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UNIVERSITY of FLORIDA

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

FDOT GRIP Meeting

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FDOT

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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

Unyielding Condition

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

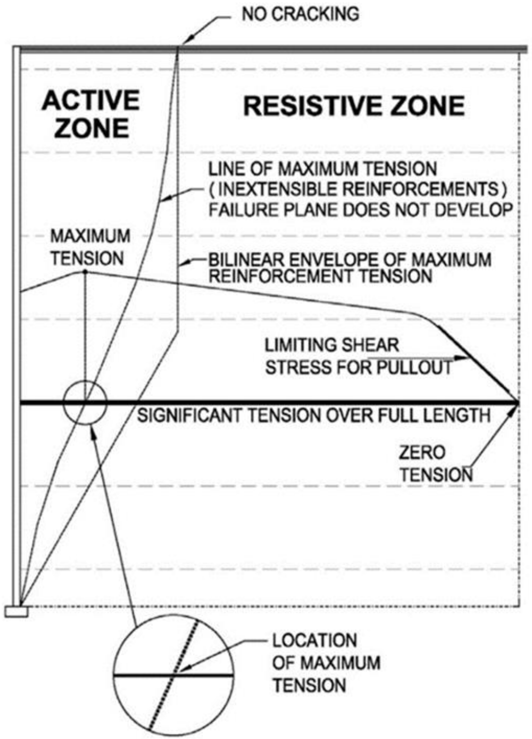
- Task (1) – Literature Review and Preliminary Design
- Task (2) – Final Design, Site Preparation, and Materials Purchasing
- Task (3) – MSE Wall Construction with Two Designated Relative Compaction Efforts
- Task (4) – Draft Final and Closeout Teleconference
- Task (5) – Final Report

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

Reinforcement Type

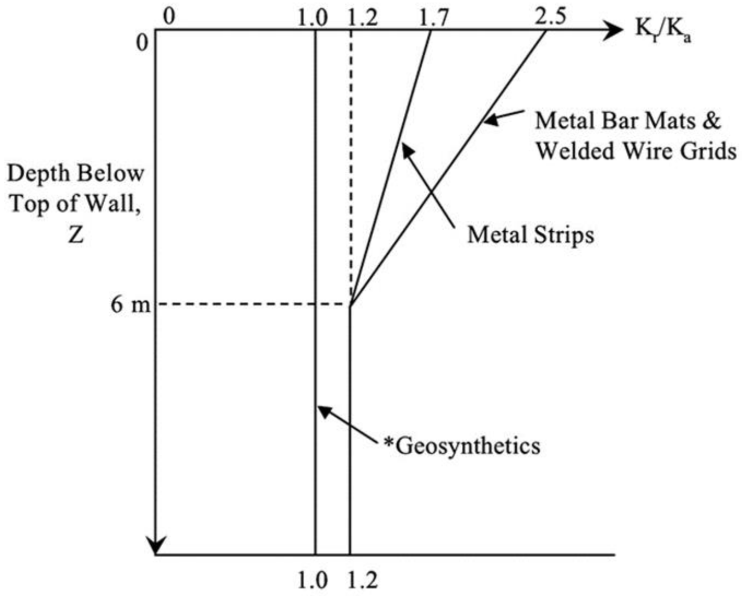
- Two types of reinforcement
  - Extensible and Inextensible
- Inextensible Reinforcement
  - Metal strips, metal bar mats, and welded wire grids
- MSE structures that utilize inextensible reinforcement behave as a rigid body
  - Reinforcement prevents internal deformation
  - Under tension over full reinforcement length
- Maximum tension occurs within the active zone
  - Strain gages strategically placed near active failure surface in multiple locations



Anderson et al. 2010

Simplified Method

- Simplified Coherent Gravity Method used in design
- AASHTO recommended method
- Combines the best and simplest features of various AASHTO approved designed methods
  - Coherent Gravity
  - FHWA Structure Stiffness
  - Tieback Wedge
- Provides a single k_r/k_a curve for each reinforcement type
- Design methodology is similar to FHWA Structure Stiffness and Tieback Wedge Methods for calculating peak reinforcement load (T_{max})
  - k_r is calculated from curves



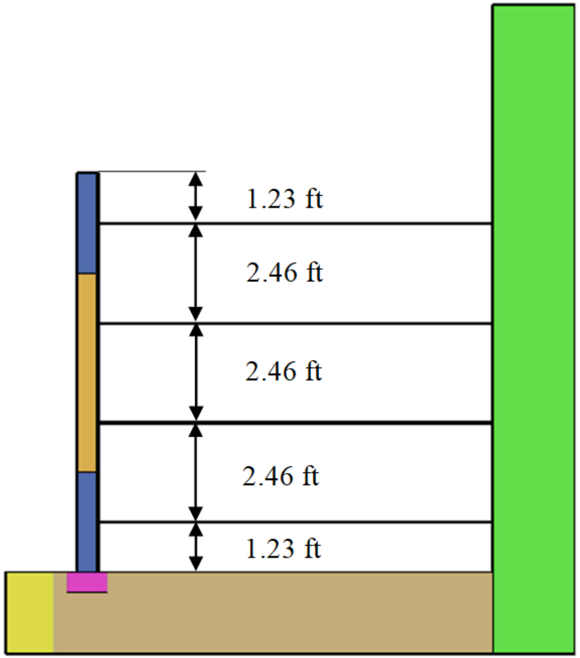
*Does not apply to polymer strip reinforcement.

$$k_r = k_a\left(1.2 + (1.7 - 1.2)\left(\frac{20 - z(ft)}{20}\right)\right)$$

Wall Panel Size & Reinforcement Spacing

- Surveyed approved FDOT vendors
  - SSL - 5' x 5' square panel
  - The Neel Company - 5' x 7' rectangular
  - Tensar Int. Corp. - 5' x 5' square panel
  - Tri-Con Precast - 5' x 5' square panel
  - Sine Wall, LLC - 5' x 5' square panel
  - Sanders Pre-cast - 5' x 5' square panel
  - Earth Wall Products - 4' x 8' rectangular
  - Visit-A-Wall Systems - 5' x 5' square panel
  - RECo - 5' x 5' square panel
- 5’ x 5’ determined standard/generic wall panel size for Florida
- Vertical reinforcement spacing
  - S_V = 2.46’
- Horizontal reinforcement spacing
  - S_H = 2.46’

Vertical Reinforcement Layout



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

- $D_{10} \approx 0.105$ mm
- $D_{60} \approx 0.210$ mm
- $D_{85} \approx 0.270$ 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

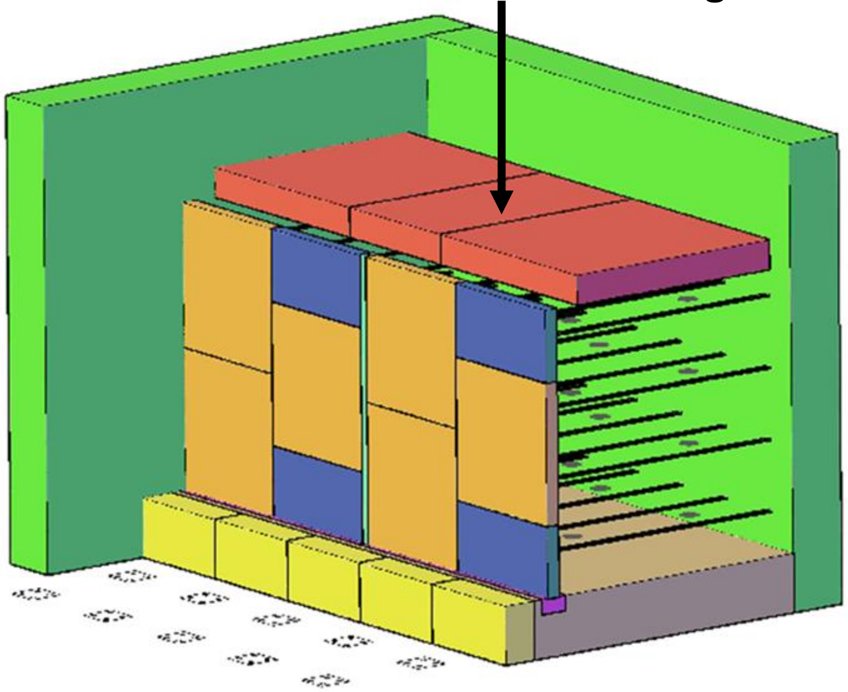
- Maximum Dry Density ($\gamma_{d\text{-}max}$) = 105.7 pcf
- Optimum Moisture Content (w_{opt}) = 12.7 %
- Compaction Effort 1 (T-180)
  - Compaction (%) = 95.7 %
  - Dry Density (γ_d) = 101.2 pcf
  - Moisture Content (w) = 12.8 %
  - Internal Friction Angle (Φ) = 31.0°
- Compaction Effort 2 (T-180)
  - Compaction (%) = 103.5 %
  - Dry Density (γ_d) = 109.4 pcf
  - Moisture Content (w) = 12.8 %
  - Internal Friction Angle (Φ) = 40.5°
- Electrochemical properties
  - 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

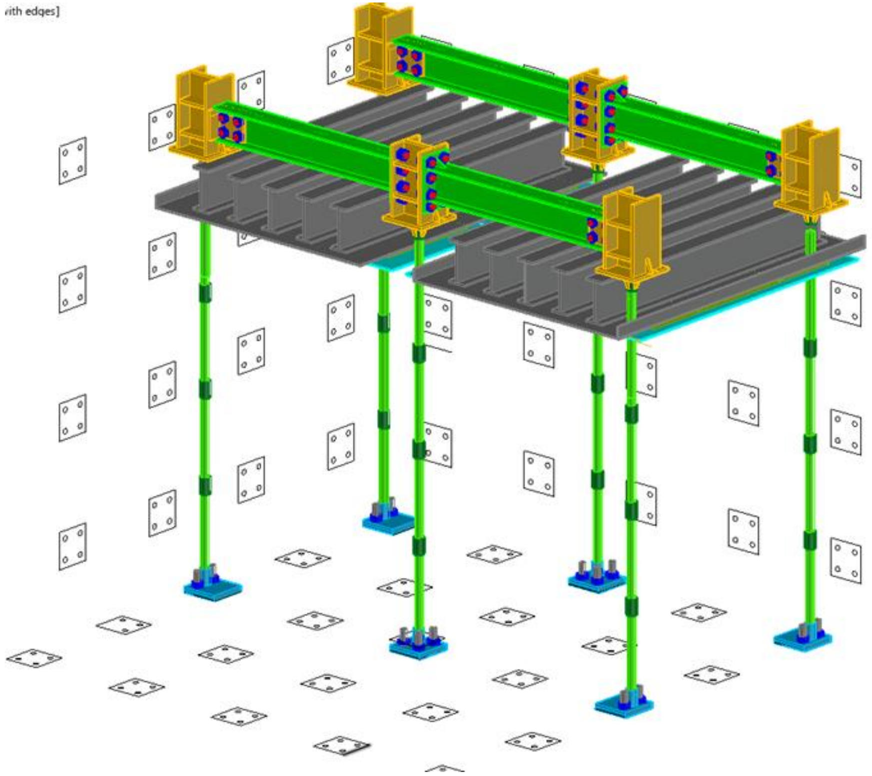
MSE Wall Initial Surcharge Design

- 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

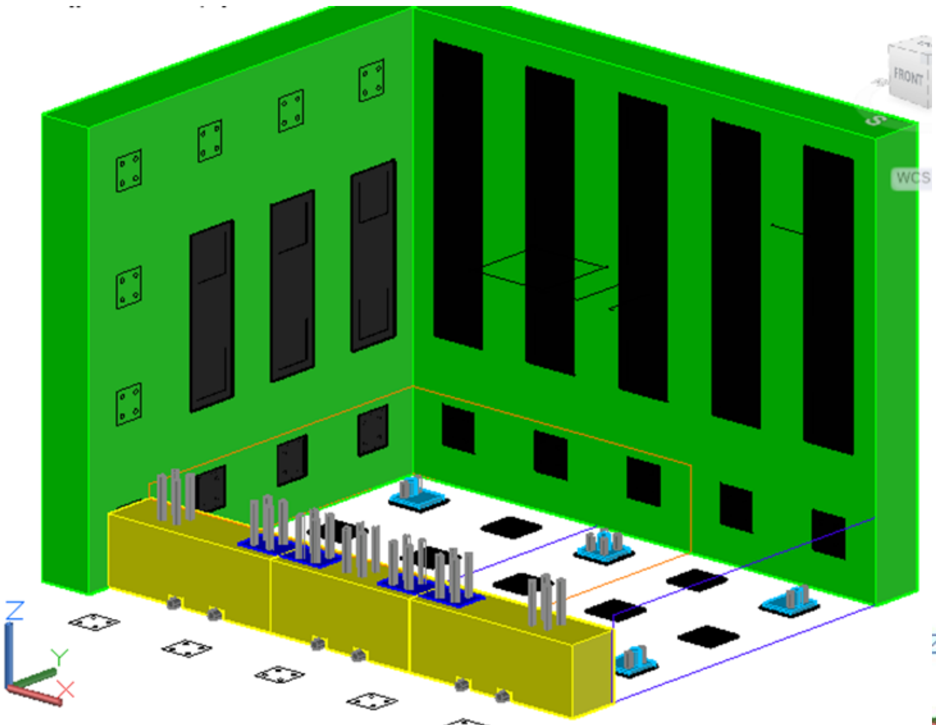


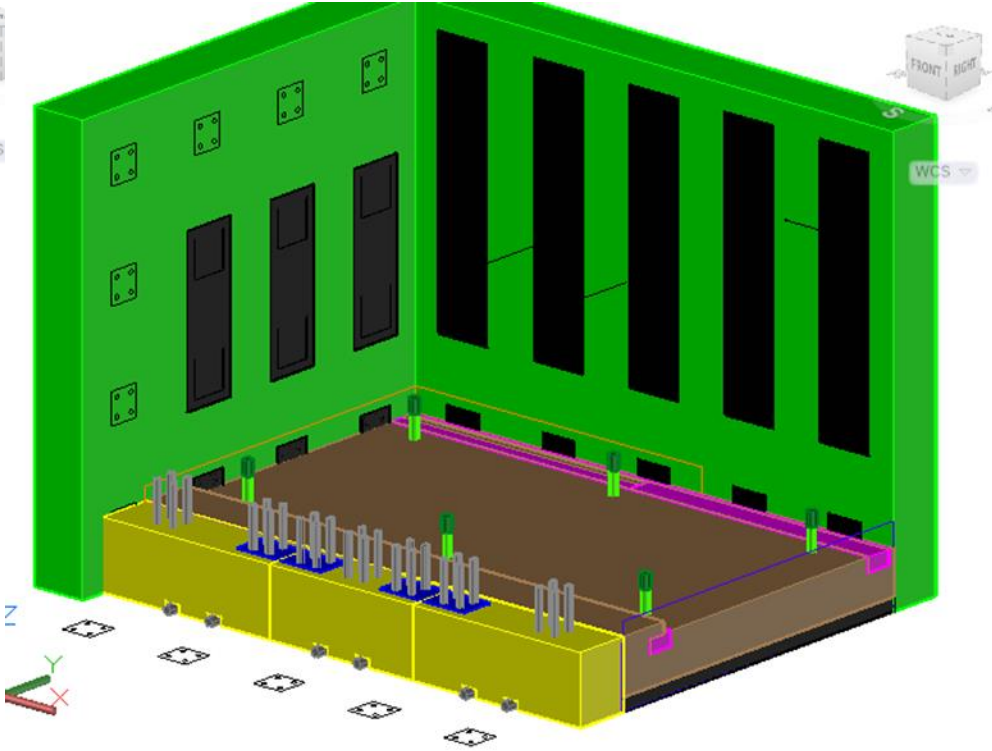
MSE Wall Surcharge Redesign

- 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



Construction Sequence



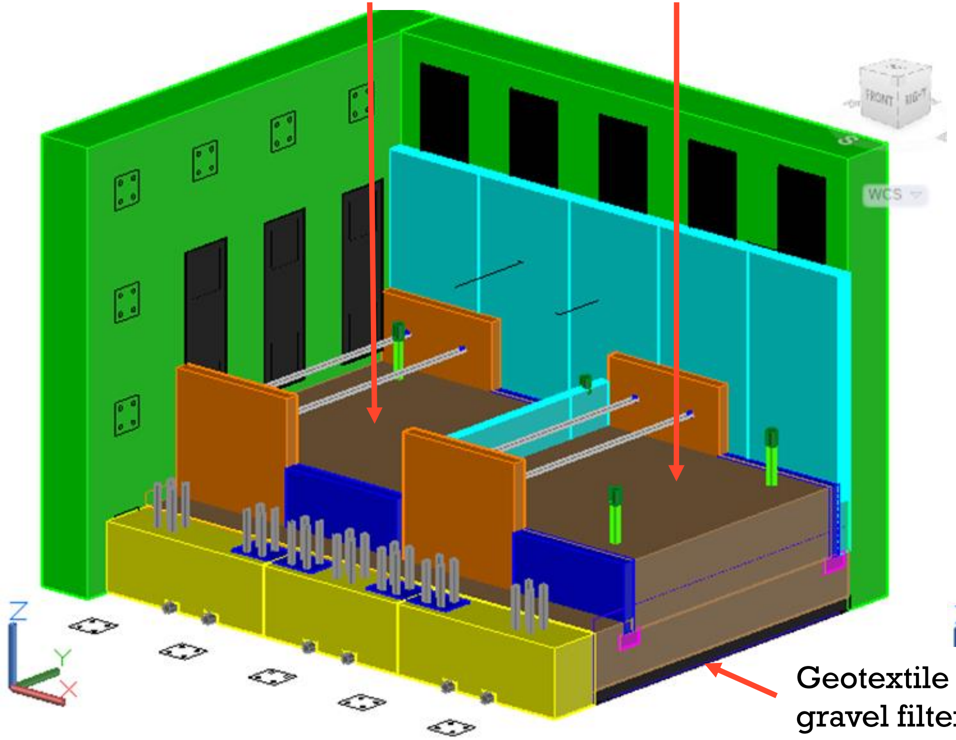


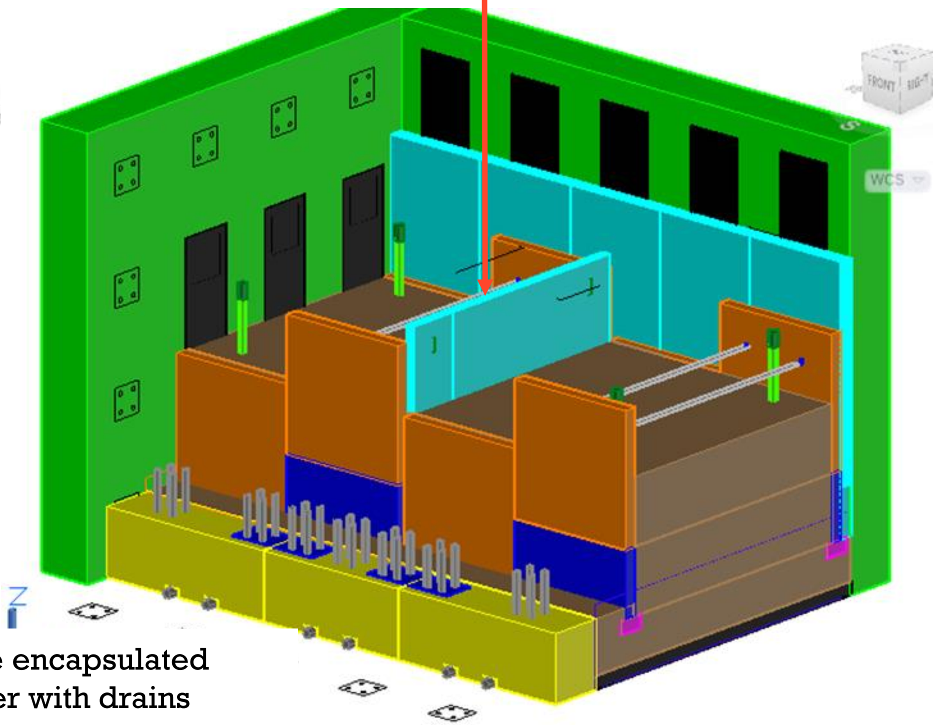
Construction Sequence

95% of T-180

104% of T-180

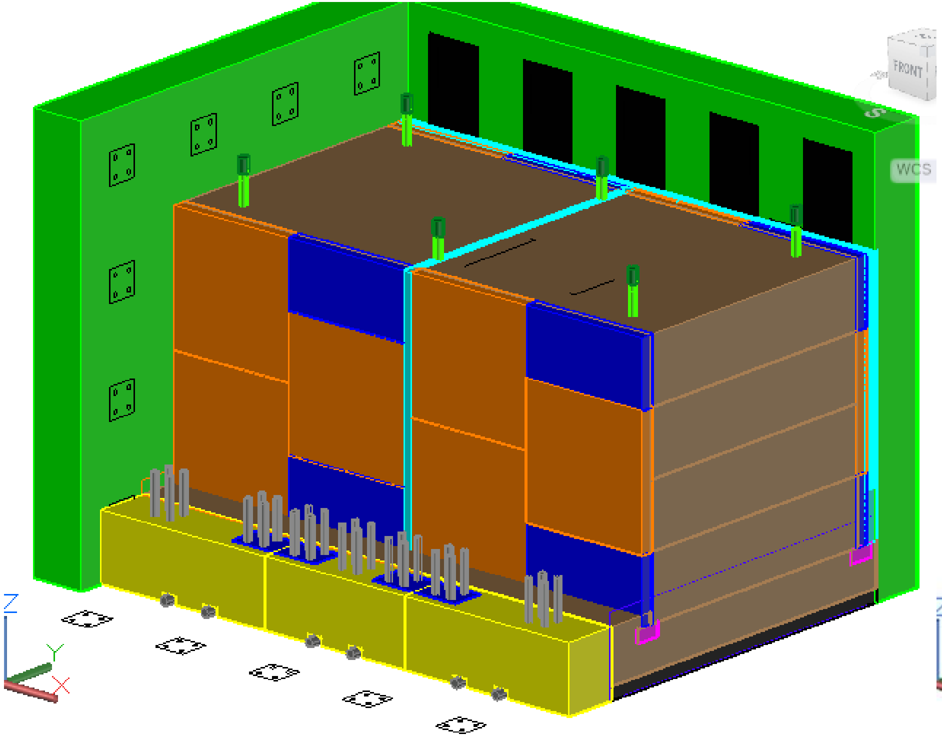
Separation Boundary

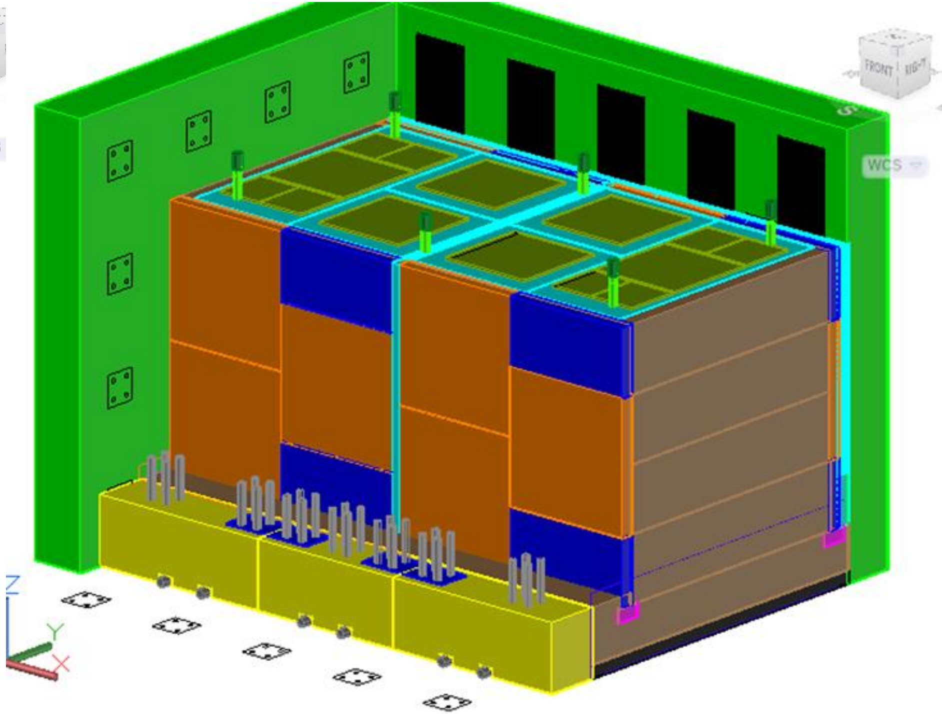




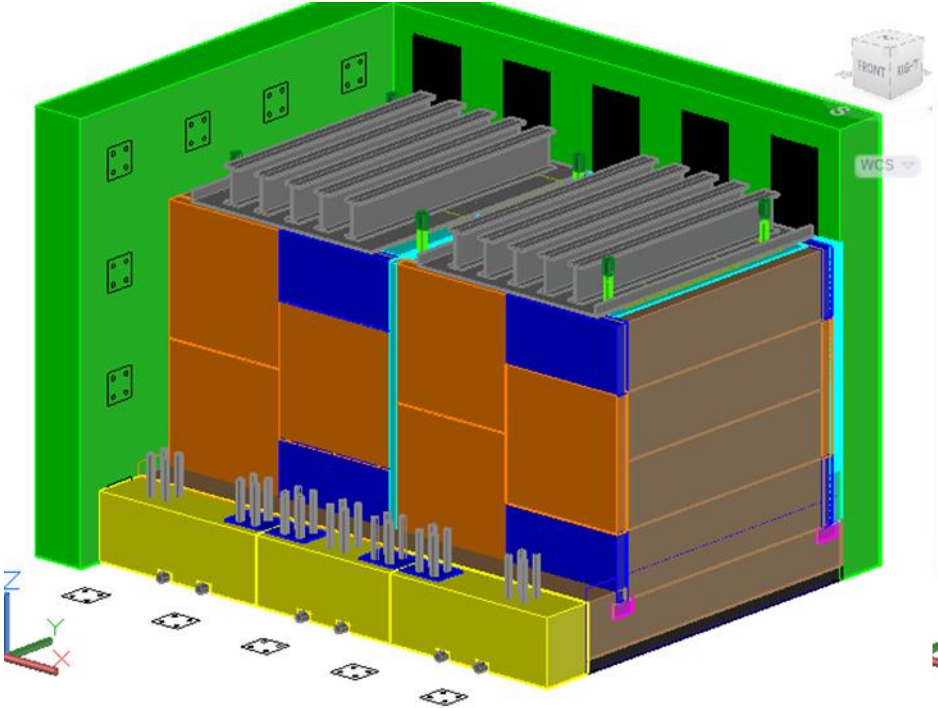
Geotextile encapsulated gravel filter with drains

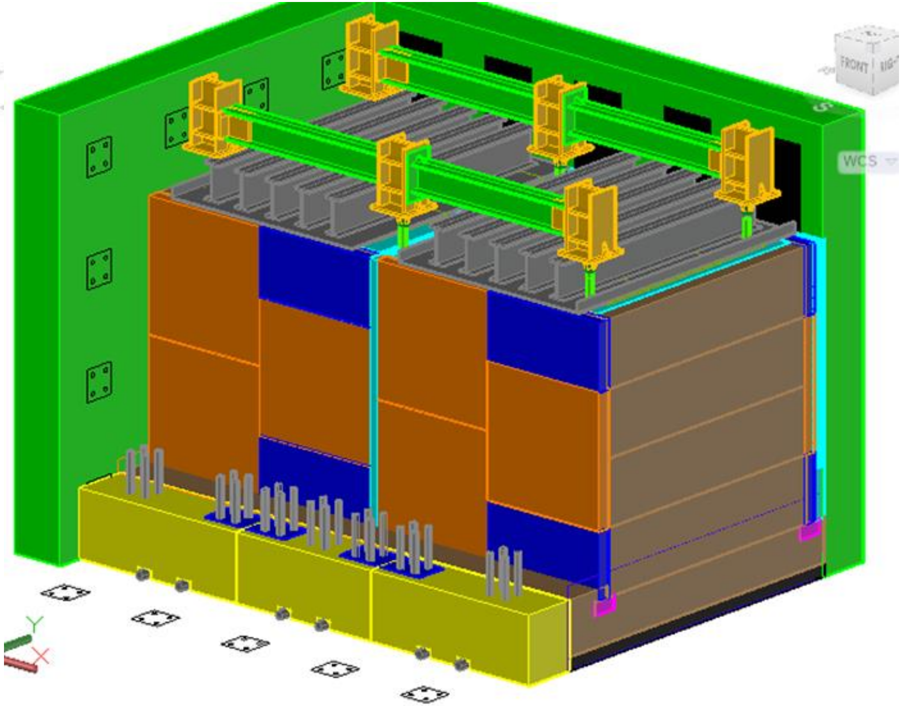
Construction Sequence





Construction Sequence





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

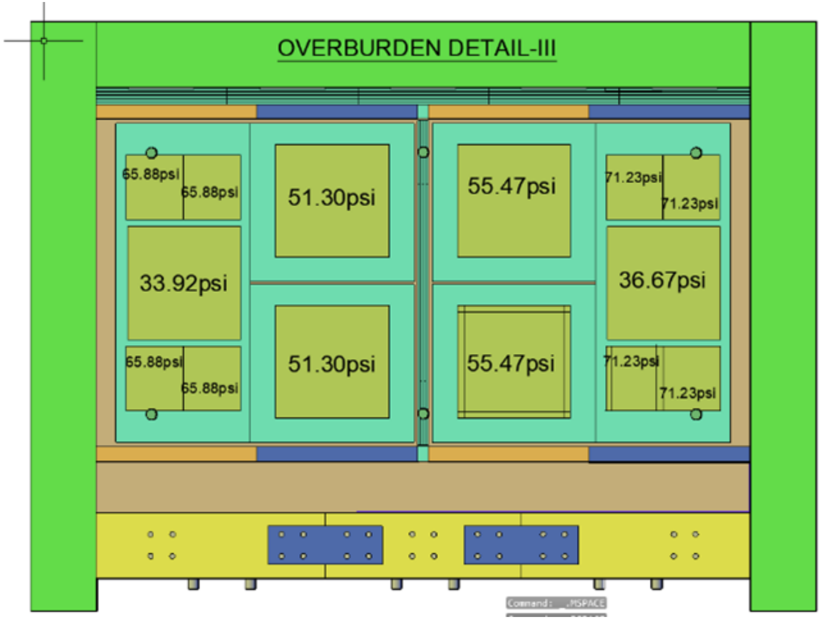
LRFD Design – Internal Stability

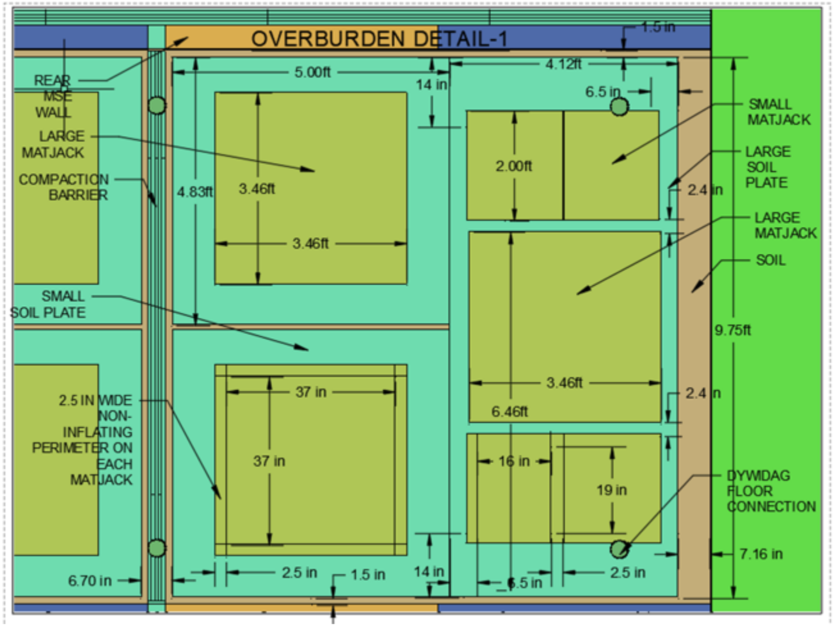
Resistance Component	Resistance (kips)	
	Factored	Unfactored
2 Tie strips tensile resistance (embedded connection)	19.9	26.5
Tie Strips tensile resistance at bolt hole (2 tie strips)	18.5	24.6
Tie Strips bolt hole bearing resistance (2 tie strips)	15.8	21.0
Reinforing strip tensile resistance	15.1	20.2
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

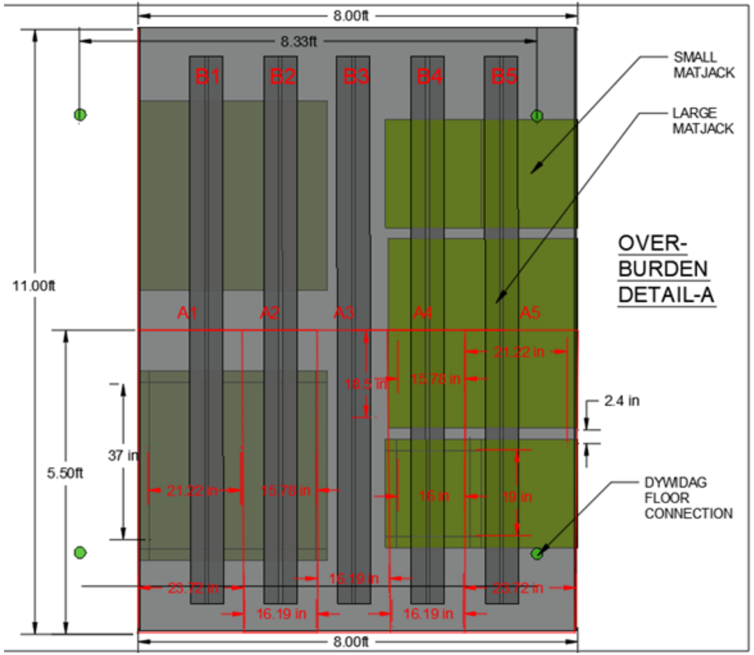
- 95.7% Compaction effort:
  - 23.3ft (114.15pcf) = 2659.70 lbs/ft^2 = 18.47psi
- 103.5% Compaction effort:
  - 23.3ft (123.4pcf) = 2875.22 lbs/ft^2 = 19.97 psi

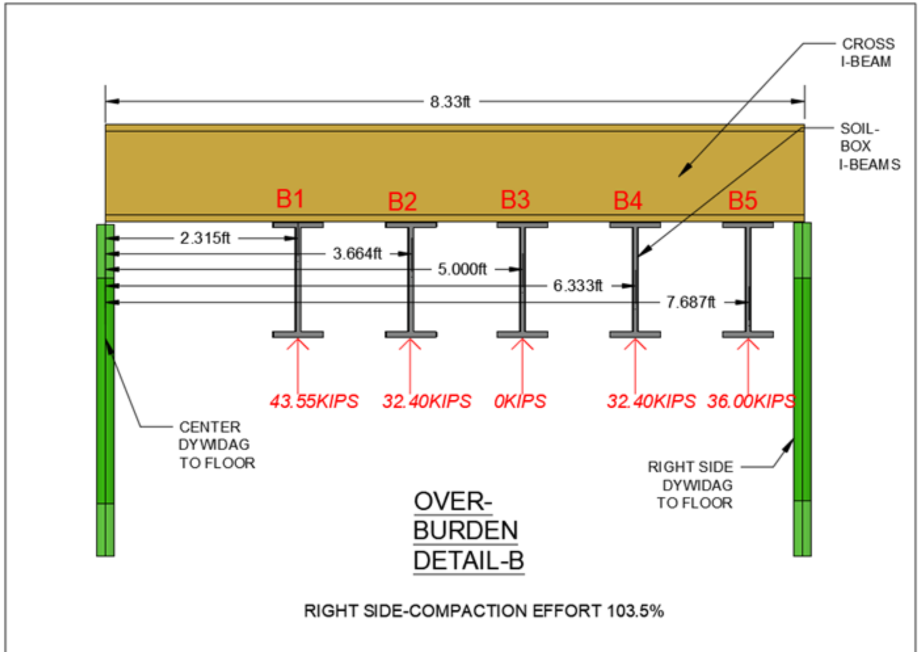




Reaction Frame Calculations – Method 1

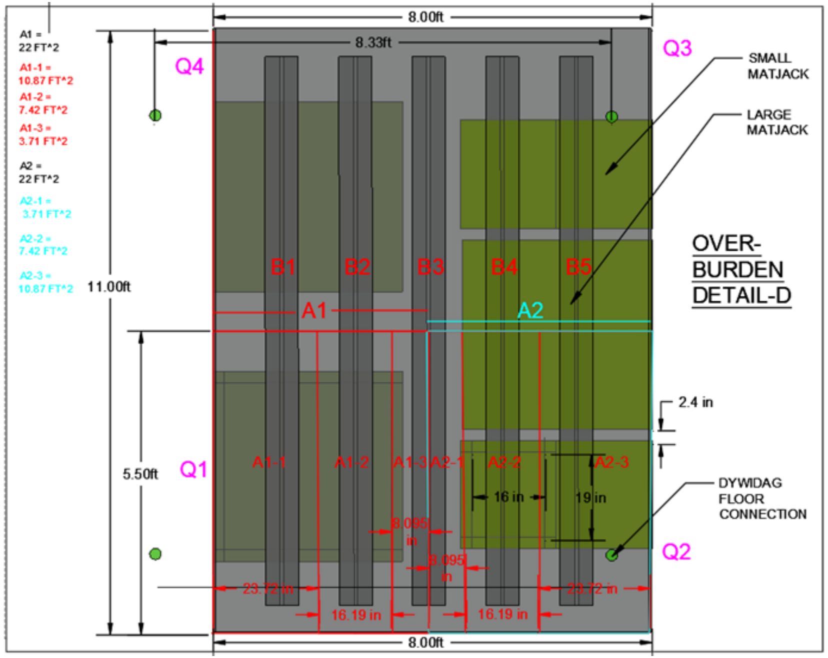
- Soil wall I-beams take load from Matjacks directly within I-beam tributary area

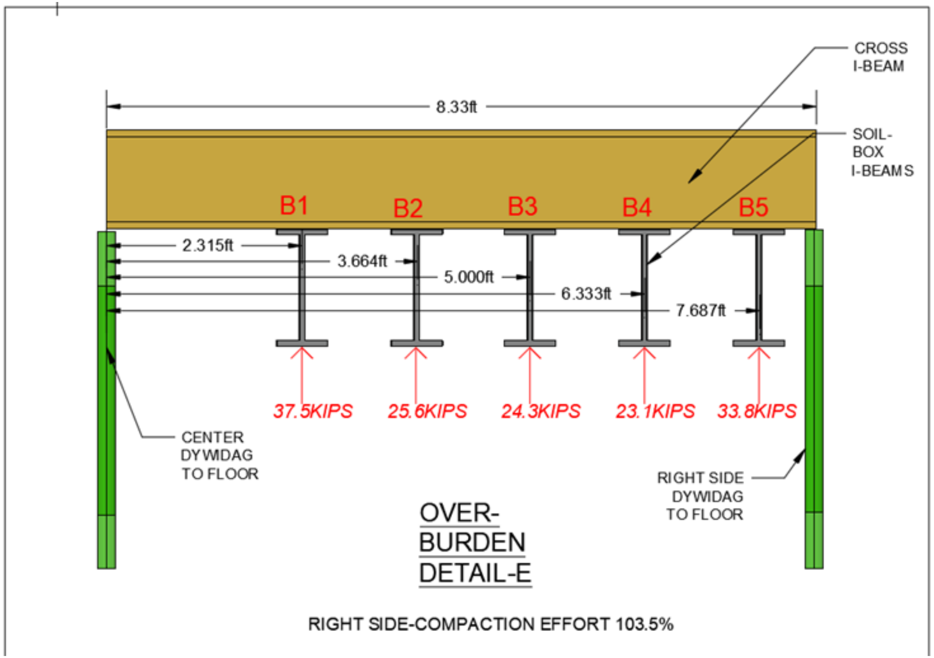




Reaction Frame Calculations – Method 2

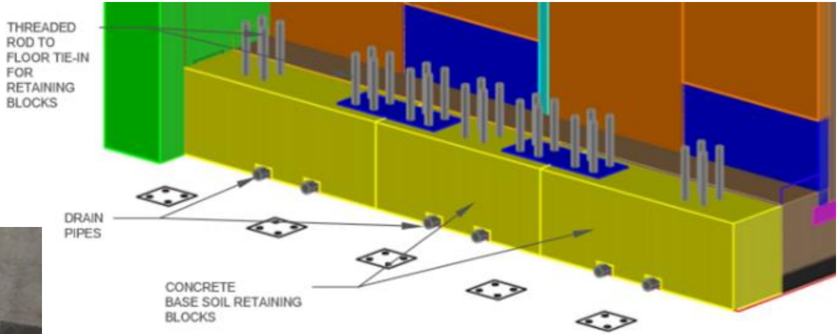
- Load from Matjacks is distributed across 4 quadrants of the soil box wall
- Load to Soil Box wall I-beams based on size of quadrant tributary area





Construction - Strong Wall Preparation

- Base layer retaining block construction
  - Three reinforced concrete blocks tied to floor
  - Template/ Form work
  - Lift points/ Installation



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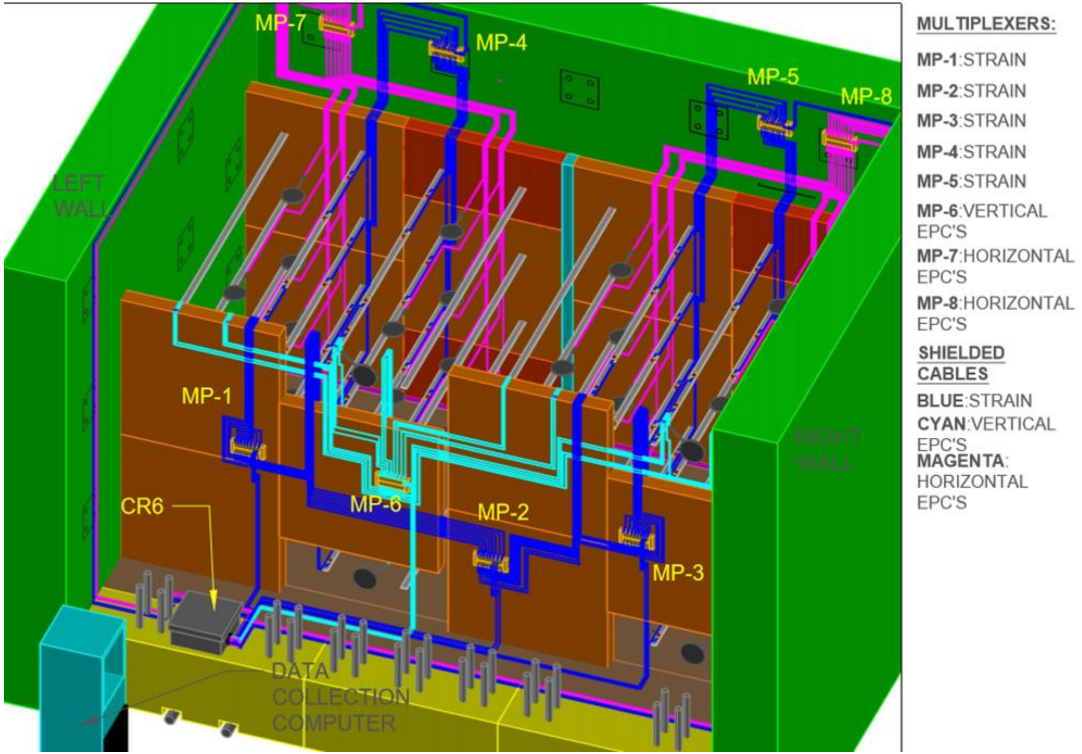
Geosystems Department

Construction - Strong Wall Preparation

- Tensioned threaded rod to secure blocks
- Added Moisture protection
  - UF Structures Department requirement
  - Double layer of EDPM roofing rubber
  - Weep holes
  - Visqueen Liner

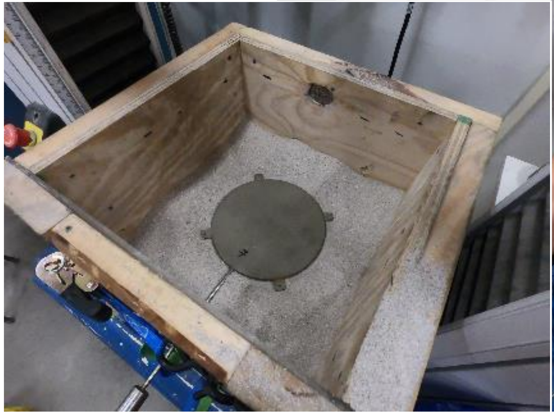
Construction Plan - Instrumentation

- 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
- 4 LVDT's



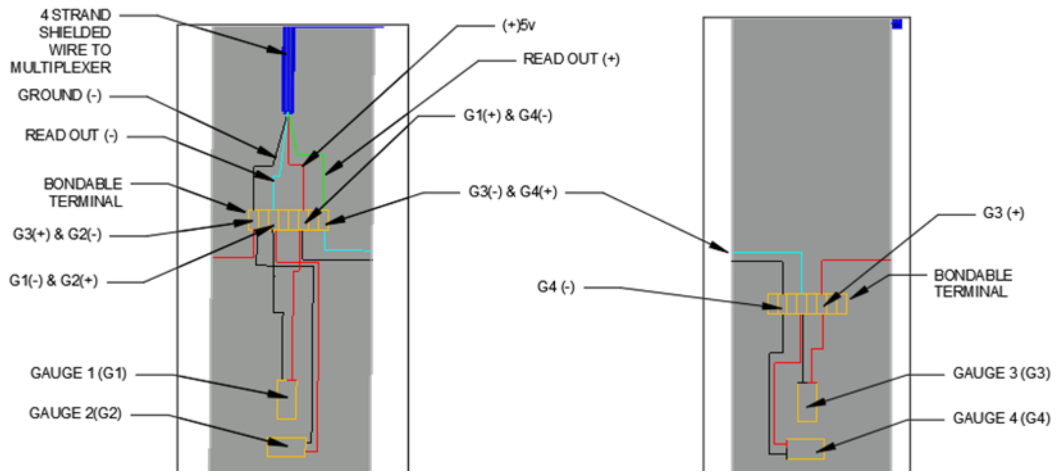
Construction - Instrumentation Preparation

- Earth Pressure Cells
  - 48 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



Construction - Instrumentation Preparation

- Strain Gauges (Vishay C2A-06-062LW-350)
  - 5 locations on 16 strips
  - Full bridge set up
    - 4 gauges, 2 terminals with epoxy coat
  - Testing strips to ensure proper measurements
    - Tested using crane, known weights, and CR6



Remaining Tasks

- Task (2) – Final Design, Site Preparation, and Materials Purchasing
  - New final design will be submitted at the end of August 2019
  - Task 3 will begin once new final design is approved by FDOT
- Task (3) – MSE Wall Construction with Two Designated Relative Compaction Efforts
  - 7-month construction window after final approval of Task 2
- Task (4) – Draft Final and Closeout Teleconference
- Task (5) – Final Report

Project Benefits

- Qualitative
  - Directly address the uncertainty of the engineering design for this special case of MSE wall construction
  - Increase the reliability of the engineering design for this special case of MSE wall construction
  - Provide guidelines for implementation
    - FDOT's Structures Design Guidelines and/or Soils and Foundations Handbook
- Quantitative
  - Possible savings by alleviating overly conservative designs for this type of MSE wall construction

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