MSE Retaining Wall Design Considerations

by

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Wall Selection

**Fill Situations**
- MSE
- Concrete Block
- Spread Footing
- Temporary Earth
- Gabion

**Cut Situations**
- Drilled Shaft
- Tiedback
- Soil Nail

**Cut/Fill Situations**
- MSE with Shoring
- Spread Footing with Shoring
- Hybrid – Soil Nail/MSE
Wall Usage by TxDOT
(August 2010 through September 2011)
<table>
<thead>
<tr>
<th>Wall Type</th>
<th>Area (ft²)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSE</td>
<td>3,196,417</td>
<td>72</td>
</tr>
<tr>
<td>Concrete block (no r/f)</td>
<td>47,791</td>
<td>1</td>
</tr>
<tr>
<td>Cantilever drilled shaft</td>
<td>72,286</td>
<td>2</td>
</tr>
<tr>
<td>Soil Nailed</td>
<td>146,793</td>
<td>3</td>
</tr>
<tr>
<td>Rock Nailed</td>
<td>197,216</td>
<td>5</td>
</tr>
<tr>
<td>Tied-back</td>
<td>161,827</td>
<td>4</td>
</tr>
<tr>
<td>Spread footing</td>
<td>505,019</td>
<td>12</td>
</tr>
<tr>
<td>Other</td>
<td>22,389</td>
<td>1</td>
</tr>
</tbody>
</table>
Responsibility

The Project Engineer (Designer of Record) must ensure that the retaining wall system (design) selected for a given location is appropriate.
MSEW Construction Project Development

- External Stability Check by TXDOT or Consultant
  - Sliding
  - Limiting Eccentricity
  - Bearing Capacity
  - Global Stability
  - Settlement

- Internal Stability Check by Vendor
  - Tensile Resistance
  - Pullout Resistance
  - Face Element
  - Face Element Connection

- MSEW reinforcement and wall type is NOT specified at project bidding stage
MSEW Construction Project Development

- External Stability Check by TXDOT or Consultant
  - Sliding – $FS \geq 1.5$
  - Limiting Eccentricity – $e \leq \frac{B}{6}$
  - Bearing Capacity – $FS \geq 2.0$
  - Global Stability – $FS \geq 1.3$
  - Settlement
## Assumed Soil Parameters (External Analysis)

<table>
<thead>
<tr>
<th>Material</th>
<th>Short-term</th>
<th>Long-term</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$c$ (psf)</td>
<td>$\phi$ (°)</td>
</tr>
<tr>
<td>Reinforced fill</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type A,B,D</td>
<td>0</td>
<td>34</td>
</tr>
<tr>
<td>Type C</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>Retained backfill</td>
<td></td>
<td></td>
</tr>
<tr>
<td>controlled fill, PI&lt;30</td>
<td>750</td>
<td>0</td>
</tr>
<tr>
<td>Foundation soil (Fill)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>controlled fill, PI&lt;30</td>
<td>750</td>
<td>0</td>
</tr>
</tbody>
</table>
Principal Modes of Failure - External

Figure 21. Potential external failure mechanisms for a MSE wall.
Principal Modes of Failure - External

Figure 21. Potential external failure mechanisms for a MSE wall.
External Stability - Sliding

FS – Sliding = \( \frac{V_1 \cdot \tan(\phi)}{F_1 + F_2} \)

105/125 = 0.84 or a 16% reduction in sliding resistance
Sliding Analysis

\[ W = (20')(14)(125 \text{pcf}) = 35,000 \text{ lb} = 35 \text{ kips} \]

\[ F_r = (0.33)(20')(125) = 8250 \text{ lb} = 8.25 \text{ kips} \]

\[ F_z = (0.33)(20')(250 \text{ psf}) = 1650 \text{ lb} = 1.65 \text{ kips} \]

\[ \text{Factor of Safety} = \frac{\text{Resisting}}{\text{Driving}} = \frac{35 \text{ kips} \times (\cos (30))}{8.25 \text{ kips} + 1.65 \text{ kips}} \]

\[ = \frac{20.2 \text{ kips}}{9.9 \text{ kips}} = 2.04 > 1.5 \text{ OK} \]
Sliding Analysis

\[ W = \left( \frac{35 \text{kips}}{125 \text{psf}} \right) \left( 105 \text{psf} \right) = 29.4 \text{kips} \]

\[ F.S. = \frac{29.4 \text{kips} \left( \tan(30) \right)}{9.9 \text{kips}} = 1.71 > 1.5 \quad \text{But less than 2.04} \]

If we want an equivalent F.S., as for \( \gamma = 125 \text{psf} \) \( B \) would need to be:

\[ (20') \left( B \right) \left( 105 \text{psf} \right) \left( \tan(30) \right) = 2.04 \]

\[ B = 16.7' \quad \text{or} \quad 0.84 \text{H} \]
We find that the sliding analysis is very sensitive to the unit weight in both the resisting and driving zones and to the coefficient of friction utilized at the base of the wall.
Principal Modes of Failure - External

(a) Sliding
(b) Overturning (eccentricity)
(c) Bearing capacity
(d) Deep seated stability (Rotational)

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

• Stability of every wall must be evaluated
• Short-term and Long-term conditions (make sure that the soil strengths used in analysis are valid for the given soil profile).
Soil Characteristics

If the site investigation and geotechnical analysis results in design parameters that are different from those shown on the RW(MSE) standard, minimum factors of safety for the principle external modes of failure and a ground improvement strategy is not employed that would improve strength values to meet or exceed design parameters shown on the standard, the design strengths must be communicated to the wall supplier. This can be accomplished by plan note or a modified standard reflecting lower strengths as applicable.
DETERMINATION OF THE UNDRAINED SHEAR STRENGTH OF FINE GRAINED SOILS

Short Term Analysis

- TEXAS CONE PENETROMETER
- UNDRAINED TRIAXIAL TESTING
- IN-SITU VANE SHEAR TESTING
- DIRECT SHEAR TESTING
Texas Cone Penetrometer - TCP
DETERMINATION OF THE UNDRAINED SHEAR STRENGTH OF FINE GRAINED SOILS

- TEXAS CONE PENETROMETER
- Revised Correlation for blow counts less than 15 blows/12”, CTR Research Project 0-5824

\[ Su = 300 + 60 \text{(blow count)} \]
TRIAXIAL TESTING

ADVANTAGES
• Long history of use in engineering practice
• Soil sample is retrieved
• Principle stresses are known
• Stresses can be varied to simulate the burial conditions in the field

DISADVANTAGES
• Test and Equipment are expensive
• Test is complicated
• Need a fair amount of soil for testing
• Results can vary due to:
  - End restraint conditions
  - Sample disturbance
IN-SITU VANE SHEAR TESTING

ADVANTAGES
- Rapid, simple, and inexpensive test
- Long history of use in engineering practice
- Reproducible results in homogeneous fine grained soils
- Minimal soil disturbance
- Yields the peak and residual undrained shear strength of fine grained soils

DISADVANTAGES
- No sample is recovered
- Limited to soft to medium stiff fine grained soils
- Results can be affected by roots, shells, gravel, sand seams, and lenses
SHORT TERM GLOBAL STABILITY ANALYSIS BASED ON APPROPRIATE SHEAR STRENGTH

FS = 1.45

C = 2000 psf, \( \phi = 0^\circ \)
C = 1200 psf, \( \phi = 0^\circ \)
C = 1000 psf, \( \phi = 0^\circ \)
C = 750 psf, \( \phi = 0^\circ \)
C = 2000 psf, \( \phi = 34^\circ \)
DETERMINATION OF THE DRAINED SHEAR STRENGTH OF FINE GRAINED SOILS

Long Term Analysis

- Consolidated Undrained TRIAXIAL Test with Pore Pressure measurements.

- P.I. Correlation
ADVANTAGES

- Long history of use in engineering practice
- Soil sample is retrieved
- Principle stresses are known
- Stresses can be varied to simulate the burial conditions in the field

DISADVANTAGES

- Test and Equipment are expensive
- Test is complicated
- Testing Takes Time.
- Need a fair amount of soil for testing
- Results can vary due to:
  - End restraint conditions
  - Sample disturbance
CU Triaxial Test Results

MULTISTAGE UNDRAINED TRIAXIAL COMPRESSION TEST
(ISOTROPICALLY CONSOLIDATED)

MOHR’S CIRCLES — DIAGRAM FOR: EFFECTIVE SHEAR STRESS
BORING: B-A2 — DEPTH: 6.5–8.0'

Cohesion Intercept = 2.3 psi (330 psf)

Phi = 29 degrees

Note:
1.) Initial W/C= 50 %
2.) Final W/C= 31 %
3.) HP= 2.0 TSP
4.) Dry Density= 93pcf
5.) Clay Type: Dusty Brown Clay

DATE OF TEST: 6/1/10
P.I. Strength Correlation

**ADVANTAGES**
- Quick
- History of use in engineering practice
- Various studies have contributed to the correlation charts.

**DISADVANTAGES**
- Correlation, does not take into account secondary structure of materials.
- Indirect measure of soil shear strength.
- Uncertainty in correlation.
- Cohesive component is unknown.
Fig. 11.27  Empirical correlation between $\phi'$ and PI from triaxial compression tests on normally consolidated undisturbed clays (after U.S. Navy, 1971, and Ladd, et al., 1977).
Long Term GLOBAL STABILITY ANALYSIS BASED ON APPROPRIATE SHEAR STRENGTH

FS = 1.35

C = 2000 psf, $\phi = 34^\circ$

C = 50 psf, $\phi = 30^\circ$

C = 60 psf, $\phi = 29^\circ$

C = 70 psf, $\phi = 30^\circ$

C = 2200 psf, $\phi = 0^\circ$
Principal Modes of Failure - External

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

POOR PREPARATION OF RETAINING WALL FOUNDATION SOILS
MSE Wall
W/Fill
and Ground Improvement
Foundation Settlement
Ground Water Table
Wall Drainage
Special Design Considerations

• Ground Improvement
  – Remove and Replace
  – Stone Columns
  – Rammed Aggregate Piers
Pile Supported Embankment
Stone Columns/Geopiers

- Stone Columns
- Geosynthetic Reinforcement
- MSE Wall Select Backfill
Remove and Replace/Wick Drains
Remove and Replace – Reinforced Pad

**Partial Plan - Wall 4**

- Limits of Geogrid Reinforcement
- Limits of WSE Reinforcement
- Underdrain

**Partial Elevation - Wall 4**

- Begin Wall 4
- Sta. 1+00.00
- Sta. 1+16.32
- Sta. 1+38.91
- Geogrid Reinforced Pad
- Geogrid Reinforcement

**General Notes**

- Stabilized Pad to be constructed under Wall 4 between Sta. 1+16.32 to Sta. 1+38.91. Pad to be composed of cohesive material suitably placed and compacted to the required yield strength and reinforced with the type of geogrid reinforcement. Geogrid to be installed with appropriate set of equipment and have a minimum UTS of 1500 psi/ft.
- Geogrid to be placed 10" off the top and bottom of stabilized pad.
- Underdrain pipe to be placed on the lower portion of WSE wall and tied off at STA 1+16.32 and 1+38.91.
- Run underdrain back into strip of retaining wall from Sta. 1+00 to Sta. 1+38.91-195. The underdrain is then to run down slope for 10° min.

**Estimated Quantities**

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>SELECT FILL (Stabilized Pad)</td>
<td>CY: 29</td>
</tr>
<tr>
<td>GEOREINFORCED</td>
<td>CY: 43</td>
</tr>
</tbody>
</table>

**Stabilized Pad Typical Section**

- Wall 4
- Retained fill
- Reinforced volume
- Underdrain
- Geogrid reinforcement
- Slope pad to drain to underdrain
CONCLUSIONS

• TxDOT has designed and constructed numerous MSE retaining walls.

• In spite of the increased usage, TxDOT has had relatively few retaining wall failures.

• The design and planning phase of retaining walls is critical and must address the actual site conditions, including soil and loading, that the wall will be subjected to.

• If values in the analysis of the wall (i.e. friction angle for both the retained and foundation soils) are less than that shown on the RW(MSE) standard and do not result in a ground improvement that would positively impact these values, the designer of record should include the soil strength information in the plan set for use by the wall supplier.
QUESTIONS?
Ground Conditions

- Soil Shear Strength
  - Short Term, C and phi
  - Long Term, C’ and phi’
- Ground Water Table
- Necessary Fill
- Necessary Cut
MSE Principal Modes of Failure
LOSS OF MSE BACKFILL
Obstructions
Obstructions
Incomplete connection with locking rod.

Soil reinforcing mat is rotated by wedging to the back of panel. This prevents bearing of the grid to the locking rod allowing potential of movement on the right side of the panel.
Obstructions
Omitted
Reinforcement
P.I. Strength Correlation

![Graph showing the correlation between Plasticity Index (PI) and the angle of internal friction (\(\phi\), both in degrees). The graph includes a line indicating the drained shear angle of internal friction (\(\phi_d\)) for normally consolidated and remolded clays, and a vertical line at a certain PI indicating the residual strength angle of internal friction (\(\phi_r\)).]
Design Considerations

vs

Special Design Considerations
TEW WALL
Dissimilar Earth Reinforcement
TEW WALL