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

FDOT GRIP Meeting

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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
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 Surcharge Design

- 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

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### Simplified Method

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>(a_e) (psf)</th>
<th>(\Delta a_e) (psf)</th>
<th>Simplified</th>
<th>Load Factors</th>
<th>Coherent</th>
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### Spangler and Handy – “Silo Effect”

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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

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<tr>
<td>Tie Strips tensile resistance at bolt hole (2 tie strips)</td>
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<td>Tie Strips bolt hole bearing resistance (2 tie strips)</td>
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<td>Reinforcing Strip tensile resistance at bolt hole</td>
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<td>Reinforcing Strip bolt hole bearing resistance</td>
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<td>Bolt shear resistance</td>
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Construction Plan - Instrumentation

- 80 full bridge strain gauge locations
  - 4 Instrumented strips per reinforcement level
  - 5 locations per strip
  - 320 Strain gauges total
- 36 horizontal EPC’s
  - Soil embedded in quadrants
  - 8 at each reinforcement level
  - 1 EPC under each leveling pad
- 16 vertical EPC’s
  - Wall mounted in quadrants
  - 4 at each reinforcement level
- 2 String Potentiometers
- 9 Multiplexers
- 1 Campbell CR6 Datalogger
- 1 Campbell CR10X Datalogger
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
Residual Voltage Buildup

Direct Multiplexer System

Settling Time with Direct Multiplexer Connections
CR6

- Multitiered system
- 5 multiplexers collect strain gauge data
- 1 multiplexer collects vertical EPC data
- 2 multiplexers collect horizontal EPC data
- Tier 1 collects data from 8 multiplexers
- Tier 1 data is then routed into CR6 DAQ
Resolving Settling Time Issues

Settling Time with Direct Multiplexer Connections

Settling Time With Tiered Multiplexer System
Resolving Residual Voltage Buildup

Direct Multiplexer System

Tiered Multiplexer System

![Graph showing tension over time for Direct Multiplexer System](image)

![Graph showing tension over time for Tiered Multiplexer System](image)
CR-10X

- 2 draw wire sensors
  - 1 sensor per compaction effort
  - Measures wall movement
- 4 EPCs
  - Underneath each leveling pad
- 6 Strain gauge locations
  - Placed on threadbar for load test monitoring
MSE Wall Construction Sequence
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MSE Wall Construction Sequence
MSE Wall Construction Sequence
Vertical Stress and Reinforcement Strip Tension

Row 1 Vertical Earth Pressure

Row 1 Reinforcement Tensions

Vertical Stress and Reinforcement Strip Tension
Row 1 Horizontal Earth Pressures

Row 1 Wall Mounted EPC Horizontal Earth Pressure

Row 1 Tension Converted to Horizontal Earth Pressure
Earth Pressures

Row 1 Average Earth Pressures

Earth Pressure Under Leveling Pads
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

- RECo. Documentation and Test Results for Clip Angle Connections used in Reinforced Earth Structures. 2003.
Questions?