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Rehabilitation of an Existing Mechanically Stabilized Earth Wall Using Soil Nails

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REHABILITATION OF AN EXISTING MECHANICALLY STABILIZED EARTH WALL USING SOIL NAILS

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Installation of permanent soil nails through distressed mechanically stabilized earth retaining walls is a cost effective and aesthetically pleasing solution when using the appropriate equipment and drilling methods for installation. A forensic investigation was performed on an existing mechanically stabilized earth retaining wall to determine the possible causes for the excessive horizontal displacements and visual structural flaws found along a portion of the wall. Reports concluded that the visual shifting was due to a number of factors including improper drainage in the vicinity of the wall and unsuitable compaction of the backfill material. Conceptual designs were proposed to the owner and the installation of permanent soil nails through the existing precast panels was determined to be the most practical solution. A total of ninety-three permanent soil nails were installed to lengths of up to 40 feet (12 m) through sand backfill and silty clay fill using a hydraulic rotary percussion drill attached to a tract mounted excavator.

Introduction

The Illinois State Toll Highway Authority awarded Contract RR-03-5144 in the summer of 2004. Construction work for the project consisted of the rehabilitation of two existing concrete culverts and approximately 100 linear feet (31 m) of mechanically stabilized earth (MSE) retaining wall. The retaining wall is located below the southbound lanes of the Tri-State Tollway near the intersection of Federal Highway 41 in Wadsworth, Illinois as shown in Figure 1.

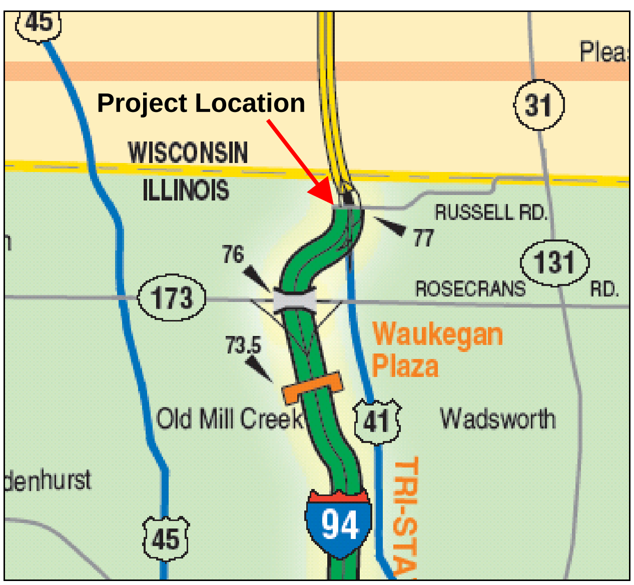

Figure 1 Project Location Map

Reports were prepared by Applied Technologies in cooperation with Giles Engineering Associates to determine the condition of the MSE wall and recommended conceptual designs to extend the service life of the wall.

Nicholson Construction Company (Nicholson) was selected as the design-build geotechnical subcontractor to install the recommended permanent soil nails through the existing precast concrete panels of the MSE wall. Rehabilitation of the wall involved the installation of ninety-three permanent soil nails through the existing wall, along with soil nail verification tests and proof tests on production nails.

Background History

Construction of the MSE retaining wall was completed in 1982. The total length of the MSE wall is 740 feet (226 m) along the footprint of a horizontal curve, with a radius of 1896 feet (578 m). The maximum wall height is 24 feet (7 m) with the grade in front of the wall being approximately 4 feet (1.2 m) above the bottom of footing elevation. Galvanized steel reinforcement straps either 14 feet (4.3 m) or 17 feet (5.2 m) long connect to the back of the precast concrete panels.

A portion of the MSE wall was built directly over an existing box culvert, 10 feet (3 m) wide and 7 feet (2.1 m) high. An inlet for the highway was constructed directly behind the top of the MSE wall and connected to a 15 inch (381 mm) diameter storm sewer that ran perpendicular and away from the retaining wall.

According to the wall manufacturer, displacements were noted shortly after construction of the MSE wall directly over the existing culvert. Unfortunately, a monitoring system was not put into place and no corrective measures were implemented on the wall after the displacement had occurred. Refer to Figure 2 for a typical cross sectional profile near station 1346+00.

Geological Conditions

Backfill material for the MSE retaining wall consists of fine to coarse sand and extends to the bottom of the MSE wall panels. The sand backfill is very loose to loose in the vicinity of the failing wall section and medium dense within the remaining sections.

Stiff to very stiff silty clay fill was encountered below the MSE wall backfill and within the retained soils behind the retaining wall. The depths of this soil ranged from 19 feet (5.8 m) to 33 feet (10 m) below the ground surface. A very stiff to hard natural silty clay soil was reported below the silty clay fill to the maximum depths explored. A perched groundwater table was determined to be near the ground surface in front of the displaced MSE wall section. Figure 2 shows a typical geologic section for the MSE wall near station 1346+00.

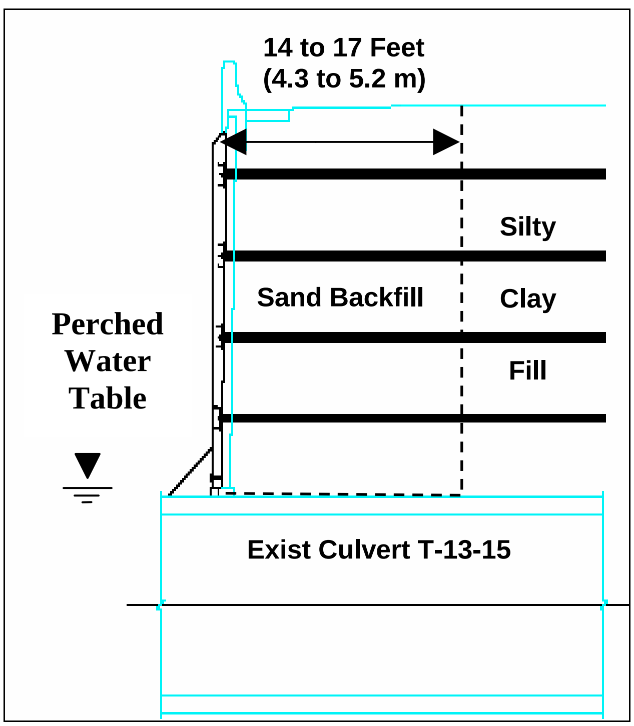

Figure 2 Typical Cross Section - Station 1346+00

Evaluation of Existing Wall

In 2003, Applied Technologies in cooperation with Giles Engineering Associates prepared documentation describing the condition of the existing MSE retaining wall. The reports summarized flaws within and surrounding the retention system that seemed to be concentrated between stations 1346+00 and 1347+00.

The following key information was contained within the forensic reports:

- Approximately 2 to 11 inches (51 to 279 mm) of horizontal displacement was reported within the height of the wall.
- The existing 15 inch (381 mm) storm sewer pipe was obstructed with debris, causing perched water near the ground surface in front of the wall.
- Sand backfill accumulated in front of the wall due to loss of ground within the MSE wall backfill.
- Very loose to loose sand backfill was sampled within the failing section while medium dense sand backfill was encountered in the remainder of the wall.
- Vehicular collision with concrete parapet occurred directly above the failing wall section.
- Concrete panels were grossly misaligned due to excessive horizontal displacements causing spalling at the edges near vertical shear pins.
- Notable settlement of the Tri-State shoulder above the wall indicated redistribution of soil within the sand backfill.

Photo 1 Pre-Construction Condition

Causes of the distress in the MSE wall were inconclusive in the reports, but undoubtedly a combination of the above factors caused the horizontal displacements.

Conceptual Design Suggestions

Applied Technologies narrowed down a compiled list of repair options to four, based on economics, aesthetics and constructability. In all scenarios the structural elements of the existing MSE retaining wall were to be ignored. Option A-1 consisted of installing one permanent soil nail per existing panel and shooting a reinforced shotcrete facing in front of the wall to adequately transfer the punching shear force of the soil nails. Option A-2 was similar to option A-1 with the exception of using a new reinforced concrete wall rather than reinforced shotcrete for punching shear resistance.

Options B and C entailed the installation of an anchored soldier pile wall in front of the existing wall using either sheet piling (option B) or precast concrete (option C) as lagging to resist the horizontal earth pressures.

Option A-2 was chosen because the cast-in-place reinforced concrete maintained the existing appearance of the MSE wall. Also, it was more economical to build option A-2, when compared to option A-1, based on preliminary cost estimates performed by the owner's engineer. Options B and C were eliminated due to aesthetics and vibration concerns based on conversations with the Illinois State Toll Highway Authority.

Soil Nail Design

There were three objectives for the soil nail wall design. One was to perform an internal wall analysis to determine required soil nail lengths for the existing ground conditions and wall geometry. Another was to confirm adequate punching shear resistance of the existing concrete panels for temporary face support along with verifying the design for bearing plate and studs. Finally, a global stability analysis for bearing capacity, overturning and sliding was performed.

Three design sections were used to economize the nail lengths for various wall heights and access constraints. The heights of the three design sections were 19 feet (5.8 m), 22 feet (6.7 m) and 23 feet (7 m). The 22 foot (6.7m) high section had horizontal soil nails over the existing box culvert. The horizontal and vertical spacing for the soil nails equaled the average dimension between precast concrete panels, 4 feet 11 inches (1.5 m).

Unit weights and friction angles for all three soil types were obtained from the design parameters in the project specifications and checked against the soil borings. Ultimate pullout resistances for each soil type were chosen based on the project borings and the geotechnical subcontractor's experience. Table 1 provides a summary of the design parameters for each soil type.

Table 1 Summary of Soil Design Parameters

Soil Type	Friction Angle degrees	Unit Weight pcf (kN/m^3)	Ultimate Pullout kips/foot (kN/m)	Allowable Bearing Pressure psf (kN/m^2)
Sand Backfill	34	125 (19.6)	5.3 (77.3)	N/A
Silty Clay Fill *(Behind Wall)*	30	125 (19.6)	2.6 (37.9)	N/A
Silty Clay Fill *(Below Wall)*	30	N/A	N/A	5000 (239)

The GoldNail program was used to analyze each design section for internal stability. GoldNail is a slope stability model based on satisfying overall limiting equilibrium defined by circular slip surfaces. Steel area and yield stress are input into the GoldNail program along with the proposed wall geometry, reinforcement locations and soil strengths.

Lengths of nails for each design section were determined through program iterations. As per the project specifications, a factor of safety for internal stability of one and a half and a factor of safety for soil nail pullout resistance of two were used as input parameters for the analyses. Existing reinforcement straps were ignored in the calculations as stated in the project specifications.

Structural calculations were performed to confirm the adequacy of the wall facing. Temporary punching shear capacity of the precast concrete panels was confirmed. Then, computations were completed for the permanent punching shear capacity of the headed stud connection with the reinforced concrete facing. Lastly, the tensile strength of the studs was verified.

A global stability analysis was also performed to conclude that a factor of safety of one and a half or greater existed for the revised retention system in regards to overturning, sliding and bearing capacity. Results showed that adequate safety factors were indeed present for the potential external failure modes.

Soil Nail Testing

Verification test nails were required according to the project specifications. Test nails would be installed toward the bottom of the existing wall for ease in setting up and testing. Verification test nail #1 was bonded into the silty clay fill with an unbonded length within the sand backfill. Verification test nail #2 was bonded only in the sand backfill material.

Test results from both verification nails showed a lower ultimate pullout resistance than used in the initial soil nail design.

The geotechnical subcontractor reviewed the test results and had the following thoughts regarding the unexpectedly low ultimate pullout resistances.

- Arching caused by the existing reinforcement straps from the MSE wall was reducing the confining stress to values below overburden pressures.
- Lower confining stresses limited the ability to effectively pressure grout the soil nails.
- Test nails installed near the bottom of the existing MSE wall experienced lower pullout capacities due to saturated/perched groundwater conditions.
- The ultimate pullout resistance values for the sand backfill and clay fill were overestimated during the initial design based on the existing soil conditions.

Three additional verification tests were performed to confirm the lower ultimate pullout resistances in the sand backfill and silty clay fill. Results of the supplemental verification tests confirmed the lower ultimate pullout resistances in both of the soil stratums. They also confirmed that there was indeed a saturated silty clay fill layer below the MSE wall, which resulted in a significantly lower pullout resistance for the bottom row of test nails. Table 2 summarizes the revised ultimate pullout resistances based on the verification testing.

Results from the verification tests were compiled and the soil nail wall design was reanalyzed. Ultimate pullout resistances for the sand backfill and silty clay fill were revised with the saturated silty clay fill added to the analysis to represent the soil below the wall. Revised soil nail lengths increased from the original design by approximately thirty-three percent.

Table 2 Revised Ultimate Pullout Resistances

Soil Type	Initial Ultimate Pullout kips/foot (kN/m)	Revised Ultimate Pullout kips/foot (kN/m)
Sand Backfill	5.3 (77.3)	3.3 (48.2)
Silty Clay Fill *(Behind Wall)*	2.6 (37.9)	2.4 (35.0)
Silty Clay Fill *(Below Wall)*	N/A	1.3 (19.0)

Construction

Project specific challenges for the soil nailing operation included entry points approximately 20 feet (6.1 m) above working bench elevation. Additional installation concerns were soil nails through granular backfill and potential conflicts with utilities, existing reinforcement straps and the concrete box culvert located directly underneath the wall.

The geotechnical subcontractor determined that a conventional drill rig would not be able to install a majority of the soil nails on this project due to the extreme heights of some of their entry points. A hydraulic excavator mounted drill was utilized in order to install the higher soil nails without special modifications being made to the work bench. The excavator mounted drill was a rotary percussion tool mounted on a mast which attached to a tract mounted excavator. The versatility and reach of the excavator drill mast allowed for proper soil nail installation.

Photo 2 Soil Nail Installation

Existing granular backfill underneath an active highway created concern for ground loss. The geotechnical subcontractor decided to use the duplex drilling method for soil nail installation. A major advantage to duplex drilling is that intimate contact between the bore hole and outer casing is achieved, minimizing ground loss. Duplex drilling uses an inner rod and an outer casing to simultaneously advance the bore hole. Water or air is circulated down through the center of the inner drill rod and returns upward through the annulus between the drill rod and outer casing removing drill cuttings.

The construction site posed a few geometrical constraints for the soil nail operation. An existing fiber optic line ran across the bottom row of soil nails. The fiber optic line was completely exposed prior to commencing soil nail operations and temporarily encased in a plastic sleeve during construction operations. Particular soil nail locations were adjusted in the field to miss the fiber optic line with the drill equipment.

A typical precast concrete facing for MSE retaining walls will have the reinforcement straps connect at up to six evenly spaced locations to the back of the panel. The reinforcement straps from the MSE wall were avoided by centering the soil nails within the individual concrete panels and allowing for only vertical inclination where appropriate.

An existing concrete culvert T-13-15, which was to be rehabilitated, was located directly below the bottom of the existing MSE wall and across three precast panel widths or an equivalent of 15 feet. The project specifications required that soil nails above the existing culvert were to be installed with no vertical inclination. A device was fabricated that attached to the precast panels and allowed for drilling of the soil nails. In addition, the device could be manipulated to retain the neat cement grout after soil nail installation was completed.

Quality assurance during construction consisted of testing five production nails to verify the allowable pullout resistances for all three soil types. The proof tests confirmed the allowable pullout resistances. Specimens of neat cement grout from the soil nails were also tested to confirm grout strength.

Conclusions

Permanent soil nails are a sensible solution for the rehabilitation and strengthening of MSE retaining walls that undergo serviceability failures. Installation techniques, specialized equipment and a design-build approach allow soil nails to be both an economical and less intrusive means for repairing MSE retention systems.

Photo 3 Post-Construction Condition

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