Second Avenue Subway, New York
Geotechnical Design and Construction

Chu Ho **Sc.D., P.Eng., M.ASCE**

Arup, New York

ARUP

TEAM

- Owner & Program Manager
- Design Consultant
- Consultant Construction Manager

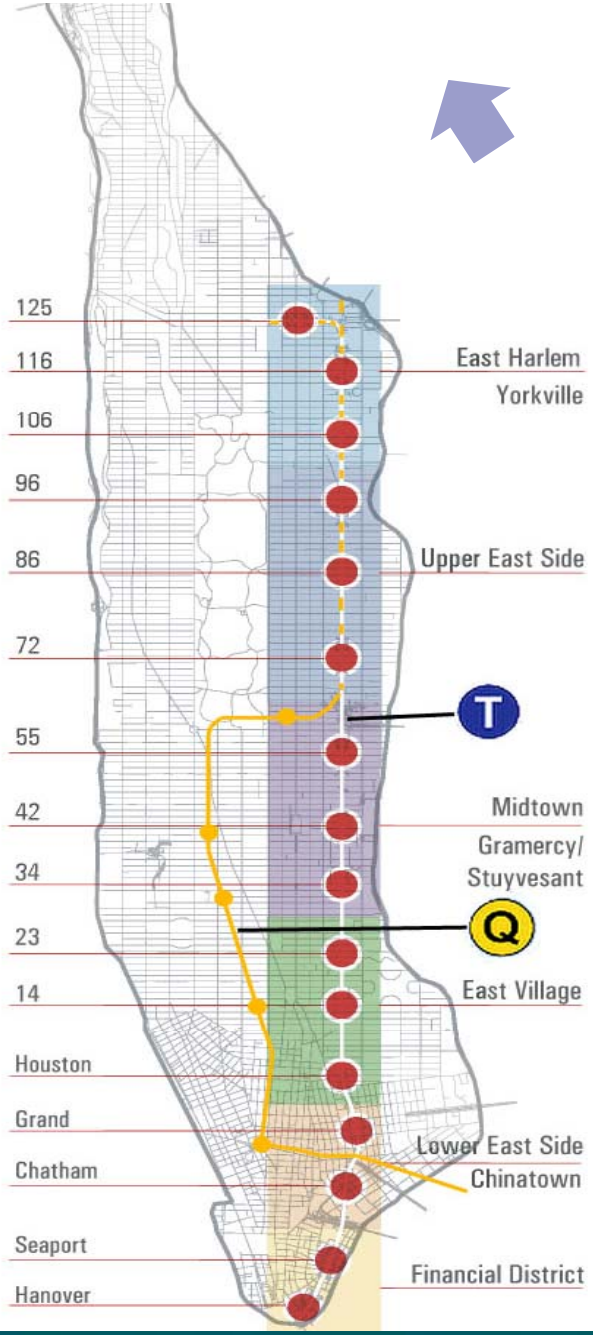
MTA Capital Construction

AECOM • ARUP
A Joint Venture

PB PARSONS BRINCKERHOFF

- 8.5 miles of new subway
- 16 new stations
- 1 renovated station
- Yards for 28 trains

- 2 services, T & Q
- Connection to existing Q line
- Transfers to 7 other rail lines



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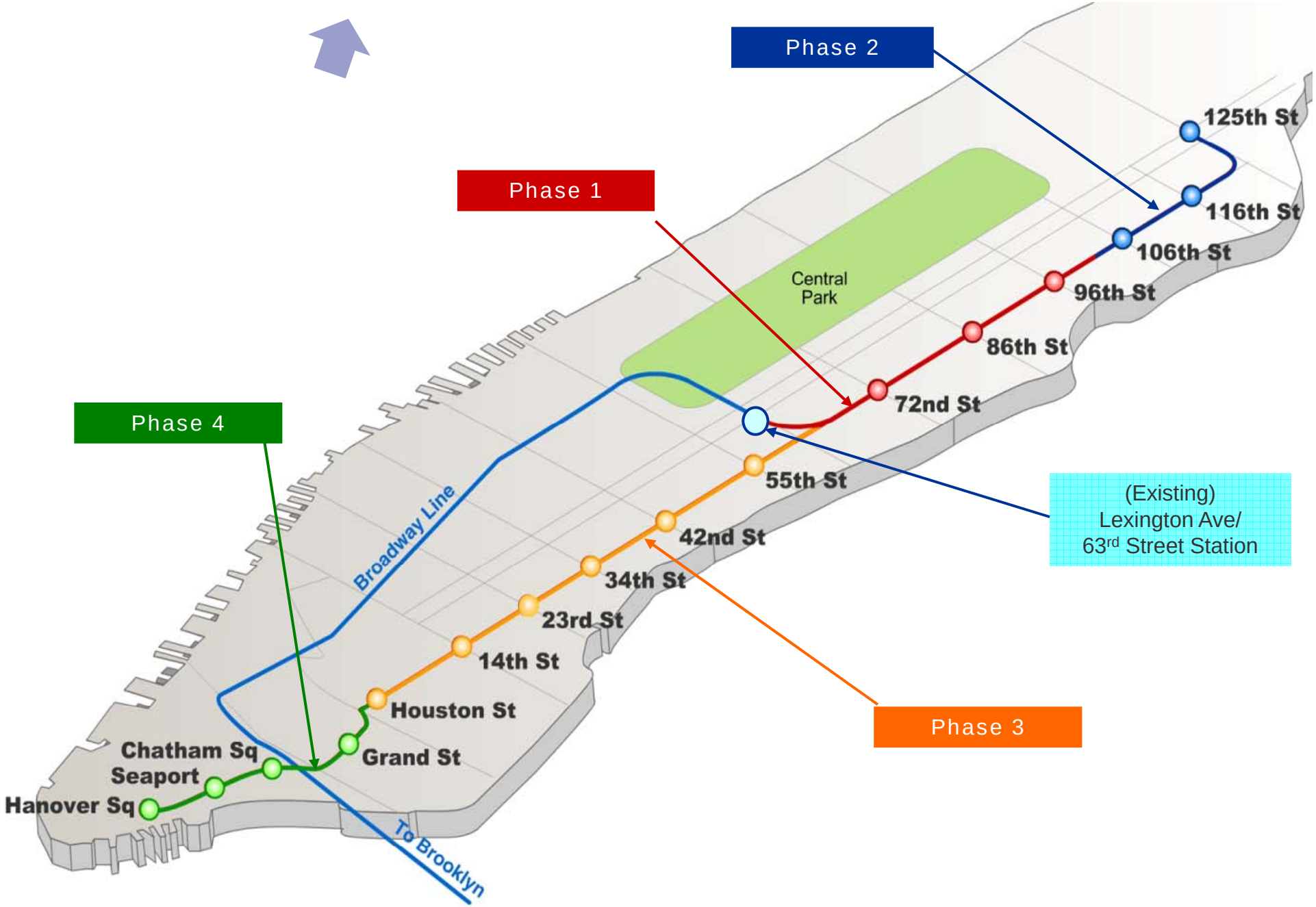
Phase 2
Phase 1
Phase 4
Phase 3
125th St
116th St
106th St
96th St
86th St
72nd St
55th St
42nd St
34th St
23rd St
14th St
Houston St
Grand St
Chatham Sq
Seaport
Hanover Sq
Central Park
Broadway Line
To Brooklyn
(Existing)
Lexington Ave/
63rd Street Station

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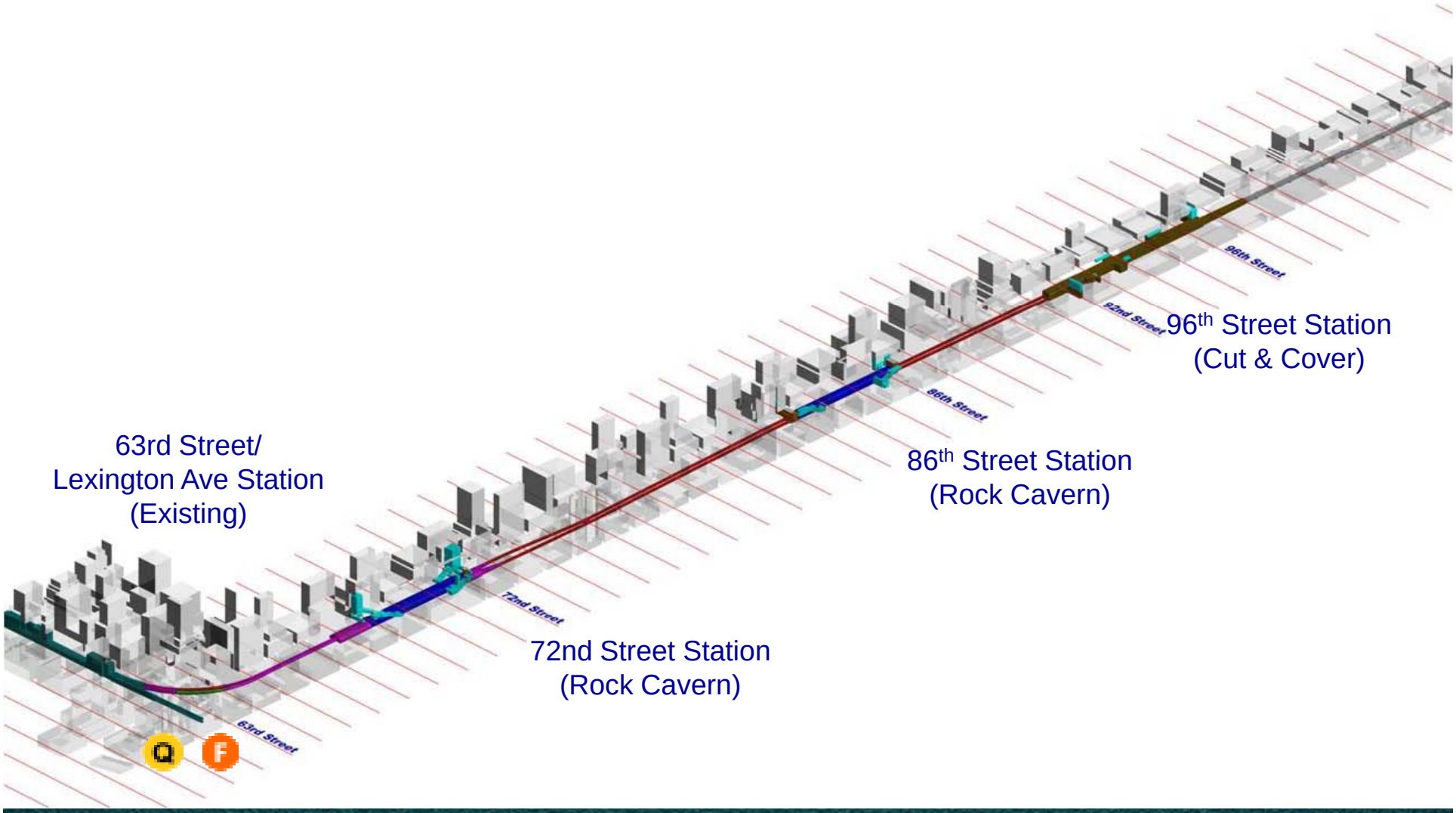
Phase 1 – Construction In Progress



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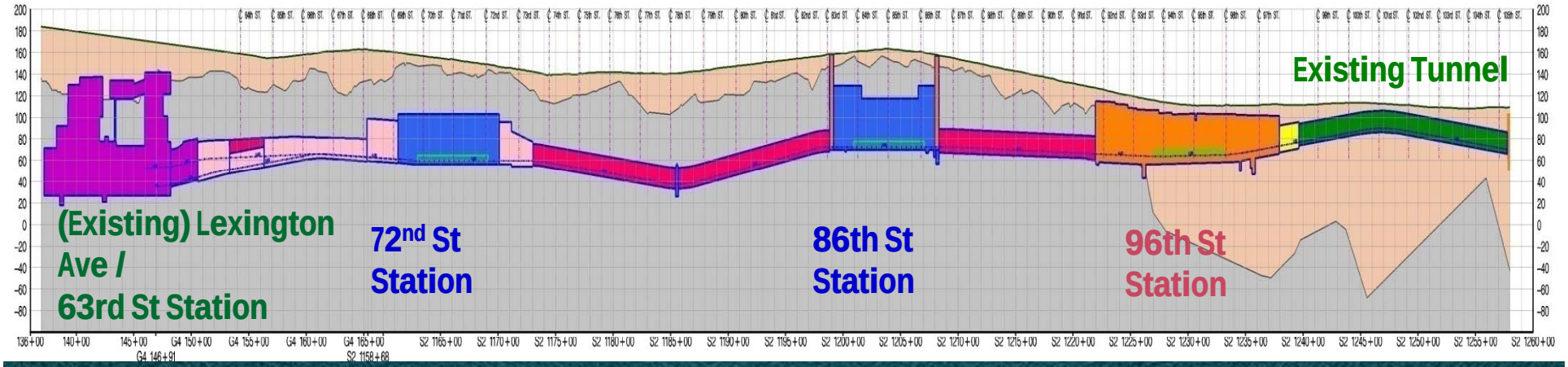
Phase 1 – Subway Alignment Geology



Subsurface Stratification

Fill

Organics

Silty Sand

Varved Silt/Clay

Glacial Till

Decomposed Rock

Bedrock (Manhattan Schist)

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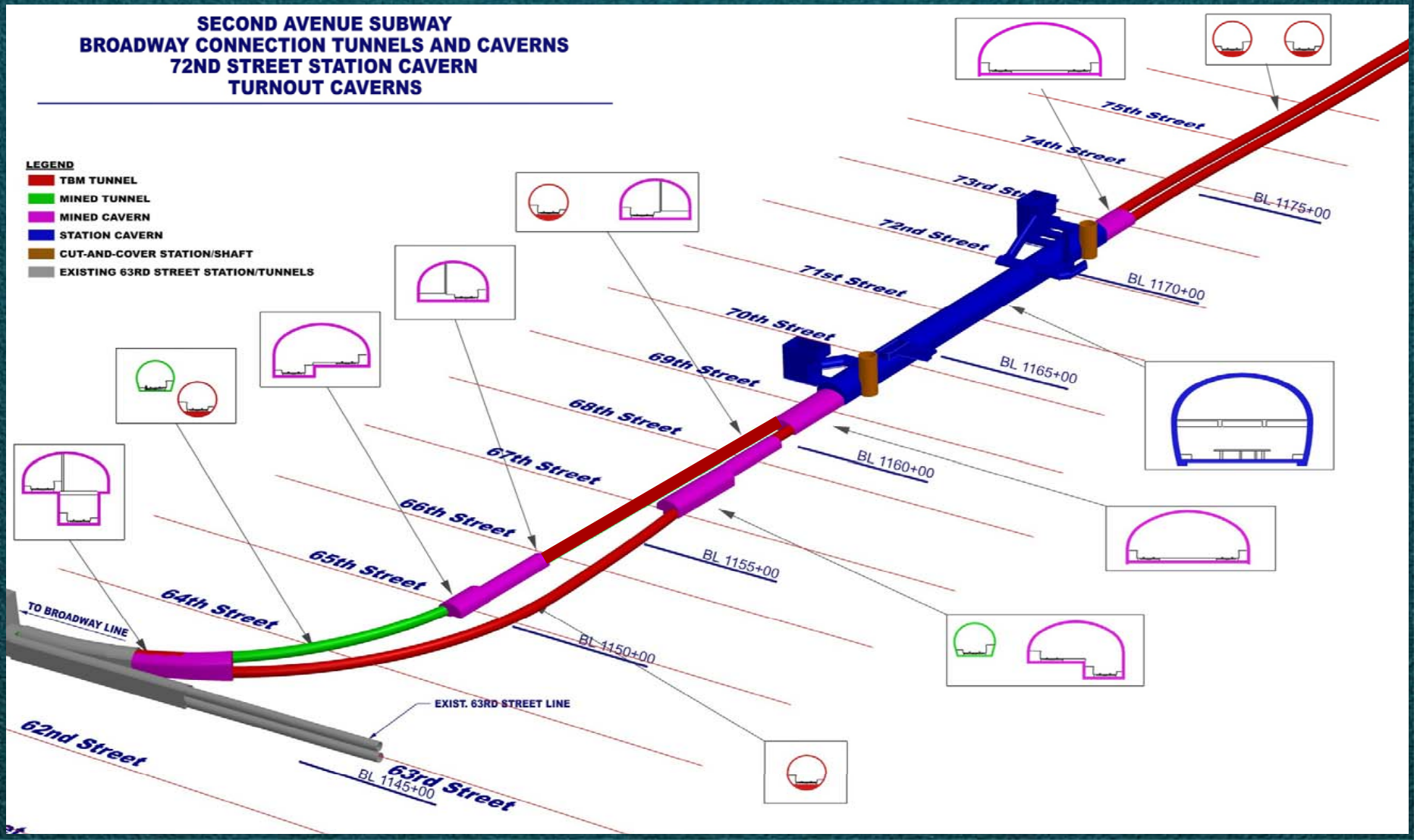
Rock Caverns and Tunnels



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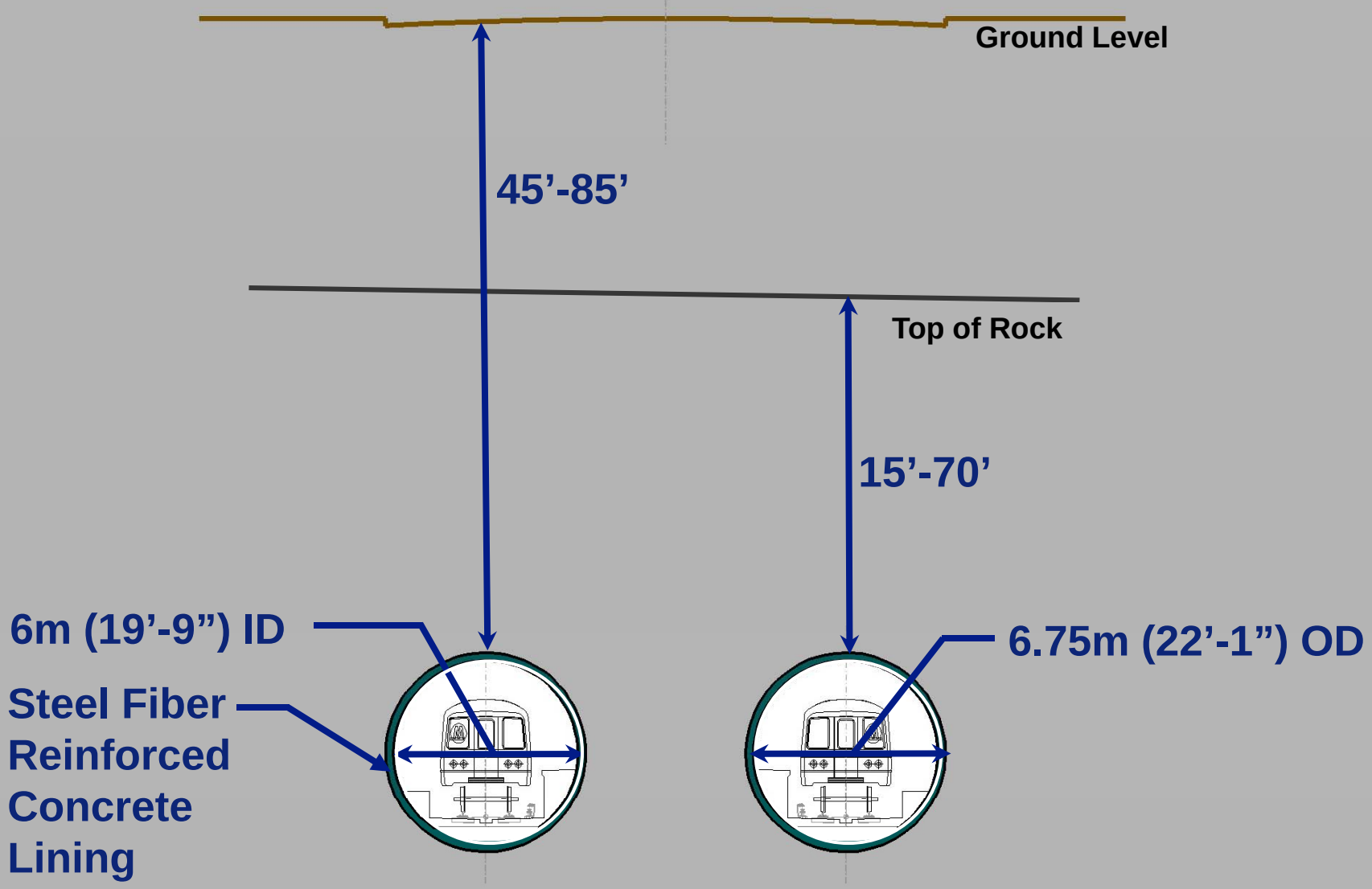
Rock Tunnels



TBM Tunneling

- Hard rock TBM drives
- Abrasive rock
- Faults and shear zones
- Curve towards 63rd Street (616’ Min Radius)
- Water-bearing fissures
- Final lining omitted through future cavern zones

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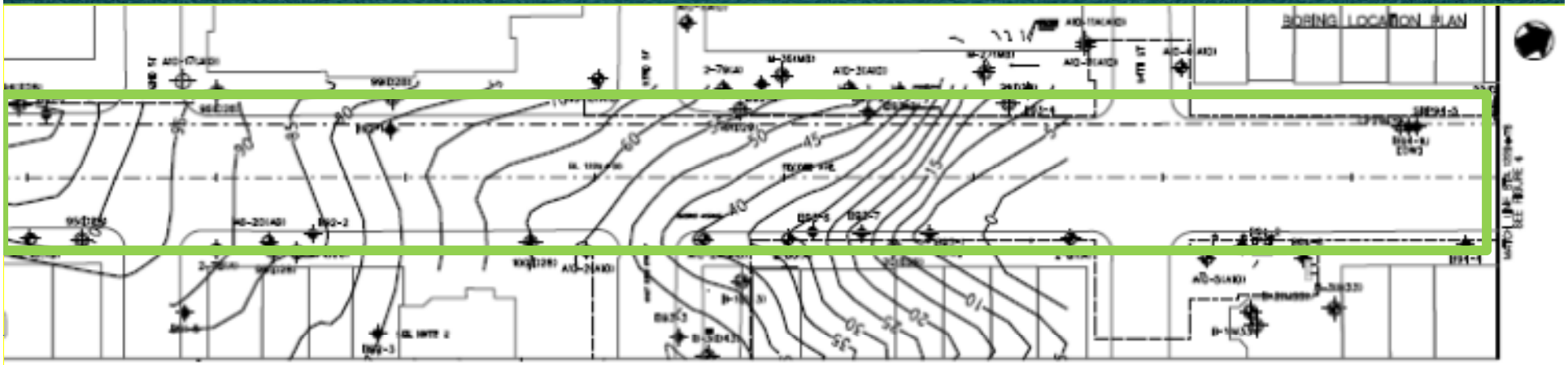
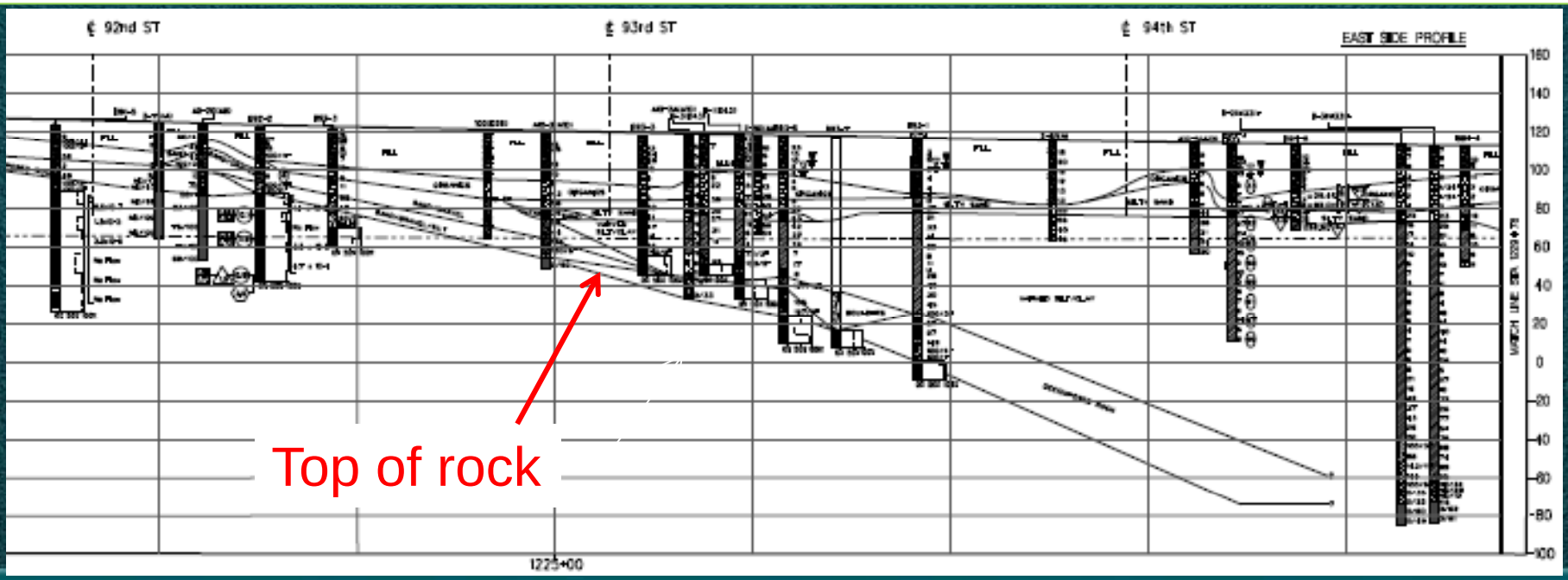
Soft Ground Conditions

92nd Street 93rd Street 94th Street





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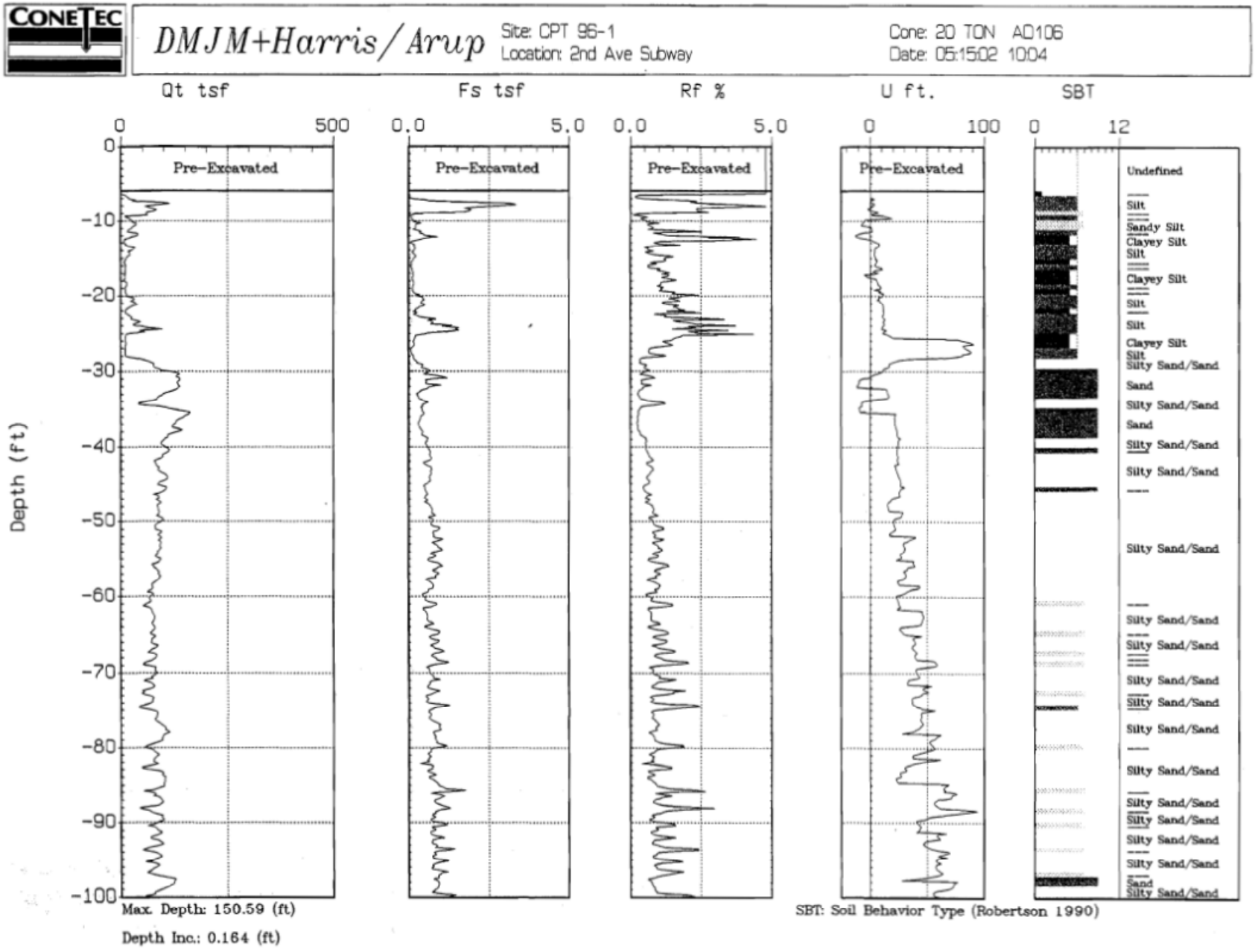
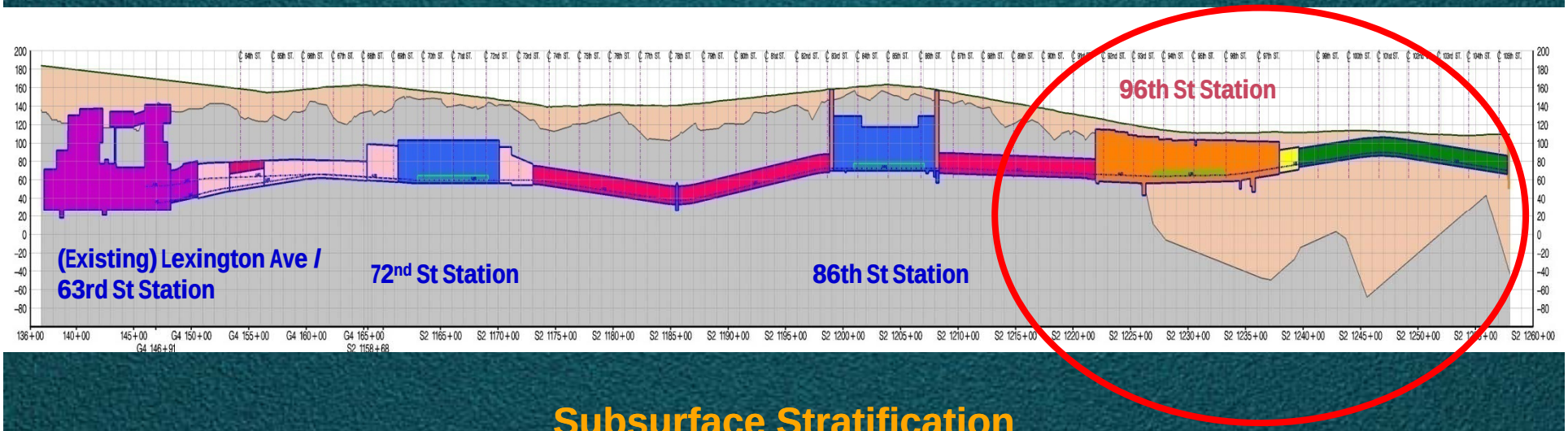

CONETEC
DMJM+Harris/Arup
Site: CPT 96-1
Location: 2nd Ave Subway
Cone: 20 TON AD106
Date: 05:15:02 10:04
Qt tsf
Fs tsf
Rf %
U ft.
SBT
Depth (ft)
Pre-Excavated
Undefined
Silt
Sandy Silt
Clayey Silt
Sand
Silty Sand/Sand
Max. Depth: 150.59 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

96th Street Station (Cut and Cover)



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Organics

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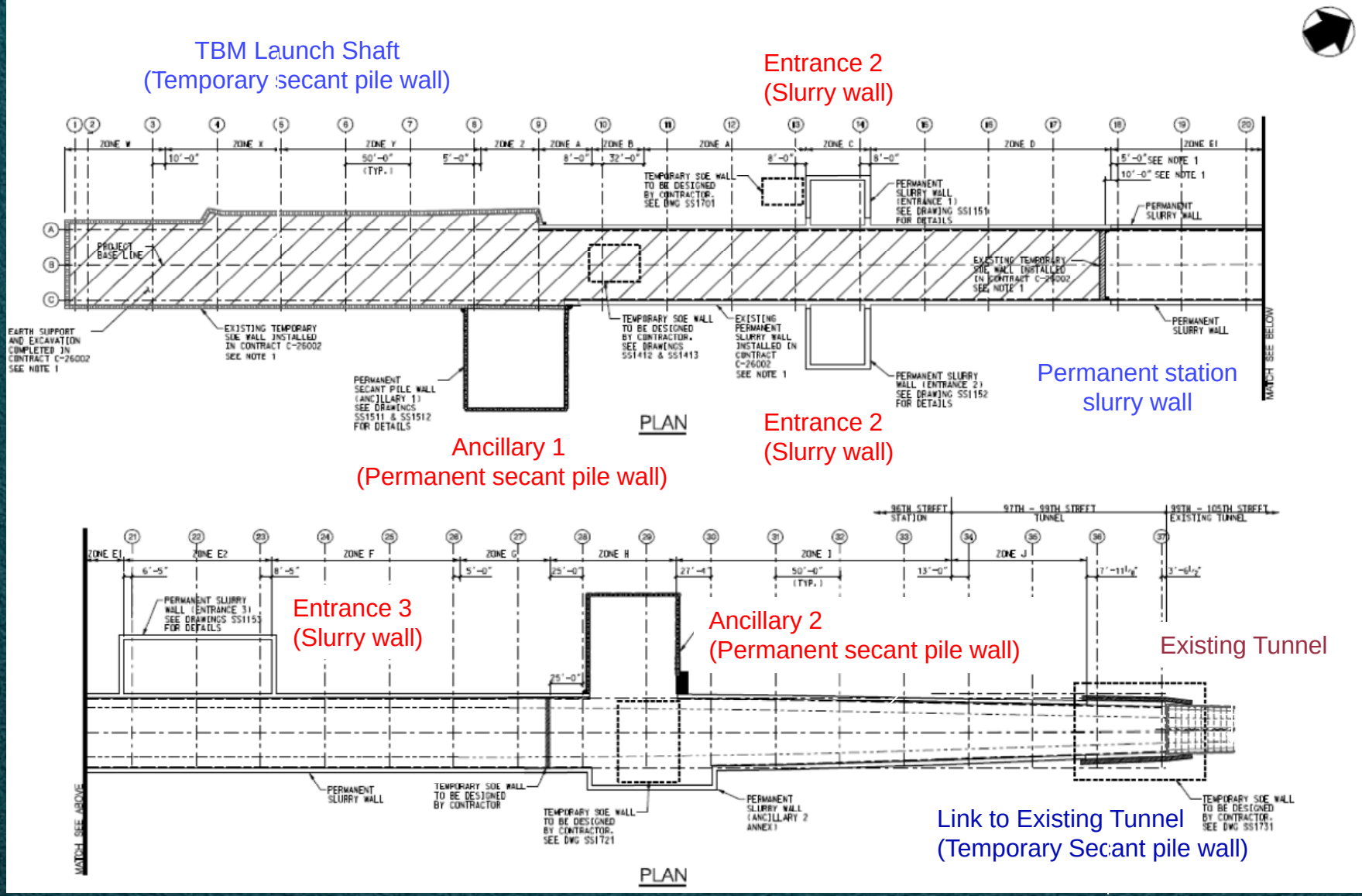

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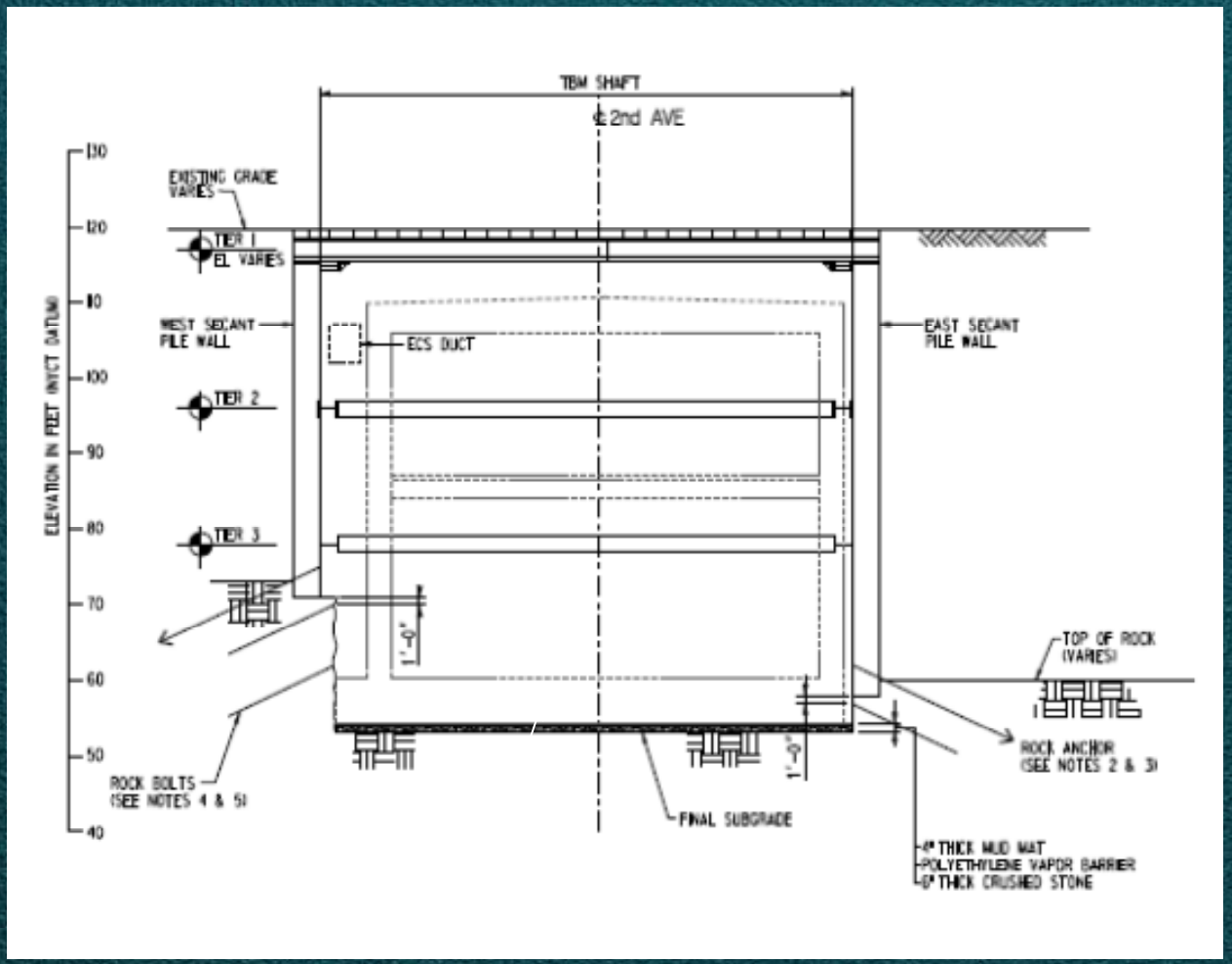
TEMPORARY SECANT PILE WALLS AT TBM LAUNCH BOX



Typical Design Profile

Fill

Sand

Decomposed rock

Sound Rock (TCR > 50%)

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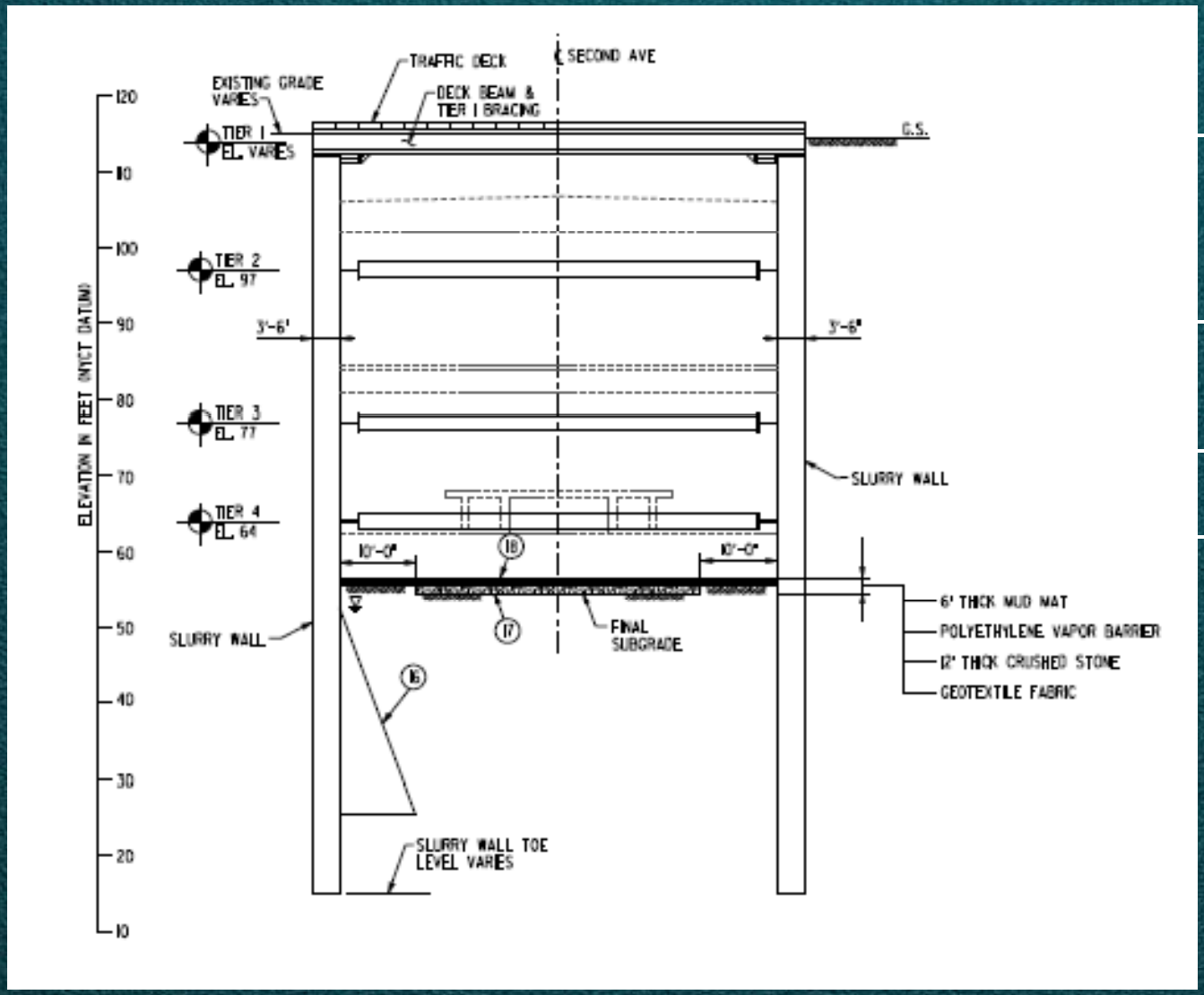
PERMANENT SLURRY WALLS FOR STATION BOX



Typical Design Profile

Fill

Organics

Silty sand

Varved Silt and Clay

Typically:

1. Water level maintained 2ft below bottom of excavation
2. Required factor of safety for bottom failure is 1.2
3. Hydrostatic pressure imposed for 25ft below water level below excavation in varved silt/clay

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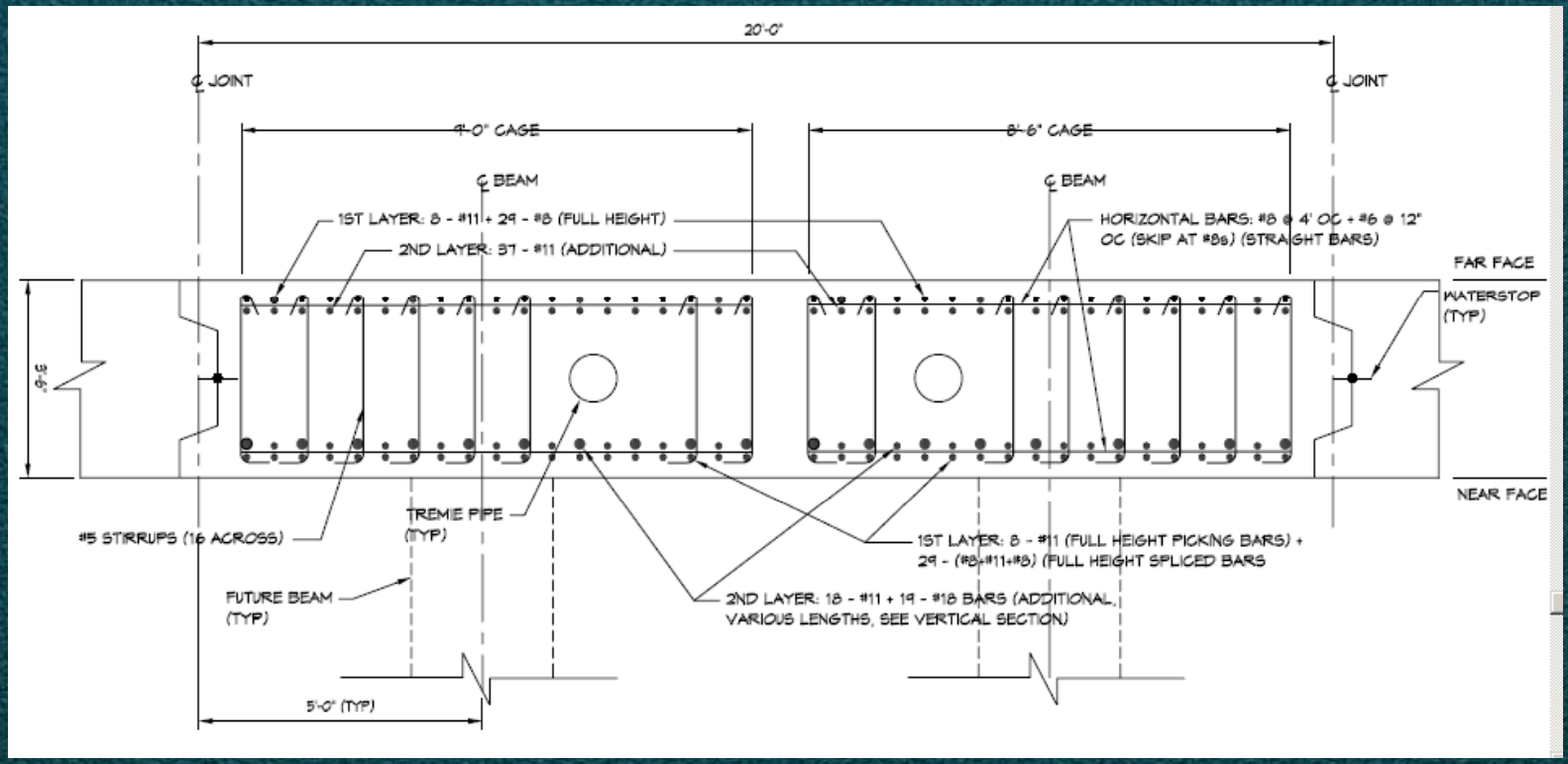
Typical Slurry Wall Panel

- 42 inches thick 20 feet long
- Maximum depth 100 feet
- Water Stop between Panels
- Couplers for mezzanine and roof slabs



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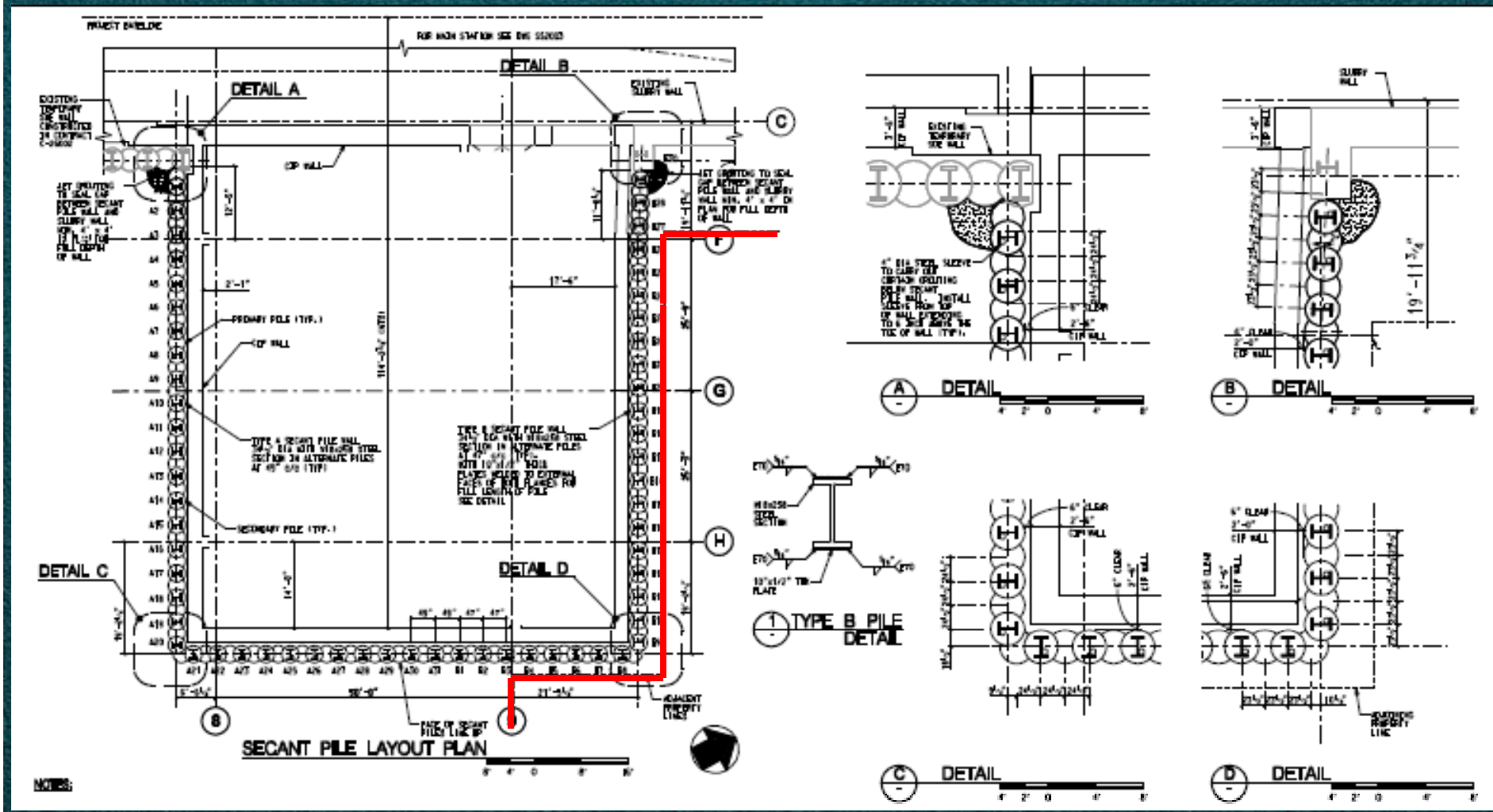
PERMANENT SECANT PILE WALLS AT ANCILLARY BUILDING 1



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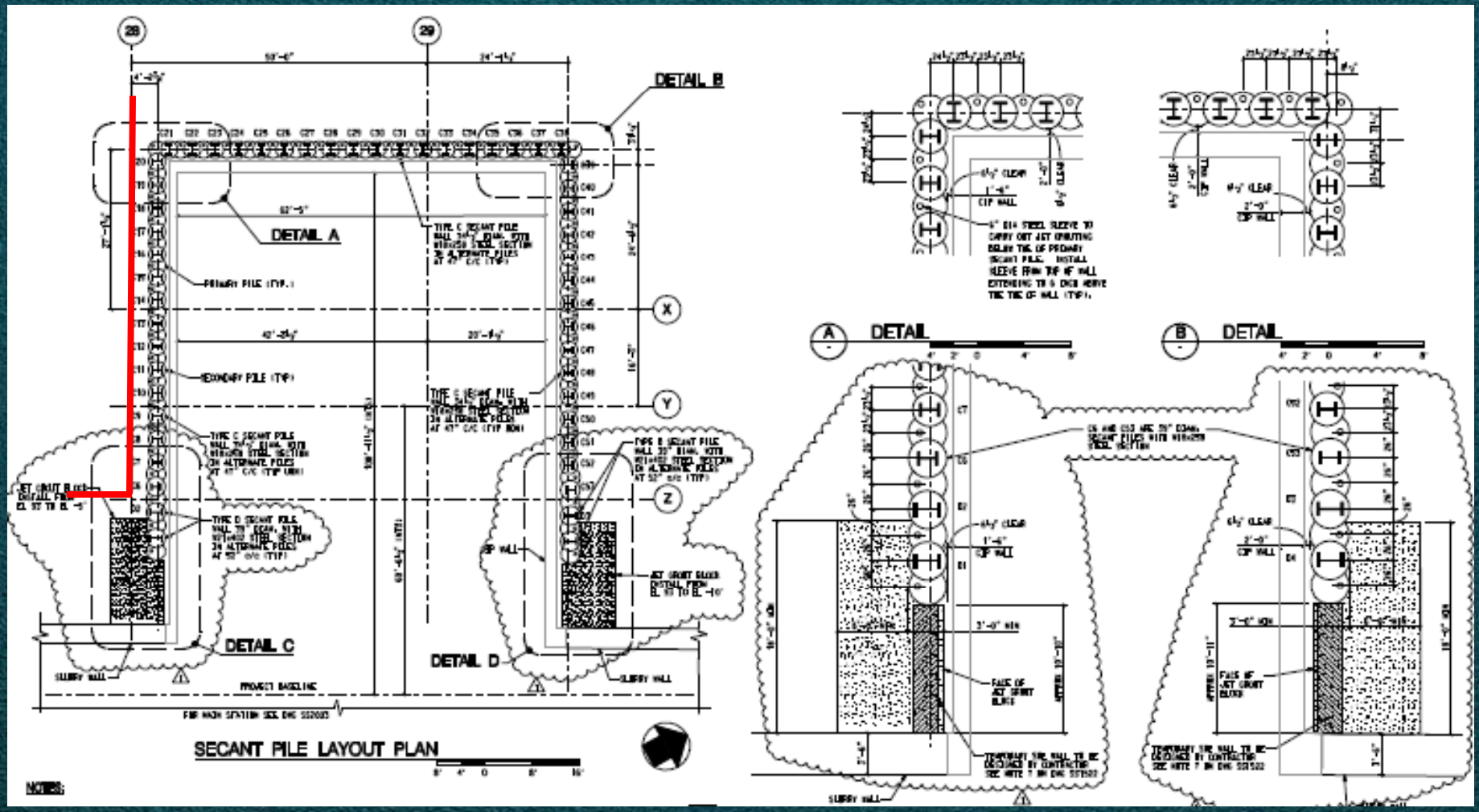
PERMANENT SECANT PILE WALLS AT ANCILLARY BUILDING 2



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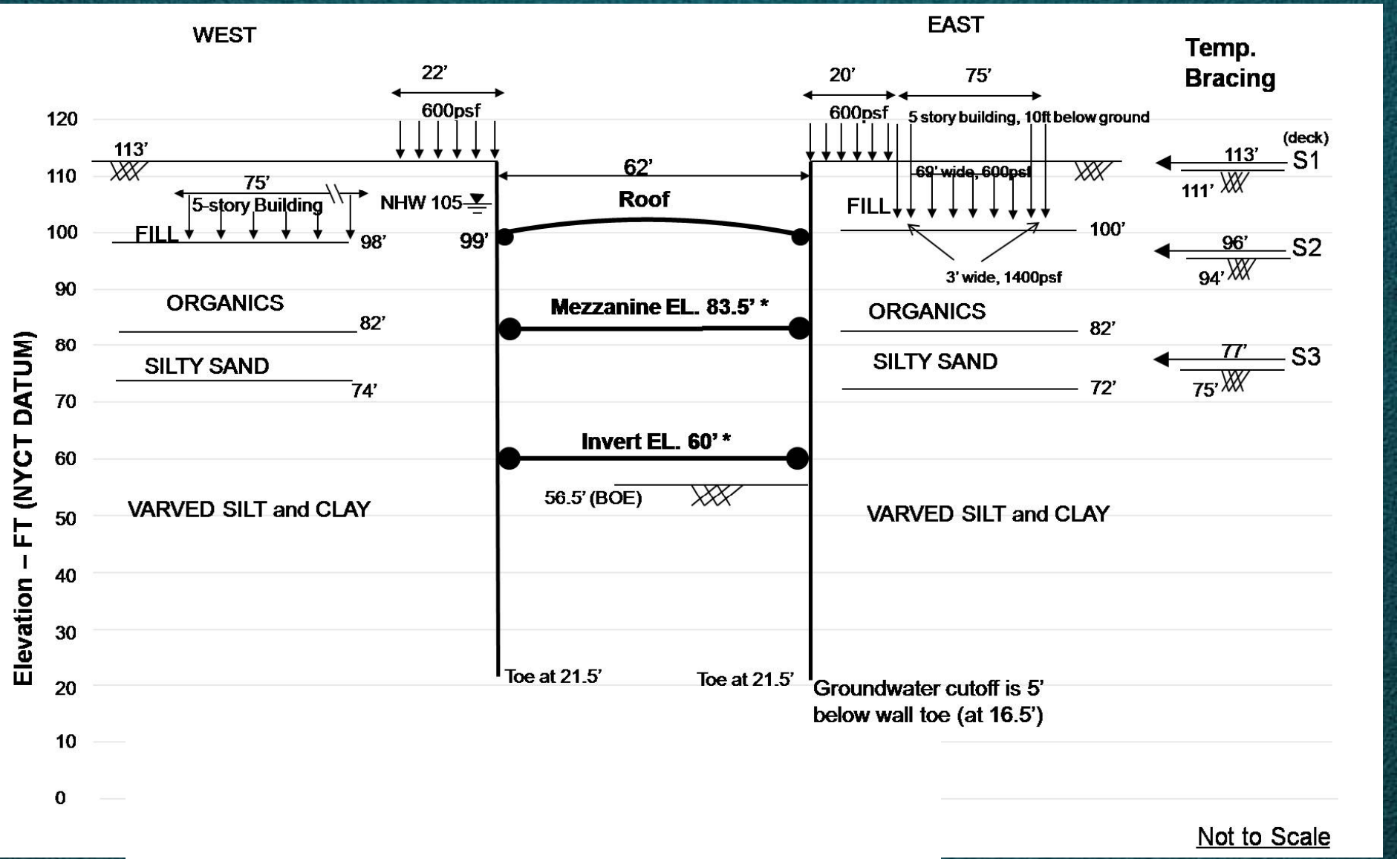
Plaxis Model



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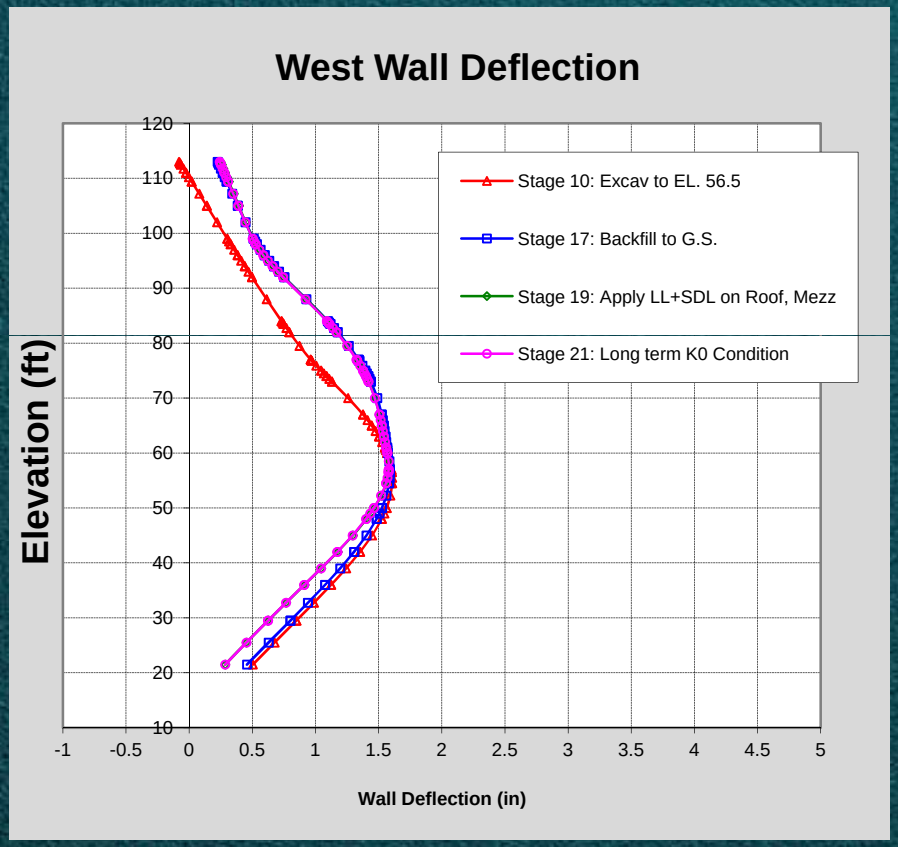
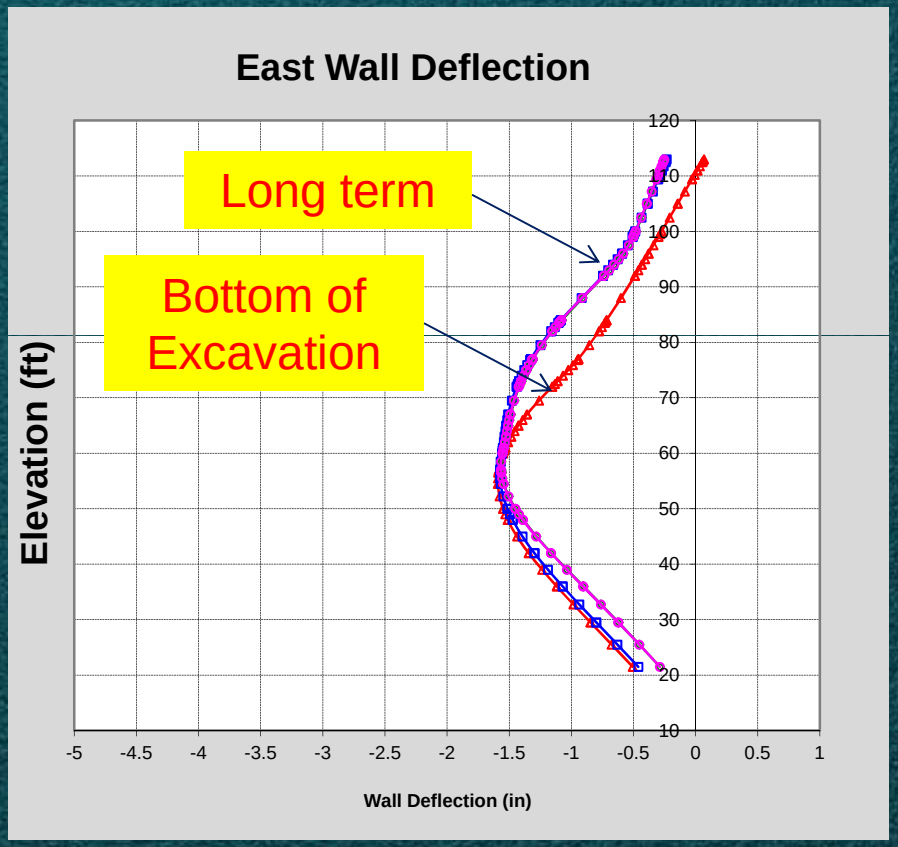
Wall Deformations





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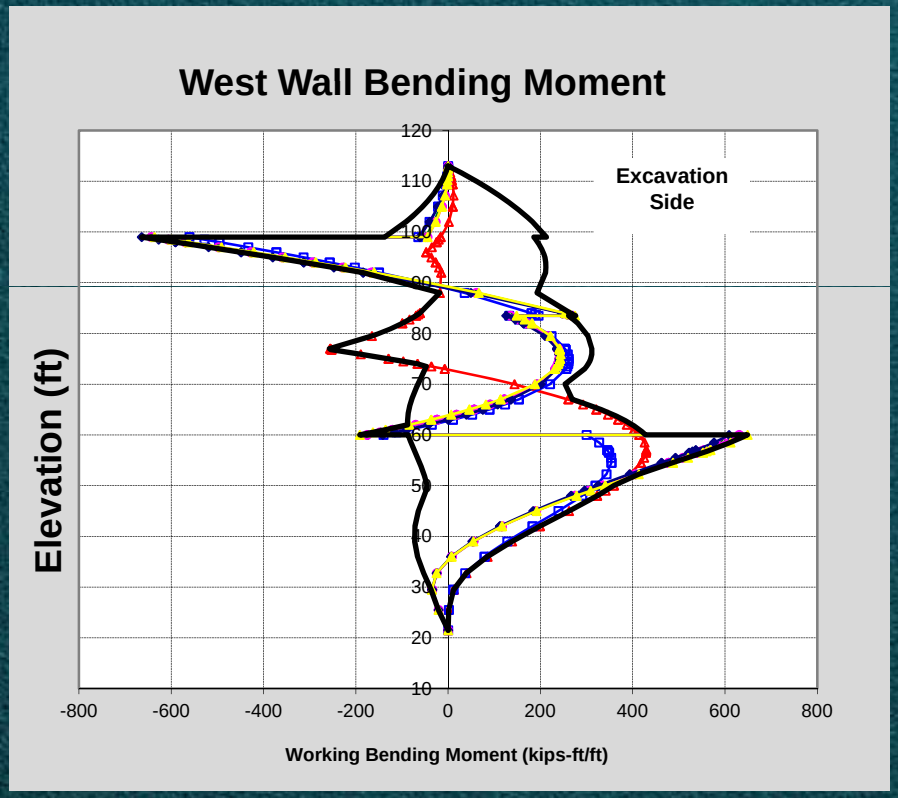
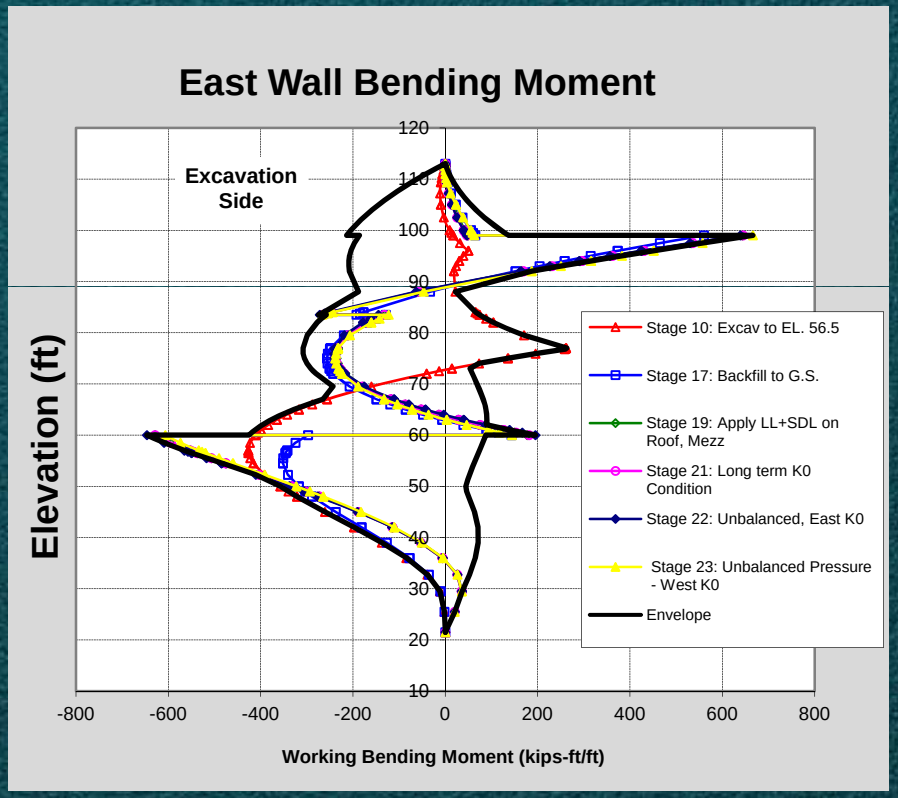
Bending Moment Diagram





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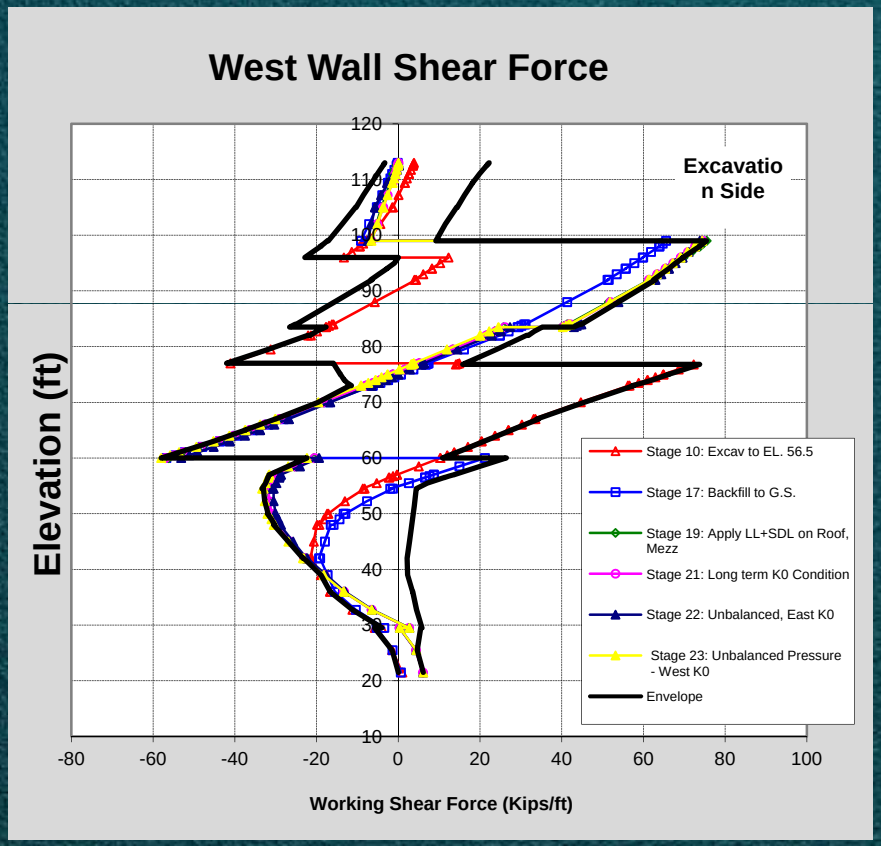
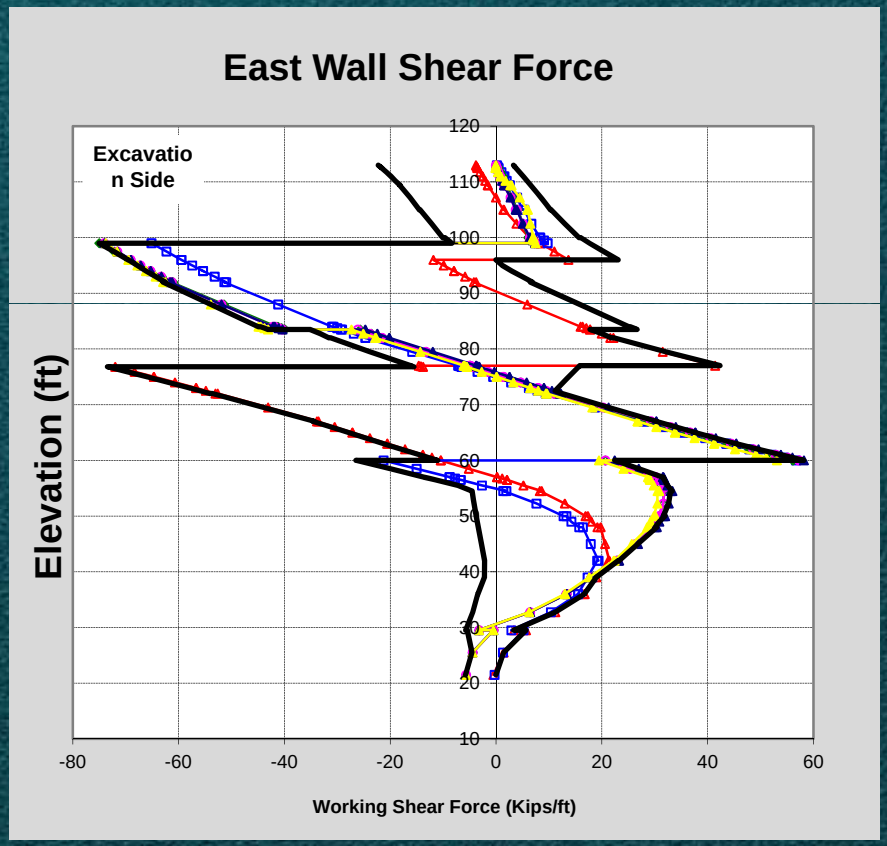
Shear Force Diagram





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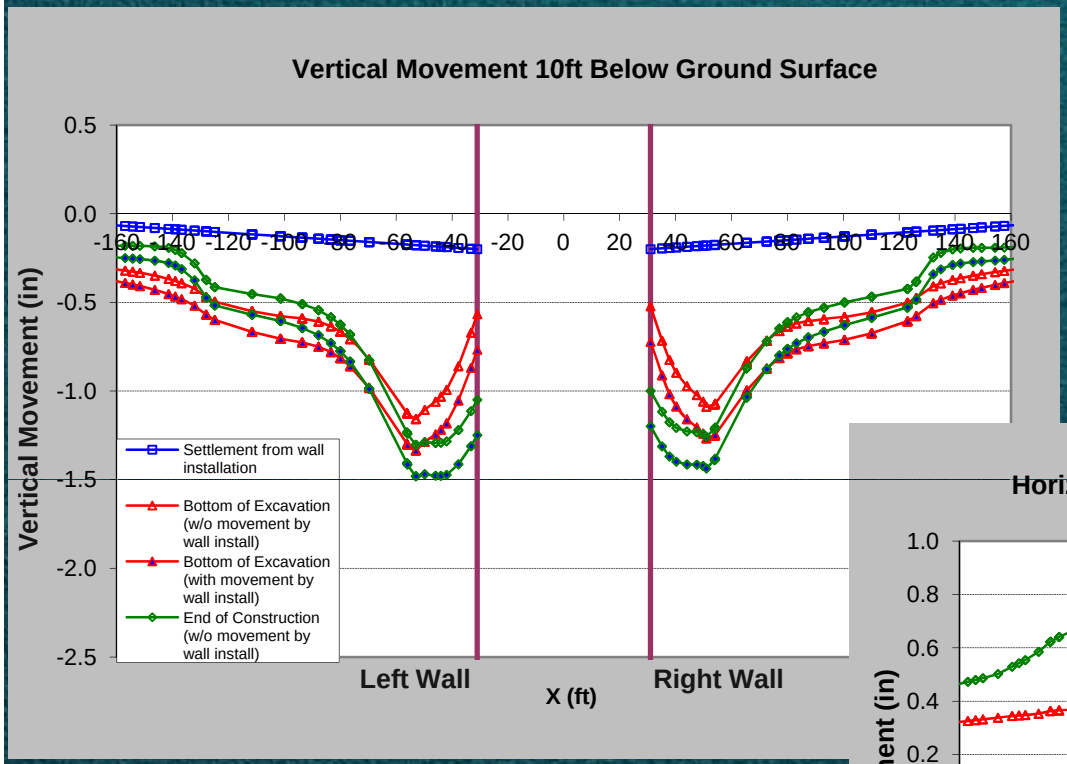
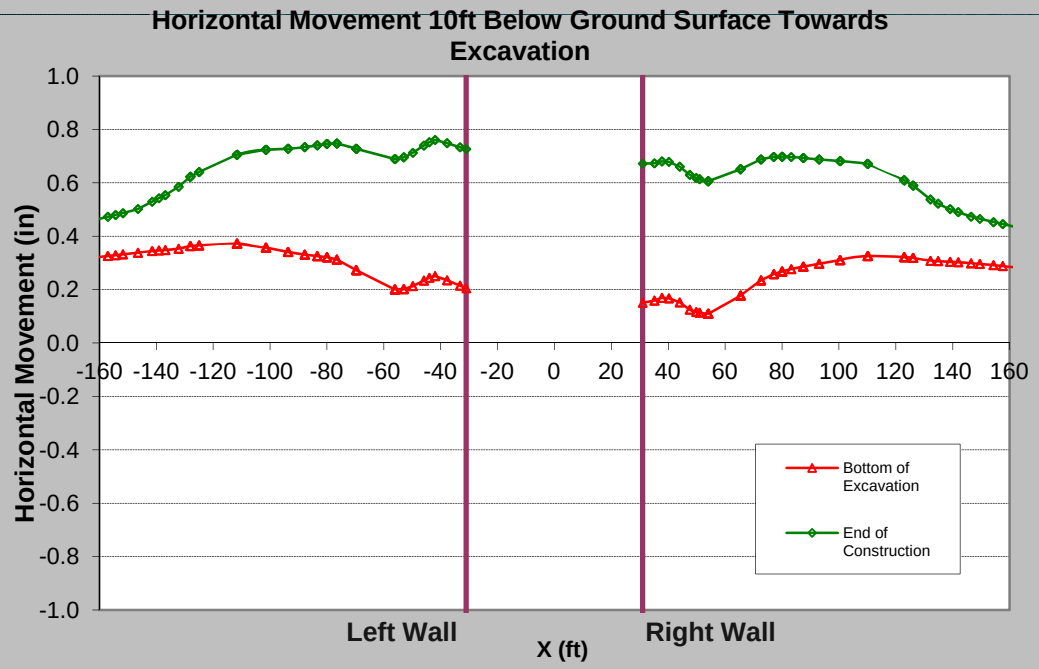
Ground Displacements





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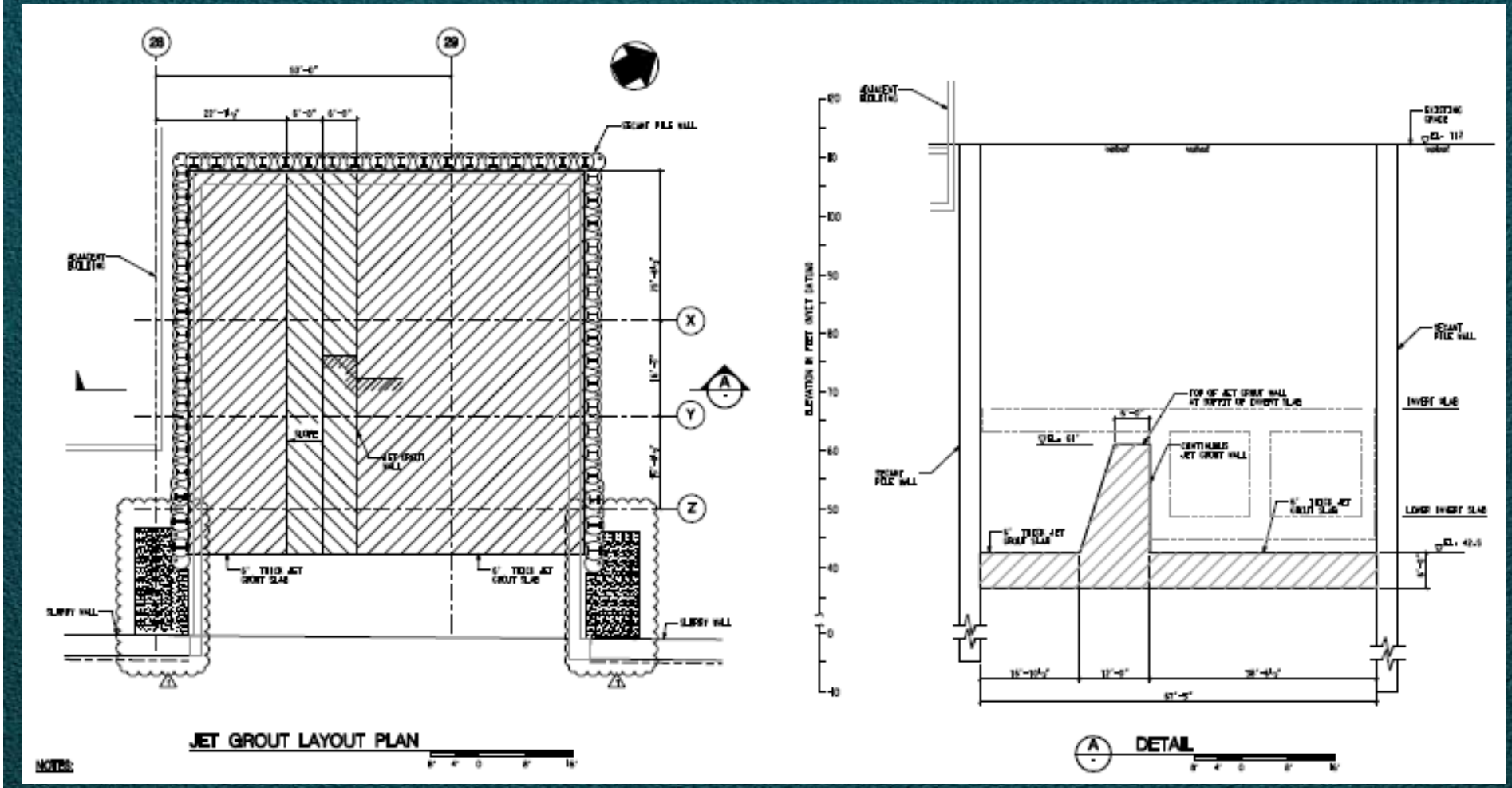
Jet Grouting for Excavation Support



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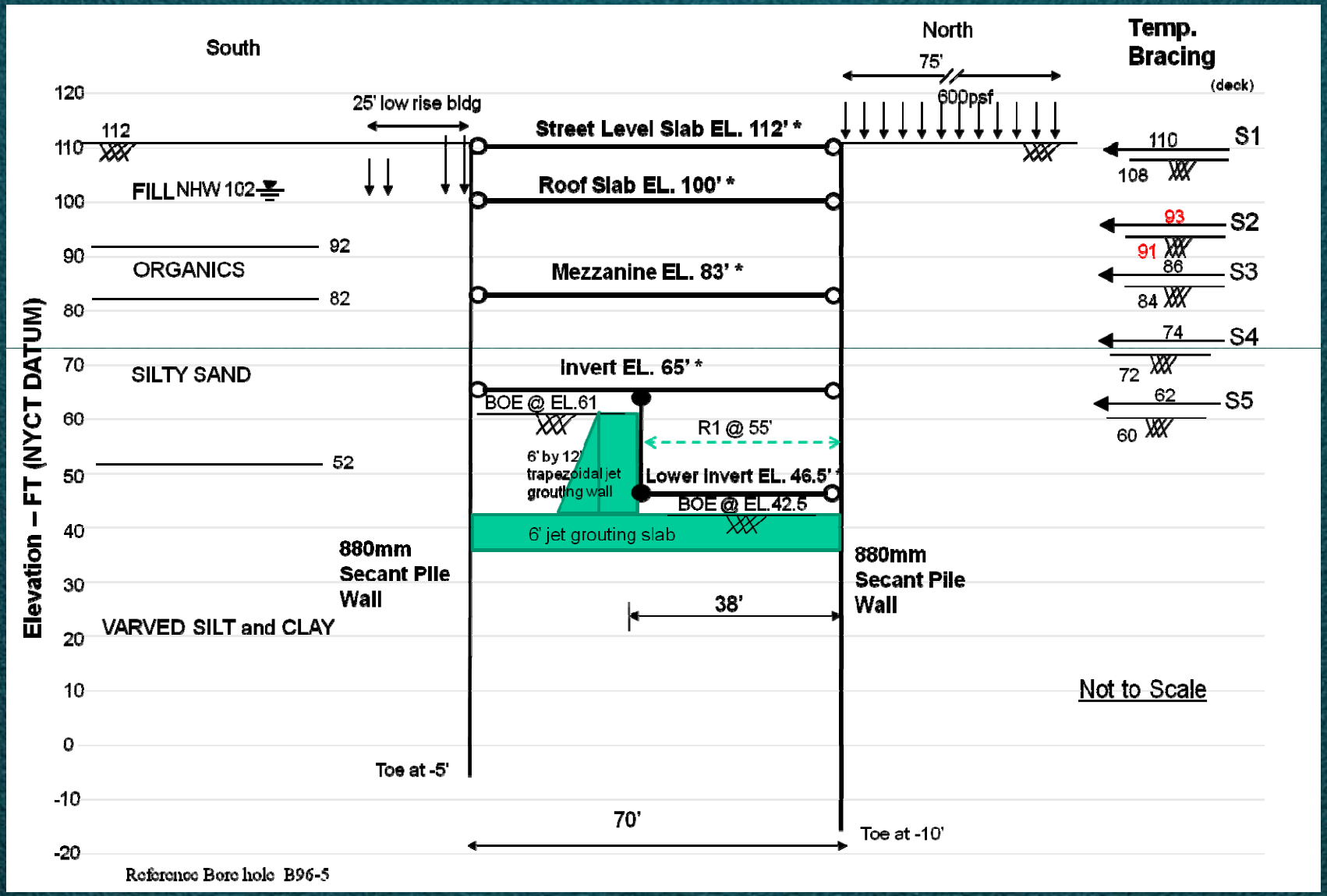

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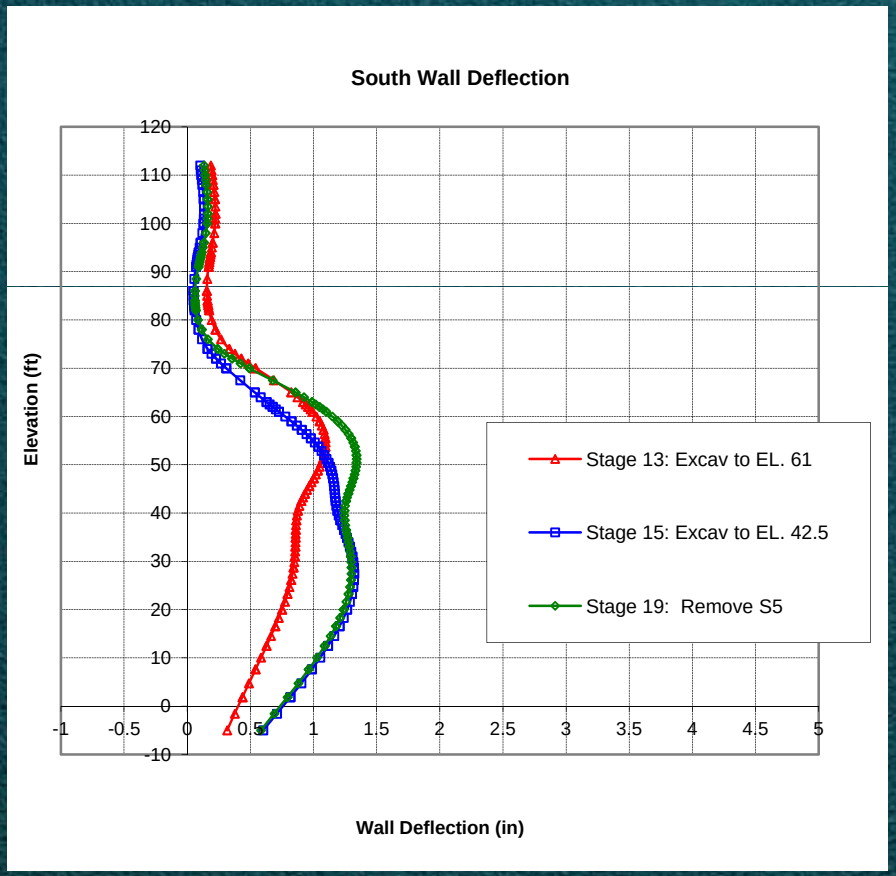

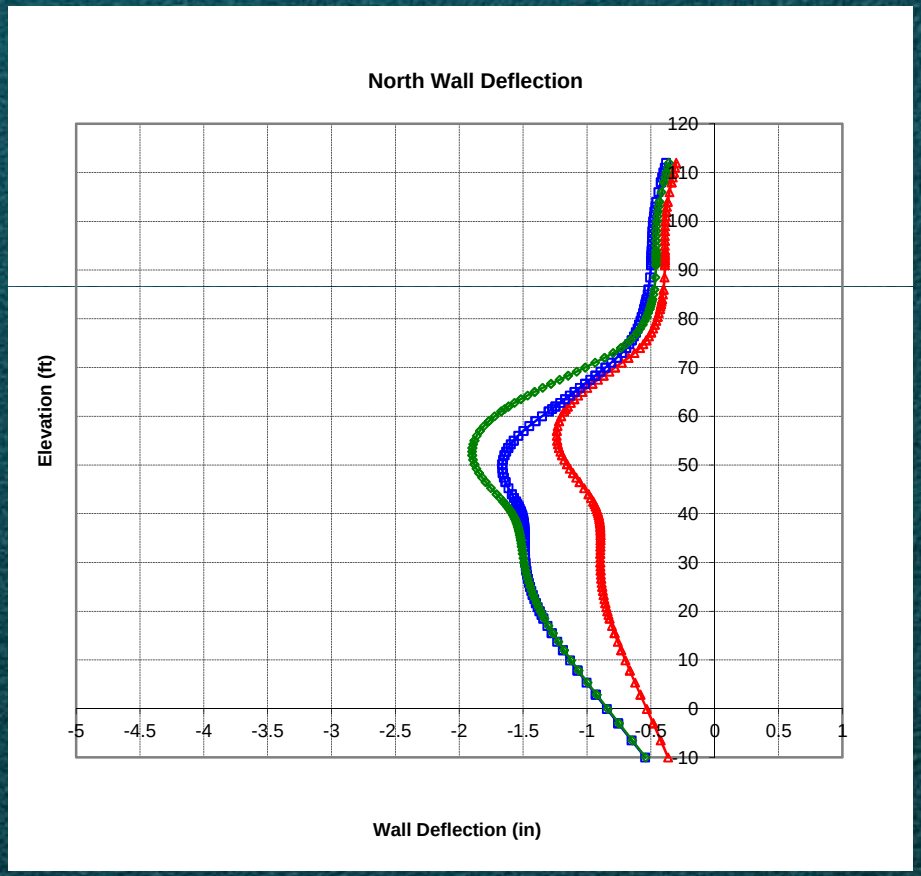

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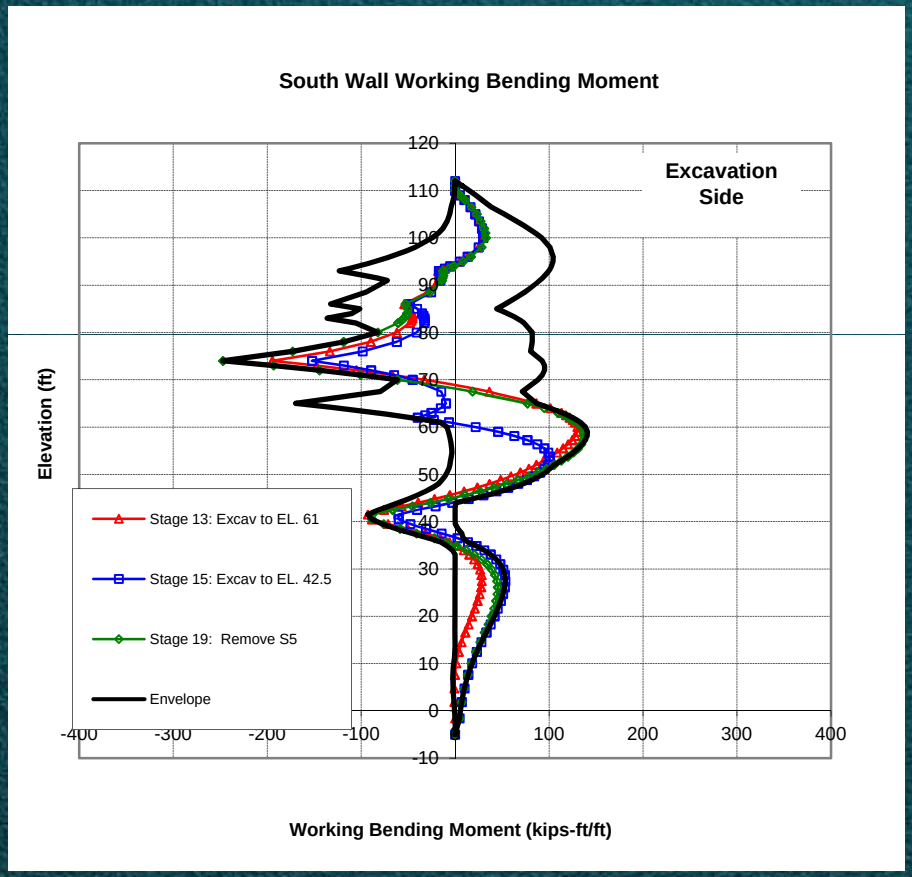

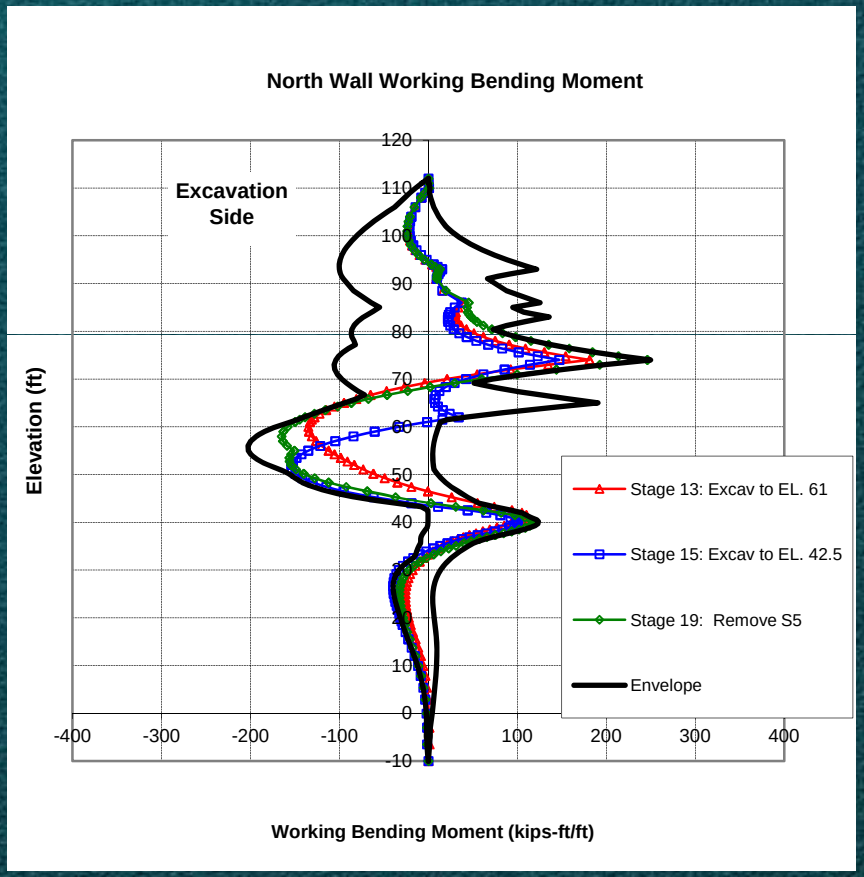

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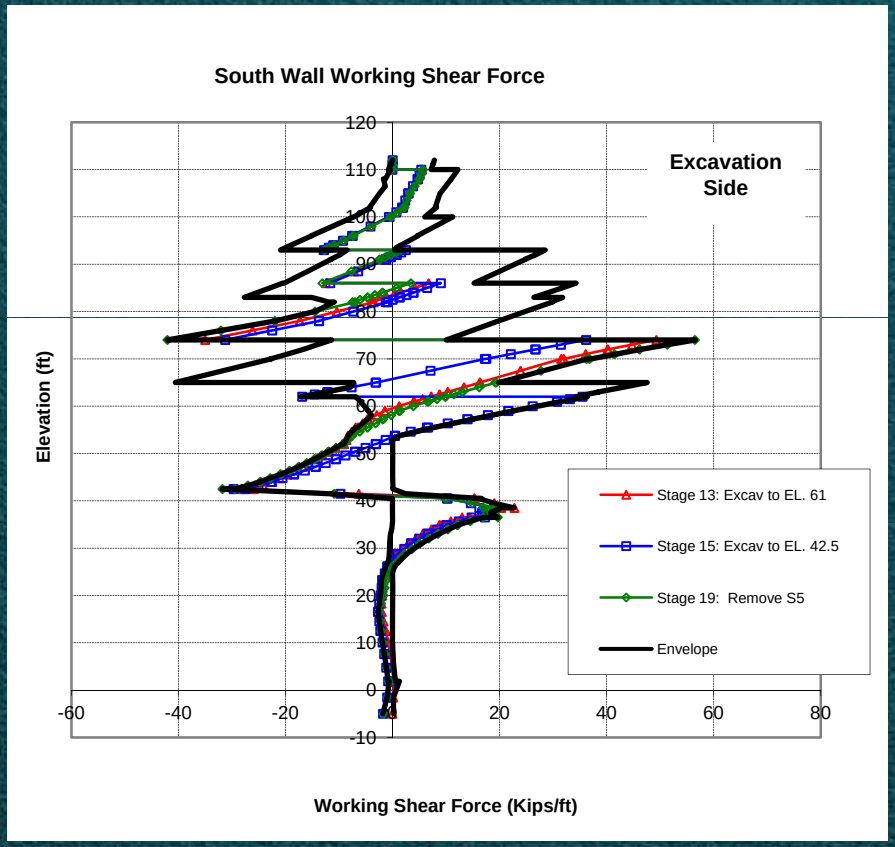

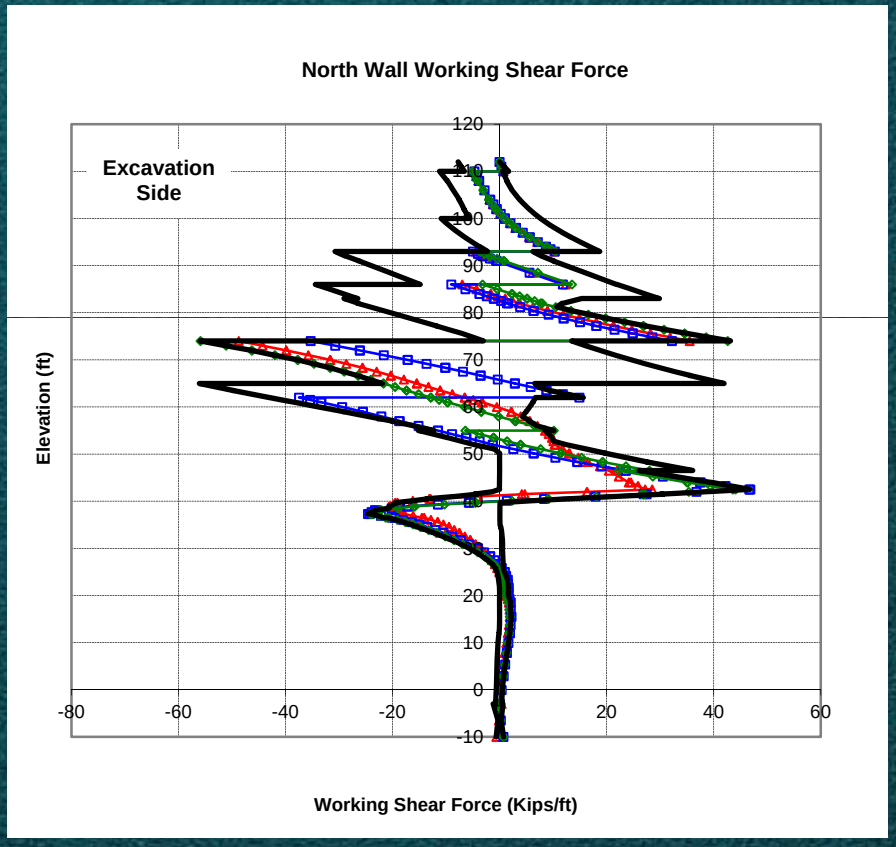

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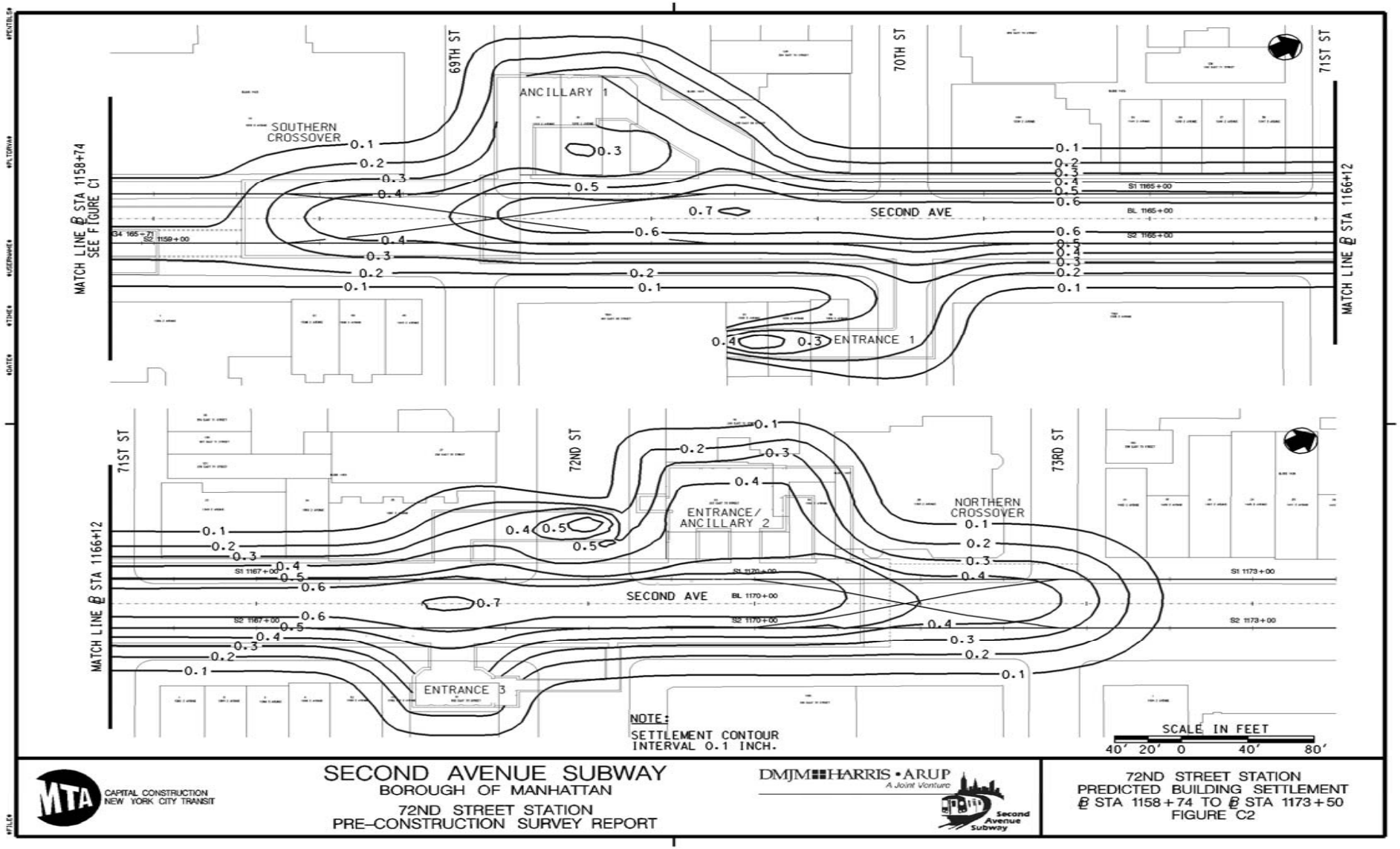
Ground Settlement Contours - XDISP



MTA CAPITAL CONSTRUCTION NEW YORK CITY TRANSIT

SECOND AVENUE SUBWAY
BOROUGH OF MANHATTAN
72ND STREET STATION
PRE-CONSTRUCTION SURVEY REPORT

DMJM HARRIS • ARUP
A Joint Venture
Second Avenue Subway

72ND STREET STATION
PREDICTED BUILDING SETTLEMENT
℄ STA 1158+74 TO ℄ STA 1173+50
FIGURE C2

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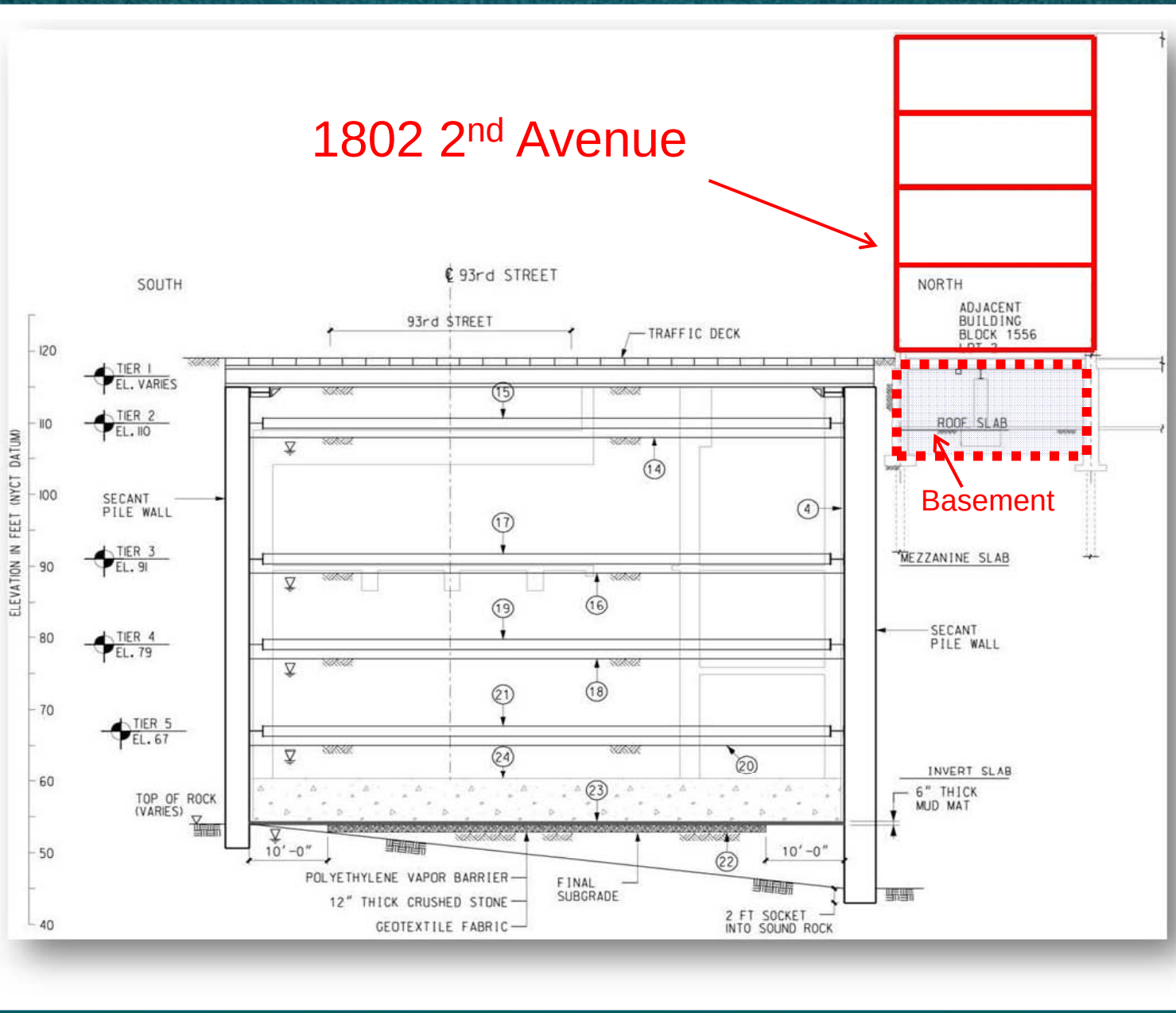
Underpinning


1802 2nd Avenue
SOUTH
℄ 93rd STREET
93rd STREET
TRAFFIC DECK
NORTH
ADJACENT BUILDING BLOCK 1556
ROOF SLAB
Basement
MEZZANINE SLAB
SECANT PILE WALL
TIER 1 EL. VARIES
TIER 2 EL. 110
TIER 3 EL. 91
TIER 4 EL. 79
TIER 5 EL. 67
ELEVATION IN FEET (NYCT DATUM)
120
110
100
90
80
70
60
50
40
TOP OF ROCK (VARIES)
INVERT SLAB
6" THICK MUD MAT
10'-0"
10'-0"
POLYETHYLENE VAPOR BARRIER
12" THICK CRUSHED STONE
GEOTEXTILE FABRIC
FINAL SUBGRADE
2 FT SOCKET INTO SOUND ROCK

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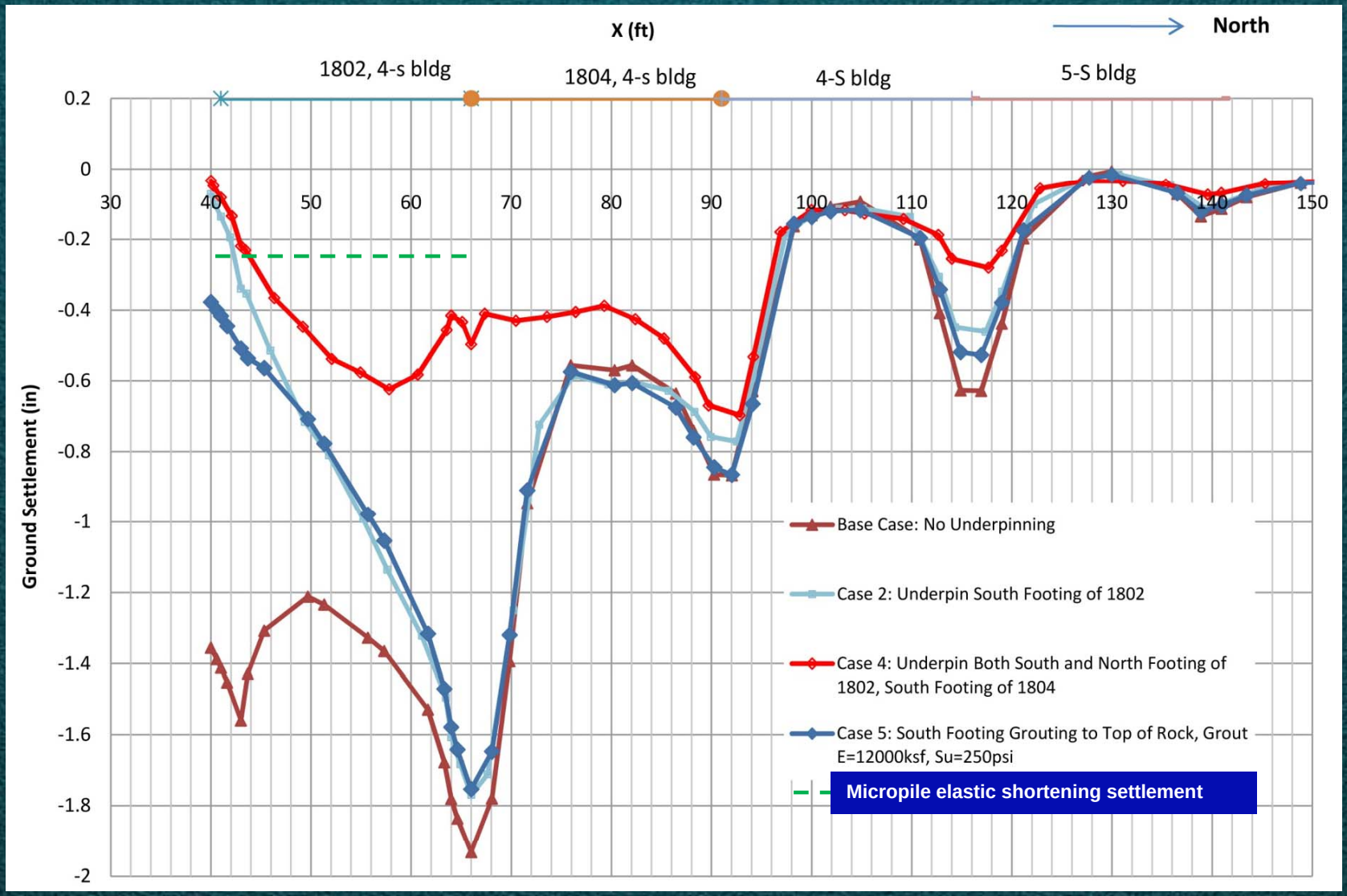
Predicted Ground Settlements



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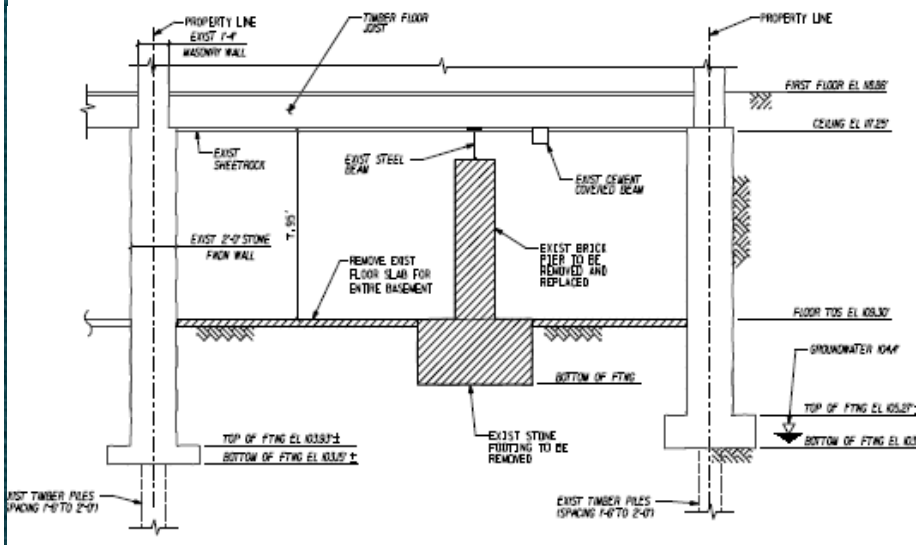
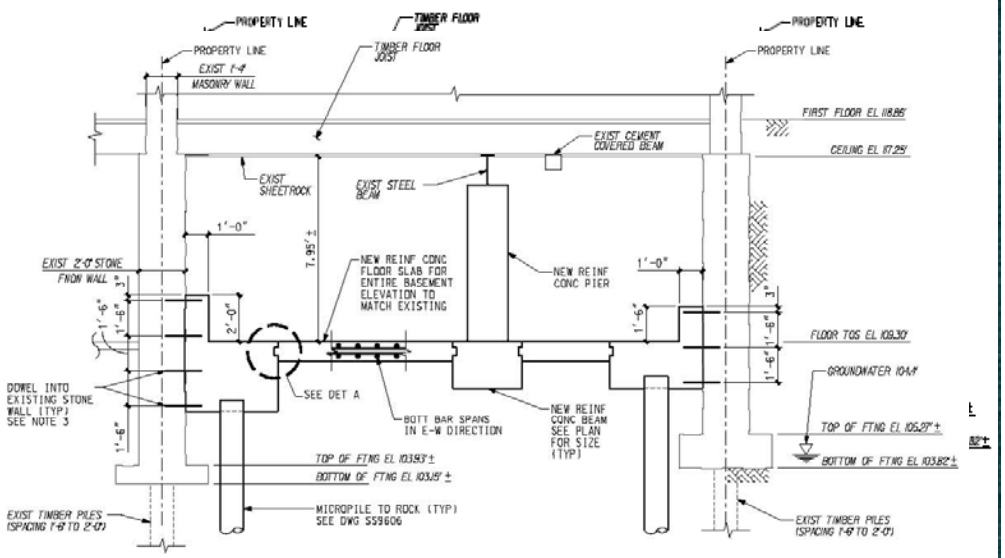
Underpinning Using Micropiles



A S59601 DEMOLITION SECTION

2' 1' 0 2' 4' 6'



B S59602 NEW STRUCTURE CROSS SECTION

2' 1' 0 2' 4' 6'

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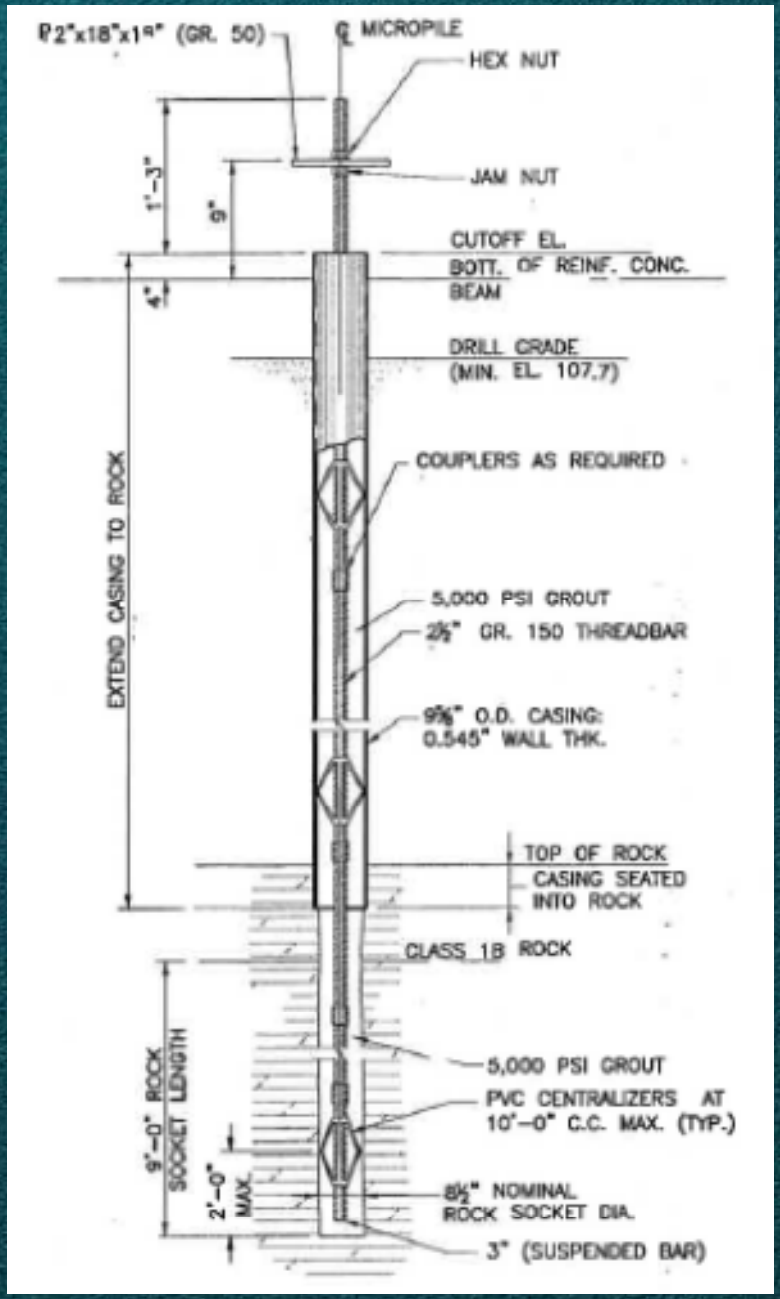
Micropile Detail

- **Working Load = 250 kips**
- **Casing: 9-5/8ins OD 0.545ins thick, Fy = 80ksi**
- **Reinforcing bar: 2.5ins diam Dywidag Threadbar, Fu = 250ksi**
- **Grout: 5000psi**
- **Centralizers at 10 ft c/c**
- **Steel plate w/ nut: 18ins x 18inx 2ins thick, Fy = 50ksi**
- **Rock socket: 8.5ins diam, 9ft long**
- **Bond strength: 200psi**



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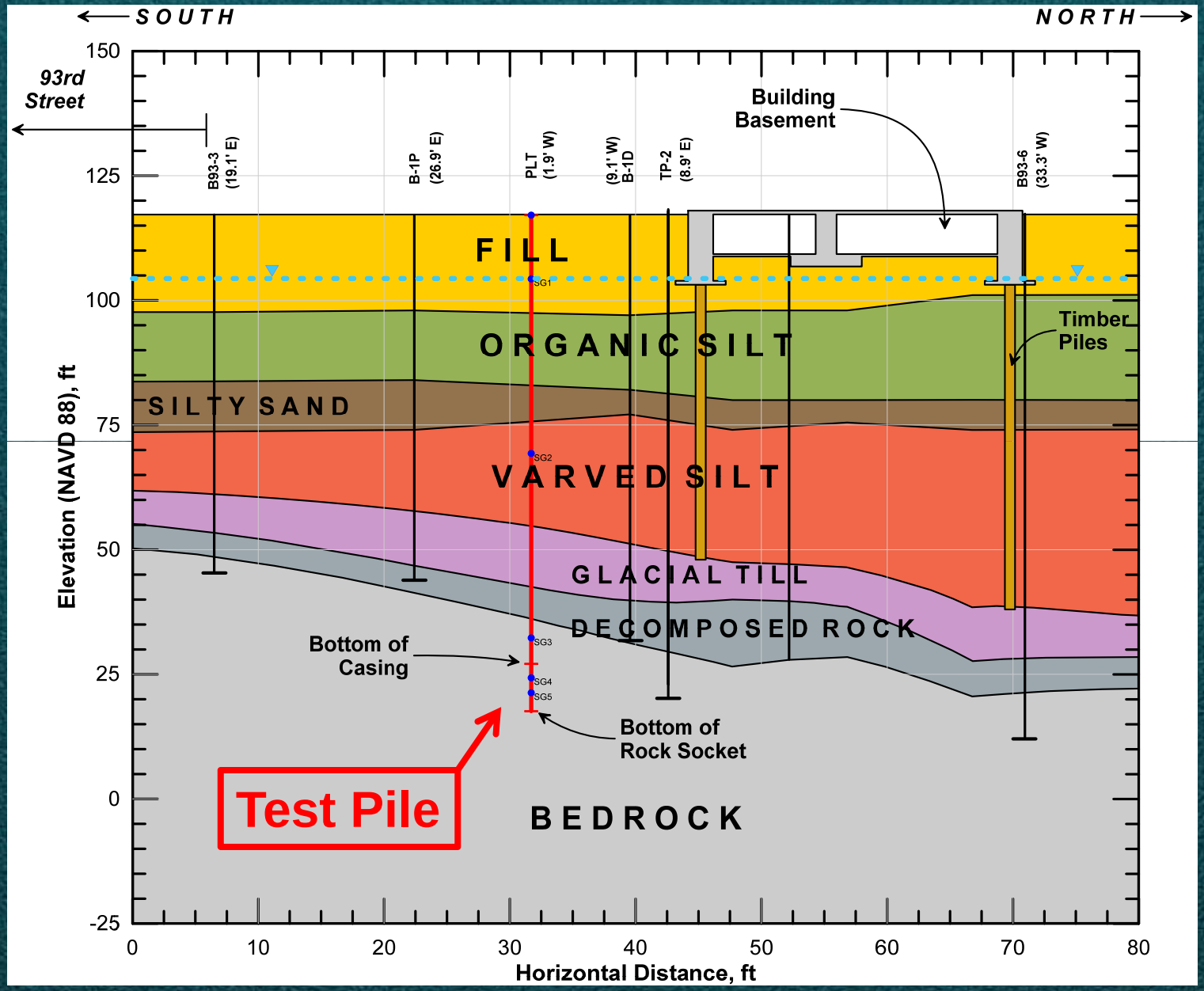
SOUTH
NORTH
93rd Street
B93-3 (19.1' E)
B-1P (26.9' E)
PLT (1.9' W)
(9.1' W) B-1D
TP-2 (8.9' E)
B93-6 (33.3' W)
Building Basement
FILL
ORGANIC SILT
SILTY SAND
VARVED SILT
GLACIAL TILL
DECOMPOSED ROCK
BEDROCK
Timber Piles
SG1
SG2
SG3
SG4
SG5
Bottom of Casing
Bottom of Rock Socket
Test Pile
Elevation (NAVD 88), ft
Horizontal Distance, ft
150
125
100
75
50
25
0
-25
0
10
20
30
40
50
60
70
80

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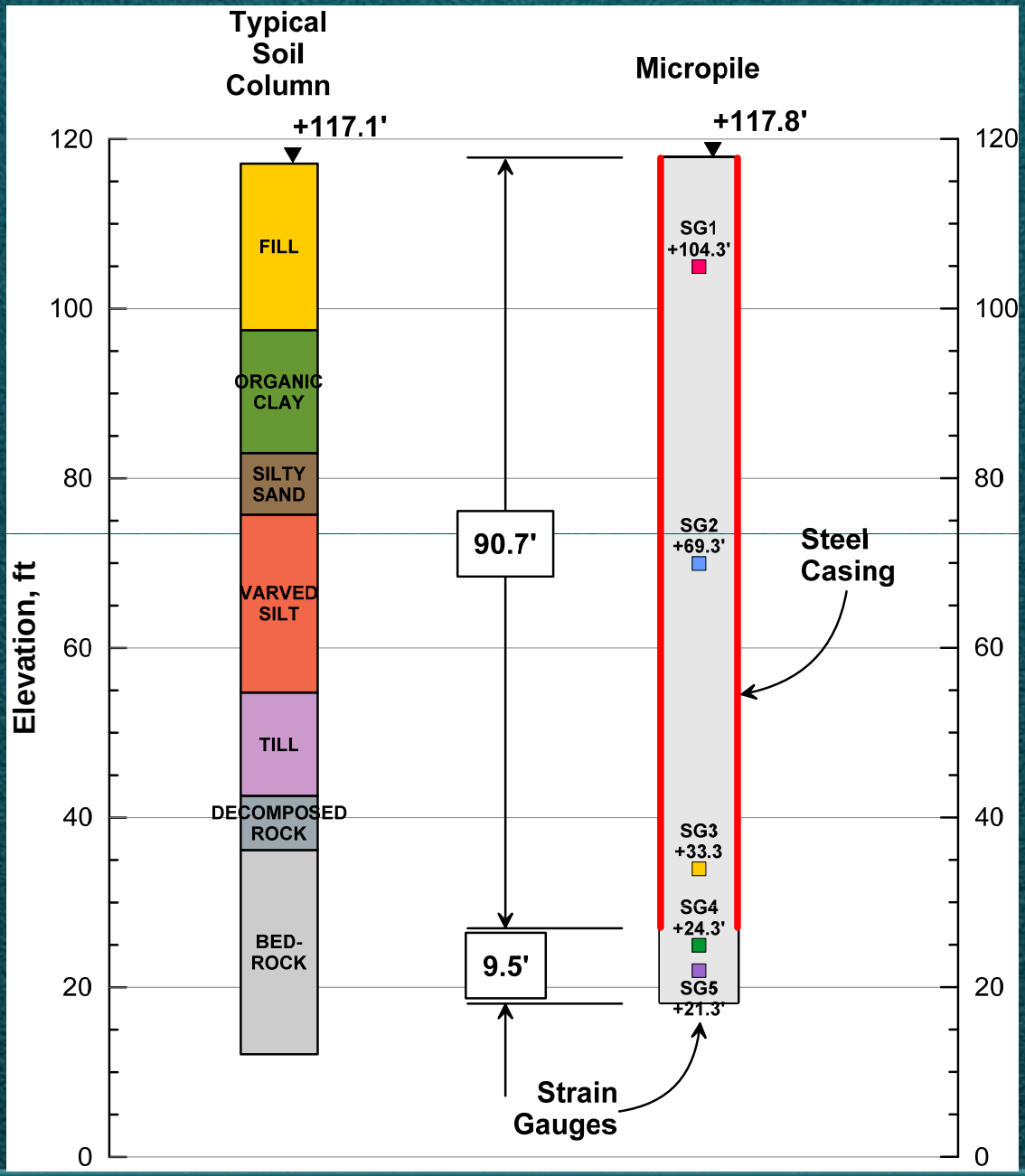

Sister bar strain gages

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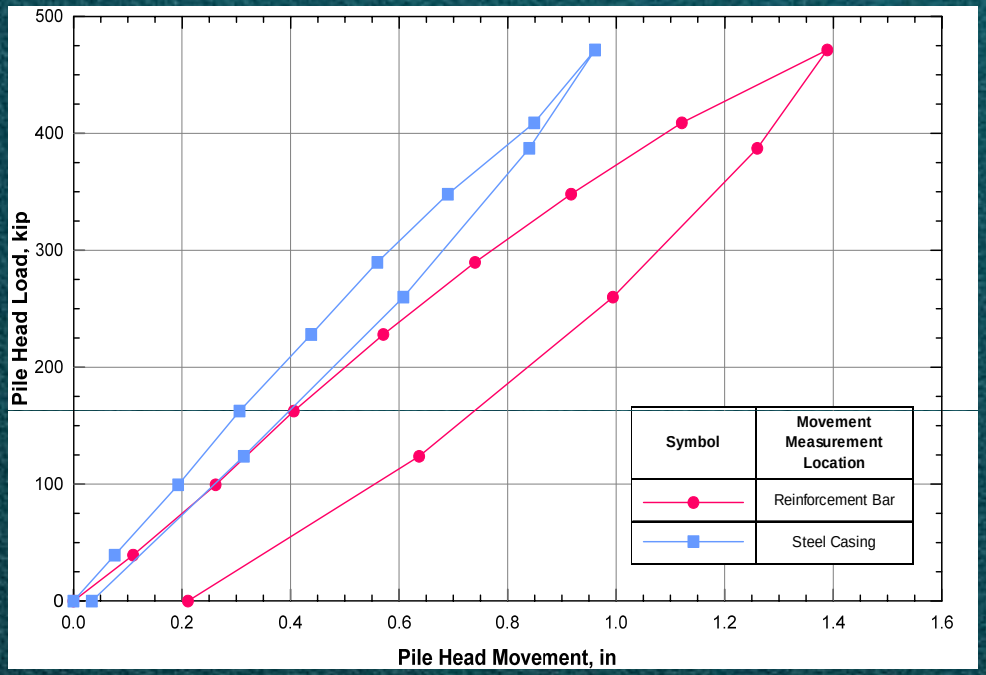
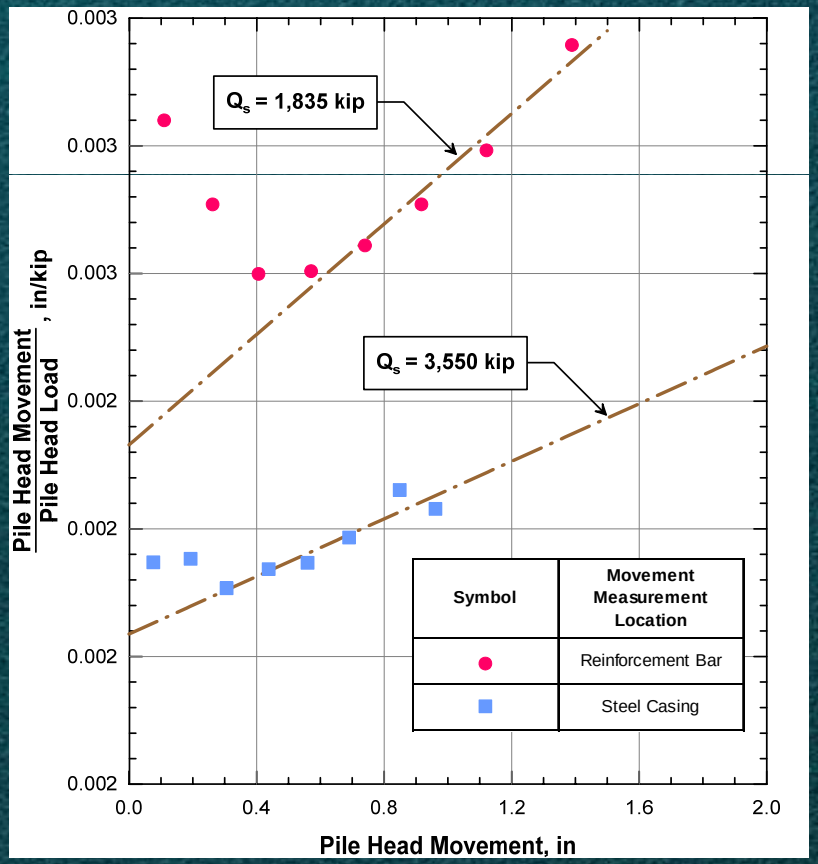
Tension Load Test





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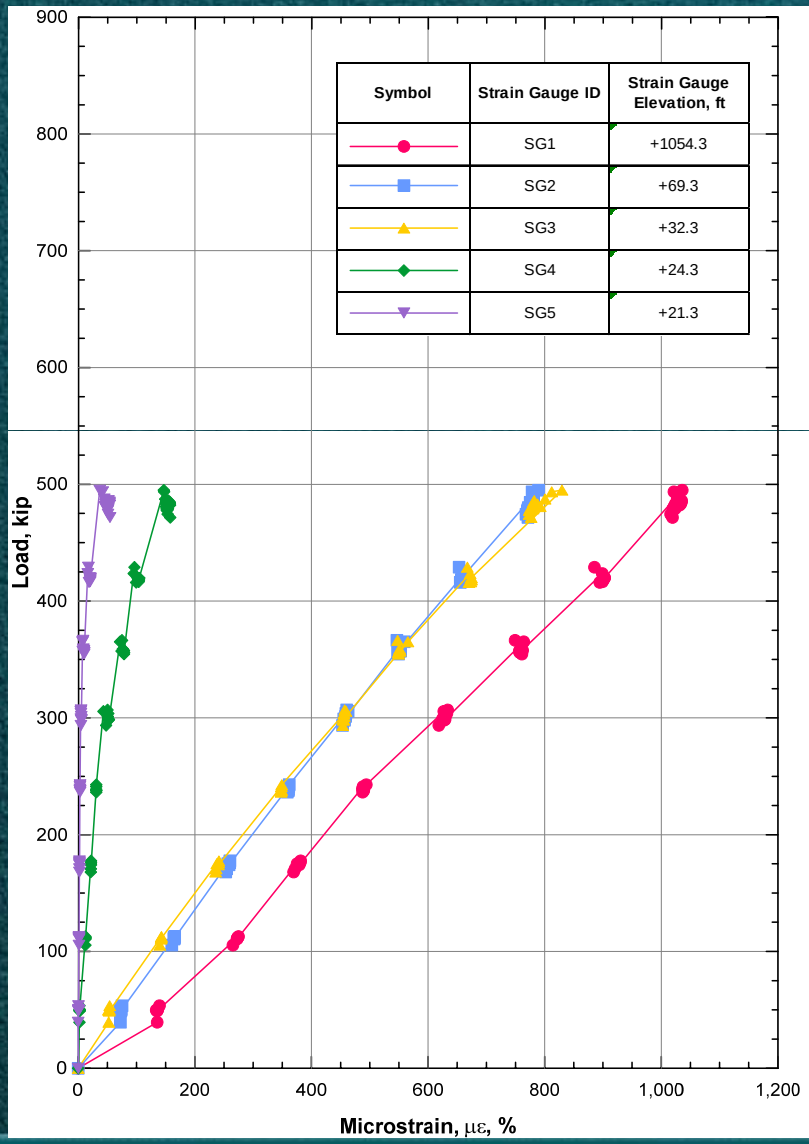
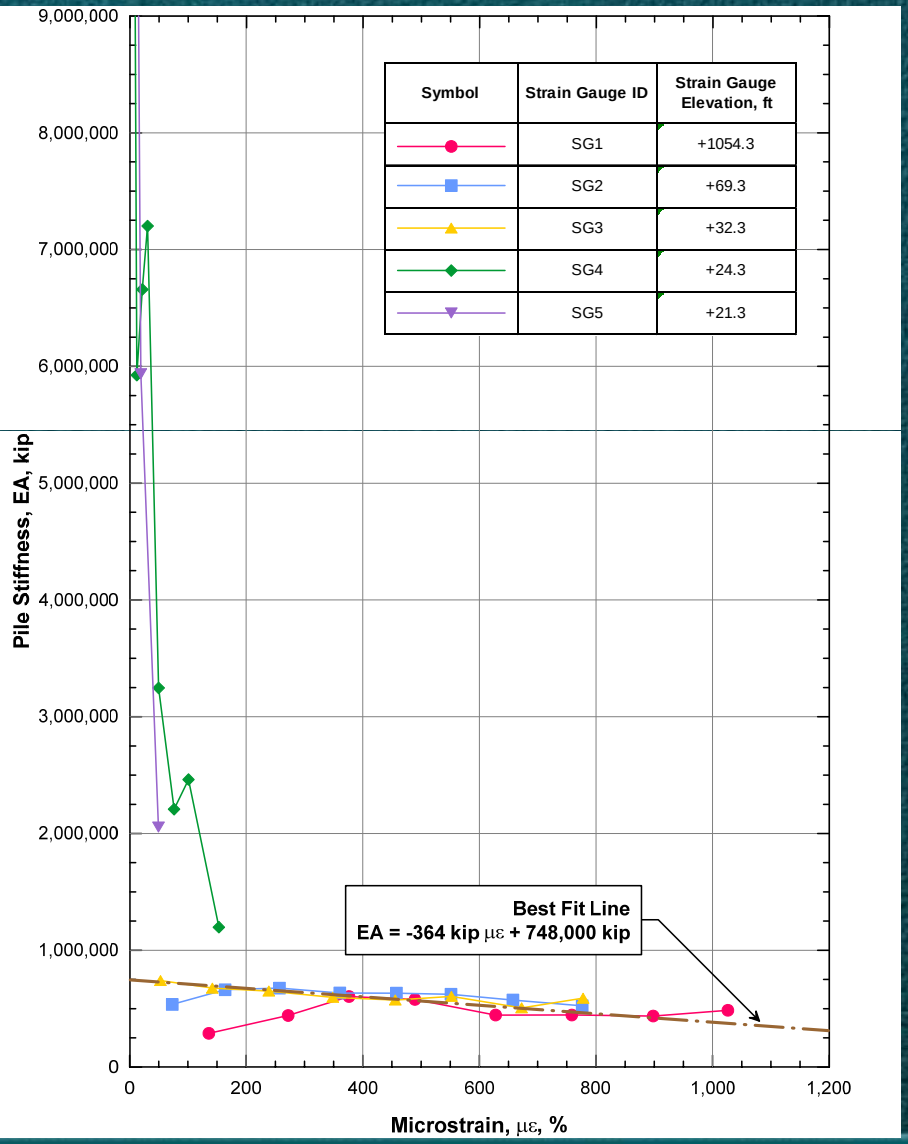
Strain Measurements





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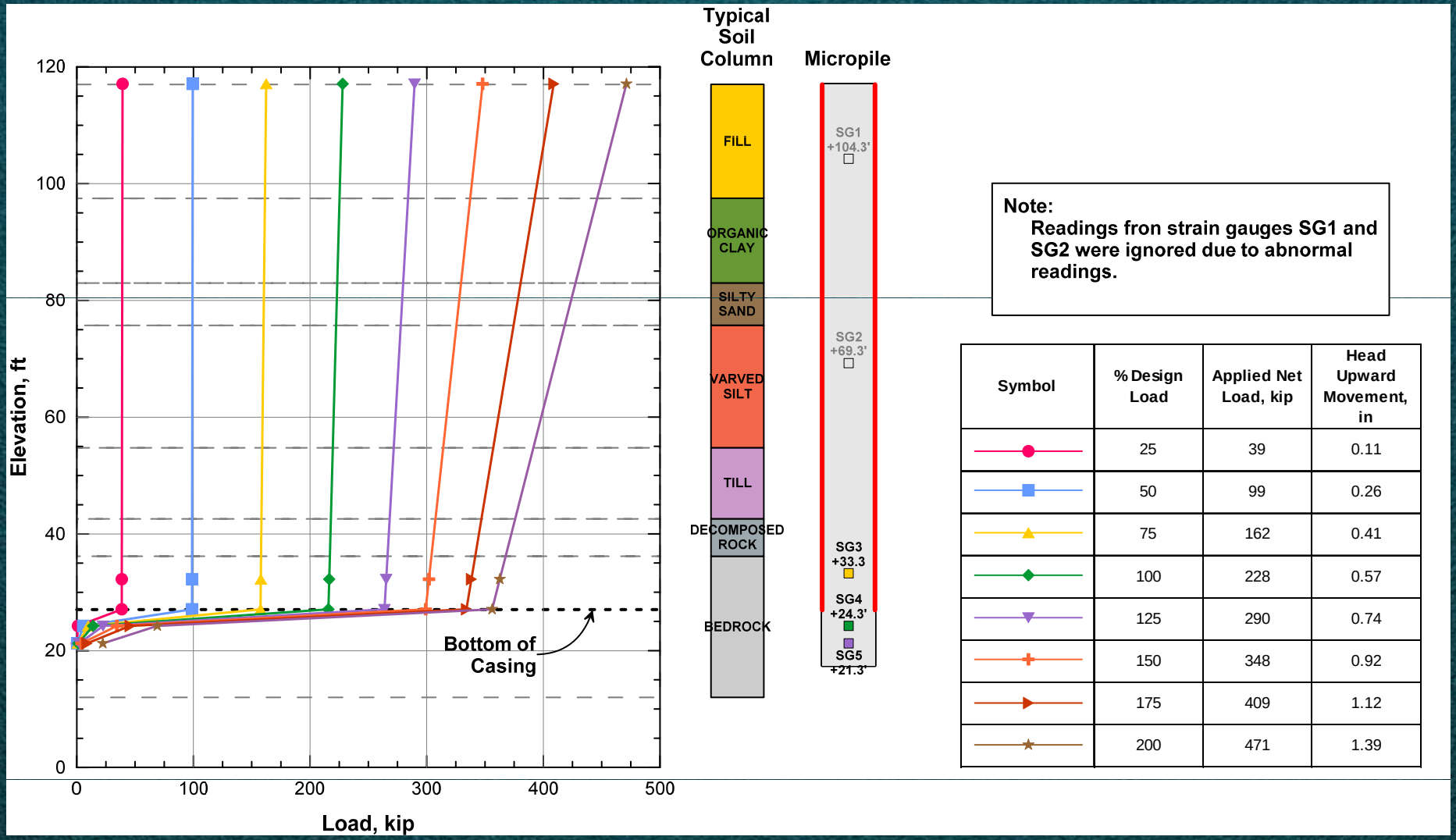
Pile Load Distribution



Note:
Readings fron strain gauges SG1 and SG2 were ignored due to abnormal readings.

Symbol	% Design Load	Applied Net Load, kip	Head Upward Movement, in
	25	39	0.11
	50	99	0.26
	75	162	0.41
	100	228	0.57
	125	290	0.74
	150	348	0.92
	175	409	1.12
	200	471	1.39

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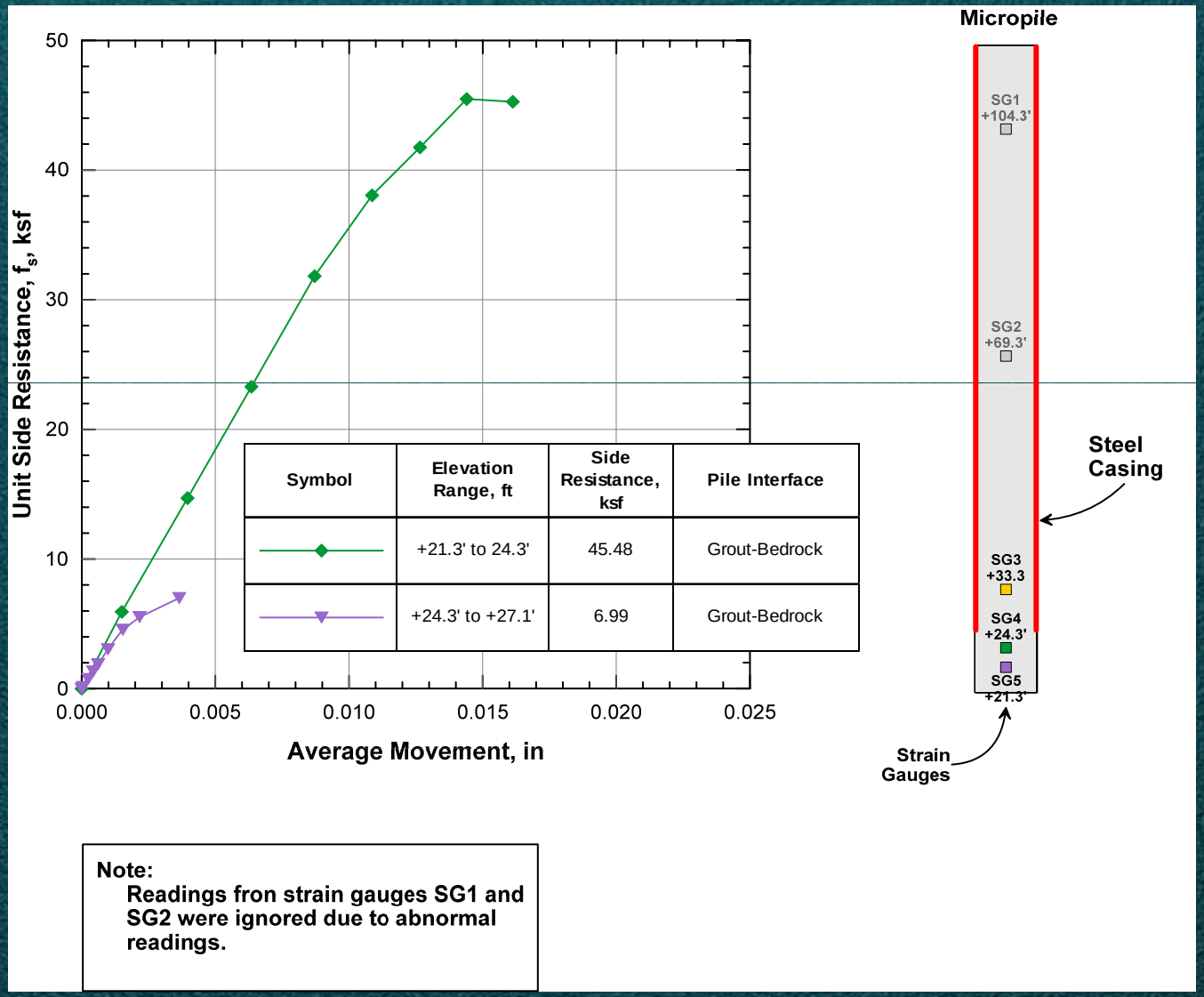
Rock Socket Bond Resistance

fsu = 315.8 psi

fs,max = 46.5 psi



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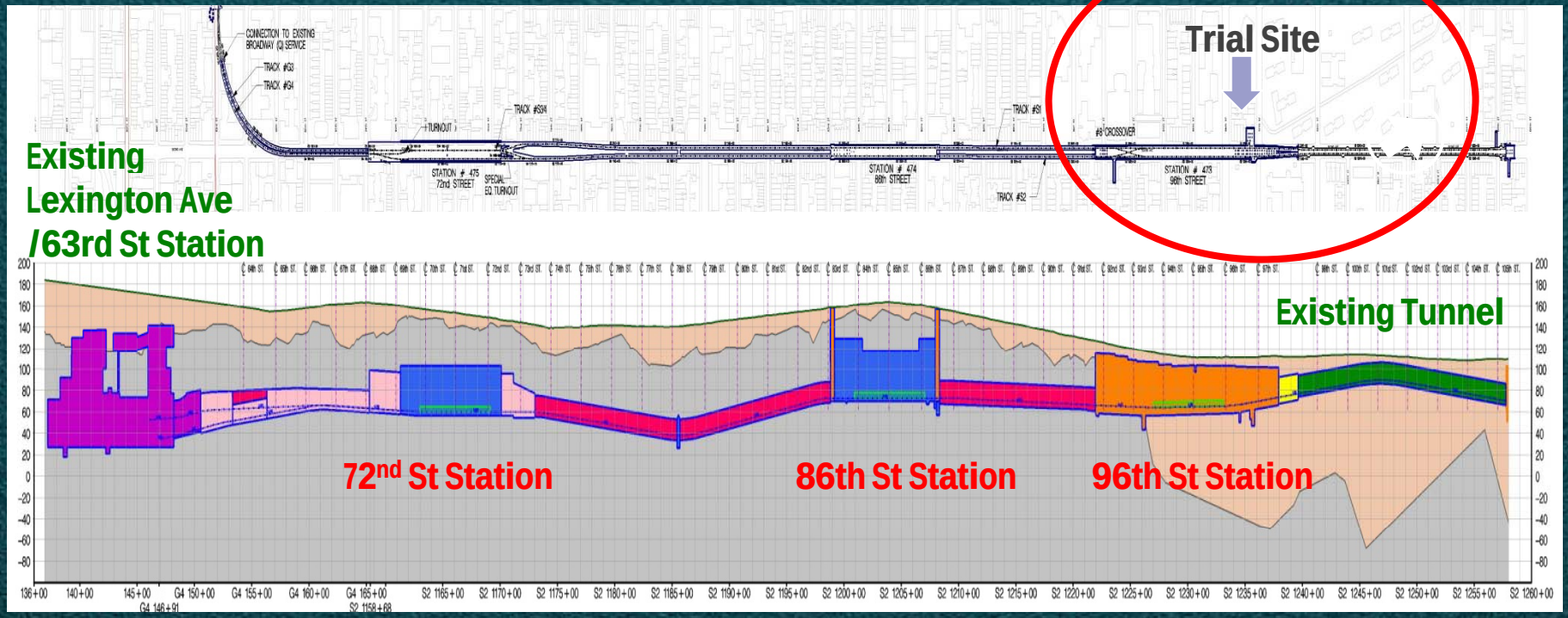
Jet Grouting Trial



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Jet Grouting Trial Site

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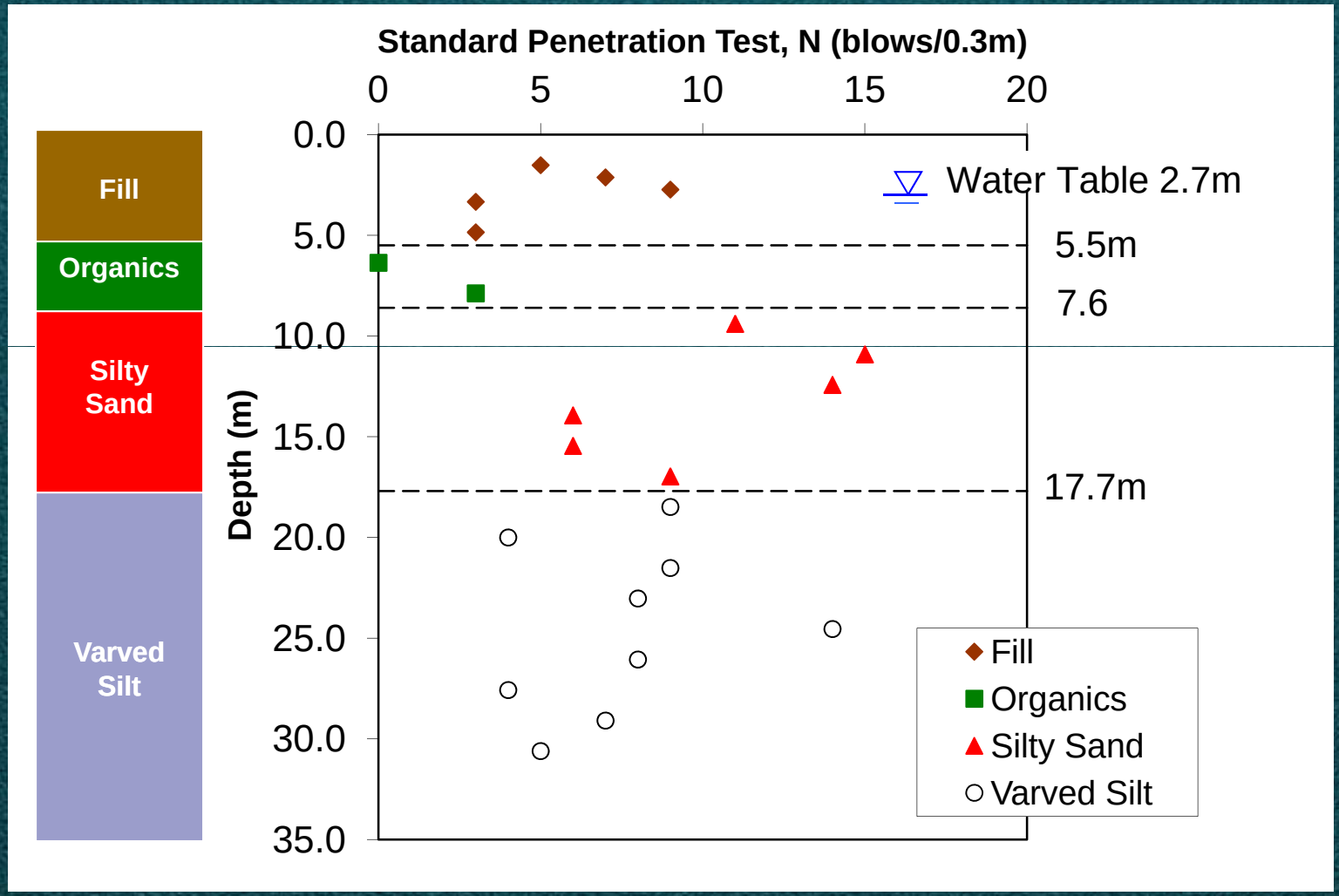
Soil Stratification at Jet Grouting Trial Site



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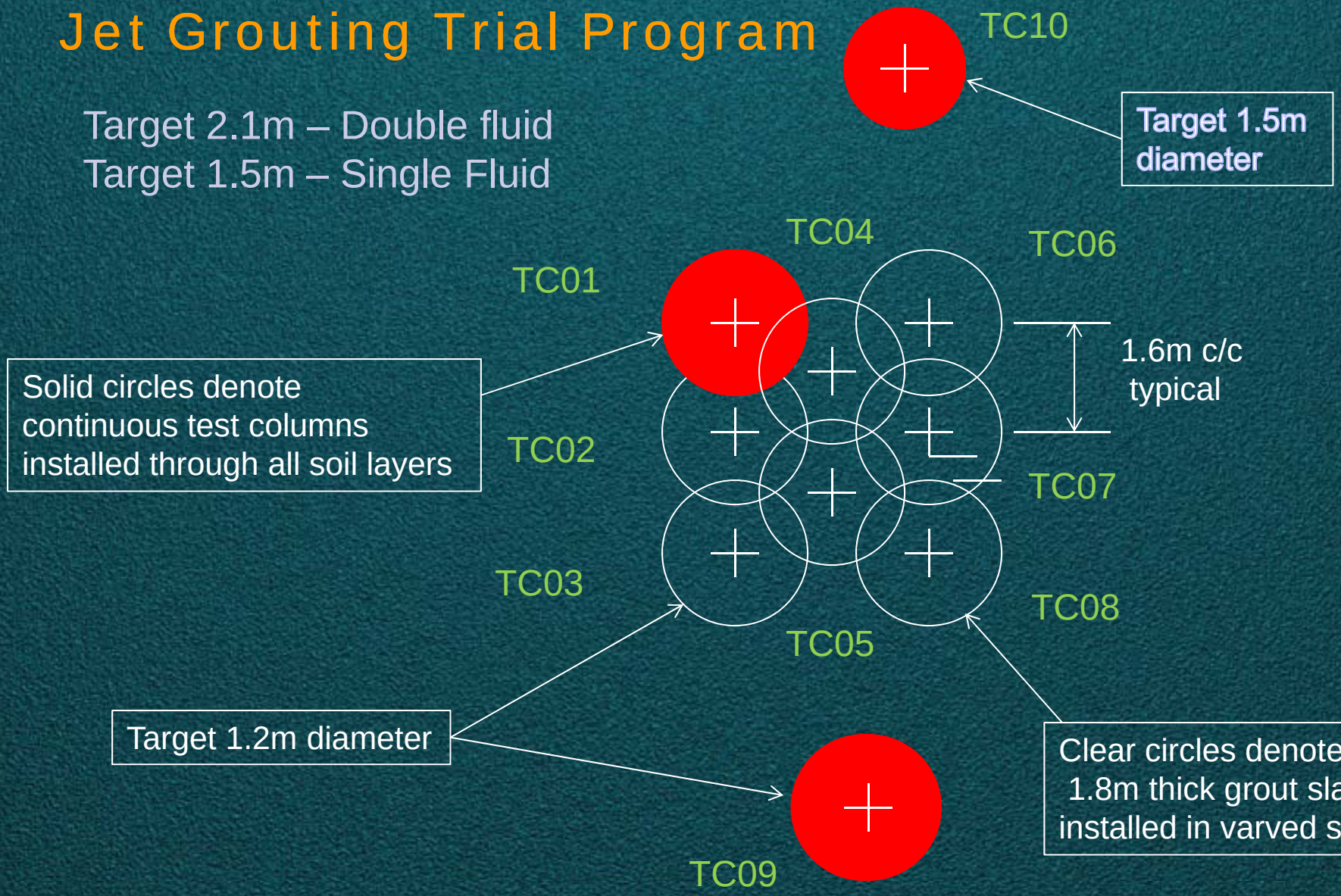
Jet Grouting Trial Program

Target 2.1m – Double fluid
Target 1.5m – Single Fluid



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Continuous Test Columns (TC01, TC09 and TC10)

Nozzle diameter = 6.0 mm
Monitor diameter = 89 mm
Rod diameter = 140 mm
Lift step = 4 cm

Interlocking Test Columns (TC02, TC03, TC04, TC05, TC06, TC07, TC08)

Nozzle diameter = 6.5 mm
Monitor diameter = 89 mm
Rod diameter = 140 mm
Lift step = 4 cm

ARUP

Continuous Test Columns - Jetting Parameters

Test Column	Soil Type	Grouting depth	Grout Pressure	Grout Flowrate	Air Pressure	Rotation speed	Lift speed
		m	bar	l/min	bar	rpm	sec/step
TC01	Fill	3.08 to 4.60	215	240	10	6.6	10
TC01	Organics	4.60 to 7.60	140	190	10	2.3	29
TC01	Silty Sand	7.60 to 17.80	240	250	10	6.6	10
TC01	Varved Silt	17.80 to 26.72	315	290	10	4.4	15
TC09	Fill	3.05 to 4.60	220	250	10	4.4	15
TC09	Organics	4.60 to 7.60	143	200	10	3.0	42
TC09	Silty Sand	7.60 to 17.80	265	270	10	4.8	14
TC09	Varved Silt	17.80 to 27.18	325	305	10	5.8	22
TC10	Fill	3.49 to 4.60	255	260	0	7.5	16
TC10	Organics	4.60 to 7.60	170	210	0	4.3	42
TC10	Silty Sand	7.60 to 17.80	275	270	0	7.5	16
TC10	Varved Silt	17.80 to 27.70	390	320	0	5.5	22

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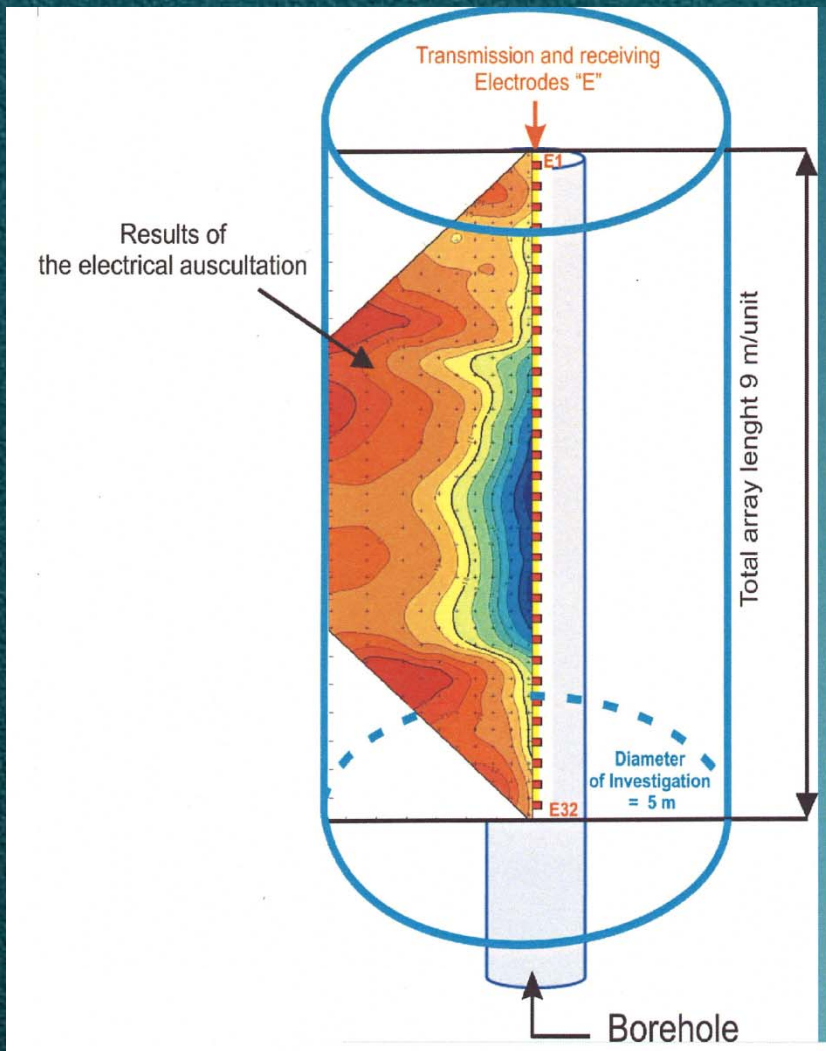
Interlocking Test Columns - Jetting Parameters

Test Column	Soil Type	Grouting depth	Grout Pressure	Grout Flowrate	Air Pressure	Rotation speed	Lift speed
		m	bar	l/min	bar	rpm	sec/step
TC08	Varved Silt	20.70 to 22.88	245	365	13	6.3	19.0
TC04	Varved Silt	20.72to 22.86	245	365	13	6.1	19.3
TC03	Varved Silt	20.16 to 22.86	250	365	12	6.2	19.1
TC06	Varved Silt	20.68 to 22.86	250	365	12	6.3	19.1
TC05	Varved Silt	20.72 to 22.88	255	365	13	6.5	19.4
TC07	Varved Silt	20.71 to 22.96	250	365	12	6.4	19.4
TC02	Varved Silt	20.72 to 22.96	245	365	12.5	6.1	19.2

In Situ Column Diameter Measurement (Cyljet)

Frappin and Vernhes (2011)



It's an application of the Electric Cylinder® Method developed and patented

consists of recording and analysing the potential differences generated by an induced electric current around a borehole.

The electric monitoring field around the hole takes the form of a cylinder 2m to 5m in diameter, depending on the electric resistivity of the ground and instrumentation system employed.

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In Situ Column Diameter Measurement (Cyljet)

Frappin and Vernhes (2011)

Multi-conductor cable connected to regularly spaced current-injecting electrodes and receiver electrodes lowered into a slotted PVC pipe inserted into jet grout column

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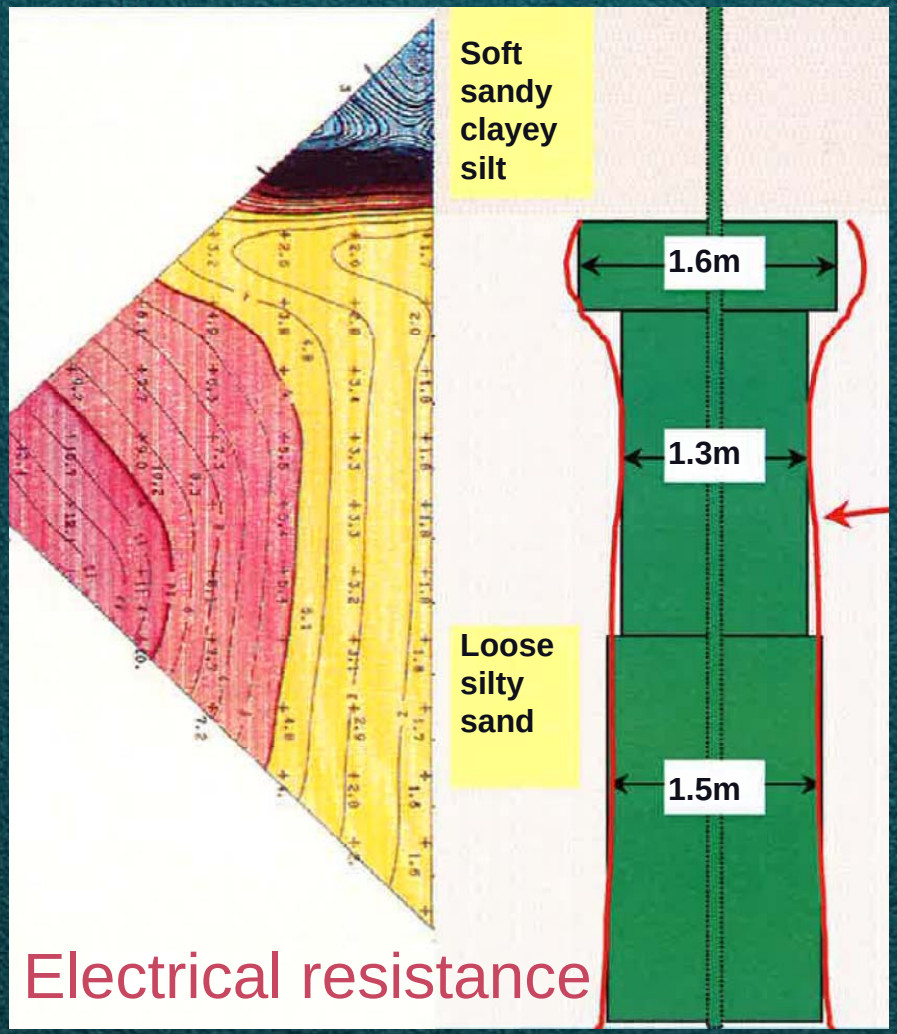
In Situ Column Diameter Measurement (Cyljet)

Frappin and Vernhes (2011)



Computer simulation to match field iso-resistivity contours

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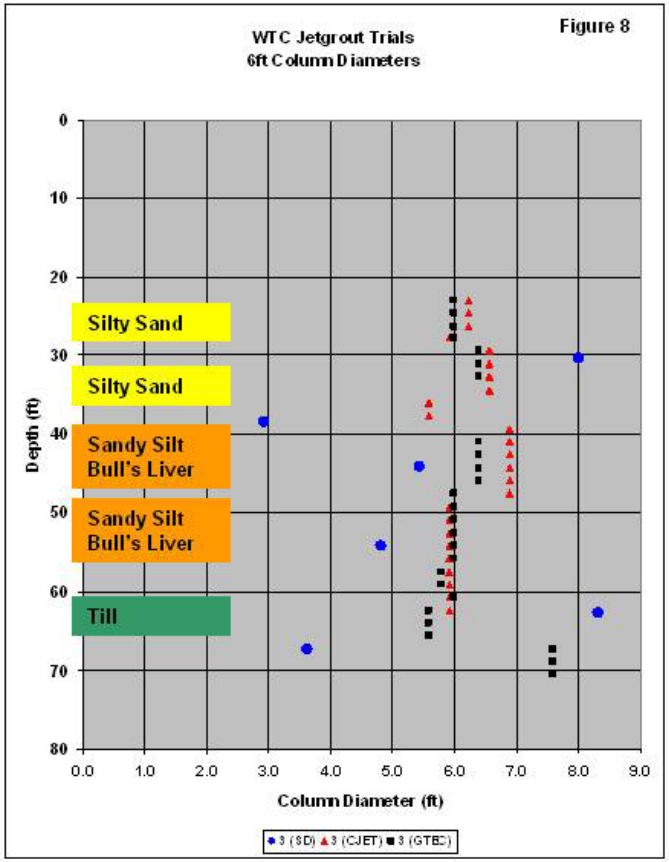
World Trade Center – Cyljet Measurements

Crockford et al. (2008)



Column 3 Measure Comparison

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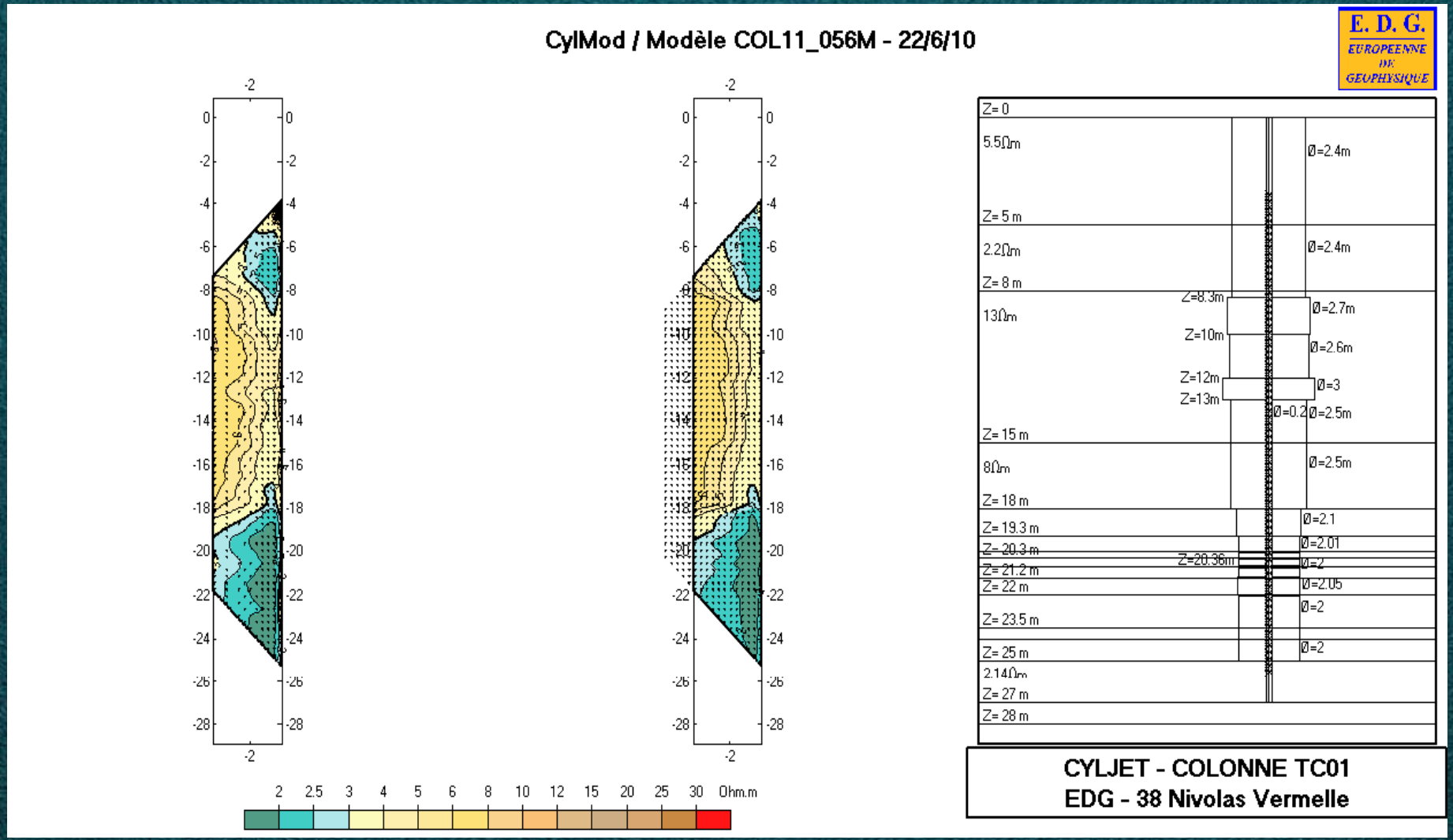
2nd Ave Subway - Test Column TC01



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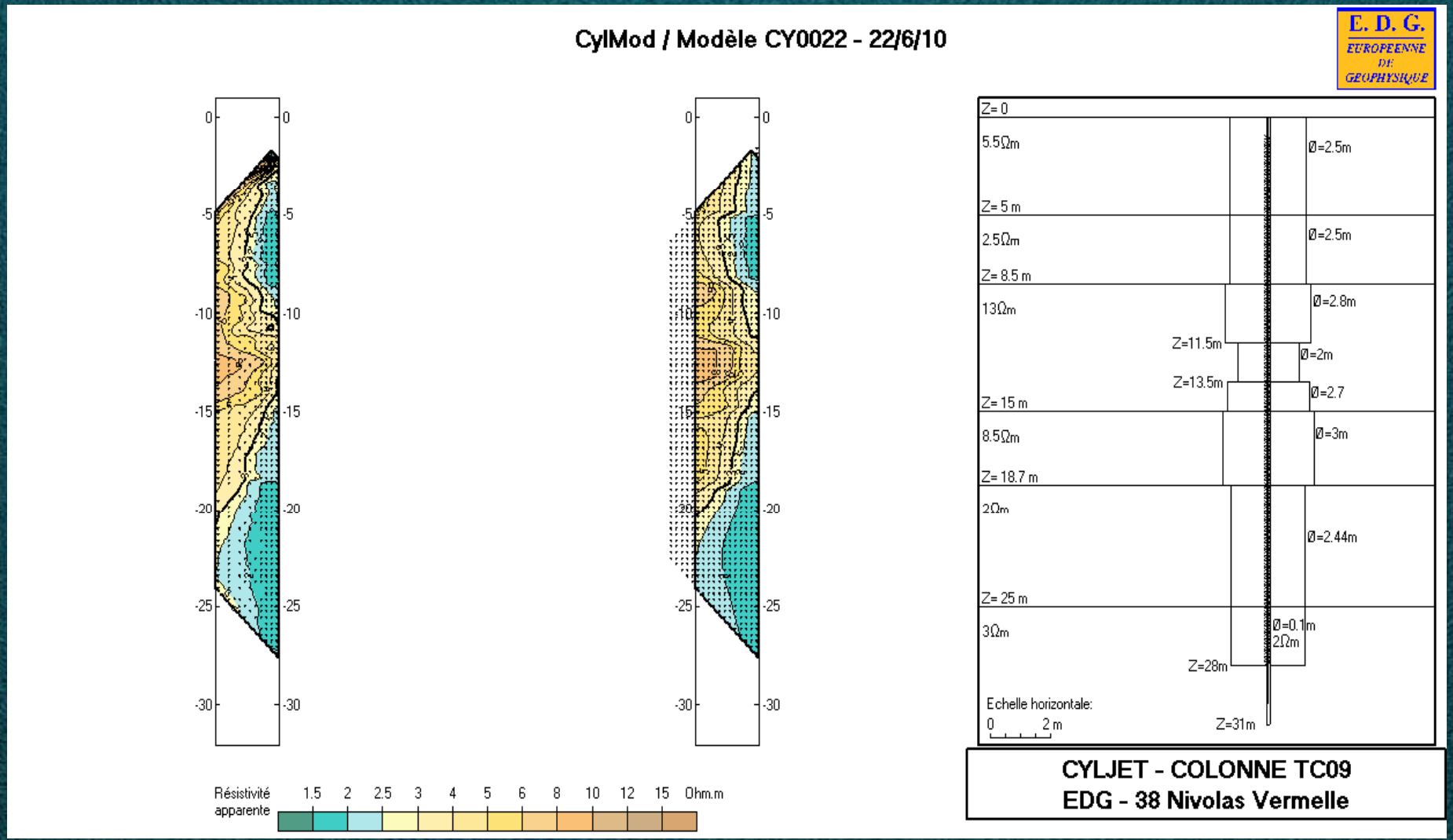
2nd Ave Subway - Test Column TC09



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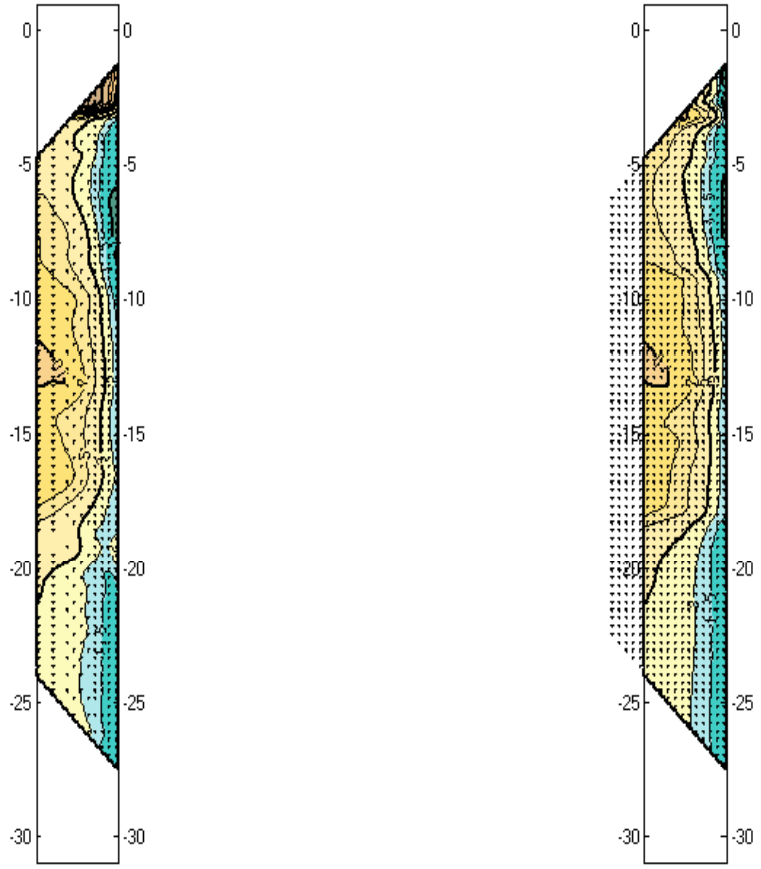
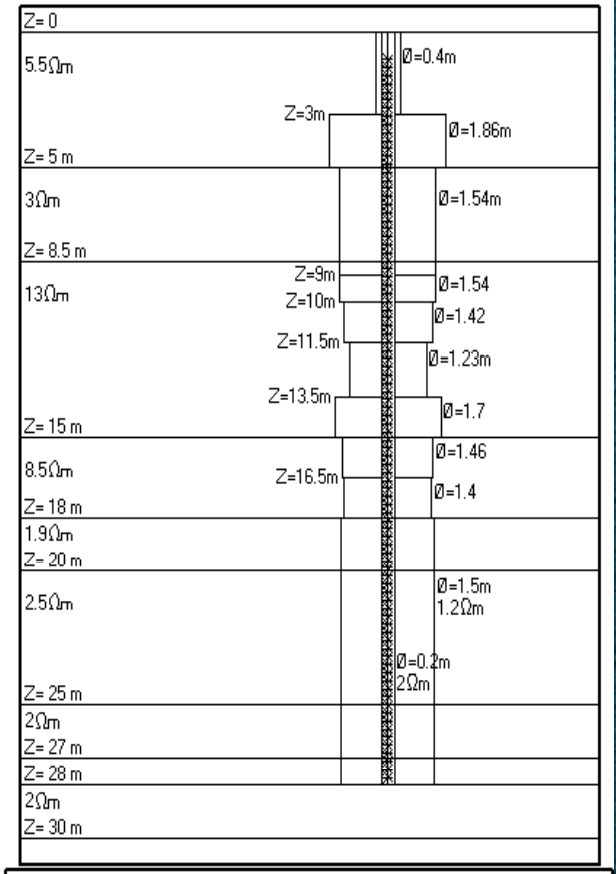
2nd Ave Subway - Test Column TC10

CylMod / Modèle CY0043M - 22/6/10

E. D. G. EUROPEENNE DE GEOPHYSIQUE



Résistivité apparente 1 1.5 2 3 5 7 10 15 20 30 50 Ohm.m



CYLJET - COLONNE TC10
EDG - 38 Nivolas Vermelle

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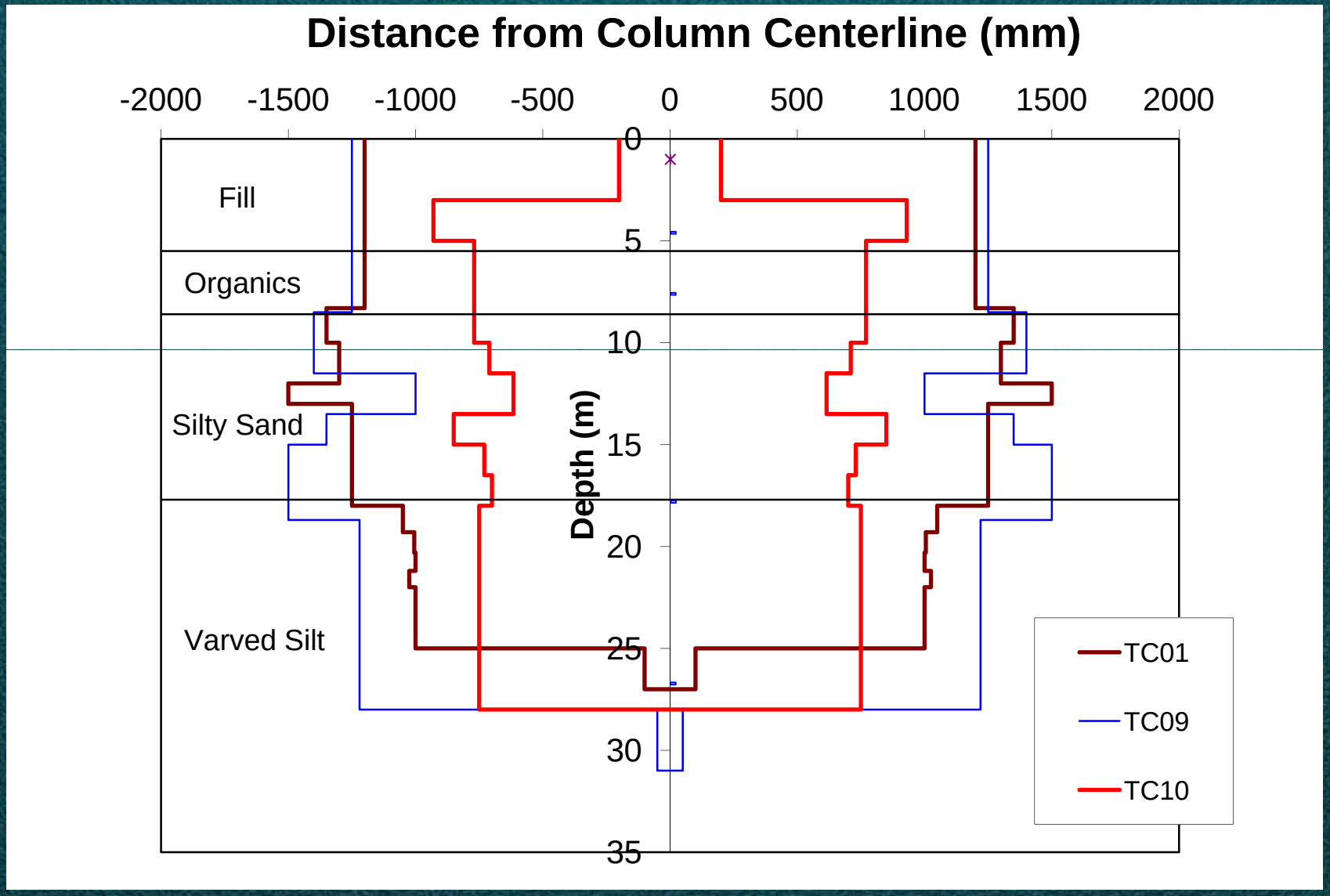
Cyljet Measurements – Summary Results



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Specific Energy for Grout Jet

Tornaghi (1989)

$$E_{sg} = 0.1\left(\frac{P_g Q_g}{L_s}\right)$$

Specific Energy for Air Jet

$$E_{sa} = \frac{0.035 Q_a \left[(10 P_a)^{0.29} - 1\right]}{L_s}$$

Total Specific Energy

$$E_s = E_{sg} + E_{sa}$$

P_g = Grout pressure (MPa)
Q_g = Grout flowrate (l/min)
P_a = Air pressure (MPa)
Q_a = Air flowrate (l/min)
L_s = Lift speed (cm/min)

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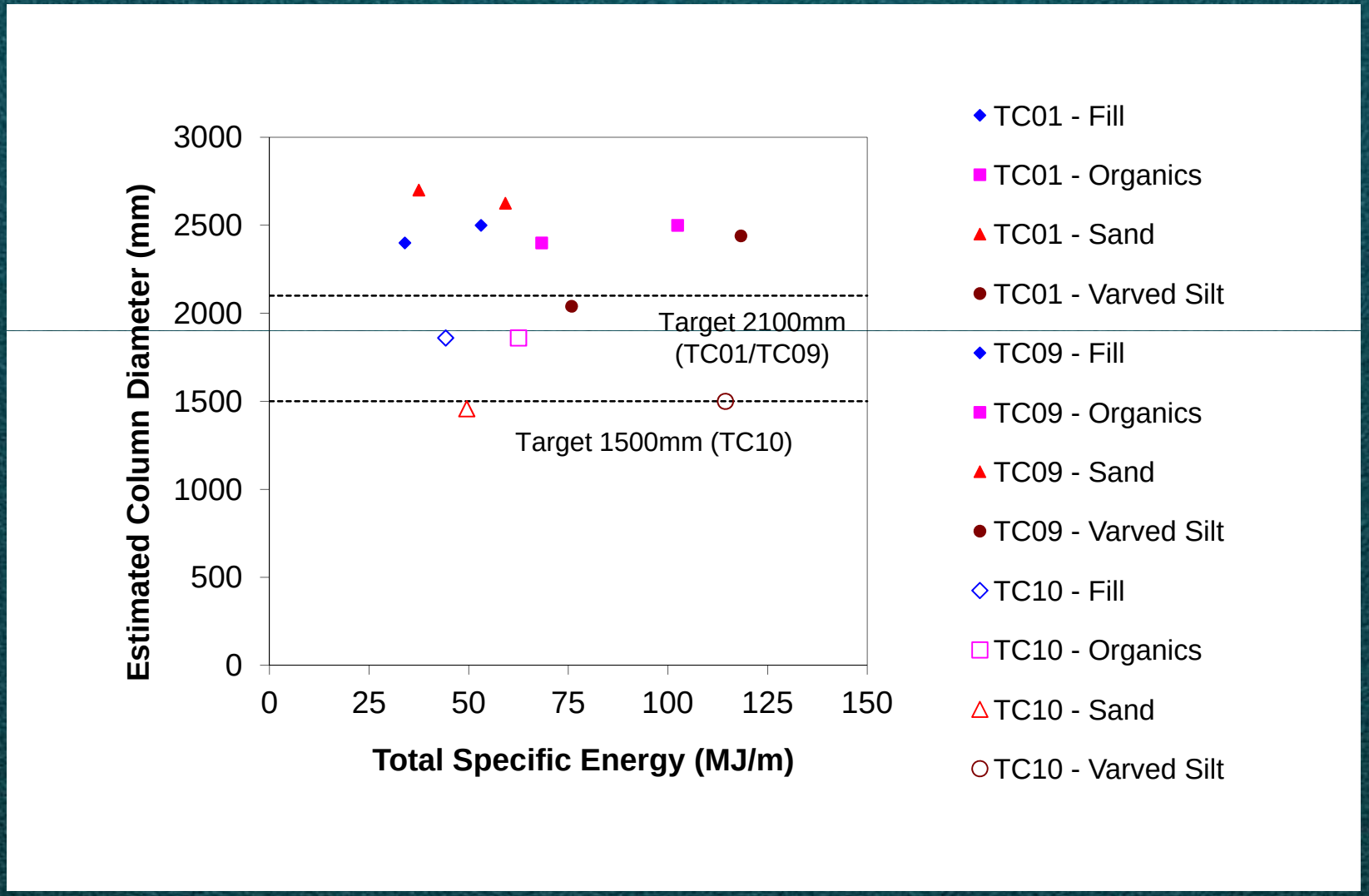
Diameter Based on Cyljet Measurements



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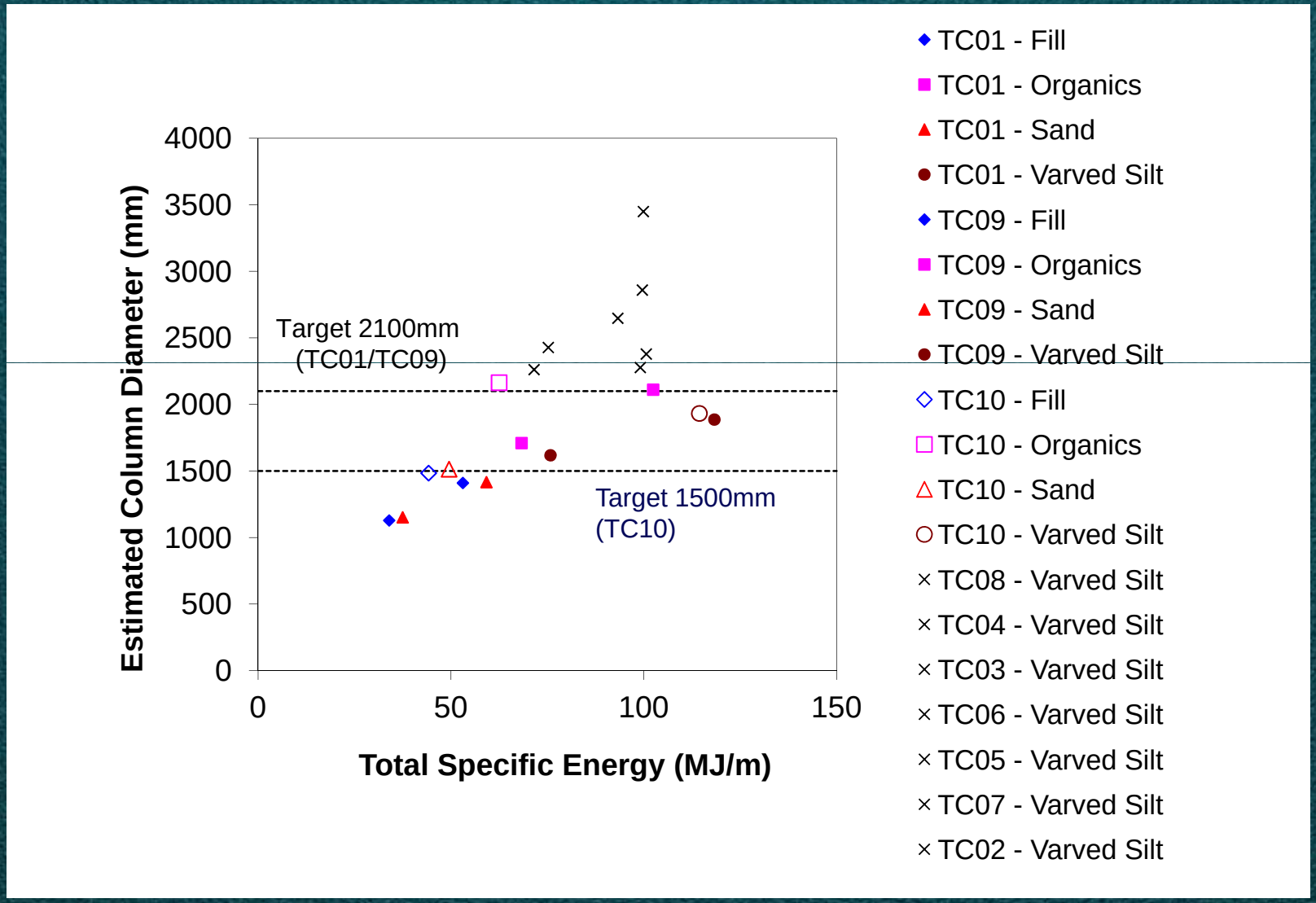
Diameter Based on Grout Consumption



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Coring Locations

TC10

C2 TCR 98.3%

TC04

TC01

TC06

1.6m c/c typical

C3 TCR 92.5%

TC02

TC07

TC03 (D = 2173mm)

TC05

TC08 (D = 2754mm)

TC09

C1 TCR 95%

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CONSTRUCTION

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Geotechnical Exploration Program

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DONATE
YOUR CAR
Free Towing
Tax Deductible
OUTREACH
THE BIG
PIZZA
INGERSOLL

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Utility Relocation

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Installation of Secant Pile Wall

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Installation of Slurry Wall

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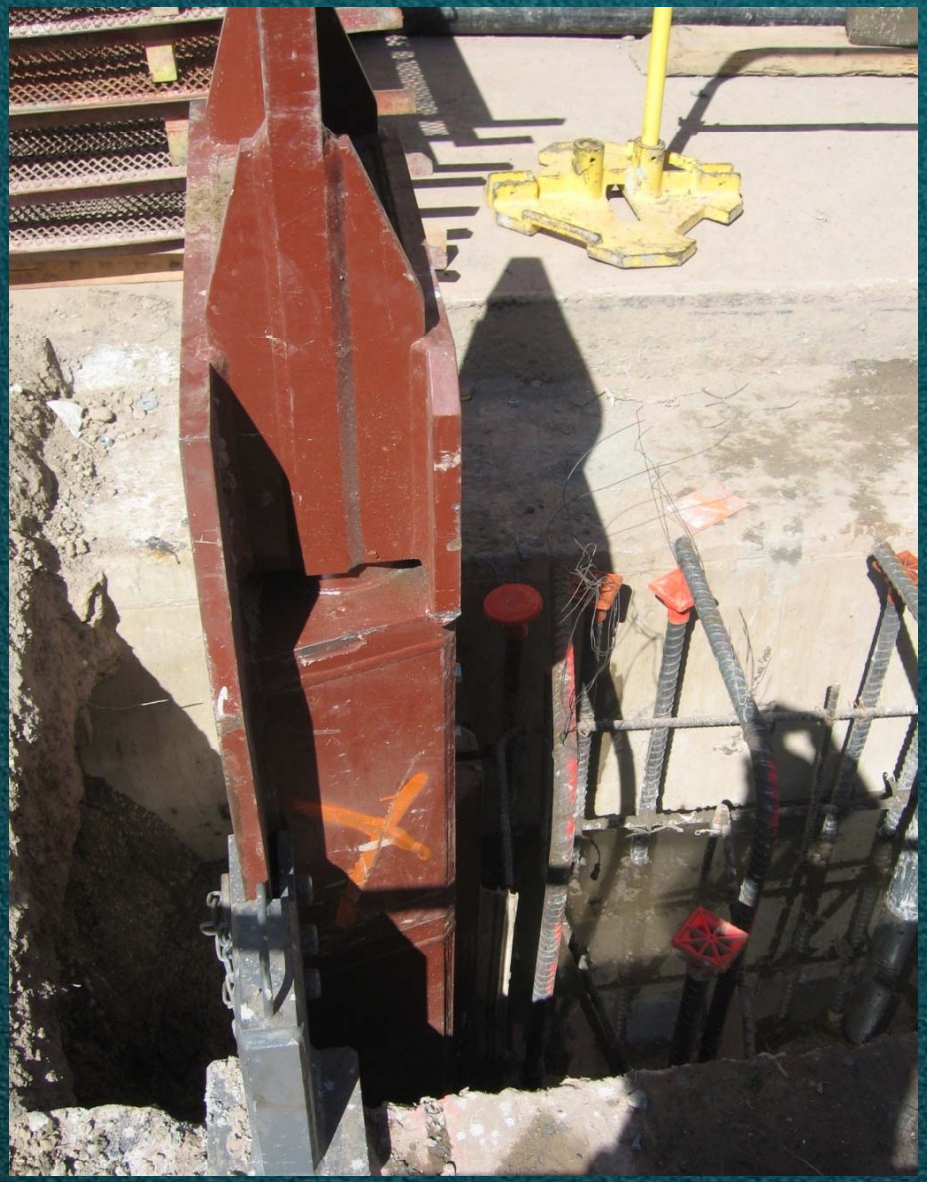

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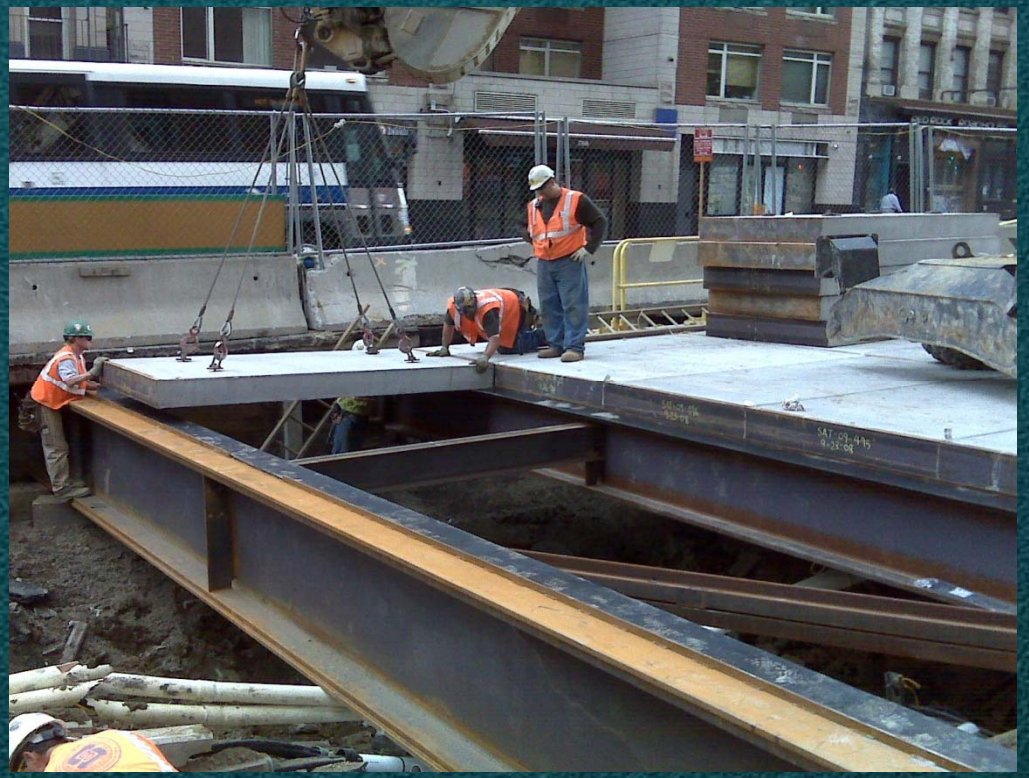
Installation of Temporary Roadway Decking

- **Steel Beams**
- **Spliced at center**
- **Supported on SOE Walls**
- **Precast Concrete Deck Panels**



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Installation of Temporary Roadway Decking

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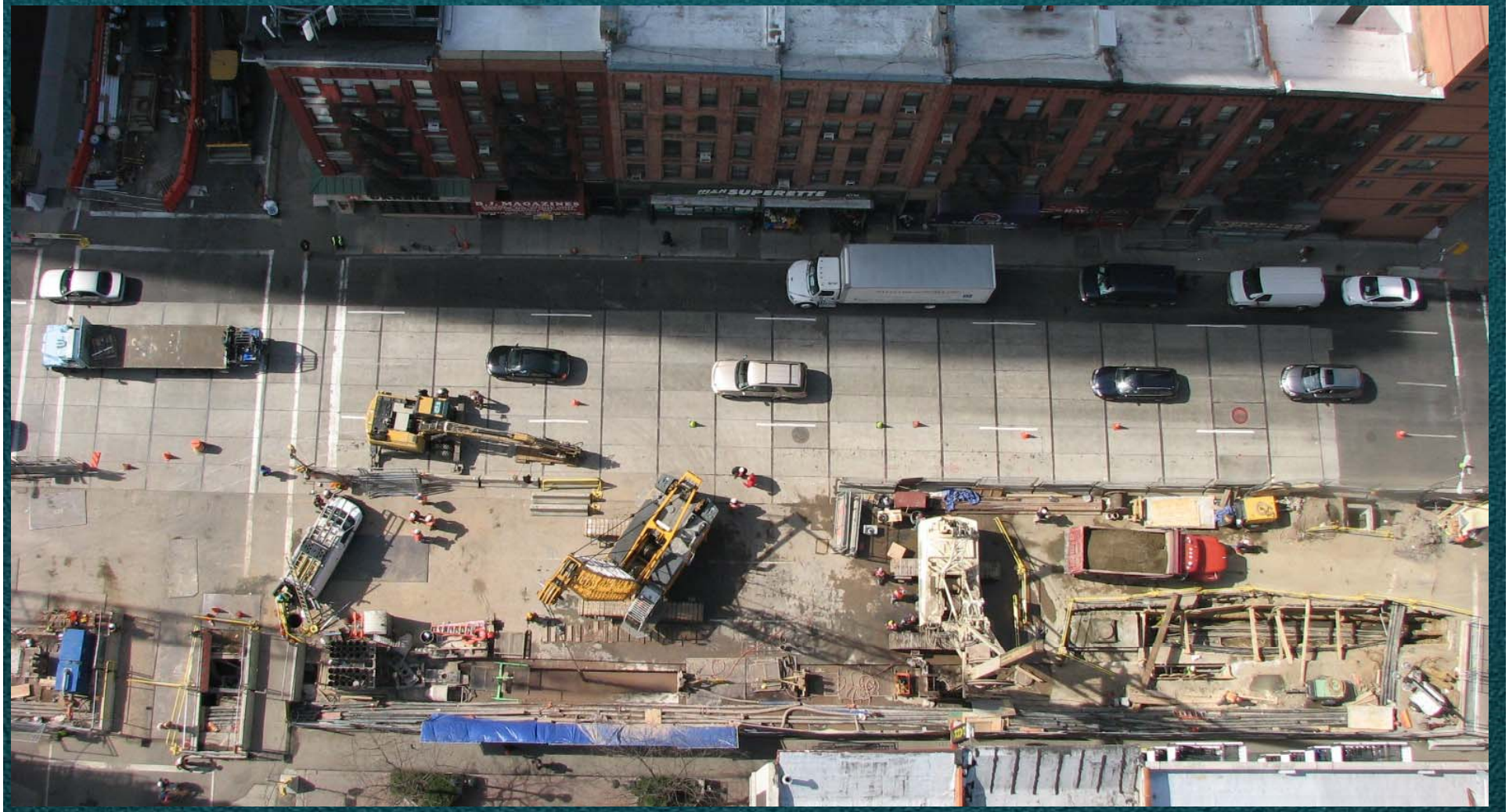
Completed Decking with Traffic



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Under the Deck

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Hanging Utilities

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Excavation in Shallow Rock

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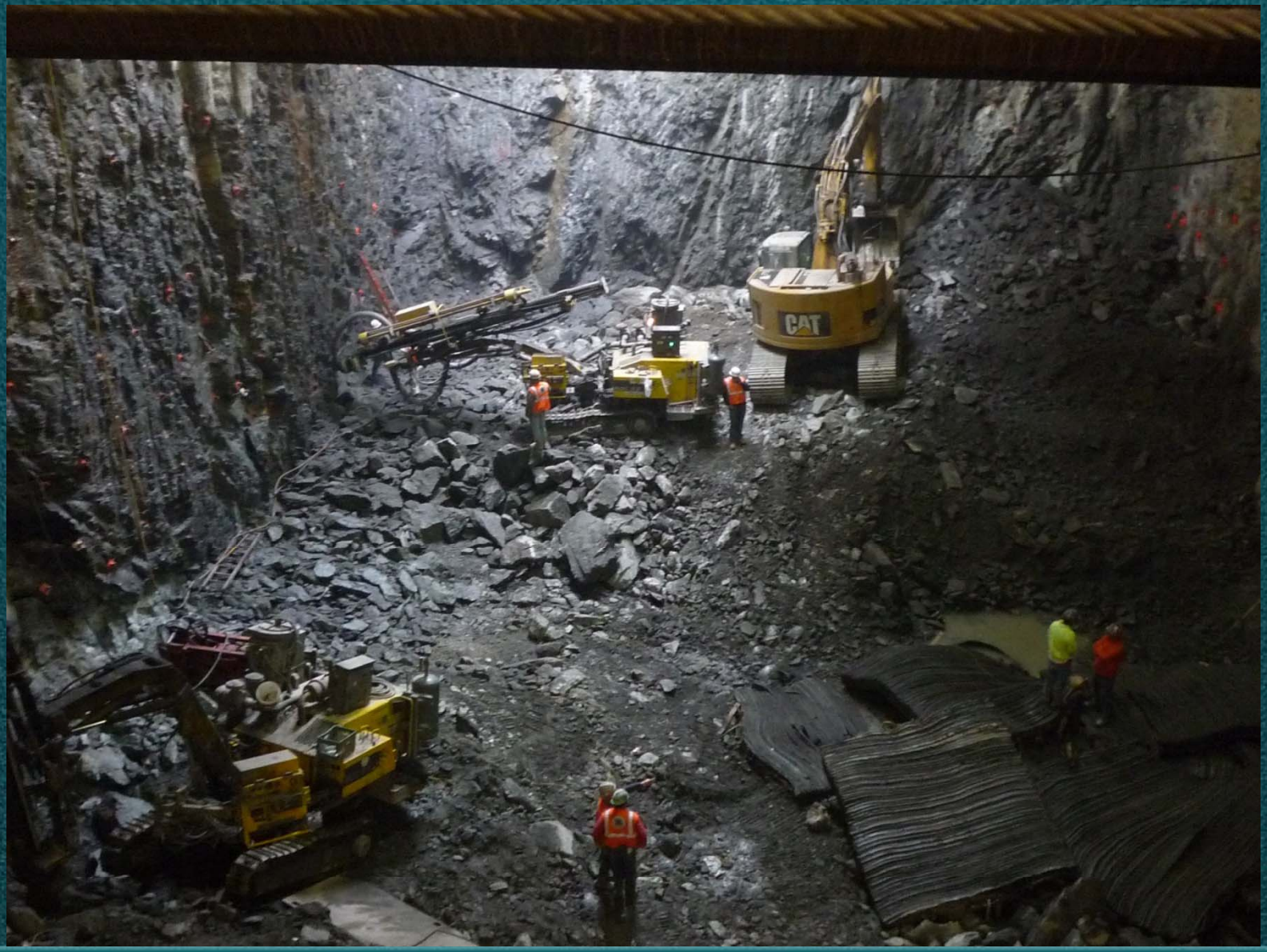
Drilling and Blasting in Rock



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Secant Pile Wall
Toe Anchors in Rock

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Slurry Wall Couplers

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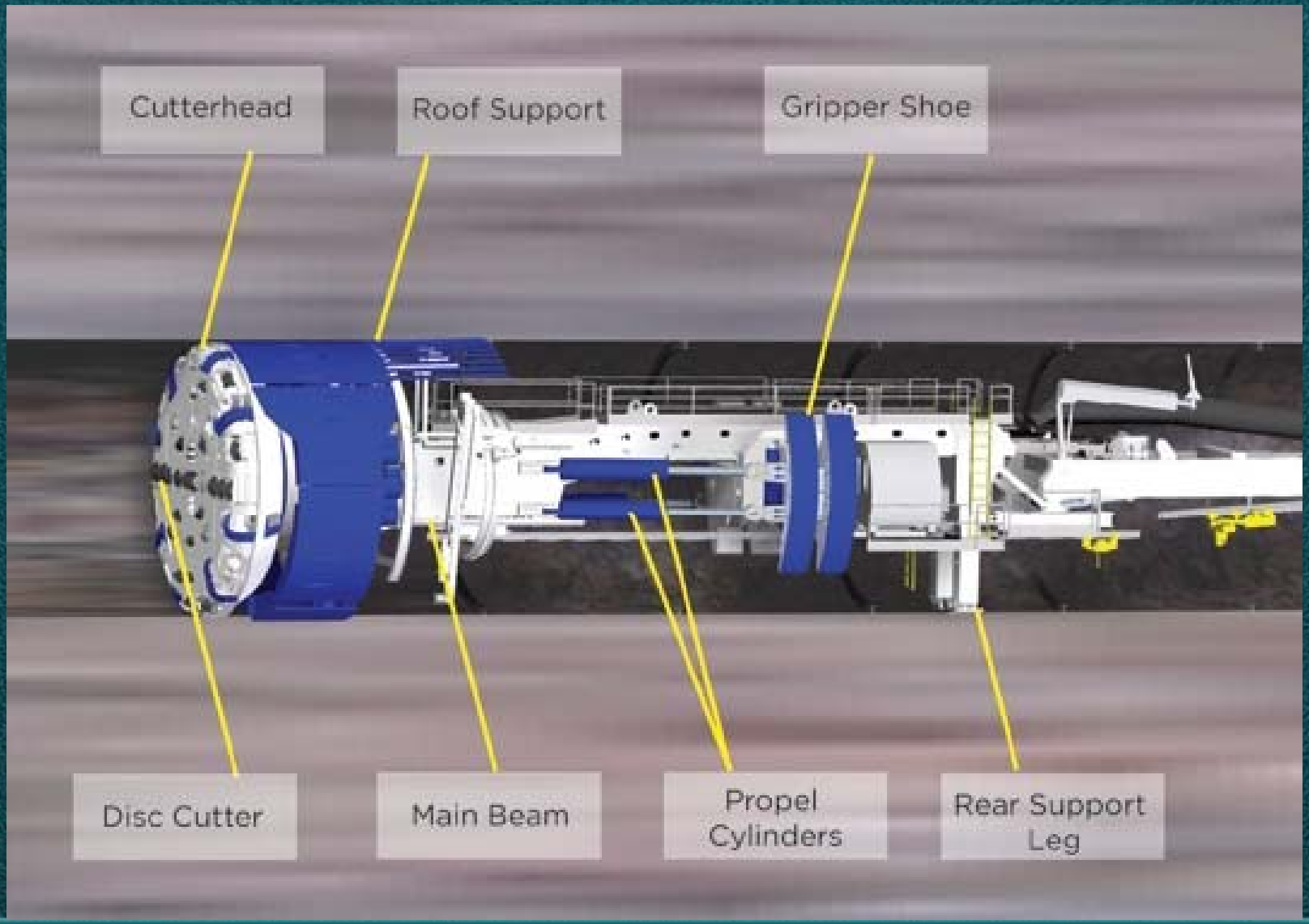
Hard Rock Tunnel Boring Machine



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Construction Shafts at 69th and 72nd Streets

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Starting Tunnels at Launch Box

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Starting Tunnels

TBM Tunneling

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Hopper Loading Truck

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Steel Ribs

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PVC Waterproofing Membrane

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Cast in Place Lining

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TBM Breakthrough

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Enlargement of TBM Bore at Turnout Cavern

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72nd St Cavern - Top Heading

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72nd St Cavern – Top Heading Complete

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Thank You

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