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
- Are most cost effective in fill situations, 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
DESIGN MANUALS AND GUIDELINES FOR DESIGN AND REPORT

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:

- The latest edition of *AASHTO LRFD Bridge Design Specifications (BDS) and California Amendments* (currently 2017 in prep), 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”, 2013
- *Memos to Designers 5-19*, “Earth Retaining Systems Communication”
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 MSEs 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 horizontal 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 for the geotechnical analysis 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)

**INVESTIGATION**

For a geotechnical investigation of a non-standard MSE, refer to the following documents:

- *Geotechnical Manual*, “Geotechnical Investigation of Mechanically Stabilized Embankment (Caltrans Pre-Designed)”
DESIGN

The geotechnical design of MSEs 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 MSEs, use 1/3 horizontal peak ground acceleration (HPGA) for the horizontal acceleration coefficient (kh) if they can tolerate the seismic displacement up to 7 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 seismic displacement up to 7 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 MSEs, and assist the structure designer in calculating kh. The kh 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 MSEs, 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 seismic displacement of 7 inches is not acceptable for MSs, use 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 (FR) for Earth Retaining Systems (ERS)”. Include design information, and assumptions made during the design. When construction concerns, such as construction difficulties, and monitoring of displacements are expected, include them in “Construction Considerations” of the FR. The information and instructions should be adequate for the specification engineers to edit and compile the Special and non-standard Special Provisions.

Design Parameters

Provide the lateral earth pressure and its distribution along vertical wall elements or engineering properties required for the calculation of lateral earth pressure. For a wall with simple geometry and homogeneous soils, provide the following engineering properties for foundation soils and rocks below design grade and retained soils and rocks behind the wall:

- Moist unit weight,
- Cohesion
- Friction angle
- Rock strength
- Static earth pressure coefficients.
- Horizontal seismic coefficient with expected displacement.
- Seismic earth pressure coefficients.
- Design groundwater elevation.

For walls with complex geometry, non-homogeneous retained soils, or cohesive soil layers, or requested by the structure designer, provide the following additional information:

- Magnitude and distribution of static earth pressure
- Magnitude and distribution of seismic earth pressure
- Magnitude and distribution of steady-state water pressure

Recommendations

- Factored bearing resistance for both 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 horizontal reinforcement length (base width) to satisfy global stability and bearing resistance criteria; The minimum base width should not be less than 8
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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)

- 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
- Liquefaction potential and associated lateral spreading, and recommended mitigation measures if needed
- Drainage system details and specifications, if drain systems other than the standard are needed to intercept the flow

**Construction Considerations**

- Corrosiveness of foundation material, retained material, and water sources
- Waiting periods and surcharge load to reduce the effect of long-term settlement if needed.
- Construction monitoring program if needed
- Availability and suitability of on-site material for use as foundation material, reinforced soil, and retained materials