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

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
- The outcome can be used to adequately address design methodology and earth pressure coefficients
  - Earthen fill compacted behind unyielding structures

Tasks

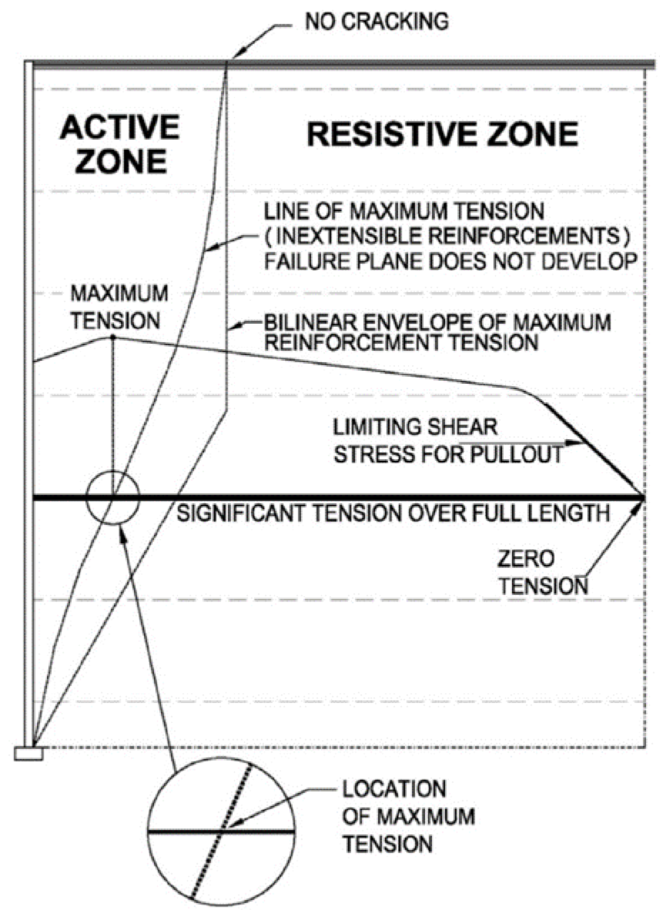
- Task (1) – Literature Review and Preliminary Design
- Task (2) – Final Design, Site Preparation, and Materials Purchasing
- Task (3) – MSE Wall Construction with Two Designated Relative Compaction Efforts
- Task (4) – Draft Final and Closeout Teleconference
- Task (5) – Final Report

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

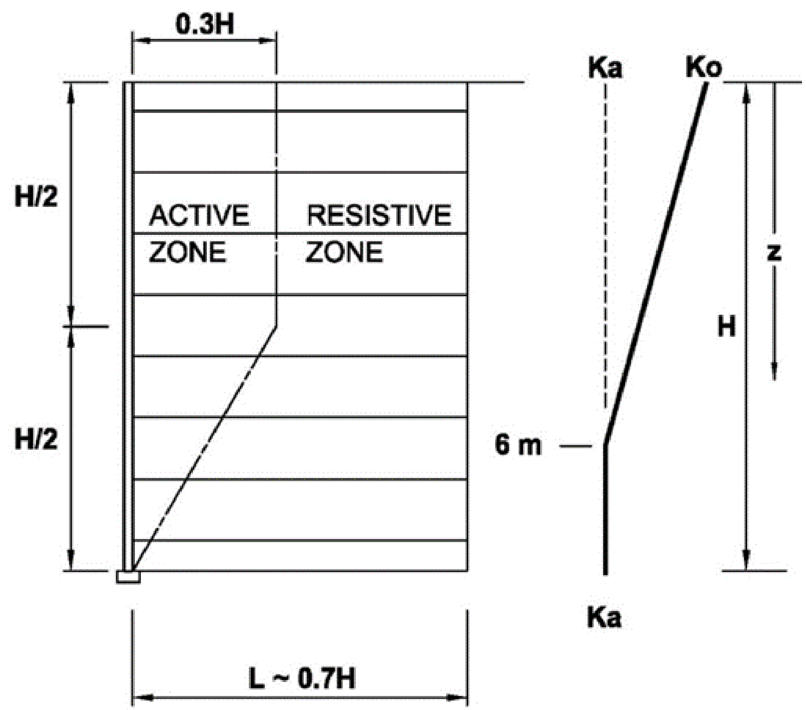
Design Methods Investigated

- National Concrete Masonry Association Procedure (NCMA)
- Geosynthetic Reinforced Soil (GRS) Analysis
- Tieback Wedge Method*
- FHWA Structure Stiffness Method*
- K-Stiffness Method*
- Coherent Gravity Method*
- The Simplified Method*

*Considered for final design and analysis

Coherent Gravity Method

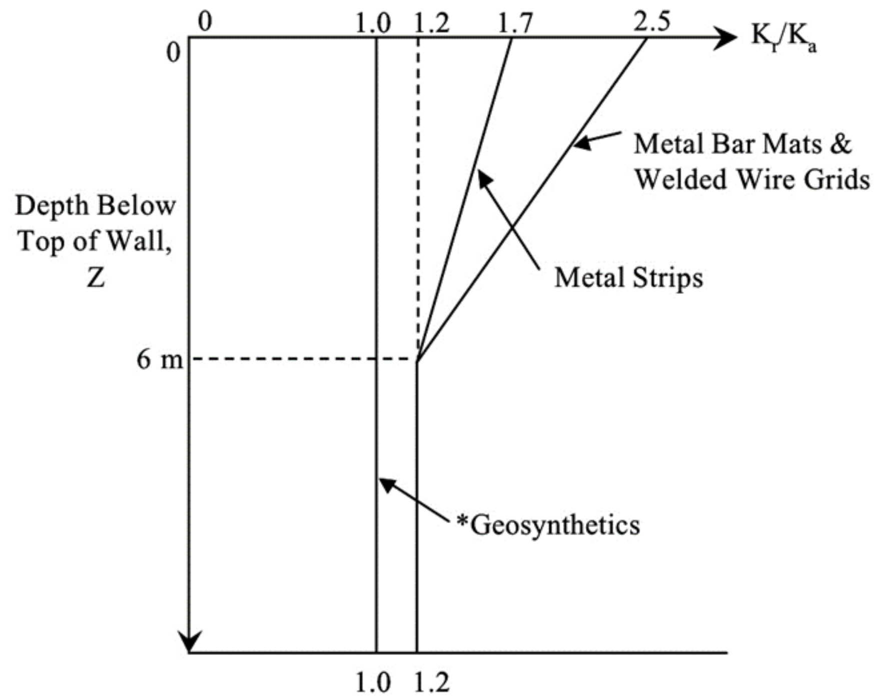
- Developed to estimate steel strip reinforcement stresses for precast panel-faced MSE Walls
- Soil mass is assumed to behave as a rigid body
- K_0 condition is assumed at the top of the wall
  - Locked-in-compaction stresses & stiff reinforcement prevent an active stress condition
- K_0 decreases to K_a at a depth (z) of 20 feet below the top of the wall
  - Overburden stress overcomes locked-in-compaction
  - Deformations become great enough to mobilize an active stress condition
- Produces a bilinear failure surface



$$k_r = k_a + (k_0 - k_a)\left(\frac{20 - z(ft)}{20}\right)$$

Simplified Method

- Simplified Coherent Gravity Method
- 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



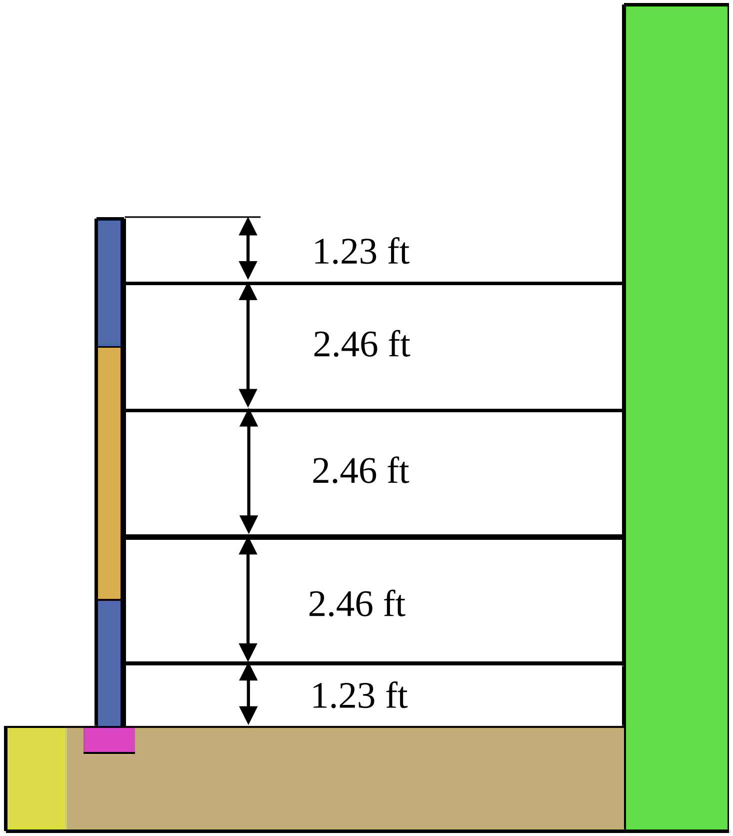
*Does not apply to polymer strip reinforcement.

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

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 pane
  - 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



Preliminary Soil Properties

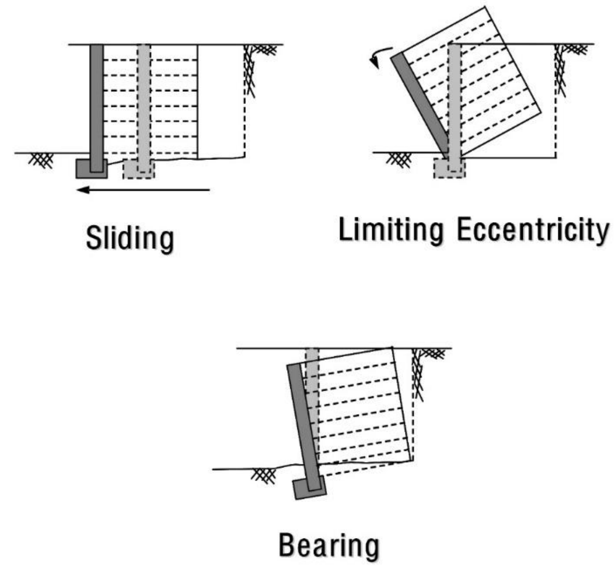
Sieve Size	Required Percent Passing (AASHTO T-27)	Reported Percent Passing (AASHTO T-88)
3-1/2 inches	100	N/A
¾ inch	70 to 100	100
No. 4	30 to 100	100
No. 40	15 to 100	99.7
No. 60	N/A	78.4
No. 100	0 to 65	19.3
No. 200	0 to 12	2.5

- D_{10} = 0.1 mm
- D_{60} = 0.2 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) = 2.673
- Maximum Dry Density (γ_{dmax}) = 107.5 pcf
- Optimum Moisture Content (w_{opt}) = 11.9 %
- Compaction (%) = 94.8
- Dry Density (γ_d) = 101.5 pcf
- Moisture Content (w) = 11.3 %
- Internal Friction Angle (Φ) = 31.3°

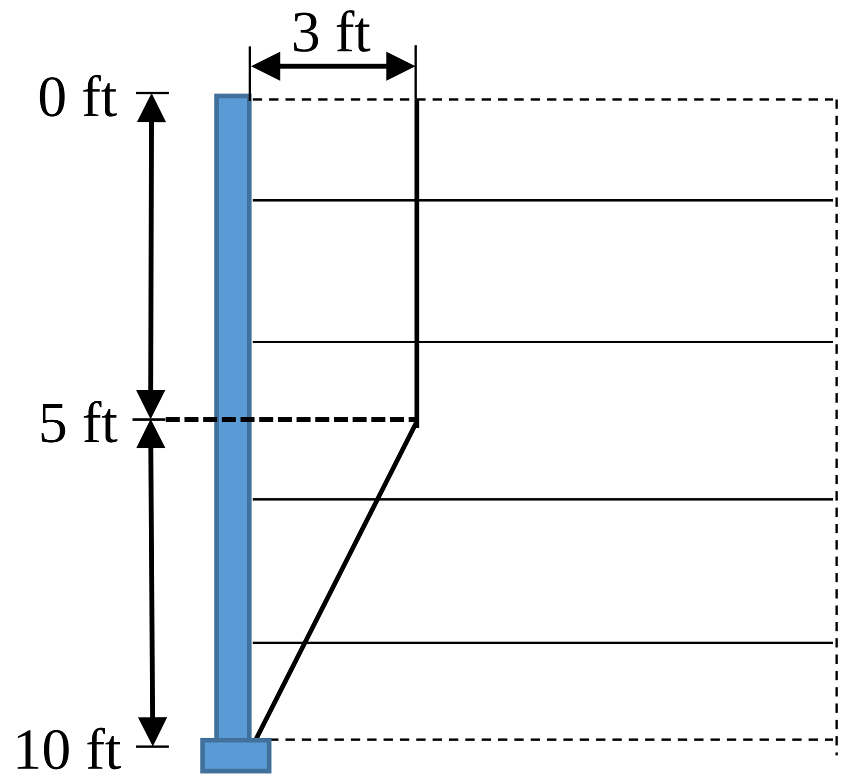
External Stability Design

- 4 potential external failure mechanisms
  - Sliding of the base
  - Limiting eccentricity
    - Formerly overturning
  - Bearing resistance
  - Overall/global stability
    - Failure planes behind or under reinforced zone
- External failure not likely
  - Strong Wall produces no external loading
  - Bearing & Global stability concerns alleviated due to wall bearing on concrete floor
- External stability checks were conducted in preliminary design – stable for all cases



Internal Stability Design

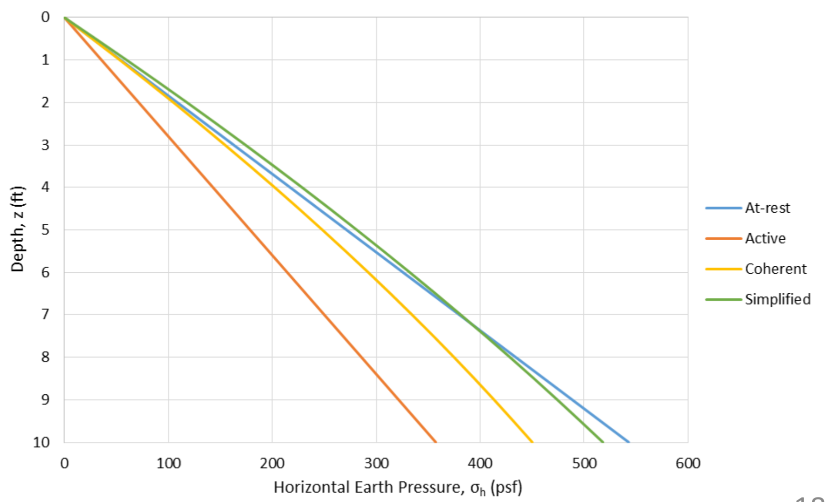
- Considers two modes of failure
  - Pullout of reinforcement
  - Structural failure of reinforcement
- Critical failure (slip) surface assumed to be bilinear
  - Inextensible reinforcement
  - Coincides w/ locus of maximum tensile force in each reinforcement layer (T_{max})
- Design wall height ≈ 10’
  - Slip surface 3’ behind facing at the top of the wall to 5’ below top of wall
  - Decreases linearly from 3’ behind the facing at 5ft below top of wall to 0’ behind facing at the base of the wall



Unfactored Loads

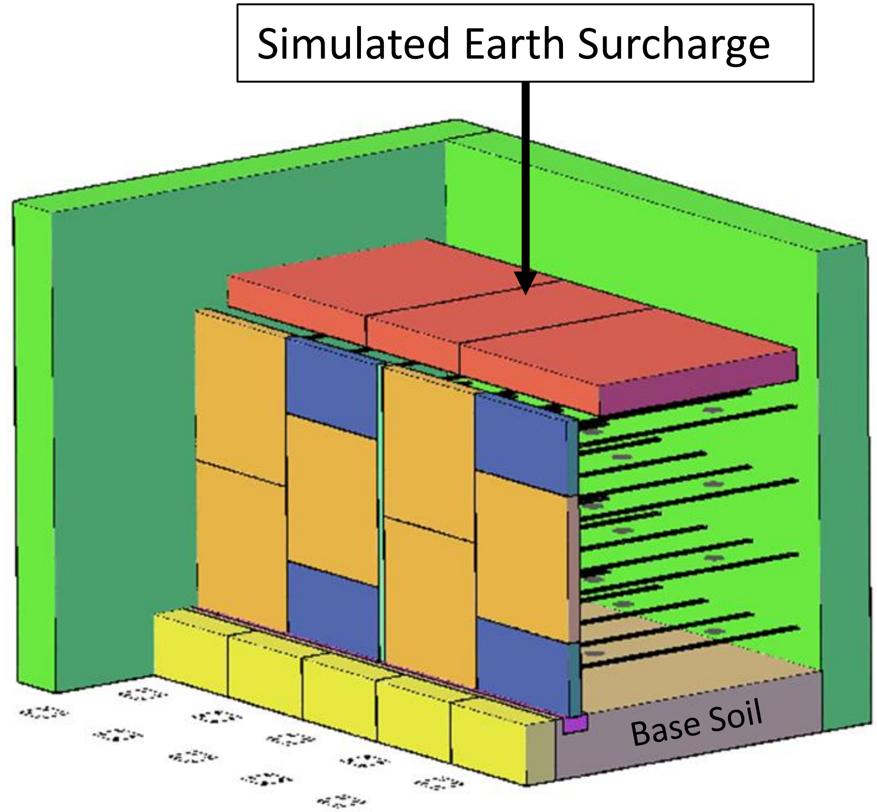
- Vertical earth pressure (EV)
  - Calculated using preliminary soil properties
- Horizontal earth pressure (EH) calculated using:
  - At-rest (k_0)
  - Active (k_a)
  - Coherent gravity method (k_r)
  - Simplified Method (k_r)
    - Used for preliminary design
- Live load surcharge (LS)
  - Weight of researchers and compaction equipment
  - Calculated for final design
- Earth surcharge (ES)
  - Simulated

Known Parameters		Earth Pressures for Various k-Values			
		k_0	k_a	k_r - Coherent	k_r - Simplified
Depth (ft)	σ_v (psf)	σ_h (psf)	σ_h (psf)	σ_h (psf)	σ_h (psf)
1	113	54	36	53	60
2	226	109	71	105	118
3	339	163	107	155	174
4	452	217	143	202	229
5	565	271	179	248	281
6	678	326	214	292	332
7	791	380	250	335	381
8	904	434	286	375	429
9	1,017	489	322	413	474
10	1,130	543	357	450	518



Surcharge Loading

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



Internal Stability Checks

- Factored horizontal stress and maximum tension

$$\sigma_h = k_r[(\gamma_r Z)\gamma_{EV-MAX} + q_s\gamma_{ES-MAX}]$$

$$\sigma_h = 0.469[(113\ pcf \times 8.61\ ft)1.35 + (250\ psf)1.5] = 792\ psf$$

$$T_{max} = \sigma_h S_v S_h = 792\ psf \times 2.46\ ft \times 2.46\ ft = 4{,}793\ lbf$$

  - Doubled the maximum load as suggested by WSDOT

$$T_{max} = 2 \times 4{,}793\ lbf = 9{,}586\ lbf$$

- Factored reinforcement tensile resistance, T_r, for static loading

$$T_r = \Phi T_{al} = \Phi F_y A_{cs} = 0.75 \times 65{,}000\ psi \times 0.31\ in^2 = 15{,}113\ lbf$$

$$T_r = 15{,}113\ lbf > T_{max} = 9{,}586\ lbf \therefore ok$$

Internal Stability Checks

- Number of strips required per tributary wall area for tensile capacity

$$N = \frac{(\sigma_h A_p)}{A_{cs}(0.55F_y)} = \frac{2(792\ psf) \times 24.2\ ft^2}{0.31\ in^2(0.55 \times 65{,}000\ psi)} = 3.46 \therefore 4\ strip/tributary\ wall\ area$$

- Connection Resistance at Facings
  - Connection resistance > reinforcement tensile resistance (per RECo)
  - Used tensile resistance for connection strength design (conservative)

Depth (ft)	σ_v (psf)	$\Delta\sigma_v$ (psf)	σ_h (psf) Factored	T_{max} (lbf) Unfactored	T_{max} (lbf) Factored	T_{max} (lbf) Doubled	Connection Strength (lbf)
1.23	139	250	297	1,243	1,797	3,594	15,113
3.69	417	250	477	2,052	2,885	5,771	15,113
6.15	695	250	642	2,796	3,885	7,771	15,113
8.61	973	250	793	3,475	4,797	9,594	15,113

∴ ok

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

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

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

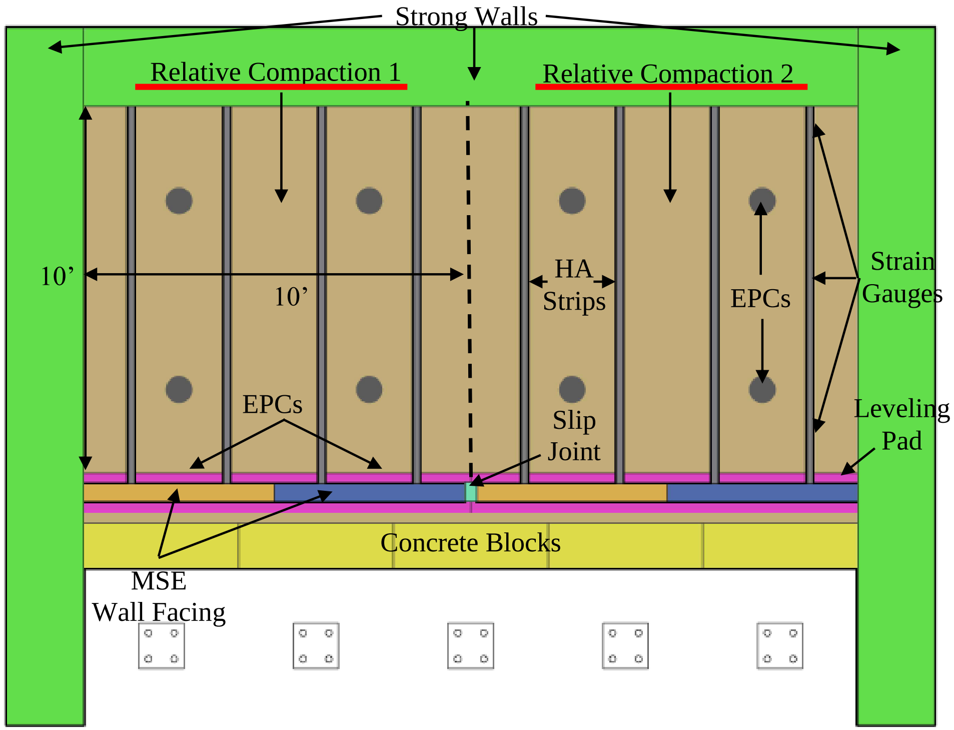
- Preliminary designs will be updated based on the results of the soil investigation
  - Designs will be reviewed by practicing engineers within the industry
    - The Reinforced Earth Company (RECo)
    - Offer guidance on construction operations and internal stability
    - Provide recommendations on number of reinforced strips required to maintain internal stability
- Final designs will be drafted and presented to FDOT for approval
  - FDOT approval must be gained before construction

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

- Site prep
  - The Strong Wall at UF will be used to conduct the research
    - Develop tie-ins on the strong wall (unyielding) to connect MSE strips
    - Develop a safety barrier and an access platform to enter the wall area
- Instrumentation purchasing and calibration (See Slide 25)
  - Earth pressure cells (embedded in soil)
  - "Fatback" earth pressure cells (wall mounted)
  - Strain gauges placed on the top and bottom of the reinforced strips (compensate for bending)
  - Displacement transducers to measure wall displacement
  - Vibrating wire readout box for spot checks during wall construction
  - Vibrating wire data logger to record and store measurements taken during the experiments

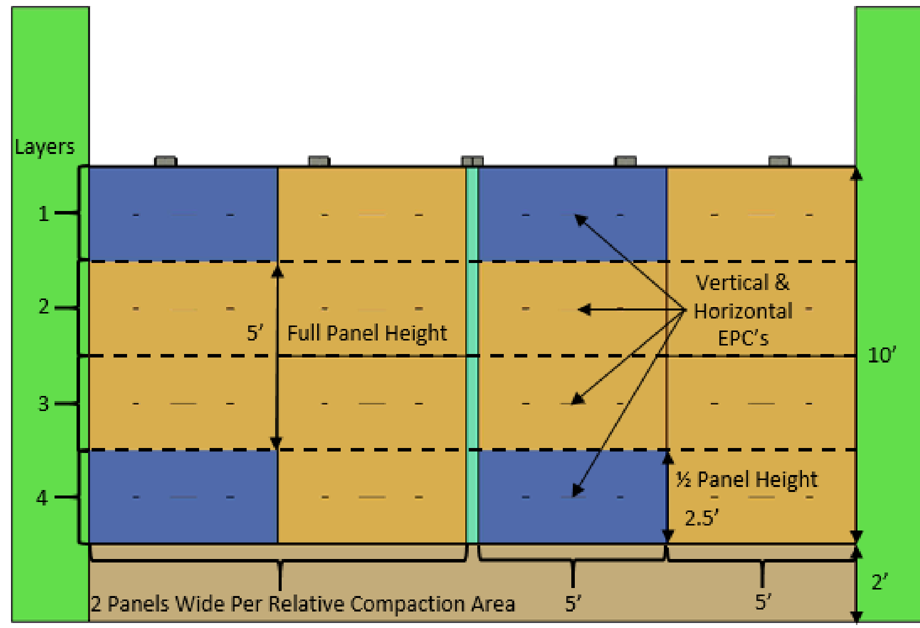
Task (3) – MSE Wall Construction with Two Designated Relative Compaction Efforts

- To properly investigate the earth pressure coefficients, two relative compaction efforts will need to implemented
  - For example, 94% of T180 and 104% of T180
- The final degree of compaction will be determined by FDOT after soil lab testing.
  - Plate compactor
  - Vibratory roller compactor
  - Develop rolling plan
  - Routine nuclear density testing



Task (3) – MSE Wall Construction with Two Designated Relative Compaction Efforts

- Design provides eight tributary wall areas (TWA)
  - ½ panel tall and 2 panels wide
  - Used to check internal stability of the structure under Coherent Gravity or Simplified methods
- Four depth layers to investigate for each compaction effort



Task (3) – MSE Wall Construction with Two Designated Relative Compaction Efforts

- Concrete blocks will be cast prior to MSE wall construction
  - Provides soil base layer containment
- A geotextile drain will be placed at the base of soil
- Leveling pads will be cast and placed in soil prior to construction
  - MSE wall is constructed atop the leveling pads
- After wall construction and backfilling is complete, surcharge loading will be induced
  - UF Soil Box walls an/or large concrete blocks
  - Length of sustained loading will be determined by Project Managers and Principle Investigators
    - Based on data collected on-site

Task (3) – MSE Wall Construction with Two Designated Relative Compaction Efforts

- Horizontal EPCs will be embedded in the soil at the midpoint of each TWA (Slide 18)
- Vertical EPCs will be mounted on the MSE wall panels at same vertical location as horizontal EPCs within each TWA
- Provides direct measurement of the horizontal and vertical stresses in 16 different zones
  - Earth pressure coefficients will be derived from multiple stress states, based on depth of embedment, simultaneously
- Strain gauges will be placed on reinforcement strips
  - At least three locations on strips (active zone)
  - Converted to axial force and lateral stress for comparison with EPCs
- Displacement transducers will measure wall movement
- Roller compactor will be driven atop soil to investigate the effects and soil disturbance

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

Questions?