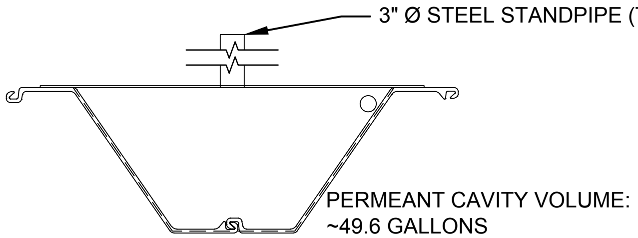
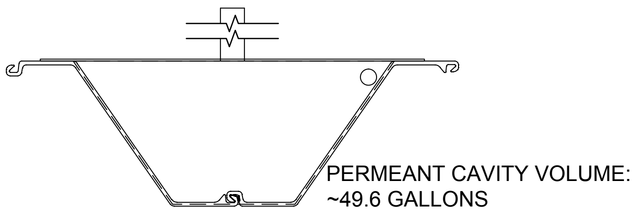
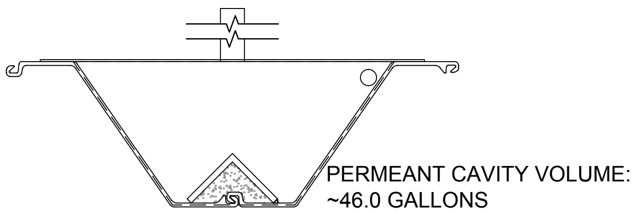


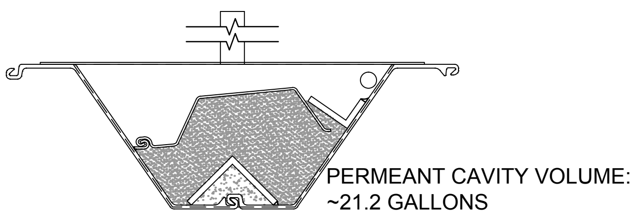
BT1: BENCH SCALE TEST CELL CONFIGURATION WITH NO INTERLOCK SEALANT OR GROUTABLE ENCLOSURE SEAL.



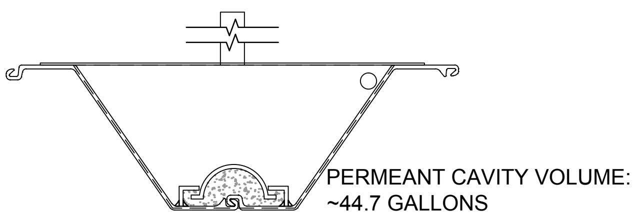
BT2: BENCH SCALE TEST CELL CONFIGURATION WITH ONLY DE NEEF SWELLSEAL WA INTERLOCK SEALANT.



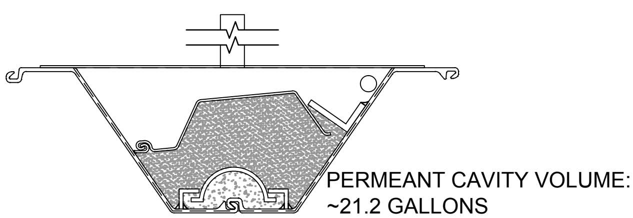
BT3: BENCH SCALE TEST CELL CONFIGURATION WITH NO INTERLOCK SEALANT AND STEEL ANGLE ENCLOSURE FILLED WITH SEALANT MATERIAL BEHIND THE INTERLOCK.



BT4: BENCH SCALE TEST CELL CONFIGURATION WITH NO INTERLOCK SEALANT, STEEL ANGLE ENCLOSURE AND SKS SHEET PILE ENCLOSURE FILLED WITH SEALANT MATERIAL BEHIND THE INTERLOCK.



BT5: BENCH SCALE TEST CELL CONFIGURATION WITH NO INTERLOCK SEALANT AND HALF PIPE ENCLOSURE FILLED WITH SEALANT MATERIAL BEHIND THE INTERLOCK.



BT6: BENCH SCALE TEST CELL CONFIGURATION WITH NO INTERLOCK SEALANT, HALF PIPE ENCLOSURE AND SKS SHEET PILE ENCLOSURE FILLED WITH SEALANT MATERIAL BEHIND THE INTERLOCK.

LEGEND:

AQUABLOK 3070SW   CETCO BENTOGROUT

NOTES:

1. EACH BENCH SCALE TEST CELL CONFIGURATION WILL BE TESTED FIRST WITH TAP WATER IN THE PERMEANT CAVITY FOLLOWED BY SITE DNAPL.
2. VOLUME OF STANDPIPE FOR ASSUMED 8.5 FOOT LENGTH APPROXIMATELY 3.1 GALLONS.

0 2 4

1/2" = 1'–0"

FORMER CITIZENS GAS WORKS MGP SITE
BOROUGH OF BROOKLYN, NEW YORK

nationalgrid

GEI Consultants

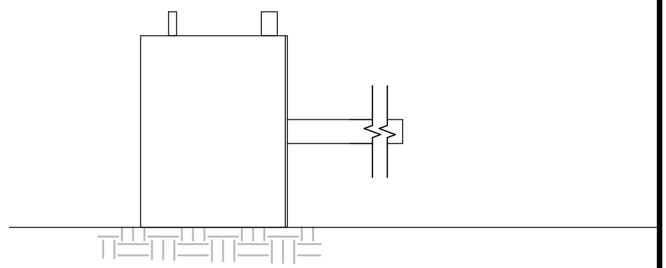
Project 093250-1-1117

BENCH SCALE
BARRIER CELL
TEST CONFIGURATIONS

August 2015

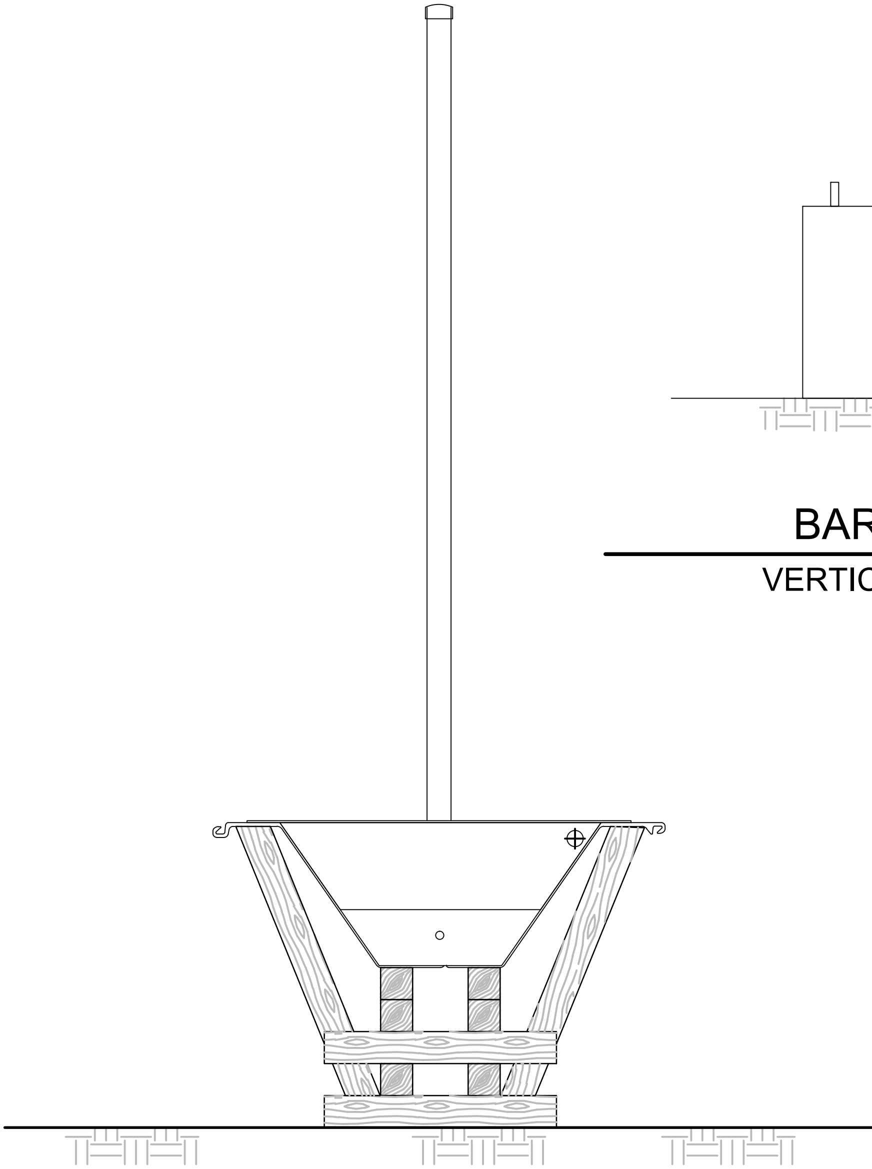
Fig. 2

\\mcl1v-fs01\Data\Tech\Projects\2009\09325-0 NG-Citizens Gas Works\DWGS-GEI\Pilot Test Work Plan\093250-06.10 Sealable Sheet Piles_Bench Test



BARRIER CELL

VERTICAL ORIENTATION



BARRIER CELL

HORIZONTAL ORIENTATION

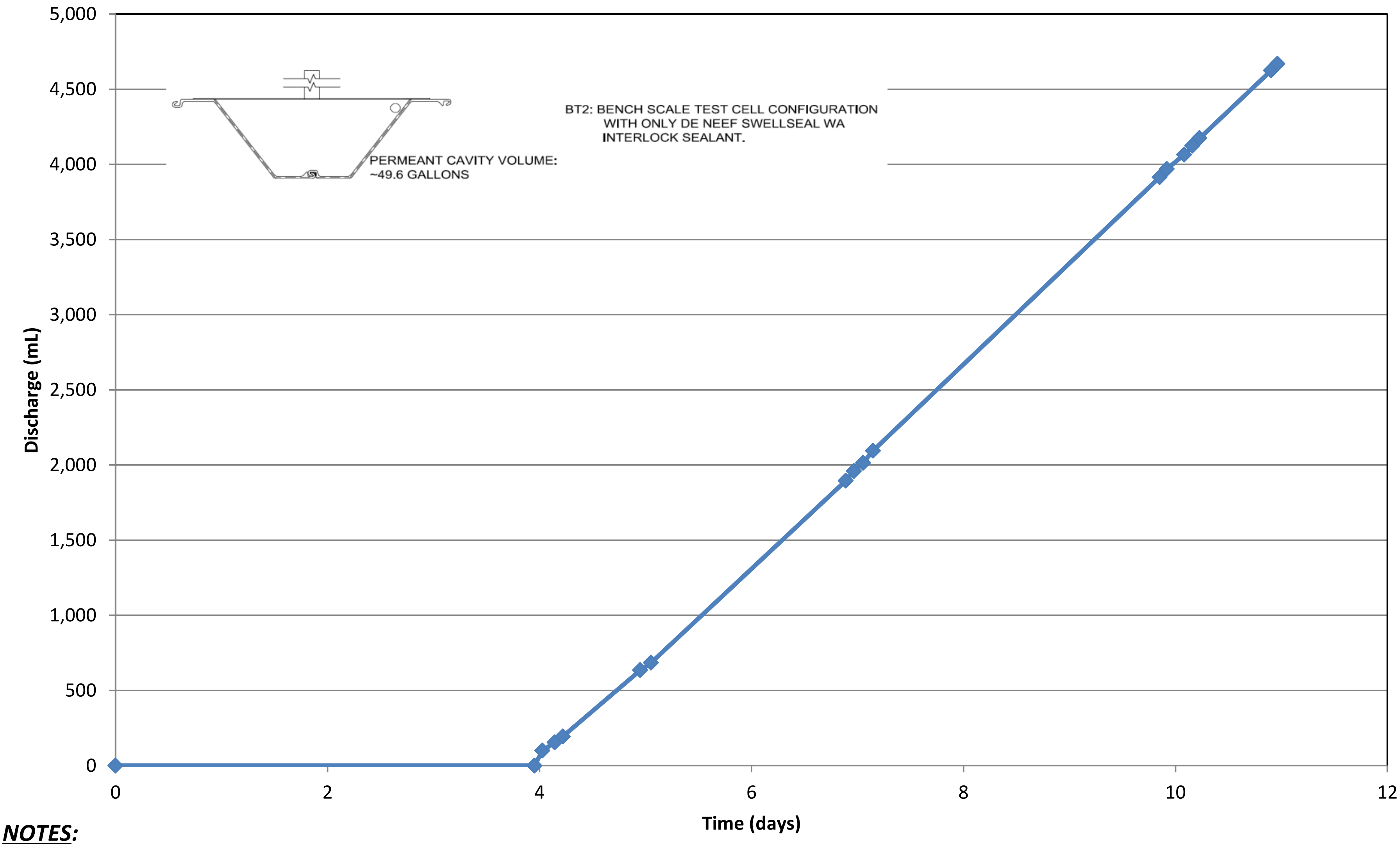
NOTES:

1. A ROLLING LADDER WAS USED TO ACCESS THE TOP OF THE STANDPIPE.

0 2 4

1/2" = 1'–0"

FORMER CITIZENS GAS WORKS MGP SITE BOROUGH OF BROOKLYN, NEW YORK	GEI Consultants	PILOT TEST BARRIER CELL TEST SETUP
nationalgrid	Project 093250-1-1117	August 2015 Fig. 3

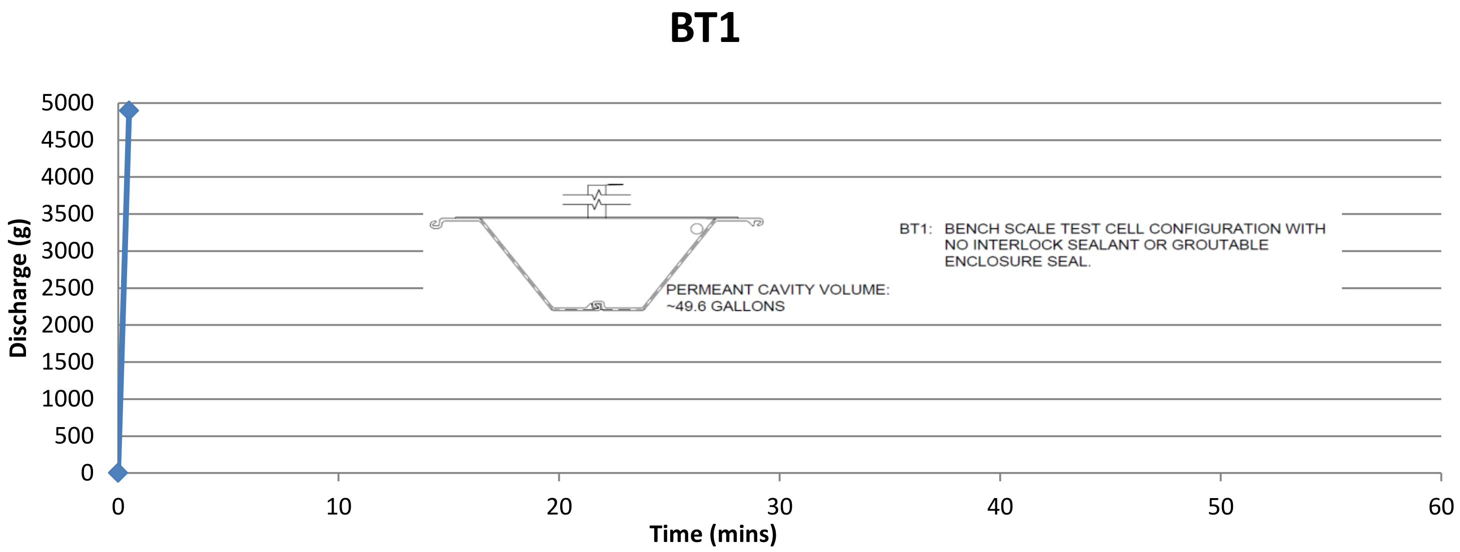


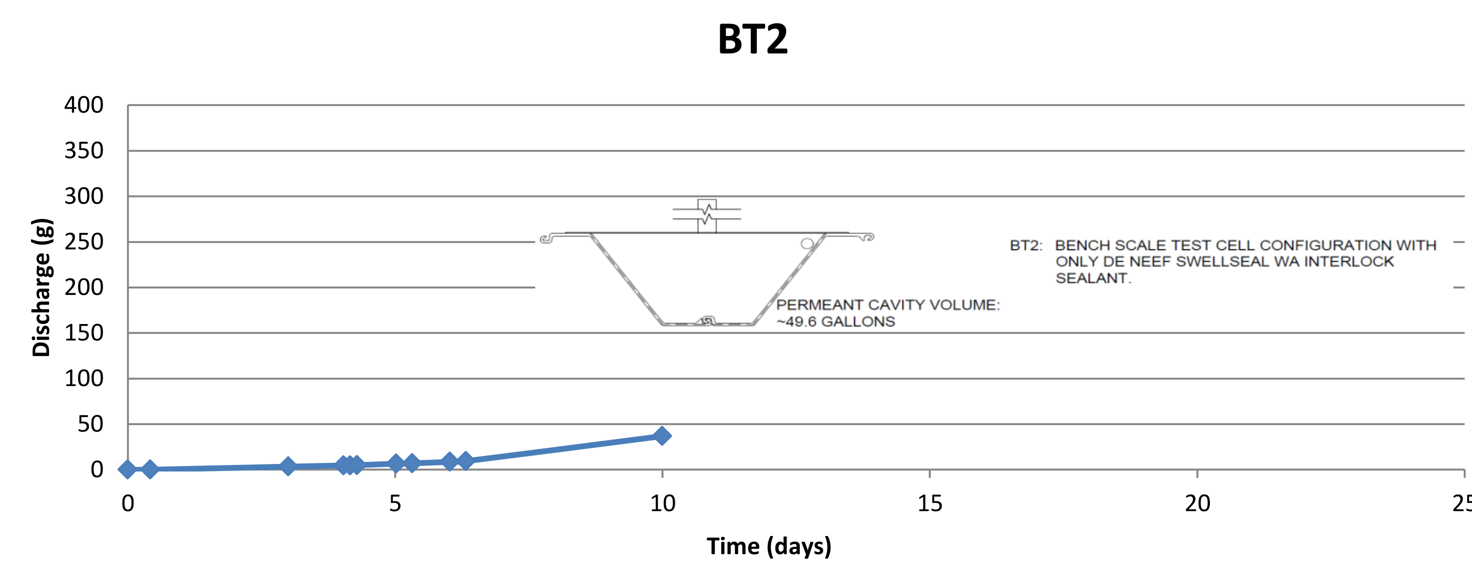
NOTES:

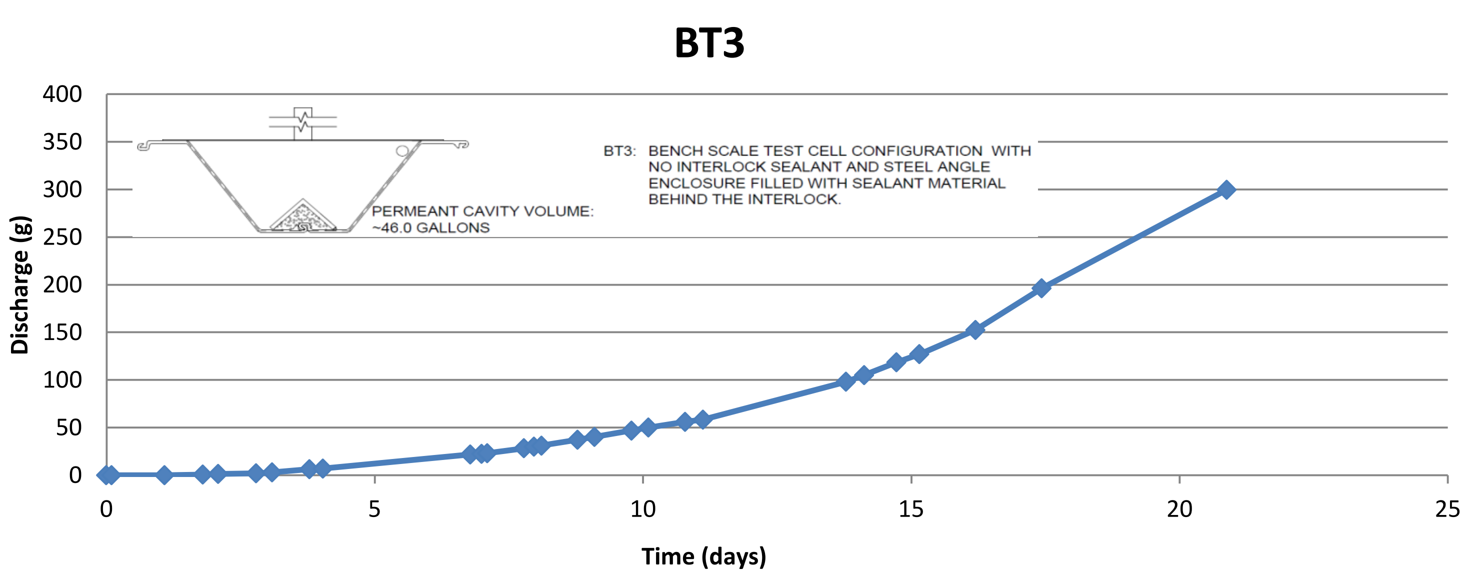
1. BT1 NOT SHOWN BECAUSE IT DID NOT RETAIN WATER.
2. BT3 THROUGH BT6 NOT SHOWN AS NO MEASURABLE DISCHARGE WAS OBSERVED DURING TEST PERIOD.

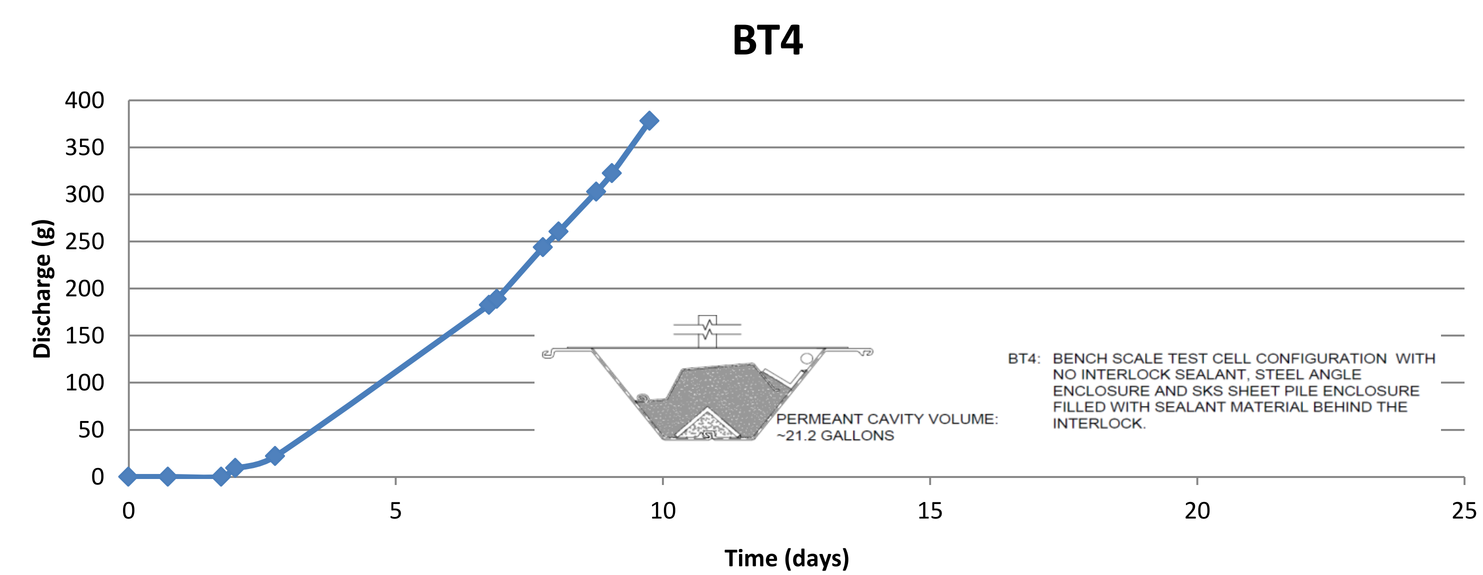
FORMER CITIZENS GAS WORKS MGP SITE BOROUGH OF BROOKLYN, NEW YORK	GEI Consultants	TAP WATER PERMEANT BT2 BENCH SCALE TEST DISCHARGE VS. TIME
nationalgrid	Project 0932501-1112	August 2015 Fig. 4

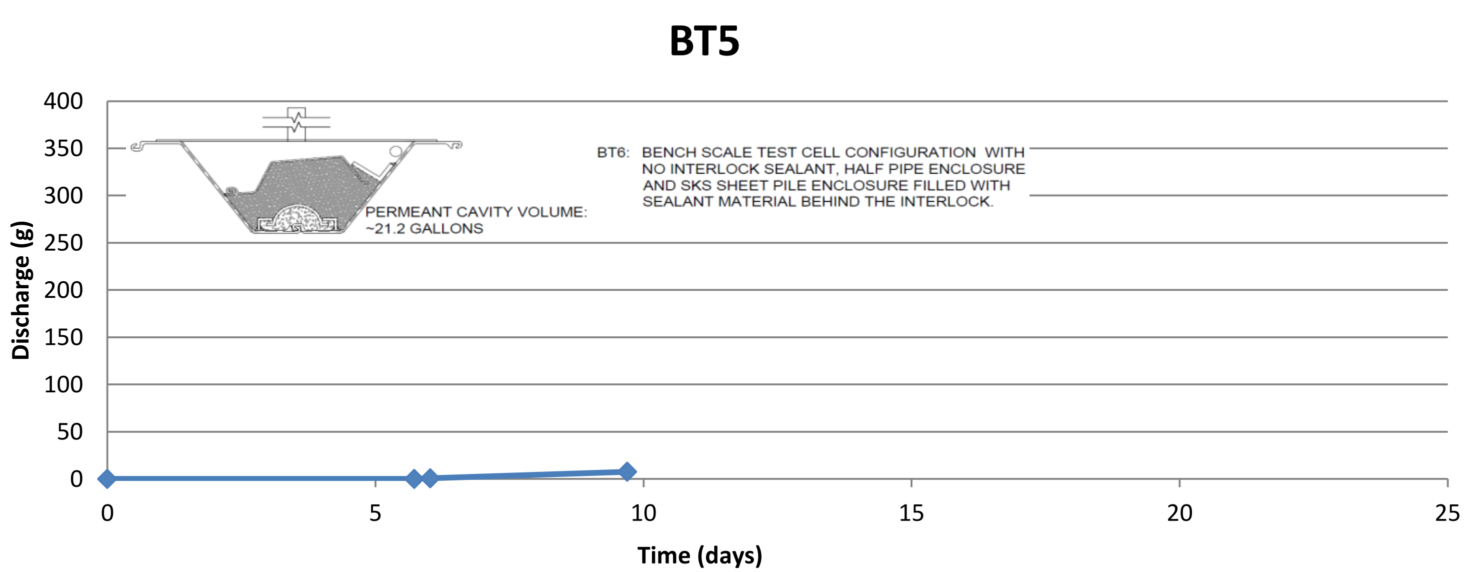
\\mcl1v-fs01\Data\Tech\Projects\2009\09325-0 NG-Citizens Gas Works\INVESTIGATIONS\Barrier Wall Pilot Test Program\BENCH-SCALE TESTING\Data\[Water Permeant Test Data.xlsx]BT1











<u>NOTES</u>:

1. BT6 NOT SHOWN AS NO DISCHARGE WAS PRODUCED DURING 12-DAY TEST RUN .
2. FOR BT1, TIME WAS MEASURED IN SECONDS. FOR ALL OTHER DISCHARGE VS. TIME GRAPHS, TIME WAS MEASURED IN DAYS. THE PERMEANT FLOWED THROUGH BT1 SO QUICKLY THAT ONLY THE INITIAL AND FINAL DISCHARGE WERE MEASURED.
3. BT3 GRAPH SHOWS 21-DAY OBSERVATION PERIOD AFTER TEST CELL WAS DRAINED. THERE WAS NO DISCHARGE OBSERVED IN BT3 THROUGH THE FIRST 9 DAYS OF TESTING. ON THE 10TH DAY WE RECORDED 3.2 GRAMS OF DISCHARGE BEFORE THE TEST CELL WAS DRAINED IN ERROR.

FORMER CITIZENS GAS WORKS MGP SITE BOROUGH OF BROOKLYN, NEW YORK	GEI Consultants	DNAPL PERMEANT BENCH SCALE TEST DISCHARGE VS. TIME GRAPHS
nationalgrid	Project 093250-1-1117	August 2015 Fig. 5

Appendix A

Fabrication Sequence and Shop Drawings

Fabrication and Grout Sequence - Configuration 1 - Sheet Pile
Former Citizens Gas Works Pilot Test: Bench Scale Test Cell Fabrication
National Grid
January 2014

Step 1.1	Weld Full Side Plate [p2] to AZ-26-700-DB sheet pile pair [BT1].
Step 1.2	Weld Full Side Plate [p3] to AZ-26-700 sheet pile pair [BT1].
Step 1.3	Weld 3" Diameter Pipe Coupling [t1] to Top Plate [p1] over 3" Permeant Cavity Hole.
Step 1.4	Weld Top Plate [p1] to AZ-26-700-DB sheet pile pair [BT1], and Full Side Plates [p2,p3].
Step 1.5	Weld 1/4" Diameter Pipe Coupling [t4] to hole in AZ-26-700 DB sheet pile pair [BT1] and screw in 1/4" Diameter Pipe Nipple [t3].
Step 1.6	Tack weld angle [a3] on either side of 1/4" port [t3/t4] for protection during shipping and handling.
Step 1.7	Weld 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2] to drain hole in Full Side Plate [p2]. May need pipe coupler to join with 1.5" NPT-threaded pipe valve provided by Terrasense.
Step 1.8	Screw 3" Diameter Sch. 40 Pipe [T7] into 3" Diameter Pipe Coupling [t1].
Step 1.9	Check assembly for water tightness and spot weld as appropriate.
Step 1.10	Testing Protocols.

Notes: 1.) Steps 1.1 to 1.7 to be performed at Dura-Bond Fabrication Plant.
2.) Steps 1.8 to 1.10 to be perfomred at Terrasense Laboratory workspace.
3.) Items to be shipped loose to lab space, along with [BT1] assembly, include:
- Permeant Collection Channel [A4]
- 3" Diameter Sch. 40 Pipe [T7]
- 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2]

Fabrication and Grout Sequence - Configuration 2 - Sheet Pile
Former Citizens Gas Works Pilot Test: Bench Scale Test Cell Fabrication
National Grid
January 2014

Step 2.1	Install Deneef Swellseal inside AZ-26-700-DB sheet pile pair [BT2] interlock.
Step 2.2	Weld Full Side Plate [p2] to AZ-26-700-DB sheet pile pair [BT2].
Step 2.3	Weld Full Side Plate [p3] to AZ-26-700 sheet pile pair [BT2].
Step 2.4	Weld 3" Diameter Pipe Coupling [t1] to Top Plate [p1] over 3" Permeant Cavity Hole.
Step 2.5	Weld Top Plate [p1] to AZ-26-700-DB sheet pile pair [BT2], and Full Side Plates [p2,p3].
Step 2.6	Weld 1/4" Diameter Pipe Coupling [t4] to hole in AZ-26-700 DB sheet pile pair [BT2] and screw in 1/4" Diameter Pipe Nipple [t3].
Step 2.7	Tack weld angle [a3] on either side of 1/4" port [t3/t4] for protection during shipping and handling.
Step 2.8	Weld 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2] to drain hole in Full Side Plate [p2]. May need pipe coupler to join with 1.5" NPT-threaded pipe valve provided by Terrasense.
Step 2.9	Screw 3" Diameter Sch. 40 Pipe [T7] into 3" Diameter Pipe Coupling [t1].
Step 2.10	Check assembly for water tightness and spot weld as appropriate.
Step 2.11	Testing Protocols.

Notes: 1.) Steps 2.1 to 2.7 to be performed at Dura-Bond Fabrication Plant.
2.) Steps 2.8 to 2.11 to be perfomred at Terrasense Laboratory workspace.
3.) Items to be shipped loose to lab space, along with [BT2] assembly, include:
- Permeant Collection Channel [A4]
- 3" Diameter Sch. 40 Pipe [T7]
- 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2]

Fabrication and Grout Sequence - Configuration 3 - Sheet Pile and Steel Angle
Former Citizens Gas Works Pilot Test: Bench Scale Test Cell Fabrication
National Grid
January 2014

Step 3.1	Weld Full Side Plate [p3] to AZ-26-700 DB sheet pile pair [BT3].
Step 3.2	Weld 8 X 8 X 3/4 Steel Angle [a1] to AZ-26-700 DB [BT3] and Full Side Plate [p3].
Step 3.3	Weld 1" Diameter Sch. 40 Steel Pipe Nipple [t5] to port hole on Angle Side Plate [p4].
Step 3.4	Screw 1" Pipe Cap [t8] onto port hole on Angle Side Side Plate [p4].
Step 3.5	Weld Angle Side Plate [p4] to AZ-26-700 DB [BT4] and 8 X 8 X 3/4 Steel Angle [a1].
Step 3.6	Weld 1/4" Diameter Pipe Coupling [t4] to hole in AZ-26-700 DB sheet pile pair [BT3] and screw in 1/4" Diameter Pipe Nipple [t3].
Step 3.7	Tack weld angle [a3] on either side of 1/4" port [t3/t4] for protection during shipping and handling.
Step 3.8	Weld 3" Diameter Pipe Coupling [t1] to Top Plate [P1] over 3" Permeant Cavity Hole.
Step 3.9	Weld 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2] to drain hole on Angle Side Plate [p4]. May need pipe coupler to join with 1.5" NPT-threaded pipe valve provided by Terrasense.
Step 3.10	Place temporary formwork behind opening between 8 X 8 X 3/4 Steel Angle [a1] and AZ-26-700 DB [BT3]. Temporarily seal sheet pile interlock before Bentogrout placement.
Step 3.11	Place CETCO Bentogrout between 8 X 8 X 8 3/4 Steel Angle [a1] and AZ-26-700 DB [BT3] sheet pile interlock.
Step 3.12	Remove temporary formwork and seals after 18 hours or when Bentogrout has set up.
Step 3.13	Weld Partial Side Plate [P5] to AZ-26-700 DB [BT3] and Angle Side Plate [p4].
Step 3.14	Weld Top Plate [P1] to AZ-26-700 DB sheet pile pair [BT3], Angle Side Plate [p4] and Partial Side Plate [P5].
Step 3.15	Screw 3" Diameter Sch. 40 Pipe [P7] into 3" Diameter Pipe Coupling [t1].
Step 3.16	Check assembly for water tightness and spot weld as appropriate.
Step 3.17	Testing Protocols.

Notes: 1.) Steps 3.1 to 3.8 to be performed at Dura-Bond Fabrication Plant.
2.) Steps 3.9 to 3.17 to be performed at Terrasense Laboratory workspace.
3.) Items to be shipped loose to lab space, along with BT3 assembly, include:
- Top Plate [P1]
- Partial Side Plate [P5]
- Permeant Collection Channel [A4]
- 3" Diameter Sch. 40 Pipe [T7]
- 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2]

Fabrication and Grout Sequence - Configuration 4 - Sheet Pile and Steel Angle and SKS 16
Former Citizens Gas Works Pilot Test: Bench Scale Test Cell Fabrication
National Grid
January 2014

Step 4.1	Weld Full Side Plate to AZ-26-700 DB sheet pile pair [BT4].
Step 4.2	Weld 8 X 8 X 3/4 Steel Angle [a1] to inside of AZ-26-700 DB [BT4] and Full Side Plate [p3].
Step 4.3	Weld SKS Interlock [k1] to inside of AZ-26-700 DB sheet pile pair [BT4].
Step 4.4	Weld 1" Diameter Sch. 40 Steel Pipe Nipples [t5] to port holes on Angle Side Plate [p7] .
Step 4.5	Screw 1" Pipe Caps [t8] onto port holes on Angle Side Side Plate [p7].
Step 4.6	Weld Angle Side Plate to AZ-26-700 DB [p7] and 8 X 8 X 3/4 Steel Angle [a1].
Step 4.7	Weld 1/4" Diameter Pipe Coupling [t4] to hole in AZ-26-700 DB sheet pile pair [BT4] and screw in 1/4" Diam. Pipe Nipple [t3].
Step 4.8	Tack weld angle [a3] on either side of 1/4" port [t3/t4] for protection during shipping and handling.
Step 4.9	Weld 3" Diameter Pipe Coupling [t1] to Top Plate [P1] over 3" Permeant Cavity Hole.
Step 4.10	Weld 1" Diameter Sch. 40 Steel Pipe Nipple [t5] to port hole on Partial Side Plate [P6] .
Step 4.11	Screw 1" Pipe Cap [t8] onto port hole on Partial Side Plate [P6].
Step 4.12	Weld 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2] to drainage hole on Partial Side Plate [P6] . May need pipe coupler to join with 1.5" NPT-threaded pipe valve provided by Terrasense.
Step 4.13	Place temporary formwork behind opening between 8 X 8 X 3/4 Steel Angle [a1] and AZ-26-700 DB [BT4]. Temporarily seal sheet pile interlock before Bentogrout placement.
Step 4.14	Place CETCO Bentogrout between 8 X 8 X 8 3/4 Steel Angle [a1] and AZ-26-700 DB [BT4] sheet pile interlock.
Step 4.15	Remove temporary formwork and seals after 18 hours or when Bentogrout has set up.
Step 4.16	Slide SKS 16 [S1] sheet pile into the SKS 16 interlock [k1].
Step 4.17	Weld SKS 16 sheet pile [S1] to Full Side Plate [P3].
Step 4.18	Place AquaBlock 3070 SW annular sealant material between SKS 16 sheet pile [S1] and 8X8X3/4 Steel Angle [a1].
Step 4.19	Weld Partial Side Plate [P6] to AZ-26-700 DB [BT4], Angle Side Plate [p7], SKS interlock [k1] and SKS 16 sheet pile [S1].
Step 4.20	Weld 6 X 4 X 3/4 Steel Angle [A5] to AZ-26-700 DB [BT3], Full Side Plate [p3], and Partial Side Plate [P6]. Maintain minimum 3/8" gap between [S1] and [A5].
Step 4.21	Fill gap betweeen [S1] and [A5] with AquaBlock 3070SW.
Step 4.22	Weld Top Plate [P1] to AZ-26-700-DB sheet pile pair [BT4], Full Side Plate [p3], and Partial Side Plate [P6].
Step 4.23	Screw 3" Diameter Sch. 40 Pipe [T7] into 3" Diameter Pipe Coupling [t1]
Step 4.24	Check assembly for water tightness and spot weld as appropriate.
Step 4.25	Testing Protocols.

Notes: 1.) Steps 4.1 to 4.11 to be performed at Dura-Bond Fabrication Plant.
2.) Steps 4.12 to 4.25 to be performed at Terrasense Laboratory workspace.
3.) Items to be shipped loose to lab space, along with BT4 assembly, include:
- Top Plate [P1]
- Partial Side Plate [P6]
- Permeant Collection Channel [A4]
- SKS 16 sheet pile [S1]
- 6 X 4 X 3/4 Steel Angle [A5]
- 3" Diameter Sch. 40 Pipe [T7]
- 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2]

Fabrication and Grout Sequence - Configuration 5 - Sheet Pile and Half Pipe
Former Citizens Gas Works Pilot Test: Bench Scale Test Cell Fabrication
National Grid
January 2014

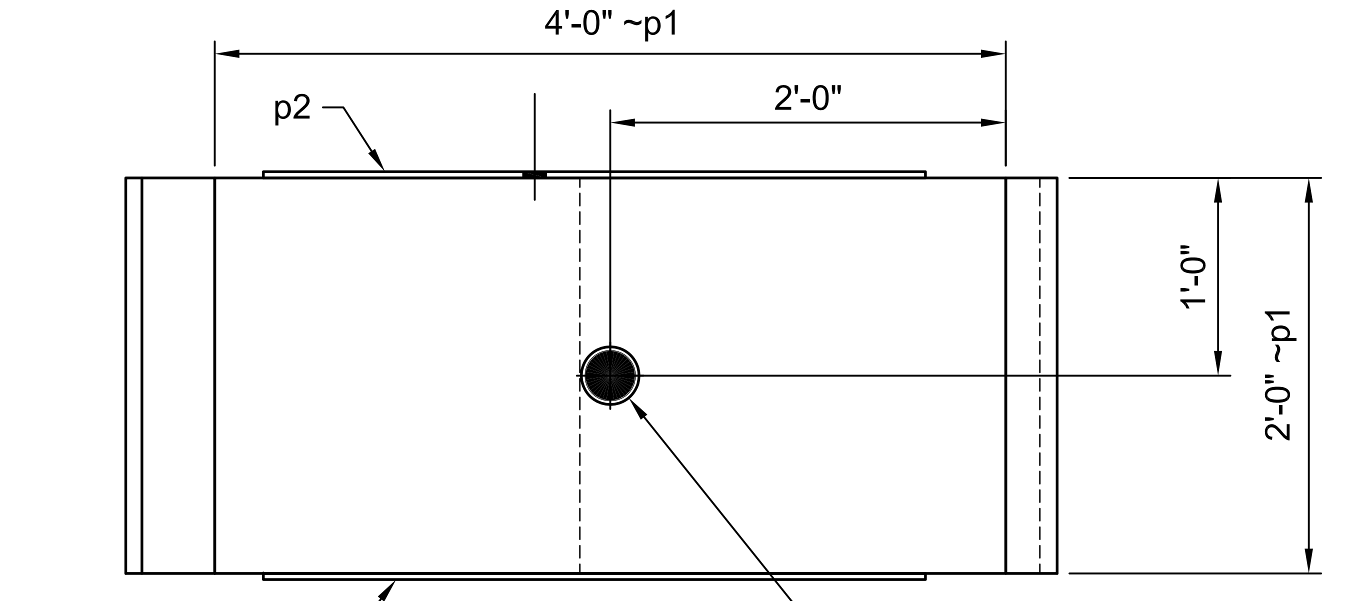
Step 5.1	Weld two 1" X 1/2" bars [b1] to HSS 8.925 Half Pipe.
Step 5.2	Weld Full Side Plate [p3] to AZ-26-700 DB sheet pile pair [BT5].
Step 5.3	Weld Half Pipe [t6] to Full Side Plate [p3] so that is positioned 1-inch above AZ-26-00 DB sheet pile pair [BT6].
Step 5.4	Weld 1" Diameter Sch. 40 Steel Pipe Nipple [t5] to port hole on HSS Side Plate [p9].
Step 5.5	Screw 1" Pipe Cap [t8] onto port hole on HSS Side Plate [p9].
Step 5.6	Weld HSS Side Plate [p9] to AZ-26-700 DB sheet pile pair [BT5] and Half Pipe [t6].
Step 5.7	Weld two 2.5 X 2.5 X 1/2 Steel Angles [a2] to AZ-26-700 DB sheet pile pair [BT5], HSS Side Plate [p9] and Full Side Plate [p3].
Step 5.8	Weld 1/4" Diameter Pipe Coupling [t4] to hole in AZ-26-700 DB sheet pile pair [BT5] and screw in 1/4" Diam. Pipe Nipple [t3].
Step 5.9	Tack weld angle [a3] on either side of 1/4" port [t3/t4] for protection during shipping and handling.
Step 5.10	Weld 3" Diameter Pipe Coupling [t1] to Top Plate [P1] over 3" Permeant Cavity Hole.
Step 5.11	Weld 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2] to drain hole on HSS Side Plate [p9]. May need pipe coupler to join with 1.5" NPT-threaded pipe valve provided by Terrasense.
Step 5.12	Place temporary formwork behind opening between Half Pipe [t6] and 2.5 X 2.5 X 1/2 Steel Angles [a2]. Temporarily seal sheet pile interlock before Bentogrout placement.
Step 5.13	Place CETCO Bentogrout between HSS Half Pipe [t6] and 2.5 X 2.5 X 1/2 Steel Angles [a2] and AZ-26-700 DB sheet pile [BT5].
Step 5.14	Remove temporary formwork and seals after 18 hours or when Bentogrout has set up.
Step 5.20	Weld Partial Side Plate [P5] to AZ-26-700 DB [BT5], and HSS Side Plate [p9].
Step 5.21	Weld Top Plate [P1] to AZ-26-700-DB sheet pile pair [BT5], Full Side Plate [p3], and Partial Side Plate [P5].
Step 5.22	Screw 3" Diameter Sch. 40 Pipe [T7] into 3" Diameter Pipe Coupling [t1].
Step 5.23	Check assembly for water tightness and spot weld as appropriate.
Step 5.24	Testing Protocols.

Notes: 1.) Steps 5.1 to 5.10 to be performed at Dura-Bond Fabrication Plant.
2.) Steps 5.11 to 5.24 to be performed at Terrasense Laboratory workspace.
3.) Items to be shipped loose to lab space, along with BT5 assembly, include:
- Top Plate [P1]
- Partial Side Plate [P5]
- Permeant Collection Channel [A4]
- 3" Diameter Sch. 40 Pipe [T7]
- 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2]

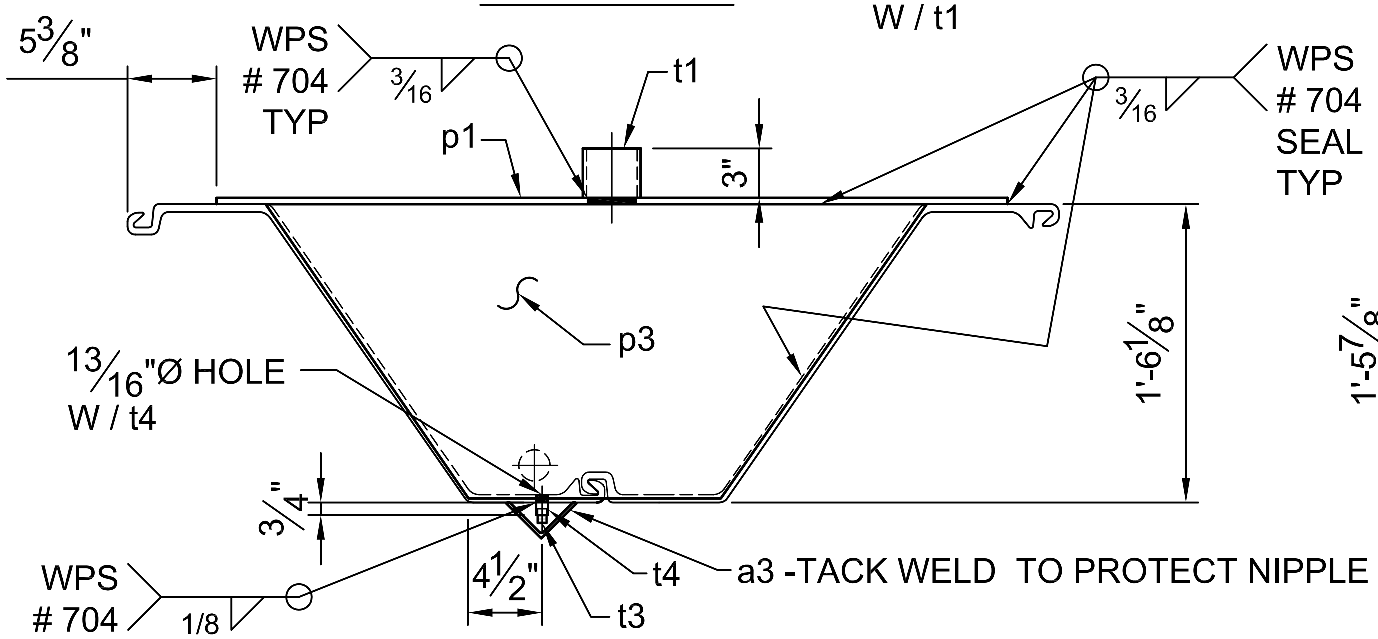
Fabrication and Grout Sequence - Configuration 6 - Sheet Pile and Half Pipe and SKS 16
Former Citizens Gas Works Pilot Test: Bench Scale Test Cell Fabrication
National Grid
January 2014

Step 6.1	Weld two 1" X 1/2" bars [b1] to HSS 8.925 Half Pipe.
Step 6.2	Weld Full Side Plate [p3] to AZ-26-700 DB sheet pile pair [BT6].
Step 6.3	Weld SKS 16 interlock [k1] to AZ-26-700 DB sheet pile pair [BT6] and Full Side Plate [p3].
Step 6.4	Weld Half Pipe [t6] to Full Side Plate [p3] so that is positioned 1-inch above AZ-26-00 DB sheet pile pair [BT6].
Step 6.5	Weld 1" Diameter Sch. 40 Steel Pipe Nipples [t5] to port holes on HSS Side Plate [p8] .
Step 6.6	Screw 1" Pipe Caps [t8] onto port holes on HSS Side Plate [p8].
Step 6.7	Weld HSS Side Plate [p8] to AZ-26-700 DB sheet pile pair [BT6] and Half Pipe [t6].
Step 6.8	Weld two 2.5 X 2.5 X 1/2 Steel Angles [a2] to AZ-26-700 DB sheet pile pair [BT6], HSS Side Plate [p8] and Full Side Plate [p3].
Step 6.9	Weld 1/4" Diameter Pipe Coupling [t4] to hole in AZ-26-700 DB sheet pile pair [BT6] and screw in 1/4" Diam. Pipe Nipple [t3].
Step 6.10	Tack weld angle [a3] on either side of 1/4" port [t3/t4] for protection during shipping and handling.
Step 6.11	Weld 3" Diameter Pipe Coupling [t1] to Top Plate [P1] over 3" Permeant Cavity Hole.
Step 6.12	Weld 1" Diameter Sch. 40 Steel Pipe Nipple [t5] to port hole on Partial Side Plate [P6] .
Step 6.13	Screw 1" Pipe Caps [t8] onto pipe nipples on Partial Side Plate [P6].
Step 6.14	Weld 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2] to drainage hole on Partial Side Plate [P6] . May need pipe coupler to join with 1.5" NPT-threaded pipe valve provided by Terrasense.
Step 6.15	Place temporary formwork behind opening between Half Pipe [t6] and 2.5 X 2.5 X 1/2 Steel Angles [a2]. Temporarily seal sheet pile interlock before Bentogrout placement.
Step 6.16	Place CETCO Bentogrout between Half Pipe [t6] and 2.5 X 2.5 X 1/2 Steel Angles [a2] and AZ-26-700 DB sheet pile [BT6].
Step 6.17	Remove temporary formwork and seals after 18 hours or when Bentogrout has set up.
Step 6.18	Slide SKS 16 [S1] sheet pile into the SKS 16 interlock [k1].
Step 6.19	Weld SKS 16 sheet pile [S1] to Full Side Plate [p3].
Step 6.20	Place AquaBlock 3070 SW annular sealant material between SKS 16 sheet pile [S1] and Half Pipe [t6].
Step 6.21	Weld Partial Side Plate [P6] to AZ-26-700 DB [BT6], HSS Side Plate [p8], and SKS 16 sheet pile [S1].
Step 6.22	Weld 6 X 4 X 3/4 Steel Angle [A5] to AZ-26-700 DB [BT6], Full Side Plate [p3], and Partial Side Plate [P6]. Maintain minimum 3/8" gap between [S1] and [A5].
Step 6.23	Fill gap betweeen [S1] and [A5] with AquaBlock 3070SW.
Step 6.24	Weld Top Plate [P1] to AZ-26-700-DB sheet pile pair [BT6], Full Side Plate [p3], and Partial Side Plate [P6].
Step 6.25	Screw 3" Diameter Sch. 40 Pipe [T7] into 3" Diameter Pipe Coupling [t1].
Step 6.26	Check assembly for water tightness and spot weld as appropriate.
Step 6.27	Testing Protocols.

Notes: 1.) Steps 6.1 to 6.13 to be performed at Dura-Bond Fabrication Plant.
2.) Steps 6.14 to 6.27 to be performed at Terrasense Laboratory workspace.
3.) Items to be shipped loose to lab space, along with BT6 assembly, include:
- Top Plate [P1]
- Partial Side Plate [P6]
- Permeant Collection Channel [A4]
- SKS 16 sheet pile [S1]
- 6 X 4 X 3/4 Steel Angle [A5]
- 3" Diameter Sch. 40 Pipe [T7]
- 1.5" Diameter Sch. 40 Steel Pipe Nipple [T2]

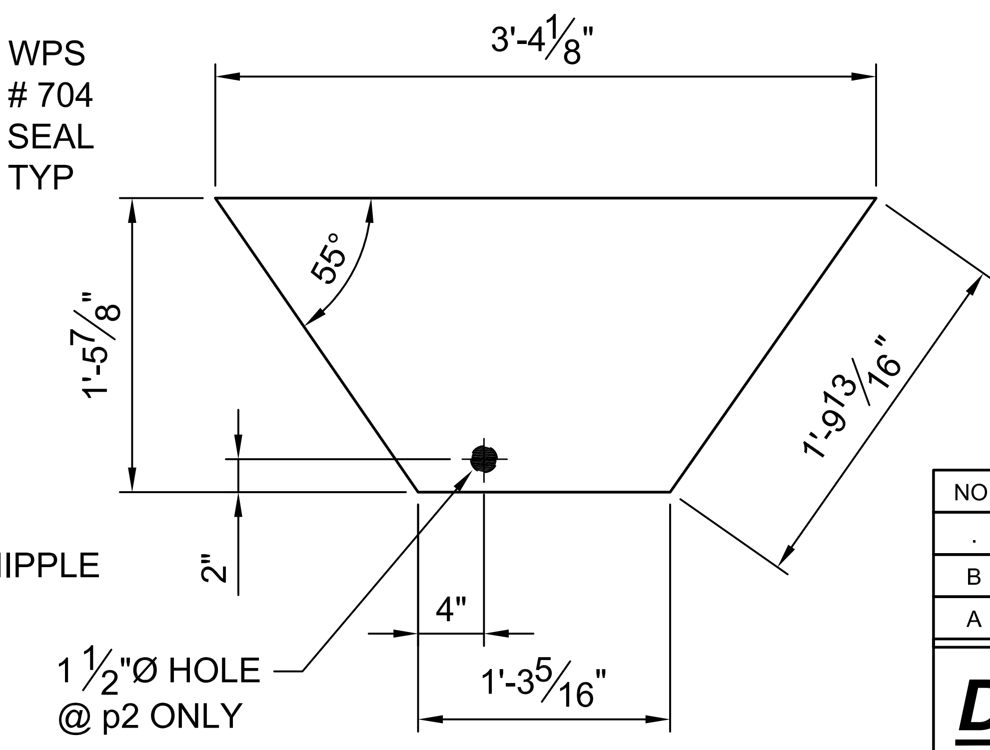


TOP VIEW



ONE - DBL AZ26-700 ~ BT1

WT = 428 LBS

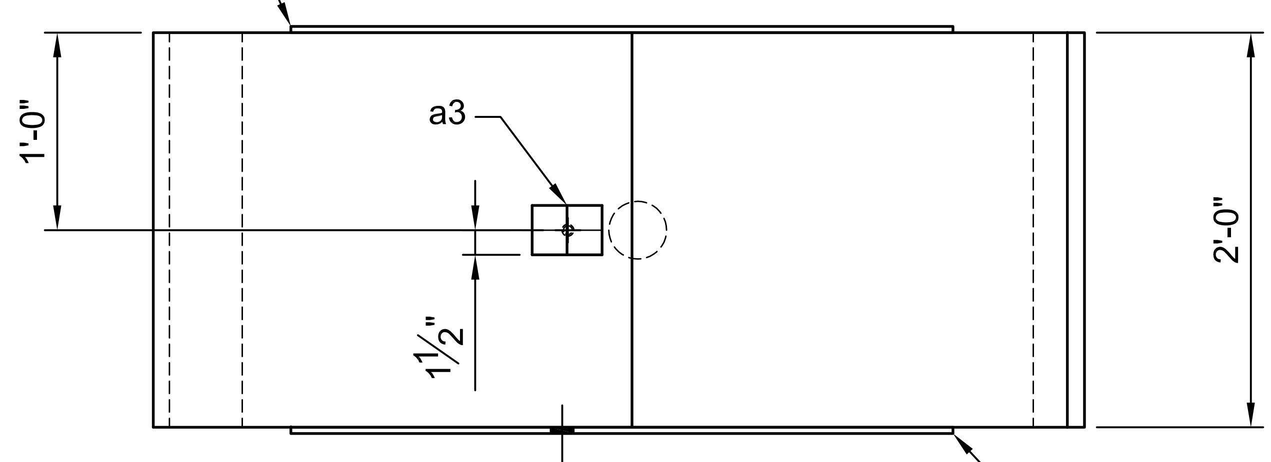


DETAIL ~ p2

WITH HOLE

DETAIL ~ p3

WITHOUT HOLE



BOTTOM VIEW

BILL OF MATERIAL

MARK	QTY	DESCRIPTION	FT	IN	REMARKS	WT
BT1	ONE	AZ26-700 DBL	2	0	A572-50	276
p1	ONE	PL 1/4" x 24"	4	0	A572-50	82
p2	ONE	PL 1/4" x 17 7/8"	3	4 1/8	A572-50	35
p3	ONE	PL 1/4" x 17 7/8"	3	4 1/8	A572-50	35
t1	ONE	3"Ø PIPE COUPLING	0	3	BLK	
t3	ONE	1/4"Ø PIPE NIPPLE	0	7/8	MC #44615K412	
t4	ONE	1/4"Ø PIPE COUPLING	0	1 3/16	MC #46685K262	
a3	ONE	L3 x 3 x 3/16	0	3	A-36	1
T2	ONE	1 1/2"Ø PIPE NIPPLE (T.1.E.)	0	3	BLK	
		SHIP LOOSE				
A4	ONE	L3 x 3 x 1/4"	2	6	A36	12
T7	ONE	3"Ø SCH 40 PIPE (T.1.E.)	8	9	BLK	65

MC - DENOTES McMASTER CARR PRODUCT

FOR CONSTRUCTION

11-15-13 (A)

1-10-14 (B)

NO.	REVISION	DATE	BY
.	.	.	.
B	Per Customer Comments of 1-6 & 9-14	1-10-14	SP
A	REVISED PER GEI'S ENG. COMMENTS	11-9-13	SP

Dura-Bond Steel

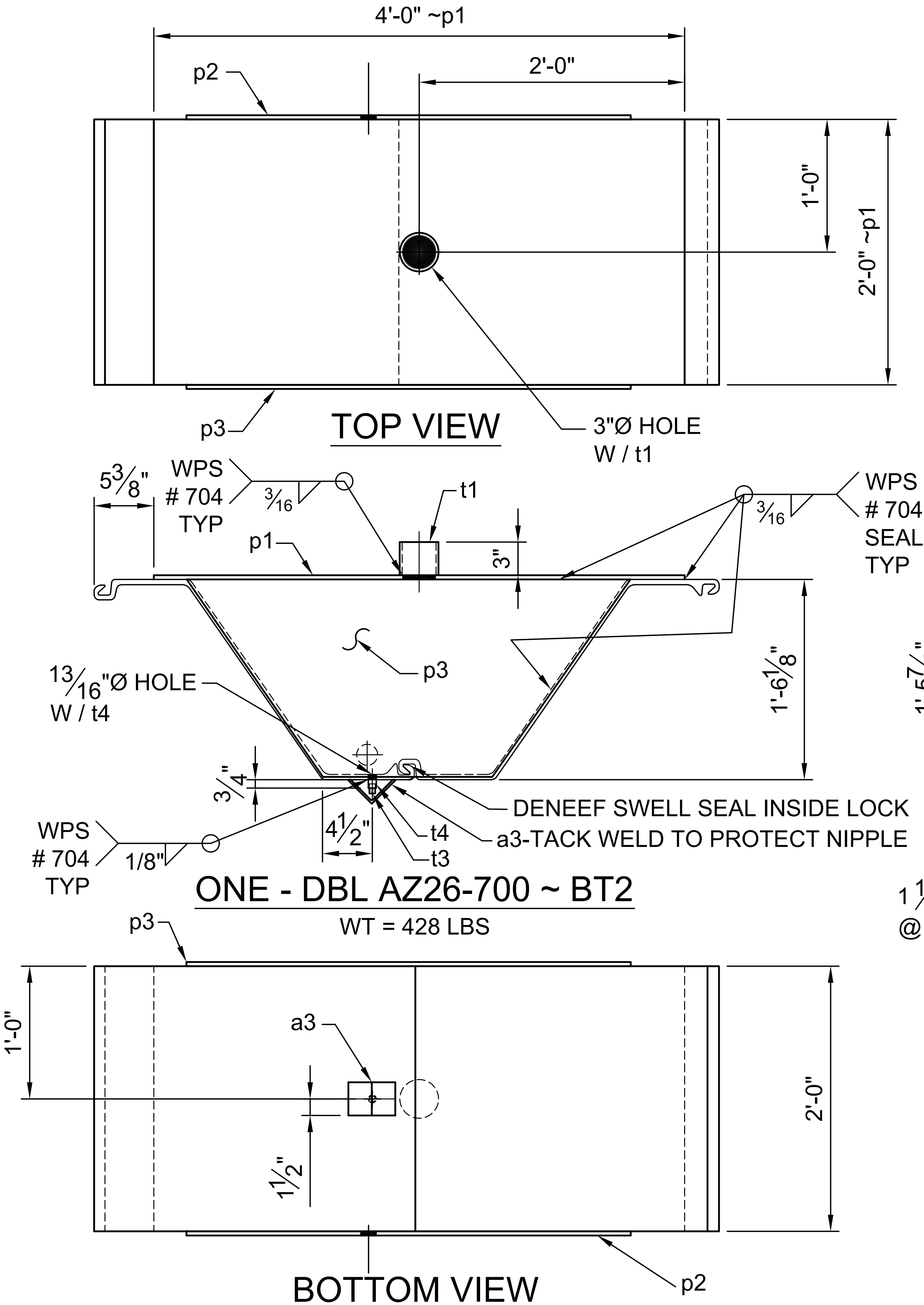
STEEL FABRICATION AND COATING SERVICES FOR THE CONSTRUCTION INDUSTRY

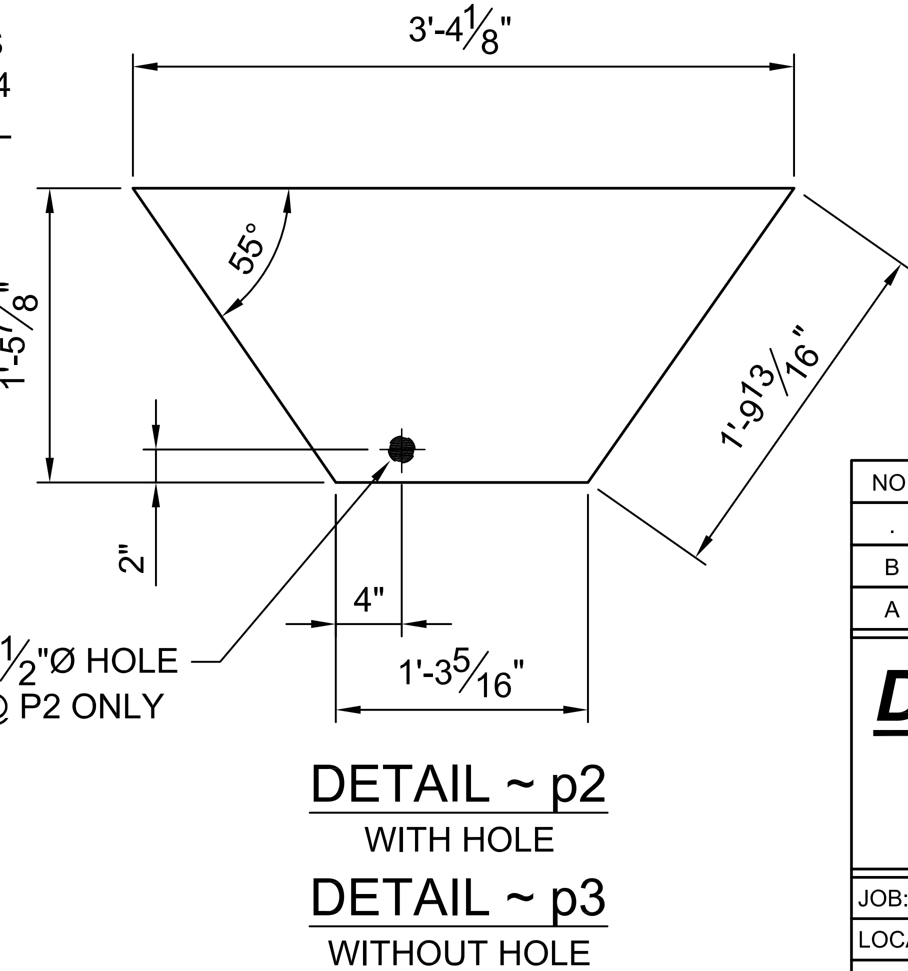
P.O. Drawer 518, 2658 Puckety Street
Export, Pennsylvania 15632
Phone: 724-327-0280 Fax: 724-327-0113

AISC CERTIFICATION

JOB: NATIONAL GRID	
LOCATION: BROOKLYN, NY	
CUSTOMER: RAYMOND PILING PRODUCTS	PO# 4312
ARCH./ENG: GEI CONSULTANTS	
DESCRIPTION: AZ26-700 TEST PILES - BENCH TEST 1	
BOLTS: N/A	HOLES: AS NOTED
WELD-A.W.S. CODE: D1.1 E7XTX FCAW	
PAINT: NONE	DRN: MB-10-29-13
.	CHKD: SPP 10-29-13
JOB NO.: 13-72-210	SHT. NO.: 1

TOLERANCES	
LENGTH	±1/4"
SQ TOP	N/A
SQ BTM	N/A
COPES	N/A
HOLES	±1/16"
DIMENSIONS	±1/8"





BILL OF MATERIAL

MARK	QTY	DESCRIPTION	FT	IN	REMARKS	WT
BT2	ONE	AZ26-700 DBL	2	0	A572-50	276
p1	ONE	PL 1/4" x 24"	4	0	A572-50	82
p2	ONE	PL 1/4" x 17 7/8"	3	4 1/8	A572-50	35
p3	ONE	PL 1/4" x 17 7/8"	3	4 1/8	A572-50	35
t1	ONE	3"Ø PIPE COUPLING	0	3	BLK	
t3	ONE	1/4"Ø PIPE NIPPLE	0	7/8	MC #44615K412	
t4	ONE	1/4"Ø PIPE COUPLING	0	1 3/16	MC #46685K262	
a3	ONE	L3 x 3 x 3/16	0	3	A-36	1
T2	ONE	1 1/2"Ø PIPE NIPPLE (T.1.E.)	0	3	BLK	
		SHIP LOOSE				
A4	ONE	L3 x 3 x 1/4"	2	6	A36	12
T7	ONE	3"Ø SCH 40 PIPE T.1.E.	8	9	BLK	65

MC - DENOTES McMASTER CARR PRODUCT

FOR CONSTRUCTION

11-15-13 (A)

1-10-14 (B)

NO.	REVISION	DATE	BY
.	.	.	.
B	Per Customer comments 1-6 & 9-14	1-10-14	SP
A	REVISED PER GEI'S ENG. COMMENTS	11-9-13	SP

Dura-Bond Steel

STEEL FABRICATION AND COATING SERVICES FOR THE CONSTRUCTION INDUSTRY

P.O. Drawer 518, 2658 Puckety Street
Export, Pennsylvania 15632
Phone: 724-327-0280 Fax: 724-327-0113

AISC CERTIFICATION

JOB: NATIONAL GRID

LOCATION: BROOKLYN, NY

CUSTOMER: RAYMOND PILING PRODUCTS PO# 4312

ARCH./ENG: GEI CONSULTANTS

DESCRIPTION: AZ26-700 TEST PILES - BENCH TEST 2

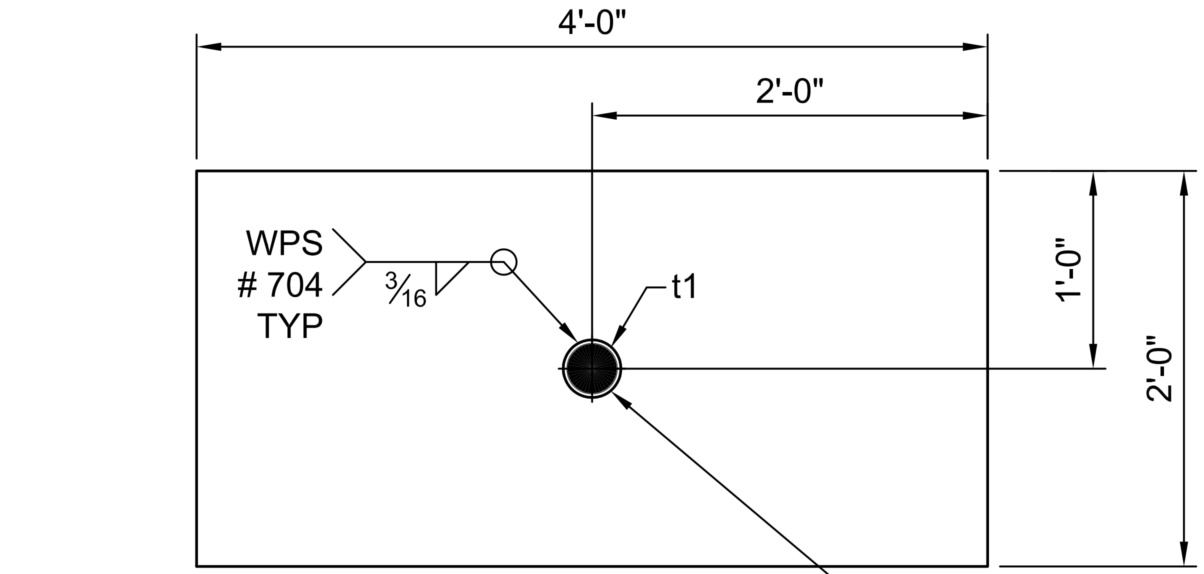
BOLTS: N/A HOLES: AS NOTED

WELD-A.W.S. CODE: D1.1 E7XTX FCAW

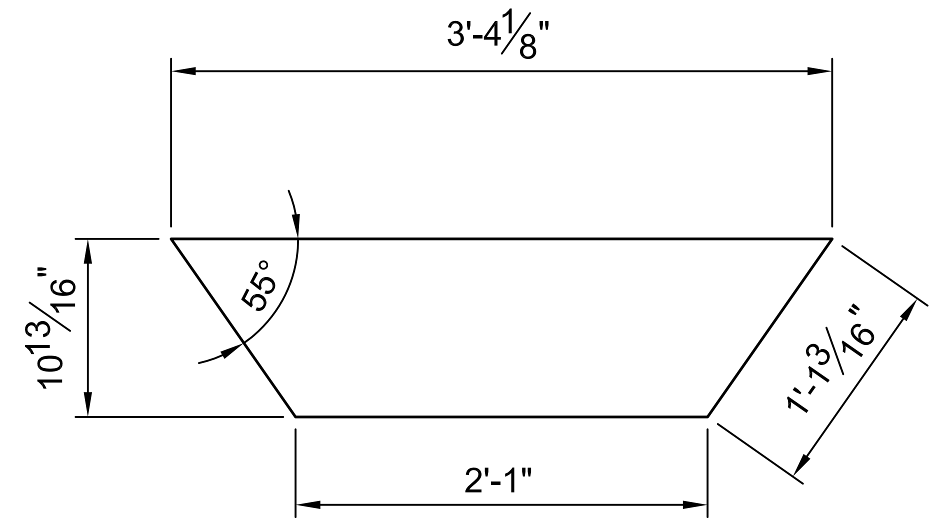
PAINT: NONE DRN: MB-10-29-13

. CHKD: SPP 10-29-13

JOB NO.: 13-72-210 SHT. NO.: 2

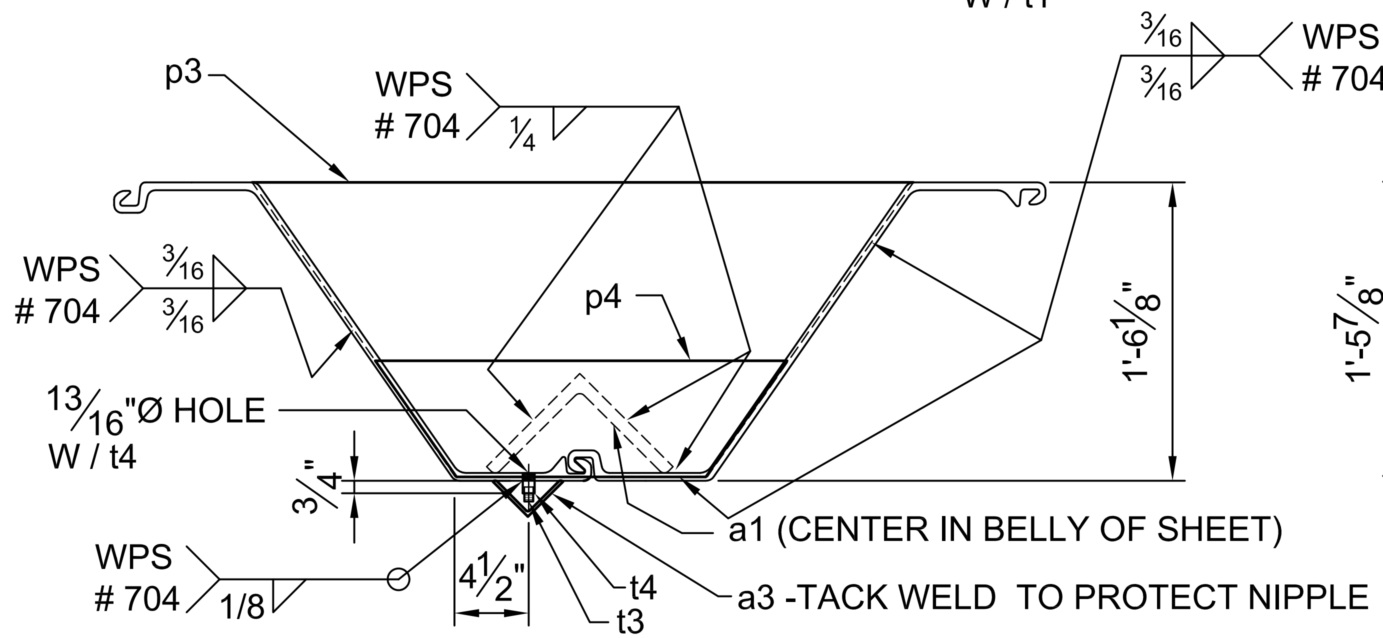


ONE - PLATE ~ P1



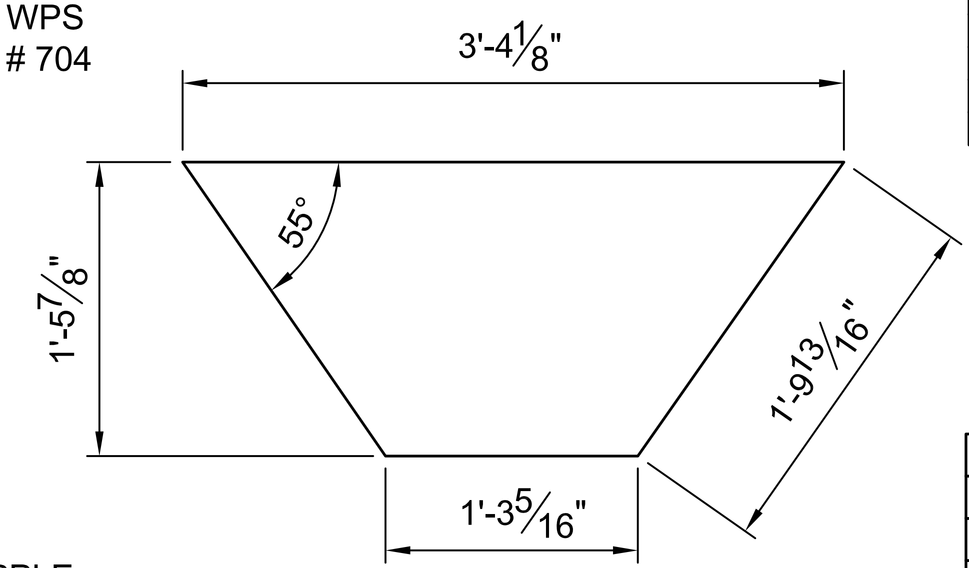
ONE - PLATE ~ P5

WT = 25 LBS

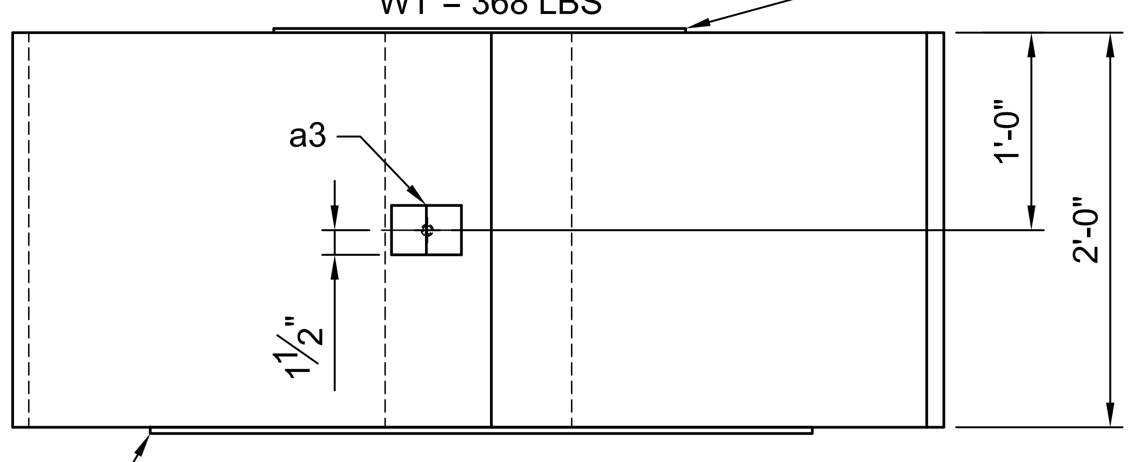


ONE - DBL AZ26-700 ~ BT3

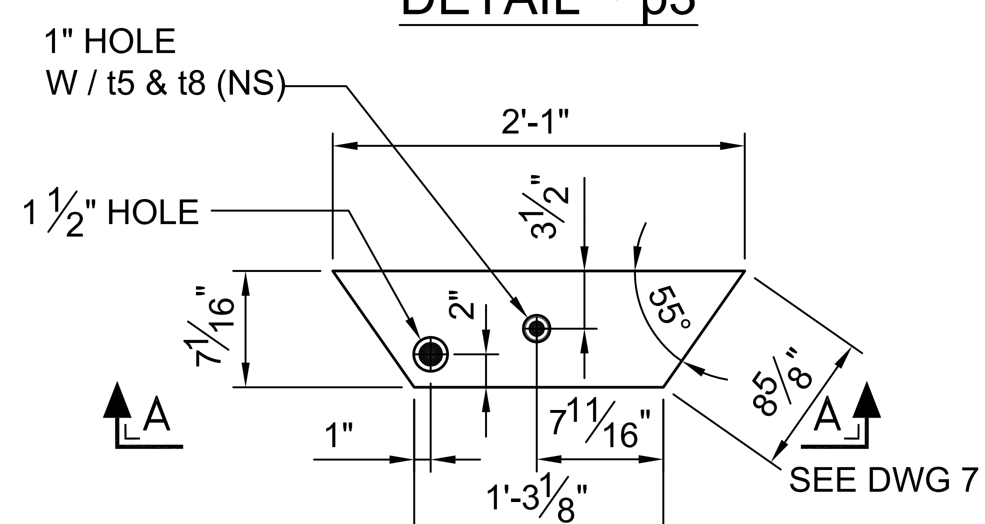
WT = 368 LBS



DETAIL ~ p3



BOTTOM VIEW



Detail ~ p4

BILL OF MATERIAL

MARK	QTY	DESCRIPTION	FT	IN	REMARKS	WT
BT3	ONE	AZ26-700 DBL	2	0	A572-50	276
a1	ONE	L8 x 8 x 3/4"	2	0	A572-50	57
p3	ONE	PL 1/4" x 17 7/8"	3	4 1/8	A572-50	35
t3	ONE	1/4"Ø PIPE NIPPLE	0	7/8	MC #44615K412	
t4	ONE	1/4"Ø PIPE COUPLING	0	1 3/16	MC #46685K262	
p4	ONE	PL 1/4" x 7 1/16"	2	1	A572-50	10
t5	ONE	1" SCH 40 PIPE NIPPLE (T.1.E.)	0	3	BLK	
t8	ONE	1" SCH 40 PIPE CAP			BLK	
a3	ONE	L3 x 3 x 3/16	0	3	A-36	1
		SHIP LOOSE				
P1	ONE	PL 1/4" x 24"	4	0	A572-50	82
t1	ONE	3"Ø PIPE COUPLING	0	3	BLK	
P5	ONE	PL 1/4" x 10 13/16"	3	4 1/8	A572-50	25
A4	ONE	L3 x 3 x 1/4"	2	6	A36	12
T2	ONE	1 1/2"Ø PIPE NIPPLE (T.1.E.)	0	3	BLK	
T7	ONE	3"Ø SCH 40 PIPE T.1.E.	8	9	BLK	65

MC - DENOTES McMASTER CARR PRODUCT

FOR CONSTRUCTION

11-15-13 (A)

1-10-14 (B)

NO.	REVISION	DATE	BY
.	.	.	.
B	Revised per cutomer comments 1-6 & 9-14	1-10-14	SP
A	REVISED PER GEI'S ENG. COMMENTS	11-9-13	SP

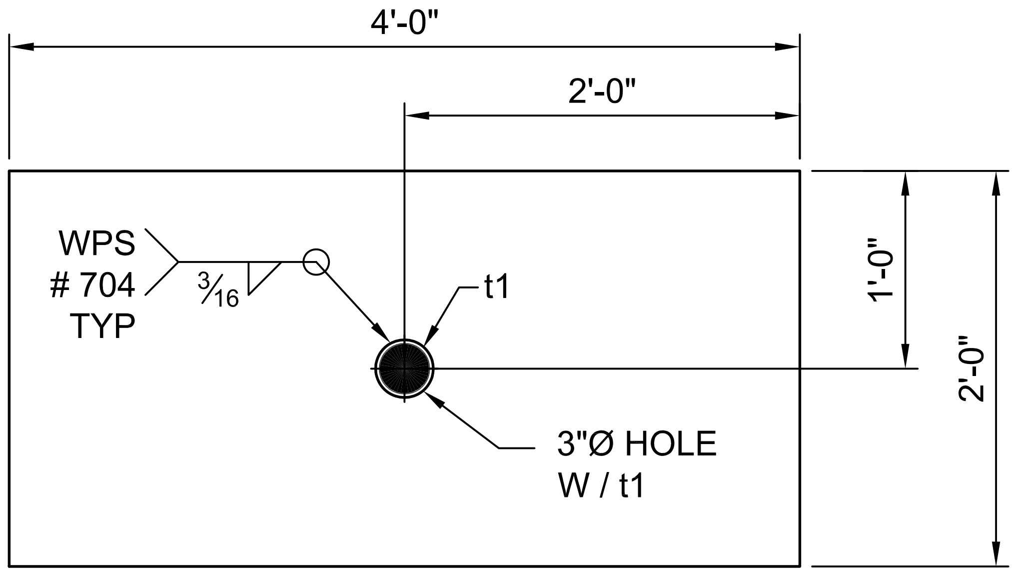
Dura-Bond Steel

STEEL FABRICATION AND COATING SERVICES FOR THE CONSTRUCTION INDUSTRY

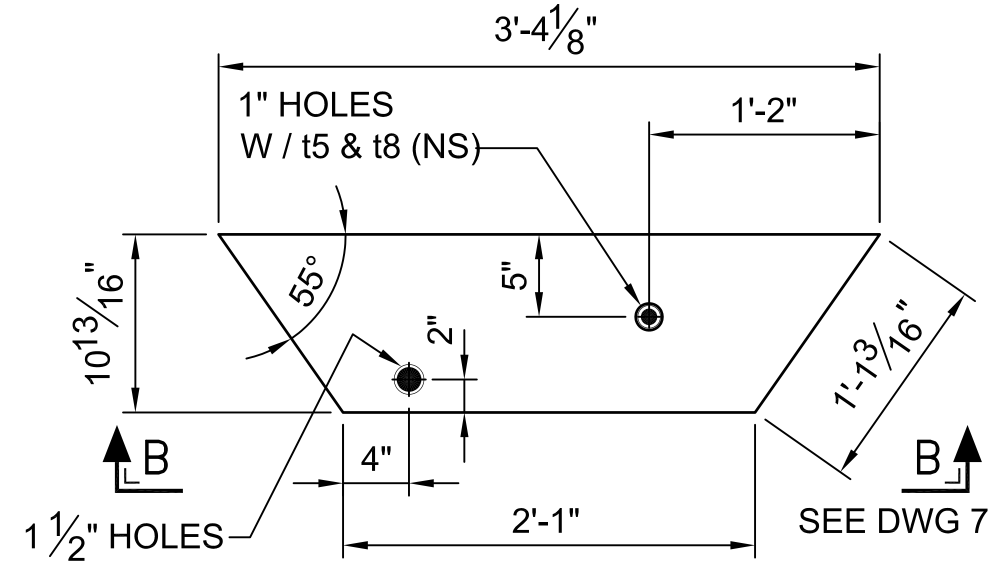
P.O. Drawer 518, 2658 Puckety Street
Export, Pennsylvania 15632
Phone: 724-327-0280 Fax: 724-327-0113

AISC CERTIFICATION

JOB: NATIONAL GRID	
LOCATION: BROOKLYN, NY	
CUSTOMER: RAYMOND PILING PRODUCTS	PO# 4312
ARCH./ENG: GEI CONSULTANTS	
DESCRIPTION: AZ26-700 TEST PILES - BENCH TEST 3	
BOLTS: N/A	HOLES: AS NOTED
WELD-A.W.S. CODE: D1.1 E7XTX FCAW	
PAINT: NONE	DRN: MB-10-29-13
.	CHKD: SPP 10-29-13
JOB NO.: 13-72-210	SHT. NO.: 3

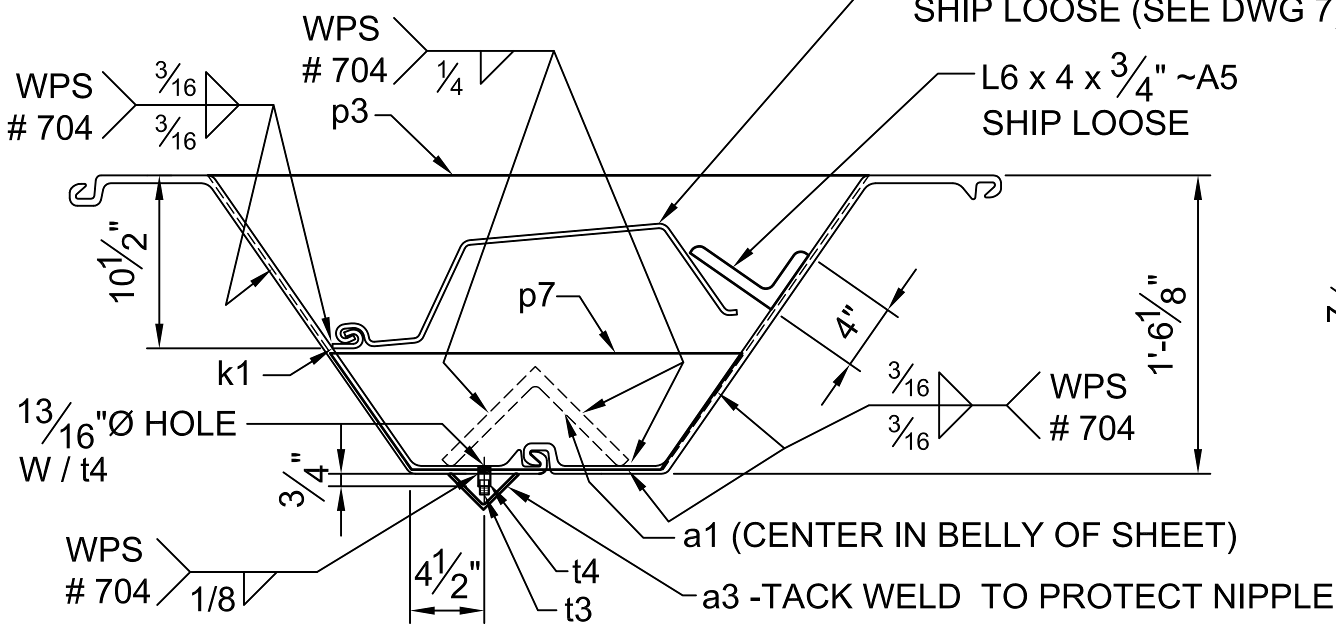


ONE - PLATE ~ P1



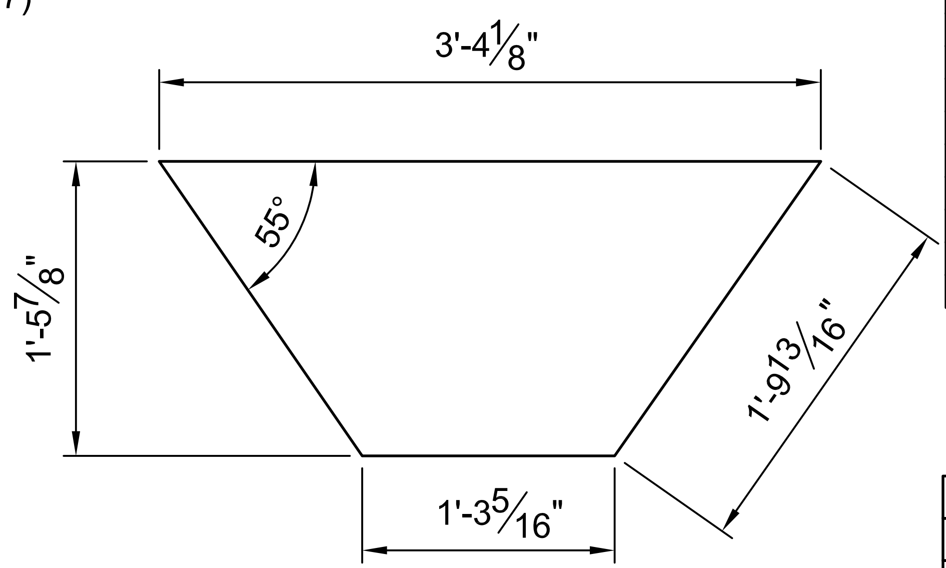
ONE - PLATE ~ P6

WT = 25 LBS

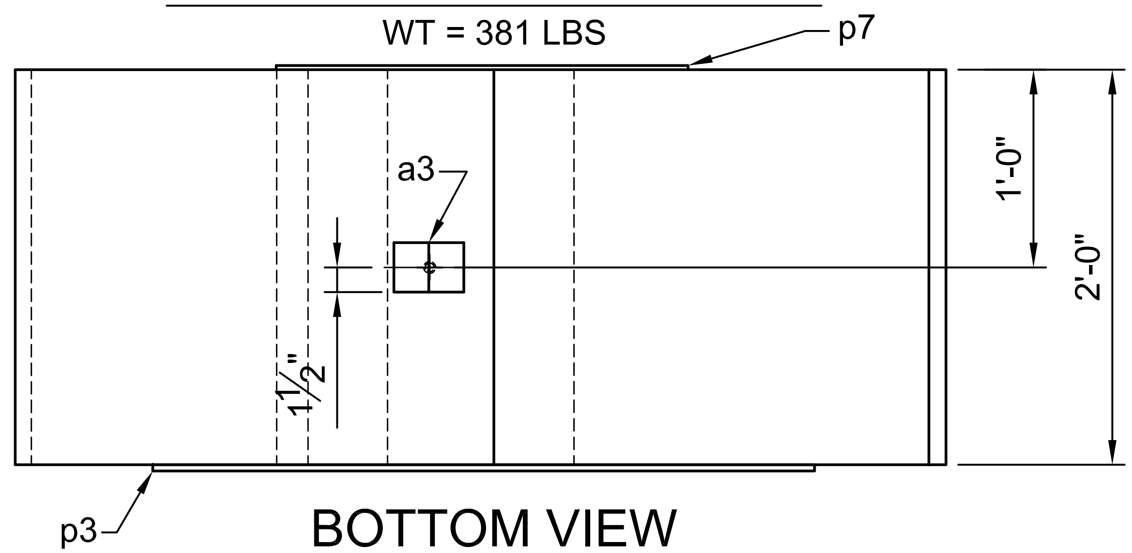


ONE - DBL AZ26-700 ~ BT4

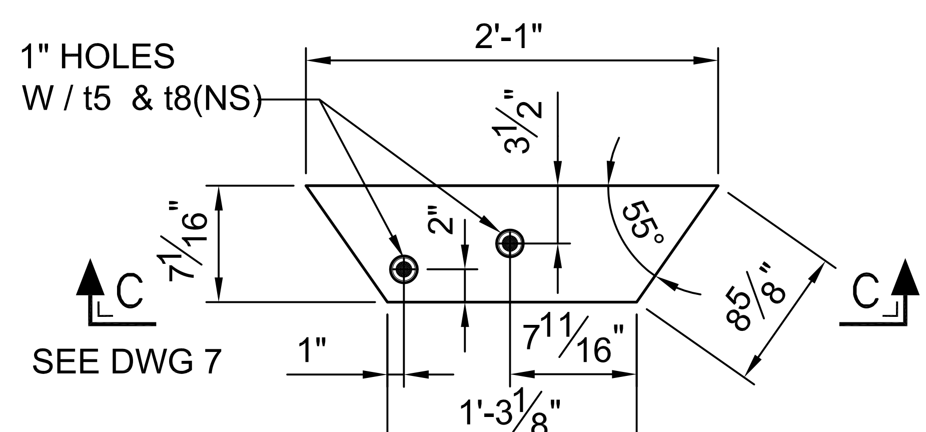
WT = 381 LBS



DETAIL ~ p3



BOTTOM VIEW



Detail ~ p7

BILL OF MATERIAL

MARK	QTY	DESCRIPTION	FT	IN	REMARKS	WT
BT4	ONE	AZ26-700 DBL	2	0	A572-50	276
a1	ONE	L8 x 8 x 3/4"	2	0	A572-50	57
k1	ONE	SKS 16 LOCK (SEE DWG 7)	2	0		10
p3	ONE	PL 1/4" x 17 7/8"	3	4 1/8	A572-50	35
t3	ONE	1/4"Ø PIPE NIPPLE	0	7/8	MC #44615K412	
t4	ONE	1/4"Ø PIPE COUPLING	0	1 3/16	MC #46685K262	
p7	ONE	PL 1/4" x 7 1/16"	2	1	A572-50	10
t5	2	1" SCH 40 PIPE NIPPLE (T.1.E.)	0	3	BLK	
a3	ONE	L3 x 3 x 3/16	0	3	A-36	1
t8	2	1" SCH 40 PIPE CAP			BLK	2
		SHIP LOOSE				
P1	ONE	PL 1/4" x 24"	4	0	A572-50	82
t1	ONE	3"Ø PIPE COUPLING	0	3	BLK	
P6	ONE	PL 1/4" x 10 13/16"	3	4 1/8	A572-50	25
t5	ONE	1" SCH 40 PIPE NIPPLE (T.1.E.)	0	3	BLK	
t8	ONE	1" SCH 40 PIPE CAP			BLK	
S1	ONE	SKS 16 (SEE DWG 7)	2	0		71
A5	ONE	L6 x 4 x 3/4"	2	0	A572-50	47
A4	ONE	L3 x 3 x 1/4"	2	6	A36	12
T2	ONE	1 1/2"Ø PIPE NIPPLE (T.1.E.)	0	3	BLK	
T7	ONE	3"Ø SCH 40 PIPE T.1.E.	8	9	BLK	65

MC - DENOTES McMASTER CARR PRODUCT

FOR CONSTRUCTION

11-15-13 (A)

1-10-14 (B)

NO.	REVISION	DATE	BY
B	Revised Per Customer comments 1-6 & 9-14	1-10-14	SP
A	REVISED PER GEI'S ENG. COMMENTS	11-9-13	SP

Dura-Bond Steel

STEEL FABRICATION AND COATING SERVICES FOR THE CONSTRUCTION INDUSTRY

P.O. Drawer 518, 2658 Puckety Street
Export, Pennsylvania 15632
Phone: 724-327-0280 Fax: 724-327-0113

AISC CERTIFICATION

JOB: NATIONAL GRID

LOCATION: BROOKLYN, NY

CUSTOMER: RAYMOND PILING PRODUCTS PO# 4312

ARCH./ENG: GEI CONSULTANTS

DESCRIPTION: AZ26-700 TEST PILES - BENCH TEST 4

BOLTS: N/A HOLES: AS NOTED

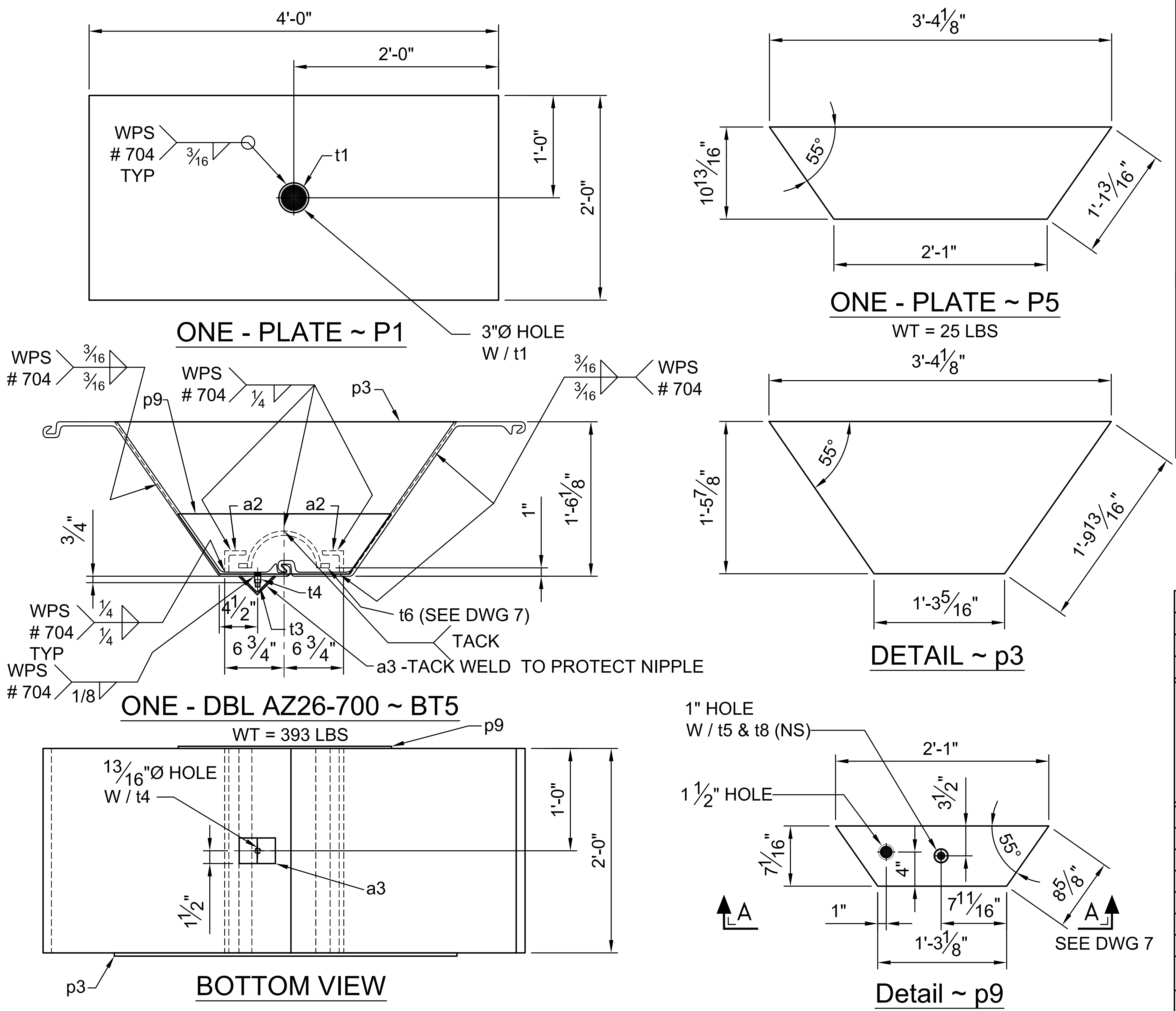
WELD-A.W.S. CODE: D1.1 E7XTX FCAW

PAINT: NONE

DRN: MB-10-29-13

CHKD: SPP 10-29-13

JOB NO.: 13-72-210 SHT. NO.: 4



BILL OF MATERIAL

MARK	QTY	DESCRIPTION	FT	IN	REMARKS	WT
BT5	ONE	AZ26-700 DBL	2	0	A572-50	276
a2	2	L2 1/2 x 2 1/2 x 1/2"	2	0	A572-50	31
p3	ONE	PL 1/4" x 17 7/8"	3	4 1/8	A572-50	35
t6	ONE	8" XH HALF PIPE	2	0	A53	44
b1	2	BAR 1" x 1/2"	2	0	A572-50	7
t3	ONE	1/4"Ø PIPE NIPPLE	0	7/8	MC #44615K412	
t4	ONE	1/4"Ø PIPE COUPLING	0	1 3/16	MC #46685K262	
p9	ONE	PL 1/4" x 7 1/16"	2	1	A572-50	10
t5	ONE	1" SCH 40 PIPE NIPPLE (T.1.E.)	0	3	BLK	
a3	ONE	L3 x 3 x 3/16	0	3	A-36	1
t8	1	1" SCH 40 PIPE CAP			BLK	1
		SHIP LOOSE				
P1	ONE	PL 1/4" x 24"	4	0	A572-50	82
t1	ONE	3"Ø PIPE COUPLING	0	3	BLK	
P5	ONE	PL 1/4" x 10 13/16"	3	4 1/8	A572-50	25
T2	ONE	1 1/2"Ø PIPE NIPPLE (T.1.E.)	0	3	BLK	
A4	ONE	L3 x 3 x 1/4"	2	6	A36	12
T7	ONE	3"Ø SCH 40 PIPE T.1.E.	8	9	BLK	65

MC - DENOTES McMASTER CARR PRODUCT

FOR CONSTRUCTION

11-15-13 (A)

1-10-14 (B)

NO.	REVISION	DATE	BY
.	.	.	.
B	revised per customer comment 1-6 & 9-14	1-10-14	SP
A	REVISED PER GEI'S ENG. COMMENTS	11-9-13	SP

Dura-Bond Steel

STEEL FABRICATION AND COATING SERVICES FOR THE CONSTRUCTION INDUSTRY

P.O. Drawer 518, 2658 Puckety Street
Export, Pennsylvania 15632
Phone: 724-327-0280 Fax: 724-327-0113

AISC CERTIFICATION

JOB: NATIONAL GRID

LOCATION: BROOKLYN, NY

CUSTOMER: RAYMOND PILING PRODUCTS PO# 4312

ARCH./ENG: GEI CONSULTANTS

DESCRIPTION: AZ26-700 TEST PILES - BENCH TEST 5

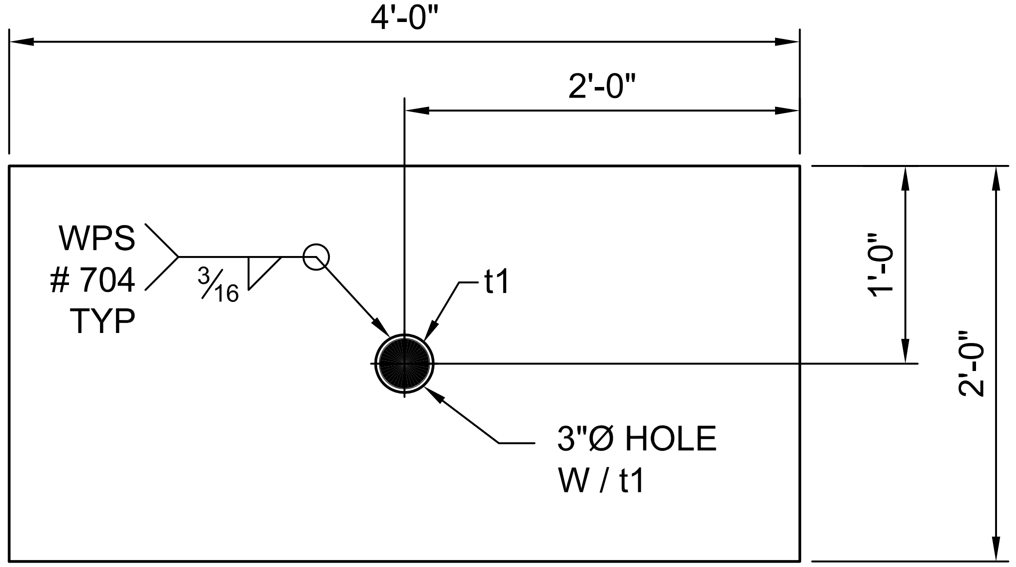
BOLTS: N/A HOLES: AS NOTED

WELD-A.W.S. CODE: D1.1 E7XTX FCAW

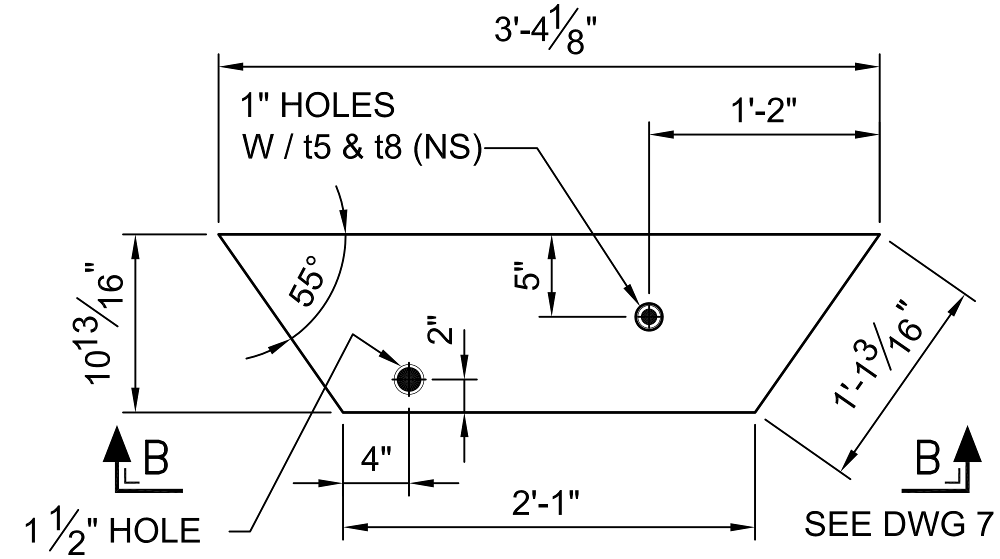
PAINT: NONE DRN: MB-10-29-13

CHKD: SPP 10-29-13

JOB NO.: 13-72-210 SHT. NO.: 5

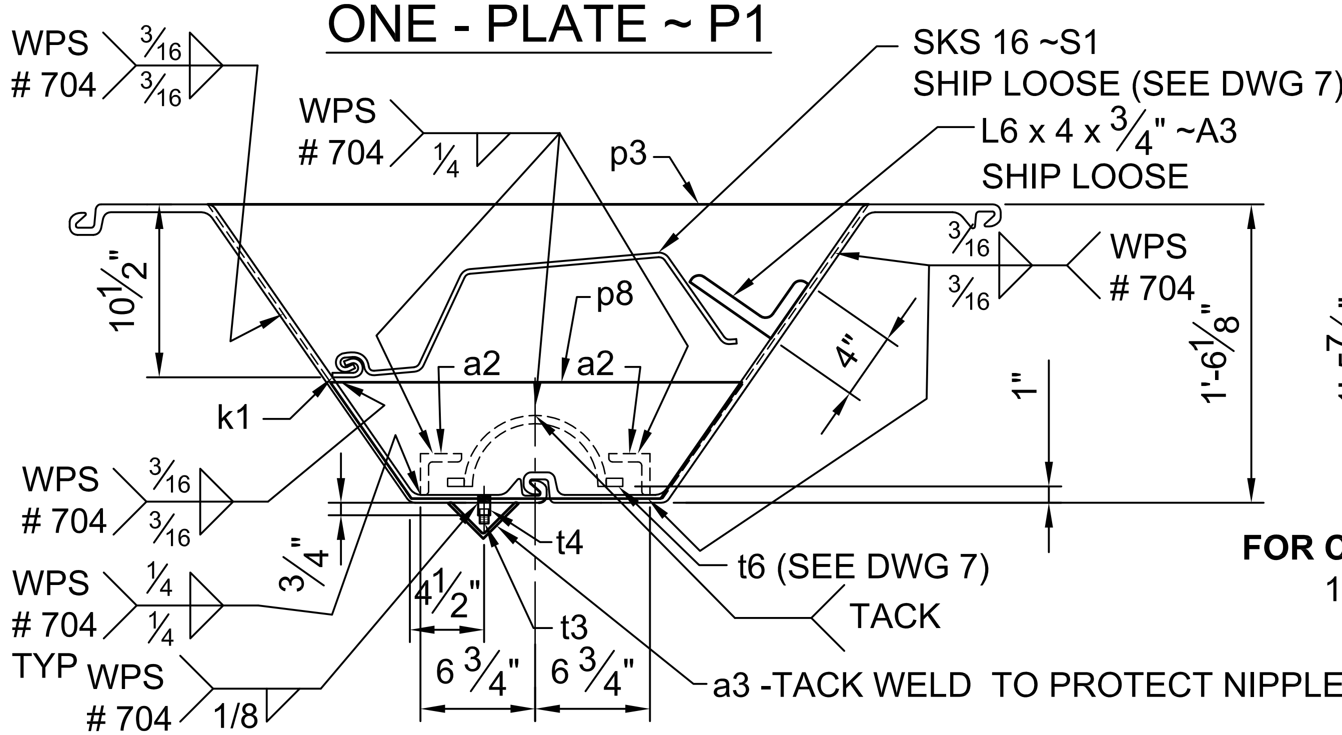


ONE - PLATE ~ P1



ONE - PLATE ~ P6

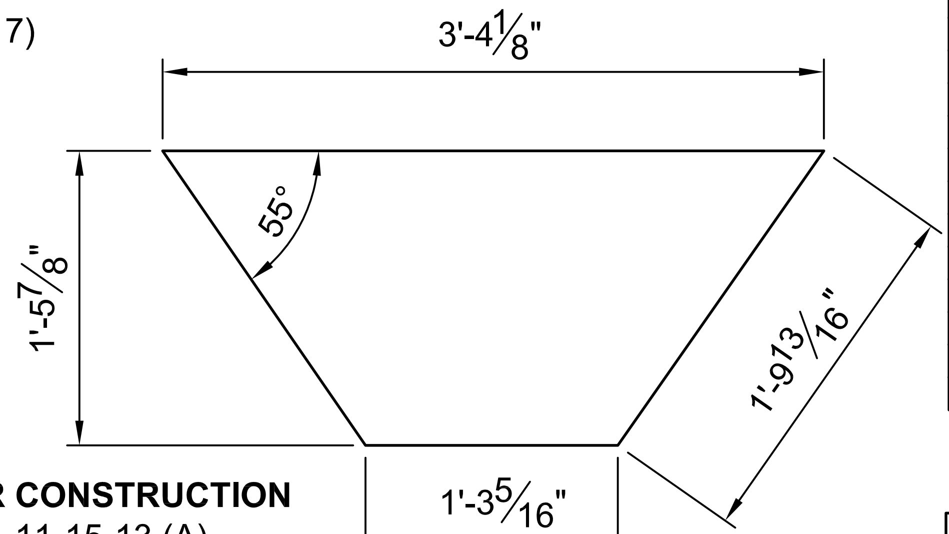
WT = 25 LBS



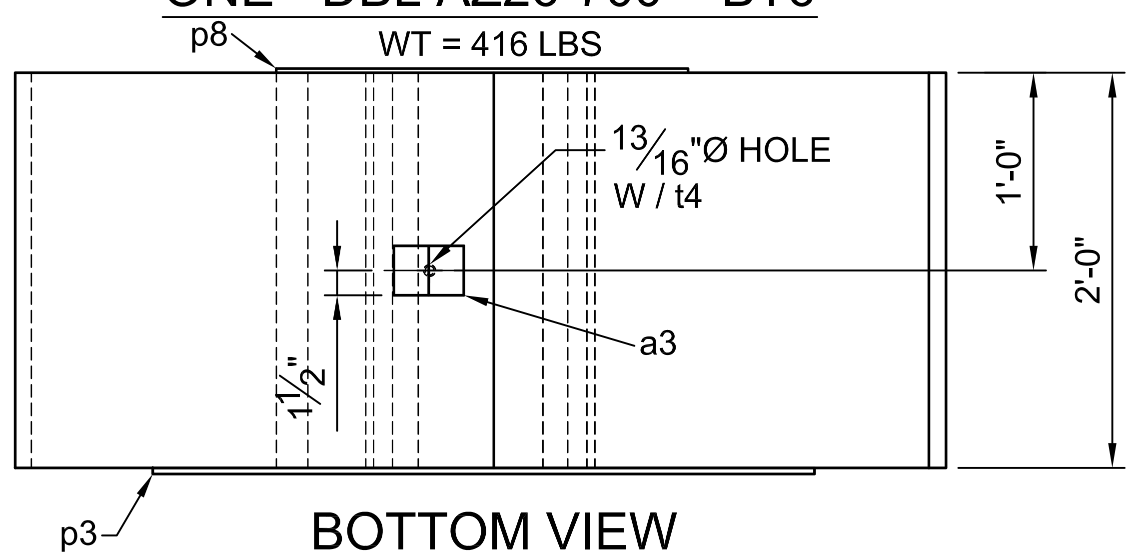
FOR CONSTRUCTION
11-15-13 (A)
1-1014 (B)

ONE - DBL AZ26-700 ~ BT6

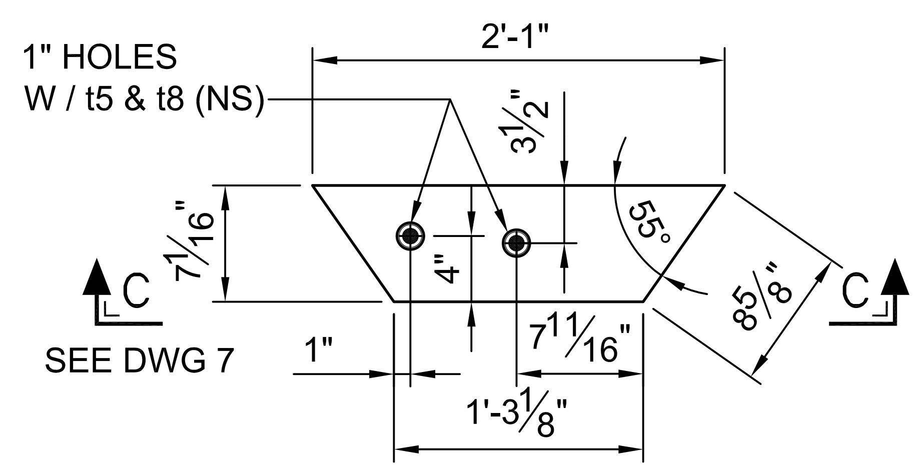
WT = 416 LBS



DETAIL ~ p3



BOTTOM VIEW



Detail ~ p8

BILL OF MATERIAL

MARK	QTY	DESCRIPTION	FT	IN	REMARKS	WT
BT6	ONE	AZ26-700 DBL	2	0	A572-50	276
a2	2	L2 1/2 x 2 1/2 x 1/2"	2	0	A572-50	31
b1	2	BAR 1" x 1/2"	2	0	A572-50	7
k1	ONE	SKS 16 LOCK (SEE DWG 7)	2	0		10
p3	ONE	PL 1/4" x 17 7/8"	3	4 1/8	A572-50	35
t3	ONE	1/4"Ø PIPE NIPPLE	0	7/8	MC #44615K412	
t4	ONE	1/4"Ø PIPE COUPLING	0	1 3/16	MC #46685K262	
t6	ONE	8" XH HALF PIPE	2	0	A53	44
p8	ONE	PL 1/4" x 7 1/16"	2	1	A572-50	10
t5	2	1" SCH 40 PIPE NIPPLE (T.1.E.)	0	3	BLK	
a3	ONE	L3 x 3 x 3/16	0	3	A-36	1
t8	2	1" SCH 40 PIPE CAP			BLK	2
		SHIP LOOSE				
P1	ONE	PL 1/4" x 24"	4	0	A572-50	82
t1	ONE	3"Ø PIPE COUPLING	0	3	BLK	
P6	ONE	PL 1/4" x 10 13/16"	3	4 1/8	A572-50	25
t5	ONE	1" SCH 40 PIPE NIPPLE (T.1.E.)	0	3	BLK	
t8	1	1" SCH 40 PIPE CAP			BLK	1
S1	ONE	SKS 16 (SEE DWG 7)	2	0		71
A5	ONE	L6 x 4 x 3/4"	2	0	A572-50	47
A4	ONE	L3 x 3 x 1/4"	2	6	A36	12
T2	ONE	1 1/2"Ø PIPE NIPPLE (T.1.E.)	0	3	BLK	
T7	ONE	3"Ø SCH 40 PIPE T.1.E.	8	9	BLK	65

MC - DENOTES McMASTER CARR PRODUCT

NO.	REVISION	DATE	BY
B	Revised Per Customer Comments 1-6 & 9-14	1-10-14	SP
A	REVISED PER GEI'S ENG. COMMENTS	11-9-13	SP

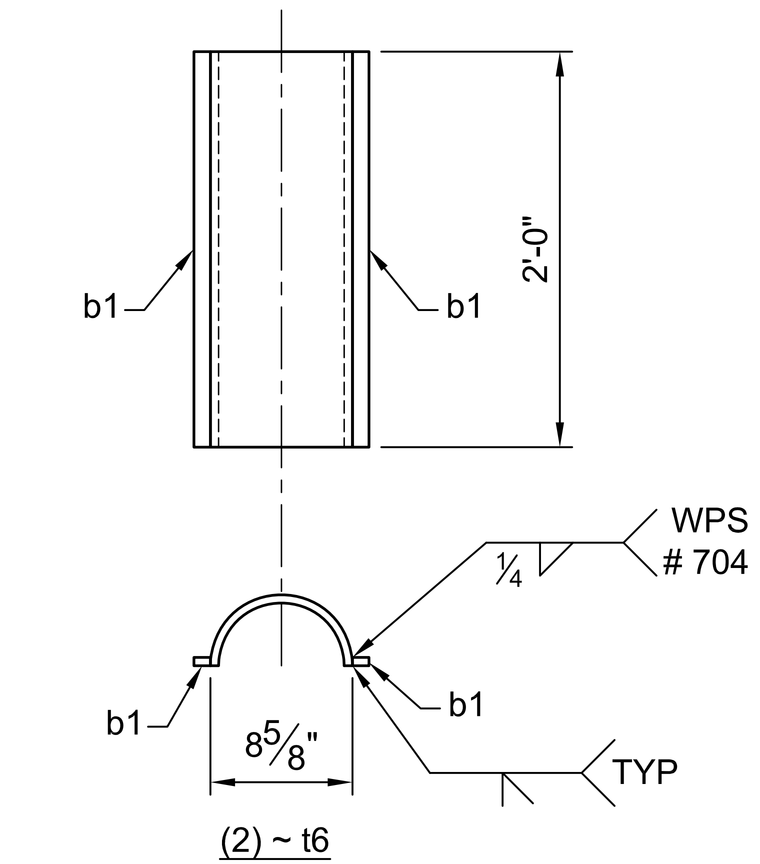
Dura-Bond Steel

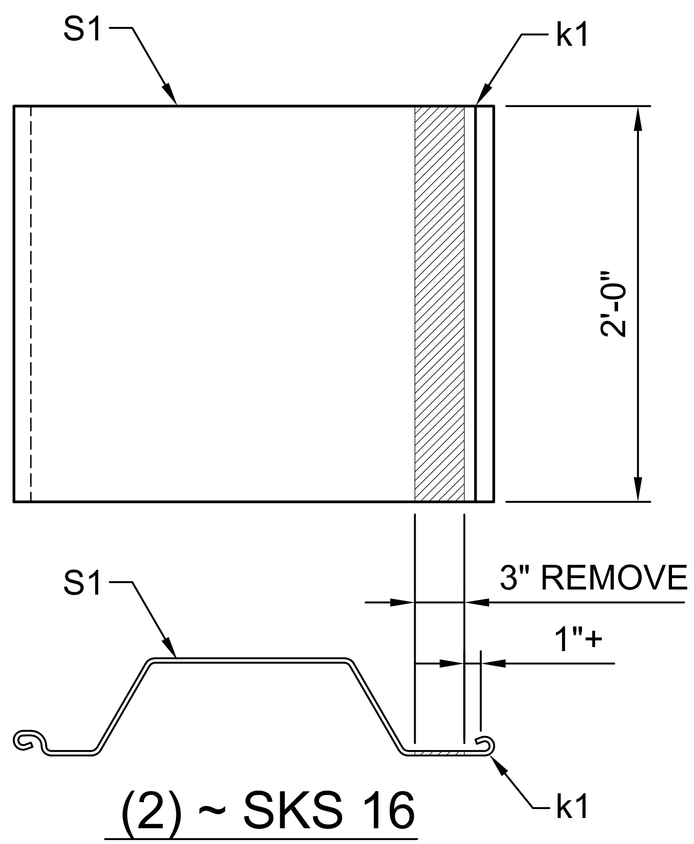
STEEL FABRICATION AND COATING SERVICES FOR THE CONSTRUCTION INDUSTRY

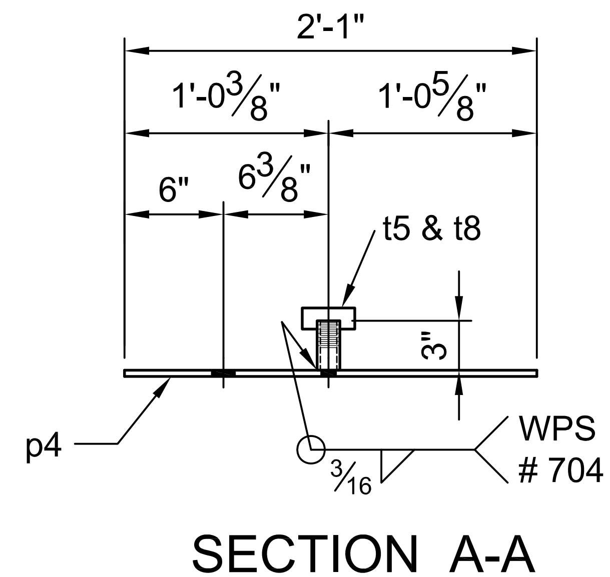
P.O. Drawer 518, 2658 Puckety Street
Export, Pennsylvania 15632
Phone: 724-327-0280 Fax: 724-327-0113

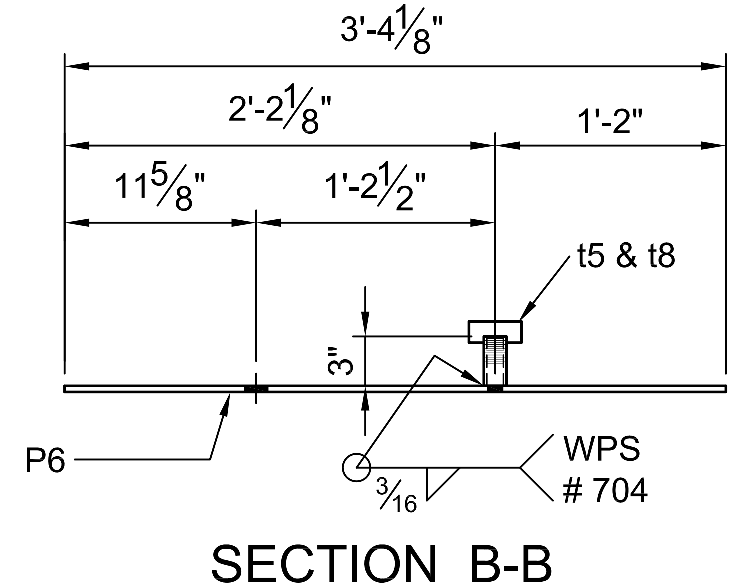
AISC CERTIFICATION

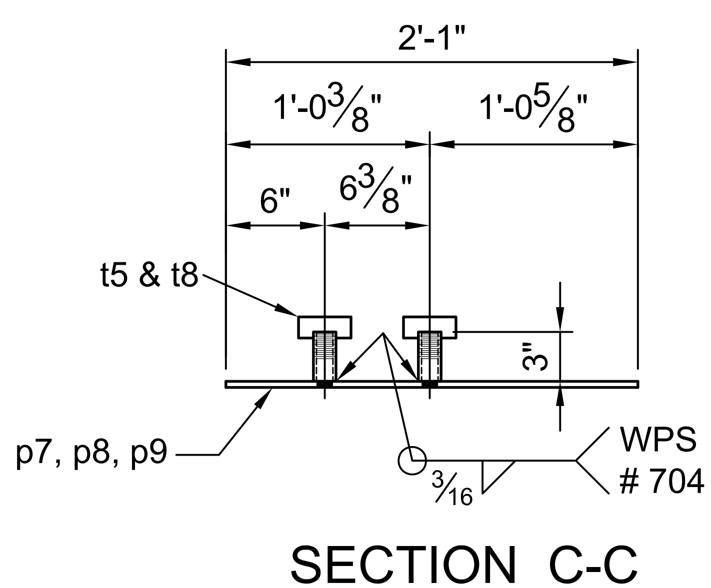
JOB: NATIONAL GRID	
LOCATION: BROOKLYN, NY	
CUSTOMER: RAYMOND PILING PRODUCTS	PO# 4312
ARCH./ENG: GEI CONSULTANTS	
DESCRIPTION: AZ26-700 TEST PILES - BENCH TEST 6	
BOLTS: N/A	HOLES: AS NOTED
WELD-A.W.S. CODE: D1.1 E7XTX FCAW	
PAINT: NONE	DRN: MB-10-29-13
	CHKD: SPP 10-29-13
JOB NO.: 13-72-210	SHT. NO.: 6

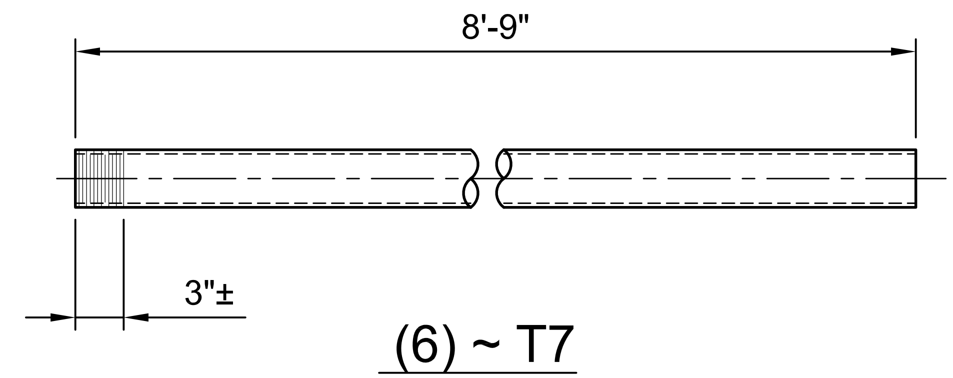


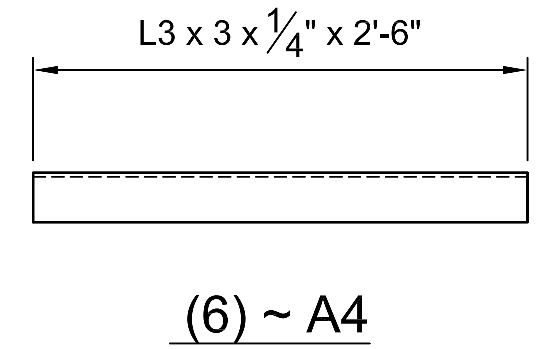












FOR CONSTRUCTION
11-15-13
1-10-14 (A)

WORK THIS DWG WITH DWG 3,4,5,& 6

NO.	REVISION	DATE	BY
.	.	.	.
A	Revised Per Customer Comments 1-6 & 9-14	1-10-14	SP

Dura-Bond Steel

STEEL FABRICATION AND COATING SERVICES FOR THE CONSTRUCTION INDUSTRY

P.O. Drawer 518, 2658 Puckety Street
Export, Pennsylvania 15632
Phone: 724-327-0280 Fax: 724-327-0113

AISC CERTIFICATION

TOLERANCES	
LENGTH	±1/4"
SQ TOP	N/A
SQ BTM	N/A
COPES	N/A
HOLES	±1/16"
DIMENSIONS	±1/8"

JOB: NATIONAL GRID
LOCATION: BROOKLYN, NY
CUSTOMER: RAYMOND PILING PRODUCTS PO# 4312
ARCH./ENG: GEI CONSULTANTS
DESCRIPTION: AZ26-700 TEST PILE SECTIONS
BOLTS: N/A HOLES: AS NOTED
WELD-A.W.S. CODE: D1.1 E7XTX FCAW
PAINT: NONE .
DRN: MB-10-29-13
CHKD: SPP 10-29-13
JOB NO.: 13-72-210 SHT. NO.: 7

Appendix B

Photographs of Bench Scale Fabrication and Testing

Fig. 1 – Delivery and Initial Setup of Barrier Cells.

Fig. 2 – Barrier Cell Enclosure filled with AquaBlock 3070 SW.

Fig. 3 – Barrier Cell Water Test.

Fig. 1 – Stairs for Access to Fill Top of Standpipe.

Fig. 2 – Preliminary Draining of Water Test.

Fig. 3 – Pump Setup in Drum filled with DNAPL.

Fig. 7 – Top of Standpipe filled with DNAPL.

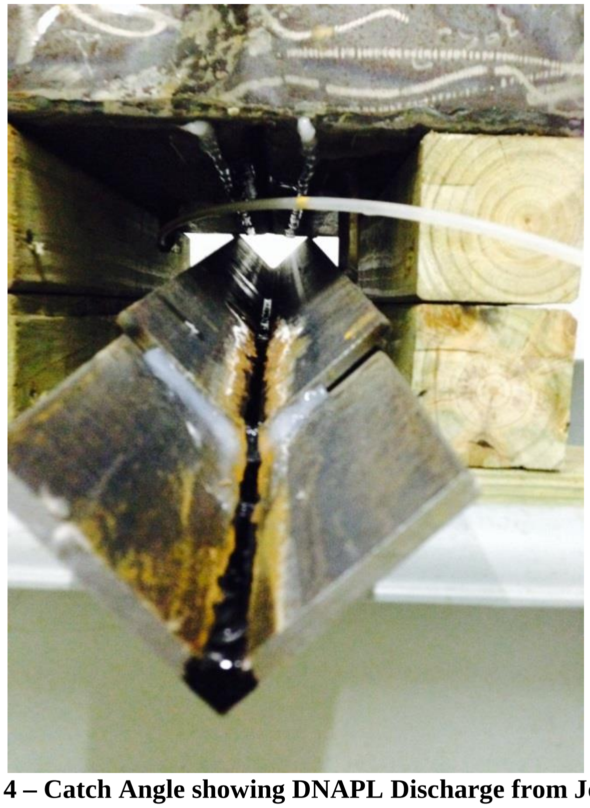


Fig. 4 – Catch Angle showing DNAPL Discharge from Joint.

Appendix C

Testing Protocols

Bench-Scale Barrier Cell Testing Protocols

1. After fabrication, place the Bench-Scale Barrier Cell on a stable and level platform to elevate the bench scale to at least 1 to 2 feet above the ground. Place the sheet pile interlock facing down and the standpipe sticking vertically up. A 5-foot by 4-foot plastic tub or similar containment method should be centered below the Barrier Cell. A 6 mil poly sheet should be placed beneath the catch bucket with adsorbent socks around the perimeter. Adsorbent pads should be available within the containment zone to adsorb any spilt liquid.
2. Place wooden blocks beneath the Barrier Cell and stabilize it as appropriate to prevent the cell from tipping.
3. Position the Permeant Collection Channel, a 3 X 3 X ¼" angle, beneath the sheet pile interlock. The channel should be tilted towards one end to direct the permeant into a catch bucket made out of poly methyl methacrylate (PMMA) (or other material compatible with DNAPL).
4. Position stairs next to the Barrier Cell to provide safe access to the top of the standpipe. Be sure the scaffold does not lean on the platform in a way that could knock the system over.
5. Fill the standpipe with tap water to the top of the standpipe. This level will be equivalent to about 10 feet of head on the sheet pile interlock. Inspect assembly for water tightness and spot weld or use plumbers' putty as appropriate. Pay special attention to the welds where the Top Plate meets the rest of the Barrier Cell components.
6. Read and record the drop in water level in the standpipe every 2 hours. When the water level in the standpipe is 6 inches below the top of the standpipe, refill the standpipe.
7. Record the volume of discharge through the sheet pile interlock, if applicable, and the time that the volume is recorded.
8. The water trial of the Bench Scale Barrier Cell will take 1 week.
9. At the completion of the first trial, drain water from the Barrier Cell as completely as possible.
10. Repeat steps 1, 2, 3, and 4, to set up and stabilize the Barrier Cell.
11. Fill the standpipe to the top with DNAPL collected from the project Site using a pump or manually using 5-gallon-buckets. Be cautious and use all recommended personal protective equipment (PPE) when handling this substance. Monitor the atmosphere in the workspace using a five gas meter and adhere to Work Zone Air Monitoring Action Levels given in GEI's Health and Safety Plan. Ventilate the space as appropriate.
12. Read and record the drop in DNAPL level in the standpipe twice daily. When the DNAPL level in the standpipe is 6 inches below the top of the standpipe, refill the standpipe.
13. Record the discharge through the sheet pile interlock by measuring the net mass of DNAPL in each catch bucket, at the same for each time interval.
14. This DNAPL trial of the Bench Scale Barrier Cell will take about 10 days.
15. Drain the Barrier Cell of DNAPL upon the completion of testing. The DNAPL should be disposed of in a drum labeled as Non-Hazardous Waste under appropriate regulatory procedures.

Appendix D

Laboratory Test Data Sheets

Project Name: Former Citizens MGP - Pilot Test Work Plan
Project ID: 93250
Test Cell ID: BT1
Cell Design: Unsealed Interlock

Start Date: 2/4/2014
End Date: 2/4/2014
Duration of Testing: 0 days

GEI Representative: L. Raup-Plummer
Construction Completed: 2/6/2014

Tank Volume:	49.6 gallons	6.63 ft^3
Pipe Volume:	3.30 gallons	0.44 ft^3
Total Volume:	52.9 gallons	7.07 ft^3
0.1' ΔH =	0.04 gallons	0.005 ft^3
Full Head =	10.475 ft	

Permeant Density @20°C

γ_w=	62.43 pcf
Coeff.	0.000214 1/°C
Temp	20 °C

Date and Time	Cumulative time (days)	Incremental Time (mins)	Water Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Permeant Density (pcf)	Head on Joint (ft)	Loss of Permeant Volume (gal)	Volume of Permeant Added (gal)	Permeant Volume (gal)	Cumulative Permeant Volume (gal)	Cumulative Loss of Permeant Volume (gal)	Comments and Remarks

* No water was retained by BT1

[1] Water level is measured from below top of casing (BTOC) to hundredths of a foot.

Project Name: Former Citizens MGP - Pilot Test Work Plan
Project ID: 93250
Test Cell ID: BT2
Cell Design: Swell Seal Interlock

Start Date: 2/7/2014
End Date: 2/18/2014
Duration of Testing: 11 days

GEI Representative: L. Raup-Plummer
Construction Completed: 2/6/2014

Tank Volume:	49.600 gallons	6.631 ft^3
Pipe Volume:	3.296 gallons	0.441 ft^3
Total Volume:	52.896 gallons	7.071 ft^3
0.1' ΔH =	0.037 gallons	0.005 ft^3
Full Head =	10.475 ft	

Permeant Density @20°C

γ_w=	62.43 pcf
Coeff.	0.000214 1/°C
Temp	20 °C

Date and Time	Cumulative Time (days)	Incremental Time (mins)	Water Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Permeant Density (pcf)	Head on Joint (ft)	Loss of Permeant Volume (gal)	Volume of Permeant Added (gal)	Permeant Volume (gal)	Cumulative Permeant Volume (gal)	Cumulative Loss of Permeant Volume (gal)	Cumulative Discharge (ml)	Piezometer Reading (psi)[2]	Comments and Remarks
2/7/14 12:25	0.00	0	7.03				3.445		50.314	50.314	50.314	0.000	-	1.0	Initial Fill Sequence
2/7/14 13:20	0.04	55	0.10				10.375		2.545	52.859	52.859	0.000	-	3.8	Initial Fill Sequence
2/10/14 9:20	2.87	4080	1.21				9.265	0.408		52.451	52.859	0.408	-	-	
2/10/14 9:20	2.87	0	0.10				10.375		0.408	52.859	53.266	0.408	-	-	Filled to 0.1' BTOC
2/10/14 13:35	3.05	255	0.17	18.7	16.6	62.48	10.305	0.026		52.833	53.266	0.433	-	-	
2/10/14 13:35	3.05	0	0.01	18.7	16.6	62.48	10.465		0.059	52.892	53.325	0.433	-	4.2	Filled to 0.01' BTOC
2/10/14 16:00	3.15	145	0.06	18.7	16.0	62.48	10.415	0.018		52.874	53.325	0.452	-	4.1	
2/11/14 8:54	3.85	1014	0.42	17.1	14.6	62.50	10.055	0.132		52.741	53.325	0.584	-	4.1	
2/11/14 8:54	3.85	0	0.09	17.1	14.6	62.50	10.385		0.121	52.863	53.446	0.584	-	4.2	Filled to 0.09' BTOC
2/11/14 11:17	3.95	143	0.14	17.1	15.2	62.49	10.335	0.018		52.844	53.446	0.602	-	4.1	
2/11/14 13:05	4.03	108	0.18	14.8	14.9	62.50	10.295	0.015		52.830	53.446	0.617	-	4.0	
2/11/14 13:05	4.03	0	0.09	14.8	14.9	62.50	10.385		0.033	52.863	53.479	0.617	100	4.2	Filled to 0.09' BTOC, catch bucket contained 100 mL
2/11/14 15:55	4.15	170	0.14	13.4	14.8	62.50	10.335	0.018		52.844	53.479	0.635	155	4.0	Catch bucket contained 55 mL
2/11/14 17:45	4.22	110	0.17	13.8	15.0	62.50	10.305	0.011		52.833	53.479	0.646	195	4.0	Catch bucket contained 40 mL
2/11/14 17:45	4.22	0	0.08	13.8	15.0	62.50	10.395		0.033	52.866	53.513	0.646	-	4.2	Filled to 0.08' BTOC
2/12/14 9:47	4.89	962	0.40	16.4	14.5	62.50	10.075	0.081		52.749	53.446	0.698	-	4.1	
2/12/14 9:47	4.89	0	0.08	16.4	14.5	62.50	10.395		0.118	52.866	53.564	0.698	-	4.2	Filled to 0.08' BTOC
2/12/14 11:15	4.95	88	0.10	13.7	14.7	62.50	10.375	0.007		52.859	53.564	0.705	635	4.2	Emptied Catch Bucket, 440 mL
2/12/14 13:40	5.05	145	0.15	15.4	15.3	62.49	10.325	0.018		52.841	53.564	0.723	-	4.4	
2/12/14 13:40	5.05	0	0.07	15.4	15.3	62.49	10.405		0.029	52.870	53.593	0.723	685	4.4	Filled to 0.07' BTOC, Catch bucket contained 50 mL
2/12/14 15:19	5.12	99	0.1	14.7	15.6	62.49	10.375	0.011		52.859	53.593	0.734	-	4.4	
2/14/14 9:47	6.89	2548	0.95	15.2	16.4	62.48	9.525	0.323		52.547	53.593	1.047	-	3.5	
2/14/14 9:47	6.89	0	0.05	15.2	16.4	62.48	10.425		0.330	52.877	53.924	1.047	1895	3.8	Filled to 0.05' BTOC, catch bucket emptied of 1210 mL
2/14/14 11:40	6.97	113	0.1	15.6	17.0	62.47	10.375	0.018		52.859	53.924	1.065	1960	3.7	Emptied Catch Bucket, 65 mL
2/14/14 13:45	7.06	125	0.14	16.4	17.6	62.46	10.335	0.015		52.844	53.924	1.080	2015	3.7	Emptied Catch Bucket, 55 mL
2/14/14 15:58	7.15	133	0.19	16.3	17.7	62.46	10.285	0.018		52.826	53.924	1.098	-	3.7	
2/14/14 15:58	7.15	0	0.08	16.3	17.7	62.46	10.395		0.040	52.866	53.964	1.098	2095	3.8	Filled to 0.08' BTOC, emptied catch bucket of 80 mL
2/17/14 8:53	9.85	3895	1.51	15.9	14.5	62.50	8.965	0.525		52.341	53.964	1.623	-	3.3	
2/17/14 8:53	9.85	0	0.07	15.9	14.5	62.50	10.405		0.529	52.870	54.493	1.623	3915	4.0	Filled to 0.07' BTOC, Emptied Catch Bucket 1820 mL
2/17/14 10:30	9.92	97	0.11	13.8	15.6	62.49	10.365	0.015		52.855	54.493	1.638	3970	3.9	Emptied Catch Bucket, 55 mL
2/17/14 14:26	10.08	236	0.18	12.9	16.6	62.48	10.295	0.026		52.830	54.493	1.663	4065	3.8	Emptied Catch Bucket, 95 mL
2/17/14 16:16	10.16	110	0.23	14.9	16.9	62.47	10.245	0.018		52.811	54.493	1.682	-	4.0	
2/17/14 16:16	10.16	0	0.06	14.9	16.9	62.47	10.415		0.062	52.874	54.555	1.682	4125	4.1	Filled to 0.06' BTOC, catch bucket emptied 60 mL
2/17/14 17:55	10.23	99	0.1	14.7	17.1	62.47	10.375	0.015		52.859	54.555	1.696	4175	4.0	Emptied Catch Bucket, 50 mL
2/18/14 10:04	10.90	969	0.43	14.9	16.6	62.48	10.045	0.121		52.738	54.555	1.818	-	3.7	
2/18/14 10:04	10.90	0	0.07	14.9	16.6	62.48	10.405		0.132	52.870	54.688	1.818	4625	4.0	Filled to 0.07' BTOC, catch bucket emptied 450 mL
2/18/14 11:32	10.96	88	0.1	14.5	16.5	62.48	10.375	0.011		52.859	54.688	1.829	4670	3.8	Emptied Catch Bucket, 45 mL

[1] Water level is measured from below top of casing (BTOC) to hundredths of a foot.
[2] Piezometer readings measured and recorded using Easy Sense Pressure Transducer set-up.

Project Name:	Former Citizens MGP - Pilot Test Work Plan	GEI Representative:	L. Raup-Plummer
Project ID:	93250	Construction Completed:	2/3/2014
Test Cell ID:	BT3		
Cell Design:	Grouted Angle		
Start Date:	2/4/2014		
End Date:	2/18/2014		
Duration of Testing:	14 days		

Tank Volume:	46.0 gallons	6.15 ft^3
Pipe Volume:	3.30 gallons	0.44 ft^3
Total Volume:	49.3 gallons	6.59 ft^3
0.1' ΔH =	0.04 gallons	0.005 ft^3
Full Head =	10.475 ft	

Permeant Density @20°C

γ_w=	62.43 pcf
Coeff.	0.000214 1/°C
Temp	20 °C

Date and Time	Cumulative time (days)	Incremental Time (mins)	Water Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Permeant Density (pcf)	Head on Joint (ft)	Loss of Permeant Volume (gal)	Volume of Permeant Added (gal)	Permeant Volume (gal)	Cumulative Permeant Volume (gal)	Cumulative Loss of Permeant Volume (gal)	Comments and Remarks
2/4/14 9:40	0.00	0	8.975				1.500		46.000	46.000	46.000	0.000	Initial Fill Sequence
2/4/14 10:56	0.05	76	0.10				10.375		3.259	49.259	49.259	0.000	Initial Fill Sequence
2/5/14 17:00	1.31	1804	0.42				10.058	0.116		49.143	49.259	0.116	
2/5/14 17:00	1.31	0	0.06				10.413		0.130	49.273	49.389	0.116	Filled to 0.06' BTOC
2/6/14 11:15	2.07	1095	0.17				10.308	0.038		49.234	49.389	0.155	
2/7/14 8:20	2.94	1265	0.28				10.195	0.042		49.193	49.389	0.196	
2/7/14 8:20	2.94	0	0.09				10.385		0.070	49.263	49.459	0.196	Filled to 0.09' BTOC
2/7/14 13:40	3.17	320	0.10				10.375	0.004		49.259	49.459	0.200	
2/10/14 8:50	5.97	4030	0.29				10.185	0.070		49.189	49.459	0.270	
2/10/14 8:50	5.97	0	0.10				10.375		0.070	49.259	49.528	0.270	Filled to 0.10' BTOC
2/10/14 13:45	6.17	295	0.11	18.7	14.6	62.50	10.365	0.004		49.255	49.528	0.273	
2/10/14 16:00	6.26	135	0.12	18.7	14.9	62.50	10.355	0.004		49.252	49.528	0.277	
2/11/14 9:12	6.98	1032	0.19	17.1	13.9	62.51	10.285	0.026		49.226	49.528	0.303	
2/11/14 9:12	6.98	0	0.08	17.1	13.9	62.51	10.395		0.040	49.266	49.569	0.303	Filled to 0.08' BTOC, collected less than 5 mL in bucket
2/11/14 11:06	7.06	114	0.09	17.1	13.6	62.52	10.385	0.004		49.263	49.569	0.306	
2/11/14 13:20	7.15	134	0.09	14.8	14.4	62.50	10.385	0.000		49.263	49.569	0.306	
2/11/14 15:44	7.25	144	0.09	13.4	14.4	62.50	10.385	0.000		49.263	49.569	0.306	
2/11/14 17:53	7.34	129	0.11	13.8	14.6	62.50	10.365	0.007		49.255	49.569	0.314	
2/12/14 9:24	7.99	931	0.15	16.4	13.9	62.51	10.325	0.015		49.241	49.569	0.328	
2/12/14 9:24	7.99	0	0.09	16.4	13.9	62.51	10.385		0.022	49.263	49.591	0.328	Filled to 0.09' BTOC
2/12/14 11:30	8.08	126	0.10	13.7	14.2	62.51	10.375	0.004		49.259	49.591	0.332	
2/12/14 13:20	8.15	110	0.10	15.4	14.8	62.50	10.375	0.000		49.259	49.591	0.332	
2/12/14 15:28	8.24	128	0.10	14.7	15.3	62.49	10.375	0.000		49.259	49.591	0.332	
2/14/14 9:34	10.00	2526	0.13	15.2	15.9	62.48	10.345	0.011		49.248	49.591	0.343	
2/14/14 9:34	10.00	0	0.09	15.2	15.9	62.48	10.385		0.015	49.263	49.606	0.343	Filled to 0.09' BTOC
2/14/14 11:18	10.07	104	0.09	15.6	16.3	62.48	10.385	0.000		49.263	49.606	0.343	
2/14/14 13:29	10.16	131	0.10	16.4	16.9	62.47	10.375	0.004		49.259	49.606	0.347	
2/14/14 15:46	10.25	137	0.10	16.3	17.5	62.46	10.375	0.000		49.259	49.606	0.347	
2/17/14 8:31	12.95	3885	0.23	15.9	14.4	62.50	10.245	0.048		49.211	49.606	0.394	
2/17/14 8:31	12.95	0	0.09	15.2	15.9	62.48	10.385		0.051	49.263	49.657	0.394	Filled to 0.09' BTOC
2/17/14 10:51	13.05	140	0.09	13.8	15.1	62.50	10.385	0.000		49.263	49.657	0.394	
2/17/14 14:08	13.19	197	0.10	12.9	15.9	62.48	10.375	0.004		49.259	49.657	0.398	
2/17/14 15:52	13.26	104	0.10	14.9	16.5	62.48	10.375	0.000		49.259	49.657	0.398	
2/17/14 18:02	13.35	130	0.10	14.7	16.8	62.47	10.375	0.000		49.259	49.657	0.398	
2/18/14 9:48	14.01	946	0.10	14.9	16.7	62.47	10.375	0.000		49.259	49.657	0.398	
2/18/14 11:43	14.09	115	0.11	14.5	16.1	62.48	10.365	0.004		49.255	49.657	0.402	

[1] Water level is measured from below top of casing (BTOC) to hundredths of a foot.

Project Name: Former Citizens MGP - Pilot Test Work Plan
Project ID: 93250
Test Cell ID: BT4
Cell Design: Grouted Angle with AquaBlok filled SKS chamber

Start Date: 2/4/2014
End Date: 2/18/2014
Duration of Testing: 14 days

GEI Representative: L. Raup-Plummer
Construction Completed: 02/03/0214

Tank Volume:	21.2 gallons	2.83 ft^3
Pipe Volume:	3.30 gallons	0.44 ft^3
Total Volume:	24.5 gallons	3.27 ft^3
0.1' ΔH =	0.04 gallons	0.005 ft^3
Full Head =	10.475 ft	

Permeant Density @20°C

γ_w=	62.43 pcf
Coeff.	0.000214 1/°C
Temp	20 °C

Date and Time	Cumulative time (days)	Incremental Time (mins)	Water Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Permeant Density (pcf)	Head on Joint (ft)	Loss of Permeant Volume (gal)	Volume of Permeant Added (gal)	Permeant Volume (gal)	Cumulative Permeant Volume (gal)	Cumulative Loss of Permeant Volume (gal)	Comments and Remarks
2/4/14 10:30	0.00	0	8.975				1.500		21.200	21.200	21.200	0.000	Initial Fill Sequence
2/4/14 11:06	0.03	36	0.10				10.375		3.259	24.459	24.459	0.000	Initial Fill Sequence
2/5/14 17:00	1.27	1794	0.80				9.675	0.257		24.202	24.459	0.257	
2/5/14 17:00	1.27	0	0.04				10.435		0.279	24.481	24.738	0.257	Filled to 0.04' BTOC
2/7/14 8:20	2.91	2360	0.38				10.095	0.125		24.356	24.738	0.382	
2/7/14 8:20	2.91	0	0.10				10.375		0.103	24.459	24.841	0.382	Filled to 0.10' BTOC
2/7/14 13:40	3.13	320	0.13				10.345	0.011		24.448	24.841	0.393	
2/10/14 8:55	5.93	4035	0.35				10.125	0.081		24.367	24.841	0.474	
2/10/14 8:55	5.93	0	0.08				10.395		0.099	24.466	24.940	0.474	Filled to 0.08' BTOC
2/10/14 13:50	6.14	295	0.10	18.7	15.1	62.50	10.375	0.007		24.459	24.940	0.481	
2/10/14 16:00	6.23	130	0.10	18.7	15.4	62.49	10.375	0.000		24.459	24.940	0.481	
2/11/14 9:15	6.95	1035	0.16	17.1	14.4	62.50	10.315	0.022		24.437	24.940	0.503	
2/11/14 9:15	6.95	0	0.09	17.1	14.4	62.50	10.385		0.026	24.463	24.966	0.503	Filled to 0.09' BTOC, no apparent leak
2/11/14 11:12	7.03	117	0.09	17.1	14.3	62.51	10.385	0.000		24.463	24.966	0.503	
2/11/14 13:24	7.12	132	0.10	14.8	14.6	62.50	10.375	0.004		24.459	24.966	0.507	
2/11/14 15:48	7.22	144	0.10	13.4	14.6	62.50	10.375	0.000		24.459	24.966	0.507	
2/11/14 17:56	7.31	128	0.11	13.8	14.8	62.50	10.365	0.004		24.455	24.966	0.510	
2/12/14 9:30	7.96	934	0.16	16.4	14.4	62.50	10.315	0.018		24.437	24.966	0.529	
2/12/14 9:30	7.96	0	0.08	16.4	14.4	62.50	10.395		0.029	24.466	24.995	0.529	Filled to 0.08' BTOC
2/12/14 11:34	8.04	124	0.08	13.7	14.5	62.50	10.395	0.000		24.466	24.995	0.529	
2/12/14 13:34	8.13	120	0.08	15.4	14.9	62.50	10.395	0.000		24.466	24.995	0.529	
2/12/14 15:35	8.21	121	0.08	14.7	15.7	62.49	10.395	0.000		24.466	24.995	0.529	
2/14/14 9:31	9.96	2516	0.08	15.2	16.3	62.48	10.395	0.000		24.466	24.995	0.529	
2/14/14 11:24	10.04	113	0.08	15.6	16.8	62.47	10.395	0.000		24.466	24.995	0.529	
2/14/14 13:33	10.13	129	0.09	16.4	17.2	62.47	10.385	0.004		24.463	24.995	0.532	
2/14/14 15:40	10.22	127	0.10	16.3	17.7	62.46	10.375	0.004		24.459	24.995	0.536	
2/17/14 8:36	12.92	3896	0.23	15.9	14.9	62.50	10.245	0.048		24.411	24.995	0.584	
2/17/14 8:36	12.92	0	0.09	15.9	14.9	62.50	10.385		0.051	24.463	25.046	0.584	Filled to 0.09' BTOC
2/17/14 10:51	13.01	135	0.09	13.8	15.4	62.49	10.385	0.000		24.463	25.046	0.584	
2/17/14 14:14	13.16	203	0.09	12.9	16.4	62.48	10.385	0.000		24.463	25.046	0.584	
2/17/14 15:58	13.23	104	0.10	14.9	16.7	62.47	10.375	0.004		24.459	25.046	0.588	
2/17/14 18:08	13.32	130	0.10	14.7	17.0	62.47	10.375	0.000		24.459	25.046	0.588	
2/18/14 9:52	13.97	944	0.10	14.9	16.7	62.47	10.375	0.000		24.459	25.046	0.588	
2/18/14 11:47	14.05	115	0.10	14.5	17.0	62.47	10.375	0.000		24.459	25.046	0.588	

[1] Water level is measured from below top of casing (BTOC) to hundredths of a foot.

Project Name:	Former Citizens MGP - Pilot Test Work Plan	GEI Representative:	L. Raup-Plummer
Project ID:	93250	Construction Completed:	2/4/2014
Test Cell ID:	BT5		
Cell Design:	Grouted Half Pipe		
Start Date:	2/4/2014		
End Date:	2/18/2014		
Duration of Testing:	14 days		

Tank Volume:	44.7 gallons	5.98 ft^3
Pipe Volume:	3.30 gallons	0.44 ft^3
Total Volume:	48.0 gallons	6.42 ft^3
0.1' ΔH =	0.04 gallons	0.005 ft^3
Full Head =	10.475 ft	

Permeant Density @20°C

γ_w=	62.43 pcf
Coeff.	0.000214 1/°C
Temp	20 °C

Date and Time	Cumulative time (days)	Incremental Time (mins)	Water Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Permeant Density (pcf)	Head on Joint (ft)	Loss of Permeant Volume (gal)	Volume of Permeant Added (gal)	Permeant Volume (gal)	Cumulative Permeant Volume (gal)	Cumulative Loss of Permeant Volume (gal)	Comments and Remarks
2/4/14 15:40	0.00	0	8.975				1.500		44.700	44.700	44.700	0.000	Initial Fill Sequence
2/4/14 15:52	0.01	12	0.10				10.375		3.259	47.959	47.959	0.000	Initial Fill Sequence
2/5/14 12:55	0.89	1263	1.00				9.475	0.330		47.628	47.959	0.330	Loss due to weep in standpipe weld
2/5/14 16:45	1.05	230	0.10				10.375		0.330	47.959	48.289	0.330	Filled to 0.10' BTOC
2/7/14 8:20	2.69	2375	0.53				9.945	0.158		47.801	48.289	0.488	
2/7/14 8:20	2.69	0	0.10				10.375		0.158	47.959	48.447	0.488	Filled to 0.10' BTOC
2/7/14 13:40	2.92	320	0.12				10.355	0.007		47.952	48.447	0.496	
2/10/14 9:05	5.73	4045	0.37				10.105	0.092		47.860	48.447	0.588	
2/10/14 9:05	5.73	0	0.10				10.375		0.099	47.959	48.546	0.588	Filled to 0.10' BTOC
2/10/14 13:40	5.92	275	0.11	18.7	15.1	62.50	10.365	0.004		47.955	48.546	0.591	
2/10/14 16:00	6.01	140	0.12	18.7	15.2	62.49	10.355	0.004		47.952	48.546	0.595	
2/11/14 9:04	6.72	1024	0.19	17.1	14.5	62.50	10.285	0.026		47.926	48.546	0.621	
2/11/14 9:04	6.72	0	0.07	17.1	14.5	62.50	10.405		0.044	47.970	48.590	0.621	Filled to 0.07' BTOC, ~5 mL collected in catch bucket
2/11/14 11:15	6.82	131	0.08	17.1	14.8	62.50	10.395	0.004		47.966	48.590	0.624	
2/11/14 13:12	6.90	117	0.09	14.8	15.0	62.50	10.385	0.004		47.963	48.590	0.628	
2/11/14 15:51	7.01	159	0.10	13.4	14.8	62.50	10.375	0.004		47.959	48.590	0.632	
2/11/14 17:53	7.09	122	0.11	13.8	14.8	62.50	10.365	0.004		47.955	48.590	0.635	
2/12/14 9:37	7.75	944	0.17	16.4	14.3	62.51	10.305	0.022		47.933	48.590	0.657	
2/12/14 9:37	7.75	0	0.07	16.4	14.3	62.51	10.405		0.037	47.970	48.627	0.657	Filled to 0.07' BTOC
2/12/14 11:24	7.82	107	0.08	13.7	14.5	62.50	10.395	0.004		47.966	48.627	0.661	
2/12/14 13:34	7.91	130	0.09	15.4	14.9	62.50	10.385	0.004		47.963	48.627	0.665	
2/12/14 15:24	7.99	110	0.09	14.7	15.5	62.49	10.385	0.000		47.963	48.627	0.665	
2/14/14 9:40	9.75	2536	0.14	15.2	16.3	62.48	10.335	0.018		47.944	48.627	0.683	
2/14/14 9:40	9.75	0	0.07	15.2	16.3	62.48	10.405		0.026	47.970	48.653	0.683	Filled to 0.07' BTOC
2/14/14 11:33	9.83	113	0.08	15.6	16.8	62.47	10.395	0.004		47.966	48.653	0.687	
2/14/14 13:38	9.92	125	0.08	16.4	17.3	62.47	10.395	0.000		47.966	48.653	0.687	
2/14/14 15:53	10.01	135	0.08	16.3	17.6	62.46	10.395	0.000		47.966	48.653	0.687	
2/17/14 8:43	12.71	3890	0.26	15.9	14.9	62.50	10.215	0.066		47.900	48.653	0.753	
2/17/14 8:43	12.71	0	0.05	15.9	14.9	62.50	10.425		0.077	47.977	48.730	0.753	Filled to 0.05' BTOC
2/17/14 10:46	12.80	123	0.06	13.8	15.4	62.49	10.415	0.004		47.974	48.730	0.756	
2/17/14 14:20	12.94	214	0.06	12.9	16.3	62.48	10.415	0.000		47.974	48.730	0.756	
2/17/14 16:10	13.02	110	0.06	14.9	16.7	62.47	10.415	0.000		47.974	48.730	0.756	
2/17/14 17:59	13.10	109	0.07	14.7	16.9	62.47	10.405	0.004		47.970	48.730	0.760	
2/18/14 9:58	13.76	959	0.10	14.9	16.7	62.47	10.375	0.011		47.959	48.730	0.771	
2/18/14 11:39	13.83	101	0.10	14.5	16.3	62.48	10.375	0.000		47.959	48.730	0.771	

[1] Water level is measured from below top of casing (BTOC) to hundredths of a foot.

Project Name: Former Citizens MGP - Pilot Test Work Plan
Project ID: 93250
Test Cell ID: BT6
Cell Design: Grouted Half Pipe with AquaBlok filled SKS chamber

Start Date: 2/4/2014
End Date: 2/18/2014
Duration of Testing: 14 days

GEI Representative: L. Raup-Plummer
Construction Completed: 2/4/2014

Tank Volume:	21.2 gallons	2.83 ft^3
Pipe Volume:	3.30 gallons	0.44 ft^3
Total Volume:	24.5 gallons	3.27 ft^3
0.1' ΔH =	0.04 gallons	0.005 ft^3
Full Head =	10.475 ft	

Permeant Density @20°C

γ_w=	62.43 pcf
Coeff.	0.000214 1/°C
Temp	20 °C

Date and Time	Cumulative time (days)	Incremental Time (mins)	Water Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Permeant Density (pcf)	Head on Joint (ft)	Loss of Permeant Volume (gal)	Volume of Permeant Added (gal)	Permeant Volume (gal)	Cumulative Permeant Volume (gal)	Cumulative Loss of Permeant Volume (gal)	Comments and Remarks
2/4/14 11:45	0.00	0	8.975				1.500		21.200	21.200	21.200	0.000	Initial Fill Sequence
2/4/14 12:10	0.02	25	0.10				10.375		3.259	24.459	24.459	0.000	Initial Fill Sequence
2/5/14 17:00	1.22	1730	1.30				9.175	0.441		24.018	24.459	0.441	BT-6 has weep in standpipe joint
2/5/14 17:00	1.22	0	0.10				10.375		0.441	24.459	24.900	0.441	Filled to 0.1' BTOC
2/6/14 11:15	1.98	1095	0.25				10.225	0.055		24.404	24.900	0.496	
2/7/14 8:20	2.86	1265	0.45				10.025	0.073		24.330	24.900	0.569	
2/7/14 8:20	2.86	0	0.10				10.375		0.129	24.459	25.028	0.569	Filled to 0.1' BTOC
2/7/14 13:40	3.08	320	0.12				10.355	0.007		24.452	25.028	0.577	
2/10/14 9:00	5.89	4040	0.41				10.065	0.106		24.345	25.028	0.683	
2/10/14 9:00	5.89	0	0.09				10.385		0.118	24.463	25.146	0.683	Filled to 0.09' BTOC
2/10/14 13:55	6.09	295	0.11	18.7	15.4	62.49	10.365	0.007		24.455	25.146	0.690	
2/10/14 16:00	6.18	125	0.12	18.7	15.5	62.49	10.355	0.004		24.452	25.146	0.694	
2/11/14 9:18	6.90	1038	0.19	17.1	14.9	62.50	10.285	0.026		24.426	25.146	0.720	
2/11/14 9:18	6.90	0	0.08	17.1	14.9	62.50	10.395		0.040	24.466	25.186	0.720	Filled to 0.08' BTOC, ~5 mL from standpipe
2/11/14 11:00	6.97	102	0.08	17.1	14.4	62.50	10.395	0.000		24.466	25.186	0.720	
2/11/14 13:34	7.08	154	0.09	14.8	14.6	62.50	10.385	0.004		24.463	25.186	0.723	
2/11/14 15:40	7.16	126	0.10	13.4	14.7	62.50	10.375	0.004		24.459	25.186	0.727	
2/11/14 18:00	7.26	140	0.11	13.8	15.0	62.50	10.365	0.004		24.455	25.186	0.731	
2/12/14 9:17	7.90	917	0.18	16.4	15.1	62.50	10.295	0.026		24.430	25.186	0.756	
2/12/14 9:17	7.90	0	0.09	16.4	15.1	62.50	10.385		0.033	24.463	25.219	0.756	Filled to 0.09' BTOC
2/12/14 11:40	8.00	143	0.10	13.7	15.0	62.50	10.375	0.004		24.459	25.219	0.760	
2/12/14 13:30	8.07	110	0.10	15.4	15.2	62.49	10.375	0.000		24.459	25.219	0.760	
2/12/14 15:47	8.17	137	0.10	14.7	16.0	62.48	10.375	0.000		24.459	25.219	0.760	
2/14/14 9:25	9.90	2498	0.17	15.2	16.6	62.48	10.305	0.026		24.433	25.219	0.786	
2/14/14 9:25	9.90	0	0.08	15.2	16.6	62.48	10.395		0.033	24.466	25.252	0.786	Filled to 0.08' BTOC
2/14/14 10:15	9.94	50	8.14	15.2	16.6	62.48	2.335	2.960		21.507	25.252	3.745	Drained to fix joint leak
2/14/14 16:05	10.18	350	8.14	16.3	--	--	2.335	0.000		21.507	25.252	3.745	Checking water level
2/17/14 8:25	12.86	3860	7.90	15.9	--	--	2.575			21.507	25.252	3.745	
2/17/14 11:04	12.97	159	7.90	13.8	--	--	2.575			21.507	25.252	3.745	
2/17/14 11:55	13.01	51	0.06	13.8	--	--	10.415		2.879	24.385	28.131	3.745	Filled to 0.06' using drained water
2/17/14 12:00	13.01	5	0.09	13.8	15.6	62.49	10.385	0.011		24.374	28.131	3.756	
2/17/14 12:10	13.02	10	0.12	13.8	15.6	62.49	10.355	0.011		24.363	28.131	3.767	
2/17/14 14:02	13.10	112	0.20	12.9	15.3	62.49	10.275	0.029		24.334	28.131	3.797	
2/17/14 14:02	13.10	0	0.08	12.9	15.3	62.49	10.395		0.044	24.378	28.175	3.797	Filled to 0.08' BTOC
2/17/14 16:04	13.18	122	0.12	14.9	16.5	62.48	10.355	0.015		24.363	28.175	3.812	
2/17/14 18:14	13.27	130	0.15	14.7	16.9	62.47	10.325	0.011		24.352	28.175	3.823	
2/17/14 18:14	13.27	0	0.07	14.7	16.9	62.47	10.405		0.029	24.382	28.204	3.823	Filled to 0.07' BTOC
2/18/14 9:40	13.91	926	0.15	14.9	16.7	62.47	10.325	0.029		24.352	28.204	3.852	
2/18/14 9:40	13.91	0	0.06	14.9	16.7	62.47	10.415		0.033	24.385	28.237	3.852	Filled to 0.06' BTOC
2/18/14 11:52	14.00	132	0.06	14.5	17.0	62.47	10.415	0.000		24.385	28.237	3.852	

[1] Water level is measured from below top of casing (BTOC) to hundredths of a foot.

Project Name: Former Citizens MGP - Pilot Test Work Plan
Project ID: 93250
Test Cell ID: BT1
Cell Design: Unsealed Interlock

Start Date: 3/3/2014
End Date: 3/3/2014
Duration of Testing: 0 days

GEI Representative: M.Potros
Construction Completed: 2/6/2014

Tank Volume:	49.6	gallons	6.63	ft^3
Pipe Volume:	3.30	gallons	0.44	ft^3
Total Volume:	52.9	gallons	7.07	ft^3
0.1' ΔH =	0.04	gallons	0.005	ft^3
Full Head =	10.475	ft		

Date	Cumulative time (hours)	NAPL Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Head on Joint (ft)	Change in Permeant Volume (gal)	Volume of Permeant Added (gal)	Cumulative Permeant Volume (gal)	Cumulative Discharge (g)	Comments and Remarks
3/3/14 14:19		0	16.6	16.6	0	0	1.3	1.3		
3/3/14 14:19	0.000347222	0	16.6	16.6	0	1.3	0	0	4896.43	

*Note test was conducted at 14:19. Began pouring 1.3 Gallons of NAPL into top of Standpipe. Noticeable leaking of NAPL onto the catch angle was immediately noted.
NAPL was observed breaching through the full length or the interlock joint as well as squirting outwardly beyond the side of the Catch Angle.
Approximately 1.3 gallons of NAPL was poured into the top of the standpipe. NAPL was continuously slow streaming out of the interlock joint and down the catch angle for 30 seconds, then began dripping until 14:27. 100 ml of NAPL used for this test was filled in a graduated cylinder and weighted prior to testing to collect density.
100ml weighed 99.5 grams. Density of NAPL = 62.14pcf at 16.5C

[1] NAPL level is measured from below top of casing (BTOC) to hundredths of a foot.

Project Name:	Former Citizens MGP - Pilot Test Work Plan	GEI Representative:	M.Potros		
Project ID:	93250	Construction Completed:	2/6/2014		
Test Cell ID:	BT2				
Cell Design:	Swell Seal Interlock	Tank Volume:	49.600 gallons	6.631	ft^3
		Pipe Volume:	3.296 gallons	0.441	ft^3
Start Date:	2/28/2014	Total Volume:	52.896 gallons	7.071	ft^3
End Date:	3/10/2014	0.1' ΔH =	0.037 gallons	0.005	ft^3
Duration of Testing:	10 days	Full Head =	10.475 ft		

Permeant Density @15.6°C

γ_{NAPL}=	66.6	pcf
Coeff.	0.000214	1/°C
Temp	15.6	°C

Date and Time	Cumulative Time (days)	Incremental Time (mins)	NAPL Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Permeant Density	Head on Joint (ft)	Loss of Permeant Volume (gal)	Volume Flux (gal/min)	Volume of Permeant Added (gal)	Permeant Volume (gal)	Cumulative Permeant Volume (gal)	Cumulative Loss of Permeant Volume (gal)	Piezometer Reading (psi)[2]	Cumulative Discharge (g)	Comments and Remarks
2/28/14 8:30	0.00	0	7.03			66.8	3.445			50.314	50.314	50.314	0.000	1.0	0.0	Initial Fill Sequence
2/28/14 18:35	0.42	605	0.01	16.0	14.1	66.6	10.465			2.578	52.892	52.892	0.000	3.8	0.0	Initial Reading
3/3/14 8:35	3.00	3720	0.35	15.5	14.7	66.6	10.125	0.125	3.356E-05		52.767	52.892	0.125	5.1	3.4	Catch Bucket contained 3.4g total at 10:05am
3/4/14 9:15	4.03	1480	0.53	13.9	12.2	66.6	9.945	0.066	4.466E-05		52.701	52.892	0.191	5.0	4.6	Catch Bucket contained 4.6g total since start
3/4/14 9:17	4.03	2	0.09	13.9	12.2	66.6	10.385			0.162	52.863	53.054	0.191			Filled to 0.09' BTOC
3/4/14 12:16	4.16	179	0.10	16.2	13.9	66.6	10.375	0.004	2.051E-05		52.859	53.054	0.195	5.3	4.7	Catch Bucket contained 4.7g total since start
3/4/14 15:21	4.29	185	0.10	18.0	16.1	66.59	10.375	0.000	0.000E+00		52.859	53.054	0.195	5.3	4.9	No change in head. Catch Bucket contained 4.9g total since start
3/5/14 8:57	5.02	1056	0.11	16.1	15.7	66.60	10.365	0.004	3.477E-06		52.855	53.054	0.198	5.28	6.6	Catch Bucket contained 6.6 g total since start
3/5/14 11:11	5.11	134	0.11	16.1	15.7	66.60	10.365	0.000	0.000E+00		52.855	53.054	0.198	5.3		
3/5/14 16:06	5.32	295	0.11	16.0	15.9	66.60	10.365	0.000	0.000E+00		52.855	53.054	0.198	5.3	7	Catch bucket contained 7.0g total since start
3/6/14 9:01	6.02	1015	0.13	14.6	14.3	66.62	10.345	0.007	7.235E-06		52.848	53.054	0.206	5.1	8.6	Catch bucket contained 8.6g total since start
3/6/14 16:13	6.32	432	0.13	17.3	16.1	66.59	10.345	0.000	0.000E+00		52.848	53.054	0.206	5.1	9.4	Catch bucket contained 9.4g total since start
3/7/14 9:01	7.02	1008	0.13	16.0	14.6	66.61	10.345	0.000	0.000E+00		52.848	53.054	0.206	5.1		
3/10/14 8:20	9.99	4279	0.04	17.4	16.5	66.59	10.435	-0.033	-7.723E-06		52.881	53.054	0.173	5.1	36.8	Catch bucket contained 36.8g total since start
3/10/14 9:20	Test Cell Drained															

[1] NAPL level is measured from below top of casing (BTOC) to hundredths of a foot.
[2] Piezometer readings measured and recorded using Easy Sense Pressure Transducer set-up.

Project Name: Former Citizens MGP - Pilot Test Work Plan
Project ID: 93250
Test Cell ID: BT3
Cell Design: Grouted Angle

Start Date: 2/28/2014
End Date: 3/31/2014
Duration of Testing: 31 days

GEI Representative: M.Potros
Construction Completed: 2/3/2014

Tank Volume:	46.0	gallons	6.15	ft^3
Pipe Volume:	3.30	gallons	0.44	ft^3
Total Volume:	49.3	gallons	6.59	ft^3
0.1' ΔH =	0.04	gallons	0.005	ft^3
Full Head =	10.475	ft		

Permeant Density @15.6°C

γ_{NAPL}=	66.6	pcf
Coeff.	0.000214	1/°C
Temp	15.6	°C

Date and Time	Cumulative time (days)	Incremental Time (mins)	NAPL Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Permeant Density	Head on Joint (ft)	Loss of Permeant Volume (gal)	Volume Flux (gal/min)	Volume of Permeant Added (gal)	Permeant Volume (gal)	Cumulative Permeant Volume (gal)	Cumulative Loss of Permeant Volume (gal)	Cumulative Discharge (g)	Comments and Remarks
2/28/14 1:00	0.00	0	8.975			66.8	1.500			46.000	46.000	46.000	0.000	0.0	Initial Fill Sequence
2/28/14 16:27	0.64	927	0.01	16	14.2	66.6	10.465			3.292	49.292	49.292	0.000	0.0	Completed Fill Sequence
3/3/14 8:40	3.32	3853	0.63	16.7	14.7	66.6	9.845	0.228	5.909E-05		49.064	49.292	0.228	0.0	
3/3/14 8:42	3.32	2	0.38	16.7	14.7	66.6	10.095			0.092	49.156	49.384	0.228	0.0	Filled to 0.38' BTOC
3/4/14 9:00	4.33	1458	0.48	13.5	11.5	66.7	9.995	0.037	2.519E-05		49.119	49.384	0.264	0.0	
3/4/14 9:05	4.34	5	0.11	13.5	11.5	66.7	10.365			0.136	49.255	49.520	0.264	0.0	Filled to 0.11' BTOC
3/4/14 12:18	4.47	193	0.12	15.3	12.6	66.6	10.355	0.004	1.903E-05		49.252	49.520	0.268	0.0	Filled to 0.09' BTOC
3/4/14 15:10	4.59	172	0.12	16.3	15.8	66.6	10.355	0.000	0.000E+00		49.252	49.520	0.268	0.0	No change in head
3/5/14 9:16	5.34	1086	0.12	16.1	14.6	66.6	10.355	0.000	0.000E+00		49.252	49.520	0.268	0.0	
3/5/14 11:01	5.42	105	0.12	16.3	14.7	66.6	10.355	0.000	0.000E+00		49.252	49.520	0.268	0.0	
3/5/14 16:18	5.64	317	0.12	16.0	15.7	66.60	10.355	0.000	0.000E+00		49.252	49.520	0.268	0.0	
3/6/14 9:11	6.34	1013	0.13	14.6	12.3	66.65	10.345	0.004	3.625E-06		49.248	49.520	0.272	0.0	No Leakage
3/6/14 16:10	6.63	419	0.12	16.5	15.4	66.60	10.355	-0.004	-8.764E-06		49.252	49.520	0.268	0.0	No Leakage
3/7/14 9:11	7.34	1021	0.12	15.2	13.5	66.63	10.355	0.000	0.000E+00		49.252	49.520	0.268	0.0	No Leakage
3/10/14 8:24	10.31	4273	0.01	17.4	15.8	66.60	10.465	-0.040	-9.453E-06		49.292	49.520	0.228	3.2	Slight runoff, measured 3.2g total
3/10/14 12:50	Test Cell Drained and Dismantled														
3/10/14 13:40	Test Cell Reset and filled														
3/10/14 13:40	0.00	0	0.10	18	15.5	66.60	10.380	0.035		49.2607286	49.226	49.261	0.035	0.0	Initial Fill Sequence
3/10/14 16:00	0.10	140	0.17	20.9	15.9	66.60	10.305	0.028	1.967E-04		49.198	49.261	0.062	0.0	Drop in Head due to initial settling, No Leakage
3/11/14 15:45	1.09	1425	0.31	17.5	16.3	66.59	10.165	0.051	3.608E-05		49.147	49.261	0.114	0.0	No Leakage
3/12/14 8:45	1.80	1020	0.32	20.3	18.5	66.56	10.155	0.004	3.600E-06		49.143	49.261	0.118	0.6	
3/12/14 15:45	2.09	420	0.32	21	18.7	66.56	10.155	0.000	0.000E+00		49.143	49.261	0.118	1.2	
3/13/14 8:40	2.79	1015	0.37	15.3	14.8	66.61	10.105	0.018	1.809E-05		49.125	49.261	0.136	2.0	
3/13/14 15:45	3.09	425	0.43	17.3	15	66.61	10.045	0.022	5.184E-05		49.103	49.261	0.158	3.0	
3/14/14 8:30	3.78	1005	0.54	13.9	12.1	66.65	9.940	0.039	3.836E-05		49.064	49.261	0.196	6.3	
3/14/14 14:30	4.03	360	0.54	16.2	13.1	66.64	9.935	0.002	5.100E-06		49.062	49.261	0.198	6.9	
3/17/14 8:30	6.78	3960	0.56	15.3	13.9	66.62	9.915	0.007	1.855E-06		49.055	49.261	0.206	21.7	
3/17/14 8:30	6.78	0	0.09	15.3	13.9	66.62	10.385			0.173	49.228	49.433	0.206		Standpipe topped off to 0.09ft BTOC
3/17/14 13:30	6.99	300	0.11	17.8	14.8	66.61	10.365	0.007	2.448E-05		49.220	49.433	0.213	22.2	
3/17/14 16:00	7.10	150	0.11	18.1	16.3	66.59	10.365	0.000	0.000E+00		49.220	49.433	0.213	23.0	
3/18/14 8:30	7.78	990	0.15	15	13.5	66.63	10.325	0.015	1.484E-05		49.206	49.433	0.228	28.1	
3/18/14 13:00	7.97	270	0.15	18.8	16	66.59	10.325	0.000	0.000E+00		49.206	49.433	0.228	29.8	
3/18/14 16:15	8.11	195	0.15	18.9	17.7	66.57	10.325	0.000	0.000E+00		49.206	49.433	0.228	31.0	
3/19/14 8:30	8.78	975	0.16	16.2	15.2	66.61	10.315	0.004	3.766E-06		49.202	49.433	0.231	37.1	
3/19/14 16:00	9.10	450	0.16	17.6	16	66.59	10.315	0.000	0.000E+00		49.202	49.433	0.231	40.2	
3/20/14 8:30	9.78	990	0.16	17.5	16.8	66.58	10.315	0.000	0.000E+00		49.202	49.433	0.231	46.8	
3/20/14 16:10	10.10	460.00	0.14	21.4	19.9	66.54	10.335	-0.007	-1.597E-05		49.209	49.433	0.224	50.0	
3/21/14 8:30	10.78	980.00	0.14	17.3	16.5	66.59	10.335	0.000	0.000E+00		49.209	49.433	0.224	56.0	
3/21/14 16:30	11.12	480.00	0.14	21.8	20.2	66.53	10.340	-0.002	-3.825E-06		49.211	49.433	0.222	58.2	
3/24/2014 08:30	13.78	3840.00	0.22	15.1	13.8	66.63	10.255	0.031	8.128E-06		49.180	49.433	0.253	98.0	
3/24/2014 16:35	14.12	485.00	0.24	20.8	17.7	66.57	10.235	0.007	1.514E-05		49.173	49.433	0.261	105.1	
3/25/2014 07:10	14.73	875.00	0.26	16.1	11.7	66.66	10.215	0.007	8.393E-06		49.165	49.433	0.268	118.4	
3/25/2014 17:20	15.15	610.00	0.29	19.4	13.1	66.64	10.185	0.011	1.806E-05		49.154	49.433	0.279	126.9	
3/26/2014 18:25	16.20	1505.00	0.28	17.6	13.4	66.63	10.195	-0.004	-2.440E-06		49.158	49.433	0.275	152.3	
3/28/2014 16:30	18.12	2765.00	0.35	16.5	12.6	66.64	10.125	0.026	9.296E-06		49.132	49.433	0.301	196.3	
3/31/2014 10:45	20.88	3975.00	0.38	18.2	14.3	66.62	10.095	0.011	2.771E-06		49.121	49.433	0.312	299.6	

[1] NAPL level is measured from below top of casing (BTOC) to hundredths of a foot.

Project Name:	Former Citizens MGP - Pilot Test Work Plan	GEI Representative:	M.Potros		
Project ID:	93250	Construction Completed:	02/03/0214		
Test Cell ID:	BT4				
Cell Design:	Grouted Angle with AquaBlok filled SKS chamber	Tank Volume:	21.2 gallons	2.83	ft^3
		Pipe Volume:	3.30 gallons	0.44	ft^3
Start Date:	2/25/2014	Total Volume:	24.5 gallons	3.27	ft^3
End Date:	3/7/2014	0.1' ΔH =	0.04 gallons	0.005	ft^3
Duration of Testing:	10 days	Full Head =	10.475 ft		

Permeant Density @15.6°C

γ_{NAPL}= 66.6 pcf

Coeff. 0.000214 1/°C

Temp 15.6 °C

Date and Time	Cumulative time (days)	Incremental Time (mins)	NAPL Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Permeant Density (pcf)	Head on Joint (ft)	Loss of Permeant Volume (gal)	Volume Flux (gal/min)	Volume of Permeant Added (gal)	Permeant Volume (gal)	Cumulative Permeant Volume (gal)	Cumulative Loss of Permeant Volume (gal)	Cumulative Discharge (g)	Comments and Remarks
2/25/14 15:00	0.00	0	0.16	15.6	16.8	66.58	10.315		-	24.437	24.437	24.437	0.000	0.000	Initial Fill Sequence
2/26/14 8:40	0.74	1060	0.42	13.4	15.2	66.61	10.055	0.095	9.007E-05		24.341	24.437	0.095	0.000	filled BT-4 to 4" BTOC
2/27/14 8:40	1.74	1440	0.50	13.5	13.8	66.63	9.975	0.029	2.040E-05		24.312	24.437	0.125	0.000	Noticeable seepage of DNAPL on catch angle
2/27/14 15:00	2.00	380	0.517	16	14.7	66.61	9.958	0.006	1.643E-05		24.306	24.437	0.131	9.300	9.3g of DNAPL recorded leaked off catch angle
2/28/14 8:55	2.75	1075	0.69	12	13.2	66.63	9.785	0.064	5.909E-05		24.242	24.437	0.195	22.000	22.0 g of DNAPL collected in bucket since last measurement
2/28/14 16:40	3.07	465	0.31	18.2	14.2	66.62	10.165			0.140	24.382	24.576	0.195		Filled to 0.31' BTOC
3/3/14 8:55	5.75	3855	0.90	16.7	14.7	66.61	9.575	0.217	5.620E-05		24.165	24.576	0.411		
3/3/14 8:58	5.75	3	0.42	16.7	14.7	66.61	10.055			0.176	24.341	24.753	0.411		Filled to 0.42' BTOC
3/4/14 8:55	6.75	1437	0.58	13.8	11.2	66.66	9.900	0.057	3.961E-05		24.284	24.753	0.468	182.700	Catch Bucket contained 182.7 total since start
3/4/14 8:57	6.75	2	0.10	13.8	11.2	66.66	10.375			0.174	24.459	24.927	0.468		Filled to 0.10' BTOC
3/4/14 12:25	6.89	208	0.105	15.2	13.3	66.63	10.370	0.002	8.827E-06		24.457	24.927	0.470	189.100	Catch Bucket contained 189.1 total since start
3/4/14 15:13	7.01	168	0.105	17.9	16	66.59	10.370	0.000	0.000E+00		24.457	24.927	0.470		No change in head, Catch bucket contained 201.5 total since start
3/5/14 9:13	7.76	1080	0.11	16.6	15.2	66.61	10.365	0.002	1.700E-06		24.455	24.927	0.472	244.100	Catch bucket contained 244.1g total since start
3/5/14 11:04	7.84	111	0.11	17.1	15.9	66.60	10.365	0.000	0.000E+00		24.455	24.927	0.472		
3/5/14 16:14	8.05	310	0.115	17.2	16	66.59	10.360	0.002	5.923E-06		24.453	24.927	0.474	260.800	Catch bucket contained 260.8g total since start
3/6/14 9:09	8.76	1015	0.21	14.8	12.8	66.64	10.265	0.035	3.437E-05		24.419	24.927	0.509	303.200	Catch bucket contained 303.2g total since start
3/6/14 16:07	9.05	418	0.21	17.5	15.8	66.60	10.265	0.000	0.000E+00		24.419	24.927	0.509	322.600	Catch bucket contained 322.6g total since start
3/7/14 9:08	9.76	1021	0.25	15.7	13.9	66.62	10.225	0.015	1.439E-05		24.404	24.927	0.523	378.500	Catch bucket contained 378.5g total since start
3/7/14 13:15	Test Cell Drained														

[1] NAPL level is measured from below top of casing (BTOC) to hundredths of a foot.

Project Name: Former Citizens MGP - Pilot Test Work Plan
Project ID: 93250
Test Cell ID: BT5
Cell Design: Grouted Half Pipe

Start Date: 2/28/2014
End Date: 3/10/2014
Duration of Testing: 10 days

GEI Representative: M.Potros
Construction Completed: 2/4/2014

Tank Volume:	44.7	gallons	5.98	ft^3
Pipe Volume:	3.30	gallons	0.44	ft^3
Total Volume:	48.0	gallons	6.42	ft^3
0.1' ΔH =	0.04	gallons	0.005	ft^3
Full Head =	10.475	ft		

Permeant Density @15.6°C

γ_{NAPL}=	66.6	pcf
Coeff.	0.000214	1/°C
Temp	15.6	°C

Date and Time	Cumulative time (days)	Incremental Time (mins)	NAPL Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Permeant Density	Head on Joint (ft)	Loss of Permeant Volume (gal)	Volume Flux (gal/min)	Volume of Permeant Added (gal)	Permeant Volume (gal)	Cumulative Permeant Volume (gal)	Cumulative Loss of Permeant Volume (gal)	Cumulative Discharge (g)	Comments and Remarks
2/28/14 15:40	0.00	0	8.975	13.5	14.5	66.6	1.500			44.700	44.700	44.700	0.000	0.000	Initial Fill Sequence
3/3/14 9:15	2.73	3935	0.42	16.7	14.7	66.6	10.055			3.141	47.841	47.841	0.000		Initial Reading after complete fill
3/4/14 8:40	3.71	1405	0.51	13.5	11.8	66.7	9.965	0.033	2.352E-05		47.808	47.841	0.033		
3/4/14 8:43	3.71	3	0.09	13.5	11.8	66.7	10.385			0.154	47.963	47.996	0.033		Filled to 0.09' BTOC
3/4/14 12:18	3.86	215	0.10	15.2	12.9	66.6	10.375	0.004	1.708E-05		47.959	47.996	0.037		
3/4/14 15:28	3.99	190	0.10	17.9	15.6	66.6	10.375	0.000	0.000E+00		47.959	47.996	0.037		No change in head
3/5/14 9:03	4.72	1055	0.10	17	16.8	66.6	10.375	0.000	0.000E+00		47.959	47.996	0.037		
3/5/14 11:14	4.82	131	0.10	17.1	16.8	66.6	10.375	0.000	0.000E+00		47.959	47.996	0.037		
3/5/14 16:09	5.02	295	0.10	16.9	16.8	66.58	10.375	0.000	0.000E+00		47.959	47.996	0.037		
3/6/14 9:04	5.72	1015	0.14	14.6	14.3	66.62	10.340	0.013	1.266E-05		47.946	47.996	0.050	0.000	No Leakage
3/6/14 16:16	6.02	432	0.13	16.6	15.4	66.60	10.345	-0.002	-4.250E-06		47.948	47.996	0.048	0.770	Slight runoff onto catch angle, measured 0.77g
3/7/14 9:03	6.72	1007	0.14	16	14.6	66.61	10.335	0.004	3.646E-06		47.944	47.996	0.051		
3/10/14 8:22	9.70	4279	0.09	17.5	16.6	66.59	10.385	-0.018	-4.291E-06		47.963	47.996	0.033	7.670	Total runoff since start measured: 7.67g
3/10/14 12:00	Test Cell Drained														

[1] NAPL level is measured from below top of casing (BTOC) to hundredths of a foot.

Project Name: Former Citizens MGP - Pilot Test Work Plan
Project ID: 93250
Test Cell ID: BT6
Cell Design: Grouted Half Pipe with AquaBlok filled SKS chamber

Start Date: 2/24/2014
End Date: 3/7/2014
Duration of Testing: 11 days

GEI Representative: M.Potros
Construction Completed: 2/4/2014

Tank Volume:	21.2	gallons	2.83	ft^3
Pipe Volume:	3.30	gallons	0.44	ft^3
Total Volume:	24.5	gallons	3.27	ft^3
0.1' ΔH =	0.04	gallons	0.005	ft^3
Full Head =	10.475	ft		

Permeant Density @15.6°C

γ_{NAPL}=	66.6	pcf
Coeff.	0.000214	1/°C
Temp	15.6	°C

Date and Time	Cumulative time (days)	Incremental Time (mins)	NAPL Level (ft BTOC)[1]	Room Temperature °C	Permeant Temperature °C	Permeant Density	Head on Joint (ft)	Loss of Permeant Volume (gal)	Volume Flux (gal/min)	Volume of Permeant Added (gal)	Permeant Volume (gal)	Cumulative Permeant Volume (gal)	Cumulative Loss of Permeant Volume (gal)	Cumulative Discharge (g)	Comments and Remarks
2/24/14 15:04	0.00	0	0.04	15.6	16.8	66.6	10.435			24.481	24.481	24.481	0.000	0.000	Initial Fill Sequence
2/25/14 10:00	0.79	1136	0.33	15.6	16.8	66.6	10.145	0.106	9.374E-05		24.374	24.481	0.106		Initial Fill Sequence
2/25/14 11:00	0.83	60	0.07	15.6	16.8	66.6	10.405			0.095	24.470	24.576	0.106		BT-6 was refilled to ~0.04 ft BTOC
2/26/14 8:40	1.73	1300	0.26	15.6	16.8	66.6	10.215	0.070	5.367E-05		24.400	24.576	0.176		Filled to 0.1' BTOC
2/27/14 9:15	2.76	1475	0.25	13.5	14.5	66.6	10.225			0.004	24.404	24.580	0.176		
3/3/14 9:30	6.77	5775	0.69	16.7	14.7	66.6	9.785	0.162	2.798E-05		24.242	24.580	0.338		
3/3/14 9:33	6.77	3	0.47	16.7	14.7	66.6	10.005			0.081	24.323	24.661	0.338		Filled height to 0.47' BTOC
3/4/14 8:30	7.73	1377	0.60	16.1	13.2	66.63	9.875	0.048	3.467E-05		24.275	24.661	0.386		
3/4/14 8:33	7.73	3	0.13	16.1	13.2	66.63	10.345			0.173	24.448	24.833	0.386		Filled height to 0.13' BTOC
3/4/14 12:30	7.89	237	0.145	16	13	66.64	10.330	0.006	2.324E-05		24.442	24.833	0.391		
3/4/14 15:16	8.01	166	0.145	18	16.5	66.59	10.330	0.000	0.000E+00		24.442	24.833	0.391		No change in head
3/5/14 9:08	8.75	1072	0.15	17	15.9	66.60	10.325	0.002	1.713E-06		24.441	24.833	0.393		
3/5/14 11:07	8.84	119	0.15	17.3	16.1	66.59	10.325	0.000	0.000E+00		24.441	24.833	0.393		
3/5/14 16:12	9.05	305	0.15	17.2	16.3	66.59	10.325	0.000	0.000E+00		24.441	24.833	0.393		
3/6/14 9:07	9.75	1015	0.21	15	13.7	66.63	10.265	0.022	2.171E-05		24.419	24.833	0.415		No leakage
3/6/14 16:05	10.04	418	0.22	17.2	16.5	66.59	10.255	0.004	8.785E-06		24.415	24.833	0.419		No leakage
3/7/14 9:05	10.75	1020	0.24	16	14.6	66.61	10.235	0.007	7.200E-06		24.407	24.833	0.426	0.000	No leakage, Will drain
3/7/14 11:35	Test Cell drained														

[1] Water level is measured from below top of casing (BTOC) to hundredths of a foot.

Appendix E

Inverse Joint Resistance Calculations

Citizens Former MGP - Bench Scale Test
BT2 - Inverse Joint Resistance Calculations

References

- ProfilARBED Steel Sheet Piling: The Impervious Pile Wall Part 1: Design, 2nd Ed (1998)

Tap Water Values

Specific Gravity of Tap Water: $SG := 1.00$

Density of Tap Water: $\rho_{Water} := SG \cdot 1000 \frac{kg}{m^3} = 1000 \cdot \frac{kg}{m^3}$

Unit Weight of Tap Water: $\gamma_{Water} := \rho_{Water} \cdot g$ $\quad \gamma_{Water} = 10 \frac{kN}{m^3}$

Input Data

Start time: $t_1 := 96.67hr$ *Elasped time of test at 2/11/14 13:05hrs*

End Time: $t_2 := 263.12hr$ *Elasped time of test at 2/18/14 11:32hrs*

Discharge at Start Time: $V_1 := 100mL$ *Cummulative Discharge of test at* t_1

Discharge at End Time: $V_2 := 4670mL$ *Cummulative Discharge of test at* t_2

Gravity: $g = 9.81 \cdot \frac{m}{s^2}$

Length of Joint: $L := 11in = 0.2794 \cdot m$

Pressure Head at Joint: $h := 10.475ft = 3.1928 \cdot m$

Preliminary Calculations

Filtration rate: $V := \frac{(V_2 - V_1)}{(t_2 - t_1)} = \frac{4570 \cdot mL}{-96.67 \cdot hr + 263.12 \cdot hr} = 27.5 \frac{mL}{hr}$

Discharge Per Unit of Joint Length: $q_z := \frac{V}{L} = 2.73 \times 10^{-8} \cdot \frac{m^3}{s} \cdot \frac{1}{m}$

Pressure Drop at level z: $\Delta p_{zmax} := \rho_{Water} \cdot g \cdot h = 31.31 \cdot kPa$

Calculation of Inverse Joint Resistance

Inverse Joint Resistance: $\rho := q_z \cdot \frac{\gamma_{Water}}{\Delta p_{zmax}} = 8.55 \times 10^{-9} \cdot \frac{m}{s}$

$\rho = 8.55 \times 10^{-7} \cdot \frac{cm}{s}$

Calculation of Equivalent Permeability

Assumed Equivalent Thickness of Slurry Wall: $d := 1m$ *Typical thickness of a Slurry Wall*

Width of Sheet Pile: $w := 700mm$ *Width of AZ-26 700 Sheet Pile*

System Width of Sheet Pile: $b := 2w$ *Distance between open interlocks with every other interlock welded*

Equivalent Permeability of Sheetpile Wall in Horizontal Direction: $K_e := \rho \cdot \frac{d}{b}$ *Equivalent Permeability of a 1 m Slurry Wall*

$K_e = 6.11 \times 10^{-7} \cdot \frac{cm}{s}$

Citizens Former MGP - Bench Scale Test

BT1 - Inverse Joint Resistance Calculations

References

- ProfilARBED Steel Sheet Piling: The Impervious Pile Wall Part 1: Design, 2nd Ed (1998)

DNAPL Values

Specific Gravity of NAPL: $SG := 1.09$

Density of NAPL: $\rho_{NAPL} := SG \cdot 1000 \frac{kg}{m^3} = 1090 \cdot \frac{kg}{m^3}$

Unit Weight of NAPL: $\gamma_{NAPL} := 10.69 \frac{kN}{m^3}$

Input Data

Start time: $t_1 := 0s$ *Elasped time of test at 3/3/14 14:19hrs*

End Time: $t_2 := 30s$ *Elasped time of test at 3/3/14 14:19hrs*

Discharge at Start Time: $V_1 := 0gal$ *Cummulative Discharge of test at t_1*

Discharge at End Time: $V_2 := 1.3gal$ *Cummulative Discharge of test at t_2*

Gravity: $g = 9.81 \cdot \frac{m}{s^2}$

Length of Joint: $L := 2ft = 0.6096 \cdot m$

Pressure Head at Joint: $h := 10.475ft = 3.1928 \cdot m$

Preliminary Calculations

Filtration rate: $V := \frac{(V_2 - V_1)}{(t_2 - t_1)}$ $V = 2.6 \cdot \frac{gal}{min}$

Discharge Per Unit of Joint Length: $q_z := \frac{V}{L} = 2.69 \times 10^{-4} \cdot \frac{m^3}{s} \cdot \frac{1}{m}$

Pressure Drop at level z: $\Delta p_{zmax} := \rho_{NAPL} \cdot g \cdot h = 34.13 \cdot kPa$

Calculation of Inverse Joint Resistance

Inverse Joint Resistance: $\rho := q_z \cdot \dfrac{\gamma_{NAPL}}{\Delta p_{zmax}} = 8.43 \times 10^{-5} \cdot \dfrac{m}{s}$

$\rho = 8.43 \times 10^{-3} \cdot \dfrac{cm}{s}$

Calculation of Equivalent Permeability

Assumed Equivalent Thickness of Slurry Wall: $d := 1m$ *Typical thickness of a Slurry Wall*

Width of Sheet Pile: $w := 700mm$ *Width of AZ-26 700 Sheet Pile*

System Width of Sheet Pile: $b := 2w$ *Distance between open interlocks with every other interlock welded*

Equivalent Permeability of Sheetpile Wall in Horizontal Direction: $K_e := \rho \cdot \dfrac{d}{b}$ *Equivalent Permeability of a 1 m Slurry Wall*

$K_e = 6.02 \times 10^{-3} \cdot \dfrac{cm}{s}$

Citizens Former MGP - Bench Scale Test
BT2 - Inverse Joint Resistance Calculations

References

- ProfilARBED Steel Sheet Piling: The Impervious Pile Wall Part 1: Design, 2nd Ed (1998)

DNAPL Values

Specific Gravity of NAPL: $SG := 1.09$

Density of NAPL: $\rho_{NAPL} := SG \cdot 1000 \frac{kg}{m^3} = 1090 \cdot \frac{kg}{m^3}$

Unit Weight of NAPL: $\gamma_{NAPL} := 10.69 \frac{kN}{m^3}$

Input Data

Start time: $t_1 := 144.52hr$ *Elasped time of test at 3/6/14 09:01hrs*

End Time: $t_2 := 239.83hr$ *Elasped time of test at 3/10/14 08:20hrs*

Discharge at Start Time: $V_1 := 8.6gm$ *Cummulative Discharge of test at t_1*

Discharge at End Time: $V_2 := 36.8gm$ *Cummulative Discharge of test at t_2*

Gravity: $g = 9.81 \cdot \frac{m}{s^2}$

Length of Joint: $L := 11in = 0.2794 \cdot m$

Pressure Head at Joint: $h := 10.475ft = 3.1928 \cdot m$

Preliminary Calculations

Filtration rate: $v := \frac{(V_2 - V_1)}{(t_2 - t_1)} = \frac{-8.6 \cdot gm + 36.8 \cdot gm}{239.83 \cdot hr + -144.52 \cdot hr} = 2.96 \times 10^{-4} \frac{kg}{hr}$

Volume Filtration Rate: $V := \frac{v}{\rho_{NAPL}} = 2.71 \times 10^{-7} \cdot \frac{m^3}{hr}$

Discharge Per Unit of Joint Length: $q_z := \frac{V}{L} = 2.70 \times 10^{-10} \cdot \frac{m^3}{s} \cdot \frac{1}{m}$

Pressure Drop at level z: $\Delta p_{zmax} := \rho_{NAPL} \cdot g \cdot h = 34.13 \cdot kPa$

Calculation of Inverse Joint Resistance

Inverse Joint Resistance: $\rho := q_z \cdot \frac{\gamma_{NAPL}}{\Delta p_{zmax}} = 8.45 \times 10^{-11} \cdot \frac{m}{s}$

$\rho = 8.45 \times 10^{-9} \cdot \frac{cm}{s}$

Calculation of Equivalent Permeability

Assumed Equivalent Thickness of Slurry Wall: $d := 1m$ *Typical thickness of a Slurry Wall*

Width of Sheet Pile: $w := 700mm$ *Width of AZ-26 700 Sheet Pile*

System Width of Sheet Pile: $b := 2w$ *Distance between open interlocks with every other interlock welded*

Equivalent Permeability of Sheetpile Wall in Horizontal Direction: $K_e := \rho \cdot \frac{d}{b}$ *Equivalent Permeability of a 1 m Slurry Wall*

$K_e = 6.04 \times 10^{-9} \cdot \frac{cm}{s}$

Citizens Former MGP - Bench Scale Test
BT3 - Inverse Joint Resistance Calculations

References

- ProfilARBED Steel Sheet Piling: The Impervious Pile Wall Part 1: Design, 2nd Ed (1998)

DNAPL Values

Specific Gravity of NAPL: $SG := 1.09$

Density of NAPL: $\rho_{NAPL} := SG \cdot 1000 \frac{kg}{m^3} = 1090 \cdot \frac{kg}{m^3}$

Unit Weight of NAPL: $\gamma_{NAPL} := 10.69 \frac{kN}{m^3}$

Input Data

Start time: $t_1 := 96.83hr$ *Elasped time of test at 3/14/14 14:30hrs*

End Time: $t_2 := 162.83hr$ *Elasped time of test at 3/17/14 08:30hrs*

Discharge at Start Time: $V_1 := 6.9gm$ *Cummulative Discharge of test at t_1*

Discharge at End Time: $V_2 := 21.7gm$ *Cummulative Discharge of test at t_2*

Gravity: $g = 9.81 \cdot \frac{m}{s^2}$

Length of Joint: $L := 2ft = 0.6096 \cdot m$

Pressure Head at Joint: $h := 10.475ft = 3.1928 \cdot m$

Preliminary Calculations

Filtration rate: $v := \frac{(V_2 - V_1)}{(t_2 - t_1)} = \frac{21.7 \cdot gm + -6.9 \cdot gm}{162.83 \cdot hr + -96.83 \cdot hr} = 2.24 \times 10^{-4} \frac{kg}{hr}$

Volume Filtration Rate: $V := \frac{v}{\rho_{NAPL}} = 2.06 \times 10^{-7} \cdot \frac{m^3}{hr}$

Discharge Per Unit of Joint Length: $q_z := \frac{V}{L} = 9.37 \times 10^{-11} \cdot \frac{m^3}{s} \cdot \frac{1}{m}$

Pressure Drop at level z: $\Delta p_{zmax} := \rho_{NAPL} \cdot g \cdot h = 34.13 \cdot kPa$

Calculation of Inverse Joint Resistance

Inverse Joint Resistance: $\rho := q_z \cdot \frac{\gamma_{NAPL}}{\Delta p_{zmax}} = 2.94 \times 10^{-11} \cdot \frac{m}{s}$

$\rho = 2.94 \times 10^{-9} \cdot \frac{cm}{s}$

Calculation of Equivalent Permeability

Assumed Equivalent Thickness of Slurry Wall: $d := 1m$ *Typical thickness of a Slurry Wall*

Width of Sheet Pile: $w := 700mm$ *Width of AZ-26 700 Sheet Pile*

System Width of Sheet Pile: $b := 2w$ *Distance between open interlocks with every other interlock welded*

Equivalent Permeability of Sheetpile Wall in Horizontal Direction: $K_e := \rho \cdot \frac{d}{b}$ *Equivalent Permeability of a 1 m Slurry Wall*

$K_e = 2.10 \times 10^{-9} \cdot \frac{cm}{s}$

Citizens Former MGP - Bench Scale Test
BT4 - Inverse Joint Resistance Calculations

References

- ProfilARBED Steel Sheet Piling: The Impervious Pile Wall Part 1: Design, 2nd Ed (1998)

DNAPL Values

Specific Gravity of NAPL: $SG := 1.09$

Density of NAPL: $\rho_{NAPL} := SG \cdot 1000 \frac{kg}{m^3} = 1090 \cdot \frac{kg}{m^3}$

Unit Weight of NAPL: $\gamma_{NAPL} := 10.69 \frac{kN}{m^3}$

Input Data

Start time: $t_1 := 210.15hr$ *Elasped time of test at 3/6/14 09:09hrs*

End Time: $t_2 := 234.13hr$ *Elasped time of test at 3/7/14 09:08hrs*

Discharge at Start Time: $V_1 := 303.2gm$ *Cummulative Discharge of test at t_1*

Discharge at End Time: $V_2 := 378.5gm$ *Cummulative Discharge of test at t_2*

Gravity: $g = 9.81 \cdot \frac{m}{s^2}$

Length of Joint: $L := 2ft = 0.6096 \cdot m$

Pressure Head at Joint: $h := 10.475ft = 3.1928 \cdot m$

Preliminary Calculations

Filtration rate: $v := \frac{(V_2 - V_1)}{(t_2 - t_1)} = \frac{-303.2 \cdot gm + 378.5 \cdot gm}{-210.15 \cdot hr + 234.13 \cdot hr} = 3.14 \times 10^{-3} \frac{kg}{hr}$

Volume Filtration Rate: $V := \frac{v}{\rho_{NAPL}} = 2.88 \times 10^{-6} \cdot \frac{m^3}{hr}$

Discharge Per Unit of Joint Length: $q_z := \frac{V}{L} = 1.31 \times 10^{-9} \cdot \frac{m^3}{s} \cdot \frac{1}{m}$

Pressure Drop at level z: $\Delta p_{zmax} := \rho_{NAPL} \cdot g \cdot h = 34.13 \cdot kPa$

Calculation of Inverse Joint Resistance

Inverse Joint Resistance: $\rho := q_z \cdot \dfrac{\gamma_{NAPL}}{\Delta p_{zmax}} = 4.11 \times 10^{-10} \cdot \dfrac{m}{s}$

$\rho = 4.11 \times 10^{-8} \cdot \dfrac{cm}{s}$

Calculation of Equivalent Permeability

Assumed Equivalent Thickness of Slurry Wall: $d := 1m$ *Typical thickness of a Slurry Wall*

Width of Sheet Pile: $w := 700mm$ *Width of AZ-26 700 Sheet Pile*

System Width of Sheet Pile: $b := 2w$ *Distance between open interlocks with every other interlock welded*

Equivalent Permeability of Sheetpile Wall in Horizontal Direction: $K_e := \rho \cdot \dfrac{d}{b}$ *Equivalent Permeability of a 1 m Slurry Wall*

$K_e = 2.94 \times 10^{-8} \cdot \dfrac{cm}{s}$

Citizens Former MGP - Bench Scale Test
BT5 - Inverse Joint Resistance Calculations

References

- ProfilARBED Steel Sheet Piling: The Impervious Pile Wall Part 1: Design, 2nd Ed (1998)

DNAPL Values

Specific Gravity of NAPL: $SG := 1.09$

Density of NAPL: $\rho_{NAPL} := SG \cdot 1000 \frac{kg}{m^3} = 1090 \cdot \frac{kg}{m^3}$

Unit Weight of NAPL: $\gamma_{NAPL} := 10.69 \frac{kN}{m^3}$

Input Data

Start time: $t_1 := 0hr$ *Elasped time of test at 2/28/14 15:40hrs*

End Time: $t_2 := 232.7hr$ *Elasped time of test at 3/10/14 08:22hrs*

Discharge at Start Time: $V_1 := 0.00gm$ *Cummulative Discharge of test at t_1*

Discharge at End Time: $V_2 := 7.670gm$ *Cummulative Discharge of test at t_2*

Gravity: $g = 9.81 \cdot \frac{m}{s^2}$

Length of Joint: $L := 2ft = 0.6096 \cdot m$

Pressure Head at Joint: $h := 10.475ft = 3.1928 \cdot m$

Preliminary Calculations

Filtration rate: $v := \frac{(V_2 - V_1)}{(t_2 - t_1)}$ $v = 3.30 \times 10^{-5} \cdot \frac{kg}{hr}$

Volume Filtration Rate: $V := \frac{v}{\rho_{NAPL}} = 3.02 \times 10^{-8} \cdot \frac{m^3}{hr}$

Discharge Per Unit of Joint Length: $q_z := \frac{V}{L} = 1.38 \times 10^{-11} \cdot \frac{m^3}{s} \cdot \frac{1}{m}$

Pressure Drop at level z: $\Delta p_{zmax} := \rho_{NAPL} \cdot g \cdot h = 34.13 \cdot kPa$

Calculation of Inverse Joint Resistance

Inverse Joint Resistance: $\rho := q_z \cdot \frac{\gamma_{NAPL}}{\Delta p_{zmax}} = 4.32 \times 10^{-12} \cdot \frac{m}{s}$

$\rho = 4.32 \times 10^{-10} \cdot \frac{cm}{s}$

Calculation of Equivalent Permeability

Assumed Equivalent Thickness of Slurry Wall: $d := 1m$ *Typical thickness of a Slurry Wall*

Width of Sheet Pile: $w := 700mm$ *Width of AZ-26 700 Sheet Pile*

System Width of Sheet Pile: $b := 2w$ *Distance between open interlocks with every other interlock welded*

Equivalent Permeability of Sheetpile Wall in Horizontal Direction: $K_e := \rho \cdot \frac{d}{b}$ *Equivalent Permeability of a 1 m Slurry Wall*

$K_e = 3.08 \times 10^{-10} \cdot \frac{cm}{s}$

PROFIL ARBED

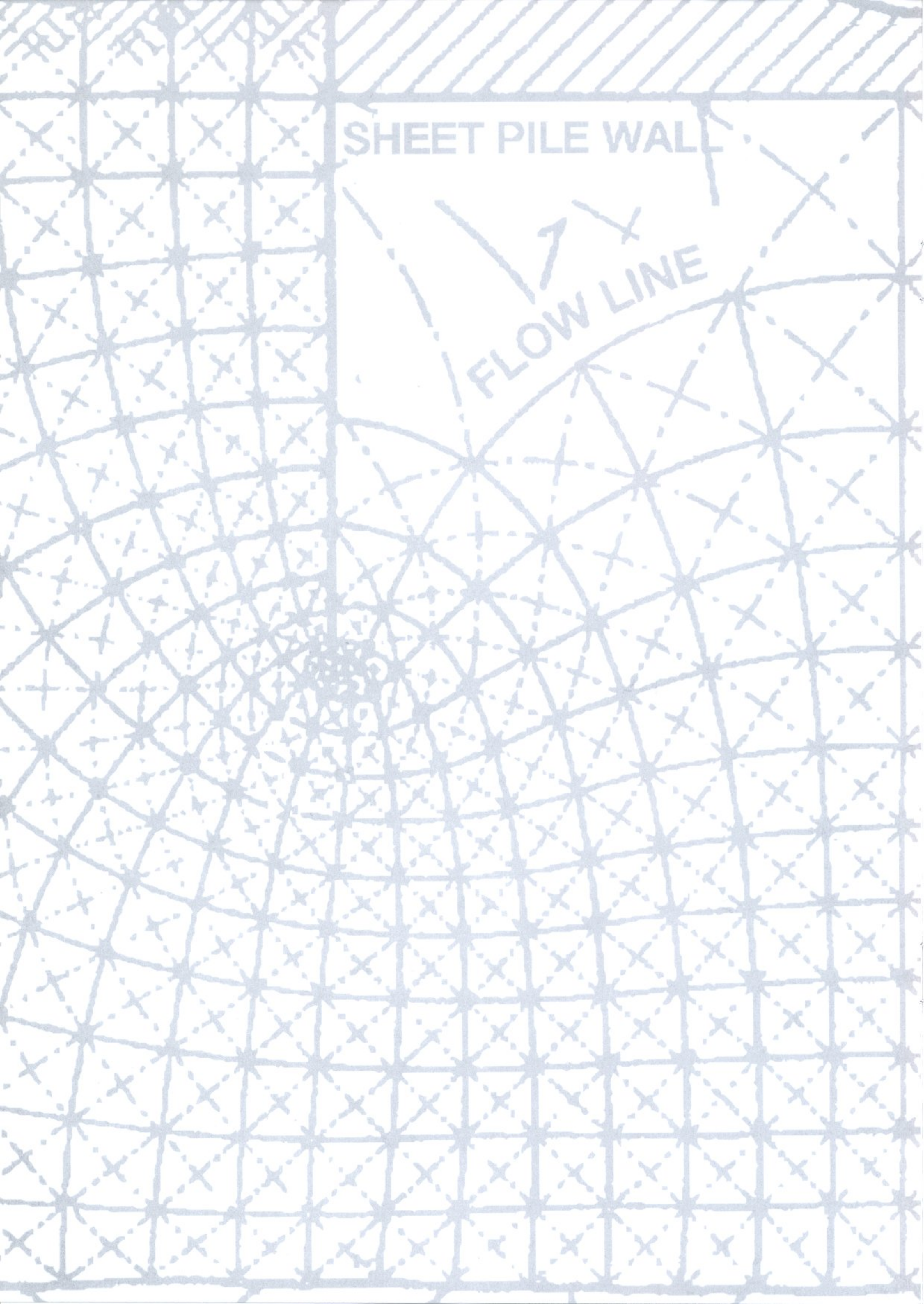
Steel Sheet Piling

The Impervious Steel Sheet Pile Wall

Part 1: Design

ARBED GROUP

Special technical aspects


SHEET PILE WALL
FLOW LINE

Rational Analysis of Impervious Steel Sheet Pile Walls

1. Introduction

Until recently no consistent methodology has been available for the assessment of the seepage resistance of steel sheet pile (SSP) walls. The lack of such a methodology can conceivably lead to uneconomic design, especially in cases where the seepage resistance is substantially greater than the specific design requires.

ProfilARBED, the leading European producer of sheet piles, has carried out an exhaustive research project in collaboration with Delft Geotechnics. The aim of the project was to determine the rate of seepage through SSP walls for various joint filler materials, as well as for empty and welded joints.

Two key areas of research were addressed:

- Setting up a consistent theory to describe the leakage behaviour through individual joints.
- In situ experimentation on SSP walls.

In this paper the research results are deployed to enable the practical designer to make a rational assessment of the rate of seepage for a specific case. A range of possibilities is discussed: highly permeable unfilled joints, filled joints for medium permeability and completely impervious welded joints.

The cost involved in each case can be balanced against the seepage resistance requirements and the most appropriate solution will present itself on the basis of the analysis.

2. The concept of joint resistance

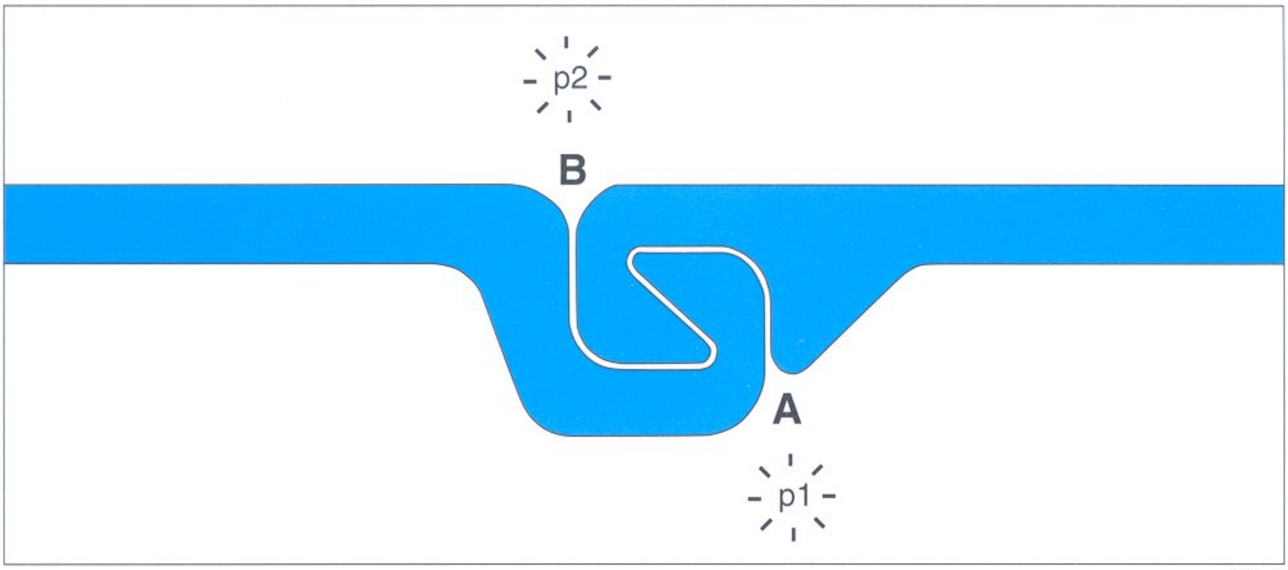


Fig. 1

The steel sheet piles themselves are completely impervious and therefore the only possible route for the fluid to traverse the wall is via the joints. Unlike slurry walls - for which the seepage problem can be treated with the aid of Darcy's law with a suitably chosen coefficient of permeability K:

$$v = K \bullet i \qquad (1)$$

where v is the so-called filtration rate and i represents the hydraulic gradient:

$$i = (\Delta p / \gamma) / s \qquad (2)$$

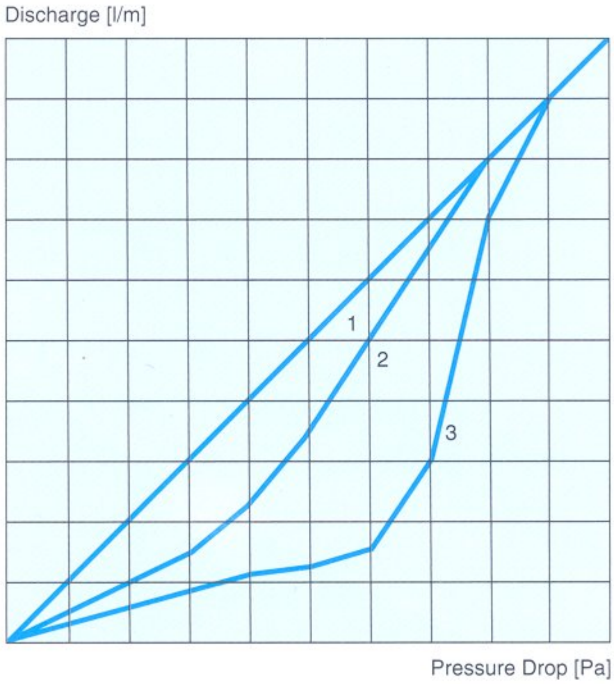
The latter is defined in a horizontal plane as the ratio of the difference in pressure height ($\Delta p / \gamma$) and the length of the filtration path (s), see reference 4.

Fig. 1 shows a horizontal cross section of a SSP joint. The positive pressure difference between the points A and B : $p_2 - p_1$ is associated with a flow from B to A.

The kind of flow (pipe, potential,...) is difficult to determine, but most likely it will not be a porous media type of flow and Darcy's law does not hold for the local seepage through a SSP joint. To accommodate this difficulty, researchers at Delft Geotechnics have introduced the concept of **Joint Resistance.**

Fig. 2 shows a typical application of SSP with different water levels on either sides of the wall which gives rise to a pressure difference that depends on z.

Neglecting the vertical flow in the joint, the relation between the discharge through the joint in the horizontal plane and the related pressure drop $p_2 - p_1$, is roughly as depicted in Fig. 3. The hypothesis that no discharge occurs in the vertical direction of the joint is rather more general than the commonly used Dupuit-Forchheimer assumption for the treatment of these kinds of flows (see reference 2).



1. Empty
2. Plugged Soil
3. Filler Material

Fig. 3

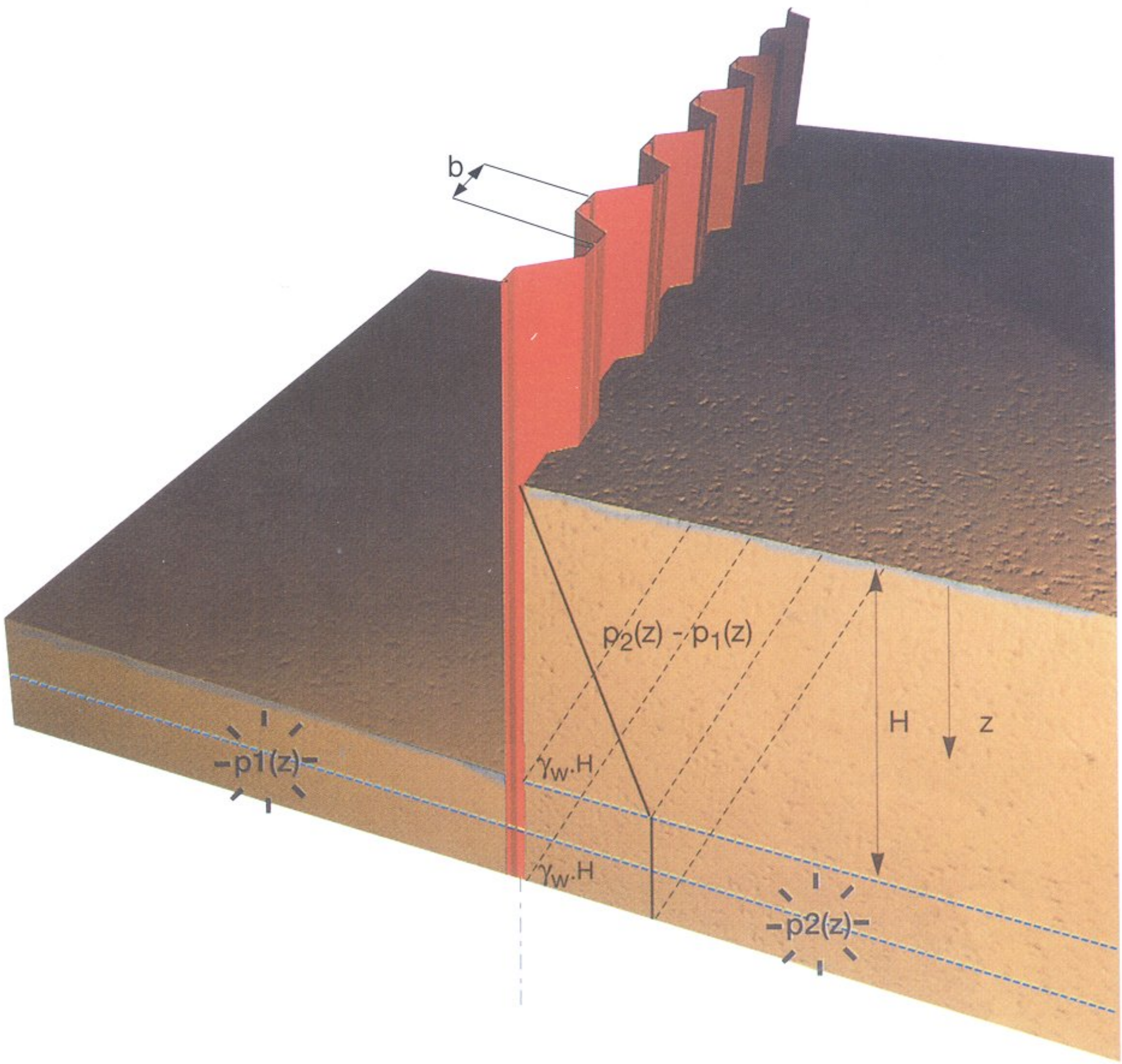


Fig. 2

A straightforward approach is to assume that the discharge is proportional to the pressure drop:

q(z) proportional $\Delta p(z)$

The proportionality coefficient is denoted by ρ :

$$q(z) = \rho \bullet \Delta p(z)/\gamma \qquad (3)$$

The meaning of the symbols is as follows:

q(z): the discharge per unit of the joint length at level z, [$m^3/s/m$]

Δp(z): the pressure drop at level z, [kPa]

ρ: the inverse joint resistance, [m/s]

γ: unit weight of water [kN/m^3]

Note that (3) does not suppose a Darcy type of flow. All interlock properties are encased in ρ and this parameter is determined from experiments.

3. In situ measurements

In order to allow the design engineer to make practical use of equation (3) Delft Geotechnics and ProfilARBED have carried out field tests on a large number of filler materials. The results of these tests yield values for ρ.

To expose the filler material to extreme site conditions, the sheet piles for the test wall have been driven in by vibrohammer. Each filler material has been applied in several joints.

The discharge through each joint was measured as a function of the applied pressure drop using a special test apparatus, see Fig. 4. The time dependent behaviour is monitored by taking readings at specific time intervals.

Table 1 shows the relevant criteria for selecting a water sealing system for an SSP wall and the range of values obtained from the tests for different types of filler materials (bituminous ones as well as water swelling products); the results of the empty joints are also shown. It is most important to note that the ρ-values obtained for empty joints strongly depend on the soil properties, the variations being very large.

The test results are plotted in Fig. 5 which generally confirms that the hypothesis which leads up to formula (3) is well-founded (see also Fig. 3), at least for a certain pressure range.

The testing programme carried out by Delft Geotechnics and ProfilARBED, clearly demonstrates that the use of filler products in the joints of a SSP wall considerably reduces the seepage rate.

In addition it transpires that the filler material in the joints remains in place, even after the application of a vibrohammer - provided the manufacturer's specifications are strictly adhered to and the special tools, as developed by ProfilARBED for the implantation of the filler materials, are deployed.

Table 1

WATERTIGHTENING SYSTEM	ρ [10^{-9}m/s] 100kPa	200kPa	APPLICATION OF THE SYSTEM	COSTS RATIO **
EMPTY JOINTS	>100	*	-	0
BITUMINOUS FILLER MATERIAL	< 60	not recommended	EASY	1
WATERSWELLING PRODUCT	≤ 0.3	0.3	WITH CARE	2
WELDING OF THE JOINTS	0	0	ONLY AFTER EXCAVATION FOR THE INTERLOCK TO BE THREADED ON JOBSITE	5

* VALUE AVAILABLE ONLY AT 150 kPa: < 450

** The costs ratio = $\dfrac{\text{Costs of the watertightening system}}{\text{Costs of the bituminous filler material solution}}$

Note: See table inside rear cover for values to be used for a first order design approach.

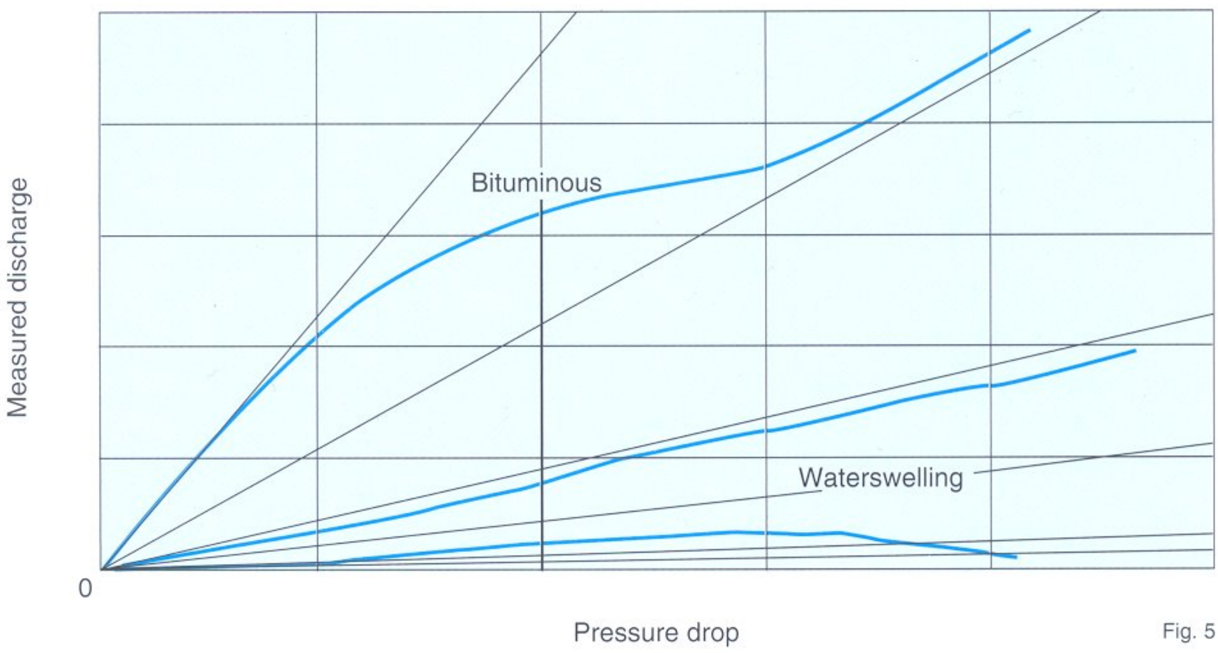

Measured discharge
Bituminous
Waterswelling
0
Pressure drop

Fig. 5

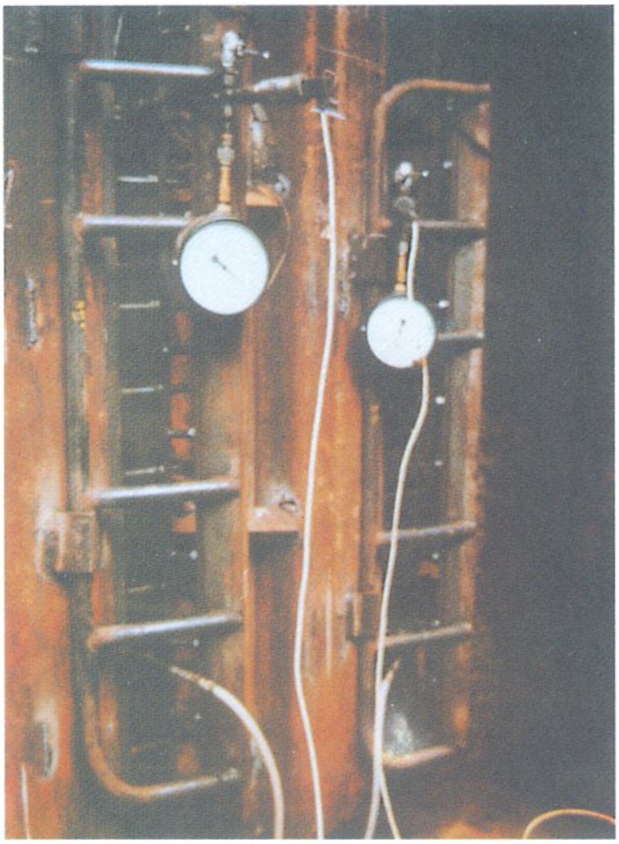


Fig. 4

4. Practical use of the concept

The key design formula is:

$$q(z) = \rho \bullet \Delta p(z)/\gamma \qquad (3)$$

q(z): the discharge per unit of the joint length at level z, [$m^3/s/m$]
$\Delta p(z)$: the pressure drop at level z, [kPa]
ρ: the inverse joint resistance, [m/s]
γ: unit weight of water [kN/m^3]

The geometrical definitions are given in Fig. 1 and 2

4.1. The discharge through a SSP wall The simple case

Fig. 6 shows a building pit in which the water table has been lowered about 5 m. The toe of the SSP wall goes right down to the bottom layer; the latter is assumed to be virtually impervious.

This assumption allows to neglect the flow around the toe. (The question as to what K value is required to be able to regard the bottom layer as impervious will be dealt with in section 4.3.)

The resulting hydrostatic pressure diagram is easily drawn (Fig. 6): max (Δp) = $\gamma \bullet H$, the total discharge through one joint is obtained:

$$Q_1 = \int_0^{H+h} q(z) \bullet dz = (\rho/\gamma) \bullet \int_0^{H+h} \Delta p(z) \bullet dz \qquad (4)$$

With the pressure drop:

$$(\Delta p) = \begin{cases} \gamma \bullet z, & z <= H \\ \gamma \bullet H, & H < z <= H + h \end{cases}$$

Thus the integral in (4) yields the area in the pressure diagramm and a result for Q_1 follows:

$$Q_1 = \rho \bullet H \bullet (0.5\,H + h) \qquad (5)$$

The total number of interlocks in the SSP wall for the building pit is:

$$n = L / b \qquad (6)$$

L: length of the perimeter of the building pit, [m]
b: system width of the pile, [m]

The total discharge into the pit is:

$$Q = n \bullet Q_1 \qquad (7)$$

(7) represents a safe approximation for the discharge, as certain aspects have been neglected, for example the influence of the flow pattern on the geometry of the water table.

NUMERICAL EXAMPLE:

For a building pit with a SSP wall made of AZ18: b = 0.63 m, the perimeter length is L = 160 m.

Fig. 6 shows the geometrical data: H = 5 m and h = 2 m. The joint is fully described by its inverse joint resistance: $\rho = 3.0 \bullet 10^{-10}$ m/s, using a waterswelling filler.

The number of interlocks:

$$n = 160 / 0.63 \cong 254 \qquad (6)$$

Discharge per joint:

$$Q_1 = 3.0 \bullet 10^{-10} \bullet 5.0 \bullet (0.5 \bullet 5.0 + 2.0) \qquad (5)$$
$$Q_1 = 6.75 \bullet 10^{-9}\ m^3/s$$

Total discharge into the pit:

$$Q = 254 \bullet 6.75 \bullet 10^{-9}\ m^3/s \qquad (7)$$
$$Q = 1.715 \bullet 10^{-6}\ m^3/s$$
$$Q = 6.17\ l/h$$

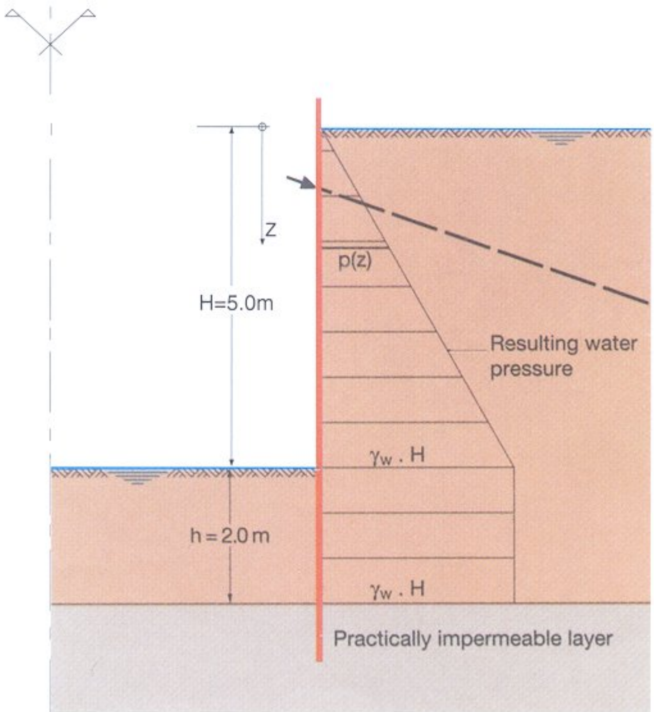


Fig. 6

4.2. Comparison with porous media flow

In everyday practice the design engineer often needs to compare the performance (seepage resistance) of a SSP wall with other types of wall design, such as a slurry wall (SW); a cut-off wall is an example where such a comparison is relevant. The slurry wall may be considered as a porous medium and the flow is governed by Darcy's law.

The comparison between the SSP wall and the slurry wall can be carried out by **assuming that the discharge per unit wall area is the same.** With the definitions given in fig. 7, Darcy's law (reference 2 and 4) yields a specific discharge:

$$\mathbf{Q_{sw} = K \bullet (\Delta p / \gamma) / d} \qquad (8)$$

where

d : thickness of the slurry wall, [m]
K : permeability of the wall in horizontal direction, [m/s]
Δp : pressure drop on both sides of the wall, [kPa]

The specific discharge for a SSP wall (Fig. 7) follows from (3), (6) and (7) with L = 1 m:

$$\mathbf{Q_{ssp} = (1 / b) \bullet \rho \bullet (\Delta p / \gamma)} \qquad (9)$$

Both specific discharges are equal:

$$\mathbf{Q_{sw} = Q_{ssp}} \qquad (10)$$

This condition yields:

$$\mathbf{(K / d) = (\rho / b)} \qquad (11)$$

For a given SSP wall relation (11) permits the calculation of the properties of a slurry wall with the same seepage properties. Assuming a slurry wall of a thickness d = 1m, the equivalent K-value is:

$$\mathbf{K_e = \rho \bullet (1m) / b} \qquad (12)$$

It must be kept in mind however that the nature of the two flows is quite different!

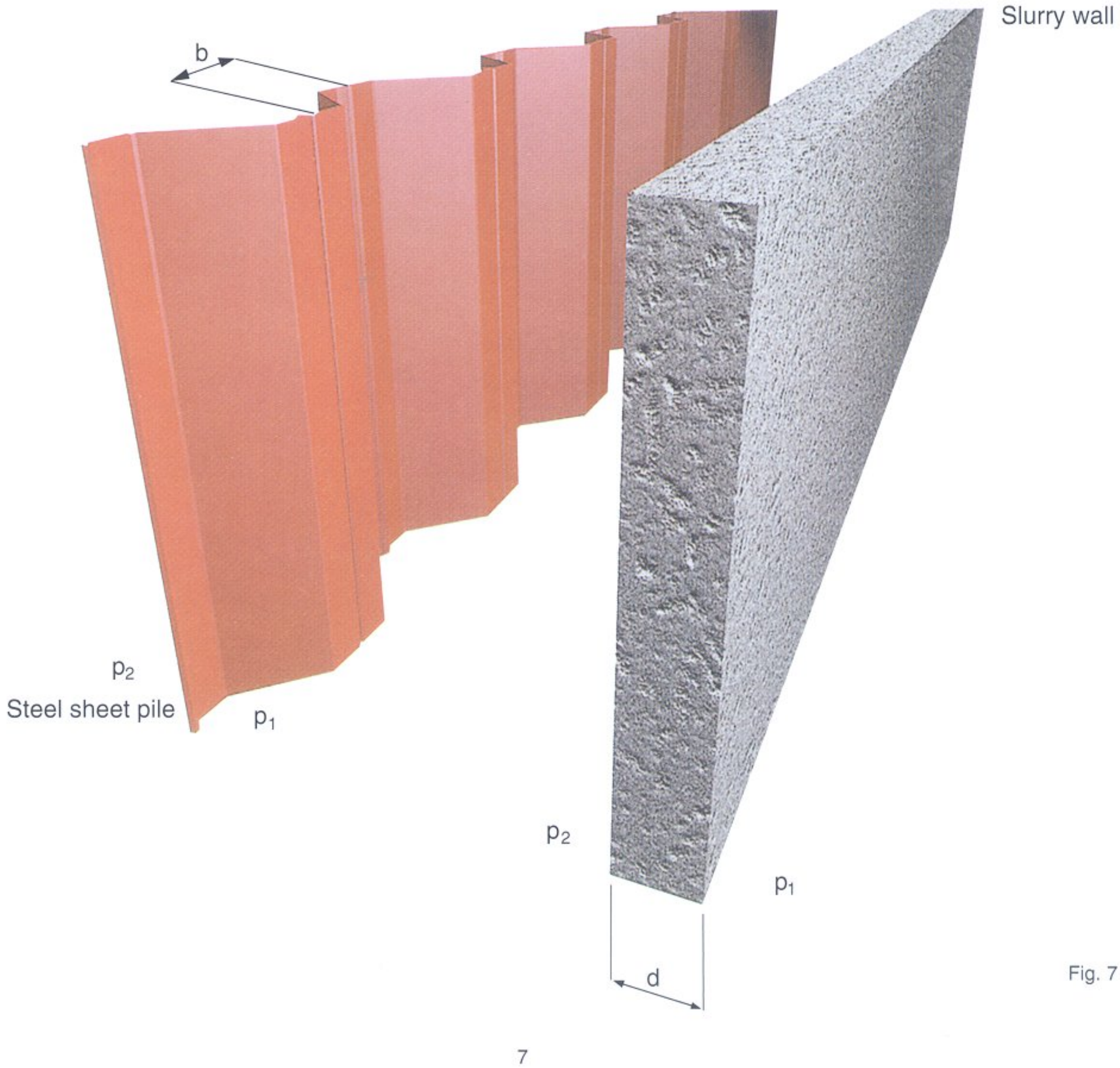


Fig. 7

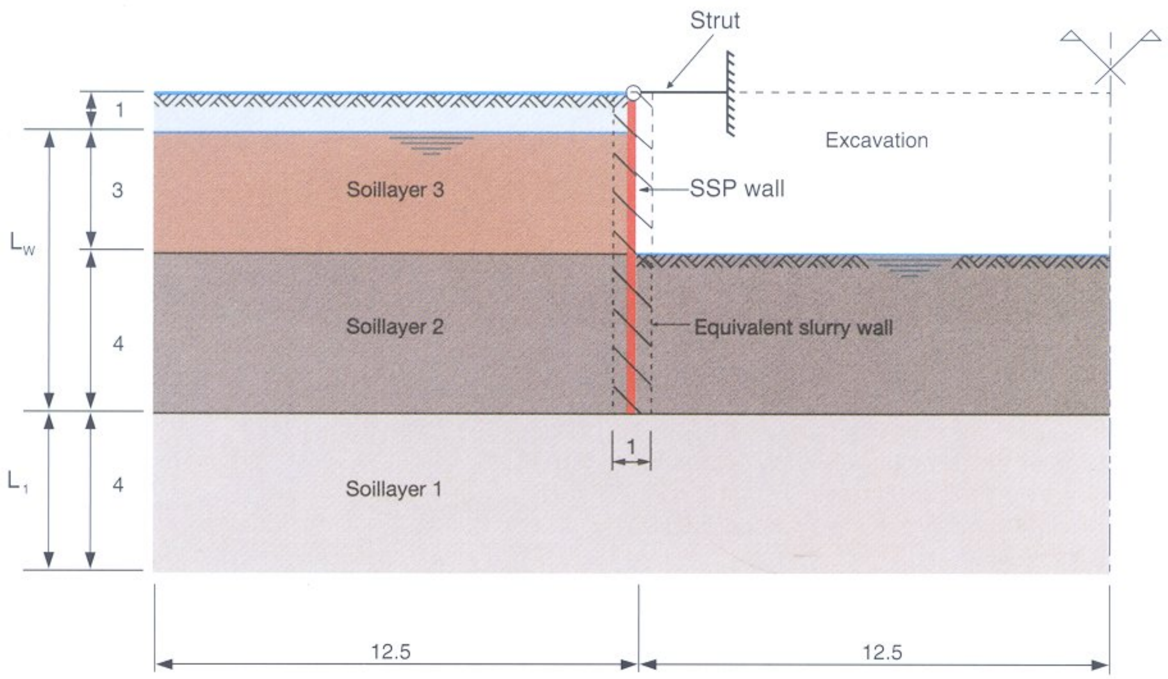


Fig. 8

4.3. Two dimensional flow through and around the toe of an SSP wall

In section 4.1 the flow around the toe of the SSP wall was neglected. This is only correct if the bottom layer is much less pervious than the wall. If this is not the case, then the water flow both through and around the wall need to be considered. This is done with the aid of a 2D-seepage calculation program - nowadays available for PCs. Because these programs deal with Darcy type flows only, the behaviour of the SSP wall has to be treated as a porous media flow, using an equivalent slurry wall defined by its thickness d and its permeability K - according to (11).

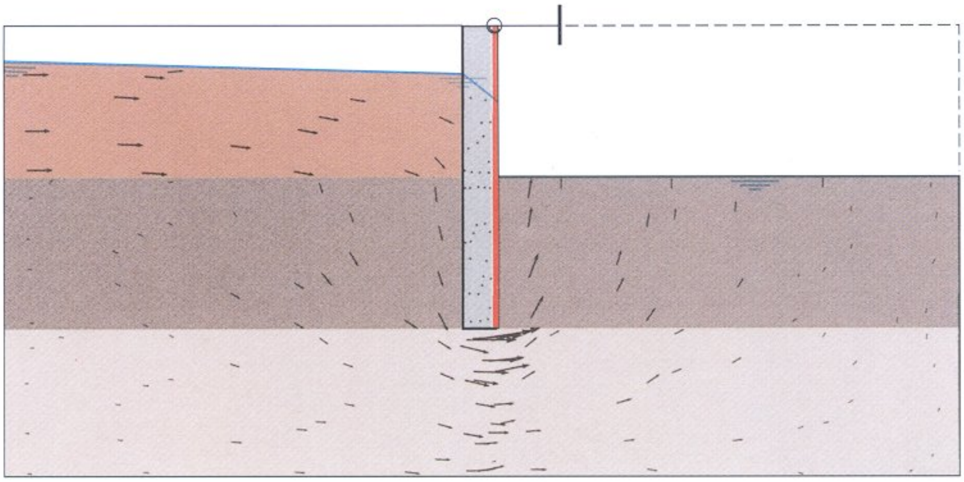
In order to show the versatility of this approach and the influence of the bottom layer on the flow, four different cases have been analysed.

All cases pertain to the same situation: an excavation for a building pit (Fig. 8). The SSP wall is used as a retaining structure and is simulated by an equivalent slurry wall with a thickness d = 1m. The hydraulic conductivity of the slurry wall Kw can be evaluated using (12).

The calculations are performed with the PLAXIS finite element code. Table 2 summarises the input- and output data of the four cases. The resulting flow fields are shown in Figs. 9, 10, 11, 12.

TABLE 2

ROW	ITEM	CASE 1	CASE 2	CASE 3	CASE 4
1	Ki [m/s]: SOILLAYER 1, i=1 SOILLAYER 2, i=2 SOILLAYER 3, i=3	10^{-4} 10^{-4} 10^{-3}	10^{-4} 10^{-4} 10^{-3}	10^{-7} 10^{-4} 10^{-3}	10^{-4} 10^{-4} 10^{-3}
2	EQUIVALENT SLURRY WALL : $K_w = \rho/b$ [m/s]	10^{-6}	10^{-5}	10^{-6}	10^{-5}
3	GEOMETRY : L_w/L_1	7/4	7/4	7/4	7/8
4	$K_w \bullet L_w / K_1 \bullet L_1$	0.0175	0.175	17.5	0.0875
5	TOTAL DISCHARGE (WALL + BOTTOM LAYER) ACCORDING TO THE PLAXIS MODEL : D_t [l/h]	518	742	60.5	887
6	DISCHARGE THROUGH WALL ACCORDING TO 4.1 D_w [l/h]	59.4	594	59.4	594
7	D_w / D_t [%]	11.5	80	98.2	67



Ultimate flow field with phreatic line
Extreme velocity 6.57E-05 units

Fig. 9

Case 1: $K_w \bullet L_w/K_1 \bullet L_1 = 0.0175$
The wall is much less pervious than the bottom layer. There is hardly any discharge through the wall; most of the flow takes place around the toe (Fig. 9).

Case 2: $K_w \bullet L_w/K_1 \bullet L_1 = 0.175$
The discharge through and around the wall are of the same order of magnitude (Fig. 10).

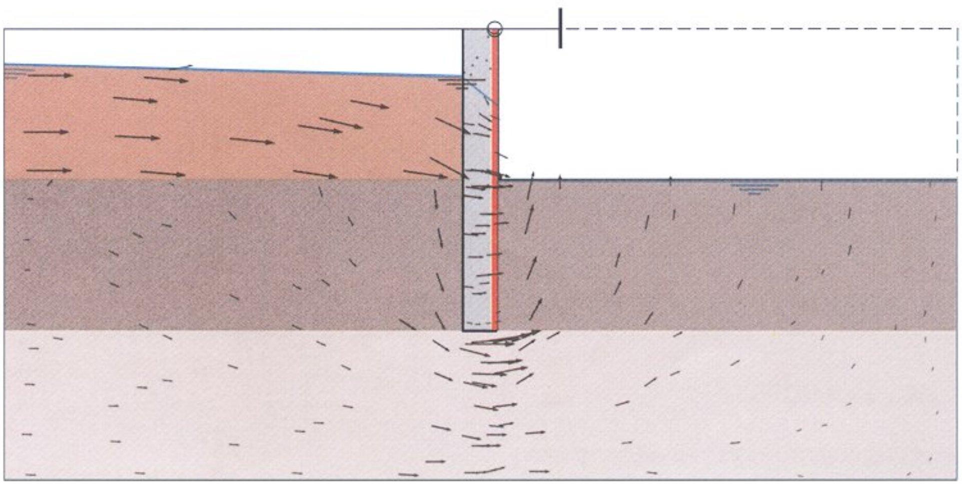
Case 3: $K_w \bullet L_w/K_1 \bullet L_1 = 17.5$
The bottom layer is practically speaking impervious. Seepage through the wall dominates the flow field (Fig. 11).

Case 4: $K_w \bullet L_w/K_1 \bullet L_1 = 0.0875$
The K-values are the same as in case 2, but the thickness of the bottom layer has been doubled (Fig. 12).

This emphasises the influence of the geometry on the flow field. Compared to case 2, the total discharge has increased due to the extra seepage around the toe and through the bottom layer (Table 2).

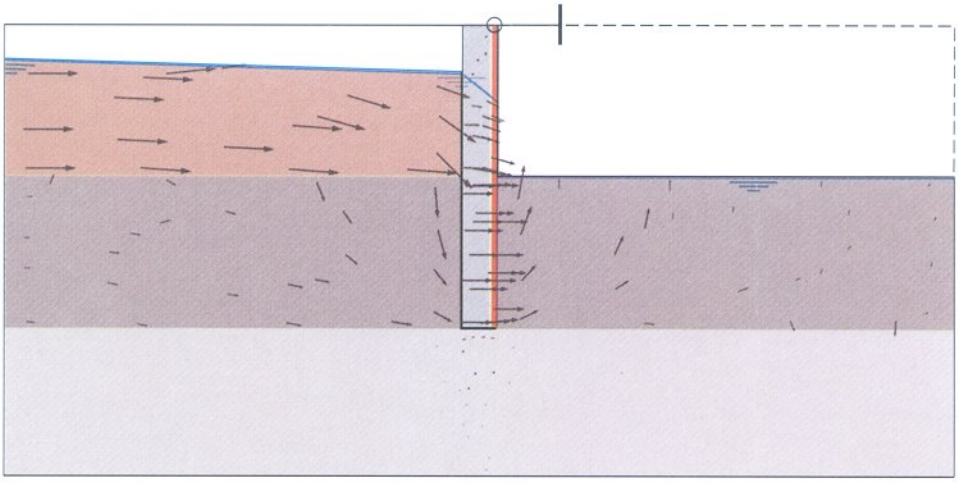
In Table 2, row 5 gives the total discharge (D_t) per m normal to the drawing plane (Fig. 8);
row 6 contains the discharge D_w through the wall itself according to the simplified approach of section 4.1.

The ratio D_w / D_t is the ratio of the discharge through the wall compared to the total discharge, while the ratio $K_w \bullet L_w/K_1 \bullet L_1$ encases all that is relevant for the geometry and the permeability of the wall expressed in the permeability of the bottom layer.



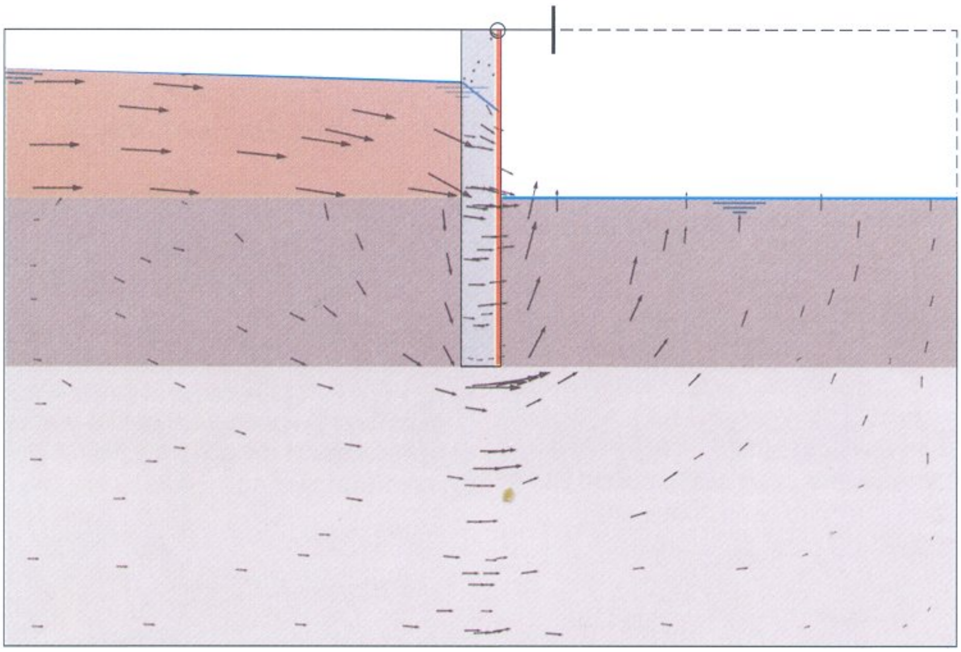
Ultimate flow field with phreatic line
Extreme velocity 4.21E-05 units

Fig. 10



Ultimate flow field with phreatic line
Extreme velocity 4.61E-06 units

Fig.11



Ultimate flow field with phreatic line
Extreme velocity 4.74E-05 units

Fig. 12

Inspection of both ratios in Table 2 confirms the hypothesis of 4.1.
(case 3: $K_w \bullet L_w/K_1 \bullet L_1 = 17{,}5 => D_w/D_t = 98.2\%$).

The diagram of Fig. 13 warrants the conclusion that for ratios as low as

$$\mathbf{K_w \bullet L_w/K_1 \bullet L_1 > 0.175,}$$

80% of the discharge occurs through the wall and therefore the simplified approach yields acceptable results.

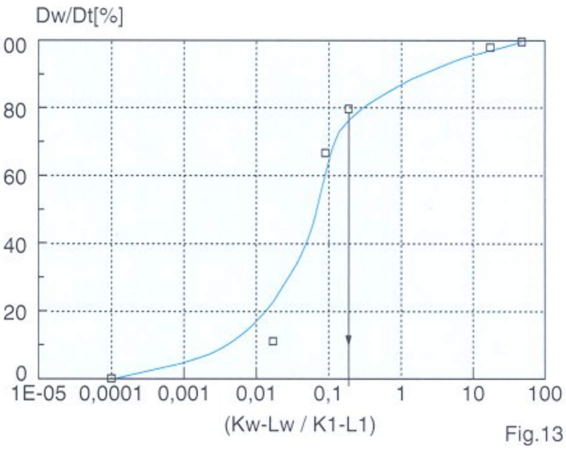


Fig.13

5. Remarks

- It is important to note, that all ρ values given in this document are characteristic values (maximum values as "cautious estimates") which are results of in situ tests.
  For the determination of the design values, a safety factor has to be carefully chosen in order to balance the scattering of the test results and the imponderables inherent to the installation of the piles, the soil, local defects, etc. Please contact the Technical Assistance department of ISPC for guidelines on this matter.

- All the information included in this brochure has to be considered as informative only and has to be carefully checked by any user.

6. References

For additional background information, please refer to:

1) Steel Sheet Pile Seepage Resistance, J.B. Sellmeijer, Fourth International Landfill Symposium, Cagliari, Italy, 1993

2) Joint resistance of steel sheet piles, Definition, J.B. Sellmeijer, August 1993, unpublished

3) The hydraulic resistance of steel sheet pile joints, J.B. Sellmeijer, J.P.A.E. Cools, W.J. Post, J. Decker, 1993

4) EAU 1990, Recommendations of the Committee for Waterfront Structures Harbours and Waterways, 1992, Berlin

The practical aspects associated with the sealing of SSP walls such as the implantation of the filler material in the joints, welding procedures, combining vertical and horizontal sealing and pile installation are treated in part 2 of this ISPC brochure.

Part 2: "PRACTICAL ASPECTS"

A resume of the system for ensuring a watertight seal of steel sheet piles is inside the rear cover

The Imperviousness of Steel Sheet Pile Walls

For practical design purposes it is advisable to assess the degree of the required seepage resistance in order that a cost effective solution may be selected. Depending on the requirements, there are basically three possible solutions:

1. In applications such as temporary retaining walls a moderate rate of seepage is often tolerable. An SSP wall made of piles with the famous Larssen interlock provides sufficient seepage resistance.

2. In applications where a medium to high seepage resistance is required - such as cut-off walls for contaminated sites, retaining structures for bridge abutments and tunnels - double piles with a workshop welded intermediate joint should be used. The workshop weld is as impervious as the steel itself.
   The free interlock of the double pile needs to be threaded on site with a filler material. The lower end of the resistance range is adequately served by the various bituminous fillers, but it is noted that their use is limited to water pressures less than 100 kPa.
   For high resistance requirements, as well as water pressures up to 200 kPa, a water swelling product should be used as a filler material. A wall designed in this way is between 100 to 1000 times more impervious than the simple sheet pile wall with Larssen interlocks.

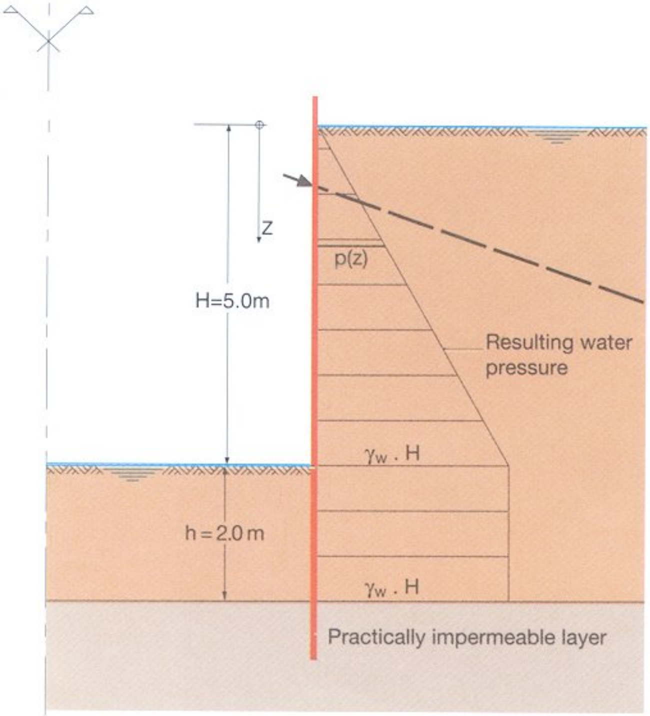
3. A 100% watertightness may be obtained by welding every joint.
   Double piles with a workshop weld are used for the construction of the wall. The interlock that needs to be threaded on the job has to be welded on site after excavation.

If a comparison needs to be made between the rate of seepage of an SSP wall and a slurry wall, the table below may be used. For a given SSP wall, the hydraulic conductivity which a slurry wall of a thickness D has to provide in order to obtain the same upper limit on the discharge - at the same water pressure - as the SSP wall, can be determined.

Example: An SSP wall is selected made of AZ double piles with a shop welded intermediate interlock and a water swelling filler material in the interlock to be threaded on site.
In order to have the equivalent discharge, a slurry wall of 80 cm thickness has a hydraulic conductivity $K = 1,9.10^{-10}$ m/s.

To form an impression of the rate of discharge through the SSP wall the data that need to be provided are (see figure):

STEEL SHEET PILE WALL			HYDRAULIC CONDUCTIVITY K [m/s] OF AN EQUIVALENT SLURRY WALL WITH A THICKNESS D		
SECTION	EVERY 2nd INTERLOCK IS SHOPWELDED	FILLER	D = 60 cm	D = 80 cm	D = 100 cm
AZ	YES	BITUMINOUS	2.86 E-08	3.81 E-08	4.76 E-08
	YES	WATERSWELLING	1.43 E-10	1.90 E-10	2.38 E-10
	NO	BITUMINOUS	5.71 E-08	7.62 E-08	9.52 E-08
	NO	WATERSWELLING	2.86 E-10	3.81 E-10	4.76 E-10
PU	YES	BITUMINOUS	3.00 E-08	4.00 E-08	5.00 E-08
	YES	WATERSWELLING	1.50 E-10	2.00 E-10	2.50 E-10
	NO	BITUMINOUS	6.00 E-08	8.00 E-08	1.00 E-07
	NO	WATERSWELLING	3.00 E-10	4.00 E-10	5.00 E-10
LS	YES	BITUMINOUS	3.60 E-08	4.80 E-08	6.00 E-08
	YES	WATERSWELLING	1.80 E-10	2.40 E-10	3.00 E-10
	NO	BITUMINOUS	7.20 E-08	9.60 E-08	1.20 E-07
	NO	WATERSWELLING	3.60 E-10	4.80 E-10	6.00 E-10
JSP	YES	BITUMINOUS	4.50 E-08	6.00 E-08	7.50 E-08
	YES	WATERSWELLING	2.25 E-10	3.00 E-10	3.75 E-10
	NO	BITUMINOUS	9.00 E-08	1.20 E-08	1.50 E-07
	NO	WATERSWELLING	4.50 E-10	6.00 E-10	7.50 E-10



H: the difference in head between the water tables at either side of the wall
h: the distance from the top of the impervious bottom layer up to the lower water table level.

The discharge through one not welded interlock is:

$$Q_1 = \rho \bullet H \bullet (H/2 + h)$$

According to the tests the inverse joint resistance ρ may be assumed to be as follows for a first order design approach:

bituminous filler material: $= 6 \bullet 10^{-8}$ m/s ($p < 100$kPa)
waterswelling filler material : $= 3 \bullet 10^{-10}$ m/s ($p \leq 200$kPa)

For further details please refer to 4.1 of the brochure.

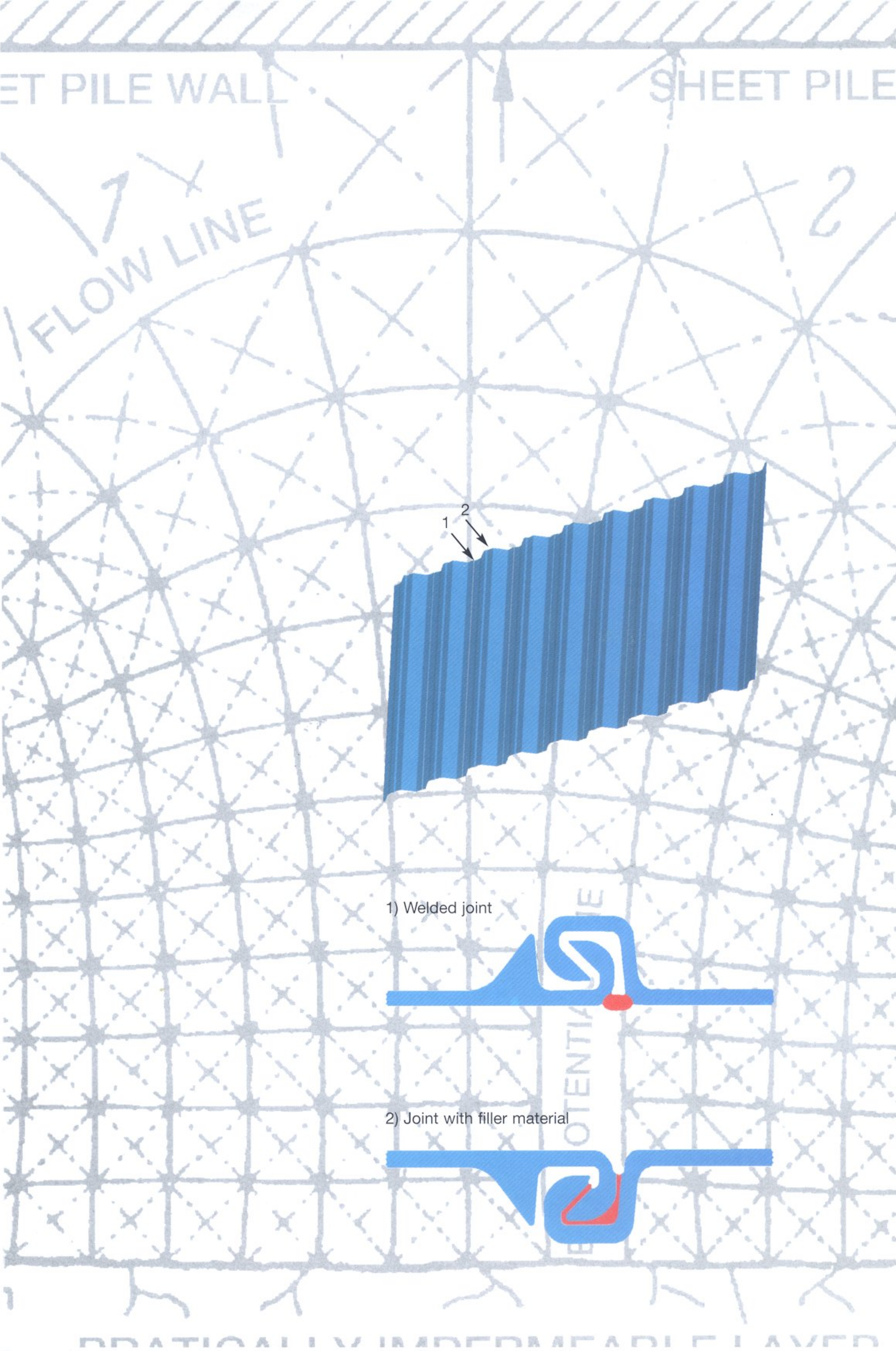
Importantly, this table gives an impression of the cost per m per joint for the different solutions. The cost ratio gives the ratio of the cost of a particular solution to the bituminous filler solution.
These costs cover the filler material including the implantation in the joint.

Seepage resistance solution	Cost ratio
empty joint	0
joint with bituminous filler material	1
joint with water swelling product	2
welding of the joints	5

Values of ρ for a first order design approach

Watertightening System	ρ [10^{-10} m/s]	maximum differential water pressure [k Pa]
Empty joints	>1000	100
Bituminous filler material	600	100
Waterswelling filler material (Roxan(TM))	3	200

Roxan(TM) System (Trademark of ProfilArbed)


ET PILE WALL
SHEET PILE
FLOW LINE
1
2
1) Welded joint
2) Joint with filler material

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