MSE Wall Engineering – A New Look at Contracting, Design, and Construction

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ABSTRACT

Poor performance of mechanically stabilized earth (MSE) walls that have been designed and constructed using the traditional approach can be attributed to disconnects among the design team members. Commonly, site-specific design criteria are not included in the geotechnical reports, and/or design team members do not see the reports. Designs are developed on the basis of assumed or published values that are typical, resulting in poor performance or, alternatively, the need for costly change orders.

After researching the processes and events leading up to numerous poorly performing MSE walls, we propose a change in the design process. First, the design should be developed along with the civil and structural aspects of the project, allowing uncertainties to be resolved before the project is bid. Quality assurance and quality control should be integral to the process in order to assure that construction incorporates the specified criteria, and that all aspects of the construction are adequately documented. Such documentation allows owners to determine causes for MSE wall poor performance if necessary, and to pursue remedies.

In support of our research findings, a case study illustrates many of the disconnects among design team members, and failures in QA and QC that lead to MSE wall poor performance.

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MSE WALLS: A Brief History

Mechanically stabilized earth (MSE) wall systems are essential elements of many highway designs, and they represent the retention system of choice more frequently than in the past. For many years, retaining structures were almost exclusively cast-in-place (CIP) concrete structures that cannot accommodate significant differential settlement, specifically with tall walls and poor subgrade conditions.

MSE wall systems are generally used for slope stabilization and to minimize right-of-way embankment requirements, and are also used for bridge abutments and wing walls on a more limited basis. A typical MSE wall section is depicted in Figure 1.

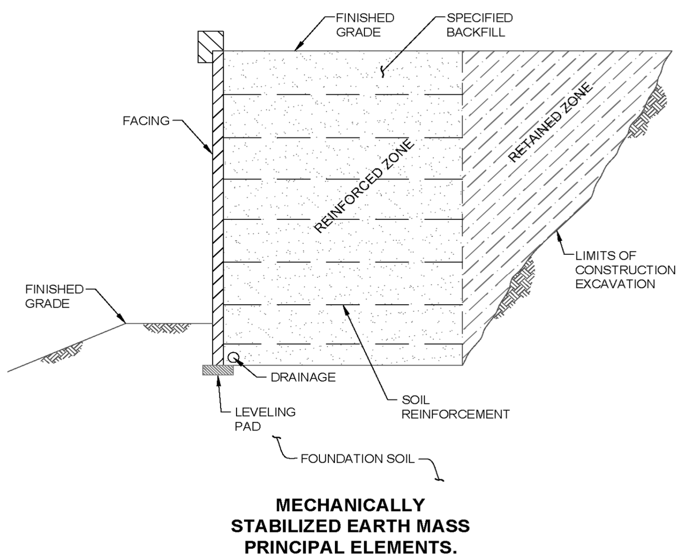


Figure 1 – Typical MSE Wall Section

MSE wall systems are cost-effective earth-retaining structures that can tolerate larger settlements than conventional retaining wall systems, such as CIP walls. By placing tensile reinforcing elements (inclusions) in the soil, the strength of the soil can be improved significantly such that the near-vertical face of the soil/reinforcement system is self-supporting. Use of a facing system (such as modular blocks or concrete panels) to prevent soil raveling between the reinforcing elements allows near-vertical walls to be constructed safely.

The Traditional Design Approach

Historically, the responsibility for the design and construction of MSE walls has been distributed among multiple entities, including the MSE wall installer or the MSE wall supplier, under subcontract to the general contractor. Commonly, there is a significant disconnect between the overall project civil and structural design engineer and geotechnical engineer, and the MSE wall design engineer that contributes to scheduling conflicts and poor performance of some walls.

Once the design is completed, the MSE wall is constructed. Quality control (QC) would typically be performed by the general contractor and quality assurance (QA) would be performed by a consultant retained by the owner. The QC and QA testing firms are tasked with confirming that the materials types and placement meet the project and MSE wall design specifications; and verifying the soil strength parameters for the foundation, retained, and reinforced zones used by the MSE wall design engineer.

Design Issues – the Disconnect

Often during the initial project design phase, the geotechnical engineer will prepare their report with little or no information about proposed MSE wall locations or heights. The geotechnical engineer may not even be aware that MSE walls are planned for the project, and this disconnect commonly results in inadequate or inappropriate design.

MSE wall design requires specific criteria; i.e., allowable soil bearing capacities, global stability analyses based on wall heights and designs, minimum reinforcing lengths; and soil strength parameters (phi angle and cohesion), and soil unit weights for specific soils that will ultimately need to be used in the reinforced zone, retained zone, and foundation soils. When the geotechnical engineer is aware that MSE walls are planned, these criteria would typically (or should) be included in the geotechnical report.

If the necessary information is not provided during the initial design phase, the general contractor must prepare 100-percent MSE wall plans and specifications, and therefore must include an MSE wall design engineer on their team. To win most conventionally bid projects, the general contractor is tasked with developing the lowest cost for the various design elements. As a result, they generally retain the lowest price MSE wall design engineer and propose the lowest cost MSE wall.

Figure 2 – A Low Cost MSE Wall Design

Figure 3 – Distressed MSE Wall

The Consequences

On the basis of our review of the processes preceding construction of numerous distressed and failed MSE walls we have found a common denominator: an inadequate geotechnical report that failed to provide the criteria necessary for constructing a successful MSE wall. Specifically, one or more of the following shortfalls were apparent for each of the cases we reviewed:

- The geotechnical engineering report did not provide site-specific MSE wall design criteria, such as allowable soil bearing capacities, global stability analyses, minimum reinforcement lengths, soil strength parameters (phi angle and cohesion), and soil unit weights.

- The geotechnical engineering report did not provide calculations or recommendations for minimum global stability, sliding, overturning, and soil bearing capacity safety factors for designing the MSE walls.

- Commonly, the geotechnical engineering report was dated prior to the completion of the site/civil drawings identifying the locations, configurations, and heights of the proposed MSE walls.

- The MSE wall design engineer assumed soil strength parameters on the basis of local knowledge or on ideal values for imported fill that were provided by the MSE wall installers, rather than on site-specific values provided in a geotechnical engineering report. (In some cases, the design engineer had not even been provided a copy of the geotechnical report.)

Figure 4 – Observed MSE Wall Movement

- MSE wall plans and specifications typically did not require that the QC and QA firms confirm that soil used within the retained zone and reinforced zone, and/or foundation soil met soil strength parameters used for the design. Therefore, the MSE wall design engineer had no way of confirming if the design soil strength values were met during construction.

- Lack of documentation confirming whether or not the geotechnical engineer was asked to review the MSE wall design for conformance with the geotechnical design and construction recommendations.

The Solution = Quality Assurance and Quality Control

The shortfalls in MSE wall design that we have observed can be mitigated by stringent application of common QA and QC procedures. These procedures should be performed to document that MSE walls are being constructed in accordance with the plans and specifications and that assumptions made by the MSE wall designer are validated.

QA comprises a broad general view of the entire MSE wall design and construction process and verification that QC is performed in accordance with the plans and specifications. QA should be performed by an engineering firm under contract with the project Owner. The QA firm should have experience with MSE wall construction and forensic evaluation. The geotechnical engineer is typically the best qualified and most knowledgeable entity to perform the QA activities.

The geotechnical engineer should review the MSE wall plan, specifications, and calculations to verify that the geotechnical recommendations have been interpreted correctly.

The QA consultant must, at a minimum, conduct the following reviews, checks, and assessments:

- Review the geotechnical report.
- Review the civil engineering plans showing the locations of the proposed MSE walls.
- Evaluate site design issues, such as fencing, guide rails, storm water drainage, water distribution pipelines, irrigation, and proposed landscaping, as these items can impact the proposed MSE design.
- Review the MSE design engineer’s plans and specifications.
- Review the MSE wall design/shop drawings.
- Check the MSE wall design calculations.
- Review the proposed construction QC testing plan.
- Assess existing conditions affecting stability factors of safety (global stability, bearing capacity, sliding, and eccentric loading).

The QA consultant should also verify the geotechnical engineer has reviewed and concurred with the use of the project specific geotechnical design and construction recommendations.

CASE HISTORY – A FORENSIC STUDY

We performed an independent design check on several MSE walls that were exhibiting signs of movement and distress, but had not collapsed. The owner, a transportation agency, hoped that the results of our forensic investigation would identify the cause(s) of the wall movement, and if possible, the responsible parties.

The distressed MSE walls were designed following the traditional design approach as we have described. The owner contracted with the project design engineer, the geotechnical engineer, and the general contractor. The MSE wall designer was contracted by the wall facing supplier, who was contracted by the general contractor.

Throughout the independent design check, it was apparent that the responsibility for the MSE wall's successful performance was distributed among several design firms, and that there was a lack of communication and coordination among the project design engineer, the geotechnical engineer, and the MSE wall design engineer. The evidence follows:

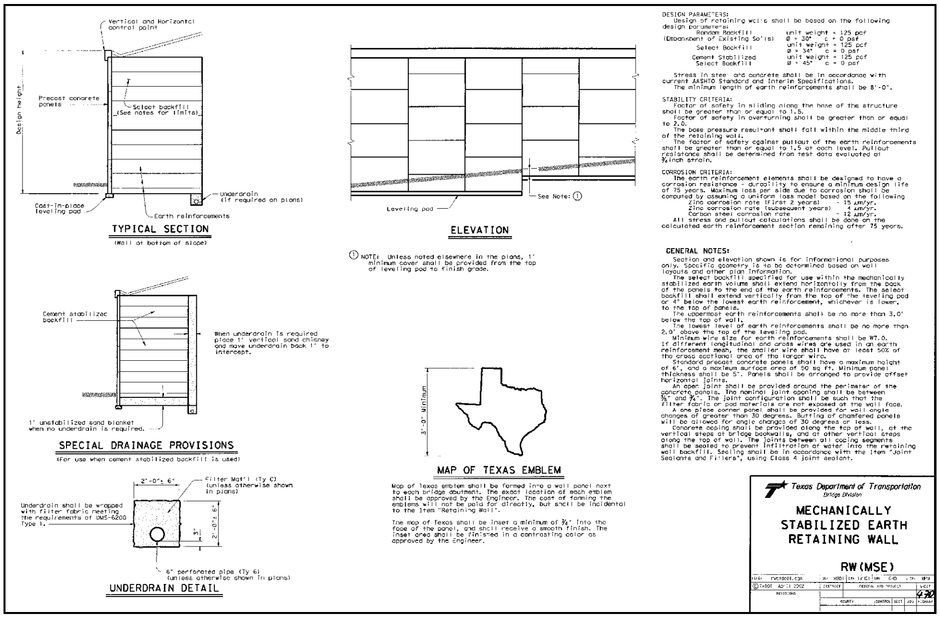
Inadequate Geotechnical Report

Our forensic review started with the geotechnical report, which provided recommendations for lateral earth pressures and minimum reinforcing lengths based on global stability analyses performed on assumed MSE wall heights and embedment depths. In addition, it provided allowable soil bearing capacities for various wall heights.

The geotechnical report did not provide site-specific MSE wall design criteria, such as internal angle of friction, cohesion; and unit weights for the retained zone and reinforced zones, and foundation soil, although these soil strength parameters could be gleaned from the global stability analyses. Further, it did not provide recommendations for minimum safety factors for global stability, sliding, overturning, and bearing capacity.

MSE Wall Design Discrepancies

After reviewing the geotechnical report, we reviewed the MSE wall design drawings and calculations. For most of the wall designs, the MSE wall design engineer did not incorporate the soil strength parameters used by the geotechnical engineer in the global stability analyses. The values used by the MSE wall design engineer were taken from the local DOT standard detail provided in the plan set (see Figure 5). According to the MSE wall design engineer, neither the project specifications nor the contract between the owner and the general contractor required the use of the geotechnical report for MSE wall design.



DESIGN PARAMETERS:
Design of retaining walls shall be based on the following design parameters:

Random Backfill (Embankment of Existing Soils)	unit weight = 125 pcf Ø = 30° c = 0 psf
Select Backfill	unit weight = 125 pcf Ø = 34° c = 0 psf
Cement Stabilized Select Backfill	unit weight = 125 pcf Ø = 45° c = 0 psf

Figure 5 – Typical DOT Standard Detail

The MSE wall plans and specifications did not require that the general contractor confirm that the soil used within the retained and reinforced zones, and/or the foundation soil meet the soil strength parameters used for the design. Therefore, the MSE wall design engineer had no way of confirming if the assumed soil strength values used in the design were met during construction.

We found no documentation confirming whether or not the geotechnical engineer was asked to review the MSE wall drawings and calculations for conformance with the geotechnical design and construction recommendations. Similarly, we found no documentation in the daily field reports (DFRs), field test data, or laboratory test reports from the QC and QA firms that the following design criteria met the project plans and specifications:

- Reinforcement grid length and spacing;
- Foundation improvement;
- Foundation soil strength parameters;

- Retained zone strength parameters;
- Reinforced zone strength parameters;
- Reinforced zone material type and compaction;
- Retained zone material type and compaction; and
- Wall drainage materials or placement.

Investigation Findings

Lack of communication and coordination among all parties involved with the MSE wall design and construction was apparent. Because so little proper documentation of the design and construction existed, we were unable to discern either a cause for the wall movement or a possible responsible party. However, we did identify the following potential contributing factors:

- The soil strength parameters used by the geotechnical engineer differed from those used by the MSE wall design engineer.
- Local DOT Standard details with generalized parameters were incorporated into the drawings rather than project specific details/parameters.
- Factors of safety for bearing capacity, global stability, and sliding were below AASHTO- and FHWA-recommended levels.
- Insufficient/inadequate or no communication took place between the geotechnical engineer and the MSE wall design engineer throughout the project design and construction.
- The owner's contract did not require the MSE wall design engineer to use the geotechnical engineer's recommended design parameters.
- Neither the QC nor the QA firm verified design parameters during construction.

Figures 6 and 7 show poorly designed MSE walls.

Figure 6 – MSE Wall Movement and Distress

Figure 7 – MSE Wall Movement and Distress

MSE WALL DESIGN AND CONSTRUCTION--MOVING FORWARD

We recommend changes to the standard of practice currently being used for designing and verifying MSE wall construction, as follows:

Design Phase – Paradigm Shift

During the project design phase, the owner should independently contract with the geotechnical engineer and require that the geotechnical report include appropriate strength parameter recommendations for designing and constructing MSE walls. These parameters should include the internal angle of friction (ϕ), cohesion, and unit weight (γ) for the foundation, retained zone, and reinforced zones soils; and the foundation ultimate soil bearing capacity, as those shown in Figure 8. The geotechnical engineer should also include the minimum grid length; and minimum global, sliding, and bearing capacity if they need to be reduced from the FHWA and/or AASHTO minimums. Further, the geotechnical engineer should specify ground improvement recommendations if it is necessary to increase the ultimate soil bearing capacity.

Wall ID	WALL STATION RANGE	SELECT FILL SOIL		RETAINED SOIL			FOUNDATION SOIL									
								Effective Stress Parameters for Calculating Sliding FS and Allow. Bearing Pressure			Total Stress Parameters for Calculating Sliding FS			Total Stress Parameters for Calculating Allow. Bearing Pressure		
		U. WEIGHT - PCF	FRICTION ANGLE, φ	SOIL TYPE	U. WEIGHT - PCF	EFFECTIVE STRESS FRICTION ANGLE, φ	SOIL TYPE	U. WEIGHT - PCF	FRICTION ANGLE, φ	COHESION, (C) - PSF	U. WEIGHT - PCF	FRICTION ANGLE, φ	COHESION, (C) - PSF	U. WEIGHT - PCF	FRICTION ANGLE, φ	COHESION, (C) - PSF
E1	0+00 to 8+52	130	34	non-select	125	25	undisturbed clay	125	25	0	125	0	2000	125	0	1709
E2	0+00 to 17+79	130	34	combination of non-select and Type A emb.	125	30	undisturbed clay	125	25	0	125	0	1728	125	0	1938
E3	0+00 to 7+35	130	34	non-select	125	25	undisturbed clay	125	25	0	125	0	1250	125	0	1250
E5	0+00 to 3+76	130	34	non-select	125	25	undisturbed clay	125	25	0	125	0	1385	125	0	1385
E6	0+00 to 7+00	130	34	non-select	125	25	undisturbed clay	125	25	0	125	0	865	125	0	1953
E7	0+00 to 4+60	130	34	combination of non-select and Type A emb.	125	30	undisturbed clay	125	25	0	125	0	865	125	0	1953
	4+60 to 6+10						combination of undisturbed clay and 5' of Type A emb.	63	30	0	N/A			125	0	2316
	6+10 to 10+40						combination of undisturbed clay and 5'-16' of Type A emb.	63	30	0	N/A			125	0	3250
	10+40 to 12+60						undisturbed clay	125	25	0	125	0	865	125	0	1953
	12+60 to 16+90						combination of undisturbed clay and 0'-11' of Type A emb.	63	30	0	N/A			125	0	3250
	16+90 to 25+65						undisturbed clay	125	25	0	125	0	1500	125	0	2000

Figure 8 – Typical Geotechnical Parameters

MSE wall design should be performed by either the project design engineer or the MSE wall design engineer under subcontract to the owner. The MSE wall should be designed to 100 percent along with the remainder of the project (roadways, bridges, utilities, etc.). This allows the owner to maintain control and acceptable risk of the MSE wall design. This further allows the owner to specify the materials (facing, backfill material, grid type) to be incorporated into the design and obtain competitive bids. It can also significantly reduce the potential for change orders associated with the general contractor bidding typical design sections.

MSE wall plans and specifications should include frequencies and methods for testing the soil strength parameters to be used within the retained and reinforced zones. The specifications must also provide requirements for confirming the density of the material being placed. Specifications should mandate that the geotechnical engineer verify that the foundation material type and strength meet or exceed those provided in the geotechnical report.

The geotechnical engineer should review the design for conformance with the geotechnical design and construction recommendations; perform stability analyses for global, sliding, and bearing capacity; and provide additional recommendations as necessary.

MSE wall design should be performed by geotechnical engineers with design experience. They have a unique understanding of the soil structure interaction, soil materials, foundation improvement requirements; global, sliding, and bearing capacity safety factors; and the risks associated with modifying these materials and requirements. For this reason, geotechnical engineers are well qualified to identify project risks associated with design and materials modifications.

The Roles of QA and QC

QA and QC should be paramount, and the roles of the QC and QA testing firms should not be underestimated. Documenting that the construction and the materials meet the plans and specifications is a critical aspect of MSE wall construction, and it is imperative that the QC and QA firms document and record the appropriate information in DFRs.

Too often, the role of QC and QA is reduced to measuring and recording the density of the MSE wall backfill. Since MSE wall designs are largely based on the strength of the soil used for backfill and the length and spacing of the geogrids (straps) used for load transfer in the wall system, many critical items need to be monitored, verified, and recorded for the data set to be complete. These include:

- Foundation soil material type, shear strength parameters, and in-place densities;
- Reinforced zone material type, soil strength parameters, and in-place densities;
- Retained zone material type, soil strength parameters, and in-place densities;
- Geogrid type;
- Geogrid length and spacing;
- Wall face connections;
- Soil placement and compaction; and
- Utility conflicts.

GOAL: IMPROVED MSE WALL PERFORMANCE

The goal of the proposed MSE wall design process described above is to allow the owner to better control long- and short-term risks associated with MSE wall design and construction. Historically the owner did not have much control of the MSE wall design other than providing performance specifications. The owner would not know how the MSE wall would perform until long after the project was completed or even after the warranty period. Using the proposed design schema, which incorporates vigilant QA/QC, owners can rely on their design team's MSE wall design. They can utilize this design for obtaining consistent and competitive bids.

The proposed design schema will provide owners with more assurance of the MSE wall performance as the wall is being constructed. It will also provide the owner and design team with the documentation to verify that the wall was constructed in accordance with the plans and specifications. Additionally, because the MSE wall would be designed along with the civil and structural aspects of the project, the performance risks and issues would be resolved well before the project is bid.

Designing and constructing MSE walls in this fashion will produce high quality MSE walls that will perform better over the long term. Figures 9 and 10 show well-constructed MSE walls.

Figure 9 – Well Constructed MSE Wall

Figure 10 – Well Constructed MSE Wall

CONCLUSIONS

In conclusion:

- A higher level of communication and coordination with respect to the soil strength parameters should exist between the geotechnical engineer and the MSE wall design engineer.
- A higher level of communication and coordination related to utility and other conflicts should exist between the MSE wall design engineer and the project civil and structural engineers.
- The MSE wall designs should be performed along with the project civil and structural designs.
- Factors of safety for bearing capacity, global stability, and sliding need to be checked by the geotechnical engineer prior to bidding.
- Full-time QA control is required to be compliant with the "Special Inspections" sections of the International Building Code. Based on the level and amount of data needed to be generated to verify construction is performed in accordance with the MSE wall design, the standard of care must be followed for full-time QC monitoring of MSE wall construction activities.
- The QC and QA consultants' DFRs must contain sufficient information and test results to verify that construction activities and materials used meet or exceed the MSE wall plans and specifications.
- The QC and QA consultants must present their test results to the MSE wall design engineer for verification.

The role of QC and QA in this process cannot be underestimated. It is imperative that the QC and QA consultants provide complete and detailed documentation and record this information so that if problems arise in the future they can be resolved.

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