PERMANENT SHEET PILE WALL SYSTEM

PENNSYLVANIA TURNPIKE, MP 40.84 WB

As Part of Four to Six Lane Widening Associated with
Total Roadway and Bridge Reconstruction,
MP 39.62 to MP 44.04 in Allegheny County, PA

Presented at ASHE National Conference
Michael Sydlik, P.E., Earth, Inc.
May 10, 2019

EARTH, INC. Est. 1983

Honor Award winner in Special Projects category in ACEC National's 50th Engineering Excellence Awards competition

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Designer: Earth, Inc./Pittsburgh, PA
Client: Trumbull Corporation/Pittsburgh, PA
Owner: Pennsylvania Turnpike Commission

Wall face sheets on left and perpendicular (resistance) fin sheets to right

Patent No. 10,094,088

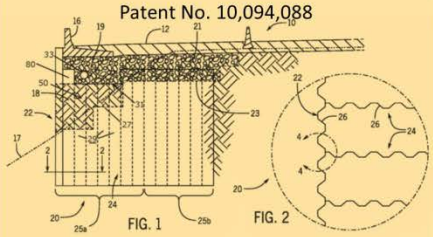


FIG. 1 FIG. 2

Cementitious backfill defining bottom of pipe/utility cradle

This project is a 1,573-foot long, permanent, value engineering, sheetpile retaining wall system to accommodate embankment widening of the Pennsylvania Turnpike from four to six lanes (including widening of the center median). It consists of Z-shaped, steel sheetpiles comprising the wall face which are restrained by similarly-shaped sheetpiles serving as vertically-planar, continuous tiebacks, i.e., fins attached to the wall face via three way connectors which provide resistance to lateral loading acting on the wall system.

Between the slope of the existing embankment and the wall face up to the top of the cradle sheets is cementitious backfill for pre-stressing the wall system when fluid – and when set, supporting the pipe/utility cradle. Basically, this wall system consists of a one-stage rather than two-stage construction process, i.e., the installation of interconnected, sheetpile elements effectively serving as their own temporary shoring – as compared to other types of construction including MSE wall, T-wall, or reinforced concrete cantilever wall – which would require the installation of temporary shoring to support the adjacent highway prior to the beginning of wall construction.

Downslope side of completed wall

Completed wall prior to moment slab/ barrier placement and paving

Completed wall showing both widened roadway and steep existing embankment slope below wall

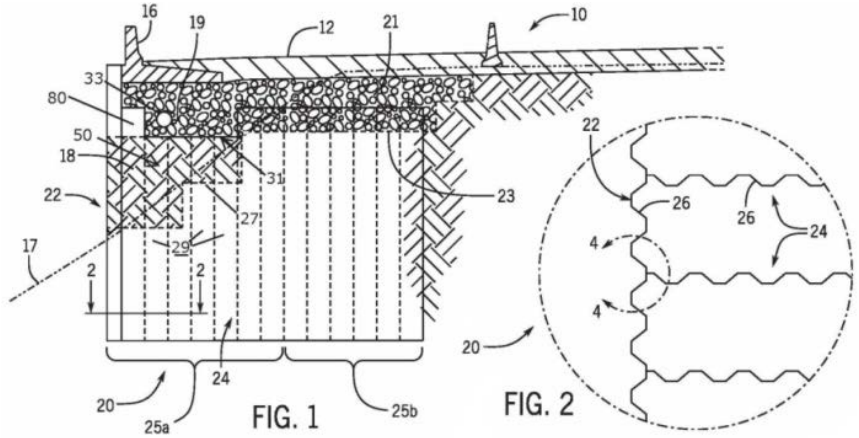
EARTH, INC.

ACEC
American Council of Engineering Companies
100 Years of Excellence

PERMANENT SHEET PILE WALL SYSTEM
PENNSYLVANIA TURNPIKE, MP 40.84 WB

- (from LinkedIn post of January 18, 2018)

Patent ~~Pending~~ No. 10,094,088*



* Patent allowed/received October 9, 2018

OUTLINE

- INTRODUCTION
- DESIGN CRITERIA/ANALYSIS
- SHEET PILE STRENGTH
- CONNECTION STRENGTH
- DRIVING OF SHEET PILES
- PHOTOGRAPHS
- FIELD MEASUREMENTS OF STRESS
- CONCLUSIONS

INTRODUCTION

PERMANENT SHEET PILE WALL SYSTEM

PENNSYLVANIA TURNPIKE, M.P. 40.84 WB

Owner: Pennsylvania Turnpike Commission, Brad Heigel, P.E. , Chief Engineer

Contractor: Trumbull Corporation, John Nemmer, Project Manager

Subcontractor: Brayman Construction, Logan Hamilton, Project Manager

Sheet Pile Supplier: LB Foster Piling, Richard Morales, P.E., M.Sc., F.ASCE, Director of Engineering

Designer: Earth, Inc., Michael Sydlik, P.E., M.Sc., M.ASCE, President

Original As-Bid T-Wall - $7,645,000

Estimated Construction Time (including temporary shoring) – 11 Months

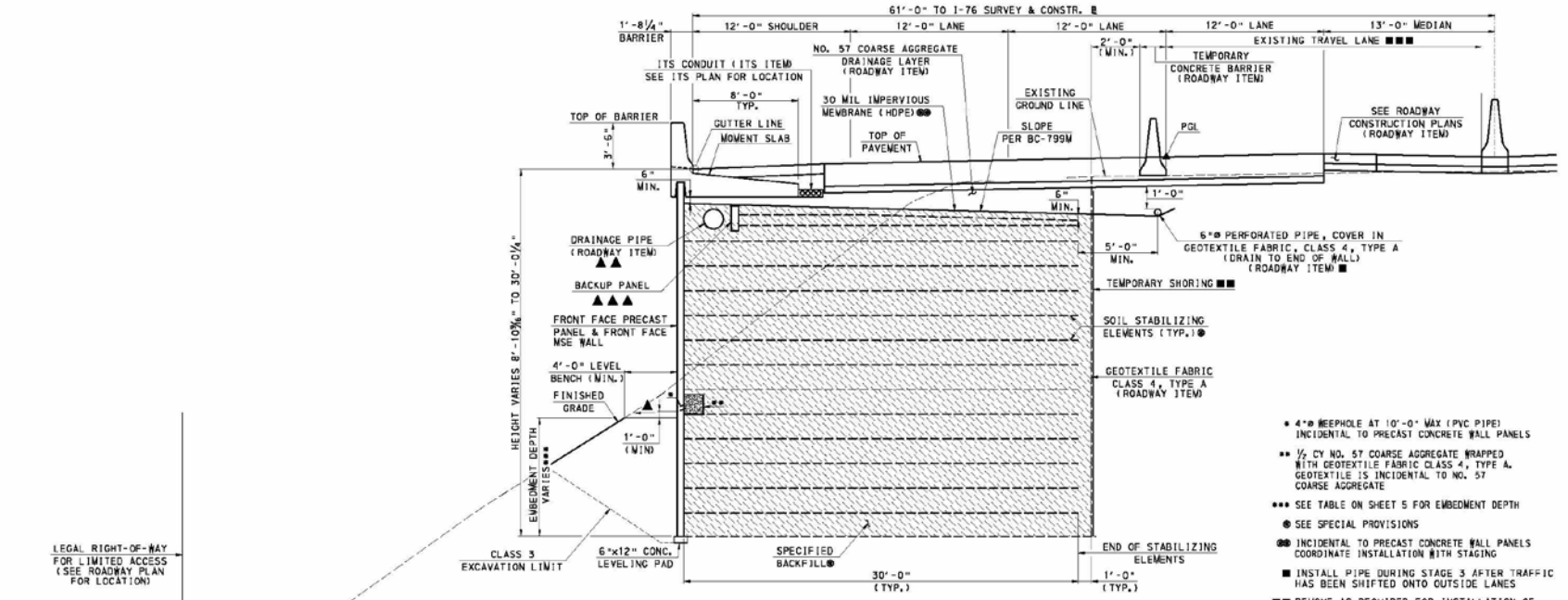
Value Engineering Sheet Pile Wall - $7,263,499

Actual Construction Time – 6 Months

Project Statistics:

- Length of Wall – 1,573 feet
- Max. Height of Wall – 21 feet exposed overtop existing 1-1/2:1 embankment slope
- PZC 26 Wall Face Sheets & PZC 13 Fin Sheets – 2,000 tons of steel
- Type C Flowable Backfill (300 psi) – 5,200 cy
- No. 57 Coarse Aggregate – 1,100 tons

AS-DESIGNED MSE WALL



TYPICAL SECTION
MECHANICALLY STABILIZED EARTH RETAINING WALL

NOTES:
- FOR GENERAL NOTES, SEE SHEET 5.
- FOR INDEX OF DRAWINGS, SEE SHEET 5.

DES. BSB | CKD. RDM | DWN. TAD | CKD. BSB

PREPARED BY:
McCORMICK TAYLOR, INC.
5 CAPITAL DRIVE
SUITE 400
HARRISBURG, PA 17110

PREPARED FOR:
THE PENNSYLVANIA TURNPIKE COMMISSION

PENNA TURNPIKE

NO.	REVISIONS	DATE	APPR.

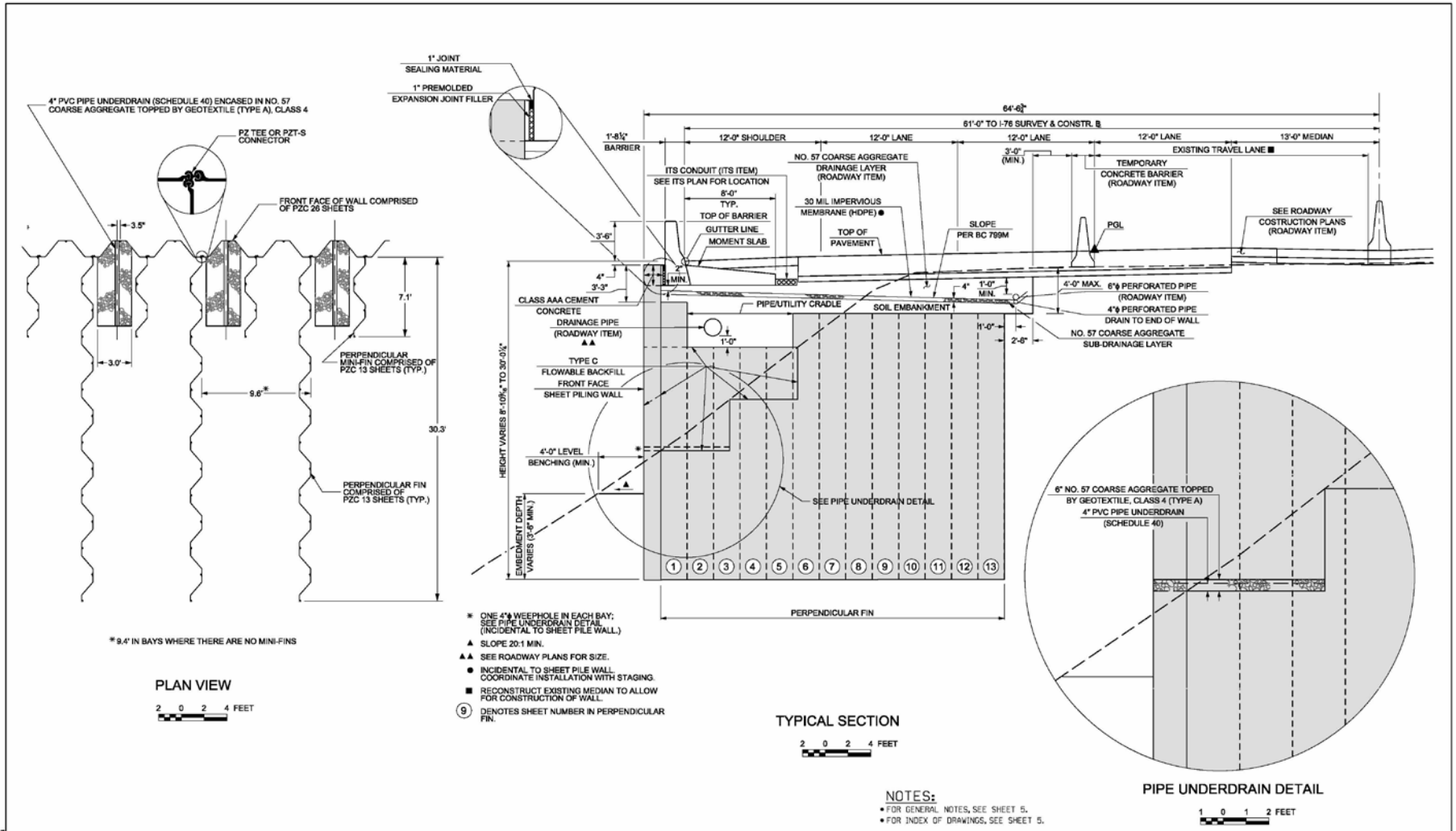
WBS NO. T-040.00T001-3-09
NETWORK NUMBER: 7004280
FILE NAME: MSE-RW40.84P8.DGN
DRAWING TYPE: 2G
STRUCTURE NUMBER: RE40.84WB
SCALE: AS NOTED

ROADWAY AND BRIDGE RECONSTRUCTION
MILEPOST 39.62 TO MILEPOST 44.04

STATION 635+21.62 TO
STATION 651+01.89, MILEPOST 40.84
RETAINING WALL RE40.84WB
MSE TYPICAL SECTION

DISTRICT: 1 | COUNTY: ALLEGHENY | DWG. NO. 8 OF 10
TOWNSHIP / BOROUGH: WEST DEER/INDIANA/HAMPTON TOWNSHIP | SHEET NO. 8 OF 19

SHEET PILE WALL



NOTES:
- FOR GENERAL NOTES, SEE SHEET 5.
- FOR INDEX OF DRAWINGS, SEE SHEET 5.

DES. MS	CKD. PEB	DWN. PWH	CKD. MS

PREPARED BY:
EARTH, INC.
THE GRISTMILL - SUITE 100
101 BELLEVUE ROAD
PITTSBURGH, PA 15229

PREPARED FOR:
THE PENNSYLVANIA TURNPIKE COMMISSION

PENNA TURN PIKE

NO.	REVISIONS	DATE	APPR.

WBS NO. T-040.00T001-3-09
NETWORK NUMBER: 7004280
FILE NAME: SP-RW40.84P8.DGN
DRAWING TYPE: 2G
STRUCTURE NUMBER: RE40.84WB

ROADWAY AND BRIDGE RECONSTRUCTION
MILEPOST 39.62 TO MILEPOST 44.04

STATION 635+21.62 TO
STATION 651+03.30, MILEPOST 40.84
RETAINING WALL RE40.84WB
SHEET PILE RETAINING WALL SYSTEM TYPICAL SECTION

DISTRICT: 1	COUNTY: ALLEGHENY	DWG. NO.	8 OF 14
TOWNSHIP / BOROUGH: WEST DEER/INDIANA/HAMPTON TOWNSHIP		SHEET NO.	8 OF 23

PERMANENT SHEET PILE WALL SYSTEM

PENNSYLVANIA TURNPIKE, MP 40.84 WB

Description of System

- Length of wall = 1,573 feet
- Maximum exposed height above existing 1½:1 embankment slope = 21 feet
- Sheet pile wall system founded at same depth and same horizontal extent as as-designed MSE wall
- Outer row of PZC 26 sheets constituting the wall portion of the system/lengths of sheets varying from 15 to 31 feet
- Resistance to earth pressure loading provided by fins of interconnected PZC 13 sheets serving as vertically-planar, continuous tiebacks
- Three-way connectors spaced at 9.4 to 9.6-foot lengths along the wall face (every 4 wall sheets) connecting fin sheets to wall face
- How do fin sheets provide resistance to the wall system?
  a) soil/steel interaction, i.e., friction, and
  b) the dead weight of the fins including soil contained within them to provide additional restoring moment.

PERMANENT SHEET PILE WALL SYSTEM
PENNSYLVANIA TURNPIKE, MP 40.84 WB

Key Supplementary Component

- Cementitious backfill in basically the middle third (height-wise) of the wall system
- Flowable, cementitious backfill is the preferred form of backfilling in the wedge defined by the wall face, steep existing embankment slope, and bottom of pipe/utility cradle for the following reasons:

  a) easier and faster to place than common or select embankment backfill

  b) cementitious backfill will pre-stress the wall system when fluid and reduce pressure on the wall system when solidified

  c) cementitious backfill is stronger than either common or select embankment, a key component in helping control stresses and deflections in the wall face

Advantages of Sheet Pile Wall System over other Wall Types

- TEMPORARY SHORING IS NOT REQUIRED TO BUILD THE SHEET PILE WALL ALTERNATIVE which results in one stage of wall construction – not two as would be required for an MSE wall or T-wall which would require the installation of temporary shoring before wall construction could even begin. In effect, the sheet pile wall system acts as its own temporary shoring.
- NET RESULT: SIGNIFICANT TIME SAVINGS IN ADDITION TO COST SAVINGS

DESIGN CRITERIA/ANALYSIS

PERMANENT SHEET PILE WALL SYSTEM

PENNSYLVANIA TURNPIKE, MP 40.84 WB

Existing Embankment Parameters

γ_m = 120 pcf

γ_{sat} = 125 pcf

C = 0 psf

ϕ = 32°

LRFD Analysis

- Pullout Resistance Performance Ratio = 1.53 > 1.0
- Overturning Performance Ratio = 1.17 > 1.0
- Tension in Fin Sheets = 7.8 ksi < 37.5 ksi
- Required Section Modulus of Wall Face = 11.4 in^3/ft < 39.08 in^3/ft
- Factor of Safety for Global Stability = 1.53 to 1.68 > 1.5

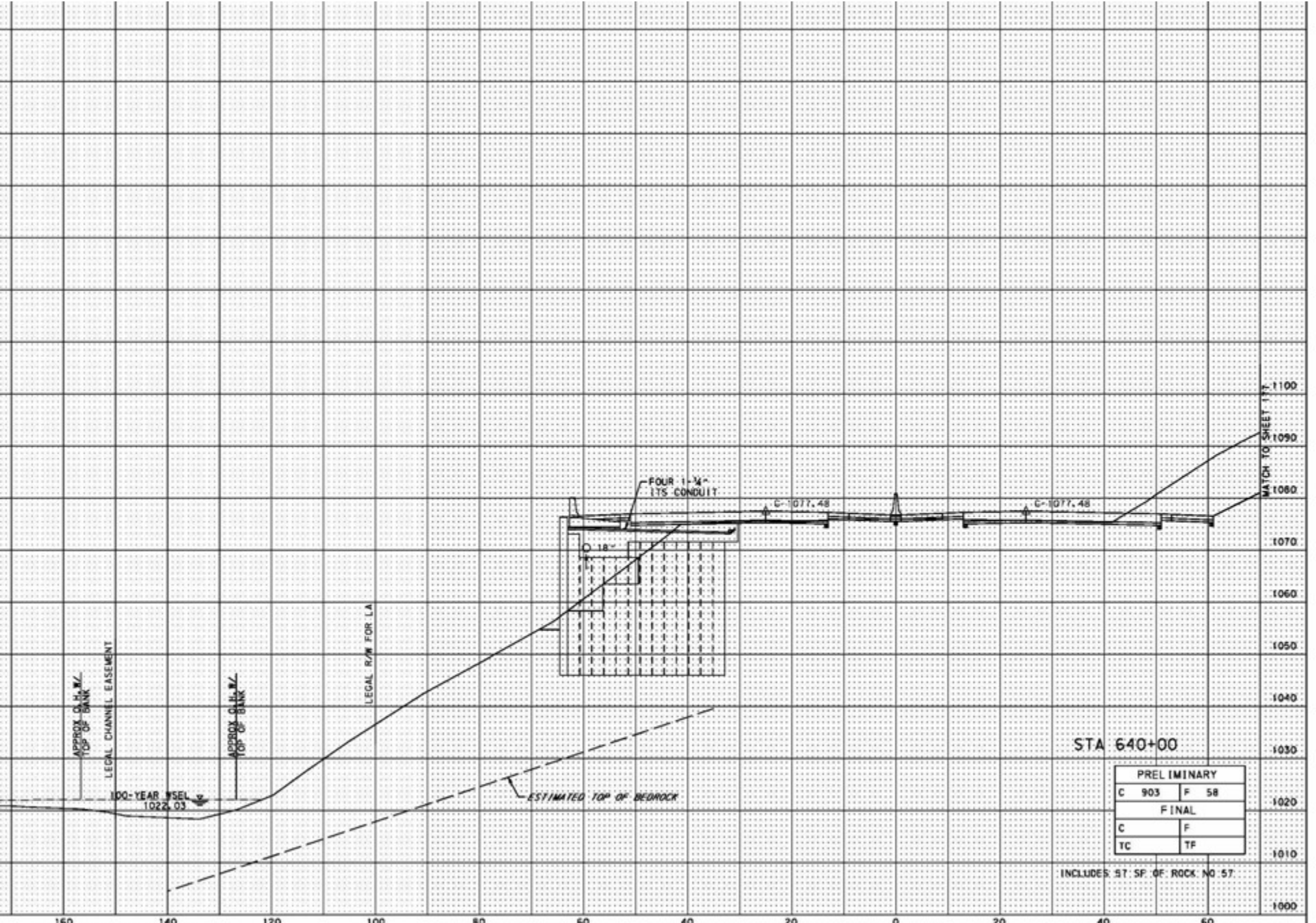
- Conclusion: more than satisfactory measures of the overall sheet pile wall system's performance have been achieved.

PERMANENT SHEET PILE WALL SYSTEM
PENNSYLVANIA TURNPIKE, MP 40.84 WB

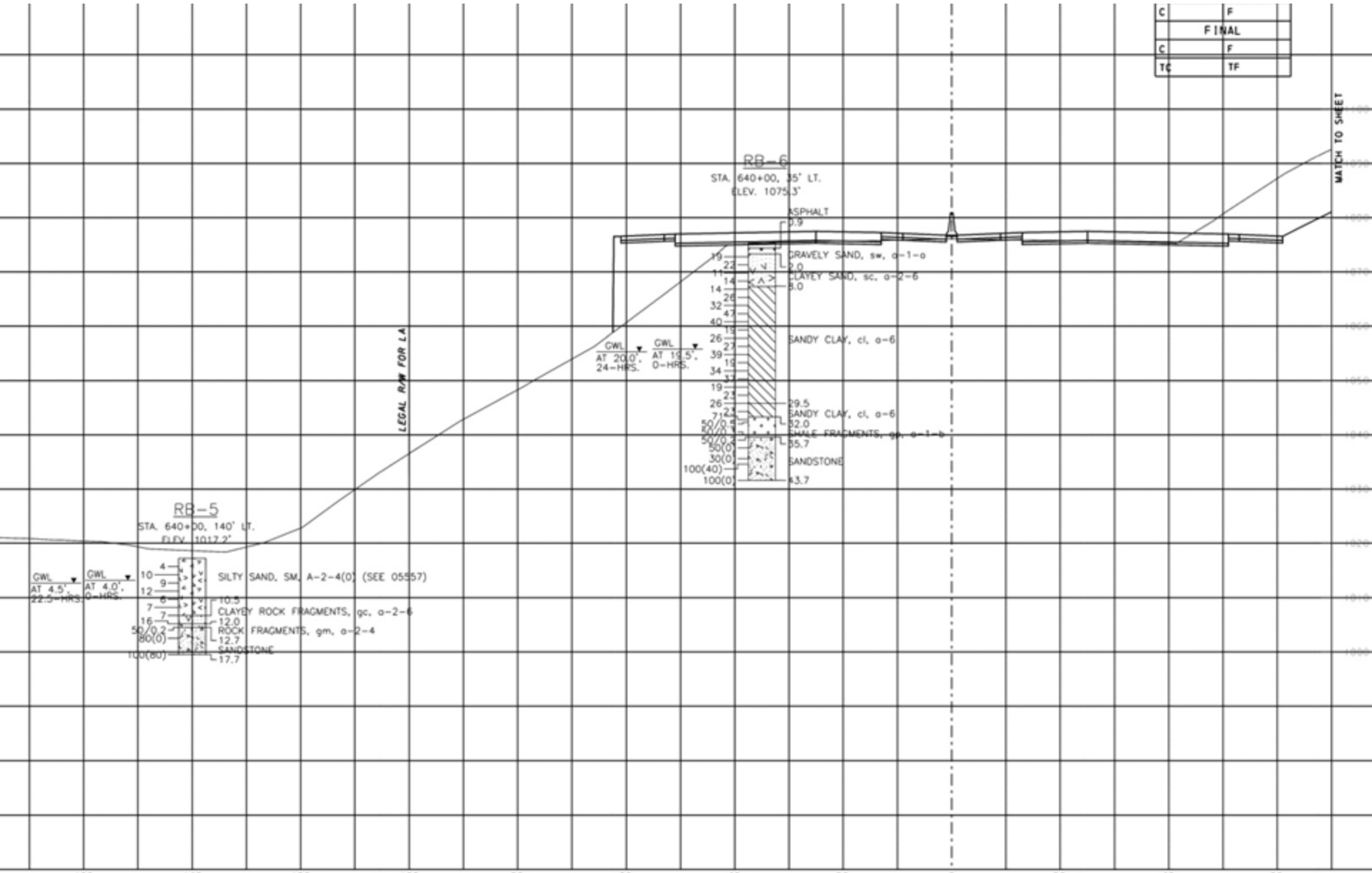
Ancillary Considerations:

- The 32 degree frictional design strength used in our sheet pile wall system design – as was the case for the as-designed MSE wall – was likely very conservative. Our experience with cantilever sheeting associated with the Pennsylvania Turnpike's MP A101 to MP A104 total reconstruction project on the Northeast Extension is that the actual strength of soil in the near vicinity of driven sheet piles can be effectively much greater given the vibration/densification action of the pile hammer installing the piles, the effect of which would result in an even stronger wall system.

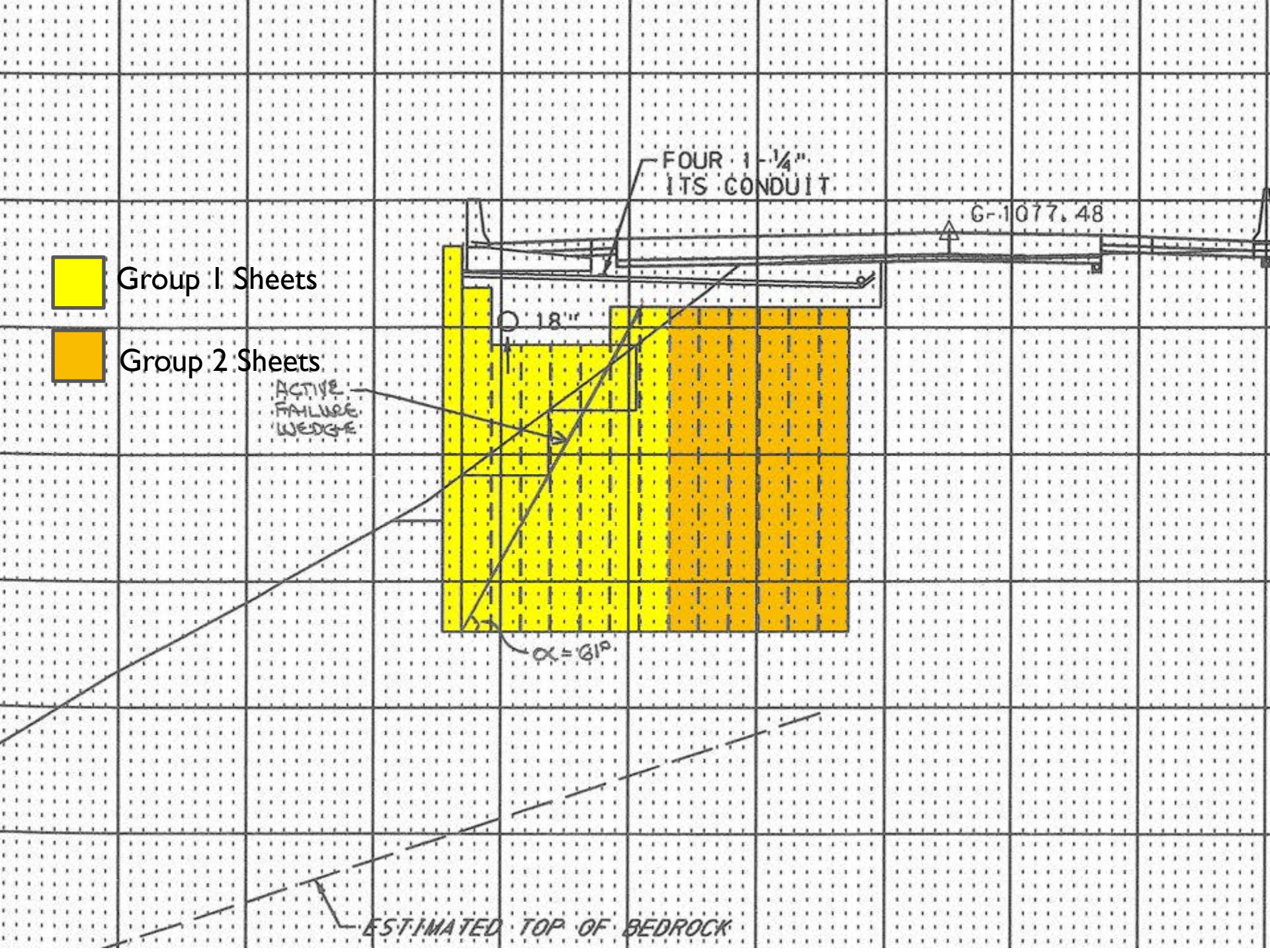
- SAI Consulting Engineers, Inc. was contracted by Trumbull to perform a peer review of the retaining wall design. As part of their review, SAI performed a structural analysis of the sheet pile wall utilizing a finite element analysis program. Based on their analysis, mini-fins - which are considered a structural component of the wall - located between the main fins were added to the design to limit the amount of stresses and deflection in the wall face (they do not contribute to global stability).



	NETWORK NUMBER: 7004280	WBS NO. T-040.00T001-3-09	ROADWAY AND BRIDGE RECONSTRUCTION MILEPOST 39.62 TO MILEPOST 44.04	ROUTE: I-76	STA 640+00
	FILE NAME: TC40-48_XS04-PLOT.dgn				
	DRAWING TYPE: 18	0 10 20 FEET		DISTRICT: 1 COUNTY: ALLEGHENY	DWG. NO. 175 OF 674
APPR.	STRUCTURE NUMBER:			TOWNSHIP / BOROUGH: WEST DEER TOWNSHIP	SHEET NO. 176 OF 679



	NETWORK NUMBER: 7004280	WBS NO. T-040.00T001-3-09	ROADWAY AND BRIDGE RECONSTRUCTION MILEPOST 39.62 TO MILEPOST 44.04	ROUTE: I-76	STA. 640+00 TO STA. 640+00
	FILE NAME: -			DISTRICT: 1 COUNTY: ALLEGHENY	DWG. NO. 20 OF 61
	DRAWING TYPE: 1B	0 10 20		TOWNSHIP / BOROUGH: HAMPTON, WEST DEER AND INDIANA TOWNSHIPS	SHEET NO. 39 OF 98
APPR.	STRUCTURE NUMBER:				


Group 1 Sheets
Group 2 Sheets
FOUR 1-¼" ITS CONDUIT
G-1077.48
18"
ACTIVE FAILURE WEDGE
α = 61°
ESTIMATED TOP OF BEDROCK

For walls with one anchor level:

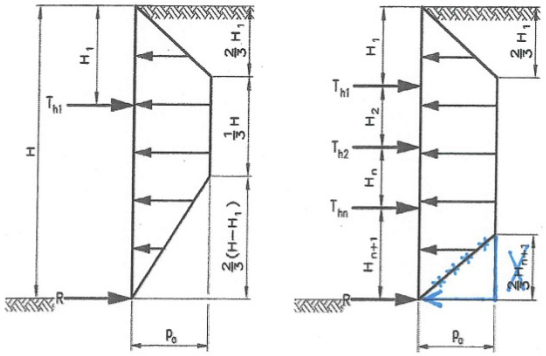
$$p_a = k_a \gamma'_s H \qquad (3.11.5.7.1\text{-}1)$$

For walls with multiple anchor levels:

$$p_a = \frac{k_a \gamma'_s H^2}{1.5H - 0.5H_1 - 0.5H_{n+1}} \qquad (3.11.5.7.1\text{-}2)$$

where:

p_a = maximum ordinate of pressure diagram (ksf)
k_a = active earth pressure coefficient
= $\tan^2(45 \text{ degrees} - \phi_f/2)$ (dim.) for $\beta = 0$
use Eq. 3.11.5.3-1 for $\beta \neq 0$
γ'_s = effective unit weight of soil (kcf)
H = total excavation depth (ft)
H_1 = distance from ground surface to uppermost ground anchor (ft)
H_{n+1} = distance from base of excavation to lowermost ground anchor (ft)
T_{hi} = horizontal load in ground anchor i (kip/ft)
R = reaction force to be resisted by subgrade (i.e., below base of excavation) (kip/ft)



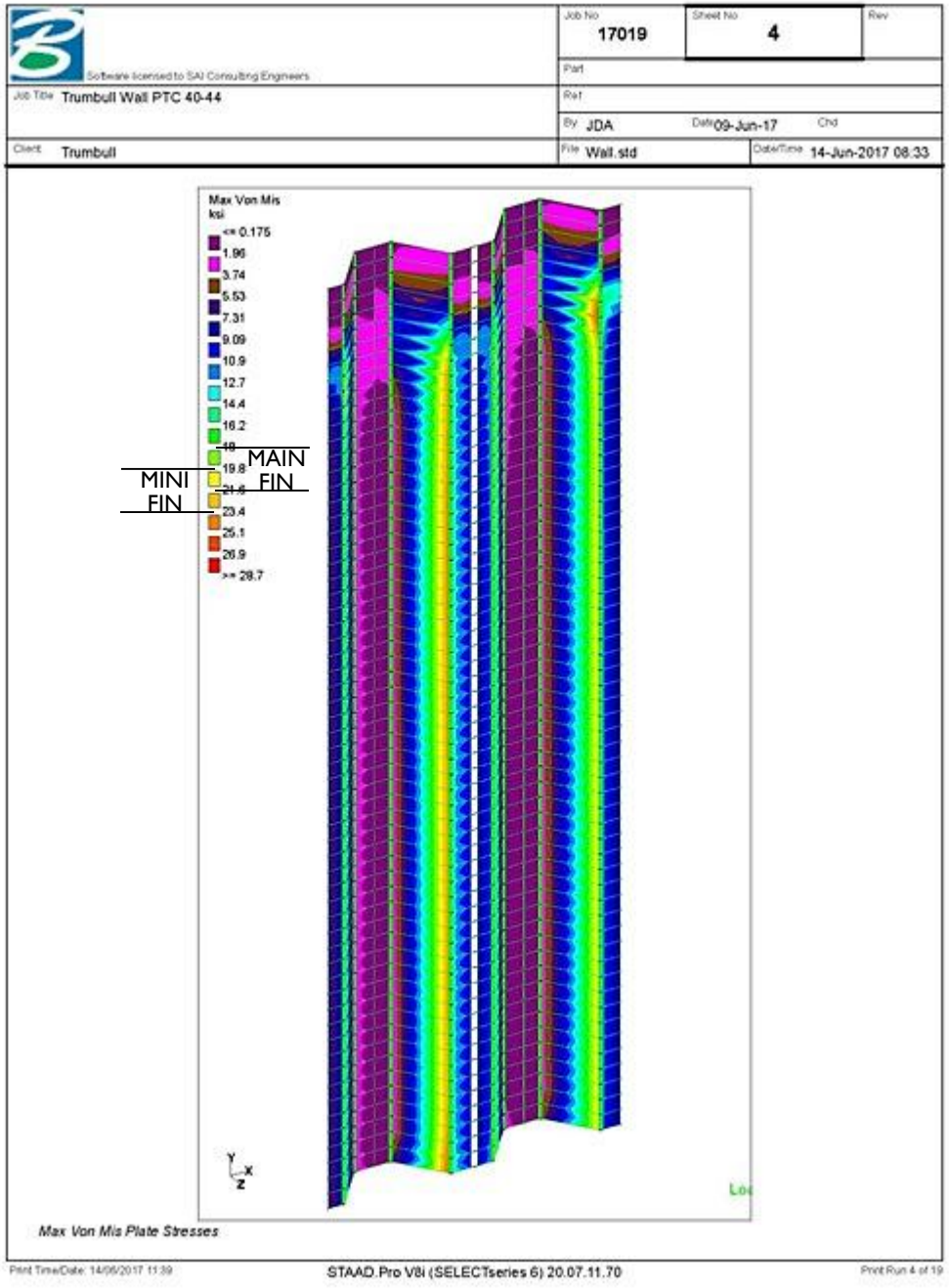
(a) Wall with one level of ground anchors

(b) Walls with multiple levels of ground anchors

Figure 3.11.5.7.1-1—Apparent Earth Pressure Distributions for Anchored Walls Constructed from the Top Down in Cohesionless Soils

3.11.5.7.2—Cohesive Soils

The apparent earth pressure distribution for cohesive soils is related to the stability number, N_s, which is defined as:



HORIZONTAL STRESS

MAIN FIN = 20 KSI
MINI-FIN = 21.5 KSI

SHEET PILE STRENGTH

GERDAU

US-ML-PETERSBURG
25801 HOFHEIMER WAY
PETERSBURG, VA 23803
USA

CERTIFIED MATERIAL TEST REPORT

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE
LB FOSTER 1501 BAXTER ROAD ROCKFORD,IL 61109 USA	L B FOSTER COMPANY INC PITTSBURGH,PA 15230-2806 USA	A572-50 LENGTH 75'00"
SALES ORDER 286932/000030		SPECIFICATION / A572/A572M-07 ASTM A6/A6M-11

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
208485	1330-0000017538	04/08/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %
0.11	0.98	0.018	0.019	0.18	0.36	0.11	0.15	0.027	0.016

CHEMICAL COMPOSITION

CEqvA6 %
0.3

MECHANICAL PROPERTIES

YS KSI	UTS KSI	YS MPa	UTS MPa	G/L Inch
71.0	80.6	490	556	8.000
67.9	77.1	468	532	8.000

AVE = 69.5 ksi

AVE = 78.9 ksi

MECHANICAL PROPERTIES

Elong %	Y/T rati %
18.80	0.881
20.10	0.881

COMMENTS / NOTES

Yield Strength = 69.5 ksi
Tensile Strength = 78.9 ksi

CONNECTION STRENGTH

Sheet Piling Interlocks Tested

Table 1: Test matrix

1		U PILES	4		COMBINATION WALLS
2		EUROPEAN Z PILES	5		FLAT SHEET PILES
3		EUROPEAN Z PILES	6		BALL AND SOCKET Z PILES

- * Take additional specimens (3 in total) featuring differing production tolerances in order to obtain 3 specimen per test setup and manufacturer.

- Underlined specimen to be tested double in declutching test

Table 1: Test matrix

1		U PILES	4		COMBINATION WALLS
2		EUROPEAN Z PILES	5		FLAT SHEET PILES
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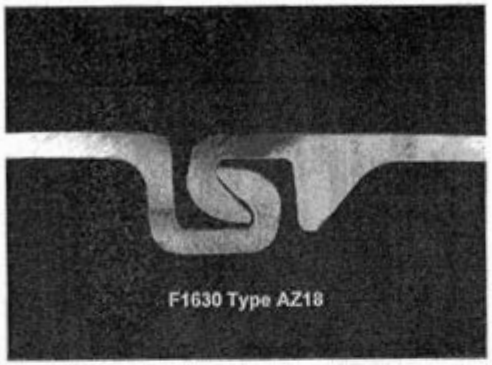
- * Take additional specimens (3 in total) featuring differing production tolerances in order to obtain 3 specimen per test setup and manufacturer.

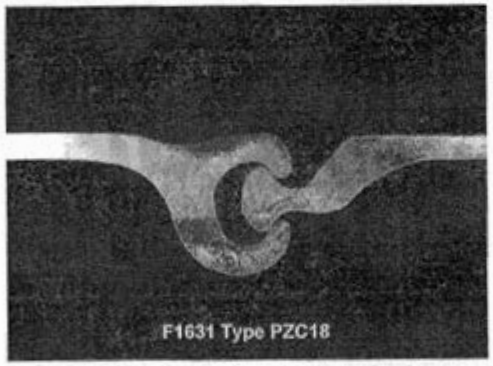
- Underlined specimen to be tested double in declutching test

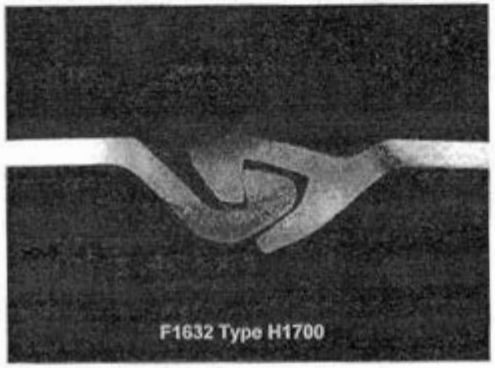
STORK® Materials Technology

CERTIFICATE

OVERVIEWPICTURES OF THE DIFFERENT SHEETPILECONNECTIONS BEFORE TESTING







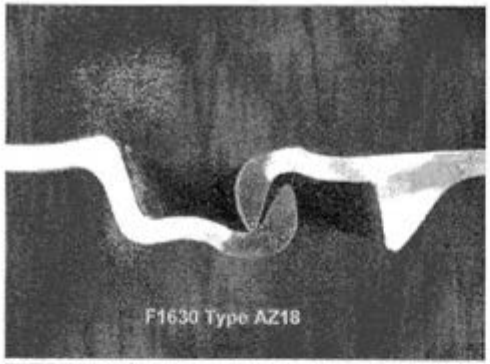
CONNECTOR TYPE

Hook
European Z Piles

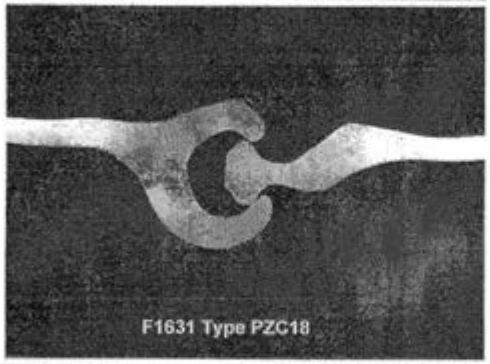
Ball and Socket
Z Piles

Claw
European Z Piles

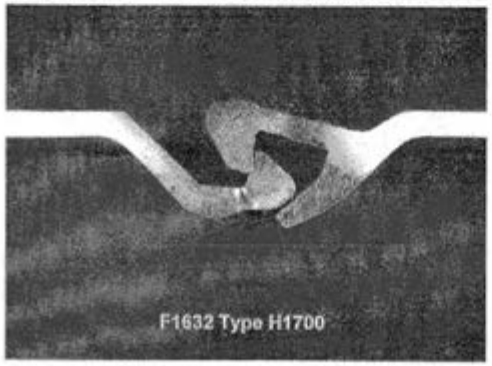
FAILURE LOAD
4" wide band, 3/8" thick



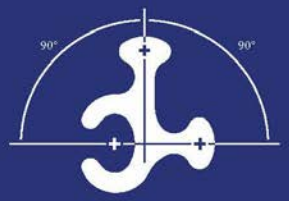
18 Kips



44 Kips



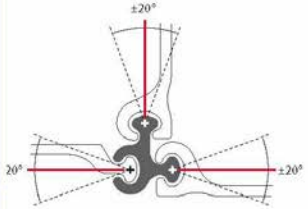
20 Kips



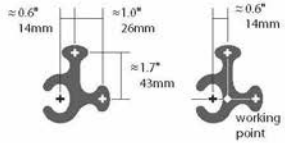
PZ Tee

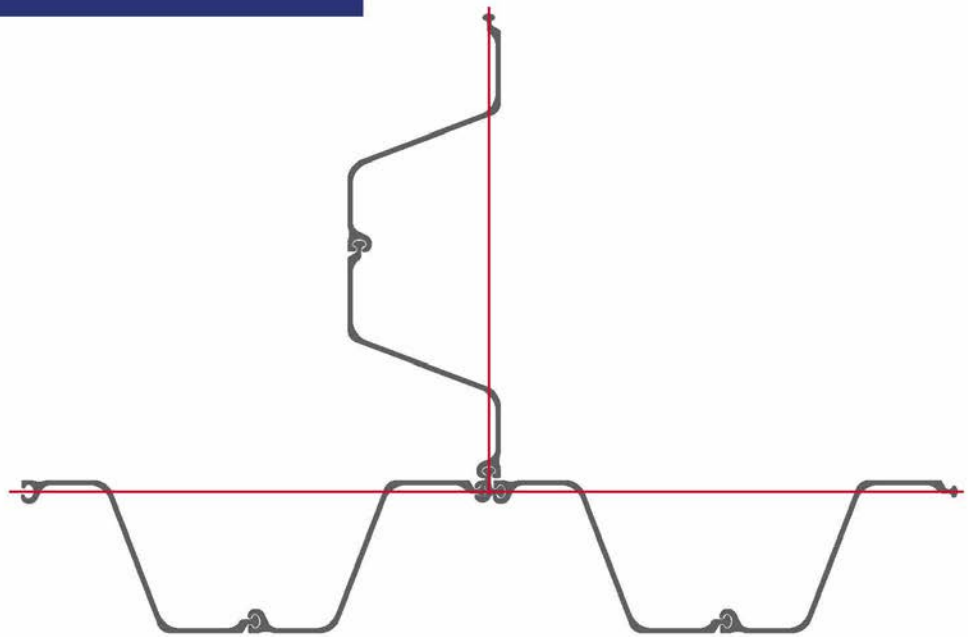
For T-corners, For 90° corners (± 40°)

Flexibility



Dimensions





WEIGHT:
~ 9.0 lb/ft
~ 13.4 kg/m

TYPICAL STEEL GRADES:
ASTM A572 Gr. 50/60
ASTM A690
Other steel grades available upon request.

For additional details:
pilepro.com/pztee

Delivery of the most typical connectors can be made to most US destinations within 2 to 4 days.

Mill Test Report

PilePro
A PilePro Group Company

Test Date: 2/18/14

DESCRIPTION: PZ-TEE — PATENTED PILEPRO CONNECTOR

Steel Grade: ASTM A572-07 GRADE 50
Cast Number: A134743
Sample Number: 1

	PSI
Yield Strength (0.2% offset):	94235
Tensile Strength:	109308
% Elongation (in 1"):	26

Yield Strength = 94.2 ksi
Tensile Strength = 109.3 ksi

Chem:

C	0.1800
CB	0.0000
Cr	0.1700
Cu	0.2400
MN	1.3800
Mo	0.0500
Ni	0.0900
P	0.0100
S	0.0180
SI	0.2700
V	0.0710

MTR ID: 4122

100% MELTED AND MANUFACTURED IN THE U.S.A

THIS TEST REPORT IS IN COMPLIANCE WITH EN STANDARD 10204 SECTION 3.1
WE CERTIFY THIS REPORT TO BE CORRECT AND MEETS ALL SPECIFICATIONS

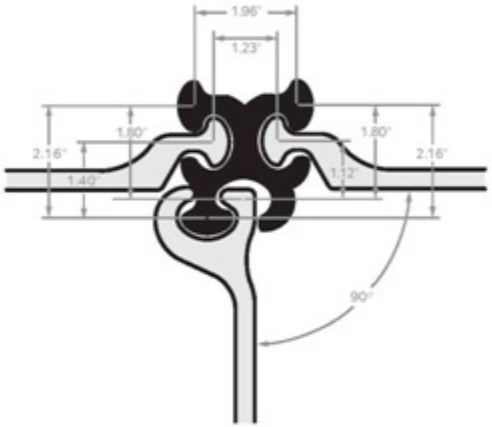
Data sheets available at www.PilePro.com

Electronically generated document, no additional signatures required

Issued by PilePro Steel, LP., 10808 FM 1625, Austin, Texas 78747 Tel 866 666 7453 www.PilePro.com

SKPT

Steel Sheet Pile Connectors

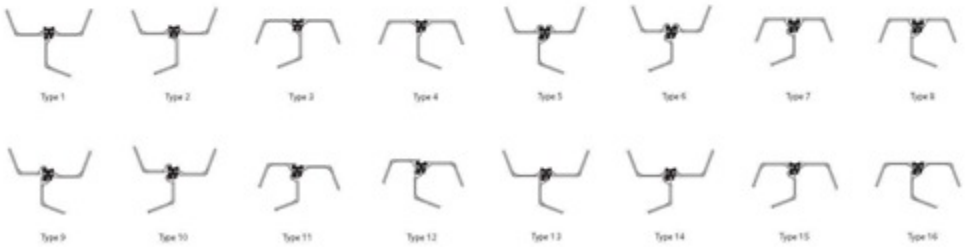


- Designed for use in Ball & Socket (PZ/PZC) Applications
- Can Be Used in 64 Different Orientations

ATTACHMENT PROCEDURE
1. Thread connector into interlock of sheet pile.
2. Tack weld connector to pile.

ASTM A572 Gr. 65
11.30 lb/ft

Orientations



DRIVING OF SHEET PILES

Teleskopmäkler
Telescopic leader mast

MOBILRAM-System
TM 13/16 SL

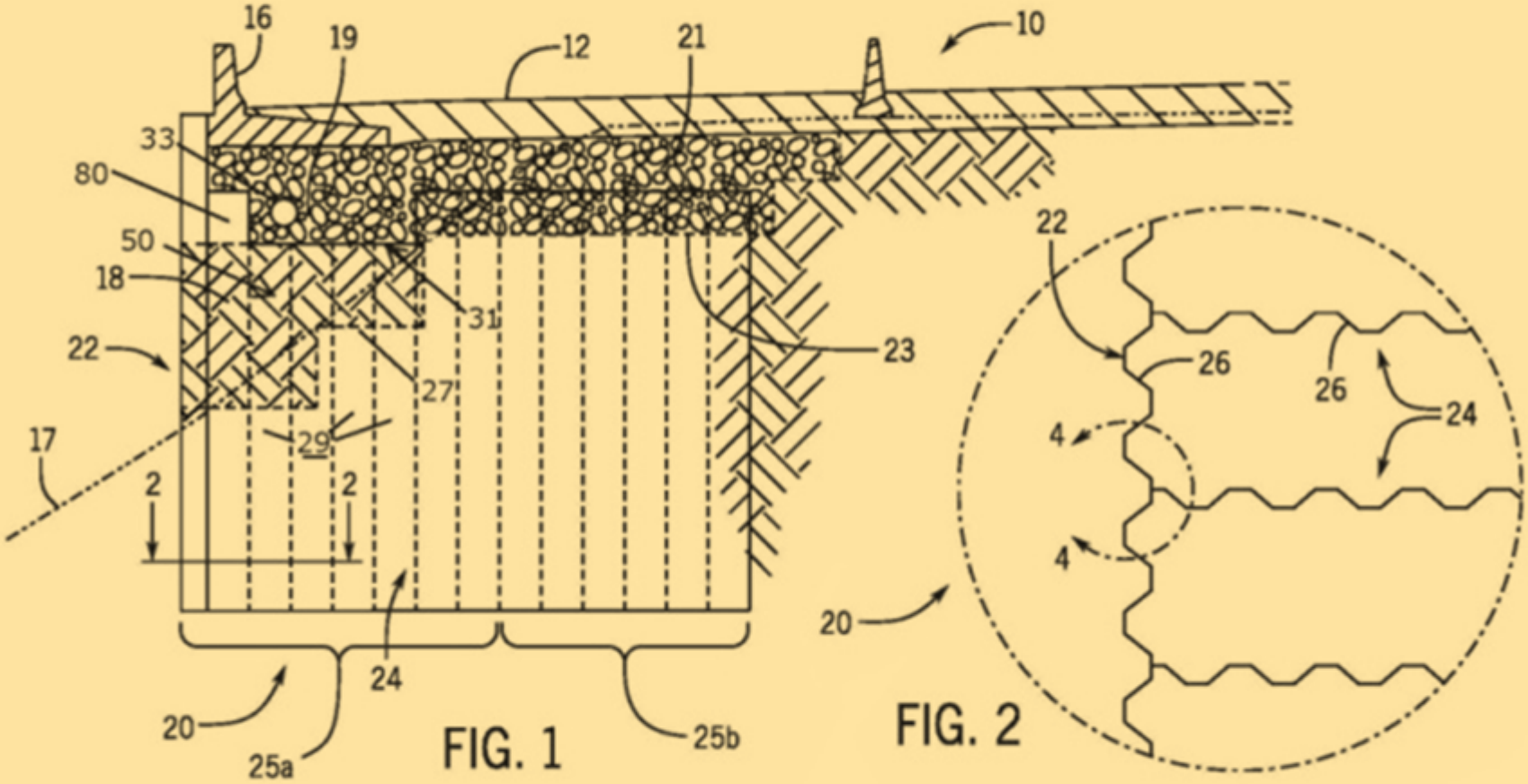
Technische Daten - Technical data

Sheet Pile Installation

https://vimeo.com/261888574/31e6c10c67

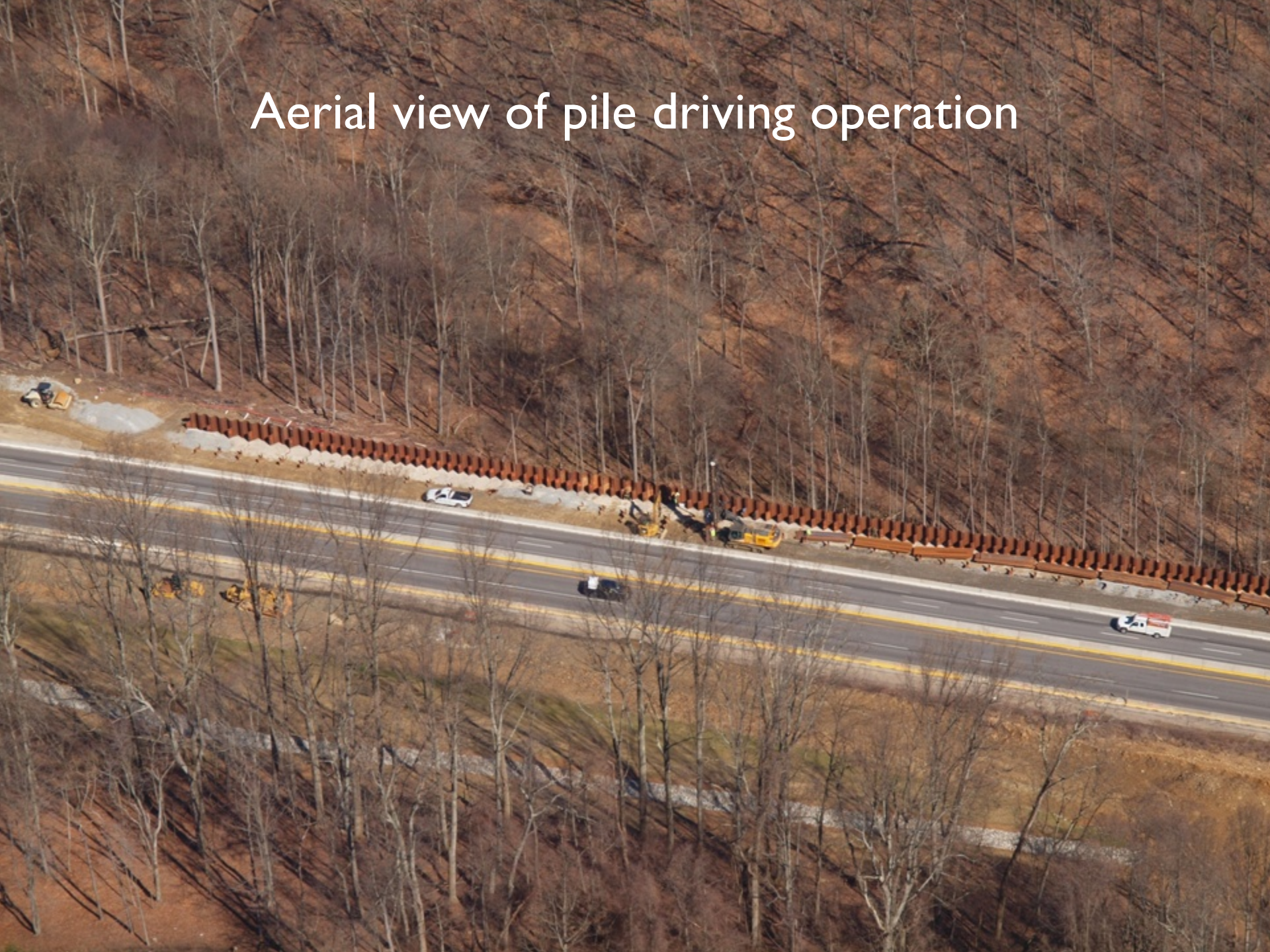
PHOTOGRAPHS

Patent No. 10,094,088



Perspective view of sheet pile wall

Aerial view of pile driving operation




Transition from only main fins on left (lesser wall height) to main fins with intermediate/mini-fins (greater wall height)


Wall face sheets on left
and perpendicular (resistance) fin
sheets to right


Cementitious backfill defining bottom of pipe/utility cradle

Closeup showing cementitious backfill against wall face, main fins, and mini-fins

Closeup of ball and socket connection

Closeup of ball and socket connection with 3-way connector

Group 2 Piles
(6 fin sheets)

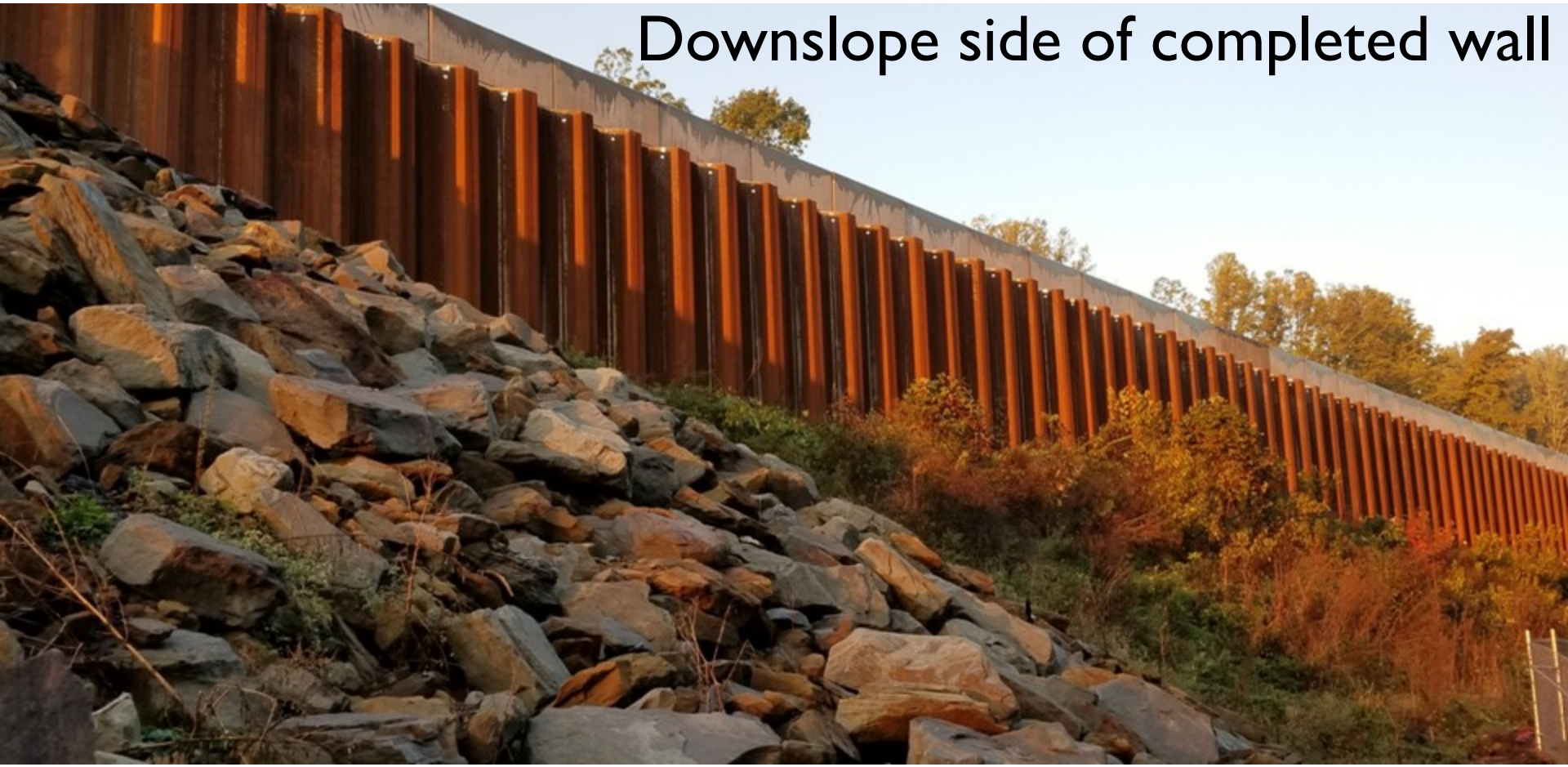
Group 1 Piles
(7 fin sheets and wall face sheets)

Completed wall prior to moment slab/barrier placement and paving

Sheet pile wall system fully backfilled with barrier and moment slab in place

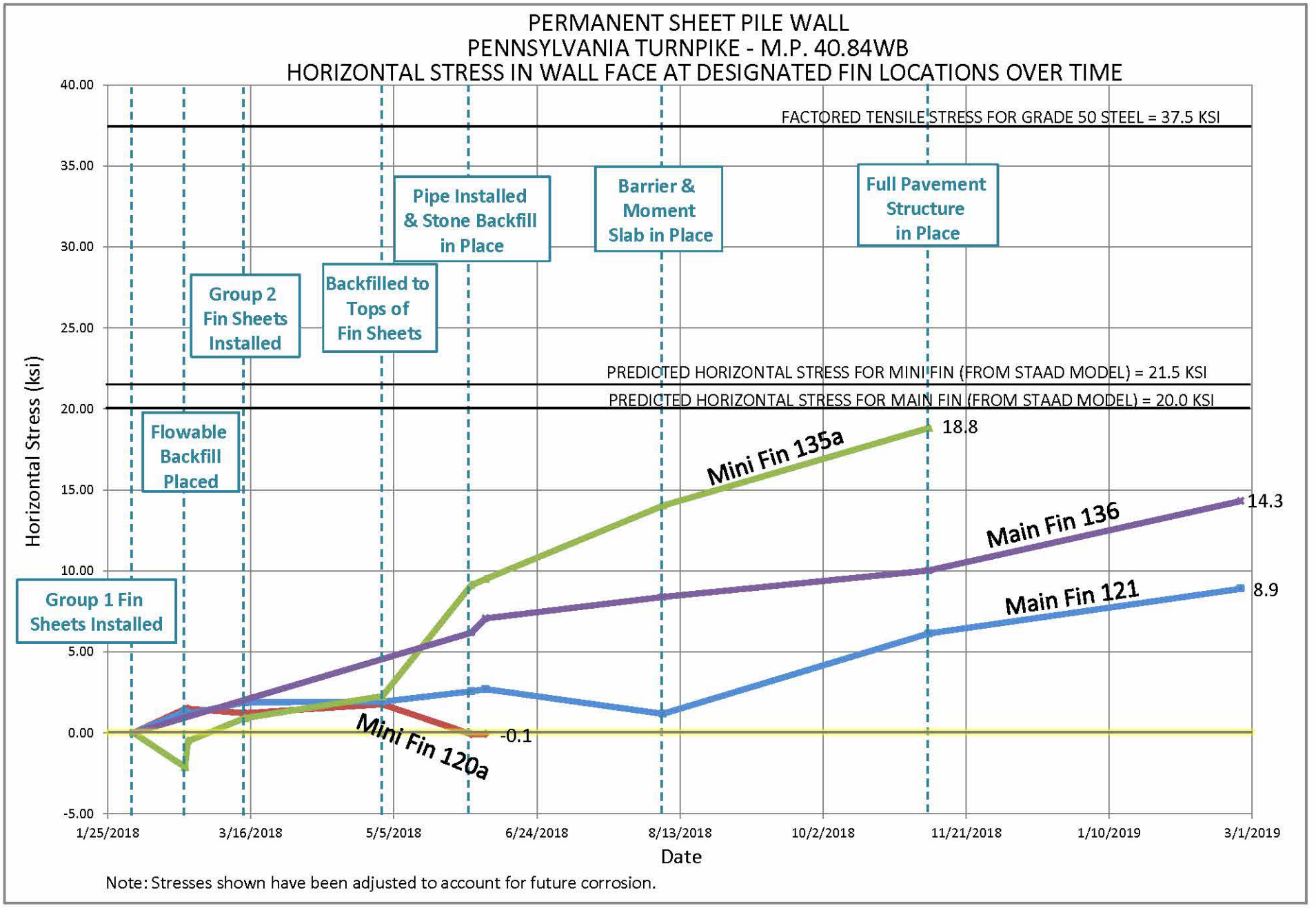
Downslope side of completed wall


Completed wall showing both
widened roadway and steep existing
embankment slope below wall

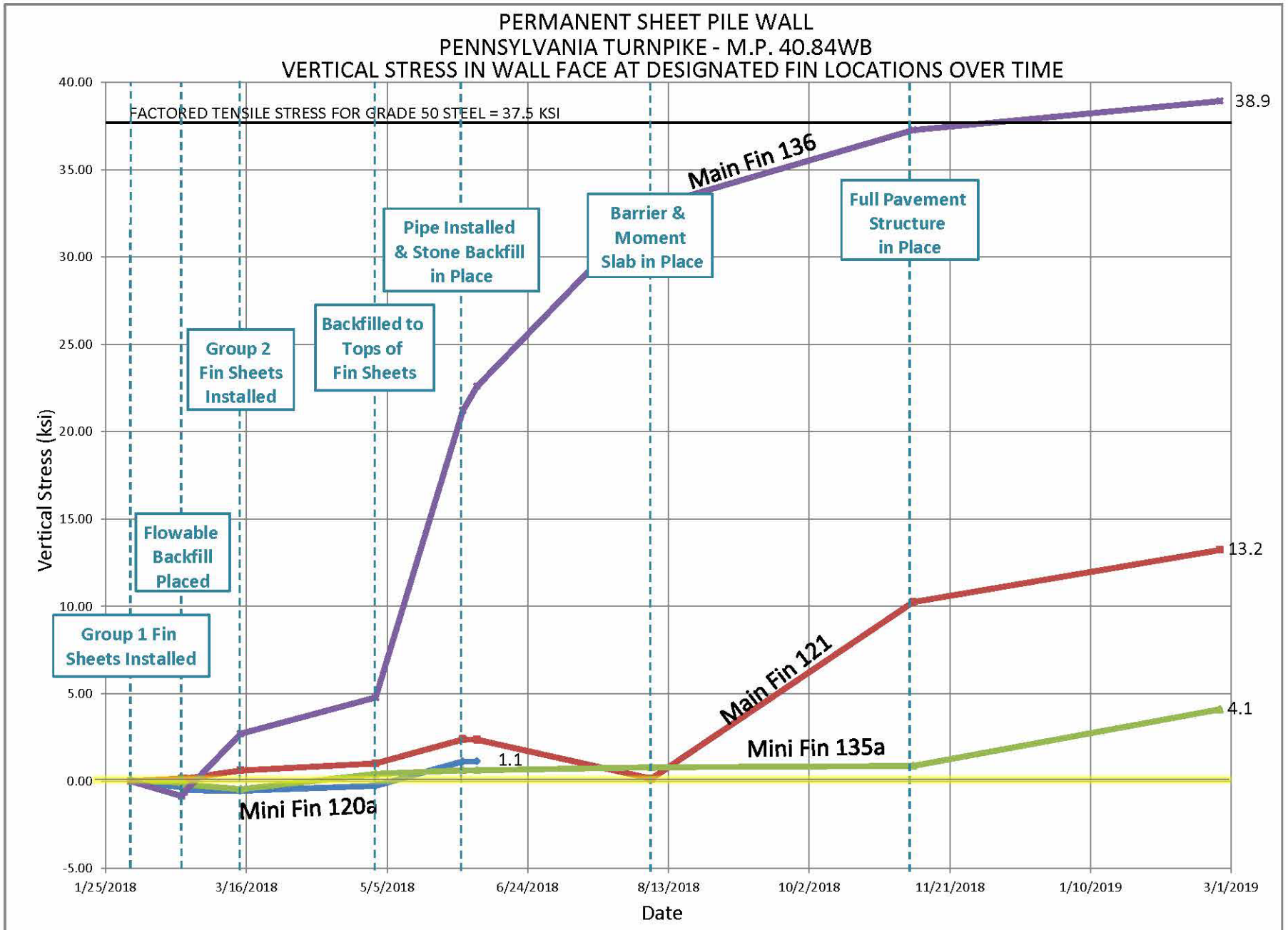

Downslope side of completed wall

FIELD MEASUREMENT OF STRESS

Horizontal and vertical strain gauges positioned at base of exposed wall face



Note: Stresses shown have been adjusted to account for future corrosion.



Note: Stresses shown have been adjusted to account for future corrosion.

CONCLUSIONS

- Based on stress measurements to date, this Sheet Pile Retaining Wall System appears to be functioning as anticipated.
- This sheet pile wall system is probably only cost effective where there is an existing highway that must be protected, i.e., there would need to be temporary shoring that had to be installed to offset the rather large material requirements of the sheet pile wall system.
- Certainly, this sheet pile wall system could not be used where installation of the sheets via vibratory hammer would induce unacceptable settlement/lateral movement to nearby structures.
- If hard driving is expected, this sheet pile wall system would probably not be the way to go, as costs for increased construction time to advance the sheets could quickly escalate, thereby negating the cost savings.
- If this sheet pile wall system is a valid alternative, the time savings can be huge when compared to other types of wall construction.
- If the construction of this sheet pile wall system is on the critical path, even more cost savings may be realized due to the reduced time required for construction when compared to other types of walls.