Welcome to Mechanically Stabilized Earth: A Bridging Consideration

Moderator: Brian Osborn, CDM Smith
Speaker:
• John Sankey, P.E., Vice President, The Reinforced Earth Company
Introduction to MSE Wall & Abutment Technology

John Sankey, International Engineering Manager

2017 S.A.M.E. Europe Region Engineer Capabilities Workshop

Introduction to MSE Wall & Abutment Technology
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www.reinforcedearth.com
Outline of Presentation

I. Introduction to Mechanically Stabilized Earth
II. Components & Wall Types
III. Basic Rules of the Practice
IV. Abutment Walls
V. Wire Faced Walls
VI. Construction
VII. Military Applications
VIII. Questions & Answers
Introduction

Mechanically Stabilized Earth (MSE)
Seen Widely Along Highways But Not Always Recognized

France - A 40 Motorway
Invented by Henri Vidal (1924-2007)
French Architect
Legend is - On a beach in Ibiza Spain Henry was reinforcing sand with pine needles to build sand castles

And thus developed the idea of the MSE Wall Technology

MSE Walls have been Recognized as a major innovation in civil engineering
Growth of Practice Internationally

Initial patent obtained in 1965 in France (Terre Armée)....Then in over 30 countries

Launched The Reinforced Earth Company in the USA in 1971

Other MSE wall suppliers have launched a variety of steel or geosynthetic reinforced systems
Principles

- Friction between the Backfill and Reinforcing Elements creates artificial cohesion (Composite Material).
- Tensile strength of Reinforcing Elements allows to build a vertical wall.
- This Basic principle can be called the main structural support of the MSE wall.

Select backfill combined with the Reinforcing Element
Principles

- The Facing Panel is required to connect to the reinforcing elements.
- The Facing Panel provides local stability of the select backfill between reinforcing elements and protects against erosion.
- The Facing Panel is considered a secondary structural element of the MSE wall.
Basic Components of a MSE Wall

- Facing Element
- Select Backfill
- Reinforcing Element
Sizing Up the MSE Industry

• Approximately 25% to 50% savings over conventional reinforced concrete retaining walls

• Internationally, approximately 18 million ft\(^2\) of MSE wall built annually (largest user is USA)

• Breakdown of relative costs (FHWA):
  - 20% to 30% Erection Costs and Contractor Profit
  - 15% to 40% Facing Costs
  - 30% to 60% Backfill Costs
  - Add On for Top Outs & Any Unusual Foundation Conditions
Main Physical Advantage

Total settlement is not a problem.

However, differential Settlement is limited by the Joint Width between facing elements

<table>
<thead>
<tr>
<th>Joint Width</th>
<th>Limiting Differential Settlements</th>
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</thead>
<tbody>
<tr>
<td>¾”</td>
<td>1/100 *</td>
</tr>
<tr>
<td>½”</td>
<td>1/200</td>
</tr>
<tr>
<td>¼”</td>
<td>1/300</td>
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*When significant differential settlements are anticipated (greater than 1/100) slip joints must be provided.
More on the Components

- Backfill (Granular; $\phi > 34^\circ$)
- Reinforcing Strips (Steel or Geosynthetic)
- Facing (Panel or Wire)
- Attachments
- Cushion at Joints (Panels)
- Cover at Joints (Panels)
- Top Treatments
- Leveling Pad
Types of MSE Walls

Concrete Facing with Metallic Strips
Types of MSE Walls

Concrete Facing with Synthetic Strips

High-tenacity polyester yarns protected by polyethylene sheath
Types of MSE Walls

Concrete Facing with Metallic Mesh
Types of MSE Walls

Concrete Block Facing with GeoGrid Mesh
Types of MSE Walls

Wire Facing Either GeoGrid or Steel Reinforcement
Basic Rules of the Practice

Service Life

- Related to Durability of Reinforcements in Contact with Soil and Moisture
  - Metallic Reinforcements – Metal Loss
  - Geosynthetic Reinforcements – Creep, Installation Damage and Material Dependent Durability

- End of Life Consideration
  - Structure will still be “safe” at end of service life (well beyond imminent failure – at least double intended life)
Service Life

3 Functional Time Categories

- Temporary Structures – Maximum 5 years
- Semi Permanent Structures – Minimum 30 years
- Permanent Structures – Typically 70 to 120 years
  (lower range for ordinary retaining walls and higher range for critical structures such as bridge abutments)
Service Life – Site Agressiveness

- 4 Functional Environment Categories
  - “Out-of-Water” or “In the Dry”
  - Exposed to “Fresh Water”
    - Cl or SO₄ ≤ 250 mg/l
  - Exposed to Maritime Conditions
    - Salt or Briny Water
  - “Particular Structures”
    - Storage or Containment of Aggressive Liquids
2 Functional Criticality Categories

- Ordinary Retaining Walls
- High Security Walls
  - Bridge Abutments
  - Railways
  - Dams
Reinforced Earth is a composite wall system based essentially on the existence of friction between the earth and the reinforcements.
Global Behavior

L < H_m Meyerhof Method

L > H_m General Method

\[ B'' = B' - 2 \frac{M}{R_v} \]

\[ q_{ref} = \frac{R_v}{B - 2 \frac{M}{R_v}} \]

Note: Distribution of \( q_{ref} \) changes with \( L > H \)
With Bridge Abutment Loads
Maintain Consistent Design Code

Factored Forces < Reduced Resistance

This is true under any code!

Major International Codes: AASHTO, BS and Euro/French
Internal & External Modes to Check

- **Reinforcement Breakage**
  - Insufficient tensile capacity in reinforcement

- **Lack of Adherence (Pull Out)**
  - Slippage of reinforcement with respect to soil

- **External Stability**
  - Bearing Capacity
  - Sliding
  - Overturning
  - Global Stability
  - Propagation failure $L > H$ (external to internal – see figure)
Internal Stability – Tensile Strength

Types of Analyses

Steel (Inextensible) Strips

- Active Zone
- Resistant zone

Geosynthetic (Extensible) Strips

- Active Zone
- Resistant zone

Determine $T_{\text{max}}$ Based on ‘Line of Maximum Stress’

Conceptual vs Practice Depends on Codes
Internal Stability - Adherence

Reinforcement Surface Influence

- Smooth compared to high adherent surfaces
  - Smooth Surface – Noticeable $f^*$ peak with displacement
  - HA Surface – Less noticeable $f^*$ peak with displacement

\[ f^* = \frac{T_{\text{max}}}{\sigma_1} \]
Internal Stability - Adherence

\[ R = 2 \times b \times f^* \times \text{Leff.} \times \text{unit wt.} \times h \times N \]

R = Resisting Force of reinforcement = \( T_{\text{max}} \)

b = width of strip or grid

f* = Pullout Friction Factor

Leff = effective strip length

h = height of overburden over the reinforcement

N = Number of strips
External Stability

- Sliding
- Limiting Eccentricity

Note: Overturning not considered universally, since bearing is primary basis.
Sliding Evaluation

Does cohesion have a role?

\[ T = \sigma \tan \phi + c \quad \text{Mohr-Coulomb Theory} \]

Stability basis:

\[ R_h \leq \frac{R_v \cdot \tan \phi + c \cdot L}{\gamma_{R;h}} \]

Apply appropriate load & resistance factors
Evaluate Eccentricity (Overturning)

\[ e = \frac{\sum M_D - \sum M_R}{\sum R_v} \]

- \( M_D \) = Driving moment
- \( M_R \) = Resisting moment

Apply appropriate load & resistance factors (minimum and maximum)
Evaluate Bearing Pressure

Bearing pressure $q_{ref}$ evaluated from a Meyerhof distribution

$$q_{ref} = \frac{R_v}{2.x} = \frac{R_v}{L-2.e}$$

Apply appropriate load & resistance factors

Compare to Bearing Capacity of Foundation Soils
MSE Bridge Applications

Precast Panel Faced MSE

Wire Faced MSE
MSE Bridge Application Types

True Abutments

Mixed Abutments
• Abutment design using technology started in 1969 (Strasburg, France), soon after development of Reinforced Earth.

• Similar considerations as basic technology with expanded basis to consider additional bridge loads & design details.

• Flexibility & load distribution provides advantages to support abutment needs.
Measured Projects (Steel)

Studies based upon direct bearing bridge seat supported by RE wall (From 1970s to Present)

Early French projects (Dunkirk, Angers & Thionsville) indicated tensile distribution in steel strip reinforcements.

Amersfoot, Netherlands (1975) indicated reduction in reinforcement stresses with increased bearing capacity of foundation soils.

Figure 5: Tensile stress measurement at Amersfoot.

Figures 4a, 4b: Tensile stress measurement in reinforcements at Dunkirk and Angers.
Studies from 1980s to Present

Carmarthen, Scotland (1983) – Looked at Paraweb (high tenacity polyester strip reinforcements)
- Instrumentation indicated lateral earth pressures varying from at-rest to active
- Provided information on positive settlement performance of wall (significant differential settlements)
- Showed tensile distribution in strips
**AdditionaL Cautions (Geosynthetic)**

1. Deformation control limits wall heights
2. Deformation control criteria
3. At SLS the strip long term strain shall be limited to 2.5%

**Additional Reductions**

Design strength limited to:
- 16% for GeoStrap
- 27% for EcoStrap
Distortion of the bridge bearing pad can be induced by:

- Normal loads
- Horizontal loads
- Rotation

At ULS (EN §5.3.3):

\[ \varepsilon_c + \varepsilon_q + \varepsilon_\alpha < 7 \]
\[ \varepsilon_\alpha < 1 \]
Bridge Bearing Pad Consideration

- A strong and wrong assumption made by structural engineers:

  Beam seat resting on a **rigid base**...

  

  \[ \varepsilon \text{ induced by RE has to be taken into account} \]

  

  \[ \text{RE will deform under high loads} \]
Wire Faced Walls
Design Basis – Wire Faced Walls

- Design basis consistent with MSE rules
- More flexible facing – need to consider bulging based on mesh spacing & wire size
- Either steel or geosynthetic reinforcements may be used
- Temporary or permanent
- Connection basis is critical
- No leveling pad or embedment typically needed
- Faster construction
- Portability of materials
Selection of Wire Mesh

- Use of 5” x 5” (125x125 mm) mesh typical
- W5 wire (0.252” dia) for temp and semi-perm walls under 20 ft
- W8 wire (0.319” dia) for temporary walls over 20 ft and all permanent walls
- Panel sizes to 5 ft x 10 ft (1.5 x 3.0m)

Varies by Country
USA sizes indicated
Reinforcement Selection

- Steel grid reinforcement hooks on facing
- Intermediate hook connection on geogrid
- Discrete geosynthetic strips with discrete connector
- Discrete steel strips
  - Slotted hairpin
  - Connector bar
Discrete Reinforcement Placement

- Horizontal spacing: Min. 3 per panel for discrete reinforcements
- Mesh reinforcements can give continuous connection
- Vertical spacing: Min. 20 inches
- Add intermediate strips to prevent bulging if needed for purpose
Geotextile Backing in Temporary Walls
Semi-Permanent and Permanent

- Rock facing backed by geotextile preferred
- Wire cloth where rock unavailable
  - Size wire cloth mesh at $D_{85}$ of retained backfill
Restrictions

• Geosynthetic reinforcements may add to wall face deformations

• Steel contact requirements:
  ➢ Temp walls may have galvanized & black steel in contact
  ➢ Semi-perm and perm walls should have no galvanized & black steel in contact (1 inch min separation)

• In true abutments, setback edge of footings at least 6 inches behind wire facing (suggest modeling to verify restraint of bulging)
Precast Panel – Long Term Basis

6" x 1'-0" UNREINFORCED CONC. LEVELING PAD.
Construction - Process

Leveling Pad Placement
(Not Needed for Wire Walls)

1st Level of Panels & Bracing
Compacted Fill Placement

Light Walk behind compactor

Static Drum Roller

3’

Static Drum Roller – 95%

Fill in 10” Lifts to Reinforcement

Sheep Foot Roller – Not Allowed
SPECIFICATION FOR REINFORCED EARTH
SELECT BACKFILL MATERIAL

1. GRADATION LIMITS (AASHTO-T-27)

<table>
<thead>
<tr>
<th>SIEVE OPENING</th>
<th>PERCENT PASSING</th>
</tr>
</thead>
<tbody>
<tr>
<td>6”</td>
<td>100</td>
</tr>
<tr>
<td>3”</td>
<td>75-100</td>
</tr>
<tr>
<td>No.200</td>
<td>0-15</td>
</tr>
</tbody>
</table>

2. PLASTICITY INDEX (AASHTO T-90): P.I. \( \leq 6 \)

3. INTERNAL FRICTION ANGLE (AASHTO T-236): \( \phi \geq 34^0 \)
(SAMPLE COMPACTION TO 95% OF AASHTO T-99)
(CONTINUED)
SPECIFICATION FOR REINFORCED EARTH
SELECT BACKFILL MATERIAL

4. SOUNDNESS:
   A. SUBSTANTIALLY FREE OF SHALE OR OTHER
      SOFT, POOR DURABILITY PARTICLES.
   
   B. MAGNESIUM SULFATE SOUNDNESS LOSS OF LESS
      THAN 30% AFTER FOUR CYCLES.

5. ELECTROCHEMICAL REQUIREMENTS:

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
<th>TEST METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5-10</td>
<td>AASHTO T289</td>
</tr>
<tr>
<td>RESISTIVITY</td>
<td>≥3,000 Ω-cm</td>
<td>AASHTO T288</td>
</tr>
<tr>
<td>CHLORIDES</td>
<td>≤ 100 ppm</td>
<td>AASHTO T291</td>
</tr>
<tr>
<td>SULFATES</td>
<td>≤ 200 ppm</td>
<td>AASHTO T290</td>
</tr>
</tbody>
</table>

Steel requires these; synthetic has only pH restriction in range of 5 to 9
Construction - Process

Placement of Elastomeric Bearing Pads, (Between Panel Horizontal Joints), Joint Cover & Reinforcements

Continue in Stepwise Fashion To Top of Wall Completion
Military Applications

Tactical Vehicle Bridge over Haan Road, Fort Bliss, El Paso, TX
(Steel Reinforced Strip MSE Wall)
Military Applications

Owner / Client:
U.S. Army Corps of Engineers

Engineer:
Army Corps of Engineers, Omaha
Nebraska

Main contractor:
Prime Contractor: Medvolt
Installation: Slaton Bros., Inc.
(Vinci Construction)

Terre Armée entity:
The Reinforced Earth Company
(United States)

Date:
2016

Ft. Carson Vehicle Bridge
Colorado
(Geosynthetic Strip MSE Wall)
Military Applications

Standard ACOE Precast Munitions Igloos  Special Precast Munitions Igloos

Three Hinge Precast Concrete Arch and Reinforced Earth® (steel reinforced)
Military Applications

- Storage Function (Munitions Igloos & Storage Bunkers)
- Protective Walls & Shields
- Blast Barriers
- Noise & Projectile Barriers
- Bridges & Roadways
- Wharf Bulkheads
- Launch Support Platforms
QUESTIONS & ANSWERS

Contacts:

- John Sankey, International Engineering Manager
  jsankey@reinforcedearth.com
- John Shall, USA Business Manager
  jshall@reinforcedearth.com
- Anne-Cecile Gass, International Business Manager
  anne-cecile.gass@terre-armee.com

Web Sites

- www.reinforcedearth.com
- www.terre-armee.com