Mechanically Stabilized Embankments

This module presents Caltrans practice for the geotechnical investigation, design, and reporting for Mechanically Stabilized Embankments (MSE). A mechanically stabilized embankment (MSE) consists of facing, tensile reinforcements, and reinforced soil. The facing can be precast concrete panels, modular blocks, wire mesh etc. The tensile reinforcements can be either metallic (e.g., strip, grid, wire mesh mat) or geosynthetic (e.g., strip, grid, sheet). Caltrans standard MSE uses wire mesh as the tensile reinforcement and standard precast concrete panels as the facing. MSE are defined as having a face inclination of 70 degrees to vertical.

The following terms are defined (Figure 1):

- 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.

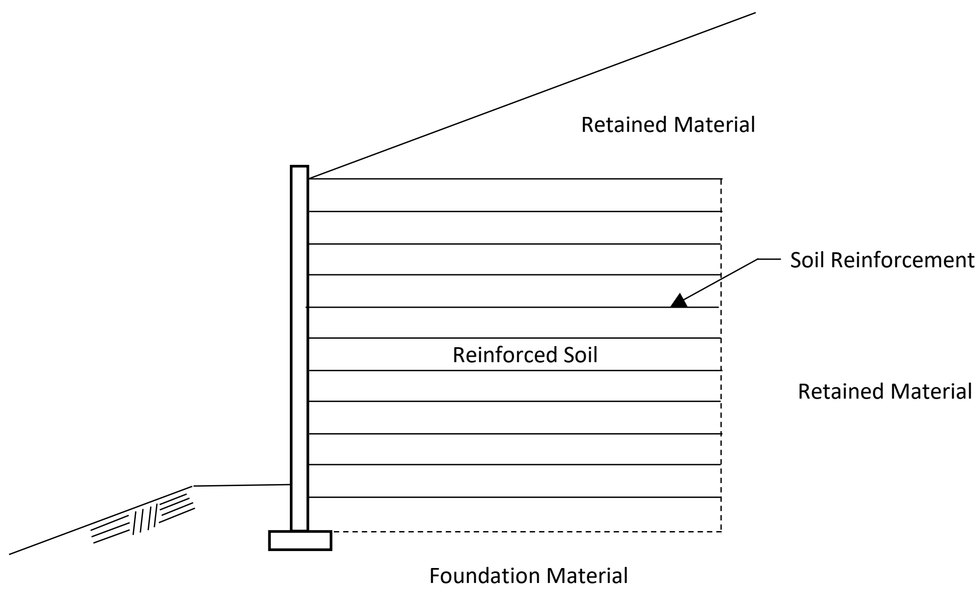

Figure 1: MSE

This module addresses both Caltrans pre-designed MSE and special-designed MSE. A pre-designed MSE conforms with Section 13 of *Bridge Standard Details (XS Sheets)*, and Section 3.8 of *Bridge Design Aids,* and uses a standard welded wire mat for reinforcement and a standard precast concrete panel for facing. 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).

An MSE requires special design when:

- Design parameters, load cases, and wall geometry do not meet the design parameters presented in Section 13 of *Bridge Standard Details (XS Sheets)*, and Section 3.8 of *Bridge Design Aids.* The geotechnical parameters shown in the XS-Sheets are:
    - 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
- Tensile reinforcements other than the standard welded wire mat are used.
- Facing elements other than standard precast concrete facing panels are used.
- Use of reinforced soil that does not meet the requirements of either SS47-2.02C or those shown on the XS-Sheets.
- 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).

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
- Standard Specifications 47-2, Mechanically Stabilized Embankment
- Bridge Standard Detail Sheets (XS-Sheets) Section 13
- Bridge Design Aids (BDA) 3-8, Mechanically Stabilized Embankments
- Memo to Designers (MTD) 5-19, Earth Retaining Systems Communication
- Geotechnical Manual
    - Seismic Design of Earth Retaining Systems
    - Overall Stability of Earth Retaining Systems
    - Foundation Reports for Earth Retaining Systems

Investigation

Refer to the *Geotechnical Investigations* module for general instructions on performing the planning-phase site investigation (e.g., literature review, site visit) and the design-phase site investigation (e.g., site visit, selection of investigative methods, locations, and depths). In some instances, the information obtained through a literature search 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 geotechnical investigation should provide information to evaluate the stability and performance of the MSE, which should include:

- Strength and unit weight of the (1) reinforced soil, (2) retained material, and (3) 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.
- Design Groundwater
- Suitability of excavated soil to be used as reinforced soil, retained material, and/or foundation material.

The Geoprofessional should:

- Perform geologic field mapping of the wall site. The mapping should be sufficient to generate geologic cross sections along the retaining wall alignment when combined with other terrain data.
- Develop a subsurface exploration and laboratory testing plan to supplement information gathered through the literature search and field mapping. Locate exploratory borings or Cone Penetration Tests at intervals of 100 to 200 feet along the proposed alignment, with borings positioned in front, behind, and directly on the layout line.
- Advance the subsurface exploration to the deepest of:
    - 15 feet
    - 2 times the height of the MSE
    - 4 times the base width
    - the full depth of soft, loose, weak soils upon which wall stability and settlement is dependent.
    - 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 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 on saturated clay (e.g., very soft, soft, medium stiff)

Roles and Responsibilities (Pre-designed MSE)

Refer to *Caltrans Memo to Designers 5-19, Earth Retaining Systems Communication* for the communication protocol between the Structure Designer and Geoprofessional.

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:

1. Service Limit State: Total Permissible Settlement
2. 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
3. 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
4. Additional considerations, such as corrosion, drainage, traffic barriers, and facing elements.
5. Scour elevation

Roles and Responsibilities (Special-Design MSE)

Geotechnical Services’ responsibilities in the design of special-design MSE are:

- Develop interpreted subsurface cross sections. For a long wall, several subsurface cross sections along the alignment may be needed.
- Determine engineering properties such as unit weight, cohesion, friction angle, and associated lateral earth pressure coefficients.
- Analyze the magnitude and distribution of lateral earth pressure for complex wall geometries when conventional earth pressure theories are not applicable or when requested by the structure designer.
- Analyze the minimum horizonal reinforcement length (base width) based on global stability requirements and bearing capacity requirements at the wall base.
- Determine the bearing capacity and settlement at the wall base.

Information that should be provided by the structure designer over the course of special-design MSE investigation and design are:

- Plans showing the location of wall (begin and end, length, alignment)
- Elevation view of wall (maximum and minimum design height)
- Cross sections of wall (for example, every 10 to 50 feet)
- Bottom of MSE leveling pad elevation
- Base width
- Effective base width for service, strength, and extreme limit states
- Vertical bearing stress for service, strength, and extreme limit states

Design Procedures

The geotechnical design of MSE must meet displacement and stability requirements for following limit states:

- Service Limit State: Movement and Global Stability (AASHTO 11.10.4).
- Strength Limit State: Bearing Resistance under Safety against Soil Failure (External Stability) (AASHTO 11.10.5.4).
- Extreme Limit State: Bearing Resistance and Global Stability (AASHTO 11.10.7).

For each of the limit states, load and resistance factors should be applied in accordance with AASHTO 3.4.1 (Table 3.4.1-1) and 11.5.6 and *California Amendments* (Tables 3.4.1-1 and 11.5.7-1).

Assist the Structure Designer in estimating all applicable lateral pressures including static and seismic earth pressure, surcharge load induced earth pressure, and hydrostatic pressure. For the estimation of lateral pressures, refer to AASHTO 11.10.5.2, 11.10.10, 11.6.5 and 11.10.7.

For the seismic design of MSE, use 1/3 horizontal peak ground acceleration (HPGA) for the horizontal acceleration coefficient (k_h) if they can tolerate the expected mean seismic displacement of 5.0 inches during seismic event. The HPGA is the peak ground acceleration (PGA) calculated using Caltrans ARS online (v.2.3.09), which is the acceleration at zero period (T=0 second). If the MSE cannot tolerate the expected mean seismic displacement of 5.0 inches or sliding stability at wall base is not satisfied by using the 1/3 HPGA, consult the Structure Designer for tolerable seismic displacement of the MSE, and assist the Structure Designer in calculating k_h. The k_h based on the tolerable permanent seismic displacement should be used for the seismic design.

Service Limit State

Displacement

The design must ensure that the vertical and lateral displacement does not affect the performance of the wall. As the MSE is a flexible system, it can accommodate greater settlement than a typical retaining wall. As a rule of thumb, a total vertical settlement of about 6 inches is considered acceptable. For the calculation of settlement, refer to AASHTO 10.6.2.4.2, 10.6.2.4.3 and 11.10.4.1. For the tolerable limits of differential settlement, refer to AASHTO 11.10.4.1, and verify with the Project Development Team.

Global Stability

The global stability is evaluated using limit equilibrium (LE) slope stability analysis such as Morgenstern-Price, Modified Bishop, Janbu, or Spencer methods. For the global stability analysis and resistance factors, refer to AASHTO 11.10.4.3 and 11.6.2.3, and Figure 11.10.4.3-1.

Strength Limit State

Bearing Resistance

For the bearing resistance, refer to AASHTO 11.10.5.4, 10.6.3.1 and 10.6.3.2. When calculating the bearing resistance, use the effective footing width, and a resistance factor of 0.65 (Table 11.5.7-1 of *California Amendments*). If there is downward sloping ground near or adjacent to the MSE, adjust the bearing capacity equation as necessary to account for sloping ground conditions according to AASHTO 10.6.3.1.2c.

Extreme Limit State

Bearing Resistance

For the seismic bearing resistance, refer to AASHTO 11.5.8, 11.10.7.1, 11.10.5.4, 10.6.3.1 and 10.6.3.2. When calculating the bearing resistance, use the effective footing width, and a resistance factor of 0.9 (AASHTO 11.5.8). If there is downward sloping ground near or adjacent to the MSE, adjust the bearing capacity equation as necessary to account for sloping ground conditions according to AASHTO 10.6.3.1.2c).

Seismic Global Stability

Refer to the *Geotechnical Seismic Design for ERS* module.

Reporting

Present MSE recommendations in accordance with the *Foundation Reports for Earth Retaining Systems* module.

Include the following in the *Analyses and Design* section of the Preliminary Foundation Report or Foundation Report:

1. Describe the representative cross-sectional geometry and ground line condition. Reference the plan sheets when possible.
2. Description of external loads (e.g., surcharge)
3. Design groundwater elevation.

Provide the following additional information for Special-design MSE:

4. Calculated resistance factor for overall global stability and local slope stability (service and extreme event limit states). Provide the method of analysis.
5. Differential settlement from the application of the vertical bearing stress (service limit state) along the alignment of the MSE and facing elements, and between the front and back of the MSE.
6. Effects of MSE construction on adjacent ground and/or existing structures, utilities, both above and below ground. Present related recommendations in the *Recommendations* section.

Include the following in the *Recommendations* section of the Preliminary Foundation Report or Foundation Report:

1. Standard Design MSE: Provide a statement that the geotechnical conditions at the site meet the requirements for pre-designed MSE.
2. Seismic hazard recommendations required in the following modules, as applicable:
    a. Fault Rupture
    b. Liquefaction Evaluation
    c. Lateral Spreading
    d. Seismic Design for ERS (for seismic global stability)
3. Provide mitigation recommendations for specific seismic hazards identified in #1 when requested by Bridge Design.
4. Foundation improvements required to meet geotechnical design objectives, such as sub-excavation, foundation preloading and surcharge delay periods.

Include the following additional recommendations for special-design MSE:

5. Soil and/or rock parameters used to develop the earth pressures. Provide parameters for short-term and long-term design. Use multiple tables if design parameters vary along the wall length.

ERS ID: Design Parameters for Earth Pressures (Station XX to Station YY)

Layer No.	Depth Below Top of Wall (ft)	Elevation (ft)	Group or Rock Name	Design Parameters
1	0			
2				
3				
4				

6. State the method used to determine the earth pressures and include the two following tables. The layers presented must match the layers presented in #5.

Table X: Active Lateral Earth Pressures

Layer	Depth Below Top of Wall (ft)	Unit Weight (pcf)	Vertical Stress (psf)	Active Static σ_h (psf)	Passive Static σ_h (psf)	Active Seismic σ_h (psf)	Passive Seismic σ_h (psf)
1							
2							
3							
4							

7. Minimum horizonal reinforcement length (base width) to meet global stability requirement. The minimum base width should not be less than 8 feet for uniform compaction and constructability and shall be greater than 70 percent of the wall height measured from the leveling pad (refer to AASHTO 11.10.2.1).
8. Minimum MSE facing embedment below finish grade to meet the requirement for erosion, future excavation, local stability and global stability (refer to AASHTO 11.10.2.2); according to *Caltrans Bridge Design Aid 3-8*, the embedment depth shall not be less than 10 percent of the design wall height with a minimum of 2 feet. A minimum horizontal bench width of 4 feet in front of wall is also recommended for walls founded on sloping ground.

9. Magnitude and distribution of static/seismic lateral earth pressure behind the reinforced soil mass if needed or requested.
10. Permissible net bearing stress corresponding to tolerable settlement (service limit state) or total settlement.
11. Horizontal acceleration coefficient (kh) and associated seismic displacement.

Provide the following tables for all MSE:

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		
	Effective Base Width[1] (feet)	Vertical Bearing Stress[1] (psf)	Calculated Settlement at Vertical Bearing Stress[2] (inch)	Effective Base Width[1] (feet)	Vertical Bearing Stress[1] (psf)	Factored Bearing Resistance (ϕ = 0.65) (psf)	Effective Base Width[1] (feet)	Vertical Bearing Stress[1] (psf)	Factored Bearing Resistance (ϕ = 0.9) (psf)

1. BDA 3-8, Attachment 2
2. Total Permissible Settlement = YY (provided by Bridge 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*