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STABILIZATION OF A FAILED HIGHWAY SLOPE: A MULTI-PHASED APPROACH

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ABSTRACT

A county road department in Southeastern Michigan was faced with the problem of stabilizing a slope along the Clinton River supporting a heavily trafficked roadway. The roadway and supporting slope had performed satisfactorily for over 50 years. However, a reinforced concrete seawall that had partially supported the slope deteriorated over time, contributing to progressive failure of the slope and resulting damage to the roadway. The site is situated within the glacial lake plain district of Southeastern Michigan. The site geology consists of approximately 7 feet of over-consolidated clays underlain by approximately 17 feet of normally consolidated glacial-lacustrine clays. Below the normally consolidated clay, highly over-consolidated sandy clay till and dense fine to medium sands are present. The sands contain a confined aquifer with a hydrostatic head on the order of 20 feet. The 14-foot high, 35 degree slope has experienced progressive, creep type movement since approximately the year 2000 resulting in settlement and cracking of the roadway shoulder and pavement. Maintenance procedures to maintain serviceability of the roadway created increased surcharge loads that appear to have precipitated further creep movement. Our analyses indicated the unreinforced slope possessed a factor of safety of approximately one or less with respect to global and direct sliding failure mechanisms under both drained and undrained conditions. A number of alternatives were considered to obtain the desired factory of safety values. Upon analysis, these alternatives were not considered satisfactory due to failure to meet the project objectives, typically cost and/or failure to obtain the desired factor of safety against slope failure. A multi-phased approach was selected that was aimed at both reducing the destabilization forces as well as increasing the resisting forces by replacing the upper portion of the slope with geogrid-reinforced lightweight, angular blast furnace slag, and intercepting the slope failure surface with passive piles extending into the highly over-consolidated sandy clay till and/or dense sands. This approach allowed the project objective to be met with the work being accomplished on schedule and within budget. A cost savings of approximately $400,000 was realized with respect to other stabilization alternatives.

INTRODUCTION

An approximately 250-foot long section of the South River Road embankment above the Clinton River west of the I-94 Expressway in Harrison Township, Macomb County, Michigan had experienced progressive slope movement with resulting pavement distress for several years. Ongoing maintenance activities performed by the Macomb County Department of Roads (MCDR) included placement of additional aggregate within the shoulder area and hot mix asphalt pavement within the traffic lane. The resulting surcharge load appears to have precipitated further creep movement of the slope. The maintenance activities were performed in response to pavement cracking and deflection due to continued downward and outward movement of the northern portion of the roadway.

Figure 1 shows a view of the area of concern taken from the south side of S. River Road facing northeast. The pronounced dip in the guardrail due to the previous ongoing movement of the embankment is visible.

Figure 1: Photograph Showing dip in the guard rail along north side of South River Road.

Within the study area, the South River Road embankment possessed a height of 14 feet and a slope angle of approximately 35 degrees (1.43 units horizontal to 1 unit vertical). A badly deteriorated reinforced concrete seawall/retaining wall was present at the toe of the embankment. Information regarding the age and structural characteristics of the seawall were not available. However, our visual observations indicated the structural integrity of the wall had been severely compromised and was no longer capable of resisting lateral earth pressure and surcharge loads generated by the roadway and embankment.

The strategy of the MCDR included reconstruction of the flexible pavement section east and west of the embankment failure area and installation of storm sewers along the alignment concur with the slope stabilization construction.

SITE GEOLOGY

The site area is situated within the glacial lake plain of southeastern Michigan. This area was generally submerged during the retreat of the Erie-Huron Lobe of the Wisconsin Glacier. The surficial geology of the area is associated with deglaciation and deposition within a proglacial lake environment during the Wisconsinan Stage of the Pleistocene Series glacial episode. Subsurface glacial drift materials within the study area typically consist of lacustrine sands, silts, soft, normally consolidated lacustrine clays and waterlain till. These deposits are generally underlain by unsorted overconsolidated clayey till. Glacial drift deposits underlying the study area reportedly range in thickness from approximately 80 to 120 feet (Nowlin, J.O., Water Resources of the Clinton River Basin, Southeastern Michigan, US Department of Interior, Geological Survey, 1973). The glacial drift is reportedly underlain by the Devonian Age Antrim Shale Formation.

The site geotechnical exploration revealed subsurface conditions consistent with the generalized site geology. The subsoil conditions encountered at the site are summarized as follows:

<u>Silty Fine Sand and Silty Fine Sand Fill:</u> Silty fine sand or silty fine sand fill was encountered to depths of approximately 2½ to 4 feet below the existing ground surface. The relative density of these materials ranged from very loose to loose with Standard Penetrometer Test (SPT) ASTM D1586 N-values of 4 to 9 blows per foot (bpf).

<u>Mottled Brown & Gray Silty Clay</u>: Mottled brown and gray silty clays were encountered to depths ranging from approximately 7 to 11 feet below the pavement surface. These soils were typically stiff to very stiff with unconfined compressive strengths ranging from 1 to 2½ tons per square foot (tsf) and natural moisture contents ranging from approximately 19 to 39 percent. The soil had a moist unit weight of approximately 130 pounds per cubic foot (pcf).

<u>Gray Silty Clays</u>: Normally consolidated gray silty clays were encountered at each of the boring locations to approximate depths of 23 to 24½ feet below the pavement surface. The gray silty clays were typically very soft to soft with unconfined compressive strengths ranging from 0.1 to 0.45 tsf and natural moisture contents of 31 to 45 percent. The moist unit weights for the samples ranged from approximately 105 to 125 pcf.

Atterberg limit (liquid and plastic limits) testing (ASTM D4318-10) produced liquid limits ranging from 44 to 40, plastic limits of 20 and plasticity indices of 20 to 24 indicating a Unified Soil Classification System designation of “CL”.

<u>Gray Sandy Clays</u>: Highly over consolidated sandy clays were encountered to depths ranging from approximately 23 to 28 feet below the pavement surface. The gray sandy clays were hard with unconfined compressive strength values of at least 4 tsf. The natural moisture contents ranged from 8 to 12 percent.

<u>Fine to Medium Sands</u>:

Fine to medium sands were encountered from depths of 24½ to 32 feet below the pavement surface to the maximum explored depth of 45 feet. The sands were typically medium dense to very dense with SPT N-values ranging from 28 to 71 blows per foot.

Groundwater was encountered in the borings during drilling at depths ranging from 24½ to 32 feet below the pavement surface. Upon completion of the drilling, groundwater was typically present at depths ranging from approximately 7 to 8 feet below the pavement surface. Based on the available, short-term groundwater level readings, the shallow aquifer within the fine to medium sands is under confined conditions with a piezometric head of approximately 17 to 18 feet.

EMBANKMENT SLOPE EVALUATION, PRE-STABILIZATION CONDITIONS

To evaluate the apparent progressive creep failure of the embankment slope, the embankment was analyzed in its present condition for relative factor of safety values against the following failure mechanisms:

- Direct sliding via the Two-Part Wedge method;
- Circularly cylindrical failure surfaces via the Modified Bishop Method of Slices;
- Lateral squeeze via the FHWA-NHI-00-043 Method.

During the analyses, an undrained shear strength value of 200 psf and a drained angle of internal friction value of 12 degrees were used for the very soft to soft silty clays.

The existing embankment was found to possess factor of safety values of less than 1 with respect to circularly cylindrical failure mechanisms under drained conditions and factor of safety values equal or less than approximately 1.1 under undrained conditions. The embankment was also found to have factor of safety values of less than 1 with respect to direct sliding under both drained and undrained conditions and approximately 1 with respect to lateral squeeze.

The slope stabilization objectives included obtaining a minimum factor of safety for global and direct sliding failure mechanisms of at least 1.3, preferably 1.5 or higher.

SLOPE STABILIZATION ALTERNATIVES

A number of conceptual design alternatives were considered to stabilize the existing embankment slope and obtain the desired minimum factor of safety values. The task of stabilizing the embankment slope was complicated due to the limited construction budget, restricted construction staging area available, the environmental sensitivity of the adjacent Clinton River, and the need to limit traffic disruptions to South River Road. In consideration of the instability of the existing embankment, the following four general slope stabilization alternatives were considered:

- Cantilevered and anchored sheet piling;
- Geogrid reinforced aggregate mattress without columnar reinforcement;
- Geogrid reinforced aggregate mattress with columnar reinforcement.
- Auger Cast in Place Secant Pile Retaining Wall.

The use of cantilevered hot rolled steel sheet piling was considered for stabilization of the embankment. Difficulties were encountered in attempting to limit lateral deflection of cantilevered sheet piling due to the thickness of the soft to very soft silty clays. Furthermore, experience indicates settlement behind cantilevered sheet piling may be as much as twice the lateral deflection. The use of anchored sheet piling was also considered. However, given the presence of very soft to soft silty clays to an approximate depth of 25 feet, typical drilled and grouted tieback anchors were not considered feasible. An anchored sheeting system consisting of a second row of sheet piling installed along the south side of South River Road to act as a deadman anchor was also considered. However, each of the sheet pile alternatives failed to meet the MCDR's budgetary constraints.

An auger cast in place pile (ACIP) secant pile retaining wall was also considered, a preliminary design consisting of an 18-inch diameter pile system placed on a 12-inch center to center spacing extending to a depth of approximately 30 feet was developed. This alternative achieved the required minimum factor of safety values for the various failure mechanisms. However, similar to the sheet pile alternatives, this method did not appear to meet the MCDR's budgetary requirements. We note that qualified secant pile wall contractors within the general project area appear to be limited. This limitation likely impacted the projected cost of the secant pile wall system.

The feasibility of the use of a geogrid-reinforced aggregate mattress constructed after undercutting the existing roadway subgrade to a depth of approximately 7 feet (i.e., slightly above the very soft to soft silty clays) was also evaluated. An aggregate mattress consisting of one to three inch nominal particle size lightweight blast furnace slag (BFS) aggregate reinforced with four layers of Tensar BX1300 biaxial geogrid was considered. The factor of safety of the geogrid-reinforced aggregate mattress with respect to a direct sliding failure mechanism was evaluated via the Two Part Wedge Analysis method (Design Procedure for Geosynthetic Reinforced Steep Slopes" by Dov Leshchinsky, Ph.D., January 1997, US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, Technical Report REMR-GT-23). The analysis indicates the geogrid aggregate mattress has a factor of safety of slightly less than one for both drained and undrained conditions with respect to a direct sliding failure mechanism. The relatively low factor of safety value resulted from the low shear strength of the very soft to soft silty clays and their inability to provide sufficient shear resistance to sliding of the overlying soil mass.

The global slope stability evaluation of the geogrid-reinforced aggregate mattress was performed using the Ensoft STABLPRO V3.0 software program. The program is based on the STABLPRO computer program developed at the Purdue University and was written for the general solution of slope-stability problems by a two-dimensional, limiting-equilibrium method. The program determines a factor of safety using the Modified Bishop Method of slices procedure. Using this analysis procedure, the geogrid-reinforced aggregate mattress-reinforced slope was found to have a circularly cylindrical failure surface factor of the safety of approximately 1.2 under undrained conditions and approximately 0.7 under drained conditions.

The factor of safety against the lateral squeeze failure mechanism was evaluated via the FHWA-NHI-00-043 Method. The results are presented in Figure 2 as factor of safety versus undrained shear strength (Cu).

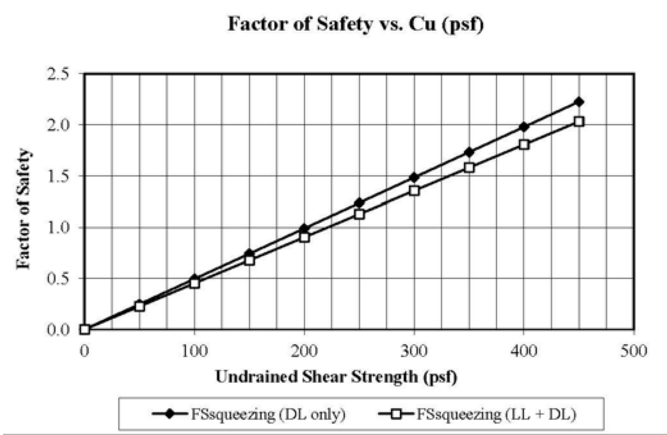

Figure 2: Factor of Safety vs. Cu (psf) for lateral squeeze analysis.

As shown on the graph, the FHWA lateral squeeze analysis indicates for the design undrained shear strength value of 200 psf, the embankment has a factor of safety of 1 with no live load surcharge included and less than 1 with a construction live load of 360 psf.

The modeling of the various potential slope failure mechanisms indicated it was not feasible to stabilize the embankment using only a geogrid-reinforced aggregate mattress. It became evident that a satisfactory slope stabilization method must intersect the respective potential shear failure slip surfaces to provide sufficient factor of safety values with respect to direct sliding, global stability, and lateral squeeze failure mechanisms.

MULTI PHASED APPROACH USING COLUMNAR REINFORCEMENT OF SOFT CLAYS WITH GEOGRID REINFORCED AGGREGATE MATTRESS

Upon evaluation of the various embankment stabilization alternatives, a columnar reinforced geogrid reinforced aggregate mattress was eventually selected for the South River Road embankment. Columnar reinforcement of soft ground beneath roadway embankments was the subject of a recent research project sponsored by the Virginia Transportation Research Council, the Virginia DOT, and Virginia Polytechnic Institute and State University (Report No. VTRC 06-CR13, June 2006). The research indicated that the columnar reinforcement method has great potential where highway embankments are constructed over soft ground such as encountered at the South River Road site.

The South River Road embankment stabilization system included the use of a geogrid-reinforced aggregate mattress and auger cast in place (ACIP) cement grout piles to intersect potential slip surfaces extending through the very soft to soft silty clays. As shown in Figure 3, two alternating rows of 16-inch diameter ACIP grout piles were placed at 8-foot on center within the north shoulder of the roadway. The piles were reinforced with a single No. 11 resteel bar and were extended to a depth of approximately 30 feet below the existing top of pavement, or 6 feet into the hard sandy clays and/or medium dense to dense fine to medium sands. The piles possessed a design 28-day compressive strength of 4,000 pounds per square inch (psi).

The aggregate mattress was constructed by placing a layer of 300 pound woven geotextile on the subgrade surface after undercutting to a depth of approximately 7 feet. A layer of Tensar BX-1300® biaxial geogrid was then placed on the woven geotextile. A 12-inch thick layer of 3"X1" lightweight blast furnace slag (BFS) was placed above the geogrid layer, followed by a second layer of geogrid. The remainder of the aggregate mattress was constructed by placing alternating layers of geogrid and 18-inch thick layers of 3"X1" BFS to the bottom of the proposed pavement section. Each layer of aggregate was seated by tracking thoroughly with a track bull dozer. Construction details for various phases of the stabilization process are shown in Figure 3.

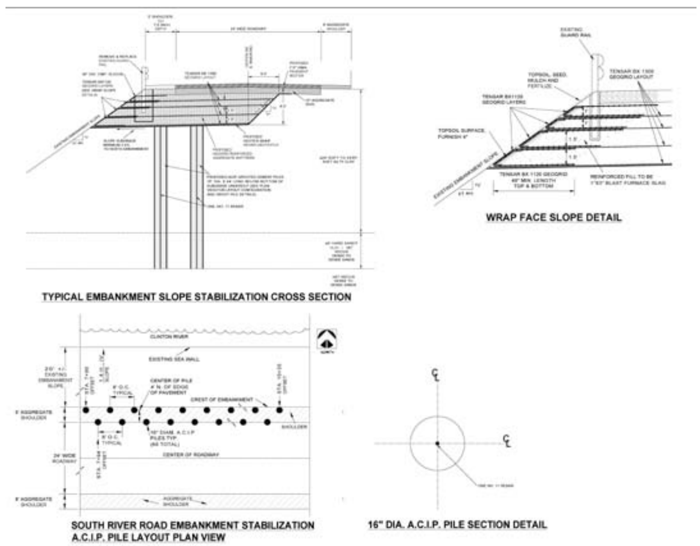

Figure 3: Construction details for various phases of the stabilization process.

The geogrid-reinforced aggregate mattress with columnar reinforcement alternative was analyzed by considering the composite shear strength of the grout pile columns and the soft to very soft silty clay soil matrix. The composite shear strength value was computed by calculating the weighted average of the respective shear strength values. The factor of safety with respect to a direct sliding failure mechanism was evaluated via the Two Part Wedge Analysis. The analysis indicated the system possessed a factor of safety of 1.5 for both drained and undrained conditions using geogrid lengths of approximately 25 feet. The critical failure surface for the direct sliding slip surface failure mode is shown in figure 4.

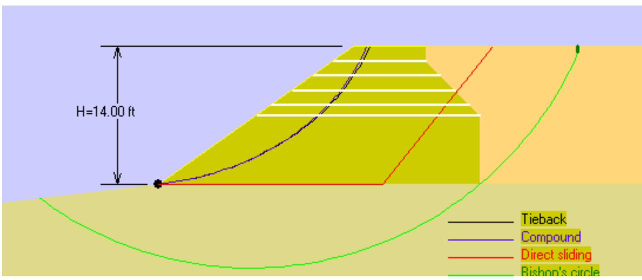

Figure 4: Critical failure surface for direct sliding slip surface failure mode.

The evaluation of circularly cylindrical failure surfaces for the aggregate mattress-columnar reinforcement system was performed using the Ensoft STABLPRO software program described above. The analyses indicate the factor of safety values are over 7 for both drained and undrained conditions. The results of the global stability modeling for drained conditions is shown below.

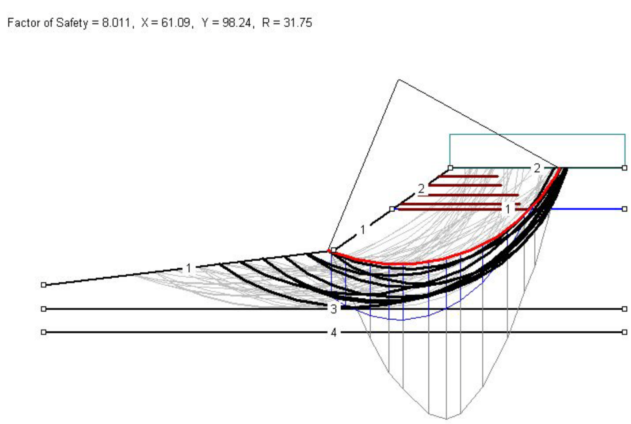

Figure 5: Evaluation of circularly cylinder failure surfaces for undrained conditions.

The factor of safety against the lateral squeeze failure mechanism was evaluated via the FHWA-NHI-00-043 Method. The results are presented in the figure 6 as graph of factor of safety versus undrained shear strength (Cu). As shown in figure 6, for a composite undrained sheet strength value of 2,000 psf, a factor of safety of over 8 is obtained for both dead load only and dead load plus live load conditions.

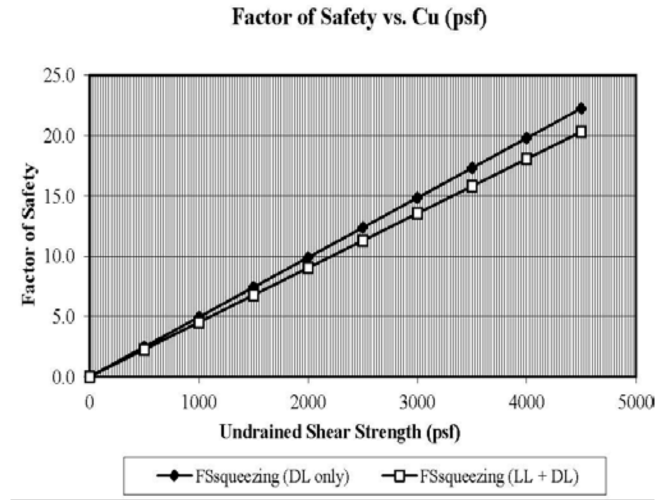

Figure 6: Factor of safety vs undrained shear strength for lateral squeeze analysis.

PROJECT STATUS

A formal, competitive bid process was conducted by the MCDR in September 2011. The bids were generally consistent with the engineer's estimate. The contract was awarded in mid-October 2011 and the project was completed on schedule in mid-November 2011. No significant problems or delays were encountered during construction.

At the present time the system appears to be performing in a satisfactory manner. The project budget did not include funding of post-construction instrumentation of the embankment slope. However, based on visual observations, the slope movement appears to have ceased and no pavement displacement or distress has occurred to date.

CONCLUSIONS

This paper describes the design and construction of an aggregate mattress-columnar reinforcement system for an embankment underlain by normally consolidated, soft to very soft, low plasticity silty clays within the glacial lake plain area of Southeastern Michigan. The project met the budgetary constraints of the local country department of roads and appears to be performing in a satisfactory manner.

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