Mechanically Stabilized Embankment (Caltrans Pre-Designed)

This module presents Caltrans practice for the geotechnical investigation, design, and reporting for Mechanically Stabilized Embankments (MSE). The AASHTO LRFD Bridge Design Specifications describe MSE as:

> *"Mechanically Stabilized Earth (MSE) systems, whose elements may be proprietary, employ either metallic (strip or grid type) or geosynthetic (geotextile, strip, or geogrid) tensile reinforcements in the soil mass, and a facing element which is vertical or near vertical."*

MSE are defined as having a face inclination of 70 degrees to vertical, whereas GRE are flatter than 70 degrees. MSE have a maximum vertical height of 50 feet.

This module addresses Caltrans pre-designed MSE, which must meet minimum requirements presented in the Design section of this module. It does not address MSE with geosynthetic reinforcement or Geosynthetic Reinforced Embankments (GRE). Refer to the MSE (Non-Standard) module for design of MSE that do not meet the criteria of this module.

When the Caltrans pre-designed MSE is shown on the Contract Plans, the Contractor has the option to construct a Proprietary Earth Retaining System (Caltrans Pre-approved Alternative Earth Retaining Systems).

The following terms are defined:

- Reinforced Soil: The material that contains the reinforcement.
- Retained Material: The material located behind or above the reinforced soil block.
- Foundation Material: The material located below the reinforced soil block.

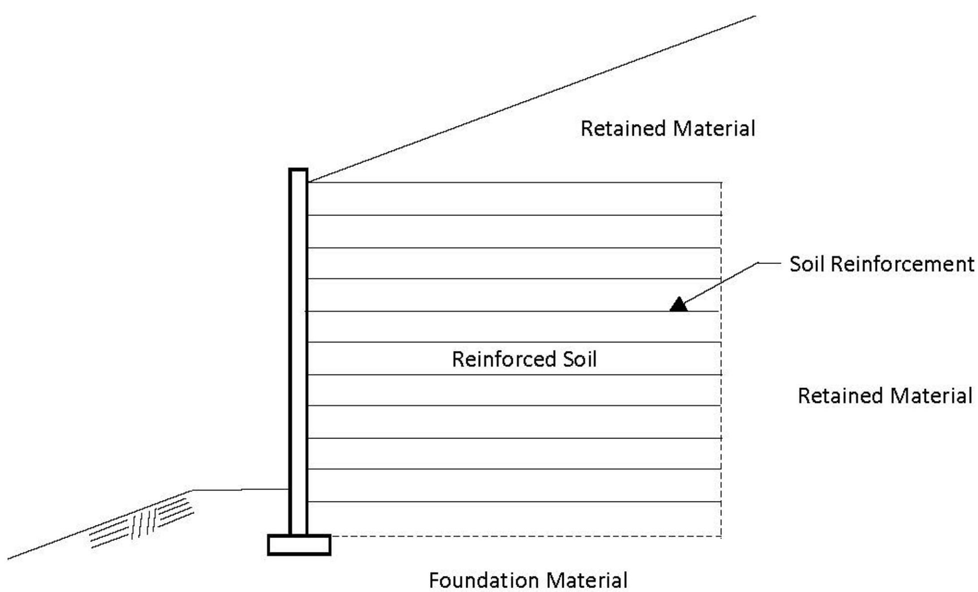

Figure 1: MSE

In addition to this module, the documents that govern or guide the investigation, design, and reporting for MSE include:

- AASHTO LRFD Bridge Design Specifications with California Amendments
- Caltrans Standard Specifications 47-2, *Mechanically Stabilized Embankment*
- Caltrans Bridge Standard Detail Sheets (XS-Sheets) Section 13
- Caltrans Bridge Design Aids (BDA) 3-8, *Mechanically Stabilized Embankments*
- Caltrans Memo to Designers (MTD) 5-19, *Earth Retaining Systems Communication*
- Caltrans Geotechnical Manual, *Foundation Reports for Earth Retaining Systems*

The Geoprofessional's role is to assist in all phases of project development as requested by the Structure Designer. This assistance may include: literature search, preliminary design, and type selection during the project planning or early design phase; field investigation, analyses, external MSE design, and design support during the project design phase; and construction support and possible retaining wall alterations due to project changes or unforeseen conditions discovered during the construction phase. The geotechnical effort must be documented and communicated in appropriate reports and memorandum.

Investigations

A geotechnical investigation must be conducted for all MSE. The goal of the investigation is to determine the distribution, properties, and behavior of the soil and rock that will affect MSE design and construction; the groundwater condition that will affect MSE design and construction; the distribution of unsuitable or weak materials requiring planned remedial measures; and the suitability of excavated soil to be used as reinforced soil, retained material, and/or foundation material.

The geotechnical investigation should provide information to evaluate the stability and performance of the MSE, which should include:

- Strength and unit weight of the reinforced soil, retained material, and foundation material
- Settlement characteristics of the foundation material
- Strength and unit weight of materials affecting slope stability
- Corrosion potential of materials in contact with the MSE
- Groundwater location and quantity of seepage

In some instances, the information obtained through a literature search (see *Geotechnical Investigations Module*) and field mapping will be sufficient for MSE design. Examples of such instances are MSE built in a sequence of sedimentary strata where nearby borings exist for the same sequence of sedimentary units, or walls founded on rock with abundant rock exposures and previous testing to sufficiently characterize the rock.

The Geoprofessional should develop a prudent exploration plan considering site constraints and available resources, and consider uncertainty and risk of not adequately investigating a location. The Geoprofessional should:

- Establish MSE layout and configuration as accurately as possible. Final layout and height may not be determined until late in the design phase.
- Perform a literature research to gather all relevant information related to site geology, strength of soils, and geologic hazards.
- Perform geologic field mapping of the site. The mapping should be sufficient to generate geologic cross sections at the MSE when combined with other terrain data, and to identify geologic hazards.
- Develop a subsurface exploration and laboratory testing plan to obtain information gathered through the literature research and field mapping. Locate exploratory borings or Cone Penetration Tests spaced at intervals of 100 to 200 feet along the proposed alignment, with borings strategically positioned in front, behind, and directly on the layout line. The number of borings necessary to delineate site conditions may be greatly reduced or increased due to the value of pre-existing data, uniformity of site geology, and the quality of site specific geologic mapping.
- Advance the subsurface exploration to an appropriate depth. The depth of exploration should generally extend below the foundation to the deepest of:
    - 15 feet
    - 2 times the height of the MSE
    - 4 times the base width
    - To the full depth of soft, loose, weak soils upon which wall stability and settlement is dependent
    - To a depth below where material strength and strain characteristics are acceptable
- Conduct Standard Penetration Tests (SPT) at maximum intervals of 5 feet. Closer intervals of SPT testing should be considered within a depth of 2 times the base width below the proposed reinforced zone (the zone of greatest bearing loads), and where soil strength properties are projected to be low and/or highly varied, such as poorly compacted fill or soft/loose alluvial soils.
- Gather all information necessary to evaluate the stability of permanent and temporary excavations and cut slopes that will influence design and construction of the MSE.
- Estimate soil strengths based on index properties established through SPT correlations, pocket penetrometer, torvane, and CPT (see *Correlations Module*). Perform laboratory strength tests when correlation-based strengths are borderline acceptable or unacceptable, or otherwise questionable.
- For MSE founded on rock, strengths may be sufficiently estimated by reviewing data developed for similar rock on nearby projects. Perform laboratory strength testing as necessary to confirm that the rock meets the minimum strength requirements, or if rock excavation is anticipated.
- Conduct consolidation testing of clay soils wherever settlement magnitude and rate are project considerations.

- Sample and test potential borrow sites and cut locations to determine if the material satisfies gradation and/or corrosion criteria for the reinforced soil (SS47-2.02C), retained material, and foundation material.

Design Procedures

MSE are designed through a coordinated effort between the Geoprofessional and the Structure Designer. Refer to *Caltrans Memo to Designers 5-19, Earth Retaining Systems Communication* for the communication protocol between the Structure Designer and Geoprofessional. MTD 5-19 provides tables to facilitate communication between the Structure Designer and Geoprofessional.

Design of an MSE involves evaluation of:

(i) Service Limit State: Overall (Global) and Compound Stability, Settlement
(ii) Strength Limit State:
   a. External Stability: Bearing Resistance, Sliding, Limiting Eccentricity
   b. Internal Stability: Tensile and pullout resistance of reinforcement, structural resistance of face elements and connections
(iii) Extreme Limit State:
   a. External Stability: Overall (Global) and Compound Stability, Bearing Resistance, Sliding, Limiting Eccentricity
   b. Internal Stability: Tensile and pullout resistance of reinforcement, structural resistance of face elements and connections
(iv) Additional considerations, such as corrosion, drainage, traffic barriers, and facing elements.
(v) Geologic Hazards

For a Caltrans pre-designed MSE the Geoprofessional is responsible for:

(i) Service Limit State: Overall (Global) and Compound Stability, Settlement
(ii) Strength Limit State: Bearing Resistance
(iii) Extreme Limit State: Overall (Global) and Compound Stability, Bearing Resistance
(iv) Drainage, Corrosion sampling and testing
(v) Geologic Hazards

For a Caltrans pre-designed MSE the Structure Designer is responsible for:

(i) Service Limit State: Total Permissible Settlement
(ii) Strength Limit State:
   a. External Stability: Sliding, Limiting Eccentricity
   b. Internal Stability: Tensile and pullout resistance of reinforcement, structural resistance of face elements and connections
(iii) Extreme Limit State:
   a. External Stability: Sliding, Limiting Eccentricity
   b. Internal Stability: Tensile and pullout resistance of reinforcement, structural resistance of face elements and connections

(iv) Additional considerations, such as corrosion, drainage, traffic barriers, and facing elements.
(v) Scour elevation

The geotechnical parameters shown in the Caltrans Bridge Standard Detail Sheets (XS-Sheets) are as follows:

- Internal Design: Friction Angle (ϕ) = 34°, Unit Weight (γ) = 120 pcf
- External Design: ϕ (retained backfill) = 30°, γ = 120 pcf
- ϕ (foundation) = 30°
- Horizontal Seismic Coefficient (k_h) = 0.2

Typical factors that would disqualify use of the Caltrans pre-designed MSE include:

- Use of reinforced soil that does not meet the requirements of either SS47-2.02C or those shown on the XS-Sheets.
- External loading that exceeds those used in the Caltrans pre-designed MSE.
- Bearing resistance and/or overall stability requirements cannot be met.
- Where the k_h is greater than 0.2. Caltrans practice is to calculate k_h as 1/3 PGA (PGA is the horizontal peak ground acceleration).

<u>Overall (Global) and Compound Stability</u>

Perform static stability analyses (Service Limit State) and pseudo-static stability analyses (Extreme Limit State) using the parameters of the foundation material, reinforced soil, reinforcement, and retained material, and the anticipated groundwater surface. The analysis should include evaluation of failure surfaces behind the MSE, through the MSE (compound), and beneath the MSE (AASHTO Fig. 11.10.2-1, Fig. 11.10.4.3-1). For overall stability, the reinforced soil mass can be modeled as a block, using a high cohesion value to force the failure surfaces behind the MSE.

Perform the pseudo-static slope stability analysis using a k_h = 1/3 PGA.

The calculated resistance factor (□), the inverse of the calculated factor of safety, must be less than the required resistance factor in AASHTO 11.6.2.3.

If overall stability cannot be satisfied, consider:

(i) Increasing the reinforcement length
(ii) Lowering the foundation elevation
(iii) Ground improvement

Settlement

Calculate settlement using the vertical bearing stress and effective footing width for the Service Limit State (BDA 3-8, Attachment 2). Use a LRFD Resistance Factor (□) of 1.0 for all settlement calculations (AASHTO 10.5.5.1). Settlement magnitudes greater than the total permissible settlement should be discussed with the Structure Designer (MTD 5-19, Attachment 3).

- Cohesionless Soils: Use the Hough method or the elastic half-space method (AASHTO 10.6.2.4.2). As both methods can be overly conservative, calculate settlement using both methods prior to considering ground improvement or alternative wall types.
- Cohesive Soils: Use AASHTO (10.6.2.4.3).
- Rock: Use AASHTO (10.6.2.4.4). For foundations on sloping ground, make appropriate reductions in overburden stresses.

Bearing Resistance

Calculate bearing resistance of soil using the bearing capacity equation (AASHTO 10.6.3.1.2) and the effective footing widths (BDA 3-8, Attachment 2). Use a resistance factor (ϕ) of 0.45 to 0.55 for the Strength Limit State, and 1.0 for the Extreme Limit State. Adjust the bearing capacity equation as necessary to account for sloping ground conditions (AASHTO 10.6.3.1.2c). The factored bearing resistance must be greater than or equal to the vertical bearing stress found in BDA 3-8, Attachment 2. The methods discussed above may also be used for design in Intermediate Geomaterial or weak rock that behaves like a very dense or hard soil. For more competent rock, calculate bearing resistance on rock using AASHTO 10.6.3.2.

In cases where unacceptable settlements are predicted, or low bearing resistance results from the presence of near-surface loose, soft, or non-uniform materials, consider removing the inadequate material and recompacting it, or replacing it with structure backfill.

Drainage

Drainage details and considerations are presented in BDA 3-8 and the Bridge Standard Detail Sheets (XS-Sheets). Evaluate the surface water drainage and provide recommendations to direct water away from the MSE.

Evaluate the potential for groundwater flow into the reinforced soil mass and retained backfill, and select either the 8-inch corrugated perforated plastic pipe or the 4-inch (or larger) smooth-walled perforated rigid plastic pipe. Select the flexible pipe when differential settlement is anticipated. Specify chimney drains or drainage blankets as necessary to supplement the underdrain system (AASHTO 11.10.8).

Where a potential for inundation of the MSE system exists specify a rapidly-draining reinforced soil by modifying the gradation requirements for Structure Backfill (SS47-2.02C).

Do not allow drainage systems from temporary shoring or surface drainage to be combined with the MSE underdrain system.

Geologic Hazards

The design must also account for geologic hazards such as:

- Liquefaction, Lateral Spreading: The estimated seismic settlement and/or displacement should be communicated to the Structure Designer and Project Engineer to determine acceptability. Unacceptable displacement might be reduced using remove and replace or ground improvement methods.
- Landslides: Lateral thrust forces from landslides should be calculated and provided to the Structure Designer for analysis of adequacy of the Caltrans pre-designed system.
- Scour: MSE may be constructed adjacent to a watercourse provided that the top of footing is located at least two feet below the total scour elevation (AASHTO 11.10.2.2).

Reporting

Caltrans pre-designed MSE recommendations must be reported in accordance with *Foundation Reports for Earth Retaining Systems* and the requirements herein.

Geotechnical recommendations Caltrans pre-designed MSE must include the following:

- Soil and/or rock parameters (unit weight, friction angle and cohesion for soil, and unit weight and shear strength of the rock mass). This applies to the foundation material, reinforced soil, and retained materials.
- Suitability of on-site material for use as foundation material, reinforced soil, and retained materials.
- Factored bearing resistances (strength and extreme event limit states)
- Total and differential settlement as a result of application of the vertical bearing stress (service limit state). Differential settlement should be examined both along the alignment of the MSE and between the front and back of the MSE.
- Effects of MSE construction on adjacent ground and/or existing structures, utilities and other structures, both above and below ground.
- Calculated resistance factor for overall (global) and local stability (service and extreme event limit states). Provide the method of analysis.
- Susceptibility of foundation material to erosion and recommended mitigation.
- Seismic stability of foundation material: seismic settlement, liquefaction impacts to overall stability (including estimated permanent lateral displacement) and bearing resistance. Provide recommended mitigation measures.
- Discuss the groundwater condition anticipated over the design life of the MSE, and requirements for a blanket drain located behind the reinforced soil block. Describe the drainage system location and configuration. Reference the Standard Specifications for permeable material and geosynthetic filter fabric type.
- Corrosiveness of foundation material, retained material, and water sources.
- Foundation improvements required to meet geotechnical design objectives, such as sub-excavation, foundation preloading, and surcharge delay periods.
- The minimum embedment depth to account for erosion, overall stability, bearing resistance, scour, and settlement.
- Minimum base width to meet overall stability requirements.

Provide the following tables:

Design Data for MSE XX

MSE Station (feet)	Design Height (H) (feet)	Bottom of Leveling Pad Elevation (feet)	Base Width (B) (feet)	Minimum Embedment Depth (feet)

Foundation Data for MSE XX

MSE Station	Service Limit State			Strength Limit State			Extreme Limit State		
	Service Limit State, Effective Base Width[1] (feet)	Service Limit State, Vertical Bearing Stress[1] (psf)	Service Limit State, Calculated Settlement at Vertical Bearing Stress2 (inch)	Strength Limit State, Effective Base Width[1] (feet)	Strength Limit State, Vertical Bearing Stress[1] (psf)	Strength Limit State, Factored Bearing Resistance (ϕ = __) (psf)	Extreme Limit State, Effective Base Width1 (feet)	Extreme Limit State, Vertical Bearing Stress[1] (psf)	Extreme Limit State, Factored Bearing Resistance (ϕ = __) (psf)

1. BDA 3-8, Attachment 2
2. Total Permissible Settlement = YY (provided by Structure Designer)

References

1. AASHTO LRFD Bridge Design Specifications with California Amendments
2. Caltrans Standard Specifications 47-2, *Mechanically Stabilized Embankment*
3. Caltrans Bridge Standard Detail Sheets (XS Sheets), Section 13
4. Caltrans Bridge Design Aids (BDA) 3-8, *Mechanically Stabilized Embankments*
5. Caltrans Memo to Designers (MTD)
    - MTD 5-19, *Earth Retaining Systems Communication*
    - MTD 5-5, *Design Criteria of Standard Earth Retaining System*s
6. Caltrans Geotechnical Manual
    - *Foundation Reports for Earth Retaining Systems*
    - *Geotechnical Investigations*
7. FHWA-NHI-10-024 and 025, *Geotechnical Engineering Circular No. 11 - Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*
    - Volume I
    - Volume II
8. FHWA-NHI-09-087, *Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Slopes*