Lessons Learned

problems and solutions encountered by practicing structural engineers

Mechanically Stabilized Earth Walls

Pitfalls in Design and Construction

By Scott J. DiFiore, P.E. and Bryan P. Strohman, P.E.

Scott J. DiFiore, P.E. is a senior project manager at Simpson Gumpertz & Heger Inc., Waltham, Massachusetts. He can be reached at ***sjdifiore@sgh.com****.*

Bryan P. Strohman, P.E. is a Senior Staff II – Structures at Simpson Gumpertz & Heger Inc., Waltham, Massachusetts. He can be reached at ***bpstrohman@sgh.com****.*

Due to advantages in economics, constructability, and aesthetics, the construction of mechanically stabilized earth (MSE) walls is now commonplace. An MSE wall consists of soil, reinforcement, and facing to retain earth and support overlying structures (*Figure 1*). Thirty- to forty-foot high walls are not uncommon. Reinforcement often consists of geogrids or steel reinforcement strips, while the facing commonly consists of segmental precast concrete units, gabion baskets, metallic panels, or geosynthetic facing. There are many different MSE wall construction materials, making it more important for Contractors and design Engineers to understand how the products work with the remainder of the system.

For various reasons, some systems fail and require costly repair (*Figure 2*). Based on lessons learned from case studies, the authors discuss common pitfalls of MSE wall design and construction, in the form of a hypothetical case study.

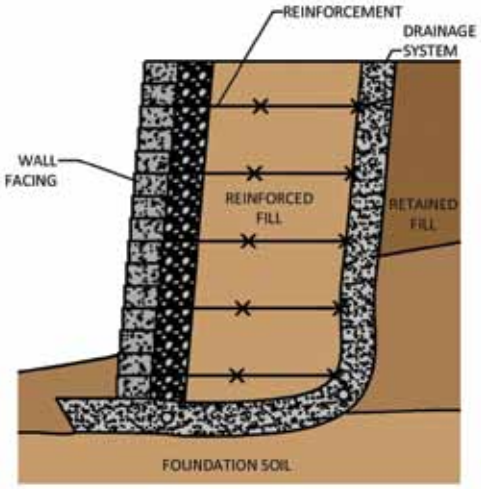

Figure 1: Typical MSE Wall Cross-Section.

It's Just a Retaining Wall… Don't Sweat It!

An Owner selects an affordable but complex site to construct a retail outlet with four, one-story buildings. The multiple-acre site slopes significantly from west to east, with more than 40-feet of grade differential, and a marsh at the lower elevations covering less than 10 percent of the site. The Owner engages a Geotechnical Engineer to: drill one boring beneath each building, perform soil gradation tests, and prepare a report with site grading, building foundation, and generic retaining wall recommendations. Site soils, from the limited boring data, vary from clayey sand to sandy clay.

The Owner hires a Civil Engineer to layout the roadways, parking lot, buildings, and site utilities. Site utilities include pressurized waterlines, sanitary sewer lines, and a storm drainage pipe system to collect runoff from the roadway, parking lot, and roof drainage. The retaining wall is an afterthought. The plans show a bold black line at the property line to represent the retaining wall with the label "retaining wall – to be designed by others," with a 30-foot grade change from the top to the bottom of the wall. The exposed side of the wall will be visible from local neighborhoods and a shopping center. The marsh is just outside the limit of the retaining wall.

Figure 2: Costly repairs to failed MSE wall.

The Contractor submits a bid that utilizes an MSE wall, and engages a Fabricator who provides proprietary masonry blocks for MSE systems. The Fabricator works with a design Engineer who is not local to the site, but regularly designs the proprietary MSE system. The Fabricator and his design Engineer assemble their standard design plans using subsurface information and recommendations from the geotechnical report. They do not visit the site, discuss the subsurface conditions with the Geotechnical Engineer, review the site topography and utilities with the Civil Engineer, or discuss whether soil backfill will be imported or reused from the site development work. The design plans provided to the Contractor contain notes stating that others are responsible to check the bearing capacity below the wall, the settlement of the wall, and the slope stability of the wall and retained backfill.

The Owner hires the Geotechnical Engineer at the start of construction to perform periodic site inspections. However, the Geotechnical Engineer was not involved with the project through the course of the site or retaining wall design. The Geotechnical Engineer assigns his recently promoted professional engineer (Inspector) to monitor site and retaining wall construction, who has no experience with MSE walls. The Inspector visits the site daily and diligently conducts compaction testing on the onsite clayey fill placed in the reinforced zone of the wall. The onsite soils vary significantly as the project progresses, due to the large amount of earthwork required, and the Inspector obtains new laboratory compaction data to correlate with the field-density tests. The Inspector observes water bearing utilities installed in the retained backfill, and storm drain manholes along the top of the wall at the edge of the pavement. The Fabricator and

Figure 3: Water collecting in clay backfill immediately behind MSE wall facing.

his design Engineer provided no specific wall drainage systems in the design. The Contractor constructs the wall from the specified modular blocks and geogrid reinforcement, and the clayey site soils.

The project team is primarily focused on the building, utility, and pavement construction. After all, the project is a retail center. But, as the project developed, the MSE wall became its own significant construction project. It is up to 30-feet high, next to an established neighborhood, with water sources in the wall backfill, supports building foundations and a parking lot. Treating the MSE wall as "incidental" to the project could be disastrous. Is the project team giving the wall its due consideration?

The Imperfect Site

Much of the easily-developed land has already been taken; this site has its development challenges. The primary development consists of four, simple one-story retail structures. Just bring the site to grade, install spread footings and pavement, and the development is off and running. What has the project team neglected that could come back to haunt them?

Subsurface Data

By performing only four borings over a multi-acre site, the team focused on the buildings, but neglected ancillary development which includes significant earthworks and soil reuse. Retaining wall construction is near the edge of the marsh, which likely consists of unsuitable compressible soils. Could unsuitable soils extend beyond the marsh and into the MSE wall area? Backfilling over the unsuitable soils will result in settlement. What about other unclassified soils outside the building footprints? Incomplete soil characterization could cause construction problems or project delays.

Soil Backfill

Clayey soils dominate the site, which are intended for reuse. MSE walls ideally use sand and gravel backfill in the reinforced zone. How do clayey soils impact MSE wall design and construction?

- Settlement: Sands and gravels undergo immediate settlement, whereas fine-grained soils (clays and silts) are susceptible to long-term settlement (consolidation). The Geotechnical Engineer did not perform consolidation tests, and no one predicted the amount of wall settlement. If the wall settles over the long-term, the pavement, utilities, buildings, and other site features will go along for the ride.
- Geogrid-Soil Interaction: The geogrids interact with the soil through friction. Together, the geogrids and soil act as a gravity structure. Geogrid and reinforcing manufacturers regularly test for interface friction with sand and gravel backfill, but not always for silts and clays, which have different behavior. The reinforcing could also be more susceptible to creep in clayey soils.
- Compaction: Fine-grained soils require special attention to compaction methods and moisture content, more so than sands and gravels which are easier to compact. Poor compaction results in weaker soils, reducing soil-reinforcement interface friction and increasing wall pressures.
- Soil Migration: As water flows through soil, it collects fine-grained particles and transports them. If the wall design did not include filter fabric or other protective measures against soil migration and erosion, the soil mass will lose volume and strength, resulting in additional wall pressures and settlement.
- Water Retention: Compared to sands and gravels, fine-grained soils are orders of magnitude less permeable. Water readily collects on and within fine-grained soils (*Figure 3*), which, (a) introduces groundwater and seepage forces, (b) reduces soil strength (increasing wall pressures), (c) reduces interface friction between backfill and reinforcing, and (d) in colder environments introduces freeze-thaw cycles in soils at and below ground surface and just behind the facing, which can create frost-jacking pressures.

Water, Enemy of the Wall

Water comes from a variety of sources (*Figure 4*), including precipitation, leaky utilities, irrigation in landscaped areas, and groundwater. Unless actively managed by the project team, all sources can have detrimental effects on MSE walls.

continued on next page

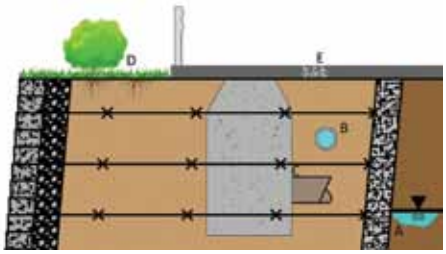

Figure 4: Water sources include: (A) groundwater, (B) pressurized water lines, (C) storm drain systems, (D) infiltration through open landscape areas, and (E) runoff through pavement cracks.

- Utilities: Water-bearing utilities are commonly placed directly within or behind the MSE wall, including pressurized water lines, storm drains and sewer lines. MSE walls are flexible structures and expected to move laterally as they reach an equilibrium condition. Can the utilities accommodate the anticipated movement without damage? What if they leak due to design or installation deficiencies? It is reasonable to expect that utilities will leak during their lifetime, possibly catastrophically, which introduces seepage or hydrostatic pressures.
- Landscaping: Most development projects include a landscaping component that requires irrigation. Open landscape areas are often located immediately at the top of the wall behind a curb line, or perhaps in islands set back from the wall. Irrigation lines and sprinkler systems, just like other water bearing utilities, are susceptible to leakage.
- Infiltration: Rainwater and snow melt infiltrate the ground through open landscape areas and act on the MSE wall. Rainwater also penetrates cracks in pavement. Significant storms can produce many inches of water in the course of just a day.
- Groundwater: Natural groundwater fluctuates over time and during different seasons. What happens during a flood? Is there a perched water table? Site characterization, prior to design, should identify groundwater elevations and potential fluctuations during seasonal and extreme weather events.

MSE walls are typically designed without consideration for hydrostatic or seepage pressures. This design approach is acceptable provided that the design and construction effectively manages all water sources. It is essential to identify water sources and divert water away from the wall. Collection/retention of water within the wall backfill adds hydrostatic or seepage pressures. When water pressures are large enough, performance or stability problems occur. Drainage systems are particularly important where fine-grained soil backfill is used, since water does not readily flow through such soils.

Figure 5: Drainage swale at top of wall intended to collect water. However, open landscaping behind swale allows water to enter soil mass.

Reference manuals by the *Federal Highway Administration* and *National Concrete Masonry Association* have provisions for wall drainage with varying site conditions. External and internal drainage systems, usually used in combination, collect and divert water away from the wall system. External systems typically include drainage swales and impermeable barriers to collect and divert surface runoff (*Figure 5*). Internal systems typically include chimney and blanket drains at the rear and bottom of the reinforced zone, respectively, with drain pipes and periodic outlets through the wall.

Has the Wall Received Its Due Attention?

The retaining wall? It's just a line on the drawings; incidental to the project, right? Engineers and contractors design and install them every day; they must be routine. As described above, challenges exist with site topography, soil conditions, and water sources.

Each project requires several players – Owner, Geotechnical Engineer, Civil Engineer, Contractor, Fabricator, Contractor/Fabricator's Engineer–but many times each member may not have a full understanding of their role and responsibilities.

Project Delivery

In this hypothetical case, the wall design flowed down to the Contractor, who passed it down to the Fabricator and his design Engineer. The Fabricator's Engineer designs many walls and follows his typical protocol. He often assumes a "typical" soil type (sands and gravels),

continued on page 14

Figure 6: Vertical wall with no batter, leaning over adjacent roadway. Construction with inward batter could alleviate this performance problem.

with "typical" strength properties and gradation, to be verified by "others" during construction. All parties often assume that everything is fine, since the Contractor's team has done this many times before. But, this site is going to use clayey backfill, which differs from the design assumptions and will alter the reported factors of safety. How does this impact wall performance?

Soils and Stability

The Fabricator's Engineer has a note on the drawings: "Fabricator and its Engineer accept no responsibility for settlement, bearing capacity, and global stability of existing soils and subsurface water mitigation." The Owner and his Engineers, if they have limited experience, may miss this critical exclusion and neglect to act on it. Without design consideration of these potential failure modes, the wall is at risk.

Wall Performance

MSE walls are flexible and will move laterally, particularly during construction. The designer must consider this movement and design the wall with sufficient batter to compensate. Building a vertical wall, which eventually leans outward, results in a perceived failure even if it is technically stable (*Figure 6*).

Miscellaneous Obstructions

At this site, there may be utilities, manholes, parking lots, guardrails, and light poles that penetrate the soil reinforcement. Such obstructions result in additional loads (e.g., impact on guardrails) or decreased resistance (e.g., damage to reinforcing from installation). Did the design Engineer consider these obstructions? Has the Civil Engineer looked at the MSE wall plans, and considered how the civil improvements affect the wall? Are the Contractor and Owner's Engineer experienced enough to acknowledge these issues if encountered during construction?

Long-Term Stability

Due to the limited subsurface investigation, no strength testing was performed on the foundation and backfill soils. What are the appropriate soil strengths for design, and how do they compare with the assumed parameters from the design drawings? It may be appropriate to consider residual strengths in some cases.

Quality Assurance and Quality Control

The Inspector is prepared to make regular visits to the site, but has no MSE wall experience. The Contractor has not installed this specific facing block before, and has not talked to the Fabricator. What are the connection details at the wall facing? At what elevations are the geogrids installed? Has the Contractor installed the drainage controls? Regular, proactive project meetings are required to vet these issues; if not, they often remain unresolved.

Putting it All Together

In this hypothetical project, there are many players, each with a different contract identifying their responsibility. But with so many players, and the MSE wall taking a back seat to the buildings, it is common for everyone to simply "assume" that the wall will be taken care of. It's a bad assumption. Vigilance is required by all project team members, from the Owner, to his Geotechnical and Civil Engineer, to Contractor, Fabricator, Fabricator's design Engineer, and the site Inspector. It is important to know how buildings, utilities, or other adjacent construction could affect the MSE walls. It is also critical to verify the soils and drainage are appropriate for the wall, and that all relevant stability checks have been addressed. Periodic meetings with experienced personnel, both during project development and during construction, are effective in vetting out and coordinating the potential pitfalls.

MSE walls can be cost-effective, aesthetically pleasing, and a technically sound approach for permanent earth retention on a site, provided that they are given due consideration during design and construction. When the project team considers the retaining wall "incidental to the project," and they lightly treat the site topography, soil type, water management, or project team coordination, the entire team may be faced with performance problems or even a wall failure.▪

References

United States Department of Transportation (USDOT) and Federal Highway Administration (FHWA). (2001). *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines*, Publication No. FHWA-NHI-00-043, Washington, DC. (FHWA 2001).

National Concrete and Masonry Association (NCMA). (2010). *Design Manual for Segmental Retaining Walls*, Third Edition, Herndon, VA. (NCMA 2010).

Naval Facilities Engineering Command. (1986). *Foundations and Earth Structures*, Design Manual 7.02, Alexandria, VA. (NAVFAC 7.02).