Geotechnical Symposium on Slope Stability

Wednesday, April 19, 2017

Time	Topic	Speaker(s)
7:30 am – 7:45 am	Check-in	
7:45 am – 8:00 am	Welcome & Introductions	
8:00 am – 8:30 am	Fiber Optic Sensing Applications for Deformation Monitoring	Polly Brown Roctest, Ltd.
8:30 am – 9:00 am	Design of Fill Embankments Over Soft Foundations Near Waterfront Structures in Baltimore, Maryland	Tom Shafer, Jr., PE, Moffatt & Nichol
9:00 am – 9:45 am	Slope Stability Case History – Highway Embankment on Soft Soils	Tim Stark, Ph.D., PE, D.GE, F.ASCE; University of Illinois
9:45 am – 10:00 am	Break	
10:00 am – 10:30 am	The use of geocomposite drainage in slip repair along a 55 mile pipeline	Aaron MacNab AWD – American Wick Drains Kow Eshun, PE; Civil & Environmental Consultants
10:30 am – 11:00 am	Deformation of MSE Wall Constructed Using Fine-Grained Soils: A Case History	Mike Houlihan, PE Geosyntec Consultants
11:00 am –12:00 pm	Limit Equilibrium Design Framework for MSE Structures with Extensible Reinforcement	Professor Dov Leshchinsky University of Delaware (retired)
12:00 pm – 1:00 pm	Lunch	
1:00 pm – 1:30 pm	Stabilization of Cut Slope Failure in River Deposits Along the Monongahela	Corey Mislinski, PE GeoStabilization International
1:30 pm – 2:00 pm	Runout Parameter Estimation of Known Slope Failures: A Back-Analysis Approach	Kimberly Hummer, PE; Hillol Guha, Ph.D, PE; Jose Clemente Ph.D, PE, F. ASCE; Bechtel Nuclear Security Environmental
2:00 pm – 2:45 pm	Slope Stability Case History – Oso, Washington Landslide Analysis	Tim Stark, Ph.D., PE, D.GE, F.ASCE ; University of Illinois
2:45 pm – 3:00 pm	Break	
3:00 pm – 3:30 pm	Stabilization of SR38 Emlenton Hill Improvements	Jon Bennett, PE, D.GE Moretrench American Corporation
3:30 pm – 4:00 pm	North Dakota Slope Stabilization using Geopier Rammed Aggregate Piers®	James Hite, PE Geopier Foundation Company
4:00 pm – 4:30 pm	Assessment of Slope Stability of Century- Old Earth Dam Embankment	Bob Bruhn, PE GAI Consultants, Inc.
4:30 pm – 5:00 pm	Choosing Shear Strength Parameters for Potomac Clays in Conformance with 2014 AASHTO LRFD	Bill Billiet, PE Schnabel Engineering, Inc.

8:00 am – 8:30 am

Fiber Optic Sensing Applications for Deformation Monitoring; Polly Brown

Structural Health Monitoring provides accurate and real-time information concerning site conditions and structural performance. The need for monitoring instability in landslide and sinkhole prone areas, and other unstable zones has increased in the last few decades, stimulated by heightened risk adversity. Simultaneously, ambitious construction projects and ageing infrastructure introduce new uncertainties that must be properly addressed. These requirements have stimulated new developments in sensing technologies. Fiber optic sensing and conventional instrumentation used together provide a tool for integrity monitoring and direct, early detection of deformation. Distributed optical fiber sensing technology opens new possibilities in monitoring instability. Distributed deformation sensors (sensing cables) are sensitive at each point of their length to strain and temperature changes. When installed over the entire length of a large structure (levee, landslide, sinkhole area, tunnel, etc.), one-dimensional strain fields are recorded. These sensors are not only able to measure strain (the "how much" question), but can localize damage areas (the "where" question). They are ideal for monitoring structures where the location of instability would otherwise remain unknown. For example, they detect and localize the formation of cracks in a tunnel liner or the onset of a sinkhole. Traditional sensors used with fiber optic yield a greater understanding of an area's behavior. Long-gage deformation sensors allow static or dynamic measurements for structural analysis. Long-gauge sensors measure deformation or average strain over a measurement basis comparable to the size of a structural element, yielding values representative of the performance of the entire structural element, e.g. a column's axial load or a beam section's bending moment. Local defects, such as concrete cracks or material inhomogeneity, are accounted for in this averaging, but not addressed or identified individually. Finally, several large scale case studies are presented, including sinkhole detection, soil erosion detection, and strain changes generated by landslide movement.

8:30 am – 9:00 am

Design of Fill Embankments over Soft Foundations Near Water Front Structures in Baltimore, MD; Tom Shafer, Jr., PE

The paper presents the results of evaluation and design of fill embankments over soft foundations in the area of existing slips that are now being reclaimed to provide more yard area at several marine terminals owned by the Maryland Port Administration. The slips were previously used for such diverse uses as ship building, ship breaking, and cargo operations.
The paper describes four reclamation projects, all having soft alluvial soils. Design considerations include derelict structures, abandoned barges, permitting constraints, and the need to relocate existing storm drain outfalls. This paper describes the methods that were used to obtain soil samples from a barge, the sampling and testing procedures used to generate the soil design characteristics, and a description of the analysis and design for the phased placement of new fill. The details regarding the different procedures considered for removal and/or displacement of the soft soils to provide a suitable foundation for the proposed embankments are also outlined.

9:00 am – 9:45 am

Slope Stability Case History – Highway Embankment on Soft Soils

Tim Stark, Ph.D., PE, D.GE, F. ASCE

This presentation will describe failure of an interstate connecting-ramp embankment during construction and investigates the failure mechanism, performance of the prefabricated vertical drains (PVDs) installed to accelerate consolidation of the weak embankment foundation soils, and embankment stability analyses. The weak, fine-grained foundation soil experienced less drainage, and thus less consolidation and strength gain, than expected through the PVDs because of an overestimate of the horizontal coefficient of consolidation. The inverse stability analyses show the design over-estimated the shear strength of the embankment and foundation soils. In particular, the embankment fill strength was characterized using an undrained shear strength, i.e., cohesion, without a tension crack, which inflated the factor of safety.

10:00 am – 10:30 am

The use of geocomposite drainage in slip repair along a 55 mile pipeline

Aaron MacNab & Kow Eshun, PE

The Marcellus and Utica shale formations of Ohio, Pennsylvania and West Virginia are a source of relatively cheap natural gas. However, there have been challenges in infrastructure development due to slope stability issues. The stability issues focus in a 75 mile radius around the southwest corner of Pennsylvania and have been caused by a combination of ground water, surface water and inadequate placement and compaction of fill. During the construction of energy infrastructure, the historical groundwater flow patterns may be disrupted resulting in saturated, unstable fill. This case study will focus on the use of geocomposites in the remediation of slips along a pipeline right of way that bisect this slip prone area under consideration. Prefabricated geocomposite drains where used for subsurface drainage instead of geotextile wrapped aggregate. Several factures dictated the use of prefabricated geocomposites including site conditions, budget, safety, and timeline. At completion of the project, the prefabricated geocomposites met the subjective and objective performance criteria set-forth during design. Prefabricated geocomposite drains were used successfully in the remediation of slope failures on this pipeline right-of-way project and may be advantageous in preventing slips when installed on new pipelines.

10:30 am – 11:00 am

Deformation of MSE Wall Constructed Using Fine-Grained Soils: A Case History
Mike Houlihan, PE

Mechanically Stabilized Earth (MSE) walls have an outstanding record of successful service in the United States. Designers benefit from the availability of good design methods, technical support from material manufacturers, and numerous publications of the performance of MSE walls in a variety of conditions. However, some conditions represent significant challenges for designers of MSW walls, including the use of fine-grained soils in the reinforced zone of the wall. Use of such soils can result in significant post-construction deformation of the MSE wall, which can impair the ability of the wall structure to fulfill its intended function. This topic involves a site where approximately 2,000 linear feet of MSE walls, as high as forty feet and constructed using fine-grained soils, experienced significant post-construction deformation. The deformation caused substantial damage to the concrete block facing units on the wall, and impaired the function of features that were constructed on top of the fill retained behind the walls. In assessing the causes of the deformation, Geosyntec identified several problems that likely contributed to the wall deformation, including problems with the design of the walls and with the quality assurance provided during construction of the wall. Also, Geosyntec performed numerical analyses of the deformation of the wall and the concrete block facing units (using ABACUS and Plaxis) to assess the impacts of backfill material type, geogrid length and spacing, wall batter, soil-structure interaction, and the stresses acting on the individual concrete block facing units that resulted in the cracking of the blocks. The analyses explain the causes of the wall deformation and facing block cracking, and provide useful lessons for the design of MSE walls having fine-grained soil in the reinforced zone. The analyses also highlight the importance of good construction quality assurance and the need to plan for wall deformation during design.

11:00 am – 11:30 am

Assessment of Slope Stability of Century-Old Earth Dam Embankment; Bob Bruhn, PE

The Bradford City Water Authority Dam No. 3, commonly known as Marilla Dam, is a 47 foot high diaphragm-earth embankment structure located a few miles west of the City of Bradford in McKean County, Pennsylvania. The dam was constructed in the late nineteenth century to create a water supply impoundment for the municipality and continues in that capacity today. Although the dam had served its function admirably over the past hundred years, its stability had never been formally evaluated nor had the potential for overtopping. This prompted a detailed assessment and upgrade to the dam to meet state regulatory requirements. The drilling and testing program conducted to establish the types and properties of the embankment and foundation soils revealed soft zones within the embankment that were evidenced by Standard Penetration Test N-values near zero, accompanied by settlement of the drilling tools under their own weight. Difficulties experienced in procuring and testing representative “undisturbed” embankment samples prompted a program of dilatometer and borehole shear testing to more reliably define and characterize the soils. These in-place tests contributed greatly to a rational assessment of the stability of the dam embankment and to the design of cost-effective rehabilitation measures that are expected to extend the life of the dam for decades to come.

11:30 am – 12:00 pm

Choosing Shear Strength Parameters for Potomac Clays in Conformance with 2014 AASHTO LRFD; Bill Billiet, PE

A highway interchange project in southwest Washington, D.C. is underlain by cretaceous aged Potomac Group clays. They clays have low residual friction angles and have been the cause of several historical slope failures in the region. The selection of appropriate shear strength parameters for this material is important to developing an economical and safe design.

AASHTO LRFD requires that the subsurface soil properties be determined using in-situ testing during the field exploration, laboratory testing, and/or back analysis of design parameters based on site performance data. Consolidated drained repeated direct shear box tests (RDS) were performed on undisturbed samples of the Potomac Clay. The variability of the drained shear strength of the Potomac Clay was evaluated by determining the Coefficient of Variation (COV) of the test results across the site. Where the COV exceeded 25%, the authors describe dividing the site into “subsites” based on engineering judgment until the COV is less than 25%.

The authors also performed a sensitivity analysis in accordance with LRFD Commentary Section C10.4.6.1 using both the overall average residual friction angle and the residual friction angle reduced by one standard deviation. This approach allowed the authors to evaluate the sensitivity of the slope stability to variation in design residual friction angles.

By reducing the variation of the strength parameters and evaluating the sensitivity of the project elements to the proposed strength values, shear strength values for the Potomac Clay were selected that allowed for an economical design with an appropriate level of confidence in the safety of the systems.

1:00 pm – 1:30 pm

Stabilization of Cut Slope Failure in River Deposits Along the Monongahela; Corey Mislinski, PE

The Monongahela (a Native American word meaning 'falling banks') River meanders from Pittsburgh, PA to Morgantown, WV. Infrastructure developed along the river has a long-standing history of issues with slope and foundation stability.

An oil and gas exploration and production company was developing a new well pad just south of Morgantown, approximately 2,000 feet from the rivers edge. The development required a cut slope excavation to achieve the desired grades and well pad geometry. Soon after the excavation was complete, a landslide occurred directly upslope from the newly constructed well pad, and directly downslope from an existing gas meter station. To prevent the landslide from reaching the well pad or meter station, the Owner needed a quick and effective way to stabilize the slope and preserve their infrastructure.

This presentation will describe the chain of events leading to the landslide, the options considered by the Owner, and the solution that was selected to provide long-term stability of the slope.

1:30 pm – 2:00 pm

Runout Parameter Estimation of Known Slope Failures: A Back-Analysis Approach

Kimberly Hummer, PE; Hillol Guha, Ph.D, PE; Jose Clemente, Ph.D, PE, F. ASCE

Slope stability analysis is commonly performed on engineering projects, and the analysis establishes a factor of safety for an existing or engineered slope. Under extreme conditions, the slope may be unstable, resulting in failure leading to a landslide/mudflow/debris flow that may impact human life and/or engineered structures. Predicting runout, depositional thickness, and velocity of potential slope failures helps to guide engineered mitigating solutions before a slope failure happens.

Prior to undertaking runout analysis of potential slope failures, runout back-analysis of historical slope failures with a similar geology can be carried out to. Back-analysis provides estimation of calibrated geotechnical parameters by closely approximating the runout distance of a historical slope failure. We present here a back-analysis of a known historical landslide, identified by United States Geological Survey (USGS) in the valley and ridge province of Tennessee. Pre-slide surfaces of the identified historical landslide were estimated based on the existing topography, and a two-dimensional numerical simulation, using a dynamic landslide simulation software (DAN-W), was conducted to model landslide runout. A series of back-analyses were conducted varying the input parameters to closely match the runout distance of the historical landslide, as depicted on the USGS maps. The back-analyses revealed that the parameters are not unique, and varying multiple parameters can result in a similar runout distance. As a result, multiple sets of runout engineering parameters were determined, and these sets of parameters can then be used in the predictive modeling of other slopes in similar geology.

2:00 pm – 2:45 pm

Limit Equilibrium Design Framework for MSE Structures with Extensible Reinforcement
Professor Dov Leshchinsky, University of Delaware (retired)

FHWA has published in December 2016 a report titled "Limit Equilibrium Design Framework for MSE Structures with Extensible Reinforcement" (FHWA-HIF-17-004). This report, co-authored by the presenter, presents a methodology using a unified design approach for internal, external, compound, and global stability of geosynthetic-reinforced walls and slopes. It considers design of reinforced soil as a subset of slope stability analysis. Hence the presenter often refers to this approach as "Soil Reinforcement 101" although the technology was implemented commercially over 35 years ago and since then has been growing exponentially. The approach promotes a consistent and rational method to account for complex geometry, loading, and geotechnical conditions in the design of MSE walls. For a given problem including specified layout of reinforcement and permissible long-term strength of soil, it produces the reactive distribution of tensile force in each reinforcement layer. It also produces the required minimum load at the connection to the facing. It overcomes the disjointed analyses used in current design while rendering an assumption-free solution. Compared with AASHTO, the methodology results in much lower required force in the reinforcement and at the connection. Several instructive examples are presented illustrating aspects such as effects of facing units, closely spaced reinforcement, short secondary reinforcement layers, earthquake loading, and complex geometries.

3:00 pm – 3:30 pm

Stabilization of SR38 Emlenton Hill Improvements; Jon Bennett, PE, D.GE

As part of the reconstruction of SR 0038, Section A00, a roadway fill was constructed to accommodate realignment of SR 0038 between the I-80 Exit 42 interchange and the SR 0268 intersection near the bridge over the Allegheny River into Emlenton Borough. Structural retaining walls were constructed to support the realigned roadway along the steeply sloped hillside. The tallest of these Walls (Wall 4) consists of a tied-back soldier pile retaining wall requiring embedment into rock. Finite element models were created for each design height to analyze construction staging for the unique bottom up construction. This presentation discusses the intricacies of the wall design along with some of the challenges associated with its location along the steeply sloped hillside and includes the construction process, specialty equipment and unique procedures which were required to install the soldier piles, steel wales and the rock anchors using bottom-up construction methods.

3:30 pm – 4:15 pm

North Dakota Slope Stabilization Using Geopier Rammed Aggregate Piers®

James Hite, PE

The excavation for oil well pads in the rolling hills of the upper Midwest oil patch often means excavating in to the hills to allow for real estate for the oil pads. When this excavation is performed and the hills are then sloped at much steeper inclinations than the natural inclination with soft soil conditions, this often results in slope instability. Historically, the severity of these problems has been reduced using over-excavation and replacement of the soft soils at the base of the slope. Alternatively, structural solutions such as secant wall, soil nail, and/or tie back walls are also used but the use of these structural systems depend on the driving mass to be stabilized. More recently, *Rammed Aggregate Piers®* have been used to provide cost-saving alternatives to over-excavation and replacement, while also affording significant time schedule savings. The installation of Rammed Aggregate Piers reinforces weak slope base soils while establishing the slope final geometry. The installation of Rammed Aggregate Piers increases the factor of safety against slope instability as a result of the high angle of internal friction (48 to 52 degrees) achieved during ramming and also provides an increased unit weight within the toe of the slope to further increase the factor of safety against slope instability.

This presentation outlines a slope stabilization project case history discussing the use of Rammed Aggregate Piers to reinforce an existing landslide and slope near Killdeer, North Dakota. The design methodology is also illustrated in the case history discussion. This work is of particular significance because it provides project details and design recommendations for an effective ground reinforcement technique used to reinforce existing slopes and landslides. Additionally, the case history provides an option when aesthetics of the final slope and high schedule demands are required for a solution.

4:45 pm – 5:00 pm

Slope Stability Case History – Oso, Washington Landslide Analysis

Tim Stark, Ph.D., PE, D.GE, F. ASCE

This presentation describes investigation, testing, analysis, and slope history used to determine the two phase failure mechanism involved in the 2014 landslide near Oso, Washington. The first phase involved a slide mass located above the colluvium from prior landslides along the lower portion of the slope and extends to near the slope crest. This slide mass had a large potential energy, which moved downslope, and pushed the water filled colluvium toe across the valley resulting in it flowing almost 1.5 km and killing 43 people. Evacuation of the Phase I slide mass left the upper portion of the slope unbuttressed and oversteepened causing a second landslide (Phase II) that primarily remained on the source slope because the unsaturated upper soils did not undergo a significant strength loss like the water filled colluvium.