ENCE 4610
Foundations and Earth Structures

MECHANICALLY STABILIZED EARTH WALLS

Lecture 9
Overview of MSE Walls

• Definitions
  o **Mechanically Stabilized Earth Wall** (MSEW) is a generic term that includes reinforced soil (a term used when multiple layers of inclusions act as reinforcement in soils placed as fill).
  o **Geosynthetics** is a generic term that encompasses flexible polymeric materials used in geotechnical engineering such as geotextiles, geomembranes, geonets, and grids (also known as geogrids).
  o **Facing** is a component of the reinforced soil system used to prevent the soil from raveling out between the rows of reinforcement. Common facings include precast concrete panels, dry cast modular blocks, metal sheets and plates, gabions, welded wire mesh, shotcrete, wood lagging and panels, and wrapped sheets of geosynthetics. The facing also plays a minor structural role in the stability of the structure. For RSS structures it usually consists of some type of erosion control material.
  o **Retained backfill** is the fill material located between the mechanically stabilized soil mass and the natural soil.
  o **Reinforced backfill** is the fill material in which the reinforcements are placed.
Applications of MSE Walls

Retaining Wall

Bridge Approach Fill Over Compressible Foundation

Interchange with Access Ramps

Standard Solution

MSE Wall

Select Backfill

MARINE WALL

STANDARD SOLUTION

MSE WALL

BRIDGE ABUTMENT

LOOSE SAND

CLAY
Advantages and Disadvantages of MSE Walls

**Advantages**
- Use simple and rapid construction procedures and do not require large construction equipment.
- Do not require experienced craftsmen with special skills for construction.
- Require less site preparation than other alternatives.
- Need less space in front of the structure for construction operations.
- Reduce right-of-way acquisition.
- Do not need rigid, unyielding foundation support because MSE structures are tolerant to deformations.
- Are cost effective.
- Are technically feasible to heights in excess of 25 m (80 ft).

**Disadvantages**
- Require a relatively large space behind the wall or outward face to obtain enough wall width for internal and external stability.
- MSEW require select granular fill. (At sites where there is a lack of granular soils, the cost of importing suitable fill material may render the system uneconomical).
- Suitable design criteria are required to address corrosion of steel reinforcing elements, deterioration of certain types of exposed facing elements such as geosynthetics by ultra violet rays, and potential degradation of polymer reinforcement in the ground.
- Since design and construction practice of all reinforced systems are still evolving, specifications and contracting practices have not been fully standardized, especially for RSS.
- The design of soil-reinforced systems often requires a shared design responsibility between material suppliers and owners and greater input from agencies geotechnical specialists in a domain often dominated by structural engineers.
MSE Wall Facings
MSE Wall Construction

Figure 11. Erection of precast panels.

Figure 12. Fill spreading and reinforcement connection.

Figure 13. Compaction of backfill.
Types of Reinforcement

- **Steel Strips**
  - The currently commercially available strips are ribbed top and bottom, 50 mm (2 inches) wide and 4 mm (5/32-inch) thick. Smooth strips 60 to 120 mm (2 to 4¾-inch) wide, 3 to 4 mm (c to 5/32-inch) thick have been used.

- **Steel Grids**
  - Welded wire grid using 2 to 6 W7.5 to W24 longitudinal wire spaced at either 150 or 200 mm (6 or 8 inches). The transverse wire may vary from W11 to W20 and are spaced based on design requirements from 230 to 600 mm (9 to 24 inches). Welded steel wire mesh spaced at 50 by 50 mm (2 by 2-inch) of thinner wire has been used in conjunction with a welded wire facing. Some MBW systems use steel grids with 2 longitudinal wires.

- **Geogrids**
  - High Density Polyethylene (HDPE) geogrid. These are of uniaxial manufacture and are available in up to 6 styles differing in strength.
  - PVC coated polyester (PET) geogrid. Available from a number of manufacturers. They are characterized by bundled high tenacity PET fibers in the longitudinal load carrying direction. For longevity the PET is supplied as a high molecular weight fiber and is further characterized by a low carboxyl end group number.

- **Geotextiles**
  - High strength geotextiles can be used principally in connection with reinforced soil slope (RSS) construction. Both polyester (PET) and polypropylene (PP) geotextiles have been used.
Steel Reinforcement

Figure 10-1. Schematic diagram of reinforced earth retaining wall.
Geogrid Reinforcement
MSE Backfill

- MSE walls require high quality backfill for durability, good drainage, constructability, and good soil reinforcement interaction which can be obtained from well graded, granular materials. Many MSE systems depend on friction between the reinforcing elements and the soil. In such cases, a material with high friction characteristics is specified and required. Some systems rely on passive pressure on reinforcing elements, and, in those cases, the quality of backfill is still critical. These performance requirements generally eliminate soils with high clay contents.

- From a reinforcement capacity point of view, lower quality backfills could be used for MSEW structures; however, a high quality granular backfill has the advantages of being free draining, providing better durability for metallic reinforcement, and requiring less reinforcement. There are also significant handling, placement and compaction advantages in using granular soils. These include an increased rate of wall erection and improved maintenance of wall alignment tolerances.
Design of MSE Walls

- External Stability
- Internal Stability

![Diagram of MSE Wall Failures](image)

Figure 21. Potential external failure mechanisms for a MSE wall.

Figure 4-9. Location of potential failure surface for internal stability design of MSE Walls
(a) inextensible reinforcements and (b) extensible reinforcements.
MSE Design Flowchart

Define wall geometry and soil properties

Select performance criteria

Preliminary sizing

Evaluate static external stability

Sliding

Overturning (eccentricity)

Bearing capacity

Overall slope stability

Settlement/lateral deform.

Establish reinforcement length

Check seismic stability
Basic Concept of MSE Reinforcement Design
(Elevation View) with Steel Strips

Elevation View of MSE Wall for Static Equilibrium Against Sliding

Driving Force of Lateral Earth Pressure = \( \text{Effective Stress} \times \text{Area} \times \text{Height} \)

Structural Resisting Force of Strip = \( \text{Strip Axial Stress} \times \text{Strip Thickness} \times \text{Strip Width} \)

For Static Equilibrium,
Driving Force of Lateral Earth Pressure = Max. Resisting Force of Strip
Geogrid Design

MSE Wall Equations for Geogrids:

\[ FS_{mech} = \frac{T_{allow}}{T_{req}} \]
\[ FS_{pullout} = \frac{T_{ten}}{T_{req}} \]

where

- \( FS_{mech}, FS_{pullout} = \) factor of safety
- \( T_{allow} = \) allowable tensile strength of geogrid, based on laboratory testing, kN/m or kips/ft of wall and geogrid
- \( T_{ten} = \) allowable tension pull on geogrid based on frictional interaction of geogrid with soil, kN/m or kips/ft of wall and geogrid
- \( T_{req} = \) strength required by the application, kN/m or kips/ft of wall and geogrid
Geogrid Design

Allowable tension pull on geogrid based on mechanical properties of material:

\[ T_{allow} = \frac{T_{ult}}{RF_{ID} \times RF_{CR} \times RF_{CD} \times RF_{BD}} \]

where

- \( T_{ult} \) = ultimate tensile strength of geogrid before reduction due to environmental factors, kN/m or kips/ft of wall and geogrid
- \( RF_{ID} \) = reduction factor for installation damage = 1.1 to 1.4 for MSE walls
- \( RF_{CR} \) = reduction factor to avoid creep over the lifetime of the structure = 2.0 to 3.0 for MSE walls
- \( RF_{CD} \) = reduction factor against chemical degradation = 1.1 to 1.4 for MSE walls
- \( RF_{BD} \) = reduction factor against biological degradation = 1.0 to 1.2 for MSE walls
Geogrid Design

Allowable tension pull on geogrid based on frictional interaction of geogrid with soil:

\[ T_{ten} = 2C_i C_r L_e \sigma_v' \tan \delta' \]

where

- \( C_i \) = interaction coefficient
- \( C_r \) = coverage ratio
- \( L_e \) = length of geogrid embedment with soil which can resist pullout (with MSE walls, the soil which is past the Rankine failure surface)
- \( \sigma_v' \) = vertical effective stress at the level of the geogrid
- \( \delta' \) = friction angle between soil and geogrid/straps, degrees or radians

For design to be valid,

\[ T_{req} F S_{pullout} \leq T_{ten} \]
\[ T_{req} F S_{mech} \leq T_{allow} \]
Geogrid Design

Earth Pressure on strip of wall which is supported by a given level of geogrid

\[ T_{req} = s_v \sigma'_h \]

where

- \( s_v \) = vertical spacing of geogrid sheets, m or ft
- \( \sigma'_h \) = horizontal (lateral) earth pressure

Substituting,

\[ s_v (\sigma'_h F_{pullout}) = L_e (2C_t C_r \sigma'_v \tan \delta') \]

Notes:

- This can be used to solve for either the geogrid embedment or the vertical spacing of the geogrid sheets
- The vertical effective stress does not include the effects of overburden; the horizontal effective stress does
- With MSE walls, the backfill is chosen and the wall is porous, so no water effects are included
MSE Wall Factors of Safety (ASD Design)

Recommended minimum factors of safety with respect to failure modes are as follows:

**External Stability**
- Sliding: F.S. ≥ 1.5 (MSEW); 1.3 (RSS)
- Eccentricity e, at Base: ≤ L/6 in soil L/4 in rock
- Bearing Capacity: F.S. ≥ 2.5
- Deep Seated Stability: F.S. ≥ 1.3
- Compound Stability: F.S. ≥ 1.3
- Seismic Stability: F.S. ≥ 75% of static F.S. (All failure modes)

**Internal Stability**
- Pullout Resistance: F.S. ≥ 1.5 (MSEW and RSS)
- Internal Stability for RSS: F.S. ≥ 1.3

**Allowable Tensile Strength**
- for steel strip reinforcement: 0.55 $F_y$
- for steel grid reinforcement: 0.48 $F_y$ (connected to concrete panels or blocks)
- for geosynthetic reinforcements: $T_a$ - See design life, below
MSE Wall Design Criteria

A number of site specific project criteria need to be established at the inception of design:

- **Design limits and wall height.** The length and height required to meet project geometric requirements must be established to determine the type of structure and external loading configurations.

- **Alignment limits.** The horizontal (perpendicular to wall face) limits of bottom and top of wall alignment must be established as alignments vary with batter of wall system. The alignment constraints may limit the type and maximum batter, particularly with MBW units, of wall facing.

- **Length of reinforcement.** A minimum reinforcement length of 0.7H is recommended for MSE walls. Longer lengths are required for structures subject to surcharge loads. Shorter lengths can be used in special situations.

- **External loads.** The external loads may be soil surcharges required by the geometry, adjoining footing loads, line loads as from traffic, and/or traffic impact loads. Traffic line loads and impact loads are applicable where the traffic lane is located horizontally from the face of the wall within a distance less than one half the wall height. The magnitude of the minimum traffic loads outlined in Articles 3.20.3 and 5.8 of current AASHTO, is a uniform load equivalent to 0.6 m (2 ft) of soil over the traffic lanes.

- **Wall embedment.** The minimum embedment depth for walls from adjoining finished grade to the top of the leveling pad should be based on bearing capacity, settlement and stability considerations. Current practice based on local bearing capacity considerations, recommends the following embedment depths:

<table>
<thead>
<tr>
<th>Slope in Front of Wall</th>
<th>Minimum to Top of Levelling Pad</th>
</tr>
</thead>
<tbody>
<tr>
<td>horizontal (walls)</td>
<td>H/20</td>
</tr>
<tr>
<td>horizontal (abutments)</td>
<td>H/10</td>
</tr>
<tr>
<td>3H:1V</td>
<td>H/10</td>
</tr>
<tr>
<td>2H:1V</td>
<td>H/7</td>
</tr>
<tr>
<td>3H:2V</td>
<td>H/5</td>
</tr>
</tbody>
</table>

  Larger values may be required, depending on depth of frost penetration, shrinkage and swelling of foundation soils, seismic activity, and scour. Minimum in any case is 0.5 m, except for structures founded on rock at the surface, where no embedment may be used. Alternately, frost-susceptible soils could be overexcavated and replaced with non frost susceptible backfill, hence reducing the overall wall height.

  A minimum horizontal bench 1.2 m (4 ft) wide as measured from the face shall be provided in front of walls founded on slopes.

  For walls constructed along rivers and streams where the depth of scour has been reliably determined, a minimum embedment of 0.6 m (2 ft) below this depth is recommended.

  Embedment is not required for RSS unless dictated by stability requirements.

- **Seismic Activity.** Due to their flexibility, MSE wall and slope structures are quite resistant to dynamic forces developed during a seismic event, as confirmed by the excellent performance in several recent earthquakes.

  The peak horizontal ground acceleration for each site can be obtained from Section 3 of AASHTO Division 1-A, Seismic Design. For sites where the Acceleration Coefficient “A” in AASHTO is less or equal to 0.05, static design considerations govern and dynamic performance or design requirements may be omitted.

  For sites where the Acceleration Coefficient is greater than 0.29, significant total lateral structure movements may occur, and a seismic design specialist should review the stability and potential deformation for the structure. All sites where the “A” coefficient is greater than 0.65 should be designed checked for seismic stability. For RSS structures, seismic analyses should be included regardless of acceleration.

- **Tolerance of precast facing panels to settlement.** MSE structures have significant deformation tolerance both longitudinally along a wall and perpendicular to the front face. Therefore, poor foundation conditions seldom preclude their use. However, where significant differential settlement are anticipated (greater than 1/100) sufficient joint width and/or slip joints must be provided to preclude panel cracking. This factor may influence the type and design of the facing panel selected.

  Square panels generally adapt to larger longitudinal differential settlements better than long rectangular panels of the same surface area. Guidance on minimum joint width and limiting differential settlements that can be tolerated is presented in table 3, for panels with a surface area typically less than 4.5 m² (50 ft²).

  MSE walls constructed with full height panels should be limited to differential settlements of 1/500. Walls with drycast facing (MBW) should be limited to settlements of 1/200. For walls with welded wire faceings, the limiting differential settlement should be 1/50.

  Where significant differential settlement perpendicular to the wall face is anticipated, the reinforcement connection may be overstressed. Where the back of the reinforced soil zone will settle more than the face, the reinforcement could be placed on a sloping fill surface which is higher at the back end of the reinforcement to compensate for the greater vertical settlement. This may be the case where a steep surcharge slope is constructed. This latter construction technique, however, require that surface drainage be carefully controlled after each day's construction.

  Alternatively, where significant differential settlements are anticipated, ground improvement techniques may be warranted to limit the settlements, as outlined in geological conditions.

Table 3. Relationship between joint width and limiting differential settlements for MSE precast panels.

<table>
<thead>
<tr>
<th>Joint Width</th>
<th>Limiting Differential Settlement</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mm</td>
<td>1/100</td>
</tr>
<tr>
<td>13 mm</td>
<td>1/200</td>
</tr>
<tr>
<td>6 mm</td>
<td>1/300</td>
</tr>
</tbody>
</table>

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**Design Example**

- **Given**
  - Project Nature
    - A typical urban highway retaining wall design with inextensible steel linear reinforcements and precast concrete panels
    - Geogrid reinforcement
    - Vertical spacing of strips = 750 mm (based on selection of wall configuration)
  - Design Height, External Loads
    - Total design height $H = 7.8$ m, to gutter grade.
    - Required panel height = 7.5 m vertical.
    - Uniform traffic surcharge = 9.4 kPa.

- **Given**
  - Foundation Soils
    - $\phi' = 30^\circ$. (clayey sand, dense)
    - Allowable bearing capacity - 300 kPa.
    - Differential settlements on the order of 1/300 are estimated.
  - Reinforced (Wall) Backfill
    - $\phi = 34^\circ$, $\gamma_T = 18.8$ kN/m$^3$, $\delta = 11^\circ$
  - Retained Backfill
    - $\phi = 30^\circ$, $\gamma_T = 18.8$ kN/m$^3$
Design Example

• **Given**
  o Geogrid Ultimate Strength = 600 kN/m
  o Factors of Safety
    • External Stability FS.
      o Sliding = 1.5.
      o Maximum foundation pressure < allowable bearing capacity.
    • Internal Stability FS.
      o Pullout = 1.5.
      o Mechanical = 1.5.
  o Vertical Spacing: Given the panel size, the most efficient vertical spacing is 0.75 m. The first row is located 375 mm from the topmost panel plus 300 mm of barrier to pavement grade.

• **Find:** MSE Wall Design

• **Solution:**
  o Specify Panel Joints from Differential Settlement Criteria
    • Based on the urban location a precast concrete facing with an architectural finish is required. For aesthetic reasons a maximum panel dimensions of 1.5 x 1.5 m (5 ft x 5 ft) are required with joints no greater than 19 mm (¾-inch). Since the estimated differential settlements along the wall are 1/300, and precast panels are to be used, panel joints of 19 mm (¾-inch) are acceptable.

  • Solution given in spreadsheet accompanying this slide set.
Gabion Walls

Gabion Retaining Wall

Types - Common Gabion walls shown on accompanying diagrams are:

a) Battered face wall with horizontal backfill.
b) Stepped face wall with sloped backfill.
c) Battered face wall with sloped backfill.
d) Stepped face wall with horizontal backfill.

The choice of either battered or stepped faces rests with designer; stepped face recommended if wall is more than 10 feet high.

Gabion Fill - Hard, durable, clean stone 4 to 8 inches in size or other approved size.

Design: Design criteria for gravity walls apply. Wall section resisting overturning and sliding. To increase wall stability, recommended to tilt the wall at an angle of 6° (i.e. 1:10).

The angle of friction between the base of gabion wall and granular soil may be assumed 0.9 times the angle of internal friction of soil.

For retaining clay slopes, a system of gabion counterforts is recommended.

Compute active soil pressure behind the wall using Coulomb Wedge theory and design mass of the wall to balance the force exerted by that soil wedge. (Higher than active pressures may be used depending on compaction conditions and limitations on deformations.)

Maximum pressure at the base of gabion wall must be less than the anticipated bearing capacity of the soil under the wall.

When water quality is in doubt (pH below 6 or greater than 12) or where high concentration of organic acids may be present, use of PVC (polyvinylchloride) coated gabions is recommended.
Soil Nailing

Figure 2.1: Typical Cross-Section of a Soil Nail Wall.

Figure 2.2: Typical Soil Nail Wall Construction Sequence.

Modified after Porterfield et al. (1994).
Questions