9th Annual Technical Forum

GEOHAZARDS IN TRANSPORTATION IN THE APPALACHIAN REGION

August 4-6, 2009
Lexington, KY

Hosted by:

The University of Kentucky:

The Kentucky Geological Survey

The Kentucky Transportation Center, Technology Transfer Program

Sponsored by:

CENTER FOR ENVIRONMENTAL, GEOTECHNICAL, AND APPLIED SCIENCES

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Embassy Suites Hotel, Lexington, Kentucky, August 4-6, 2009

TECHNICAL PROGRAM

August 4th

5:00 – 7:00 p.m. Exhibitor Set Up ***Foyer 3***
7:00 – 9:00 p.m. Registration and Reception ***Lobby Foyer and Coldstream 4 & 5***

DAY 1: August 5th

7:00 a.m. Registration: ***Lobby foyer***

7:00 a.m. Continental breakfast: ***Foyer***

8:00 a.m. Welcome: Tony Szwilski (CEGAS): ***Coldstream 3***

Opening Session: Landslides **Chair: Kirk Beach (ODOT)** ***Coldstream 3***

1) *Implementation of the ODOT Landslide Hazard Rating Matrix* – Randy Daub

2) *Seismic Refraction Survey near Wolf Creek Pass* Along US 160, South Fork, Colorado – Jim Pfeiffer and Kanaan Hanna

3) *Secondary Toppling and Rock Slope Failures in Tennessee* – Vanessa Bateman

4) *Tied-back Grade Beams for Stabilization of Route 7 in Jefferson Co. Ohio* – Stan A. Harris

10:00 a.m. BREAK

10:30 a.m.
Session 2: Seismic Issues: Earthquake Damage Response and Mitigation
Chair: Wael Zatar (RTI/Marshall) ***Coldstream 3***

1) *Ground deformation in New Madrid seismic zone great earthquakes: past and future* – Roy Van Arsdale

2) *Seismic Hazard and the Kentucky Seismic Strong Motion Network (KSSMN)* – Jonathan McIntyre, Zhenming Wang, and Edward W. Woolery

3) *Seismic Hazard Mitigation of Transportation Structures* – Issam E. Harik

12:00 p.m. LUNCH: ***Speaker* – Dave Harris, Kentucky Geological Survey** ***Coldstream 4 & 5***

1:30 p.m. Concurrent Sessions

Session 3: Instrumentation **Chair: John Stanton (USCE Nashville)** ***Coldstream 1***

1) *Embankment Load Tests On a Coal Ash Basin* – Tom Pace

2) *Wolf Creek and Center Hill Dams: Case Studies in the Value of Instrumentation* – Dewayne Ponds

3) *Instrumentation for Transportation Applications* – Kenneth M. Berry

Session 4: Mapping and Information Technology **Chair: Matt Crawford (KGS)** ***Coldstream 2***

1) *Incorporation of Seismic and Geotechnical Data Into a 3D Geologic Model of the Ohio River Valley Near Henderson, KY.* – William M Andrews Jr.,

2) *Building an Enterprise Database of Geotechnical Drillhole Records For Future Planning and Engineering Studies* – Gerald A. Weisenfluh and Bill Broyles

3) *GIS Tools and Information Sources to Help Assess the Potential For Geohazards to Transportation* – Demetrio Zourarakis

4) *Geology Along Kentucky's Roads and Parkways* – Dan Carey

3:15 p.m. BREAK

4:00 p.m. Concurrent Sessions

Session 5: Other Geotechnical Issues in Transportation
Chair: Vanessa Bateman (TDOT) ***Coldstream 1***

1) *Foundation Problems and Pyrite Oxidation In the Chattanooga Shale, Estill Co. Kentucky* – Warren Anderson

2) *Passive Treatment of Metal-Bearing Runoff/Seepage 101: An Overview of the Technologies* – James J. Gusek

3) *unknown title* – Dan Hurst

4) *Remediation of Pyritic Rock For the Interstate-99 Highway Project In Centre County, Pennsylvania* – Archie Filshill

5) *Practical Solution for a Cave Located on a School Campus in Central Kentucky* – Richard Wilson

Session 6: Mine Subsidence **Chair: John Kiefer (KGS)** ***Coldstream 2***

1) *Investigation of the Long Term Stability of Abandoned Room and Pillar Coal Mines* – Gennaro G. Marino

2) *Applied Mine Grouting Technologies* – Paul Painter and Kirk Beach

3) *Subsidence Misconceptions and Myths* – Richard E. Gray, Robert W. Bruhn, and David L. Knott

4) *Engineering-Geophysical Investigation of Abandoned Coal Mines Along Planned US-69 Pittsburg Bypass, Pittsburg, Kansas* – Kanaan Hanna and Jim Pfeiffer

Adjourn 5:45 p.m.

DAY 2: August 6th

7:00 a.m. Registration: ***Lobby Foyer***

7:00 a.m. Continental breakfast: ***Foyer***

8:00 a.m.

Session 7: Water Issues **Chair: Steve Brewster (USCE Huntington)** ***Coldstream 3***

1) *I-40 Toe Scour Protection System* – Joseph Bigger

2) *Correlation of Rock Quality Designation and Rock Scour Around Bridge Piers and Abutments Founded on Rock* – Tommy C. Hopkins and Tony L. Beckham

3) *Investigations of Karst Hydrogeology as a Technique to Minimize Karst Geohazards Transportation Corridors* – Jim Currens

4) *An Un-Natural Disaster – Taum Sauk Upper Reservoir Breach* – Nicholas G. Schmitt

10:30 a.m. BREAK

Session 8: Rockfalls **Chair: John Tomlin (Norfolk Southern Railway)** ***Coldstream 3***

1) *Engineering for the Wolf Creek Dam Rock Overhang* – Richard Wilson

2) *Rockfall Hazard Rating System for Railroads* – Roberto Guardia

3) *Case Study: Widening Dead Man's Gap* – John Tomlin

12:30 p.m. CLOSING REMARKS

GEOHAZARDS IN TRANSPORTATION IN THE APPALACHIAN REGION

ABSTRACTS

DAY 1

Opening Session: Landslides — Chair: Kirk Beach (ODOT)

Implementation of the ODOT Landslide Hazard Rating Matrix

Randy Daub, Professional Service Industries, Inc., randy.daub@psiusa.com

Landslides or embankment/slope failures occur on highways due to a variety of reasons. As a result of landslides, pavement surface may become undulated, developing cracks and dips, which could cause loss of driving control leading to car accident, fatalities and property loss. Thus, preventing slope failure by timely maintenance or repair/stabilization is the goal of the Ohio Department of Transportation (ODOT). However, with limited financial resources, ODOT is required to make rational decisions on the priority of different landslide (slope failure) maintenance and remediation needs. Therefore, a landslide hazard rating system is necessary.

The Office of Geotechnical Engineering (OGE) within ODOT has taken a proactive approach to developing a comprehensive Geological Hazard Management System (GHMS) to better manage data and activities related to planning, design, construction, and maintenance of both existing and new highway infrastructures that may be affected by geological hazards in Ohio, including landslides, rockfalls, abandoned underground mines, karst, and shoreline erosion. Specific to the landslide inventory, the University of Akron (UofA) was contracted by ODOT to develop a user-friendly form as part of site reconnaissance for collecting pertinent landslide site information. In addition, UofA developed a web-enabled, GIS-based landslide database in order for engineers or consultants to collect, sort, query, and manipulate the landslide information. Finally, UofA developed a field-validated, landslide hazard rating system to assign a numerical value to each landslide site based on both quantitative data and qualitative judgment. The numerical values will then be used to prioritize the landslide sites within each Ohio County.

Professional Service Industries, Inc. (PSI) was contracted by ODOT to implement the Statewide Database Population of Landslide Inventory and Risk Assessment in the summer of 2008. The population of the landslide inventory consisted of two phases, including an initial Pilot Study Program of three (3) counties (Phase I) and the completion of the remaining counties as part of the main inventory program (Phase II). PSI's scope of work includes:

- Initial Training
- Office Reconnaissance
- Interviews/meetings with ODOT County Managers/District Geotechnical Engineers
- Field Investigations and Data Collection
- Compilation of GPS data
- Database Entry
- Generation of Remediation Costs

My presentation will cover the implementation of the Landslide Inventory and Risk Assessment program, and the difficulties and hurdles experienced along the way. Although the data collection process for ODOT has only lasted approximately 9 months, many lessons have already been learned. Hopefully, other consultants and state DOT representatives can learn from the experiences of both ODOT and PSI.

References

Dr. Robert Liang, the University of Akron. "Landslide Hazard Rating Matrix and Database, A Draft Final Report," State Job Number 134615, October, 2007.

Seismic Refraction Survey near Wolf Creek Pass Along US 160, South Fork, Colorado

Jim Pfeiffer and Kanaan Hanna, Zapata Incorporated, Blackhawk Division, 301 Commercial Road, Suite B, Golden, Colorado 80401 Telephone: (303) 278-8700

Zapata Incorporated, Blackhawk Division conducted a seismic refraction survey on a road cut east of Wolf Creek Pass along US 160, South Fork, Colorado. The objective of the survey was to map depth to bedrock below the refraction lines and identify seismic velocities for the lithologic units. Four seismic refraction lines were acquired resulting in a total of 570 feet.

The field area covered a steep slope (> 40 degrees in some areas) of alluvium that had undergone mass movement. A vertical scarp approximately 15 ft high had formed in the middle of the slope. Above the scarp, the slope was covered by grass and small trees. Below the scarp, the material was exposed and loose, with large boulders. The sides of the road cut and drainage were bounded on both sides by rock outcrops and steep cliffs of volcanic rock.

The results obtained from the seismic survey were of good quality. The overburden P-wave velocities obtained from all four survey lines ranged between 1,600 ft/s and 4,400 ft/s, refractor P-wave velocities ranged between 7,000 ft/s and 13,000 ft/s, and depth to the top of the interpreted bedrock ranged between 5 ft and 30 ft bgs. The seismic data also agreed relatively well with the available drill hole information. The information obtained from the study was used during the site geotechnical evaluation and remediation effort.

The significant results and findings obtained from this study will be presented.

Secondary Toppling and Rock Slope Failures in Tennessee

Vanessa Bateman, Tennessee Dept. of Transportation, 6601 Centinnial Blvd., Nashville, TN 37243-0360 Telephone: (615) 350-4137 Email: vanessa.bateman@state.tn.us

Rockfall classification and failure analysis involves the classification of the failure type at a site. Classical rock mechanics identifies three main structural failure modes, planar, wedge and toppling. Following this model Tennessee's rockfall hazard rating system explicitly identifies the following five failure modes: planar, wedge, topping, raveling (due to general weathering) and differential weathering. However, there are many sites in Tennessee that have a more complex failure mechanism where toppling of a large "column" of rock is induced by the undercutting of part of the slope. This is most often due to differential weathering rates of rock where a more resistant rock overlies a weaker rock that weathers at a much greater rate: weathering frequently exaggerated by the presence of water. This more complex failure mode, identified by Hoek and Goodman as secondary toppling, produces much larger rock slope failures that might be otherwise assumed by a differential weathering failure. When weaker rock underlies more resistant rock and there are stress relief fractures or parallel to sub-parallel joints/faults, rock slope failures can be substantially larger than that expected for differential weathering problems and these failures can occur in near horizontally bedded sedimentary rocks. Tennessee has experienced several large volume rock slope failures from secondary toppling and has a number of rockfall sites with this failure mode, primarily occurring in near horizontally bedded sedimentary rocks where shale or shaly limestone underlies more resistant limestone or sandstone along roads that traverse from the Highland Rim up to the Cumberland Plateau.

Tied-Back Grade Beams for Stabilization Of State Route 7 in Jefferson County, Ohio

Stan A. Harris, Stantec Consulting Services, Inc., 11687 Lebanon Rd., Cincinnati, OH 45241 Telephone: (513) 842-8200 Email: stan.harris@stantec.com

JEF-7-22.0 is a four-lane road approximately 2 miles north of Steubenville, Ohio in Jefferson County. The road was raised approximately 10 feet in elevation in the 1960's. The road began showing signs of instability approximately 10 years later. Signs of instability in the form of pavement dips, tension cracks and guardrail displacement continued until the remediation plans were implemented. Approximately 600 feet of roadway was impacted. Subsurface explorations were performed by ODOT in 1999 and 2002, and by Stantec (formerly FMSM) in 2004 and 2006. The explorations consisted of advancing sample borings and the installation of slope inclinometers and piezometers.

The subsurface materials encountered in the borings are commonly associated with landslide activity along State Route 7. The landslide movement appeared to be due to loading from the additional roadway embankment and fluctuations of the Ohio River. Slope inclinometer data indicated the failure was occurring along a plane of weakness through the underlying alluvial/colluvial materials.

The stabilization scheme consisted of a series of three rows of grade beams tied-back with prestressed rock anchors.. A total of 224 anchors with design loads of 195 kips were installed. Project challenges included the adjacent railroad, the presence of existing drainage structures and maintenance of traffic. It is estimated that over $500,000 was saved by using grade beams instead of drilled shafts as has been common practice.

Session 2: Seismic Issues: Earthquake Damage Response and Mitigation
Chair: Wael Zatar (RTI/Marshall)

Ground deformation in New Madrid seismic zone great earthquakes: past and future.

Roy Van Arsdale, Department of Earth Sciences, University of Memphis, Memphis, TN Telephone: (901) 678-4356 Email: rvanrsdl@memphis.edu

The New Madrid seismic zone encompassing parts of Illinois, Kentucky, Tennessee, Missouri, and Arkansas experienced at least three M 7.5+ earthquakes during the winter of 1811-1812. Some of the earthquakes were felt along the eastern seaboard of the United States. Although the magnitudes of these earthquakes are still debated, the regional ground deformation reveals very large intensities. Fault displacement and resultant earthquakes caused liquefaction, ground fissures, and lateral spreading over large areas of southeastern Missouri and eastern Arkansas, landslides along the eastern bluffs of the Mississippi River valley from northwestern Kentucky south to Memphis, Tennessee, and permanent ground warping in western Tennessee, southeastern Missouri, and eastern Arkansas. The recurrence interval of these large earthquakes is approximately 500 years and so we should expect comparable ground deformation in the future. Mapping of bedrock faults and near-surface geology, allows us to better predict the impact that future faulting and earthquakes will have on the region's landscape and transportation systems.

Seismic Hazard and the Kentucky Seismic Strong Motion Network (KSSMN)

Jonathon McIntyre[1], Zhenming Wang[1], Edward W. Woolery[2], [1]Kentucky Geological Survey, University of Kentucky, Lexington, KY, 40506 Telephone: (859) 323-0563 Email: jonathan.mcintyre@uky.edu
[2]Department of Earth and Environmental Sciences, University of Kentucky, Lexington, Kentucky 40506 Email: woolery@uky.edu

The Kentucky Geological Survey (KGS), in cooperation with the Department of Earth and Environmental Sciences of the University of Kentucky, operates the Kentucky Seismic and Strong-Motion Network (KSSMN), which has been operated continuously since the 1980's. KSSMN consists of 12 permanent short-period seismic stations, 9 strong-motion stations (including vertical arrays), and 7 temporary short-period seismic stations. The main purposes of the network are 1) monitoring earthquakes and other activities (i.e. mine blasts) in and around the state, 2) accumulating data for seismic hazard and

risk assessment and scientific research, and 3) providing real-time earthquake information to emergency managers, state and local officials, and the public online at http://www.uky.edu/KGS/geologichazards/equake3.htm. A significant addition to the KSSMN is the Central United States Seismic Observatory (CUSSO). CUSSO will consist of a 595-meter (1950-ft) cased borehole that extends from the ground surface, through 585 m (1920 ft.) of unlithified sediment, and into the bedrock. Various sensors will be placed within the borehole at various elevations and in existing boreholes at the site to record weak and strong ground motions. Five significant technical contributions to earthquake engineering are ultimately expected from the final configuration of CUSSO: 1) evaluation of the effect of deep soil conditions on earthquake ground motions, 2) characterization of the dynamic soil properties of sediments in the New Madrid Seismic Zone, 3) evaluation of current analytical models for deep soil sites. Several analytical models are currently being used to predict the seismic response of deep soil sites; however, these analytical procedures have not been validated for sites deeper than 100 m (i.e., design engineers cannot be confident in their predictions), 4) evaluation the recommended provisions of NEHRP, as they pertain to the New Madrid Seismic Zone, 5) study of lateral propagation effects and spatial variation in ground motions.

The accumulated data from KSSMN enable us to better define, assess, and communicate seismic hazard and risk in Kentucky and the central US. KGS has worked with federal and state agencies, engineers, and others to develop better engineering designs or policies for seismic hazard mitigation and risk reduction in Kentucky.

Seismic Hazard Mitigation of Transportation Structures

Issam E. Harik, University of Kentucky, Dept. of Civil Engineering, 371 O.H. Raymond Building, Lexington, KY., 40506-0281 Telephone: (859) 257-3116 Email: iharik@engr.uky.edu

Rapid assessment of a transportation structures' safety and functionality is a crucial procedure in restoring vital lifeline routes after a hazardous events. However, executing preparatory actions before a hazardous event occurs, and conducting feasible remedial actions during and after such an event, is also essential to the structures safety. This paper introduces a process for hazard mitigation of transportation structures through the example of an application of earthquake mitigation to highway bridges. Earthquake mitigation consists of three components: pre-earthquake, during-earthquake, and post-earthquake mitigation. Pre-earthquake mitigation consists of a seismic evaluation of all applicable bridges and a prioritization of the seismic vulnerability of these bridges. Simultaneously, pre-earthquake mitigation requires the implementation of earthquake-response training programs for the necessary earthquake-response personnel. Unlike hazards such as hurricanes, floods, etc., the short duration and unpredictability of earthquakes, no form of "during-earthquake" mitigation is possible. Post-earthquake mitigation consists of the use of post-earthquake investigation methodologies that assigns a bridge safety-rating to effected bridges to assist in posting or closing bridges to traffic. The methodology and concepts presented herein can be extended to all forms of man-made and natural hazards.

Key Words: Hazards, Natural, Man-Made, Transportation, Structures, Mitigation, Planning.

Session 3: Instrumentation — Chair: John Stanton (USCE Nashville)

Embankment Load Tests on a Coal Ash Basin

Tom Pace,

Two large-scale test fills were constructed on an active ash pond to gauge the response (settlement, lateral deformation, and pore pressure generation/dissipation) of the basin deposits to embankment loadings. The ash pond is located at a coal-fired generating station in central Kentucky. The embankment tests were monitored with inclinometers, magnetic extensometers, and vibrating wire piezometers. Survey-grade GPS equipment was also used extensively in the embankment tests. The

embankment tests were supplemented by borings, vane shear tests, cone penetration tests, and borehole geophysics. A pump test was also conducted to characterize the permeability of the ash. The field tests were undertaken to support the design of a vertical expansion to the ash basin, wherein the existing containment dam will be raised 60 ft. Site constraints will require constructing the embankment over fly ash and bottom ash deposits that are over 100 ft deep. The test embankments were constructed of transported bottom ash and reached average heights of 20 and 23 ft. Significantly, pore water pressures generated by the embankment loading dissipated rapidly (within a few days) due to the relatively high permeability of the ash. The embankment tests conclusively demonstrated that the proposed construction will be feasible. Lessons learned from this project on the use of instrumentation will also be presented.

Wolf Creek and Center Hill Dams: Case Studies in the Value of Instrumentation

Ponds, Dewayne A.[1,*], Zimmerman, Pete[2], Elson, Mark[3], [1] ARCADIS, 1210 Premier Drive, Chattanooga, TN 37421, [2] ARCADIS, 1210 Premier Drive, Chattanooga, TN 37421, [3] Army Corps of Engineers, Nashville District, 801 Broad St., Estes-Kefauver Building, Nashville, TN 37203

Wolf Creek and Center Hill Dams are high profile projects with dam safety concerns. Both projects have roadways across the earthen embankments which if there were a need for road closure, would create a burden on a number of industries and the public over all. Current construction is ongoing at both projects to mitigate the dam safety issues. As part of this effort, instrumentation has been installed at both projects to monitor the stability of the earthen embankments during grouting and cutoff wall construction. Inclinometers and extensometers are monitoring for movement in the embankments due to existing stability issues and any changes that may be introduced due to construction activities. The inclinometers were installed through the embankment and anchored into rock. Extensometers were mounted to the outside of the inclinometer casing and set at specific elevations based on embankment material conditions noted during drilling. These instruments were then grouted in with a grout mix which approximated the characteristics of the surrounding embankment material. The instruments were installed to indicate movement in three directions; movement along the centerline of the roadway, movement perpendicular to the centerline and changes in elevation of the roadway. These types of instruments and monitoring efforts can be applied to roadways on earthen embankments whether they are part of a dam or a standalone structure with the need for stability monitoring.

Instrumentation for Transportation Applications

Kenneth M. Berry, P.E., URS Corporation

This presentation focuses on case histories where geotechnical and structural instrumentation were used in transportation related projects. Applications include instrumentation for landslide investigations and repairs (both within soil overburden and bedrock) along highways, bridge monitoring, and the construction of an airport runway. The types of instrumentation selected and monitored were based on geologic, topographic, and site conditions. The presentation will discuss the applicability for the various instrument types and briefly discuss data acquisition options.

Session 4: Mapping and Information Technology — Chair: Matt Crawford (KGS)

Incorporation of seismic and geotechnical data into a 3D geologic model of the Ohio River Valley near Henderson, Ky.

William M Andrews Jr., Kentucky Geological Survey, University of Kentucky, 228 MMRB, Lexington, KY, 40506 Telephone: (859) 323-0506 Email: wandrews@uky.edu

Application of detailed geological information is critical for avoiding certain hazards and geotechnical issues in transportation and construction. However, that detailed information is commonly delivered in a format and vocabulary designed for use by geologists, and in some cases does not acknowledge the differing vocabulary and data-input needs of the engineering and geotechnical community. Continuing advances in GIS technology and desktop computing are allowing more sophisticated and detailed three-dimensional datasets to be developed. The Kentucky Geological Survey is working to develop a detailed 3D geologic model of Henderson County, Ky., which incorporates seismic and geotechnical data to produce applied derivative geologic maps useful to the geotechnical community and seismic hazard planners.

This effort is possible because of a long legacy of effective mapping and data collection projects at the KGS. A joint USGS-KGS program (1960–78) produced complete 1:24,000-scale geologic mapping coverage for Kentucky. Between 1996 and 2004, KGS personnel digitized those maps into vectorized GIS formats available for geospatial analysis and cartographic production. Since the early 1980's, KGS has been actively involved with industry and public agencies in the development of geologic databases of water, oil and gas, and coal information. More recent efforts have included the development of a geotechnical database in cooperation with the Kentucky Transportation Cabinet and collection of shear-wave refraction-profile data in collaboration with University of Kentucky and KGS seismologists and graduate students. The integration of these diverse and extensive data sets with the comprehensive geologic map coverage, supplemented by new field mapping in areas of high priority and need, has provided KGS a unique opportunity to develop detailed 3D geologic data in a very cost-effective manner. In the Ohio River Valley near Henderson, Ky., the 3D model has been used to produce seismic ground-condition maps useful for seismic hazard analysis and emergency response planning; they could be used for geotechnical data-collection planning as well. A series of maps based on the architecture of geologic deposits and their geologic and geotechnical parameters, with the appropriate vocabulary and terminology for the target audience, is being produced and distributed to key users by KGS.

Building an enterprise database of geotechnical drillhole records for future planning and engineering studies

Gerald A. Weisenfluh[1,*] and Bill Broyles[2], [1] Kentucky Geological Survey, University of Kentucky, 228 MMRB, Lexington, KY, 40506 Telephone: (859) 323-0505 Email: jerryw@uky.edu [2] Kentucky Transportation Cabinet Materials Branch, Frankfort, KY.

In the course of making design recommendations for State transportation construction projects, Kentucky Transportation Cabinet Geotechnical Branch staff routinely collect drillhole data and perform observations and analyses of rock and soil material. All of the associated data from this drilling and testing are currently recorded on a variety of forms and filed as hard copy with project records or, in some cases, disposed of after project completion. In order to facilitate the reuse of this legacy information and to provide easy access for Cabinet personnel and consultants, computer and Web applications have been developed to enter and track project information, archive drillhole data to a central database, and make the information available on the Internet.

The system has three components. The first is a Web application used to create and describe geotechnical projects, track their progress, and archive final reports. Descriptions of approximately 6,000 projects have been added to this database. The second component is a gINT software application developed to enter drilling and testing results for each project. PLog Enterprise software is used to archive the individual gINT projects to an enterprise database. The third application is a series of Web programs (kgsmap.uky.edu/website/kytcLinks.asp) for searching and displaying project descriptions and their associated drillhole information.

GIS Tools and Information Sources to Help Assess the Potential For Geohazards to Transportation

Demetrio Zourarakis, Division of Geographic Information, Commonwealth Office of Technology, 120 Glenns Creek Rd., Frankfort, KY 40601 Telephone: (502) 564-2480 Email: demetrio.zourarakis@ky.gov

Regional and site-specific information on the location and nature of potential geohazards relevant to transportation can often be found in geospatial data warehouses, portals, and viewers. This session will introduce the basic concepts of geographic information systems (GIS), the data models, and information layers relevant to geohazards. In addition to this, sources of information on the Web and internet and some of the capabilities that current desktop GIS software offers for analysis and mapping will be explored. ESRI's ArcGIS suite of software products and extensions offers a seamless environment for analysis and mapping, and will be used as the paradigm of a GIS. The spatial layers and services published and maintained in various sites, with emphasis on the Kentucky Geography Network (KYGEONET), will be used as an example of a comprehensive, accessible, and robust data provisioning service.

Geology Along Kentucky's Interstates and Parkways

Carey, D.I., Noger, M.C., Haney, D.C., Greb, S.F., Dever, Jr., G.R., Kentucky Geological Survey, University of Kentucky, 228 MMRB, Lexington, KY, 40506-0107 Email: carey@uky.edu Telephone: (859) 323-0529

Roadcuts along Kentucky's Interstates and parkways provide a view that spans the geologic history of the state, from the Ordovician through the Silurian, Devonian, Mississippian, and Pennsylvanian. On the older roads, many roadcuts have revegetated. In an effort to capture this geologic data before it is lost, KGS geologists have documented and described the geology of the highway roadcuts. The observed and interpreted geology at a given mile marker was recorded. Using the now-available 1:24,000-scale digital geology of the state, strip maps have been created on which to depict those notes. Photos and diagrams illustrate the notes and complement the maps. Geology, geologic resources, and landscapes are pictured and discussed. Each 13.2 x 17 inch sheet represents about 13 miles of the road at a scale of 1: 48,000.

These roadway geologic atlases have been designed to appeal to ordinary travelers, geologists, and those involved with highway transportation. The Western Kentucky Parkway, Blue Grass Parkway, and I-64 East span the geology of the state from west to east and will be produced first. Roadlogs for the Mountain Parkway/Ky. 114/U.S. 23 and the Cumberland Parkway/Ky. 80/Daniel Boone Parkway are under way. Previous versions of I-65/71 and I-75 will be updated to the new format.

The atlases will be available as PDF files, and can be printed at 8½ x 11 inches on a color home computer printer at a scale of ~1:75,000.

Session 5: Other Geotechnical Issues in Transportation (TDOT) — Chair: Vanessa Bateman

Foundation Problems and Pyrite Oxidation in the Chattanooga Shale, Estill County, Kentucky

Warren H. Anderson, Kentucky Geological Survey, University of Kentucky, 228 MMRB, Lexington, KY, 40506-0107 Email: wanderson@uky.edu Telephone: (859) 257-5500

Pyrite oxidation in the Chattanooga Shale has caused serious foundation problems in numerous buildings and structures in Estill County, Ky. Pyrite oxidizes and various secondary sulfates form when excavated shale or shale fill are used in foundations or as road base. These secondary sulfates are water- and humidity-sensitive and can form when only minor amounts of water

are present in foundation materials. These sulfates form by crystal growth and expand by volume change, which causes subsequent soil expansion and heaving of any foundation materials when the materials are confined. Several structures have undergone expensive remediation to repair damaged sidewalks, floors, walls, and foundations. Zones of high concentrations of pyrite occur in the Chattanooga Shale across the state, and these mineral zones may be responsible for the high pyrite content in Estill County.

Passive Treatment of Metal-Bearing Runoff/Seepage 101: An Overview of the Technologies

James J. Gusek, P.E., Golder Associates, Inc. 44 Union Blvd., Suite 300, Lakewood, CO 80228
Email: jgusek@golder.com

There are basically three kinds of passive treatment technologies for treating runoff or seepage containing metals and acidity. These technologies were developed by the mining industry and have application in almost any situation where low pH and elevated metals are found in post-construction runoff or seepage – even after vegetation has become established. ***Aerobic Cells*** containing cattails and other plants are typically applicable to runoff where only iron and manganese and mild acidity are problematic. ***Biochemical Reactors*** (BCRs) are typically applicable to base and heavy metal bearing runoff with high acidity/low pH and a wide range of metals. Lastly, abiotic, ***Limestone-Based*** methods for treating net-acidic runoff have been effective in adding alkalinity. Most passive treatment systems employ one or more of these cell types. The track record of aerobic cells and limestone-based methods in treating coal mine drainage is impressive, especially back in the eastern coalfields of the US. BCRs have been used at metal mines and coal mines but have not seen as wide an application.

This paper presents the advantages and disadvantages the various passive treatment approaches and is an introduction to the wide range of remediation design options available to practitioners of passive treatment. Rather than propose “cookbook” designs, the paper details a recommended staged-approach of laboratory-, bench-, and pilot-scale testing which has been shown to increase the likelihood of a successful design, especially for runoff waters with complex chemistry.

Additional Key Words: Constructed wetlands, acid seepage, heavy metals, sulfate reducing bioreactors

Unknown title

Dan Hurset

Remediation of Pyritic Rock For the Interstate-99 Highway Project In Centre County, Pennsylvania

Archie Filshill, CETCO Contracting Services Co., Philadelphia, PA. Email: archie.filshill@cetco.com

This paper summarizes the Design/Build in-situ and landfill remediation of contaminant-bearing pyritic rock using geosynthetics as implemented for the Pennsylvania Department of Transportation (PADOT) on the Interstate-99 Corridor/State Route 6220 project.

The project involves the construction of a four-lane limited access highway with 4 interchanges and approximately 18 miles of roadway. During construction, large volumes of pyrite-bearing sandstone were exposed to air and precipitation, creating the potential for acidic runoff containing elevated concentrations of heavy metals and sulfates. The runoff from these areas threatened the quality of two adjacent exceptional quality trout streams and local residential water wells.

A search for a remediation plan cost the project three year’s time and $10 million. Following a series of meetings between, PADOT, the regulatory agency, and the host community, all parties agreed to a remediation program consisting of two major components: 1) movable material and 2) immovable material. The estimated 800,000 cubic yards of movable material is encapsulated in a double-lined landfill constructed along the right-of-way of the project. Landfill construction and rock placement was sequenced to minimize stormwater runoff. Additional environmental protection was provided by blending the rock fill with lime and constructing a permanent composite cap. The design/build solution for the

approximately 1 million square feet of exposed rock slopes comprising the immovable area was to construct a composite cap. The cap consists of a High Density Polyethylene (HDPE) Geomembrane protected by two heavyweight nonwoven geotextiles and a crushed stone-filled geosynthetic cellular confinement system (geocell) layer. The geocell system is supported throughout the slope with high strength stainless steel cables supported by an anchor system above the limits of the geomembrane. This paper outlines the challenges and innovation involved in the implementation of this remediation project.

Practical Solution for a Cave Located on a School Campus in Central Kentucky

Richard Wilson, QORE, Inc. 422 Codell Drive, Lexington, KY. 40509 Telephone (859) 293-5518 Email: rwilson@qore.net

A school system in Central Kentucky found it necessary to address their expanding population of school age children by developing a new middle school campus. This campus is developing on property formerly in agricultural use. It consists of multiple buildings, miles of streets, acres of parking lots and thousands of feet of buried utilities. During construction of the middle school site and the related facilities numerous sinkholes and karst features were encountered. It was during the construction of a forced sewer main adjacent to one of the roadways that a 2 foot by 2 foot sinkhole in rock was uncovered. Subsequent excavation for remediation of the sinkhole uncovered a large multi-level cave with flowing water. The cave trends under the road and toward the new school. Remediation consisted of excavation of the cave and karst under the roadway and toward the school until sufficient roof strata thickness was obtained. Provide overflow relief from the cave into a detention basin. Support the roadway and forced sewer main with a combination of crushed stone filter fabric and structural concrete.

Session 6: Mine Subsidence — Chair: John Kiefer (KGS)

Investigation of the Long Term Stability of Abandoned Room and Pillar Coal Mines

Gennaro G. Marino, Marino Engineering Associates, Inc., 1101 E. Colorado Ave., Urbana, IL 61801
Email: gmarino@meacorporation.com

Many times when proposed construction or existing structures are located over abandoned room and pillar coal mines, the question of subsidence risk comes to the forefront. Subsidence risk, however, has two components: subsidence potential and damage potential. A significant component of subsidence potential is the expected long-term stability or instability of the abandoned workings. The long term stability can be assessed by an investigation of the subsurface conditions, rock mechanics testing and analyses. Such analyses have a different focus than during mining as the concern here is stability of the mine opening whereas for subsidence risk the concern focuses on overburden stability. General methodology will be discussed on undertaking long term stability analyses.

Applied Mine Grouting Techniques

Paul Painter and Kirk Beach, Ohio Dept. of Transportation, 1600 West Broad St., Columbus, OH 43223
Telephone: (614) 275-1342 Email: kirk.beach@dot.state.oh.us

The Ohio Department of Transportation (ODOT) inspects nearly 12,000 structures annually. During the inspection of MUS-93-12.84 bridge in 2007, a large subsidence void was noted under the right rear abutment. This bridge carries traffic over Interstate Route 70 in Muskingum County and is situated just east of the city of Zanesville in east central Ohio. The subsidence prompted a subsurface investigation to determine the extent of underground coal mining within the vicinity of the structure. Historical archives indicated that the Interstate was excavated through the mine interval, including the

bridge piers, but the north and south bridge abutments and approach roadway could be underlain by mine voids. No historical mine maps were available for the workings. To initiate the subsurface exploration, four borings were drilled confirming the coal mine void and revealing both flooded and dry mine conditions. A mine grouting plan was developed to reduce the potential risk to the structure and roadway due to the critical nature of the structure. Non-fly ash grout was selected for the project to expedite the construction activities while minimizing permit requirements. Unique to this project, a continuous automated monitoring program for the bridge structure was utilized prior to and during the grouting activities. ODOT also initiated an in-situ mapping effort utilizing a down-hole sonar scanner to identify and map the underground mine voids, to determine void volumes and to establish orientations of rooms and pillars. A total of 2,000 cubic yards of grout was placed below the approach roadway and abutments over 18 days of construction.

Subsidence Misconceptions and Myths

Richard E. Gray, Robert W. Bruhn, and David L. Knott

Subsidence due to coal mining is poorly understood by non-specialists. This has led to numerous misconceptions and myths based on limited observations and lack of knowledge. The three most common are:

1. Mine maps are inaccurate
2. Deep mines are not a problem
3. If no subsidence has occurred for many years after mining, there is no risk of future subsidence

Maps are important during mining and most are carefully prepared. Future use to evaluate conditions at mine level often includes drilling to confirm what the map shows. Usually, little or no effort is made to tie the surface survey of the property to the mine survey, to conduct a well designed drilling program to confirm the mine map, or to drill test borings vertically. When a mine entry is encountered rather than a coal pillar, or vice versa, and conditions at the mine level appear different than anticipated, the first reaction is the mine map is inaccurate.

The idea of a safe depth from subsidence is often based on the false premise that mining results in sufficient breakup of the overlying rock strata that bulking compensates for the coal extracted. The safe depth idea first appeared in the literature about 1880 and remained prevalent well into this century. Sadly, it is still encountered. The modern understanding of roof rock was first described in 1900. With full extraction mining, either longwall or retreat room and pillar, surface subsidence occurs regardless of the depth of the mine. Subsidence over longwall mines at depths of 2000 feet can be 90 percent of the mined seam thickness.

Numerous studies of undermined sites conclude that mining occurred many years ago and since no subsidence has occurred, there is no “risk of future movement.” This is true if sufficient coal pillars have been left to support the overlying strata. However, every year subsidence occurs over mines that have been closed for 100 years or more. In a study of subsidence incidents over the Pittsburgh Coal, the senior authors found that 50 percent of the incidents occurred above mines that had been closed for at least 50 years and 10 percent over mines closed for at least 80 years.

Engineering-Geophysical Investigation of Abandoned Coal Mines Along Planned US-69 Pittsburg Bypass, Pittsburg, Kansas

Kanaan Hanna[1], Jim Pfeiffer[1], Robert Henthorne[2], and Richard Ryan[2], [1]Zapata Incorporated, Blackhawk Division, 301 Commercial Road, Suite B, Golden, Colorado 80401 Telephone: (303) 278-8700 [2]Kansas Department of Transportation, Topeka, KS.

Zapata Incorporated, Blackhawk Division conducted an engineering-geophysical investigation along the planned US-69 Pittsburg Bypass (corridor) for the Kansas Department of Transportation (KDOT). The planned corridor alignment of approximately 5.8 miles in length crosses known and suspected areas of historic underground coal mining. The initial geotechnical site evaluation provides KDOT's geologists and engineers an understanding of the subsurface characteristics, ground conditions, and locations of the mine workings. The subsurface information obtained during the initial study will guide the detailed site evaluation and grouting mitigation effort throughout the design, remediation, and construction phases of the project.

A comprehensive geophysical study was implemented along the planned alignment using a suite of geophysical technologies, including multi-channel analysis of surface waves (MASW), DC-resistivity, and guided waves seismic techniques. These techniques were complemented by exploratory borings performed by KDOT. Over 35 borings were advanced along selected portions of the corridor ranging in depth from 21 ft to 102 ft bgs. Sonar mapping was performed in eight borings that encountered open voids delineating the geometry, lateral extent, and characteristics of the flooded mine workings (pillar, voids, rubble, and ground support).

The significant results and findings obtained from this ongoing study will be presented.

DAY 2

Session 7: Water Issues — Chair: Steve Brewster (USCE Huntington)

I-40 Toe Scour Protection System

Joseph Bigger, Geobrugg North America, LLC., New London, CT

Heavy rains from Hurricane Ivan in September 2004 caused stream and river levels to rise resulting in flooding, mudslides and stream bank scour. The water level in the Pigeon River rose significantly and out of its channel to severely scour the I-40 embankment at approximately milepost 3. The extent of the scour damage included the loss of the East bound lanes and severely restricted traffic flow.

The North Carolina Department of Transportation in response to the emergency situation quickly developed plans to stabilize the embankment, rebuild the lanes and prevent further toe scour. Retaining walls were designed and built to stabilize the embankment at the road level and allow the reconstruction of the lanes.

A Toe Scour Protection System is a rock embankment designed by the Department of Transportation to prevent further scour. It is placed at the edge of the river and extends over 1,000 feet along it. The system is a rock embankment that incorporates Geobrugg's ROCCO ring nets as layer reinforcement and to cover the rock face. The system has 4 layers of large diameter rock and boulders plus riprap and the layer thickness is 4 feet. The face is set at a 1:1 slope. The installation has experienced problems ranging from the tension bolts to the handling and placement of the nets. The installation is near completion and the success of the design and installation will not be known until heavy rains occur.

Correlation of Rock Quality Designation and Rock Scour Around Bridge Piers and Abutments Founded on Rock

Tommy C. Hopkins[1] and Tony L. Beckham[2] [1]Research Engineer, [2]Former Research Geologist, Kentucky Transportation Center, Geotechnology Section, University of Kentucky, College of Engineering, 282 Raymond Building, Lexington, KY, 40506-0281 Telephone: (859) 257-4516 Email: thopkins@engr.uky.edu

Local scour around the base of a bridge pier or abutment occurs as the result of flow acceleration around the obstruction, formation of a vertical pressure gradient along the upstream end, and generation of vortices at the base of the structure. The flow patterns around piers and abutments are complex in detail, and the complexity increases as a scour hole forms in the bed around the structures. The potential for local scour at a bridge pier or abutment needs to be estimated so that foundations can be designed to resist failure during large floods.

To obtain an understanding of the rock scour problem in Kentucky, on-site inspections of some 400 bridges with footings located on exposed rock were performed. A large number of bridge abutments and piers in Kentucky were found to have been placed on rock foundations that are visible during low flow. These inspections show that scour at bridge piers and abutments placed on rock does occur. As a means of evaluating rock scour at existing sites, a rock scour hazard rating system was proposed. Based on the inspections, rock scour is not a significant problem in Kentucky. Statistically, only about 0.5 percent of the observed bridges had significant vertical scour. Generally, when scour was observed the depth of vertical scour was less than about 10 inches. In the few cases observed, the scour holes could be easily repaired by filling with concrete.

An approximate relationship between vertical rock scour depth next to the abutment, or pier, and Rock Quality Designation (RQD) was developed. Also, an approximate relationship between horizontal rock scour penetration beneath a pier, or abutment, footer and Rock Quality Designation (RQD) is presented. Generally, the geology at sites where scour was observed consisted of interbedded layers of limestone and shale layers, or very thin shale partings. Freezing and thawing apparently caused the blocks to breakup and flooding velocities of the streams tended to wash out the blocks around footers.

Investigations of Karst Hydrogeology as a Technique to Minimize Karst Geohazards Transportation Corridors

Jim Currens, Kentucky Geological Survey, University of Kentucky, 228 MMRB, Lexington, KY, 40506-0107 Telephone: (859) 323-0526 Email: currens@uky.edu

Our understanding of the causes of karst geologic hazards has improved significantly in the last 20 years. Applying this knowledge to engineering and environmental problems, however, is commonly remedial rather than proactive. If consulted in time, earth scientists will often recommend a solution to avoid the problem area, in contrast with a “we can build anything anywhere give enough resources” mindset. Often the karst specialist is called in after a problem is encountered and the project design is being implemented, if not nearing completion.

Modern karst hydrologic techniques can save many times the cost of the karst investigations by reducing of construction and maintenance costs. Environmental and social costs are also important. The following karst investigations along transportation corridors that were proposed, under design, and in one case, under construction, provide examples of how karst techniques can be applied to transportation projects.

Case History Number One, 2005: Billy Miller Cave and Ky.163.

The Billy Miller Cave karst groundwater basin in Monroe County is bisected by the north-south-aligned Ky. 163. The groundwater catchment area is 1.87 mi.^{2}, 44 percent larger than the surface watershed. Two distinct springs, Combs and Skaggs Creek Church share the drainage basin, an excellent example of divergent flow. Furthermore the relative proportion of water from the two contributing karst valleys may shift between high- and low-flow conditions.

An important intersection (Rockbridge Road and Ky. 163) is in the karst valley drained by Billy Miller Cave via Woods swallow-hole. Overland flow, combined with the high-flow discharge from Combs Spring, can exceed the swallow hole inflow capacity. Flooding will occur when excess

discharge is temporarily stored in the karst valley, covering the existing roadway. Historic accounts of flooding were noted and the approximate elevation of the high-water mark determined.

Cover collapse and soil voids were expected along most of the realignment. Thick soil cover and existing collapses characterize these areas. Exceptionally well managed sediment control will be needed to minimize sediment deposition in swallow holes and underground streams. The impact of sediment deposition could be devastating on aquatic fauna.

Case History Number Two, 2005-06: Interstate 66.

A segment of I-66 is planned for Pulaski and Laurel Counties and KGS conducted 45 groundwater traces to map 75 percent of the karst groundwater basins in the hydrologic study area. KGS has found about 110 new karst features and recorded descriptive data for 35 springs. We also made multiple discharge measurements and surveyed one cave.

Karst in the western half of the I-66 area is characterized by active, water-carrying conduits, developed at shallow depths along valleys and commonly perched on the Borden Formation. Karst of the eastern half (vicinity of Sinking Valley) includes long, water-carrying caves with large crosssections. Karst development may be found throughout the thick carbonate section and there are examples of groundwater piracy. Vertical shafts occur at closely spaced intervals in the karstified carbonates along the contact with overlying noncarbonates.

Most of the groundwater basins conform to the topography. Exceptions are Big Spring, Garner Old Barn, and Elwood. Several sections of the corridor cross groundwater basins where conduits are vulnerable to blockage, which can result in ground stability or flooding hazards. The no-build option is the only way to avoid all negative karst issues. Among the build options, certain sections of the alignments "Alternate D" and "KY80 reconstruction" would encounter the fewest karst geologic hazards.

Case History Number 3: Extension of the E. T. Breathitt, Pennyrile Parkway to I-24, 2009.

After construction had begun, design for drainage handling of the southern half of the extension was being reconsidered because the potential to shift discharge from one karst groundwater basin (Adams) to another (Cherry) was recognized. Such a rerouting could have an adverse impact on two springs, one would have discharge reduced and the other surcharged, resulting in loss of a groundwater supply and more frequent flooding.

KGS scouted along the right-of-way for injection sites and springs by foot and automobile, and interviewed residents. There are abundant natural injection points along the parkway right-of-way, but the pace of construction was rendering them unusable for groundwater tracing. Therefore, two auger holes used as epikarstic injection points were drilled at strategic locations along the right-of-way by KTC geotechnical crews, for use as tracer injection sites. Three dry sets were also placed, a technique that is risky because of the uncertainty of the amount of time that will pass before sufficient rainfall occurs to move the tracer. Six traces were attempted and four were recovered. Results suggest a redesign is not needed.

The assessment of karst-related geohazards and environmentally sensitive areas should be conducted prior to project design. Procedures should include review of existing geologic maps and aerial photography in preparation for field inspection of the potential routes. If indicated by early evaluation, a qualitative groundwater tracing program, augmented where necessary with surveying of critical sections of cave passage, should be conducted. In settings where flooding that will block roadways is anticipated, quantitative tracing techniques can characterize the hydraulic capacity of the karst flow system. Well-thought-out and executed karst mapping can improve the design of runoff treatment structures, lessen the risk of flooding or collapse, lower construction and maintenance costs, preserve water quality, and help protect sensitive stygobitic species.

An Un-Natural Disaster – Taum Sauk Upper Reservoir Breach

Nicholas G. Schmitt

At 5:20 a.m. on December 4, 2005 the Taum Sauk Upper Reservoir breached sending approximately 1.4 billion gallons of water down the side of Proffit Mountain and into Johnson's Shut-ins State Park. The cause of the breach (available from the FERC web-site), the impact of the release on Johnson's Shut-ins State Park, the Jewel of the Missouri State Park system, the impact of the release on the foundation supporting the elevated walk-way, the geotechnical evaluation of the "debris dam" and the remarkable recovery and restoration efforts are discussed.

This project demonstrates the impact of water and erosion on the stability of earthen and rock structures. It presents the challenges the owner, the engineers and scientists, and the remedial contractors faced in evaluating the situation, restoring the State Park and restoring the stream; a process which has taken over three years to complete.

The failure mechanism on the upper reservoir was not studied by author, who was a member of the consulting team restoring the park and the stream. However the author has reviewed the breach failure evaluation presented by the FERC Independent Panel of Consults and has added some antidotal information based on his activities at the site.

Session 8: Rockfalls Chair: John Tomlin (Norfolk Southern Railway)

Engineering for the Wolf Creek Dam Rock Overhang

Richard Wilson, QORE, Inc. 422 Codell Drive, Lexington, KY. 40509 Telephone (859) 293-5518 Email: rwilson@qore.net.

QORE, Inc Kentucky branch was approached by the Kentucky Transportation Cabinet (KYTC), Geotechnical Branch to provide for engineering design services to correct a potential rock hazard associated with a large rock overhang which has been undermined by adverse weather conditions. This potential rockfall hazard lies adjacent to the road over Wolf Creek Dam which impounds the waters of Lake Cumberland. This is a highly visible project to the traveling public and the U.S. Army Corps of Engineers. To identify the rockfall area, QORE sent its field survey crew to generate a 3-D map of the face of the rockfall area. Using a reflectorless total station, the crew took 1300 data points on the face of the rockfall area. This field information was downloaded and modeled using the InRoads computer program to generate cross sections every five (5) feet along the centerline. This then allowed us to calculate the quantity of material in the hazard zone that needed to be removed to meet safety requirements. Due the location of the project conventional mitigation measures involving blasting were deemed inappropriate. QORE put together an approach that required the rock wedge be removed without the use of explosives. The project has not been let yet.

Rockfall Hazard Rating System for Railroads

Roberto J. Guardia, Shannon and Wilson, Inc.

A rockfall hazard rating system has been developed for Railroad applications taking into account type and volume of railroad traffic and whether warning systems are in place. This is in addition to engineering parameters such as type of rock failure, joint orientation, catchment width, slope height and inclination among others. The Rating system is useful to assign a numerical rating to each site and to determine which sites should be given priority in a multi-year rockfall prevention program. A sample project involving several hundred miles of track is rated utilizing the system and the highest ranking sites are identified. Typical remedial measures involving hand and mechanical scaling, rock bolting and shotcrete and different types of rockfall fences are described.

The talk would be presented by Mr. Neil McCulloch, P.E., L.E.G, Associate of Shannon & Wilson, Inc. Mr. McCulloch has over 14 years of experience in railroad related projects including rockslides of various sizes, landslides, embankment failures, rockfall hazard evaluations, debris flows and

torrents and river erosion. For many of these projects Mr. McCulloch prepared bid documents and observed construction of the remedial measures.

Case Study: Widening Dead Man's Gap

John Tomlin, Norfolk Southern Railway Company, Geotechnical Services, 1200 Peachtree Street NE – 7142, Atlanta, Georgia 30309 Telephone: (404) 529-1306 Email:

Case Study describing the factors warranting, measures necessary to perform, and challenges faced executing the permanent removal of a slide fence protecting the railroad main in Ooltewah, TN. An existing 40' tall slide fence in a narrow cut known as "Dead Man's Gap" was becoming antiquated and needed to be replaced if the cut was not widened and a suitable catch ditch installed. The cut was originally constructed through the edge of an inter-bedded shale and sandstone hillside which dips steeply towards the track. Complicating this construction job were factors such as rail geometry, close proximity of US highway 11, utilities located along the highway and track, rock strata orientation and type, volume of rail traffic, and permitting concerns grading near a creek. Goals of the project were to increase safety at this location and reduce costs associated with slide fence repair, maintenance, replacement, and false activation response by means of grading the cut wall back to increase side clearance and create a rock-fall catch ditch.

Geohazards in Transportation in the Appalachian Region

The 9th Annual Technical Forum is sponsored by the Nick J. Rahall, II Appalachian Transportation Institute (RTI) and the Marshall University Center for Environmental, Geotechnical and Applied Sciences (CEGAS).

RTI, a United States Department of Transportation Center was established at Marshall University by the United States Congress in the Transportation Equity Act for the 21st Century, June 8, 1998. RTI helps influence a more diverseand equitable economy for rural Appalachia and other mountain areas by providing insights into how we can create and maintain the most cost effective enhancement to our national transportation system in rural Appalachia and rural America.

CEGAS was established in May, 1993 at Marshall University with support from Congressman Nick J. Rahall II, and the United States Army Corps of Engineers. The goal of the center is to develop cooperation and communication among the business community, higher education institutions, and government agencies. The center is dedicated to research, technological innovation, and providing high-value services in information and geotechnology, environmental technology, management and engineering.

The Appalachian States Coalition for Geohazards in Transportation

The Appalachian States are tied by common geographical and geological challenges. This grassroots coalition's objectives include sharing of resources and exchange of information, experiences and methodologies, and to collaborate on geotechnical projects and research activities.

Our focus on multi-modal transportation in the Appalachian Region is essential for economic development. The coalition includes members from Kentucky, Ohio, West Virginia, Pennsylvania, Virginia, Tennessee and North Carolina, the US Geological Survey, US Army Corps of Engineers, the FHWA, CSX Railroad, and Norfolk SouthernRailway Company.

The Appalachian Coalition for Geological Hazards in Transportation

Committee Members

Tony Szwilski, Chair Professor and Director, Center for Environmental, Geotechnical and Applied Sciences (CEGAS) Marshall University Address: Gullickson Hall 112, 18th St, 3rd Av., Huntington, WV 25755 Phone: (304) 696-5457; Fax: (304) 696-5454 Email: szwilski@marshall.edu
Kirk Beach, Co-Chair Senior Geologist Geotechnical Design Section Ohio Department of Transportation Address: 1600 West Broad Street, Room Columbus, OH 43223 Phone: (614) 275-1342; Fax: (614) 275-1354 Email: kirk.beach@dot.state.oh.us

Vanessa Bateman Tennessee Department of Transportation Geotechnical Engineering Section Address: 6601 Centennial Blvd. Nashville, TN 37243-0360 Phone: (615) 350-4133 Email: vanessa.bateman@state.tn.us
Hugh Bevans District Chief U.S. Geological Survey 11 Dunbar Street, Charleston, West Virginia 25301 Phone: (304) 347-5130 ext. 23 Fax: (304) 347-5133 email: hbevans@usgs.gov
Steve Brewster Chief, Geology Section US Army Corps of Engineering Huntington District Address: 502 8th St. Huntington, WV 25701 Phone: (304)529-5279 Email: steve.brewster@lrh01.usace.army.mil
Brian Bruckno Enineering Geologis Virginia Department of Transportation P.O. Box 2249, Staunton, VA 24402-2249 Phone: 540-332-9166 email: Brian.Bruckno@vdot.virginia.gov
Scott Eaton Associate Professor Department of Geology and Environmental Science James Madison University Harrisonburg, Virginia 22807 Phone: (504) 568-3339 email: eatonls@jmu.edu
Jim Faircloth Sr. Project Engineer CSX Transportation Address: 500 Water Street - J350, Jacksonville, FL 32256 Phone: (904) 245-1042 Email: james_faircloth@csx.com

Jim Fisher

West Virginia Department of Transportation
Division of Highways Engineering Division
Address: Building 5, Room 650
1900 Kanawha Blvd., E.,
Charleston, WV 25305-0430
Phone: (304) 558-2885; Fax: (304) 558-7297
Email: jfisher@dot.state.wv.us

Tommy Hopkins

Chief Research Engineer, Head of Geotechnology
Kentucky Transportation Center
Address: University of Kentucky, 282 CE/KTC
Lexington, KY 40506-0281
Phone: (859) 257-4513; Fax: (859) 257-1815
Email: thopkins@engr.uky.edu

John D. Kiefer

Assistant State Geologist
Kentucky Geological Survey
Address: 228 Mining & Mineral Resources Building
University of Kentucky
Lexington, KY 40506-1147
Phone: (859) 257-5500; Fax: (859) 257-1147
Email: kiefer@kgs.mm.uky.edu

Jody C. Kuhne

NCDOT- Geotechnical Engineering
Asheville Area Office
Address: P.O. Box 3279
Asheville, NC 28802
Phone: (828) 298-3228
Email: jkuhne@dot.state.nc.us

Thomas Lefchik

Structural Engineer
FHWA
Address: 200 North High Street, Room 328
Columbus, OH 43215
Phone: (614) 280-6845
Email: lefchik@fhwa.dot.gov

Jane McColloch

Senior Geologist
West Virginia Geologica Survey
Address: P.O. Box 879

Morgantown, WV 26507-0879
Phone: (304) 594-2331 Ext. 425; Fax: (304) 594-2575
Email: janemc@geosrv.wvnet.edu

Kerry W. Petrasic

Chief Geotechnical Engineer
PA Department of Transportaion
Address: 1118 State Street, Harrisburg, PA 17103
Phone: (717) 787-4319; Fax: (717) 705-5750
Email: kpetrasic@state.pa.us

Benjamin Rivers

Geotechnical Engineer
FHWA - Resource Center
Address: 61 Forsyth Street, Suite 17T26
Atlanta, Georgia 30303
Phone: (404) 562-3926; Fax: (404) 562-3700
Email: benjamin.rivers@dot.gov

Thomas Smith

Division Administrator
FHWA, West Virginia Division
Address: Geary Plaza Suite 200, 700 Washington St. East
Charleston, WV 25301
Phone: (304) 347-5928; Fax: (304) 347-5103
Email: thomas.smith@fhwa.dot.gov

John Stanton

US Army Corps of Engineers, Nashville District
Geology Section
Address: P.O. Box 1070
Nashville, TN 37202
Phone: (615) 736-7906
Email: john.i.stanton@usace.army.mil

John R. Tomlin

Norfolk Southern Railway Company
Phone: (404) 529-1306
Email: John.Tomlin@nscrp.com

Wael Zatar

Associate Professor
College of Information Technology and Engineering
Address: 112 Gullickson Hall, One John Marshall Drive Marshall University
Huntington, WV 25755-2586
Phone: (304) 696-6043; Fax: (304) 696-5454 Email: zatar@marshall.edu