Mechanically Stabilized Embankments (Non-Standard)

A mechanically stabilized embankments (MSE) consists of facings, tensile reinforcements, and reinforced soils (Figure 1). The facings can be precast concrete panels, modular blocks, wire mesh etc., and tensile reinforcements can be either metallic (strip, grid or wire mesh mat) or geosynthetic (strip, grid or sheet). Caltrans standard MSE use wire mesh as the tensile reinforcements and standardized precast concrete panel as the facings.

An MSE is considered non-standard when:

- Design parameters, load cases, and wall geometry are outside of the design parameters presented in Section 13 of *Bridge Standard Details (XS Sheets)*, and Section 3.8 of *Bridge Design Aids*
- Tensile reinforcements other than welded wire mat are used such as steel strips, and geosynthetic
- Facing elements other than standardized precast concrete facing panels are used such as modular blocks, wire meshes etc.

Design and performance advantages of MSE include:

- Capable of tolerating greater total and differential settlements compared to conventional gravity retaining walls
- Cost effective in fill, especially for design wall heights greater than 10 feet

MSEs are not favorable when there are:

- Utilities or highway drainage located within the reinforced mass
- Flood plains or scour which can undermine the reinforced soil mass
- Underlying soft highly plastic clays; organic soils; collapsible soils; expansive soils

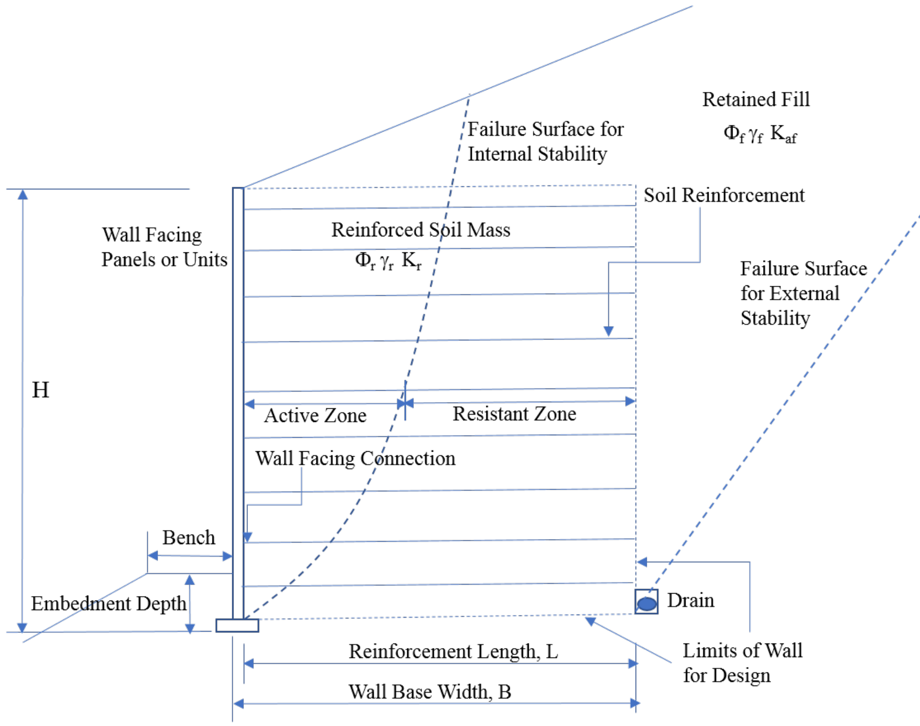

Figure 1: MSE Components and Dimensions (After AASHTO LRFD BDS, 2012)

References for Design and Reporting

Non-standard MSE design uses the same geotechnical analysis and design methodology of the standard MSE (i.e., settlement, bearing resistance and global stability). This is because the entire MSE, including all components, is modeled as a rigid block. Therefore, the “Mechanically Stabilized Embankment (Caltrans Pre-Designed)” module is applicable for the geotechnical design and analysis of non-standard MSE.

For MSE design, use this module, and:

- *AASHTO LRFD Bridge Design Specifications (BDS) with California Amendments*, hereafter AASHTO.
- *Geotechnical Manual,* “Mechanically Stabilized Embankment (Caltrans Pre-Design)”
- *Geotechnical Manual, “*Seismic Design of ERS”
- *Bridge Design Aids*, Section 3-8 “Mechanically Stabilized Embankments”
- *Memos to Designers 5-19*, “Earth Retaining Systems Communication”
- *Geotechnical Manual*, “Foundation Reports for Earth Retaining Systems”

For design cases where the guidance provided in the above documents is not applicable, refer to other FHWA reference manuals including *FHWA NHI-05-094*, “LRFD for Highway Substructures and Earth Retaining Structure” *or FHWA NHI-10-024* “Design and

Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volumes 1 and 2”.

Responsibilities for Design

Geotechnical Services’ responsibilities in the design of non-standard 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 non-standard MSE investigation and design are:

- Plans showing the location of wall (begin and end, length and 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

Investigations

The geotechnical investigation for a non-standard MSE should follow the *Investigations* section of the *Mechanically Stabilized Embankment (Caltrans Pre-Designed)* module.

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).

The Geoprofessional should 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 of MSE.

Service Limit State

Displacement

The design of the MSE 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 consult with the structure designer.

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 of MSE, 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 of MSE, 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

For the seismic global stability, use AASHTO 11.10.4.3 with a resistance factor of 1.0 and a k_h of 1/3 HPGA. If the seismic global stability is not satisfied with the k_h of 1/3 HPGA or the expected mean seismic displacement of 5.0 inches is not acceptable for MSE, use the following steps:

1. Find the horizontal yield acceleration coefficient (k_y) using iterative LE slope stability analyses.
2. Perform seismic displacement analysis using simplified seismic displacement method according to AASHTO A11.
3. Consult the structure designer for calculated and tolerable seismic displacement.

Reporting

Prepare the report in accordance with *Foundation Reports for Earth Retaining Systems.* Include geotechnical design data provided by the SD and foundation recommendations as listed below.

When construction specifications related to project-specific geotechnical design and/or recommendations for non-standard MSE are not addressed in the Standard Specifications, provide the information and instructions in the *Notes for Specifications* section of the foundation report. For the information and guidance on the geotechnical related Standard and Non-Standard Special Provisions, refer to the *Geotechnical Notes for Specifications* module.

Recommendations

- Soil and rock soil properties (unit weight, cohesion and friction angle for soil and unit weight and shear strength of rock mass). This applies to foundation soils and retained soils behind the reinforced soil mass. Foundation soil/rock properties can be used for sliding stability check and soil properties for the retained soils behind the reinforced soil mass can be used for the calculation of lateral earth pressure.
- Magnitude and distribution of static/seismic lateral earth pressure behind the reinforced soil mass if needed or requested
- Factored bearing resistance for strength and extreme limit states
- Permissible net bearing stress corresponding to tolerable settlement (service limit state) or total settlement
- Differential settlements under service limit state along alignment of the MSE and facing elements, and between the front and back of the MSE
- 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)
- Calculated resistance factor or factor of safety for global stability (service and extreme limit states)
- 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 horizonal bench width of 4 feet in front of wall is also recommended for walls founded on sloping ground
- Liquefaction potential and associated lateral spreading, and recommended mitigation measures if needed
- Horizontal acceleration coefficient (k_h) and associated seismic displacement
- Drainage system details and specifications, if drain systems other than the standard are needed to intercept the flow

Use the following tables to summarize geotechnical design data provided by the SD and foundation design recommendations:

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 Design Recommendations 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=__) (psf)	Effective Base Width1 (feet)	Vertical Bearing Stress1 (psf)	Factored Bearing Resistance (ϕ = __) (psf)