Estimating Soil Pressure Against Unyielding Surfaces (BDV31-977-89)

FDOT GRIP Meeting

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Topics Covered

- Introduction
- Background
- Objectives
- Tasks
- Project Benefits

Introduction

- Mechanically Stabilized Earth (MSE) Walls are a cost-effective option for earth retention systems.
  - Bridge abutments, highway separations, and when construction space is limited
- Reinforced strips or grids are placed between layers of compacted soil and mechanically attached to the wall facing.
- Lateral earth pressures exerted on the wall facing by granular backfill are opposed by frictional resistance developed along the surface of the reinforcement

Background

- In general design, the lateral earth pressure imposed on a retaining wall is approximately equal to the active lateral earth pressure
  - Conventional earth pressure theory
  - Reinforcement embedded in soil provides resistance
- In certain cases, the reinforcement ties two walls together resulting in an unyielding condition.
  - Widening conditions (new wall tied to existing wall)
  - Acute corners
- The actual soil pressure that results behind an unyielding surface is not well defined

Background

- FHWA GEC #11 acknowledges that “much higher” tension develops in the reinforcement when walls are tied together
- Minor deformations that typically occur in conventional MSE walls are prevented
- While GEC #11 recognizes the problem, it does not provide a clear recommendation for estimating the pressure of compacted soils

Objectives

- Investigate the resulting earth pressure coefficients derived from an approved MSE wall configuration
  - MSE reinforcement is tied to an unyielding structure
    - Prevents minor wall deformations in the yielding MSE wall
  - Two states of soil density (95% and 104% of T-180)
    - Half of the wall constructed at 95% and half at 104%
- The outcome can be used to adequately address design methodology and earth pressure coefficients
  - Earthen fill compacted behind unyielding structures

Tasks

- Task (1) – Literature Review and Preliminary Design ✓
- Task (2) – Final Design, Site Preparation, and Materials Purchasing ✓
- Task (3) – MSE Wall Construction with Two Designated Relative Compaction Efforts
- Task (4) – Draft Final and Closeout Teleconference
- Task (5) – Final Report

Task (1) – Literature Review and Preliminary Design

- Extensive literature review of current design practices and standards was conducted
  - Ensure the MSE wall configurations adhere to the FDOT standard specifications for road and bridge construction
  - Comply with AASHTO design code.
- Construction and quality control procedures developed within the industry were also investigated
  - Ensures proper construction and sequencing takes place
  - Provides structures that are representative of typical MSE wall construction
- Preliminary MSE wall design was completed

Task (2) – Final Design, Site Preparation, and Materials Purchasing

- Soil testing conducted at the SMO:
  - Sieve analysis
  - Compaction (T99 and T180)
  - Direct shear
  - Moisture content
  - Unit weight
  - Soil classification
  - pH, resistivity, chloride, and sulfate testing
  - Routine nuclear density testing during construction

Soil Properties

Sieve Size	Required Percent Passing (AASHTO T-27)	Reported Percent Passing (AASHTO T-88)
3-1/2 inches	100	N/A
¾ inch	70 to 100	100
No. 4	30 to 100	100
No. 40	15 to 100	99.4
No. 60	N/A	77.9
No. 100	0 to 65	23.8
No. 200	0 to 12	2.3

- D_{10} ≈ 0.105 mm
- D_{60} ≈ 0.210 mm
- D_{85} ≈ 0.270 mm
- Coefficient of Uniformity (C_u) = 2
- AASHTO Classification = A-3
- USCS Classification = SP – Poorly Graded Sand
- Liquid Limit = Non-plastic (NP)
- Plastic Limit = NP
- Plasticity Index = NP
- Specific Gravity (G_s) = 2.65
- Organic Content (%) = 0.3

- Maximum Dry Density ($\gamma_{d\text{-}max}$) = 105.7 pcf
- Optimum Moisture Content (w_{opt}) = 12.7 %
- <u>Compaction Effort 1 (T-180)</u>
  - Compaction (%) = 95.7 %
  - Dry Density (γ_d) = 101.2 pcf
  - Moisture Content (w) = 12.8 %
  - Internal Friction Angle (Φ) = 31.0°
- <u>Compaction Effort 2 (T-180)</u>
  - Compaction (%) = 103.5 %
  - Dry Density (γ_d) = 109.4 pcf
  - Moisture Content (w) = 12.8 %
  - Internal Friction Angle (Φ) = 40.5°
- <u>Electrochemical properties</u>
  - pH = 5.32 (Pass)
  - Resistivity = 58,900 Ω-cm (Pass)
  - Chloride = 54 ppm (Pass)
  - Sulfate = 6.5 ppm (Pass)

MSE Wall LRFD Final Design

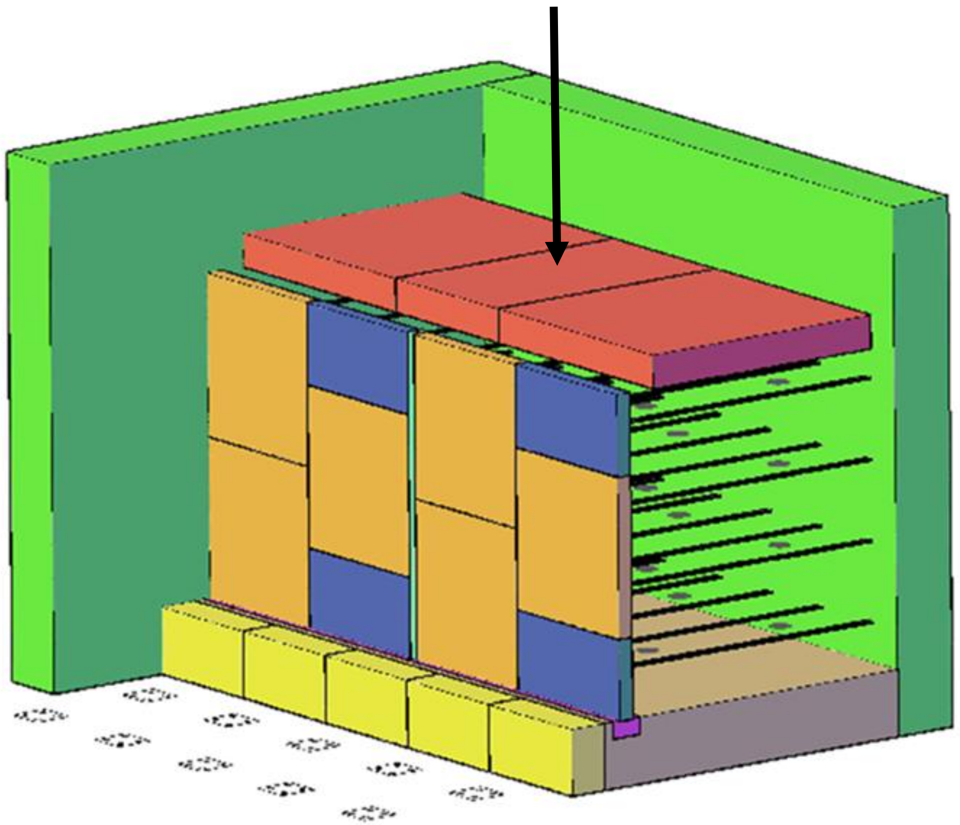
- List and quantities of instrumentation
- Geometry
- Loading conditions
- Performance criteria
- Project parameters
- Wall embedment depth, design height, and reinforcement length
- Nominal loads
- Load combinations, load factors, and resistance factors
- External stability design
- Facing elements
- Overall/global stability
- Wall drainage system

- Internal stability design
  - Soil reinforcement
  - Critical failure surface
  - Unfactored loads
  - Vertical layout of reinforcements
  - Factored horizontal stress and maximum tension (each level)
  - Grade and number of soil reinforcement elements
  - Nominal and factored pullout resistance of soil reinforcements
  - Connection resistance at MSE wall facing
  - Connection resistance at Strong Wall
  - Estimated lateral wall movement
  - Vertical movement and bearing pads

MSE Wall Initial Surcharge Design

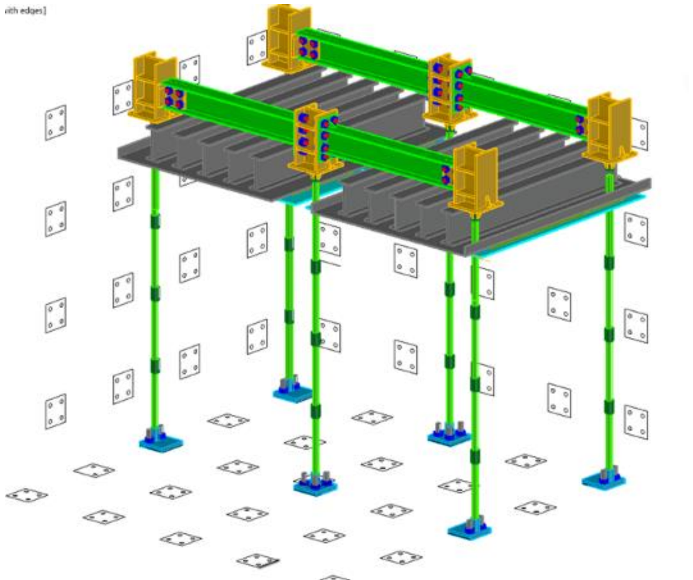
- UF Soil Box walls and/or large concrete blocks will be used for surcharge loading
    - Representative of earth surcharge (ES)
- Estimated surcharge
    - q_s = 250 psf
- Approximate equivalent to 2’ of overburden soil
    - AASHTO recommended height equivalent for traffic loads parallel to MSE walls

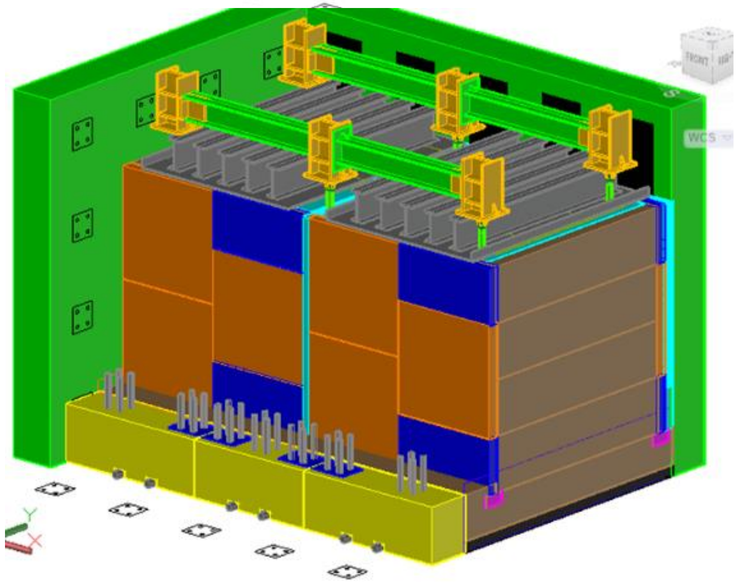
Simulated Earth Surcharge



MSE Wall Surcharge Redesign

- RECo indicated initial reinforcement/wall height ratio was not representative of practice
  - Wall height 10 ft plus 2 ft surcharge
  - Reinforcement length 10 ft
  - B/H ≈ 0.83
- Need a B/H ≈ 0.3
  - Must simulate around 23 ft of overburden
  - Total height of 33 ft
  - Not possible with dead weight and available lab overhead clearance
- Utilize parts of Soil Box to create reaction frame
  - Soil Box walls, soil plates, chain link fence, and Matjack airbag system
- Use Dywidag threaded bar system tied to Strong Floor





Connection Strength Stability Check

- Stability checks were performed using five different earth pressure coefficients for each state of soil density at each reinforcement level
    - Simplified Method
        - AASHTO Recommended
    - Coherent Gravity Method
    - At-rest Condition
    - Active State
    - Spangler and Handy
        - Silo Effect
- Surcharge equivalent to 23 feet of overburden
- 95% of T-180 estimates displayed

Simplified Method

Depth (ft)	σ_v (psf)	$\Delta\sigma_v$ (psf)	Simplified k_{rS}	σ_h (psf) Unfactored	Load Factors $\gamma_{P\text{-}EV}$	Load Factors $\gamma_{P\text{-}ES}$	σ_h (psf) Factored	Unfactored T_{max} (lbf)	Factored T_{max} (lbf)	Factored $T_{con.}$ (lbf)	Unfactored $T_{con.}$ (lbf)
1.23	139	2,603	0.534	1,465	1.35	1.5	2,187	8,866	13,232	11,340	15,120
3.69	418	2,603	0.515	1,554	1.35	1.5	2,299	9,407	13,915	11,340	15,120
6.15	696	2,603	0.495	1,633	1.35	1.5	2,397	9,881	14,509	11,340	15,120
8.61	974	2,603	0.475	1,700	1.35	1.5	2,481	10,289	15,012	11,340	15,120

Coherent Gravity Method

Depth (ft)	σ_v (psf)	$\Delta\sigma_v$ (psf)	Coherent k_{rCG}	σ_h (psf) Unfactored	Load Factors $\gamma_{P\text{-}EV}$	Load Factors $\gamma_{P\text{-}ES}$	σ_h (psf) Factored	Unfactored T_{max} (lbf)	Factored T_{max} (lbf)	Factored $T_{con.}$ (lbf)	Unfactored $T_{con.}$ (lbf)
1.23	139	2,603	0.475	1,302	1.35	1.5	1,943	7,879	11,759	11,340	15,120
3.69	418	2,603	0.455	1,373	1.35	1.5	2,031	8,308	12,290	11,340	15,120
6.15	696	2,603	0.434	1,433	1.35	1.5	2,104	8,669	12,730	11,340	15,120
8.61	974	2,603	0.414	1,481	1.35	1.5	2,161	8,962	13,077	11,340	15,120

At-rest Condition

Depth (ft)	σ_v (psf)	$\Delta\sigma_v$ (psf)	At-Rest k_0	σ_h (psf) Unfactored	Load Factors $\gamma_{P\text{-}EV}$	Load Factors $\gamma_{P\text{-}ES}$	σ_h (psf) Factored	Unfactored T_{max} (lbf)	Factored T_{max} (lbf)	Factored $T_{con.}$ (lbf)	Unfactored $T_{con.}$ (lbf)
1.23	139	2,603	0.485	1,330	1.35	1.5	1,985	8,047	12,010	11,340	15,120
3.69	418	2,603	0.485	1,465	1.35	1.5	2,167	8,864	13,113	11,340	15,120
6.15	696	2,603	0.485	1,600	1.35	1.5	2,349	9,681	14,216	11,340	15,120
8.61	974	2,603	0.485	1,735	1.35	1.5	2,531	10,498	15,319	11,340	15,120

Active State

Depth (ft)	σ_v (psf)	$\Delta\sigma_v$ (psf)	Active k_a	σ_h (psf) Unfactored	Load Factors $\gamma_{P\text{-}EV}$	Load Factors $\gamma_{P\text{-}ES}$	σ_h (psf) Factored	Unfactored T_{max} (lbf)	Factored T_{max} (lbf)	Factored $T_{con.}$ (lbf)	Unfactored $T_{con.}$ (lbf)
1.23	139	2,603	0.320	878	1.35	1.5	1,310	5,312	7,927	11,340	15,120
3.69	418	2,603	0.320	967	1.35	1.5	1,430	5,851	8,655	11,340	15,120
6.15	696	2,603	0.320	1,056	1.35	1.5	1,551	6,390	9,383	11,340	15,120
8.61	974	2,603	0.320	1,145	1.35	1.5	1,671	6,929	10,111	11,340	15,120

Spangler and Handy – "Silo Effect"

Depth (ft)	σ_v (psf)	$\Delta\sigma_v$ (psf)	S & H k_{rSH}	σ_h (psf) Unfactored	Load Factors $\gamma_{P\text{-}EV}$	Load Factors $\gamma_{P\text{-}ES}$	σ_h (psf) Factored	Unfactored T_{max} (lbf)	Factored T_{max} (lbf)	Factored $T_{con.}$ (lbf)	Unfactored $T_{con.}$ (lbf)
1.23	139	2,603	0.469	1,285	1.35	1.5	1,918	7,776	11,606	11,340	15,120
3.69	418	2,603	0.438	1,323	1.35	1.5	1,958	8,008	11,847	11,340	15,120
6.15	696	2,603	0.410	1,353	1.35	1.5	1,987	8,190	12,026	11,340	15,120
8.61	974	2,603	0.385	1,376	1.35	1.5	2,008	8,330	12,154	11,340	15,120

Incremental Surcharge Loading

- Incremental surcharge loading will be applied to the reinforced zone
  - Worst case load scenario presented
  - 95% of T-180 @ lowest reinforcement level
- Factored and unfactored resistances calculated for each reinforcement component
- Factored and unfactored loads calculated for each incremental surcharge height
- On-site monitoring will determine final simulated surcharge height applied
  - Increase in reinforcement tension is expected for unyielding MSE wall scenario

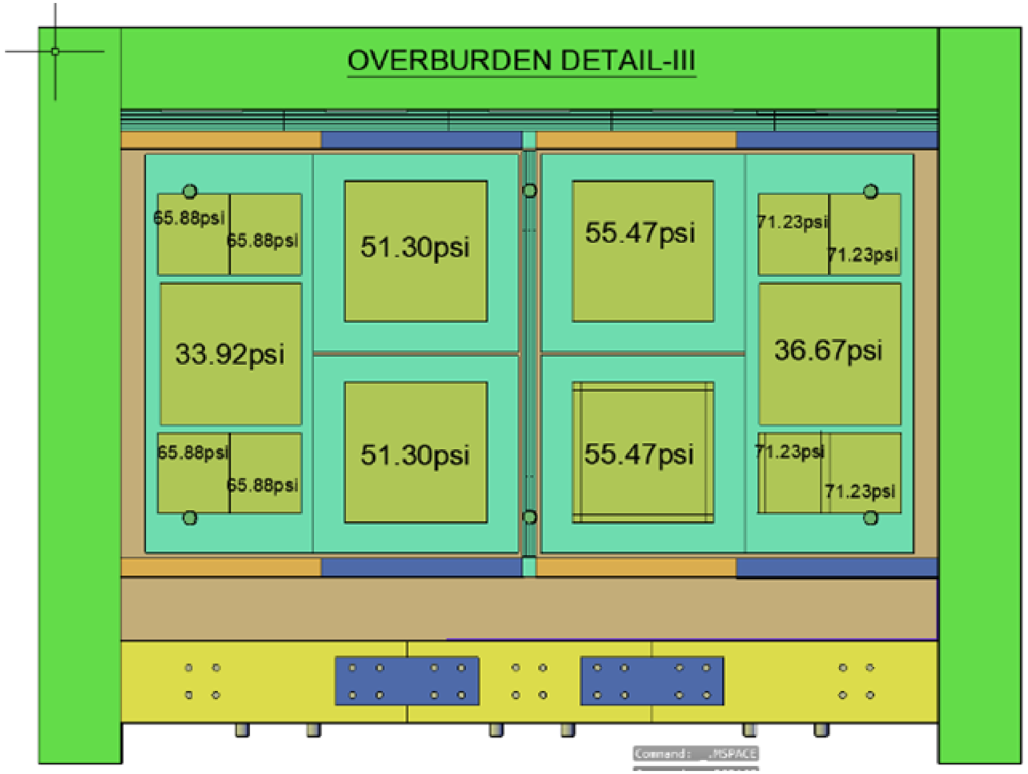
LRFD Design – Internal Stability

Resistance Component	Resistance (kips)	
	Factored	Unfactored
2 Tie strips tensile resistance (embedded connection)	19.9	26.5
Tie Strips tensile resistance at bolt hole (2 tie strips)	18.5	24.6
Tie Strips bolt hole bearing resistance (2 tie strips)	15.8	21.0
Reinforing strip tensile resistance	15.1	20.2
Reinforcing Strip tensile resistance at bolt hole	13.3	17.7
Reinforcing Strip bolt hole bearing resistance	11.3	15.1
Bolt shear resistance	17.0	22.6

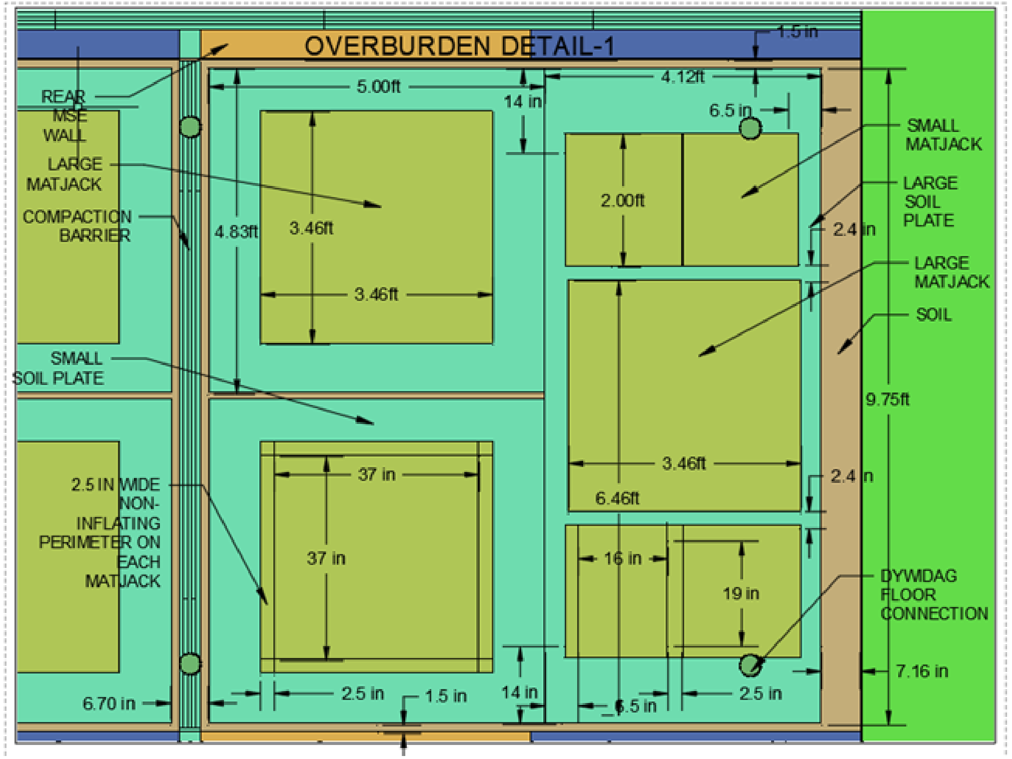
Surcharge Height (ft)	Maximum Tensile Load, T_{max} (kips)	
	Unfactored	Factored
0	2.8	3.8
5	4.4	6.2
10	6.1	8.7
15	7.7	11.1
20	9.3	13.5
23	10.3	15.0
25	10.9	16.0

Reaction Frame Calculations

- 95.7% Compaction effort:
  - 23.3ft (114.15pcf) = 2659.70 lbs/ft^2 = 18.47psi

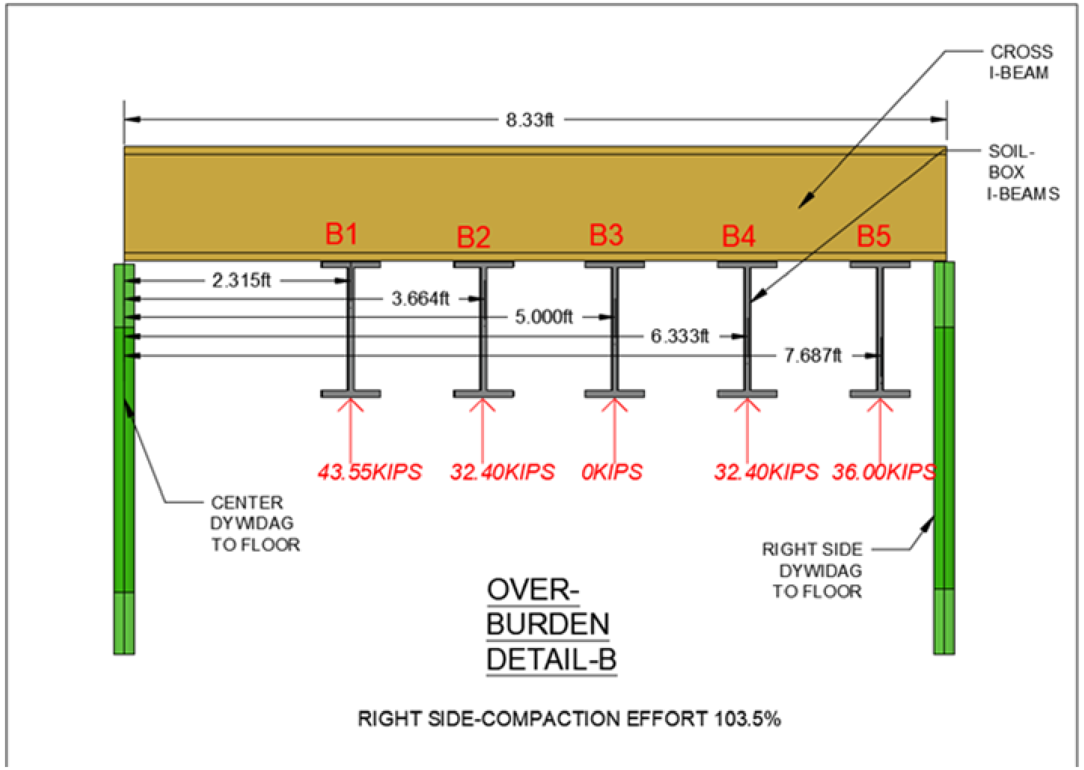


- 103.5% Compaction effort:
  - 23.3ft (123.4pcf) = 2875.22 lbs/ft^2 = 19.97 psi

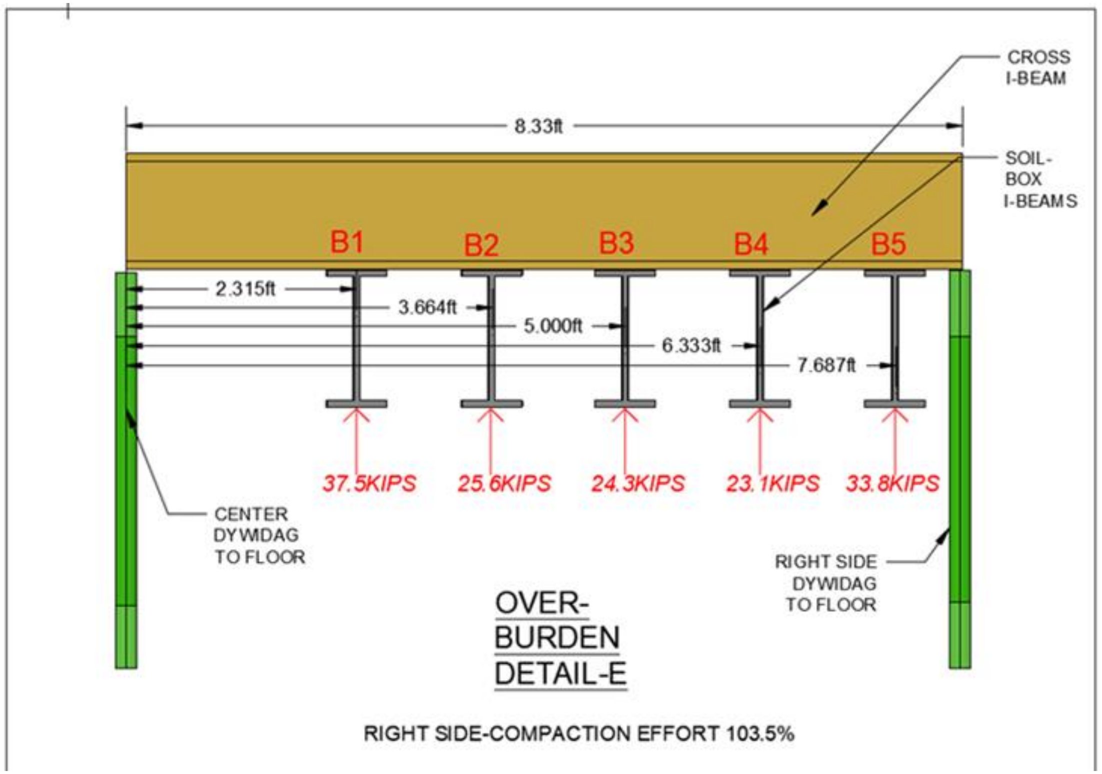


Reaction Frame Calculations

- Method 1
- Soil wall I-beams take load from Matjacks directly within I-beam tributary area

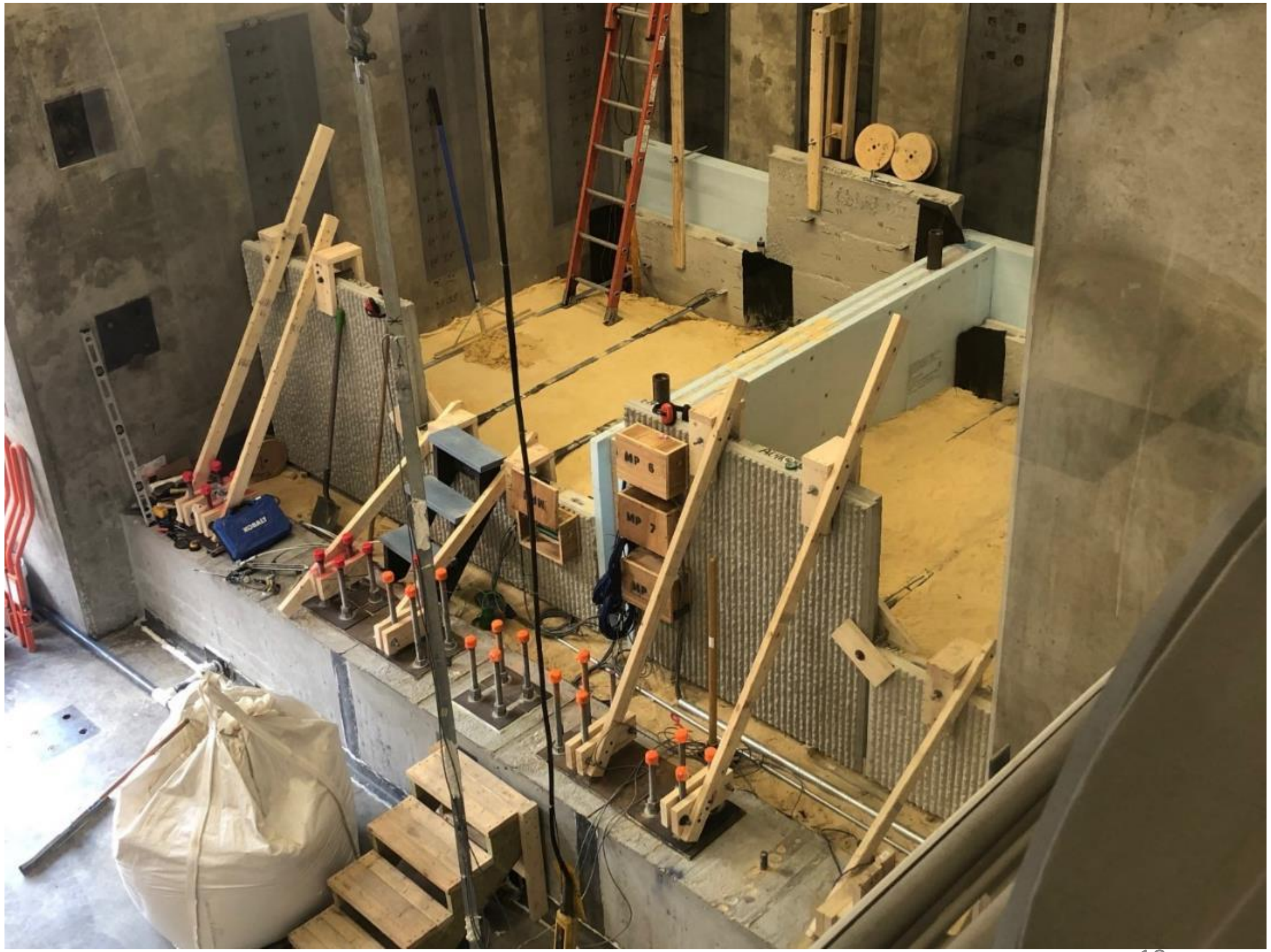


- Method 2
  - Load from Matjacks is distributed across 4 quadrants of the soil box wall
  - Load to Soil Box wall I-beams based on size of quadrant tributary area



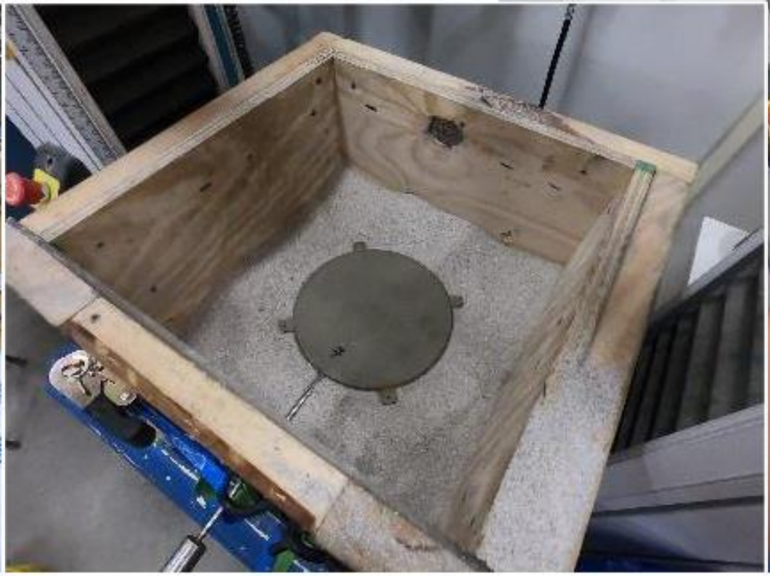
Construction Plan - Instrumentation

- 80 full bridge strain gauge locations
  - 4 Instrumented strips per reinforcement level
  - 5 locations per strip
  - 320 Strain gauges total
- 32 horizontal EPC’s
  - Soil embedded in quadrants
  - 8 at each reinforcement level
- 16 vertical EPC’s
  - Wall mounted in quadrants
  - 4 at each reinforcement level
- 8 Multiplexers
- 1 Campbell CR6 Datalogger
- 2 String Potentiometers



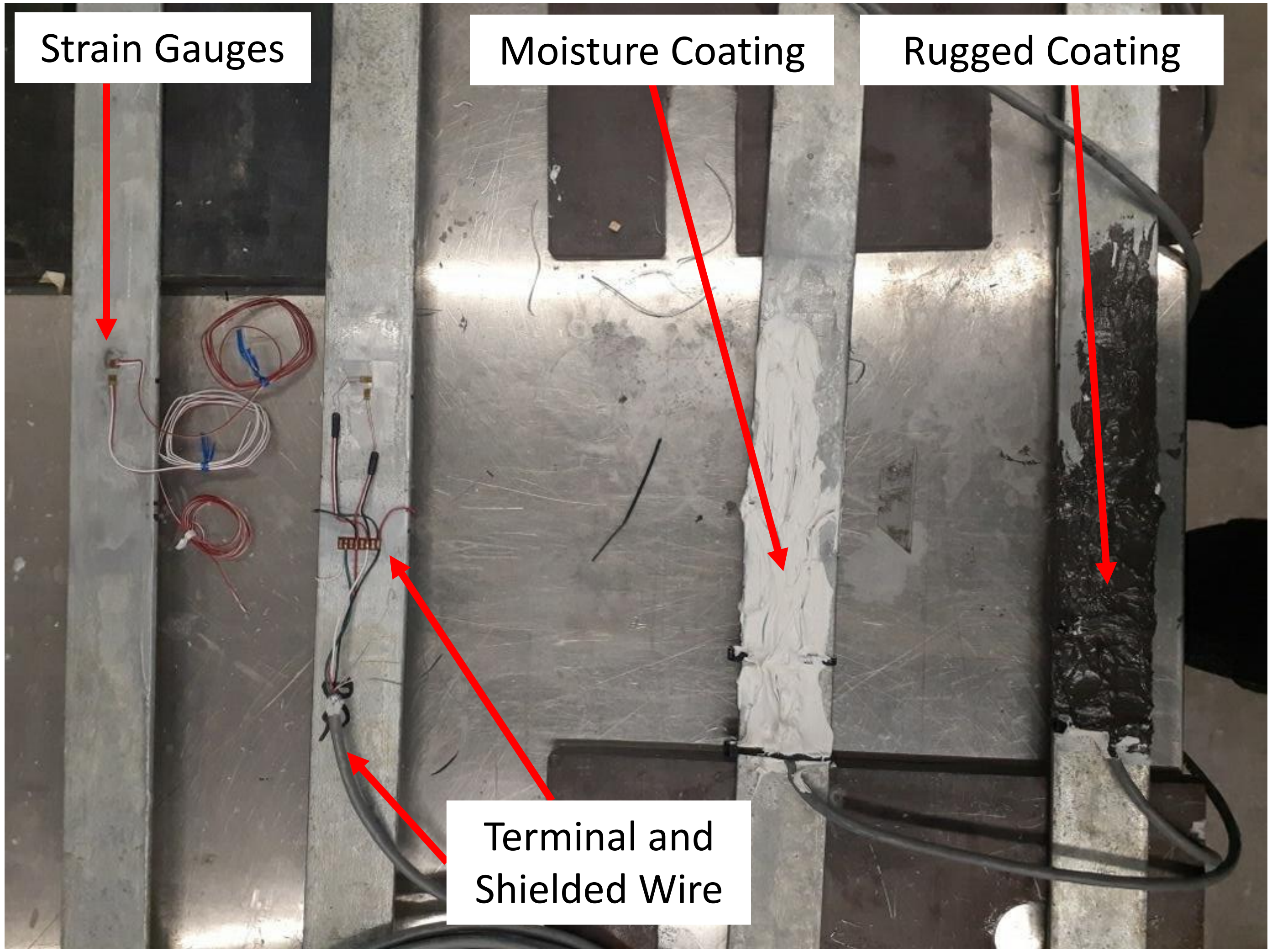
Construction - Instrumentation Preparation

- Earth Pressure Cells – Vibrating Wire
  - 32 horizontal EPC’s (GeoKon 4800-1-100)
    - Purchased 2001/Last used around 2012
    - Gauge Calibrations checked on Instron
    - New cable spliced to EPCs
  - 16 Wall-mounted EPC’s (GeoKon 4810-350)
    - Purchased New



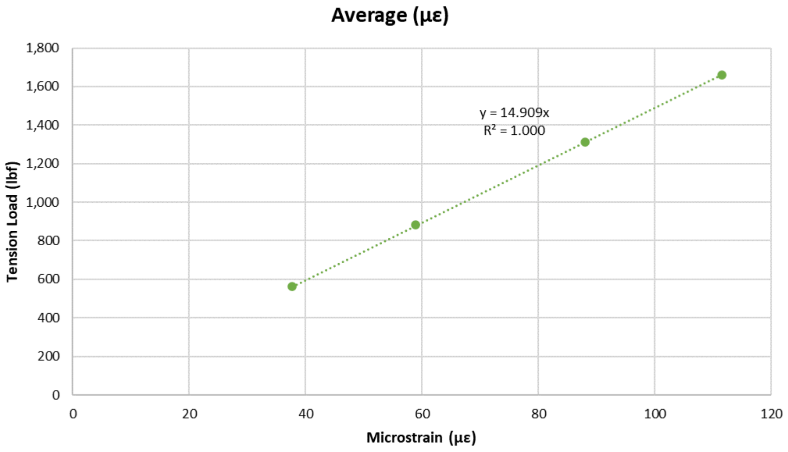
Instrumented Reinforcement Strips

- Gauges are placed on both sides of the strip
  - 5 locations on 16 strips
- Soldered onto bondable terminal in full bridge
  - Compensates for bending and thermal effects
- 4-strand shielded wire soldered onto terminal
  - Connects to DAQ system
- Load test at 4 loads
- Moisture protective coating added
  - Load tested at 4 loads
- Rugged protective coating added
  - Load tested at 4 loads
- Each strip is load tested 3 times
- 48 total load tests

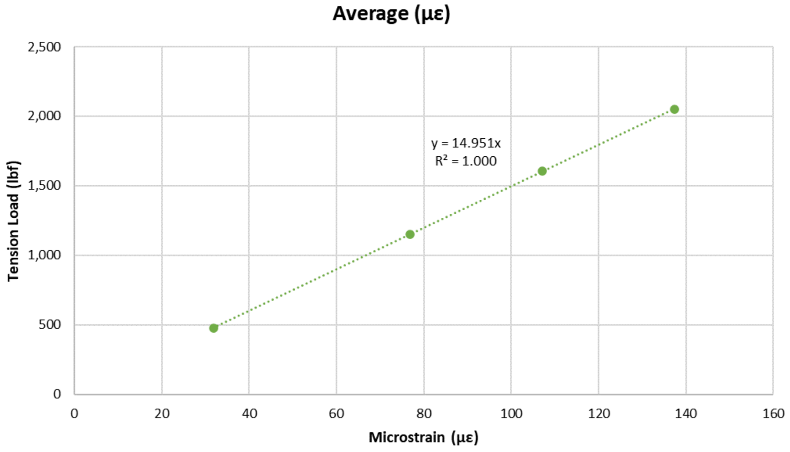


Reinforcement Strip Load Testing

Before Protective Coatings

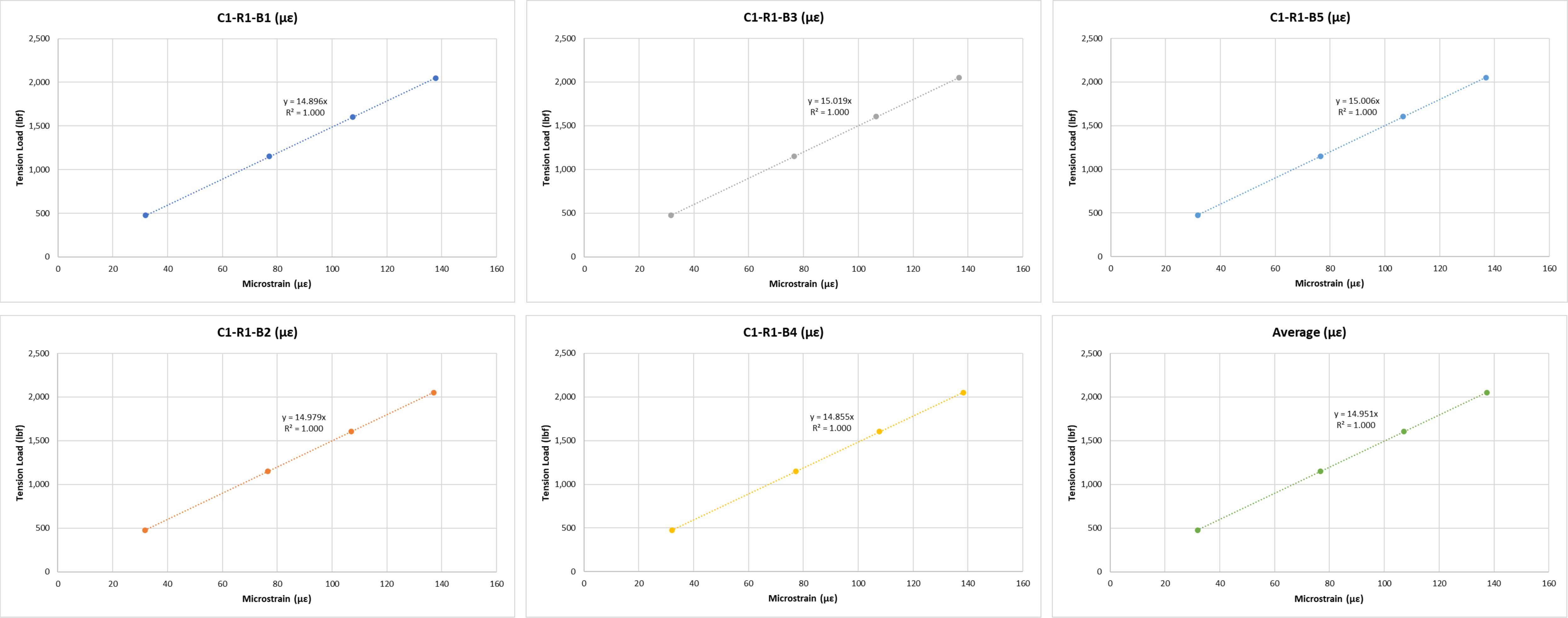


After Applying Both Coatings



- 0.3% difference in average strain readings before and after coatings were applied

Strain Gauge Slope Equations



*Predicted loads from strain gauge slope equations produce less than 1% error compared to applied loads

MSE Wall Construction Sequence

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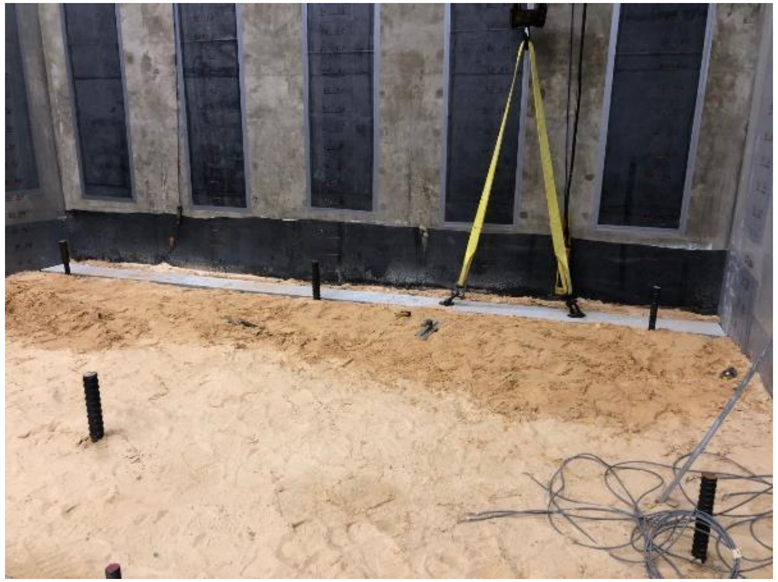
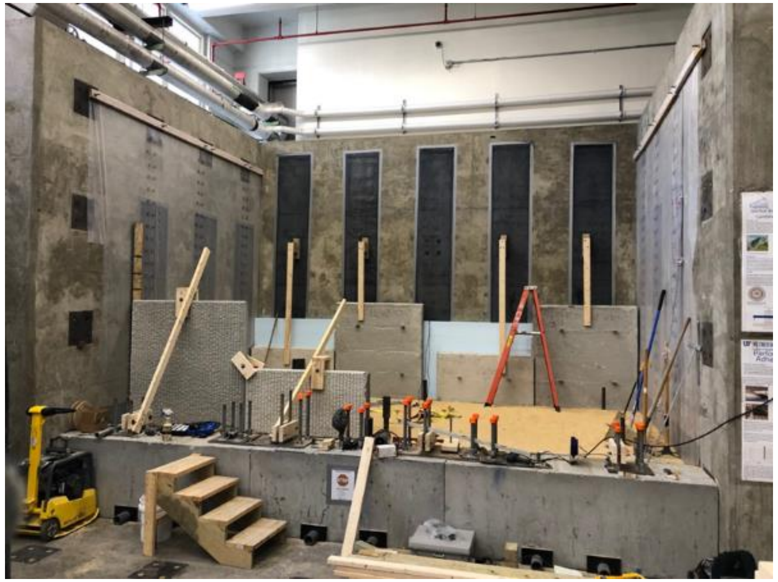
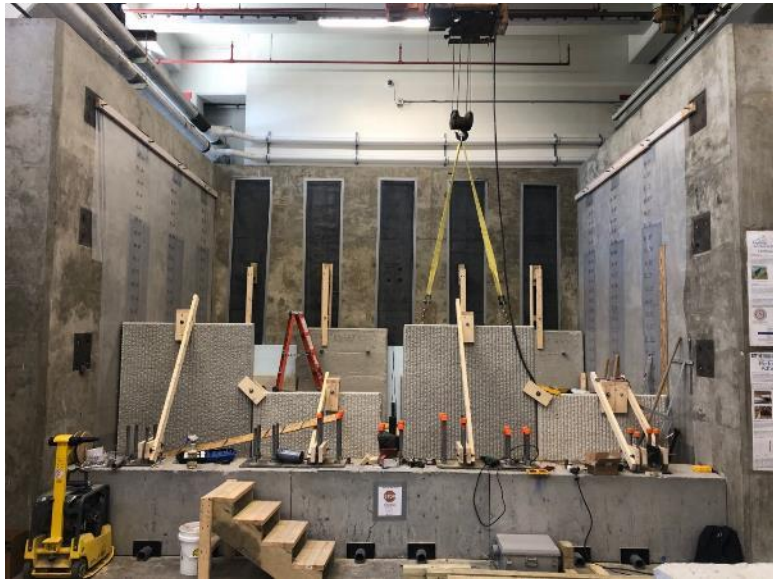
MSE Wall Construction Sequence







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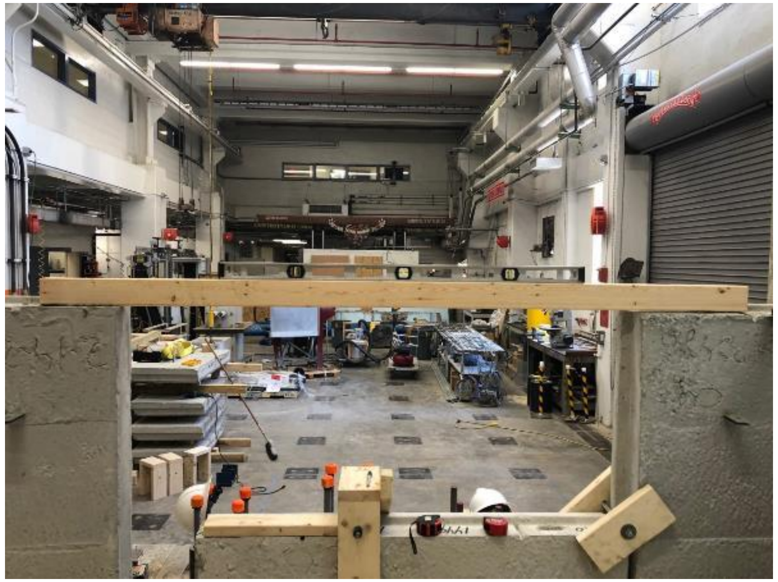


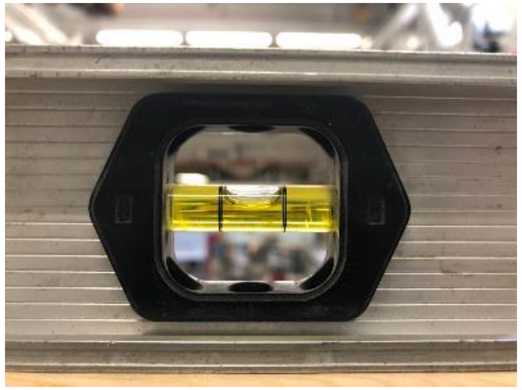


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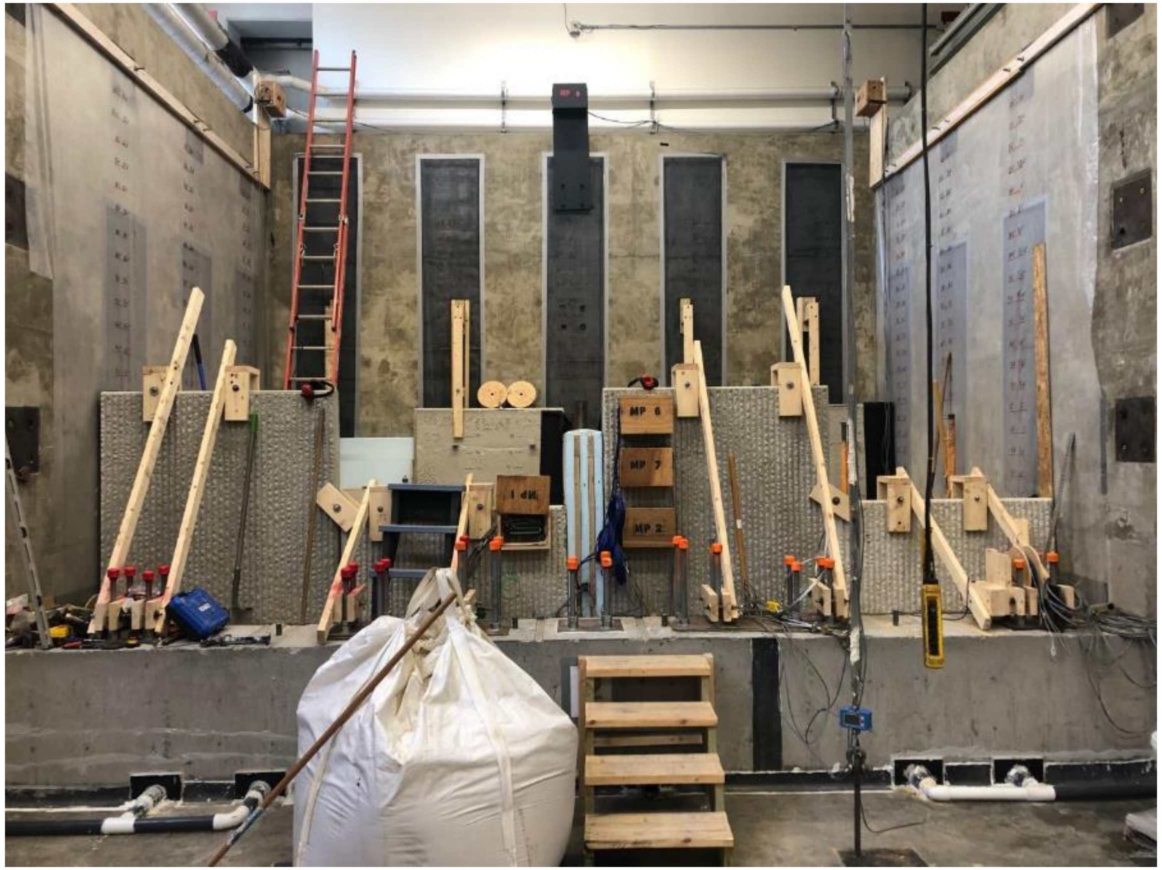

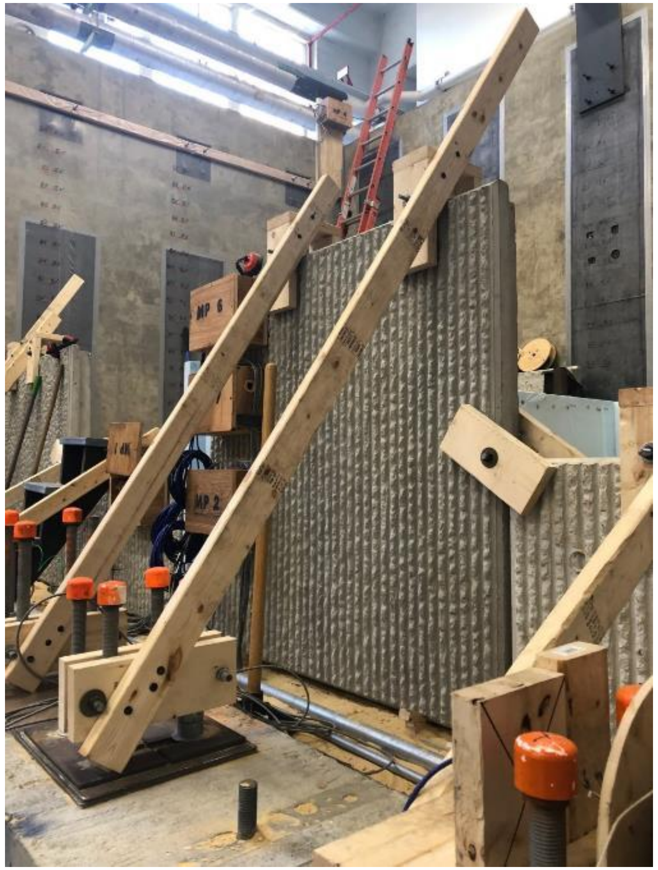

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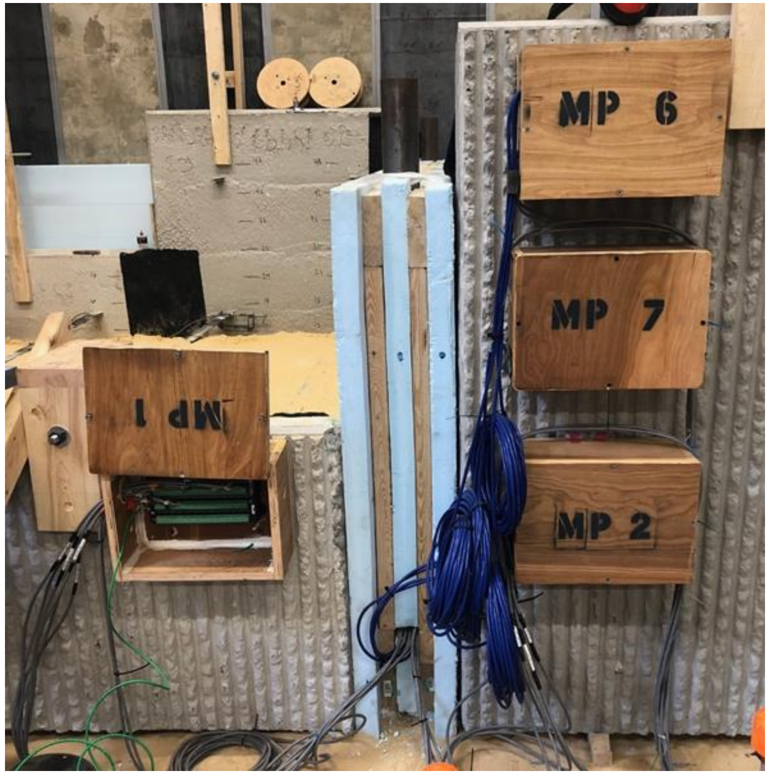

Remaining Tasks

- Task (3) – MSE Wall Construction with Two Designated Relative Compaction Efforts
- Task (4) – Draft Final and Closeout Teleconference
- Task (5) – Final Report

References

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Questions?

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