EXECUTIVE SUMMARY

The Federal Lands Highway (FLH) Program of the Federal Highway Administration (FHWA) is responsible for design and construction of roadways in rugged, mountainous terrain. Where the terrain is steep, retaining walls are frequently required to accommodate widening of existing roads or construction of new roadways. In the last 20 years, use of various types of mechanically stabilized earth (MSE) retaining walls has increased on FLH projects, proving to be reliable, constructible, and cost effective.

MSE walls, which are essentially a fill strengthening process, facilitate construction of a new road or widening of an existing narrow road by constructing the MSE wall on the outboard or "fill side" of the roadway. However, in steep terrain, excavation is required to establish a flat bench on which to construct the MSE wall. Existing state-of-practice suggests a minimum bench width and MSE reinforcement length equivalent to seventy percent of the design height of the MSE wall (i.e., $0.7H$).[1,2] Additionally, the required toe embedment depths for MSE walls are proportional to the steepness of the slope below the wall toe. In some cases, the excavation requirements for construction of an MSE wall become substantial, and unshored excavation for the MSE wall is not practical, particularly if traffic must be maintained during construction of the MSE wall.

Shoring, most often in the form of soil nail walls, has been employed to stabilize the backslope (or back-cut), with an MSE wall being designed and constructed in front of it. However, to date, the long-term stabilizing effect of the shoring system is not typically accounted for in the design. Where the two wall types are appropriate to use together, a design procedure that rationally considers both the stabilizing effect of the shoring wall with regard to reduction of lateral loads acting on the MSE wall mass as well as the significant contributions to global stability is beneficial, both to FLH and to other agencies. For this report, shored construction of an MSE wall is termed a Shored Mechanically Stabilized Earth (SMSE) wall system. The purpose of this report is to serve as an FHWA reference for highway projects involving SMSE wall systems. The current design practice for MSE walls used by FHWA is Elias et al.[2] This report does not replace that work, but instead expands that work where SMSE wall systems are deemed viable.

Where an SMSE wall system is determined to be the best alternative for wall construction, design of the MSE wall component should take into consideration the retaining benefits provided by the shoring component, as well as the long-term behavior of each wall component. Due to the long-term lateral restraint provided by the shoring wall component of an SMSE wall system, as observed from field-scale testing conducted to assist in development of this report, design of the MSE wall component should augment the traditional approach for MSE wall design. Design of the MSE wall component of an SMSE wall system should include the following components:

- Internal stability of the reinforced soil mass (i.e., rupture and pullout of reinforcements).
- External stability along the MSE wall/shoring system interface.
- Bearing capacity and settlement of the MSE wall foundation.
- Global stability of the composite SMSE wall system.

With regard to internal stability design of the MSE wall component, the pullout design equations presented were developed specifically for SMSE wall systems. No modification to the reinforcement rupture calculations currently in use for traditional MSE walls is needed.

This report has been developed specifically for use of soil nail walls as the shoring wall component. The soil nail wall should be designed and constructed as a permanent feature instead of as a temporary, or "throw away," feature, including such considerations as incorporation of a permanent drainage system, use of corrosion resistant nails (i.e., epoxy-coated or encapsulated steel bars), and adequate concrete cover to provide corrosion resistance.

Geotechnical investigations conducted for SMSE wall systems should evaluate site conditions (soil/rock, groundwater) for both the MSE wall component as well as the shoring component. This includes evaluation of the foundation conditions for the MSE wall, as well as the alignment of the shoring wall and anchorage of the shoring wall (i.e., soil nails), where appropriate.

This report presents design methodology for SMSE wall systems. The methodology is based on findings from a literature review, centrifuge modeling, field-scale testing, and numerical modeling. The comprehensive literature review included the state-of-practice with regard to shored construction of fill-side retaining walls as well as the use of short MSE reinforcements and nontraditional wall geometries. The centrifuge modeling, field-scale testing, and numerical modeling efforts were performed sequentially to answer specific questions on anticipated performance.

Based on the results of centrifuge modeling and field-scale testing, reduction of the reinforcement length to as little as 25 percent of the wall height ($0.25H$) provided sufficient wall stability, even under a considerably high degree of surcharge loading. Using the results of this research, a minimum reinforcement length equivalent to 30 percent of the wall height ($0.3H$), as measured from the top of the leveling pad, is recommended for design of the MSE wall component of an SMSE wall system. It is recommended, however, that the reinforcement length not be less than 1.5 m, which is less than the 2.4 m minimum reinforcement length set forth in AASHTO and Elias et al. for traditional MSE walls.[1,2]

This report is not written for design of MSE veneers on shoring walls, which are typically applied to provide an aesthetic improvement to the face of the shoring wall. Such walls are fundamentally different from SMSE walls in that they are typically "cut side" veneers, not supporting vehicle traffic or contributing significantly to global stability of the roadway.