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RECONSTRUCTION OF A DETERIORATING, TIERED, MSE WALL STRUCTURE IN CONNECTICUT

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ABSTRACT

At a retail development site in Southington, Connecticut, a multi-tiered Mechanically Stabilized Earth (MSE) retaining wall system was constructed in the early 1990's to facilitate development of the site. Specifically, the retaining wall system constructed consisted of a sloped structure with three tiers of MSE wall that was approximately 56-feet tall at its highest point. The MSE walls within the slope were spaced approximately 30 to 40 feet apart horizontally, were between six and nine feet in height, and ranged in length from about 375 feet to 1,325 feet. Overall, grades on the slope ranged from about elevation 225 feet at the top to about elevation 163 feet at the fire lane at the base of the slope. The graded portions of the slope between the MSE walls had an inclination of about 2H:1V.

Subsurface conditions at the site generally consisted of up to about eight feet of granular fill on the slope in the areas disturbed by the initial grading activities underlain by medium dense to dense coarse to fine sand with varying proportions of silt and gravel. Based on borings conducted at the top of the slope during remedial construction, the sand layer extends to at least elevation 145 feet, or about 15 to 20 feet below the base of the slope. Groundwater was not encountered in any of the borings conducted or during the construction phase.

Due to the lack of available information regarding the freeze-thaw effects on the modular block facing at the time of construction, the impact of this behavior was not properly considered in the original design. Consequently, less than 20 years later, freeze-thaw effects deteriorated the majority of the facing to the point where the overall stability of the wall was in question. Specifically, facing block failure was leading to localized raveling of soils and creating erosion zones at the face of the wall. If left unchecked, these areas of erosion would have continued to extend deeper into the slope, compromising the integrity of the MSE structures, and thereby the overall slope.

Several options were evaluated to achieve a cost efficient design to stabilize the walls and slope. Conceptual designs were developed and included 1) a single 25-foot tall MSE wall with a reinforced slope in front of the existing wall system and 2) a proposed tiered wall scheme. The selected design concept included a 15-foot tall large block Stone Strong gravity wall in front of the bottom tier and a 10-foot tall Stone Strong gravity wall in front of the center portion of the middle tier of the existing retaining wall system. The remainder of the upper slope was significantly regraded. Re-construction of the wall was completed between November 2008 and August 2009.

This paper describes the investigation, design, and construction methodologies that were implemented to provide an economical solution to this unique issue and mitigate long-term wall stability issues.

INTRODUCTION

In New England, anyone that is familiar with large scale land development projects will know one thing: finding flat sites that have no grading challenges or retaining wall requirements to facilitate site preparation can be a very daunting task. So naturally, over the past several decades, as the technologies to build higher walls or create steeper slopes have been successfully implemented (i.e., allowing more building footprint on the site), these technologies have been immediately implemented by project owners. However, we should always remember that whether it is the newest type of earth retention system or Apple's latest version of the iPhone, new technology always has one thing in common: there are always bugs to work out.

Such is the case with the early versions of mechanically-stabilized-earth (MSE) walls to be put into the mainstream, particularly in areas that can have weather extremes at both ends of the spectrum, such as New England. Specifically, harsh winters with heavy snow falls and sub-freezing temperatures can lead to pronounced freeze-thaw cycles that can affect masonry and concrete materials. Alternatively, wet spring weather can lead to heavy periods of rain that present drainage and erosion challenges to be overcome. In the case of the tiered retaining structure in Southington, Connecticut which is the subject of this paper, both of these conditions led to the deterioration of multiple MSE walls that threatened the overall stability of the 56-foot high slope. Ultimately, however, it was the deterioration of the masonry facing blocks used in the MSE wall construction caused by freeze thaw effects that was the beginning of problems at the site.

The remainder of this paper will focus on the series of events starting with design and construction in the early 1990's, to the deterioration issues noted in the early to mid 2000's, and through the design and construction of remedial measures which were completed in late 2009.

PRE-DEVELOPMENT SITE DESCRIPTION

The subject retaining wall site presently exists as a 16-acre retail property located on Route 10 in Southington, Connecticut. Prior to initial development of the parcel, existing grades within the overall site sloped down from east to west. The area of the proposed structure had pre-development site grades ranging from elevation 163 to elevation 225, resulting in the need to cut 10 feet to 50 feet in order to establish the finished floor elevation and the finished site grades of about elevation 169 within the area of the proposed structure. Greater cuts were required along the eastern portion of the site within the future loading dock and receiving areas adjacent to the proposed structure. The finished grades within the parking area were such that minimal cutting was required, and fills on the order of five feet were required along the western portion of the project site. The original development was constructed between 1992 and 1993.

POST-INITIAL DEVELOPMENT SITE DESCRIPTION

Presently, the site is occupied by a one-story retail structure with a footprint of about 64,000 square feet in the central portion of the site. The remainder of the site is covered with asphalt-paved at-grade parking areas and drive aisles (one of which includes a fire lane and delivery route that surrounds the building), and the associated landscape and hardscape features. Around the northern, southern, and eastern edges of the site, a three-tiered MSE wall separates the site from the properties above. A general site layout is shown in Figure 1.

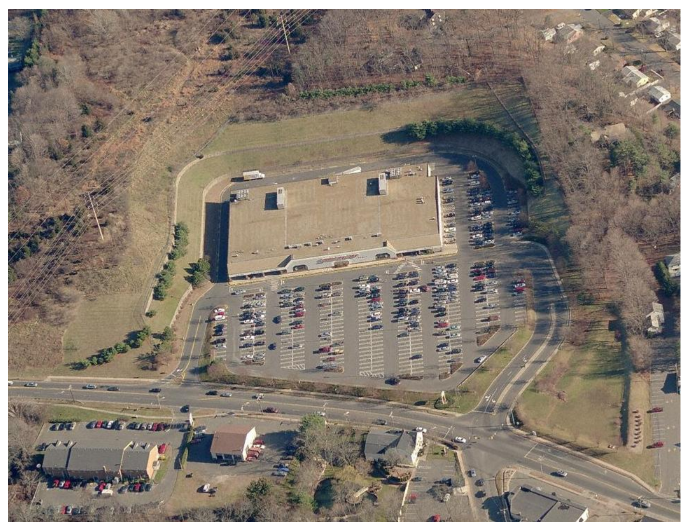

Figure 1: General Site Layout, looking east

Generally speaking, the post-development grades across the site slope downward very steeply along the eastern, northern, and southern edges of the site to the fire lane behind the retail structure. Specifically, grades at the top of the slope surrounding the three sides of the site generally range from elevation 225 feet along the eastern edge to elevation 215 along the northern and southern edges of the site. The site then slopes downward to about elevation 163 at the drive aisle in the rear of the retail structure. From there, the site slopes rather gently to the west where it meets Route 10. The finished floor elevation for the retail structure is at approximately elevation 169 feet.

GEOLOGIC SETTING AND SUBSURFACE CONDITIONS

As is the case with much of New England, the site vicinity in Southington was impacted by the most recent ice age. Specifically, the surficial soils at the site were generally placed as a result of glacial activity. The site is covered by a relatively thick deposit of poorly-graded sands mostly likely deposited by outwash during glacial retreat at the end of the last ice age. Although not encountered during any investigations at the site or during construction, the site is underlain by New Haven Arkose Bedrock. Arkose generally consists of a medium- to coarse-grained sandstone like rock which contains various proportions of several minerals. From a seismicity perspective, the site lies within a relatively inactive zone; design earthquake parameters for the area based on the International Building Code (IBC) are usually of relatively low intensity.

Based on information collected during both the original construction phase and the recent remedial construction activities, the subsurface conditions at the site generally consist of a thick layer of relatively poorly graded medium dense to dense, coarse to fine sand with varying proportions of silt and gravel. Borings completed during the recent construction period indicate that the sandy material present at the site extends to at least elevation 145 feet, which is approximately 15 to 20 feet below the existing grades at the toe of the slope. Groundwater was not encountered to the maximum depth of any borings (about elevation 145 feet) and was not observed during construction.

ORIGINAL CUT WALL DESIGN

The original cut wall, which was constructed in the early 1990's consisted of a segmental retaining wall ranging from one to three tiers in combination with slopes between tiers; see Figure 2. To provide transitions from the building and perimeter access roadways along three sides of the proposed structure, a single, double and triple tiered MSE wall system in combination with 2H:1V slopes between tiers was utilized. The MSE wall was reinforced with uniaxial geogrid and biaxial geogrids. The uniaxial geogrids were typically equal to the wall height and positioned at spacings of approximately two to three feet vertically. The biaxials geogrids were four feet long and positioned between and above the uniaxial geogrid.

The fill material utilized as wall backfill and consisted of sand with varying percentages of gravel and less than 5% passing the No. 200 sieve. The maximum dry density and optimum moisture content of the fill material typically varied from 103 pound per cubic foot to 125 pounds per cubic foot.

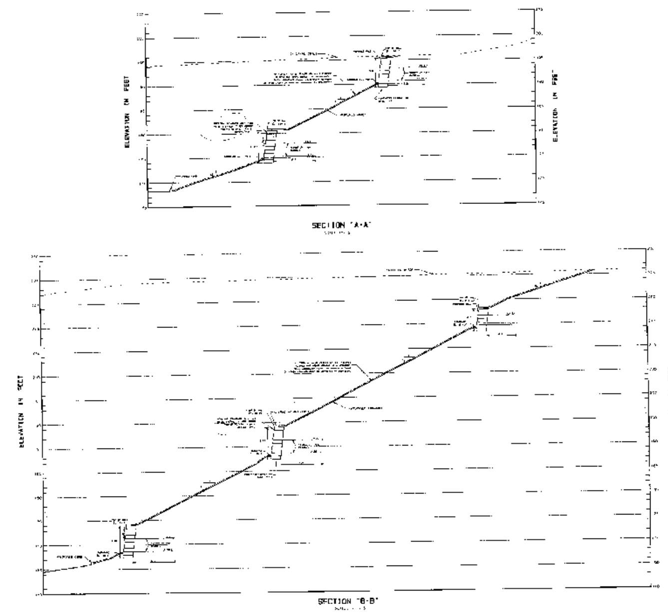

Figure 2 – Original Segmental Retaining Wall Cross-Section

In 2003, approximately 10-years after completion of installation, significant deterioration of the facing of the modular block system was documented with further deterioration being documented between 2003 and 2007. In 2004, studies were completed to determine the mechanisms of deterioration and potential causes for the significant reduction in design life of the modular block system. The conclusions of these studies indicated that the modular blocks utilized were susceptible to freeze thaw cycles and mitigation would be required in the future. The details regarding the material components, specific manufactured block makeup and causations of the reduced design life are beyond the scope of this paper. In 2007, the level of deterioration of the facing had progressed to a point where the stability of the retained soil and slope would become a concern at some point in the future; see Figure 3. In 2007, a design effort was undertaken to evaluate potential mitigation techniques in combination with continual observation/assessments of the condition of the walls and slopes relative to the need to provide immediate mitigation should a condition develop which would jeapordize the stability of the slope and the operations of the existing facility.

POTENTIAL MITIGATION SOLUTIONS

During the conceptual feasibility study, three different conceptual mitigation solutions were envisioned and consisted of the following:

1. Constructing a new, independent gravity, large modular block retaining wall which would not rely on the existing modular block wall facing for support or to resist the lateral loading;
2. Constructing a new wall face (such as shotcrete in combination with soil nails) that does not rely on the

existing modular block wall but is secured to the existing reinforced soil mass; or

3. Modifying the existing grades to construct a reinforced soil slope that would be vegetated.

Based on the order of magnitude cost comparison performed during the conceptual feasibility study, options #1 and #3 were expected to be similar in cost and option #2 was expected to be on the order of twice the cost of the other two options. The conclusion of the feasibility study indicated that a hybrid of utilizing a shotcrete and soil nailed solution for the uppermost tier of deteriorating wall face and a new, independent, gravity, large modular block retaining wall or vegetated reinforced soil slope for the lower walls would be potentially the most cost-effective solution. In addition to the engineering challenges, significant regulatory hurdles needed to be overcome to successfully permit the project and implement the mitigation solutions in a timely manner. These issues would need to be addressed prior to time becoming of the essence relative to the deterioration of the wall face and eventual destabilization of some or all of the wall and overlying slope.

Figure 3: Typical Deteriorated Conditions

SELECTED ALTERNATIVE DESIGN CONCEPT

Following several iterations of the various design concepts outlined above, discussions with the owner, and pricing exercises with the Contractor, the decision to go with a tiered reconstruction of the existing walls was made. Specifically, a concept which incorporated the construction of new, large-block Stone Strong gravity wall in front of the existing lower and middle-tier walls combined with significant grading improvements over much of the upper slope was chosen. A cross-section of the chosen alternative is shown in Figure 4.

Several factors influenced into the chosen solution, when compared with other alternatives. First, the chosen option was relatively cost effective when compared to other feasible options. Secondly, by regrading a significant portion of the slope, it became feasible to remove the upper-most tier of the wall in its entirety. This eliminated the need for several hundred square feet of wall facing, and hundreds of cubic yards of additional imported fill material, when compared to other options. Finally, by choosing an option that allowed for the lower tiers of wall to simply be buried in place, rather than demolished and removed, significant cost savings were realized in temporary stabilization and earthwork that would have been required to simply construct new walls.

Perhaps the most important consideration, however, of the ultimately chosen design concept was the ability to incorporate the original construction into the final design, while at the same time, not overstressing the existing geogrid which was part of the existing wall. Specifically, just as standards and quality used in creating masonry blocks used in MSE wall construction has improved over the years, the strength, durability, and longevity of geogrid materials also continues to improve year by year. The grid that was used in the original wall construction, when compared to materials available today, was significantly less durable and had a considerably lower allowable tensile strength. As such, significant loading introduced above the existing walls as part of the new construction would most likely overstress the existing grid, leading to a failure in the lower tier of the wall. The chosen approach achieved a balance of minimal new load being introduced as part of the proposed grade modifications with the construction of an overall new retaining system.

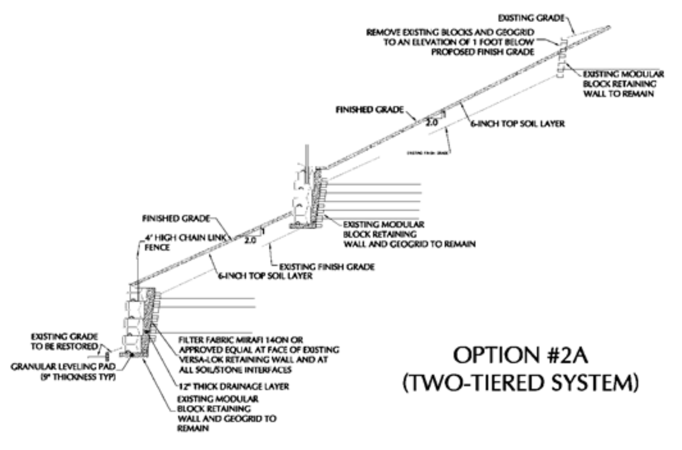

Figure 4: Typical Cross Section of Chosen Alternative

In order to verify the final design concept, the commercially available computer program MSEW was utilized in accordance with the National Concrete Masonry Associated (NCMA) design methodology. Additionally, global stability of the chosen alternative was evaluated using the program SLIDE, utilizing procedures specified by the Federal Highway Association (FHWA). Factors of safety used in the final design were as follows:

- Global Stability – 1.3
- Seismic Stability – 1.1
- Internal Stability – 1.5

REMEDIAL CONSTRUCTION PHASE

Once the alternative selection and final design phase was completed, construction of the new retaining system began in November 2008. Prior to any construction activities, the Contractor prepared the site by removing all trees on the middle of the slope between the first and second tier walls and grubbing topsoil in the areas where grading activities would take place.

Lower Wall Construction

In a staged approach, construction of the new retaining system began with the new wall in front of the lower tier wall, or wall "A". As excavation for the new wall was in front of the existing retaining wall and proposed to extend a bit below the toe of the existing wall, precautions needed to be taken by the Contractor to avoid undermining the existing structure. However, and despite the careful efforts to limit disturbance to the existing wall, the on-site sandy soils would frequently cave into the excavation and undermine the existing wall along the first few sections excavated. To combat the situation, the Contractor began to limit the work to 12-foot wide sections at one time. Additionally, survey monitoring points were established to monitor the stability of the existing wall system during construction.

Despite the precautions, there remained areas where maintaining the overall stability of the existing structure was still a challenge. At one location in the northeastern portion of the site, the subgrade soils beneath the existing retaining wall caved in resulted in a large section of the wall being locally undermined. To remediate the area, a 10-foot by 5-foot by 4-inch thick steel plate was placed in front of the failed blocks; the zone was then stabilized by pouring concrete behind the plate to replace the fallen blocks and to halt the soil from further raveling. Following this failure, the Contractor began using a trench box to assist with the excavation of the subgrade, and hand shovels were used from time to time to remove the soil in front and around the blocks of the existing wall. However, with the alignment of the wall having curvature in some locations, the trench box was not an option for all areas. As such, the Contractor continued to use the 10-foot by 5-foot plate as a temporary shoring solution in areas of curvature.

Upon reaching the proposed subgrade elevation along the wall alignment, the Contractor installed a filter fabric along the face of the existing retaining wall, to prevent migration of soils through the deteriorated blocks of the existing wall. A walk-behind plate tamper was then used to proofroll the proposed subgrade soils, which were disturbed during the excavation process. In order to protect the prepared subgrade from rain and other weathering conditions, a 9-inch thick layer of ¾-inch clean stone was placed on top of the subgrade.

As construction of wall "A" proceeded, the blocks were placed in rows, with each row staggering a half-block from the row below. Additionally, a 4-inch setback was developed on the façade of the wall for each row of block that was placed. The modular blocks where then filled in with ¾-inch clean stone. Filling the blocks with clean stone achieved several positive things. Specifically, the shear resistance between the blocks was increased and the overall mass of the wall increased, resulting in better wall stability. Additionally, the stone improved the drainage of the wall so that no hydrostatic pressure is developed behind the wall. Finally, as the blocks were installed, a 6-inch diameter encased perforated PVC pipe was also installed along the back of the wall for additional drainage. The PVC pipes were then routed to headers which projected under the new wall in selected locations, and tied into the existing site stormwater system.

Once the design wall height was achieved, the area between the back of the new wall and the front of the old wall was backfilled with ¾-inch clean stone. Along the top of the wall, PVC sleeves were installed at 10-foot centers. In these sleeves, the poles for the four-foot high chain link fence were cast in concrete. Finally, in January 2009, wall "A" was complete. Due to the relatively severe weather conditions associated with winter in New England, once wall "A" was completed, work at the site was halted until more favorable weather conditions returned in Spring 2009.

Upper Wall Construction and Slope Grading Activities

As construction of the second tier wall restarted in April 2009, the first order of business was to construct a temporary access road in front of the second tier wall to provide access to the Contractor to construct wall "B". The temporary road construction was started on the slope on the southern portion of the site and proceeded moving north. Grubbing and removing the topsoil from the slope was the first step for the construction of the temporary road. Using a relatively lightweight excavator, the Contractor proceeded to cut into the slope, allowing enough soil to remain in front of the existing second tier wall so its stability would not be jeopardized, while at the same time staying far enough away from the lower wall to avoid imposing excessive temporary surcharge loads. A photo of the temporary roadway construction is shown in Figure 5. Incidentally, this turned out to be one of the most critical aspects of construction-phase design. To verify that the temporary conditions during construction were safe, intermediate slope stability analyses were completed prior to the Contractor proceeding with the temporary roadway/bench.

The area between the two walls was gradually excavated, leveled and compacted using the excavator's bucket as a means of temporary densification of the subgrade. Temporary blocks were placed on top of the prepared areas to serve as benches, and to allow the Contractor to complete construction of the temporary road. A combination of excavated soils and imported fill material was then placed in 8 to 12-inch thick lifts and compacted with several passes of a walk-behind vibratory roller to a minimum of 95% of the soils maximum dry unit weight as determined by ASTM D1557. This process continued until the entire temporary access road was completed and the temporary road was wide enough to allow trucks, dozers and other construction equipment to safely operate on it.

Figure 5 – Construction of the Temporary Roadway between Wall "A" and Wall "B"

As the temporary road was completed, so too was the majority of the excavation required to construct the proposed retaining wall "B". The area in front of the existing middle tier wall was prepared by excavating to the proposed subgrade elevation and preparing it in a similar manner as described for wall "A". The filter fabric was installed in front of the existing middle retaining wall and the ¾-inch of crushed stone was placed for subgrade protection. Due to limited space and the need for the Contractor to operate equipment on the temporary access road, wall "B" was only partially constructed at this time.

Coincidental to wall "B" construction, the topsoil material on the slope starting in the northern portion of the site was grubbed and removed, and the existing third-tier retaining wall was partially demolished and hauled off-site. The exposed slopes were then regraded, generally to a slope on the order of 2H:1V. The slopes were established through the placement of compacted fill, similar to the criteria used to create the temporary road through the site. The grading work on the slopes then continued moving from north to south across the site. To provide a densified surface and stabilized slope face, the slopes were over-built and then cut back with a dozer, such that the firm, compacted soil slope was exposed at the design grades. Once the proposed grades were established, an erosion control blanket which was designed to facilitate vegetative growth on the face of the slope was then installed; see Figure 6. Also, as the slopes were being created, a 6-foot wide swale was constructed at approximately the midpoint of the slope to collect stormwater runoff down the face of the slope. Four yard drains were then installed along the alignment of the swale; the drains were then connected to the existing stormwater system on the site.

Once the slope work on the northern portion of the site was completed, the construction of wall "B" continued, with the Contractor moving south along the alignment of the new walls. As work continued moving south, the Contactor began to remove the temporary blocks placed to construct the bench for the temporary road and placed them on wall "B", following the same general placement procedures that were used for wall "A". By conducting the work in this manner, the Contractor had effectively completed all work in the northern portion of the site, and positioned himself to start "backing-out" of the site as construction for wall "B" continued. Slope grading and wall reconstruction then proceeded in tandem moving from north to south across the site until the grading and wall construction work was completed.

Figure 6 – Slope Stabilization Methods during Earthwork

One challenge that was encountered during slope grading activities was that between the months of July and August 2009, several heavy rain storms passed through the Southington area, often in very short periods of time. Due to the fact that no vegetation had grown on the eastern and southern portion of the site at this time; the heavy rain storms had eroded several areas along the slopes. Luckily, access to these areas was still viable along the temporary roadway, and the Contractor proceeded to remediate these eroded areas using the on-site fill material. Hydroseeding and erosion blankets were then re-installed in the remediated areas. Construction of the retaining walls and slopes was completed in mid-August, 2009; see Figure 7.

Figure 7 – Post-Construction Conditions

CONCLUSIONS

Complex project always have lessons learned, sometimes, good, sometimes bad, and sometimes both. In evaluating both the initial causes of wall deterioration at the site, looking at several potential reconstruction alternatives, and working through the construction phase to resolve issues as they arose, there are several lessons learned and conclusions that can be drawn from this project. In no particular order:

- Understanding all aspects of a construction material, whether it be long-term durability, short term strength, or many parameters in between, is paramount in assessing the long-term viability of a construction project.
- When considering implementing retaining wall technologies that are by industry standards "new", always be sure to consider the applicable construction and environmental conditions that could impact the performance of the system.
- Laboratory verification of design assumptions, particularly shear strength parameters, is critical to the successful performance of a retaining wall.
- Proper evaluation of construction-phase conditions during the design phase can determine whether a wall system can be successfully constructed.

ACKNOWLEDGEMENTS

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