72nd Highway Geology Symposium

2023 PROCEEDINGS

August 14–17, 2023 • Hotel Murano • Tacoma, Washington

Grateful Acknowledgments

We would like to thank the following people who helped make made this Symposium possible.

Samantha Denham
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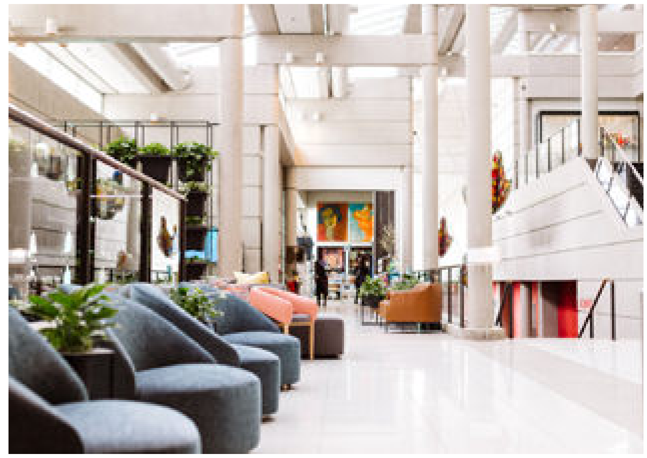
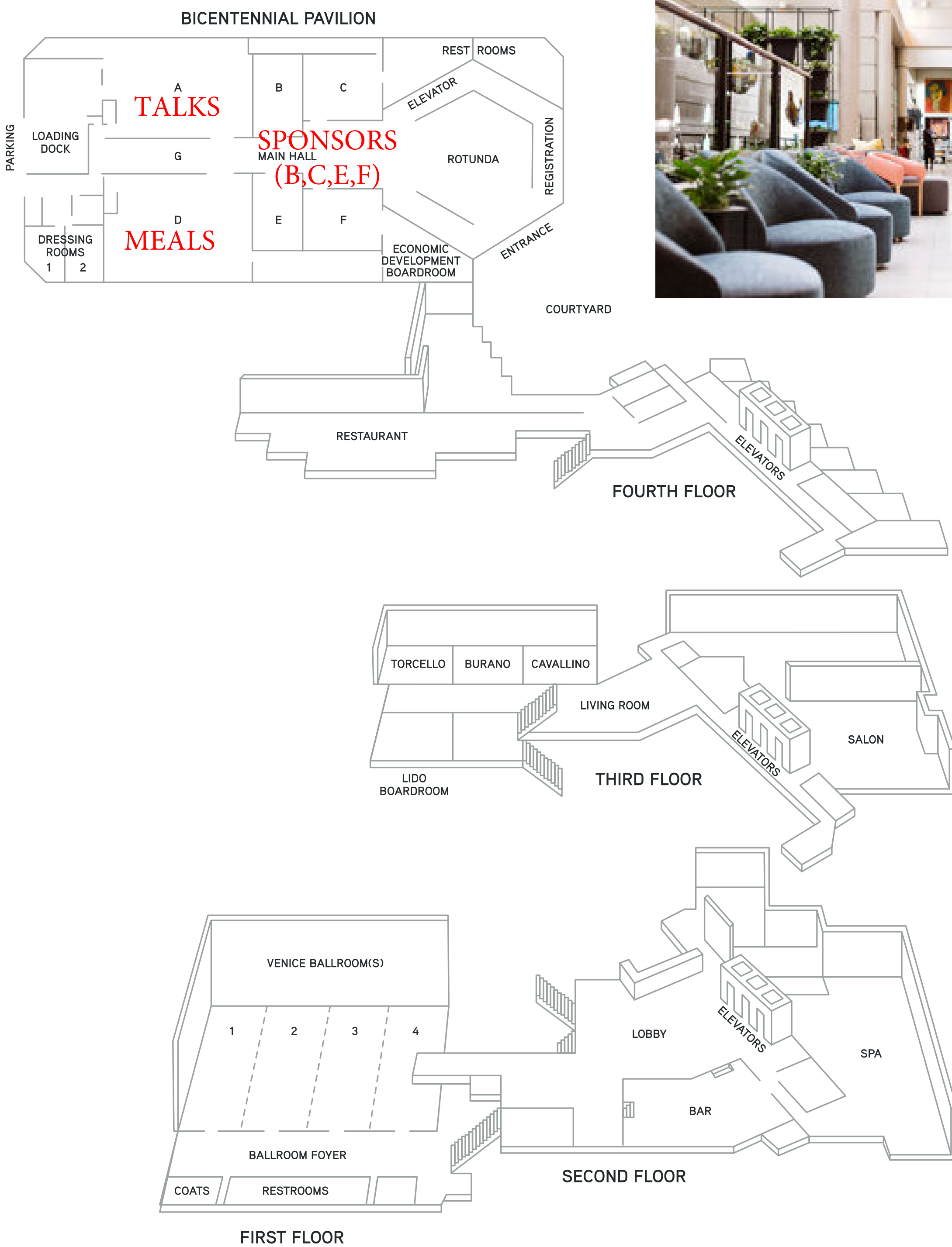
Washington Geological Survey
Pat Pringle
Delaney Event Management
Todd Hansen
Krystle Pelham

72nd Highway Geology Symposium

August 14-17, 2023

Hotel Murano
Tacoma, Washington





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SCHEDULE OF EVENTS

MONDAY, AUGUST 14, 2023

Time	Event	Location
8:00 AM – 12:00 PM	Rockfall Fragmentation Demo (Pre-Registration Required)	Offsite: UW Tacoma Milgard Hall Room 311
8:30 AM – 5:00 PM	Registration Open	Rotunda
9:00 AM – 4:00 PM	Sponsor and Exhibitor Setup	Pavilion BCEF
9:00 AM – 11:30 AM	FHWA Workshop: "What you Need to Know About Seismic Geophysics for Engineering Applications" (Pre-Registration Required)	Pavilion AG
1:00 PM – 5:00 PM	Transportation Research Board Session: "Geotechnical Data Sourcing and the Quality and Use of Models for Geotechnical Design" (Pre-Registration Required)	Pavilion AG
5:00 PM – 6:30 PM	National Steering Committee Meeting	Torcello/Burano
6:00 PM – 8:00 PM	Icebreaker Reception Sponsored by Landslide Technology	Pavilion BCEF

TUESDAY, AUGUST 15, 2023

Time	Event	Location
7:00 AM – 8:00 AM	Breakfast Sponsored by Shannon & Wilson	Pavilion D
7:00 AM – 5:00 PM	Registration	Rotunda
8:00 AM – 8:50 AM	HGS Welcome & Opening Remarks	Pavilion AG
8:00 AM – 8:30 AM	Marc Fish WSDOT State Eng. Geologist & Kerri Woehler WSDOT Deputy Asst. Secretary	
8:30 AM – 8:50 AM	Washington Geology, Trevor Contreras, WA Geological Survey	
8:50 AM – 9:30 AM	**Technical Talks – Session 1** (Moderator Chris Ruppen, Geostabilization International)	Pavilion AG
8:50 AM – 9:10 AM	Innovative Geophysical Application for Bridge Foundation Design and Construction ***Young Author: Ronan Jones***	
9:10 AM – 9:30 AM	Design and Construction of a Bottom-up Retaining Wall in Slickensided Red Bed Material ***Young Author: Kirsten Grant***	

TUESDAY, AUGUST 15, 2023 (CONTINUED)

Time	Event	Location
9:30 AM – 10:00 AM	Mid-Morning Break	Pavilion BCEF
10:00 AM – 12:00 PM	**Technical Talks – Session 2** (Moderator Sarah McInnes, PADOT)	Pavilion AG
10:00 AM – 10:20 AM	Impacts of Weak Rock Units on Cut Slope Construction ***Young Author: Justin Manning***	
10:20 AM – 10:40 AM	Comparative Analysis of Rock Slope Scaling Quantities and Crew Hours: A Strategic Approach for Standardizing the Practice ***Young Author: Katelyn Card***	
10:40 AM – 11:00 AM	Seward Highway Rockfall Mitigation, Anchorage, Alaska ***Young Author: Sebastian Dirringer***	
11:00 AM – 11:20 AM	A Multi-Phased Approach to Rockfall Mitigation at Don Pedro Dam: Lessons Learned for Critical Facilities and Roadways ***Young Author: Joey Renner***	
11:20 AM – 11:40 AM	Bolt Creek Fire: Post-Wildfire Debris Flow Risk Assessment and Barrier Design on US 2, Near Grotto, WA ***Young Author: Cody Chaussee***	
11:40 AM – 12:00 PM	Emergency planning and mitigation for post-fire debris flows in Glenwood Canyon, Colorado ***Young Author: Aliena Debelak***	
12:00 PM – 1:00 PM	Lunch Sponsored by GeoStabilization International & Access Limited	Pavilion D
1:00 PM – 3:00 PM	**Technical Talks – Session 3** (Moderator Simon Boone, Access Limited Construction)	Pavilion AG
1:00 PM – 1:20 PM	Freemont Hall Landslide ***Young Author: Jamie Cravens***	
1:20 PM – 1:40 PM	Landslide Study and Final Repair Design Route 3 Randolph County, Missouri ***Author: John Szturo***	
1:40 PM – 2:00 PM	The SR112 / Clallam Bay Landslide(s) – Characterization and Mitigation ***Author: Gabriel Taylor***	
2:00 PM – 2:20 PM	State Route 112: Landslide Alley – Striving for Resiliency ***Author: Tom Badger***	
2:20 PM – 2:40 PM	Raised Draperies – Defining Hybrid Barriers and Attenuators by Application ***Author: John Duffy***	
2:40 PM – 3:00 PM	How To Develop Rockslope Mitigation For Very Large Roadway-Dipping Blocks Along an Interstate Highway ***Author: Stephen Newman***	

TUESDAY, AUGUST 15, 2023 (CONTINUED)

Time	Event	Location
3:00 PM – 3:30 PM	Afternoon Break Sponsored by Rock Supremacy LLC	Pavilion BCEF
3:30 PM – 4:40 PM	**Technical Talks – Session 4** (Moderator Tom Badger, Landslide Technology)	Pavilion AG
3:30 PM – 3:50 PM	"What If the Rock Only Threatens to Fall?" Emergency Response to a Decoupled Cliff Face in Washington State ***Author: Eric Smith***	
3:50 PM – 4:30 PM	I-90 Rock Slopes: A Retrospective of the Snoqualmie Pass Project ***Author: Norm Norrish***	
4:40 PM – 5:00 PM	Mt. Rainier Field Trip Preview (Gabe Taylor, WSDOT)	Pavilion AG
6:00 PM – 8:00 PM	Sailing Cruise on Lady Washington (Pre-Registration Required)	Offsite

WEDNESDAY, AUGUST 16, 2023

Time	Event	Location
7:30 AM – 8:00 AM	Grab N' Go Breakfast	Hotel Lobby
8:00 AM	Board Buses for HGS Field Tour	
8:00 AM – 6:00 PM	HGS Field Tour to Mount Rainier National Park Sponsored by Geobrugg & Maccaferri Inc.	
	Spider Demonstration Geostabilization International	

THURSDAY, AUGUST 17, 2023

Time	Event	Location
7:00 AM – 8:00 AM	Breakfast Sponsored by Haley & Aldrich	Pavilion D
7:00 AM – 5:00 PM	Registration	Rotunda
8:00 AM – 5:00 PM	Exhibits Open	Pavilion BCEF
11:00 AM – 5:00 PM	Companion Activities	Offsite: 7 Seas Brewery & Museum of Glass
8:00 AM – 10:00 AM	**Technical Talks – Session 5** (Moderator Bill Gates, Delve Underground)	Pavilion AG
8:00 AM – 8:20 AM	Climate Reslience and Infrastructure Adaptation on California's National Forests ***Author: Gordon Keller***	
8:20 AM – 8:40 AM	Geohazard Management on Colorado SH 133 From Planning to Mitigation ***Author: Randy Post***	

THURSDAY, AUGUST 17, 2023 (CONTINUED)

Time	Event	Location
Technical Talks – Session 5 (continued)		
8:40 AM – 9:00 AM	The State of Measurment While Drilling for the Washington State Department of Transportation ***Author: Mike Mulhern***	
9:00 AM – 9:20 AM	Advancing Subsurface Investigations Beyond the Borehole with Passive Seismic Horizontal-to-Vertical Spectral Ratio and Electromagnetic Geophysical Methods at Transportation Infrastructure Sites in New Hampshire ***Author: J.R. Degnan***	
9:20 AM – 9:40 AM	Non-destructive Surface Wave Geophysics Characterizes Salt Dissolution 140m Under US Highway 50 at Brandy Lake, Reno County, Kansas ***Author: Johari Pannalal***	
9:40 AM – 10:00 AM	Mitigation Alternatives for Salt Dissolution Subsidence Impacting US Highway 50 at Brandy Lake, Reno County, Kansas ***Author: Jeff Keaton***	
10:00 AM – 10:30 AM	Mid-Morning Break Sponsored by Global Rope Access	Pavilion BCEF
10:30 AM – 11:50 AM	**Technical Talks – Session 6** (Moderator Ken Ashton WV Geological Survey)	Pavilion AG
10:30 AM – 10:50 AM	Using State-of-the-Art Technologies and Tools for Geotechnical Investigation and Design ***Author: Brian Collins***	
10:50 AM – 11:10 AM	The Development and Utilization of a Cloud-Based Database and Visualization App for Pile Results and Design: PileTrac ***Author: Kyle Halverson***	
11:10 AM – 11:30 AM	Pavement Bump at the Bridge End Elimination ***Author: Jeremiah Kokes***	
11:30 AM – 11:50 AM	US 460 Bridges over Marrowbone Creek, Pond Creek and Russell Fork River ***Author: Tony Beckham***	
11:50 AM – 1:00 PM	Lunch	Pavilion D
1:00 PM – 3:00 PM	**Technical Talks – Session 7** (Moderator Sebastian Dirringer, Landslide Technology)	Pavilion AG
1:00 PM – 1:20 PM	Taking into Account the Fragmentation and Variability of Rockfall and the Third Dimension in Rockfall Barrier Design ***Author: Tim Shevlin***	
1:20 PM – 1:40 PM	Introducing A New Impact Alert System for Rockfall Barriers ***Author: Sage Evans***	
1:40 PM – 2:00 PM	The Geohazard Pro must know “Section 262 Slope Scaling” ***Author: Todd Hansen***	

THURSDAY, AUGUST 17, 2023 (CONTINUED)

Time	Event	Location
Technical Talks – Session 7 (continued)		
2:00 PM – 2:20 PM	Rock Stabilization at Pompeys Pillar National Monument: The Use of Numerical Modeling to Analyze Risk of Toppling Failure ***Author: Anya Brose***	
2:20 PM – 2:40 PM	Padden Creek I-5 Stream Crossing ***Author: Mark Rose***	
2:40 PM – 3:00 PM	The Erodibility Index in Washington State's Intermediate Geomaterials: The Need for a Practical Tool ***Author: Robert Humphries***	
3:00 PM – 3:30 PM	Afternoon Break	Pavilion BCEF
3:30 PM – 5:30 PM	**Technical Talks – Session 8** (Moderator Todd Hansen FHWA WFL)	Pavilion AG
3:30 PM – 3:50 PM	Accelerating the Transition to Digital Deliverables ***Author: Katie Aguilar***	
3:50 PM – 4:10 PM	GIS Enterprise-based Prototype Erosion and Slope Stability Screening Tool for Transportation Infrastructure Management ***Author: Bin Wang***	
4:10 PM – 4:30 PM	Integrating Field Data with Physics Engine Simulations of Fragmental Rockfalls ***Author: R. MacPhail***	
4:30 PM – 4:50 PM	Emergency Response and Cures for Karst on Chemical Road ***Author: Sarah McInnes***	
4:50 PM – 5:10 PM	A Comprehensive Approach to Rock Slope Design Solutions along NC-88 in Ashe County, North Carolina ***Author: Bret Watkins***	
5:10 PM – 5:30 PM	Hybrid Design Approach for Anchored Wire Mesh: Towards A Displacement Based Design ***Author: Lucas Martins***	
5:30 PM – 6:30 PM	Student Poster Social Sponsored by Ameritech Slope Constructors, Inc.	Rotunda
6:30 PM – 9:00 PM	HGS Closing Banquet Keynote Sponsored by WSP Jon Major, Cascades Volcano Observatory, Volcanic Hazards of the Cascades	Pavilion D
	Young Author Awards – Chris Ruppen Next Year's Highway Geology Symposium – Kyle Halverson Closing Remarks and Adjournment of the Symposium	

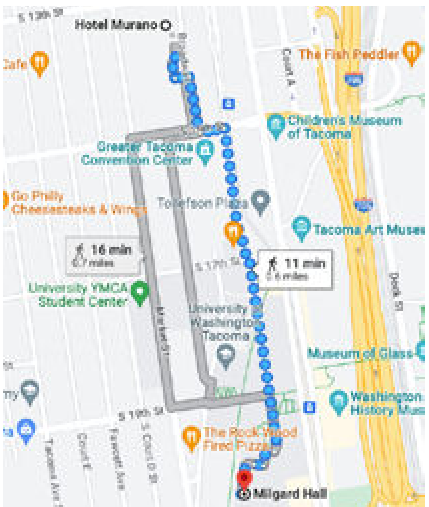
WORKSHOPS AND TRB MID-YEAR MEETING

Rockfall Fragmentation Demo

DATE
Monday, August 14

TIME
8:00 AM – 12:00 PM

LOCATION
UW Tacoma Milgard Hall
Room 311



As a part of the pool-funded study that aims to develop and calibrate fragmental rockfall models using physics engines, the research team from Oregon State University, University of Washington, and Queen's University (Canada) are hosting a workshop. The first part of the workshop will provide some hands-on training on the field procedures to track 3D trajectories followed by a demonstration of the output of the data processing work to understand the movement parameters (limited spots). The second part of the workshop will focus on selecting input data for rockfall analysis. We will consult with attendees to understand how rockfall data is collected in the field, and which parameters are most useful. This collection of the current state of practice will support our work to develop field data collection methodologies and to understand user preferences for rockfall fragmentation modeling (open to all).

Directions from Hotel Murano to UW

1. Head south toward Broadway
2. Turn left toward Broadway
3. Turn right onto Broadway
4. Turn left onto S 15th St
5. Turn right onto Commerce St
6. Turn right onto S C St
7. Turn right
8. Slight left

Destination will be on the left.

FHWA Workshop

DATE
Monday, August 14

TIME
9:00 AM – 11:30 AM

LOCATION
Bicentennial Pavilion AG

"What you Need to Know About Seismic Geophysics for Engineering Applications"

The session is intended to be practical; reviewing and discussing each of the surface and borehole methodologies, working through where and when each should be applied, and what can be expected from each: Best practices, limitations/pitfalls, benefits and the similarities and differences among the methods. Session partners include Geophysics Users Group (GPUG), TRB AKG 20 and AKG 60, DFI SCC, and GI EG&SC.

Transportation Research Board Session

DATE
Monday, August 14

TIME
1:00 PM – 5:00 PM

LOCATION
Bicentennial Pavilion AG

"Geotechnical Data Sourcing and the Quality and Use of Models for Geotechnical Design"

This session at HGS will highlight how though the application and use of new innovative sources of geotechnical data, engineers can increase reliability and certainty of various geotechnical design models. The use of these new data sources more readily available coupled with innovative technology such as measurement while drilling, CPT, and geophysical techniques can enhance our geotechnical site characterization.

BANQUET KEYNOTE SPEAKER

LAVAS AND MUDFLOWS AND ASH—OH MY!

Jon Major
Scientist-in-Charge
U.S. Geological Survey
Cascades Volcano Observatory
Vancouver, Washington

The Cascades Range is home to many volcanoes, but how active and dangerous are they? What are the greatest hazards from volcanoes in the Pacific Northwest, who monitors them, and how? In this presentation, Jon Major explores volcanic processes associated with volcanic eruptions and their aftermath, provides insights on the greatest threats posed by the Cascades volcanoes, and reveals how our regional volcanoes are monitored and why. The great 1980 eruption of Mount St. Helens fundamentally changed how scientists viewed volcanic eruptions. The four decades since have seen significant advancements in our understanding of volcanic histories, processes, hazards, monitoring capabilities, and the role that scientists have in communicating with governmental agencies and the public.

Jon received his B.S. from University of Dayton, M.S. from Penn State, and Ph.D. from the Department of Geological Sciences at the University of Washington. His research focuses on physical responses to landscape disturbances, particularly in volcanic river systems. He has worked at volcanoes in Washington, Oregon, Alaska, El Salvador, Chile, and the Philippines. He has been working at Mount St. Helens since 1981 and has been with the USGS Cascades Volcano Observatory since 1983.

FIELD TRIP SCHEDULE

August 16, 2023

Time	Bus 1	Bus 2	Bus 3	Bus 4
7:30 AM	Gather at Hotel Murano			
8:00 AM	**8:00 AM – All Buses Depart Tacoma**			
	Bus discussions: lahars, debris flows, Alder dam, rockfall			
9:00 AM	Arrive at Mt. Rainier National Park			
10:00 AM	**Bus 1**	**Bus 2**	**Bus 3**	**Bus 4**
	Arrive at Paradise		***Ricksecker Point***	
11:00 AM	LUNCH	LUNCH		
			Arrive at Paradise	
12:00 PM	Hiking and visiting Paradise	Hiking and visiting Paradise	LUNCH	LUNCH
1:00 PM			Hiking and visiting Paradise	Hiking and visiting Paradise
2:00 PM	**2:00 PM – Buses depart!**			
	Ricksecker Point			
3:00 PM			**3:00 PM – Buses depart!**	
	Travel to SR 7 Demonstration			
4:00 PM	SR 7 Demonstration			
5:00 PM				
6:00 PM	Travel back to Tacoma (Hotel Murano)			
7:00 PM				

HIGHWAY GEOLOGY SYMPOSIUM HISTORY, ORGANIZATION, AND FUNCTION

Inaugural Meeting

Established to foster a better understanding and closer cooperation between geologists and civil engineers in the highway industry, the Highway Geology Symposium (HGS) was organized and held its first meeting on March 14, 1950, in Richmond Virginia. Attending the inaugural meeting were representatives from state highway departments (as referred to at that time) from Georgia, South Carolina, North Carolina, Virginia, Kentucky, West Virginia, Maryland, and Pennsylvania. In addition, a number of federal agencies and universities were represented. A total of nine technical papers were presented.

W.T. Parrott, an engineering geologist with the Virginia Department of Highways, chaired the first meeting. It was Mr. Parrott who originated the Highway Geology Symposium.

It was at the 1956 meeting that future HGS leader, A.C. Dodson, began his active role in participating in the Symposium. Mr. Dodson was the Chief Geologist for the North Carolina State Highway and Public Works Commission, which sponsored the 7th HGS meeting.

Symposium Locations

Since the initial meeting, 69 consecutive annual meetings have been held in 33 different states. Between 1950 and 1962, the meetings were east of the Mississippi River, with Virginia, West Virginia, Ohio, Maryland, North Carolina, Pennsylvania, Georgia, Florida, and Tennessee serving as host state.

In 1962, the symposium moved west for the first time to Phoenix, Arizona where the 13th annual HGS meeting was held. Since then it has alternated, for the most part, back and forth from the east to the west. The Annual Symposium has moved to different location as shown on the next page.

Organization

Unlike most groups and organizations that meet on a regular basis, the Highway Geology Symposium has no central headquarters, no annual dues and no formal membership requirements. The governing body of the Symposium is a steering committee composed of approximately 20 – 25 engineering geologist and geotechnical engineers from state and federal agencies, colleges and universities, as well as private service companies and consulting firms throughout the country. Steering committee members are elected for three-year terms, with their elections and re-elections being determined principally by their interests and participation in and contribution to the Symposium. The officers include a chairman, vice chairman, secretary, and treasurer. all of whom are elected for a two-year term. Officers, except for the treasurer, may only succeed themselves for one additional term.

A number of three-member standing committees conduct the affairs of the organization. The lack of rigid requirements, routing and relatively relaxed overall functioning of the organization is what attracts many participants.

The symposia are generally scheduled for two and one-half days, with a day-and-a-half for technical papers plus a full day for the field trip. The Symposium usually begins with a TRB session and an evening Ice-Breaker the first day, a full day of technical presentations the second day, a field trip on the third day followed by the annual banquet that evening, and a half day of technical presentations on the final day.

The Field Trip

The field trip is the focus of the meeting. In most cases, the trips cover approximately 150 to 200 miles, provide for six to eight scheduled stops, and require about eight hours. Occasionally, cultural stops are scheduled around geological and geotechnical points of interests. To cite a few examples: in Wyoming (1973), the group viewed landslides in the Big Horn Mountains; Florida's trip (1976) included a tour of Cape Canaveral and the NASA space installation; the Idaho and South Dakota trips dealt principally with mining activities; North Carolina provided stops at a quarry site, a dam construction site, and a nuclear generation site; in Maryland, the group visited the Chesapeake Bay hydraulic model and the Goddard Space Center. The Oregon trip included visits to the Columbia River Gorge and Mount Hood; the Central mine region was visited in Texas; and the Tennessee meeting in 1981 provided stops at several repaired landslide in Appalachia regions of East Tennessee.

In Utah (1988) the field trip visited sites in Provo Canyon and stopped at the famous Thistle Landslide, while in New Mexico, in 1990, the emphasis was on rockfall treatments in the Rio Grande River canyon and included a stop at the Brugg Wire Rope headquarters in Santa Fe.

Mount St, Helens was visited by the field trip in 1994 when the meeting was in Portland, Oregon, while in 1995 the West Virginia meeting took us to the New River Gorge Bridge that has a deck elevation of 876 feet above the water.

In Cody, Wyoming the 1996 field trip visited the Chief Joseph Scenic Highway and the Beartooth Uplift in northwest Wyoming. In 1997 the meeting in Tennessee visited the newly constructed future I-26 highway in the Blue Ridge of East Tennessee. The Arizona meeting in 1998 visited the Oak Creek Canyon near Sedona and a mining ghost town at Jerome, Arizona. The Virginia meeting in 1999 visited the "Smart Road" Project that was under construction. This was a joint research project of the Virginia Department of Transportation and Virginia Tech University. The Seattle Washington meeting in 2000 visited an ancient lahar in the Mount Rainier area. A stop during the Maryland meeting in 2001 was the Sideling Hill road cut for I-68 which displayed a tightly folded syncline in the Allegheny Mountains.

The California field trip in 2002 provided a field demonstration of the effectiveness of rock netting against rock falls along the Pacific Coast Highway. The Kansas City meeting in 2004 visited the Hunt Subtropolis which is said to be the "world's largest underground business complex". It was created through the mining of limestone by way of the room and pillar method. The Rocky Point Quarry provided an opportunity to search for fossils at the North Carolina meeting in 2005. The group also visited the US-17 Wilmington Bypass Bridge which was under construction. Among the stops at the Pennsylvania meeting were the Hickory Run Boulder Field, the No.9 Mine and Wash Shanty Museum, and the Lehigh Tunnel.

The New Mexico field trip in 2008 included stops at a soil nailed wall along US-285/84 north of Santa Fe and a road cut through the Bandelier Tuff on highway 502 near Los Alamos where rockfall mesh was used to protect against rockfalls. The New York field trip in 2009 included the Niagara Falls Gorge and the Devil's Hole Trail. The Oklahoma field trip in 2010 toured the complex geology of the Arbuckle Mountains in the southern part of the state along with stops at Tucker's Tower and Turner Falls.

In the bluegrass state of Kentucky, the 2011 HGS field trip included stops at Camp Nelson which is the site of the oldest exposed rocks in Kentucky near the Lexington and Kentucky River Fault Zones. Additional stops at the Darby Dan Farm and the Woodford Reserve Distillery illustrated how the local geology has played such a large part in the success of breeding prized Thoroughbred horses and made Kentucky the "Birthplace of Bourbon".

In Redding, California, the 2012 field trip included stops at the Whiskeytown Lake, which is one in a series of lakes that provide water and power to northern California. Additional stops included Rocky Point, a roadway construction site containing Naturally Occurring Asbestos (NOA), and Oregon Mountain where the geology and high rainfall amounts have caused Hwy 299 to experience local and global instabilities since first constructed in 1920.

The 2013 field trip of New Hampshire highlighted the topography and geologic remnants left by the Pleistocene glaciation that fully retreated approximately 12,000 years ago. The field rip included stops at various overlooks of glacially-carved valleys and ranges; the Old Man of the Mountain Memorial Plaza, which is a tribute to the famous cantilevered rock mass in the Franconia Notch that collapsed on May 3, 2003; the lacustrine deposits and features of the Glacial Lake Ammonoosuc; views of the Presidential Range; bridges damaged during Tropical Storm Irene in August 2011; and the Willey Slide, located in the Crawford Notch where all members of the Willey family were buried by a landslide in 1826.

The 2014 field trip presented a breathtaking tour of the geology and history of southeast Wyoming, ascending from the high plains surrounding Laramie at 7000 feet to the Medicine Bow Mountains along the Snowy Range Scenic Byway. Visible along the way were a Precambrian shear zone, and glacial deposits and features. From the glacially carved Mirror Lake and the Snowy Range Ski Area, the path wound east to the Laramie Mountains and the Vedauwoo Recreational Area, a popular rock climbing and hiking area before returning to Laramie.

In Sturbridge, MA, the 2015 field trip focused on the Connecticut Valley, a Mesozoic rift basin that signaled the breakup of Pangea, and the Berkshires, which represents the collision and amalgamation of an island arc system with the North American Laurentian margin.

The field trip in 2016 was an urban setting along the western edge of Colorado Springs and around Manitou Springs. Stops included the Pikeview Quarry, Garden of the Gods Visitor Center, and several other locations where rockfall and debris flow mitigation, post-flooding highway embankment repair, and a nonconformity in the rock records that spans 1.3 billion years were observed.

The 2017 field trip provided an opportunity to view the geology of northern Georgia. Stops included the Bellwood Quarry, which, at one time was run by the City of Atlanta and also served as a prison labor camp. It will eventually serve as a 2.4 billion-gallon water storage facility for the City of Atlanta upon completion of a tunnel to connect the quarry to two water treatment plans and three pump stations. Additional stops included the Buzzi Unicem Cement Plant to get a close up view of the Clairmont Melange, The Cooper Furnace near the Allatoona Dam, and the New Riverside Ochre-Emerson Barite mine.

The 2018 field trip in Portland Maine provided a good overview of the geology of coastal Maine. Field trip stops included a stop at the Sherman Salt Marsh near Newcastle which was recently restored to its natural state after the dam that carried US Highway 1 washed out during a 2005 storm. Additional stops included the site of the 1996 landslide near Rockland Harbor that consumed several homes and the rock slope remediation project at the Penobscot Narrows Bridge near Prospect Maine. A lobster lunch along the shore of Penobscot Bay was one of several highlights of the field trip.

The 2019 field trip in Portland Oregon travelled the Columbia River Gorge west. Starting at the Crown Point Vista House and Portland Women's Forum State Scenic Viewpoint above the gorge to learn about the river highway. Descending into the gorge, we stopped at scenic Multnomah Falls and Benson Bridge, and saw flexible rockfall fence installed to protect the lodge and historic Columbia River Highway. Other stops included lunch at Cascade Locks, Bonneville Landslide and rockfall areas along the highway.

The 2022 field trip in the Ashville area took us through Ordovician (500 my) to Precambrian (1.2 by) migmatized ortho and paragneisses, metamorphosed intrusives, thrust faults and contacts representing three orogenies and complex sequences of basement and terranes. We crossed the Brevard Fault zone several times, which is a structure that has been studied and interpreted for 100 years. Various attempts to define the structure have been made, especially in the pre-plate tectonic era. It has been theorized that these structures were as high, or higher than the Rockies at formation. 200 million years of rifted erosion leave us with an exposed look at deep orogenic roots of multiple thrust events. Precipitation in the areas is between 60-100” per year. There are deep ancient colluvial deposits, complex mineralization and weathering profiles, and non-linear/planar discontinuities. These deposits and precipitation make for distinct issues within the state. Deep foundations rarely present problems. We traveled over I-26 and the Blue Ridge Escarpment where they highway is being widened. Stops included the I-26 Old Howard Gap Slide Area, the US 74 Gerton Slide, a shallow landslide barrier on I-40 W, and the Buckner Gap Cut.

Technical Sessions

At the technical sessions, case histories and applied state-of-the-art papers are most common; with highly theoretical papers the exception. The papers presented at the technical sessions are published in the annual proceedings. All proceedings are available to download from www.HighwayGeologySymposium.org.

Banquet speakers are also a highlight and have been varied through the years.

Member Recognition: A Medallion Award was initiated in 1970 to honor those persons who have made significant contributions to the Highway Geology Symposium. The selection was- and is currently made from the members of the national steering committee of the HGS.

Emeritus Member

A number of past members of the national steering committee have been granted Emeritus status. These individuals, usually retired, resigned from the HGS Steering Committee, or are deceased, have made significant contributions to the Highway Geology Symposium. A total of 42 persons have been granted Emeritus status.

Dedications

Several Proceedings volumes have been dedicated to past HGS Steering Committee members who have passed away. The 36th HGS Proceedings were dedicated to David L. Royster (1931 – 1985, Tennessee) at the Clarksville, Indiana Meeting in 1985. In 1991 the Proceedings of the 42nd HGS held in Albany, New York were dedicated to Burrell S. Whitlow (1929 – 1990, Virginia). The 64th HGS Proceedings were dedicated to Earl Wright (1931 – 2012) at the North Conway, New Hampshire meeting. The 65th proceedings were dedicated to Nicholas Priznar (1952 – 2014) at the Laramie, Wyoming meeting. The 76th HGS held at Colorado Springs, Colorado dedicated the proceedings to Vern McGuffy (1934 – 2016). The proceedings for the 68th HGS held in Marietta, Georgia were dedicated to Richard (Dick) Cross (1944 – 2016). The proceedings for the 69th HGS are dedicated to Dave Bingham (1932 – 2018) and Joe Gutierrez (1926 –2018). The Proceedings of the 71st HGS are dedicated to Vernon (Vern) Bump.

List of Highway Geology Symposium Meetings

Meeting sites are chosen two to four years in advance and are selected by the Steering Committee following presentations made by representatives of potential host states. These presentations are usually made at the steering committee meeting, which is held during the Annual Symposium. Upon selection, the state representative becomes the state chairman and a member of the Steering Committee.

No.	Year	HGS Location
1st	1950	Richmond, VA
2nd	1951	Richmond, VA
3rd	1952	Lexington, VA
4th	1953	Charleston, WV
5th	1954	Columbus, OH
6th	1955	Baltimore, MD
7th	1956	Raleigh, NC
8th	1957	State College, PA
9th	1958	Charlottesville, VA
10th	1959	Atlanta, GA
11th	1960	Tallahassee, FL
12th	1961	Knoxville, TN
13th	1962	Phoenix, AZ
14th	1963	College Station, TX
15th	1964	Rolla, MO
16th	1965	Lexington, KY
17th	1966	Ames, IA
18th	1967	Lafayette, IN
19th	1968	Morgantown, WV
20th	1969	Urbana, IL
21st	1970	Lawrence, KS
22nd	1971	Norman, OK
23rd	1972	Old Point Comfort, VA
24th	1973	Sheridan, WY
25th	1974	Raleigh, NC
26th	1975	Coeur d'Alene, ID
27th	1976	Orlando, FL
28th	1977	Rapid City, SD
29th	1978	Annapolis, MD
30th	1979	Portland, OR
31st	1980	Austin, TX
32nd	1981	Gatlinburg, TN
33rd	1982	Vail, CO
34th	1983	Stone Mountain, GA
35th	1984	San Jose, CA
36th	1985	Clarksville, TN

No.	Year	HGS Location
37th	1986	Helena, MT
38th	1987	Pittsburg, PA
39th	1988	Park City, UT
40th	1989	Birmingham, AL
41st	1990	Albuquerque, NM
41st	1991	Albany, NY
43rd	1992	Fayetteville AR
44rd	1993	Tampa, FL
45th	1994	Portland, OR
46th	1995	Charleston, WV
47th	1996	Cody, WY
48th	1997	Knoxville, TN
49th	1998	Prescott, AZ
50th	1999	Roanoke, VA
51st	2000	Seattle, WA
52nd	2001	Cumberland, MD
53rd	2002	San Luis Obispo, CA
54th	2003	Burlington, VT
55th	2004	Kansas City, MO
56th	2005	Wilmington, NC
57th	2006	Breckinridge, CO
58th	2007	Pocono Manor, PA
59th	2008	Santa Fe, NM
60th	2009	Buffalo, NY
61st	2010	Oklahoma City, OK
62nd	2011	Lexington, KY
63rd	2012	Redding, CA
64th	2013	North Conway, NH
65th	2014	Laramie, WY
66th	2015	Sturbridge, MA
67th	2016	Colorado Springs, CO
68th	2017	Marietta, GA
69th	2018	Portland, ME
70th	2019	Portland, OR
71st	2022	Asheville, NC
72nd	2023	Tacoma, WA

YOUNG AUTHOR AWARD

The Highway Geology Symposium has always encouraged participation of Young Professionals, realizing that Young Professionals are the future of the Organization. This participation was taken formal in 2014, with the formation of an annual National Young Author Competition, where Young Authors have the opportunity to prepare papers and present their work. To participate, Young Author's must be up to 35 years old or younger, the principal author of the paper and the sole presenter of the paper at the Symposium. Papers are reviewed and judged based on Technical Presentation of the Paper (including Geology), Originality of the Work, Applicability of the Work to Others and Paper Layout. One Young Author is selected each year to receive the coveted Young Author Award, with presentation of the award conducted at the annual Symposium banquet

Young Author Award Winners

2014 Simon Boone,
"Performance of Flexible Debris Flow Barriers in a Narrow Canyon"

2015 Cory Rinehart,
"High Quality H20: Utilizing Horizontal Drains for Landslide Stabilization"

2016 Todd Hansen,
"Geologic Exploration for Ground Classification: Widening of the I-70 Veterans Memorial Tunnels"

2017 James Arthurs,
"Construction of Transportation Infrastructure in Weathered Volcanic Ash Soils"

2018 Brian Felber,
"Geotechnical Challenges for Bridge Foundations & Roadway Embankment Design in Peats and Deep Glacial Lake Deposits"

2019 Anya Brose,
"The Assessment and Remediation of Wabasha St. Rock Fall"

2022 Christopher Mayer
"Using Geophysics to Evaluate the Results of a Grouting Program in Karstic Geology"

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R.J. Edmondson	1972
C.S. Mullin	1974
A.C. Dodson	1975
Burrell Whitlow	1978
Bill Sherman	1980
Virgil Burgat	1981
Henry Mathis	1982
David Royster	1982
Terry West	1983
Dave Bingham	1984
Vernon Bump	1986
C.W. "Bill" Lovell	1989
Joseph A. Gutierrez	1990
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W.A. "Bill" Wisner	1991
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Harry Moore	1996
Earl Wright	1997
Russell Glass	1998
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A. David Martin	2008
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Jeff Dean	2012
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Landslide Technology

Darren Beckstrand
Email: darren.beckstrand@ccilt.com
Phone: 503-452-1200
www.landslidetechnology.com

Monday

Ice Breaker Reception

Landslide Technology, a division of Cornforth Consultants, Inc., provides planning, design, and construction services to owners of transportation infrastructure impacted by slope stability and geologic hazards (i.e., landslides and rockfall). Our experienced technical staff are available to assist design teams develop projects from initial concept through successful completion. Our focused expertise and nimble size allow us to respond quickly to projects across the nation and develop cost-effective strategies to mitigate complex geotechnical issues.

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Closing Banquet
Keynote Speaker

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Thursday
AM Break

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Rowan Anderegg
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PM Break

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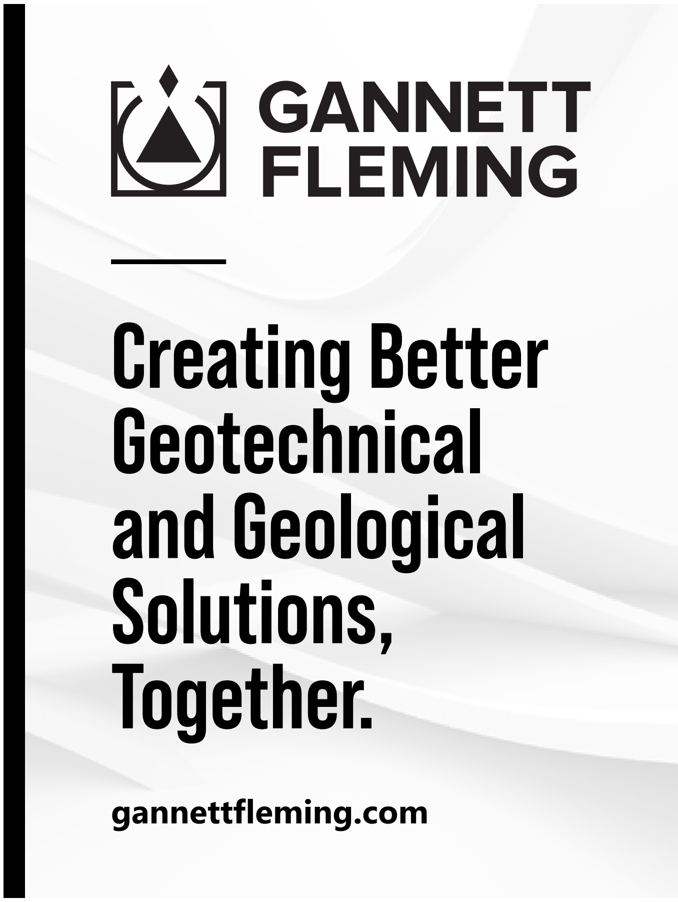
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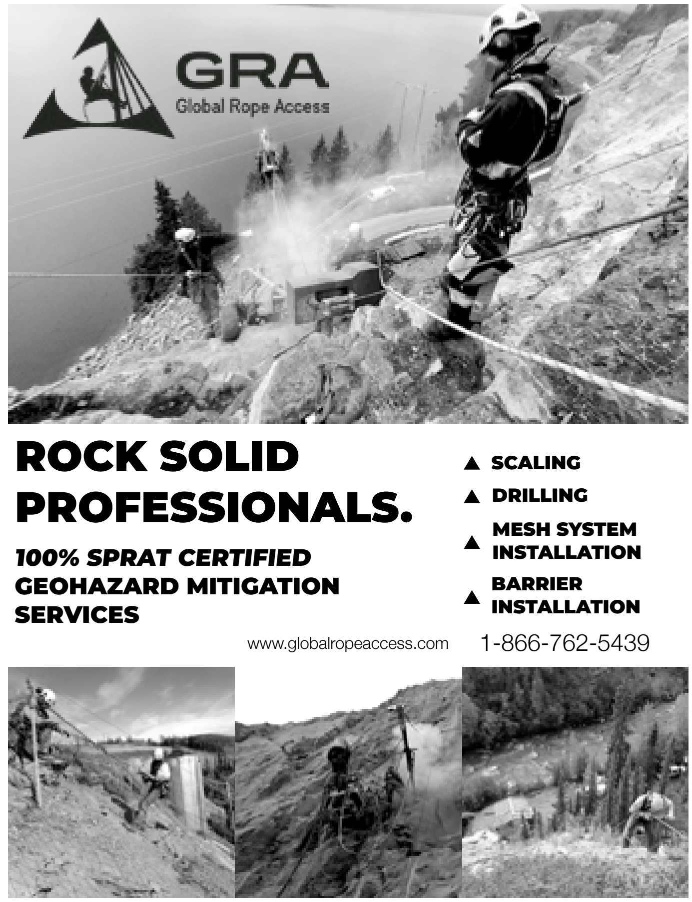
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DOWL provides a wide range of civil and structural engineering and related services, including the design of roadways, highways, airfields, and trail systems; bridges and structures; geotechnical engineering and materials testing; water, sewer and storm drain systems; environmental documentation and permitting; water rights planning and design. Our staff of dedicated professionals consistently exceeds our client's expectations and has enabled us to develop into one of the West's leading planning, surveying, civil/transportation, and environmental services firms. Today, we offer a wide range of engineering services to public and private clients, with offices in Alaska, Arizona, Colorado, Montana, Nevada, Oregon, Washington, and Wyoming. DOWL's geoscience professionals use soil & rock mechanics, geophysical surveys, and soils engineering to solve practical problems related to infrastructure development comprised of or supported by soil and rock. Drawing on the expertise of our geotechnical engineering and geoscience professionals, and using current and innovative tools, we specialize in evaluating subsurface conditions and their impacts for any project; from the planning and permitting stages, into fieldwork and data collection, and through design and construction.

Exhibitors

Foothills Drilling Equipment, Inc.

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Foothills Drilling Equipment serves the construction drilling industry with the highest quality products and equipment on the market. We pride ourselves on our excellent customer service and responsiveness. Our product line of TEI Drills, Intric Grout Plants, and now TesCar limited access shaft drilling rigs means Foothills has the solution you need to get the job done.

Foundation Testing & Consulting, LLC (FTC)

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Foundation Testing and Consulting, LLC provides the full range of deep foundation testing services to support the construction of pile and drilled shaft supported bridge foundations. Our services include cross-hole sonic logging and thermal integrity profiling of drilled shafts and dynamic pile testing.

FTC has expanded its service line to include compilation of historical pile installation data for departments for transportation into our PileTrac application. PileTrac is a relational database with cloud-based interactive dashboards that permits a full range of data analytics to understand past design and installation challenges and to identify trends and root causes. The PileTrac application is an online, subscription based service. FTC also provides seismic refraction survey services to better characterize subsurface soil and rock conditions at bridge sites and to provide better predictions for likely pile tip elevations.

Exhibitors

GeoEngineers, Inc.

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GeoEngineers is an earth science and engineering consulting firm headquartered in the Pacific Northwest. With nearly 400 employees in 21 nationwide offices, we provide local, state and Federal agencies with geotechnical, engineering geology, and seismic engineering services for transportation projects across the U.S.

GEOKON

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GEOKON is a recognized world leader in the manufacture of structural and geotechnical instrumentation. Founded in 1979, GEOKON has grown to more than 130 associates and offers a full complement of instrumentation for a wide range of industries including tunnels, dams, mines, piles, bridges, pipelines, landfills, embankments, transportation and wind turbines. Over 45 GEOKON agents distribute products globally to North and South America, Europe, Middle East, China, Russia, Asia Pacific, Australia and New Zealand. GEOKON incorporates state-of-the-art manufacturing processes and equipment to produce the highest quality and performing products on the market. Mechanical, electrical and software engineering teams collaborate to develop the most innovative, accurate and reliable instrumentation in the industry. As a result, GEOKON has been awarded ISO 9001:2015 registration from both ANSI•ANAB, USA and UKAS of Great Britain. GEOKON's calibration program complies with ANSI/NCSL Z540-1 and all primary calibration standards are traceable to the US Department of Commerce, National Institutes of Standards and Technology (NIST), in Washington, DC, and are calibrated by laboratories with ISO/IEC 17025 accreditation. In addition, GEOKON is a qualified supplier for US Nuclear Facilities in accordance with the American Society of Mechanical Engineers (ASME)/Nuclear Quality Assurance (NQA)-1, Quality Assurance Program Requirements. GEOKON products are supported by an experienced team of factory-trained associates ready to assist with instrument design, selection and installation. All products include a full, 13-month warranty. For more information, please visit www.geokon.com, email us at info@geokon.com or call +1-603-448-1562.

Exhibitors

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Geoprevent develops, installs and operates premium alarm and monitoring systems for natural hazards. We focus on customer-specific and highly reliable solutions. Thanks to our multidisciplinary team we are able to develop, build and install hardware as well as software in-house. This allows us to act fast and implement projects straightforwardly.

Geovert LLC

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Geovert is a specialist construction contractor specializing in difficult-access slope stabilization and rockfall solutions. As a global leader, Geovert offers a wide range of services that address complex. geotechnical challenges in various industries.

Exhibitors

Gilson Company Inc

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Gilson Company, Inc. is a 3rd generation family-owned company that has provided over 80 years of service to our industry. Throughout all these years our core values have never changed, we continue to treat our customers with the best care possible, even if it means pointing them in a different direction. Helping them find the best solutions to their problems is the most important thing to us. As the company has grown, so has our reputation for superior expertise, innovation, and development. While we constantly seek and develop new and better products, our values stay the same; we offer high-quality products at a competitive price, and backup our great customer service with dedicated technical support.

Multi-Power Products

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Multi-Power Products is a Canadian manufacturer of Geotechnical, Environmental and Exploration drills and drilling equipment located in Kelowna, British Columbia.

Pacific Blasting

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Pacific Blasting have provided a wide range of mining, rock slope stabilization and precision blasting services locally and internationally since 1954. During the last 60 years, our team of specialists have successfully completed hundreds of projects in the most challenging of conditions. This experience enables us to develop innovative and cost effective solutions for safely and efficiently completing any project.

Exhibitors

Rocscience

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Since 1996, Rocscience has been a company focused on bridging the gaps in analysis, design, and visualization tools for the mining and civil engineering industries. Born as a spin-off company from the University of Toronto, our software development combines innovation and research, allowing us to develop world-class software solutions that work for you today and will evolve to meet your needs tomorrow. Our motto "Geotechnical tools, inspired by you" means we are continuously listening to your specific geotechnical challenges so that we can build tools to help you overcome them. Whether you're focused on slope stability, excavation design, or foundation analysis, our comprehensive suite of 18 programs means that no matter what your needs are, we have a software solution for your projects.

SIMCO Drilling Equipment Inc.

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SIMCO® Drilling Equipment, Inc. began designing and building all-hydraulic, tophead drive drilling rigs in 1971 at our manufacturing facility located in Osceola, Iowa. SIMCO rigs are used for water well and geothermal well drilling, geotechnical and environmental drilling, mineral exploration, geothermal wells, construction and utility work, and a wide range of other diverse applications.

Exhibitors

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TRUMER SCHUTZBAUTEN is a world leader in the design and manufacturing of geohazard mitigation structures that protect against rockfall, debris flow, avalanche and unstable slopes. From slope mesh to massive barriers, we protect life, buildings and infrastructure where failure is not an option. With TRUMER's recent acquisition of Pfeifer Isofer (now TRUMER ISOFER), they offer product lines tested following Austrian, Swiss and European approvals to make sure their clients receive the solution that best suites their needs.

Williams Form Engineering Corp.

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Williams Form Engineering Corporation has been providing threaded steel bars and accessories for rock, soil and concrete anchors, post-tensioning systems, and concrete forming hardware systems in the construction industry for over 100 years. Our rock and soil anchor product line includes our Spin-Lock mechanical rock anchors, polyester resin anchors, multiple corrosion protection anchors, soil nails, strand anchors, Manta Ray soil anchors, Geo-Drill Hollow-Bar anchors, and micropiles. For concrete anchoring we offer Spin-Lock anchors, undercut anchors, reusable anchors and cast-in-place anchors. We also have a full line of All-Thread Rebar for tiebacks, micropiles and post-tensioning.

ABSTRACTS & NOTES

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5	10:40 AM – 11:00 AM	Young Author Presentation: Seward Highway Rockfall Mitigation, Anchorage, Alaska	Sebastian Dirringer	58
6	11:00 AM – 11:20 AM	Young Author Presentation: A Multi-Phased Approach to Rockfall Mitigation at Don Pedro Dam: Lessons Learned for Critical Facilities and Roadways	Joey Renner	60
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NOTES

1 SEISMIC REFRACTION CASE STUDIES: CORRELATION WITH PDA PLAN TIP ELEVATION

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ABSTRACT

Geophysics, particularly seismic refraction and multi-channel analysis of surface waves (MASW), has emerged as a reliable method for sub-surface investigations in the design of deep foundations for bridges. Our company, Foundation Testing and Consulting, has developed and brought to market an innovative geophysical application for bridge foundation design over the past year. In this research, we have developed a strong correlation between compression wave velocities and historical PDA-tested capacity and penetration depths for piling.

This paper provides a detailed discussion on the use of seismic refraction and MASW in bridge foundation design and highlights the advantages it offers over traditional methods.

This paper presents the first instance in which our geophysical application was utilized to save a contractor over $60,000 on shortened pile lengths in Wichita, Kansas. The study area included a well-known weathered Wellington shale profile that presented challenges for pile foundation design. By using our geophysical application, we were able to identify the depth of the bedrock and assess the soil properties and likely pile penetration depths within weathered shale bedrock to optimize pile order lengths and reduce project delays.

Our geophysical application offers a non-destructive, fast, and cost-effective alternative and supplement to traditional site investigation methods, making it an attractive option for pile supported projects of all sizes.

NOTES

2 DESIGN AND CONSTRUCTION OF A BOTTOM-UP RETAINING WALL IN SLICKENSIDED RED BED MATERIAL

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ABSTRACT

This paper describes the design considerations and challenges of a 4,000 ft long, 40 ft high permanent bottom-up retaining wall constructed on a slope with historic instabilities due to geologic conditions. A portion of West Virginia Route 2 (WV2) required expansion to support a new bridge crossing the Ohio River into Brilliant, Ohio just south of Wellsburg, West Virginia. The proposed location of this bridge, and therefore the area requiring expansion, is located along a mountainside sloping towards the river on the West Virginia side. Historical, deep-seated instabilities are present along the proposed roadway alignment due to a thin creep zone of low residual strength material, known as the Pittsburgh red beds, located at the soil-rock interface. A fill wall was identified as the most economical option due to the existing topography and geology of the site. The presence of the slickensided material limited the applicable wall types as global stability of the entire slope needed to be addressed. An in-depth understanding of the Pittsburgh Red Bed material and the subsurface stratigraphy were required to properly address these challenging site conditions. A three-dimensional model was created to understand the subsurface stratigraphy and identify areas of concern. Advanced numerical analyses were utilized to better identify the material properties of this complex subsurface stratigraphy and understand the impact on the design through construction staging. This paper will also address the observed subsurface conditions and challenges encountered during construction in a variable geology.

NOTES

3 IMPACTS OF WEAK ROCK UNITS ON CUT SLOPE CONSTRUCTION

Case Study: Interstate 78, Section 12M Reconstruction Project Berks County, Pennsylvania

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ABSTRACT

Sections of the recently excavated 1.5H to 2H:1V rock cut slopes along the 10-mile long I-78 Section 12M Reconstruction Project Corridor in Berks County, Pennsylvania experienced a series of planar-type rockslide failures following periods of persistent rain beginning in late January of 2022. The existing cut slopes prior to the reconstruction project generally ranged from 2H:1V to 1H:1V, were almost entirely vegetated (minimal rock exposures), and had no reported history of stability issues.

Gannett Fleming engineers and geologists worked closely with PennDOT's construction and geotechnical units, the project geotechnical engineer, and the construction manager to turn around an emergency anchored mesh design to stabilize two primary areas of stability concern within the project limits. In addition, a combination of excavation and mechanical scaling methods were used to mitigate localized areas of sliding by removing pervasive weak rock units that were observed to be daylighting the cut slope.

This case study presents the results of the stability analyses that show how the geologic structural discontinuity orientations and properties of the underlying weak rock exposed during construction aligned in such a way to intersect a very small potential failure envelope.

Unless adverse subsurface conditions are identified during design, or site history dictates, detailed stability analyses are not typically performed for shallow cut slopes (generally 2H:1V or less). The objective of this paper is to emphasize the importance of characterizing subsurface conditions during design and provide a real-world example on the impacts of encountering weak rock materials during cut slope construction.

NOTES

4 COMPARATIVE ANALYSIS OF ROCK SLOPE SCALING QUANTITIES AND CREW HOURS: A STRATEGIC APPROACH FOR STANDARDIZING THE PRACTICE

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ABSTRACT

Rock slope scaling is a common method used to reduce the risk of rockfall and debris impacting the highway. Currently, there are no set standards at the Washington State Department of Transportation (WSDOT) or industry-wide regarding design or quantity estimates for rock slope scaling. Presumably, this is because it is difficult to measure and estimate these quantities and scaling hours. Various rock types, weathering agents, and discontinuities are some of the factors that make estimating scaling quantities and crew hours very difficult. By investigating how these projects have been quantified in the past, we will be able to identify opportunities for improvement and progress toward a common standardized practice. The purpose of this paper will be to analyze past rock slope scaling projects throughout Washington state (WA) and identify potential impacts of site conditions to calculated estimates verses actual quantities of debris removal and scaling crew hours. Prior investigations into quantity estimates for rock slope scaling projects are limited. A previous study conducted by California Department of Transportation (CalTrans) in 2016 presented a method that geo-professionals may use to assess and quantify rock slope scaling operations. Based on previous WSDOT project information, we compare the estimated quantities of rock slope scaling debris and scaling crew hours with actual values after the project was completed. We compared various factors that may influence estimates determined by the Project Engineer or designer including climate and groundwater, dominant weathering agents, rock strength, discontinuity characteristics, and rock type. This paper presents the findings of this research and offers an guide to standardizing quantity estimates for rock slope scaling projects at WSDOT.

NOTES

5 SEWARD HIGHWAY ROCKFALL MITIGATION, ANCHORAGE, ALASKA

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ABSTRACT

The Alaska Department of Transportation & Public Facilities (DOT&PF) retained Landslide Technology (LT) to develop rockfall mitigation for ten rock slopes adjacent to the Seward Highway (Hwy) between mile posts (MP) 104 and 114. The project area lies along the north bank of the Turnagain Arm of the Cook Inlet and runs approximately 13 to 23 miles southeast of Anchorage, Alaska. The project skirts the western foothills of the Chugach Mountains near Rainbow Peak, South Suicide Peak, and Indian House Mountain.

The Hwy has experienced rockfall safety concerns since its construction, resulting in an increased risk to roadway users and increased maintenance efforts. Rockfall mitigation was installed in 1992 to address safety concerns at several slopes adjacent to the highway. Since construction, rockfall activity has either permanently damaged or destroyed some of the mitigation. DOT&PF Maintenance & Operations (M&O) personnel has also observed increased activity and potential rockfall sources at sites in addition to those mitigated in 1992. During the 2018 magnitude 7.1 earthquake several of the slopes along the Seward Highway produced rockfall. This was especially true for sites at MP 111.3 and MP 113.9.

This paper will describe the process DOT&PF and LT utilized to select sites based on safety considerations and hazards observed during site investigations; details of the mitigation measures that were designed on a fast paced schedule; and construction observations, unique modifications, and lessons learned. Construction of the rockfall mitigation measures was completed in June 2023.

NOTES

6 A MULTI-PHASED APPROACH TO ROCKFALL MITIGATION AT DON PEDRO DAM: LESSONS LEARNED FOR CRITICAL FACILITIES AND ROADWAYS

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ABSTRACT

Turlock Irrigation District (TID) initiated a rockfall hazard evaluation and mitigation program in 2018 to reduce risk to its personnel and the Don Pedro hydropower facility, which is located in Tuolumne County, California. Gannett Fleming geologists performed an initial "screening level" visual assessment of the existing slopes surrounding the facility and identified five potential rockfall hazard areas requiring mitigation. Each area was evaluated based on the likelihood versus consequences of rockfall events, and a prioritized list was developed for TID to consider further investigation and rockfall mitigation measures. The highest hazard area was on the west canyon slope, where numerous large rock blocks appeared at risk of dislodging and potentially impacting the powerhouse and/or it's only vehicle access road below. Gannett Fleming performed rockfall analyses and simulation, assessed alternatives, and designed TID's preferred rockfall mitigation measures of what became known as Areas 3 & 4, which comprised scaling and installation of rockfall drapery, rock anchors, and wire-rope restraints. The rockfall mitigation measures were constructed in 2020 by Access Limited Construction. The project challenges included limited slope access during the assessment and design phases, a difficult slope configuration given its proximity to the powerhouse, and a requirement to keep the access road largely open during construction. During the construction phase, close cooperation between the owner, engineer, and contractor allowed all parties to respond quickly to design/construction changes based on the actual slope conditions encountered. This paper will detail the development and implementation of a rockfall mitigation program for critical facilities and roadways, including initial reconnaissance, detailed assessment, alternatives analysis, design, procurement, and construction.

NOTES

7 BOLT CREEK FIRE: POST-WILDFIRE DEBRIS FLOW RISK ASSESSMENT AND BARRIER DESIGN ON US 2, NEAR GROTTO, WA

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ABSTRACT

Post-wildfire debris flow hazards created by the Bolt Creek Fire warranted rapid response from the USDA Forest Service, Washington Geologic Survey, and Washington State Department of Transportation (WSDOT), to analyze and mitigate the risk of debris flows reaching US Route 2 (US 2). The 2022 Bolt Creek Fire burned over 14,000 acres of forest along US 2 between approximate mileposts 40 and 50, creating debris flow hazards within the preexisting drainage network upslope. The Bolt Creek Fire burned area along US 2 is on the western slopes of the North Cascades, where the surface geology is composed of alluvial soils, Mesozoic metasedimentary, and Tertiary intrusive rock. The incised drainage network extends from US 2 approximately 4,000 feet upslope to the crests of Baring Mountain and Grotto Mountain. Post-wildfire assessments by the USDA Forest Service, USGS, and WGS provided specific points of concern for WSDOT with elevated debris flow risk, based on burn severity, and mapped alluvial fans intersecting US 2 and the town of Grotto, WA. WSDOT provided rapid response, by completing site specific evaluations of each point of concern. Evaluating available catchment and sediment delivery potential, WSDOT identified two locations with the highest risk of debris reaching US 2. To reduce the risk of debris flow impacts to the highway, WSDOT used hand calculations along with GeoBrugg Inc.'s dimensioning tools DEBFLOW and SHALLSLIDE to calculate estimated static and dynamic loads that would be generated in the event of a debris flow in these two locations. Using the results of the analysis, WSDOT recommended construction of post-supported debris flow (or shallow landslide) barriers (western and eastern) that will withstand impacts of up to 1570 psf (75 kN/m^2). Rapid response, design, and construction times are required to construct the debris flow barriers in a timely manner, considering the estimated 1–to-5-year timeline in which the post-fire debris flow risks are the greatest.

NOTES

8 EMERGENCY PLANNING AND MITIGATION FOR POST-FIRE DEBRIS FLOWS IN GLENWOOD CANYON, COLORADO

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ABSTRACT

The Grizzly Creek fire started on August 10, 2020 near Glenwood Springs, Colorado. Over the next week, the fire covered most of the area surrounding Glenwood Canyon, including many of the tributary watersheds to the Colorado River. Interstate-70 (I-70), a major highway connecting the eastern and western slopes of Colorado, is in the bottom of Glenwood Canyon. Watersheds that have had recent wildfires have a higher likelihood of a debris event occurring and producing larger debris volumes. This was proven true in the summer of 2021 when approximately 30 debris flow events occurred within the canyon, damaging both decks of I-70 and depositing over 300,000 cubic yards of sediment on the road and in the Colorado River.

After the 2020 fires, the authors completed an emergency assessment of several burned watersheds to help understand the potential consequence of debris flow events using FLO-2D software and debris flow predictions from the USGS Emergency Assessment of Post-Fire Debris-Flow Hazards program. Characteristics and results from the predictive models were compared with the 2021 debris flow events and showed reasonably strong correlation.

The models and analyses were useful tools to understand the risk of debris flows to I-70, mitigation planning, and predicting emergency clean-up efforts.

NOTES

9 STABILIZATION OF THE FREMONT HALL LANDSLIDE

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ABSTRACT

A landslide occurred at California Polytechnic State University – San Luis Obispo during a period of heavy precipitation. It originated upslope of the Fremont Hall Dormitory and deposited saturated soil against the building, leading to evacuation and closure of the dormitory.

Published geologic maps show a Quaternary age landslide at the site. It was characterized as an earthflow composed of predominantly fine-grained soil prone to creeping and periodic relatively large-scale movement associated with heavy precipitation. The active portion of this landslide, termed the "2017 Landslide," was identified based on review of historical aerial imagery, previous subsurface data, and data from the 2019 investigation. The 2019 investigation included drilling, test pits, large-diameter bucket auger borings, slope inclinometers, vibrating wire piezometers, and laboratory testing. Site geology was interpreted as interbedded colluvium/landslide deposits overlying a massive block of graywacke within the Franciscan Mélange. Concrete debris was encountered in a bucket auger boring at approximately 46 feet below the ground surface. It was concluded, based on the debris and historical aerial photograph review, that excess soil generated from the construction of the dormitories in the 1950's was placed on the body of the Quaternary age landslide.

The stabilization consisted of a series of ground anchor galleries within the landslide mass and an anchored soldier pile wall at the toe of the stabilized slope. Horizontal drains and subdrains were installed within the landslide mass to collect and maintain design groundwater elevations. The project was successfully completed in July 2022 and students have since reoccupied the dormitory.

NOTES

10 ROUTE 3, RANDOLPH COUNTY, MISSOURI LANDSLIDE REMEDIATION STUDY. DESIGN AND CONSTRUCTION

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ABSTRACT

A landslide occurred at MoDOT Route 3 after an intense rain event in April of 2021. At the landslide location, 200+ feet deep, open pit quarries are located at the limits of the thirty foot right of way on both sides of the highway. Much of the landslide mass, comprised of overburden soils, slid down the highwall to the quarry floor. The initial study was to determine the extent and cause of the slide, stability of the 200-foot vertical high wall and shallow tunnels under the roadway connecting the two open pits. The final phase would develop feasible, economic alternatives for reopening the roadway.

The site is located in a complex geologic environment at the very border of glaciation. Bedrock geology is further complicated by the location of a Pennsylvanian Age channel fill sandstone cut through the underlying Mississippian limestone. Several piezometers were installed and indicated a very erratic groundwater pattern in the glacial.

The study involved performing borings, laboratory testing, soil slope stability analysis, rock slope stability analysis of the quarry wall, and rock stability analysis of the abandoned tunnels traversing the roadway.

Several remedial alternatives were considered in the study and the favorite was relocating the roadway to one side away from the slide as well as lowering the grade to near the failure surface of the landslide. Also, the slide mass had to be removed and replaced with shot rock to provide long term stability and promote long-term internal drainage. Both were necessary to keep further movement of the ground into the deep open pit quarry.

The consensus of the study led to final design which included relocating the roadway both horizontally and vertically. Included in the final design was removal and replacement of the slide mass.

NOTES

11 SR 112 / CLALLAM BAY LANDSLIDES – CHARACTERIZATION AND MITIGATION

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ABSTRACT

In November 2021, during a period of intense rainfall, an unstable hillslope collapsed above a coastal highway on the north coast of the Olympic Peninsula on Washington State Route 112. The debris slide buried approximately 200 feet of the highway with 15- to 20-feet of debris and extended hundreds of feet into the Strait of Juan de Fuca. This large debris slide blocked the sole access to coastal communities west of Clallam Bay, WA, including the Makah Reservation. By comparing pre-debris slide lidar to a post-debris slide UAV-generated ground surface, WSDOT developed a strategy to regrade and stabilize the landslide. Stabilization was complicated by the discovery of an older landslide that had been buried by the November 2021 event. The pre-existing landslide was uncovered and further destabilized during the project's grading operations. Emergency stabilization measures were not adequate to mitigate the reactivated landslide and a subsequent phase of geotechnical work was conducted to develop permanent stabilization measures. Both landslides were found to have resulted, at least partially, from poor land use activities. This case-history summarizes the mechanisms that caused the failure and the methods employed to characterize and stabilize this complex landslide.

NOTES

12 STATE ROUTE 112: LANDSLIDE ALLEY – STRIVING FOR RESILIENCY

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ABSTRACT

State Route (SR) 112 serves as the primary access for the northwestern Olympic Peninsula of Washington State and the remote communities situated along the Strait of Juan de Fuca west of Port Angeles. Particularly unfavorable geology underlies the western half of SR 112, which combined with steep topography and an exceptionally wet winter climate, result in one of the most landslide-afflicted highway corridors in the State. Landslides and flooding of low-lying areas routinely impact highway travel most winters. Traffic interruptions are commonly limited to a single lane or closure of both lanes for short duration through persistent maintenance efforts. On a longer cycle of a few years to a decade or two, major landslide events severely damage or destroy the highway in one or more locations resulting in long-duration closures of three to six months, or more. Detour options are limited to nonexistent (for some hazard conditions), and communities and local businesses are significantly impacted during these long-duration closures until highway repairs can be made or floodwaters recede.

The WSDOT Geotechnical Office commissioned a planning-level study to assess geologic and hydrologic hazards that impact the highway and provide recommendations to improve its resiliency. The study focuses on two segments of the highway that are most frequently and severely impacted by landslides: 1) MP 0 at the Makah Reservation Boundary to MP 17 at Clallam Bay; and 2) MP 29 near the terminus of the Pysht River to MP 38 at West Twin River.

The two highway segments were subdivided into ten subsegments of two to four miles in length for detailed evaluation. Subsegments were selected based on access constraints, geographic boundaries, and geologic/topographic conditions. Seven hazard types (shallow and deep-seated landslides, lowland flooding, coastal erosion, sea-level rise, earthquakes, and tsunamis) were evaluated for each subsegment. The likelihood of occurrence and potential consequences were assessed with input from stakeholders. Consequences included service disruptions, direct and indirect costs, and public safety. Over the past decade, direct costs for repair of emergent events have totaled around $11 million, equating to an annualized cost of about $1.1 million for repairs and direct impacts. A risk matrix was then generated for each hazard type and a risk register was built for each subsegment.

Repairing damages from emergent events has been the primary management approach employed by WSDOT for this highway to address the more consequential hazard events. Given the extent of

hazards throughout the corridor and anticipated limitations in available funding, it was judged infeasible to proactively stabilize or fully protect the highway for a sufficiently large population of high-risk slopes to significantly reduce impacts within a reasonable timeframe of several decades. Mitigation strategies to build resiliency of the highway focused on reducing service disruptions and damages and improving safety. Recommendations to proactively reduce risk and impacts and build resiliency included: 1) various alternative routes, permanent or temporary, to address the subsegments most impacted by service interruptions; 2) site-specific geotechnical investigations for potentially imminent damage; and 3) management actions entailing increased regional and site-specific deformation monitoring, review of adjacent land-use practices, updating the Unstable Slopes database, and assessing Region Maintenance capabilities and resources.

NOTES

13 RAISED DRAPERIES: DEFINING HYBRID BARRIERS AND ATTENUATORS BY APPLICATION

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ABSTRACT

Beginning in the 1980s, research and development of flexible rockfall fence systems resulted in a wide variety of systems developed to protect facilities from falling rocks. These systems were basically a fence with a wire mesh supported by an infrastructure of cables and posts that were specifically designed to be flexible. Specialty manufacturers offered up a suite of designs and systems for a broad range of rock impact energies and rockfall bounce heights. Soon practitioners were applying these systems to a wide variety of terrain that included the standard fence at the base of the slope, placing modified versions of flexible rockfall barriers and unsecured draperies in incised drainages, draping long steep slopes, and placing barriers and drapery over rock slopes in narrow corridors with limited catchment. The systems designed for these slope conditions were being developed not to stop the falling rock but to attenuate the rocks energy and control the rocks trajectory so that it would be deposited at a safe location. Soon the industry ended up with two common names for these systems: Hybrids and Attenuators. Most practitioners acknowledge these two titles, but the definition of which term applies to which system often gets blurry between agencies, manufacturers, academics, and consultants. There is an important distinction. While the two systems are very similar construction, as both systems provide a standard unsecured drapery with the added benefit of elevating the upslope end of the drapery off the ground surface to catch rocks rolling down slope above. In one design, rockfall is channeled directly into a suitable containment area at the bottom of the installation, and in the other design the rockfall exits the bottom of the mesh to continue down the slope into a series of similar systems that dampen motion and control the rocks trajectory that is eventually guided into the containment area at the base of the slope. To obtain some standardization in product development, proper usage, and testing methods terms that allow distinction between these different types of systems needs to be formalized throughout the industry. This paper reviews the history and defines the terms for attenuator and hybrid systems, current design methodology, results from full scale tests and discusses nomenclature and performance characteristics that can guide the development of industry standards.

NOTES

14 HOW TO DEVELOP ROCKSLOPE MITIGATION FOR VERY LARGE ROADWAY-DIPPING BLOCKS ALONG AN INTERSTATE HIGHWAY

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ABSTRACT

Several large rock slabs sit perched above westbound Interstate 90 at milepost 40 in Washington State. A highly persistent adversely dipping joint set comprises the basal surfaces of these blocks, granting them kinematic freedom to slide towards the interstate. Two additional joint sets, oriented sub-orthogonally to the highway-dipping joint set, provide lateral/rear release. The Washington State Department of Transportation (WSDOT) recently completed engineering geologic design to mitigate the slope, with construction slated for spring 2024.

In support of design, WSDOT conducted rope-access reconnaissance to characterize the engineering geology of the 200-ft.-high slope. Safety constraints prevented rope access to the entire slope, so WSDOT supplemented the field reconnaissance with terrestrial and unmanned aerial vehicle (UAV) laser scanning, and UAV Structure-from-Motion photogrammetry. WSDOT used these datasets to construct 2D numerical models of the blocks to calculate the reinforcements required to mitigate the slope.

Mitigation will include installation of approximately 3700 linear feet of untensioned rock dowels. Mitigation will also include targeted vegetation removal, significant slope scaling to remove loose rocks and debris from the slope face, and installation of approximately 900 linear feet of uncased horizontal drains in rock.

To protect the travelling public during slope work, the rightmost westbound lane of traffic will be closed. The entire work zone will be separated from live traffic by concrete barrier and by weighted conex rockfall barrier. Crane-supported rockfall containment nets will be suspended between the conex barrier and the slope during scaling. Rolling slowdowns may also be employed during scaling of larger blocks.

NOTES

15 WHAT IF THE ROCK ONLY THREATENS TO FALL? EMERGENCY RESPONSE TO A DECOUPLED CLIFF FACE IN WASHINGTON STATE

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ABSTRACT

Many engineering geologists are familiar with the following scenario: hundreds of cubic yards of rock debris have blocked a roadway with resultant disruption to traffic and commerce. Assessment is necessary to evaluate whether additional unstable rock material remains on the slope and whether the debris on the roadway can be safely cleared to reopen (or partially reopen) the road. What if, however, instead of hundreds of cubic yards, the event included several thousand cubic yards of material, all within a single rock slab, which suddenly decoupled from the rock face, and essentially teetered above the roadway? Such an event occurred on Washington State Route 503 during the spring of 2017. A single slab of volcanic rock (measuring approximately 65 to 70 feet tall, 100 to 105 feet wide and 15 to 20 feet thick) suddenly detached from a vertical cliff face upslope of the highway, dropped approximately 15 feet, and came to rest in a precarious sub-vertical position on a highway-sloping bench. This paper will discuss the subsequent WSDOT emergency response; the follow-on design and bid contract to remove (trim-blast) the slab and mitigate (reinforce) unstable areas behind and adjacent to the failure site; the combination of geologic, topographic and hydrogeologic factors that led to this failure; and how these site conditions are informative to geohazard specialists working in volcanic terrain.

NOTES

16 I-90 ROCK SLOPES: A RETROSPECTIVE OF THE SNOQUALMIE PASS PROJECT

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ABSTRACT

In the early 2000's, the Washington State Department of Transportation (WSDOT) sought to improve the capacity of Interstate 90 (I-90) through that portion of highway that traversed Snoqualmie Pass in the Cascade Mountains. The project included widening to increase travel lanes from four to six, replacement of an aging snowshed, reduction of snow avalanche vulnerability, inclusion of wildlife passageways across the corridor, riparian upgrades and permanent stabilization of required rock and soil cut slopes. Two early phases of the project, designated 1B and 1C (collectively herein the "Project"), created two continuous miles of steep cut slopes with heights achieving 150 feet. The design and construction were complicated by the narrow corridor, Federal no-fill stipulations for the adjacent Lake Keechelus reservoir, and the current high ADT. Project concept studies were performed between 2000 and 2006, design studies from 2006 to 2010 and construction from 2010 to 2019.

The topic of specific interest to this paper is the investigation, design and construction monitoring of the required rock slopes. Concern for this component was heightened by the occurrence of an unforeseen major rock slope failure during construction of the prior alignment in 1957. Research, coupled with forensic analysis of that event, was undertaken to minimize the probability of a similar occurrence some 50 years later, especially one with the potential to be undetected prior to failure.

The rock slope program for the Project was cognizant of the site construction history, the marginal quality of the volcanic regime, the limitations imposed by the narrow traffic corridor and the intermittent excavation progress in which slope integrity had to be ensured between construction seasons. For a rock slope project of this magnitude, multiple unique (and perhaps unprecedented) design and construction strategies were implemented:

Pre-Construction:

- Structure mapping using analyses of point cloud images and terrestrial photographs.
- Borehole televiewer logging.
- Telemetry of piezometric data for multiple years prior to construction.
- Selection of reinforcement methodology.

Construction:

- Near exclusive utilization of passive reinforcement installed prior to, or contemporaneous with, slope excavation.

- Real time, remote monitoring of slope response to blasting, including input to decisions on post blast traffic control.
- Three complementary slope displacement and load detection systems; robotic total station with prisms, strain gage application to surrogate reinforcement bars, and differential terrestrial LiDAR scanning.
- Correlation of slope behavior to transient hydrologic and environmental influences.
- Modification to slope designs during construction in response to slope displacement behavior.

Post Construction:

- Long term loading behavior of passive reinforcement elements utilizing internet deployment.
- Integration of installed rock slope components with long term asset management and the requirements for future slope maintenance.

Lessons that were learned throughout the Project will hopefully add to the professional record for the benefit of future investigators on similar corridor expansions in mountainous terrain.

NOTES

17 CLIMATE RESILIENCE AND INFRASTRUCTURE ADAPTATION ON CALIFORNIA'S NATIONAL FORESTS

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ABSTRACT

California's Sierra Nevada mountain range and Southern California's forests contain a huge amount of infrastructure, including 70,000 kilometers of roads and trails, over 800 bridges, numerous culverts, and other infrastructure on land managed by the US Forest Service. Over the last 40 years these mountain regions have been hit by numerous climate change-related events including droughts, major forest fires, and major storms. Billions of dollars in damage have been sustained and numerous lives lost as a result of these events.

To address these issues and help develop climate resilient strategies, state and federal agencies, including California Department of Transportation, California Geological Survey, and the Forest Service have been involved in infrastructure assessment, risk evaluation, and the identification and implementation of climate resilient strategies and adaptation measures. Efforts have ranged from greenhouse gas reduction from agency vehicles, evaluating alternative and redundant transportation routes, and implementing "stormproofing" road design measures.

Recent projects by the Forest Service have involved climate model studies of future anticipated weather conditions and storm events, community outreach for public understanding of climate impacts, assessment efforts, identification of road adaptation and resiliency measures, and publication of these findings.

NOTES

18 GEOHAZARD MANAGEMENT ON COLORADO SH 133 FROM PLANNING TO MITIGATION

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ABSTRACT

Highway safety, mobility, and maintenance effort on Colorado State Highway (SH) 133 between Carbondale and Paonia, Colorado is severely impacted by rockfall, debris flows, landslides, avalanches, and the occasional sinkhole. This paper presents a case study on the implementation of a risk-based geohazard management approach commissioned by the Colorado Department of Transportation (CDOT) for SH 133. The goal of the study was to evaluate the geohazard sites from an asset management perspective, considering quantitative risk, life-cycle costs, and benefit/cost ratio for proactive mitigation measures. A total of 300 geohazard sites were inventoried, and 125 sites were subjected to quantitative risk assessment. The assessment considered event likelihood, consequence analysis, and annual risk exposure in terms of safety, mobility, and maintenance impacts. Conceptual mitigation options with preliminary cost estimates were prepared for 50 of the highest risk sites, allowing for benefit-cost ratios to be computed. Based on the findings, five mitigation projects were undertaken, representing 21 sites that have been mitigated, are under construction, or are under design. When these projects are completed, they will ultimately result in an approximate $18.5 million reduction in risk exposure compared to $16.8 million in construction costs. Along the way, the authors found that financial realities required that some sites were dropped out of the projects. Some of these sites became shovel ready projects for construction using other contractual mechanisms or simply ready for when future funding becomes available. The paper discusses the challenges of geohazard assessment and emphasizes the importance of expert judgment in the absence of comprehensive data. The example of the SH 133 risk-based geohazard management shows how effective these methods can be, despite the challenges of these types of programs. But it is important to remember that there is no perfect system for geohazard management, but an imperfect one is better than nothing.

NOTES

19 THE STATE OF MEASUREMENT WHILE DRILLING (MWD) FOR THE WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

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ABSTRACT

In 2022, the Washington State Department of Transportation (WSDOT) Geotechnical Office became involved with measurement while drilling (MWD) through the A-Game initiative, headed by the Federal Highway Administration (FHWA), and joined the national MWD Users Group to learn more about this technology. In mid-2022, WSDOT purchased Jean Lutz B2 ML1 MWD technology to install on an already-ordered CME LC 55 track-mounted drill rig that was expected to arrive in the Fall of 2022. Following the A-Game initiative, WSDOT's goal was to use this MWD technology to improve its drilling efficiency and interpretation of subsurface materials for geotechnical applications. Although MWD has been in use for decades (mainly for directional drilling in the oil and gas industry), it is a relatively new application in the geotechnical field.

The new drill rig and MWD technology became functional in early January 2023, and WSDOT soon realized that equipment modifications, standard operating procedures, data interpretation, data analysis, data storage, and data presentation would all be needed. Also in January 2023, WSDOT attended a MWD workshop at the annual Transportation Research Board meeting (TRB) and in March 2023, joined a FHWA sponsored peer exchange between several DOTs to discuss the efficacy of MWD in geotechnical applications.

This paper will describe WSDOT's experiences with these workshops, user groups, and peer exchanges, as well as our implementation of MWD technology into our standard operating procedures. A discussion will be presented that includes the installation of the sensors on the drill rig, training on the use of the sensors, data collection while drilling, and data management. We will also summarize our preliminary interpretation/correlation of the data, and what WSDOT's future steps may be regarding the use of MWD technology.

NOTES

20 ADVANCING SUBSURFACE INVESTIGATIONS BEYOND THE BOREHOLE WITH PASSIVE SEISMIC HORIZONTAL-TO-VERTICAL SPECTRAL RATIO AND ELECTROMAGNETIC GEOPHYSICAL METHODS AT TRANSPORTATION INFRASTRUCTURE SITES IN NEW HAMPSHIRE

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ABSTRACT

The U.S. Geological Survey (USGS), in cooperation with the New Hampshire Department of Transportation (NHDOT), surveyed transportation infrastructure sites using rapidly deployable geophysical methods to assess benefits added to a comprehensive site characterization with traditional geotechnical techniques. Horizontal-to-vertical spectral-ratio (HVSR) passive-seismic and electromagnetic-induction (EMI) methods were applied at 4 sites including a roadway-stream crossing, roadway-bridge rail-trail crossing, commuter-parking expansion, and railroad adjacent river-cutbank slope-failure sites. Additionally, ground-penetrating-radar (GPR) was used at the slope-failure site. Typically, subsurface geotechnical properties are determined from boring data; however, borings are often spaced hundreds of feet apart, potentially missing spatial variability between boreholes. Geotechnical site characterization including geophysical surveys helped provide a more continuous characterization.

Three-component ambient noise measured with HVSR was used to determine resonance frequency and estimate sediment thickness. The method works when there's a strong shear-wave acoustic impedance contrast (> 2:1) between sediment and bedrock. Sediment thickness from HVSR measurements were combined with boring data to make detailed maps of the bedrock surface altitude. The bulk electrical conductivity of the subsurface was indirectly measured with EMI and was used to identify lithologic variations, shallow bedrock, and conductive groundwater. Ground penetrating radar, which transmits pulses of electromagnetic energy into the subsurface and records the amplitude and timing of reflected signals, was used to identify bedding and changes in lithology. By combining geophysical and boring data analyses, transportation projects produced more spatially comprehensive representations of geotechnical subsurface conditions than would be determined using conventional borings alone.

NOTES

21 NON-DESTRUCTIVE SURFACE WAVE GEOPHYSICS CHARACTERIZES SALT DISSOLUTION 140M UNDER US HIGHWAY 50 AT BRANDY LAKE, RENO COUNTY, KANSAS

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ABSTRACT

US Highway 50 in Reno County, Kansas, crosses Brandy Lake where ongoing dissolution of a salt bed 134m deep is causing local subsidence. High lake levels, happening more frequently and for longer periods, inundate low spots on the busy two-lane highway. Kansas Department of Transportation (KDOT) designed the road in 1963 and resurveyed it in April 2021. KDOT-funded University of Kansas Master's theses produced terrestrial laser scanning in 2009 and seismic reflection surveys in 2015. Interferometric Synthetic Aperture Radar (InSAR), proven for subsidence detection, was tested, but agricultural conditions proved unsuitable for interpretable interferograms. Seismic refraction microtremor (ReMi) measurements, a geophysical method utilizing surface (Rayleigh) wave dispersion physics to produce vertical 1-dimensional shear-wave subsurface profiles, were collected along highway shoulders without stopping traffic. Six stratigraphic profiles interpreted from ReMi line pairs (175.3m and 36.6m long with 7.6 and 3m geophone spacings) indicated five layers corresponding to two surficial units (aeolian and alluvial) overlying three sedimentary beds of the Permian Sumner Group (Ninnescah Shale, Wellington Shale, and Hutchinson Salt). ReMi profiles revealed shear-wave velocities consistent with interpreted MS thesis reflection seismic profiles. The shallowest subsurface horizon had lower shear-wave velocities within the active subsidence zone than beyond it. The MS thesis reflection seismic profile interpreted near-vertical faults within the Permian rocks above the salt within the active subsidence zone, but not beyond it. The ReMi interpretation supplemented the KDOT conventional survey and the MS thesis laser survey to quantify subsidence over an 11.4 yr period, which allowed 30-year projection of continuing subsidence.

NOTES

22 MITIGATION ALTERNATIVES FOR SALT DISSOLUTION SUBSIDENCE IMPACTING US HIGHWAY 50 AT BRANDY LAKE, RENO COUNTY, KANSAS

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ABSTRACT

US Highway 50 bisects Brandy Lake on an embankment with a short, pile-supported bridge near the lake's east side. Ongoing dissolution of bedded salt 134m deep is causing local subsidence with increasing problems for this busy two-lane highway designed in 1963 by Kansas Department of Transportation (KDOT). A low spot on the west side of the lake ponds water more frequently and for longer periods as subsidence progresses. KDOT funded a University of Kansas master's thesis that produced a terrestrial laser scan in November 2009 and self-performed conventional centerline survey in April 2021. Centerline elevation differences between the two surveys 11.4 years apart revealed a 457m-long zone of subsidence with 366m having more pronounced subsidence. WSP estimated subsidence and projected the highway centerline profile in 2031, 2041, and 2051. High water in Brandy Lake by 2051 could inundate the road by 1.8m.

Nine alternative mitigation strategies comprising five general approaches were described in terms of merits, drawbacks, and relative costs using a value-engineering approach to geologic hazard risk management. General approaches were A) Continue current practices, B) Modify the hazard, C) Modify what is at risk, D) Modify operation or procedure, and E) Avoid the hazard. Alternative strategies were: 1) Signage and occasional pavement overlays, 2) Deep ground improvement, 3) Control lake level, 4) Dikes along right-of-way, 5) Restrict highway use or limit speed/type of vehicle, 6) Raise highway profile with embankment, 7) Raise highway profile with bridge, 8) Close the highway when inundated, and 9) Reroute the highway.

NOTES

23 USING STATE-OF-THE-ART TECHNOLOGIES AND TOOLS FOR GEOTECHNICAL INVESTIGATION AND DESIGN

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ABSTRACT

A variety of innovative site investigation and subsurface modeling tools were implemented for the site investigation and design of a 475-foot single span bridge over the Pretty Rocks Landslide in Denali National Park. Remote sensing at the site included terrestrial and airborne lidar, InSAR, photogrammetry, and timelapse cameras. Site investigations included structural geologic mapping, helicopter-access drilling investigations, surface and downhole geophysical surveys, a weather station, and installation of remote monitoring units to transmit near-real-time weather, photo, and borehole instrumentation data. The site investigation data was loaded into an interactive GIS software platform with a live link to active instrumentation. These tools were used to inform decisions on bridge design, location, and alignment. For the design phase, a 3D geological model was developed to inform bridge foundation analysis and design. In addition, a 3D model of the proposed project was built that included the road alignment, cut and fill slopes, retaining walls, bridge superstructure and foundation, and geotechnical subsurface elements including thermosiphons, soil nails, micropiles, ground anchors, and rock dowels. The 3D model was available to the design team through a mobile App, a desktop App, and through a mixed reality headset. This tool was used to communicate the features of the design to the design team, the owner, the contractor, and other project stakeholders.

NOTES

24 THE DEVELOPMENT AND UTILIZATION OF A CLOUD-BASED DATABASE AND VISUALIZATION APP FOR PILE RESULTS AND DESIGN: PILETRAC

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ABSTRACT

The Kansas Department of Transportation (KDOT) with the assistance of Foundation Testing and Consulting (FTC) is utilizing a cloud-based database and visualization application called PileTrac for providing results of high-strain dynamic pile tests. This is done by using the PDA to provide a resource for the design and installation of pile supported bridges.

FTC developed the PileTrac application initially using data obtained from 58 bridge projects across the state of Kansas (50 FTC projects and 8 KDOT). The initial data sets in Piletrac showed KDOT an opportunity to make data driven decisions as it pertains to pile foundation design.

PileTrac allows KDOT, or other users, to identify common factors when piling has been driven much shallower or greater than plan, typical pile capacities for various pile section types and sizes, typical pile penetration depths in specific soil and bedrock profiles, as well as a variety of other pile and subsurface related values that help better guide pile design decisions and installation expectations

As FTC continues to add new data sets into PileTrac, it is expected that KDOT will be able to refine recommendations to pile supported bridges and better predict outcomes for pile design and installation on future projects.

NOTES

25 PAVEMENT AT BRIDGE END BUMP ELIMINATION

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ABSTRACT

The “bump at the bridge end” has long been a concern in many states. Issues such as settlement, drainage, and poor sub-base have been identified as contributors to the problem. In addition, the transition from rigid pavement to flexible pavement may cause the “bump”. Concrete is unyielding. However, soil is not, and its compaction may vary. Quality construction is imperative to reducing the impact of the “bump”. Fill material should be placed and compacted as per TDOT specifications, but the results are not always satisfactory. TDOT Structures issued a new standard drawing STD-10-2 in 2020. This new standard drawing is supported by FHWA guidance from FHWA-HRT-17-080 “Design and Construction Guidelines for Geosynthetic Reinforced Soil Abutments and Integrated Bridge Systems”, June 2018. Current TDOT sponsored research focuses on embankment settlement and enhanced soil reinforcing in an effort to reduce or potentially eliminating the “bump”. There are numerous examples hazards to the travelling public due to the “bump” throughout the state of Tennessee, especially on interstates. One such example is the I-840 corridor in Williamson County, Tennessee. The TDOT Materials and Tests Division Roadway Profiler performed rideability tests indicating bridge issues on I-840 centered between MM 10.00 to 23.70 eastbound, and MM 17.12 to 23.93 westbound in 2018. Additional geotechnical site characterization was performed in 2018 and 2021 to identify the primary issues leading to settlement development. The net result was resurfacing projects that included bridge end remediation efforts begun in 2021. These rideability tests were again performed in 2023 for comparison, which the results are currently being compiled.

NOTES

26 MITIGATION OF BRIDGE FOUNDATIONS, US 460 BRIDGES OVER MARROWBONE CREEK AND KY 195, POND CREEK, AND CSX RR, KY 80 AND RUSSELL FORK RIVER

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ABSTRACT

Design and construction of relocated US 460 in Pike County has been done in phases for several years. The new route will replace current US 460, a narrow congested two-lane roadway in the eastern Kentucky mountains, with an alignment along many segments adjacent to the Russell Fork River. Proximity to the river causes numerous landslides. Rock falls also occur frequently.

Poor quality bedrock, not encountered during initial design borings, was discovered during construction of three large bridges on relocated US Route 460. During construction of benches needed for slope stability and bridge foundations, clastic dikes, weathered and cracked bedrock were discovered leading to numerous mitigation methods that were required to provide adequate bearing and minimum distances to top of adjacent benches for spread footing foundations. Most of the bedrock quality issues were contributed to highly weathered shale and nearly vertical clastic dike type joints with non-uniform, irregular spacing. Most of the joints were filled with highly weathered non-durable shale in vertical bedding planes. Removal of bedrock when constructing the benches contributed to loss of confinement causing the joints to relax and open, creating large crevices near pier and abutment foundations.

Construction of the three bridges was staggered using three separate contracts. Total distance between the bridges is approximately four miles. Due to bedrock issues encountered at Marrowbone and Pond Creek bridges an angle rock core drilling was performed before foundation and bench construction at the Russell Fork bridge. Although the angle drilling was performed after the contract was awarded, information obtained allowed modifications to the foundations design and construction to proceed quickly.

Successful mitigation measures consisted of lowering footings into durable bedrock, construction of drilled shaft/spread footing combinations, Portland cement and shotcrete walls with rock anchors (post tensioned cable strands and solid bars).

NOTES

27 LATEST DEVELOPMENTS TO INCREASE THE QUALITY OF FLEXIBLE ROCKFALL PROTECTION BARRIERS

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ABSTRACT

In the last 30 years, flexible rockfall barriers made of steel wire nets have become established worldwide as a protective solution. To ensure that these barriers can effectively stop the dynamic impact of rockfall, several guidelines have been introduced worldwide since 2001. Even with guidelines there is low awareness that the capacity of a rockfall barriers is dependent on the net impact location, and how to evaluate the rockfall barrier capacity in load cases outside the requirements of the approval tests differs worldwide. In 2019 an Innosuisse-sponsored 3-year research project was granted to the WSL Institute for Snow and Avalanche Research SLF, together with the industry partner Geobrugg, for testing fully instrumented rockfall barriers to investigate rockfall impact position variability into flexible barriers systems. The results justify additional tests to the existing European certification procedure allowing a better quantification of the energy capacity of the protective surface of rockfall barriers.

NOTES

28 AN INNOVATIVE EARLY WARNING SYSTEM FOR ROCKFALL PROTECTION SYSTEMS AND EVENTS

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ABSTRACT

The paper describes an innovative alert system developed to verify if a rockfall or debris flow protection system is impacted, or if an event, such as a landslide or rockfall, might happen.

This new alert system, HELLOMAC, is installed directly on the rockfall/debris flow protection structure or on the landslide or unstable rock surface, and an acquisition unit (Hubir) is used to collect the data of up to 100 devices in a radius of 5 km and transmit an alerting message by satellite and/or GPRS.

The paper describes the alert system in detail and its different applications, and it presents a very interesting installation along SS 34, a major road in northern Italy running alongside Lake Maggiore and connecting the city of Verbania with the Swiss border.

NOTES

29 AN OVERVIEW OF ROPE WORK ACCIDENTS FOR THE GEOHAZARD PROFESSION

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ABSTRACT

Major accidents have occurred in every rope access certifying organization, suggesting current standards and techniques reduce but do not eliminate the hazards associated with rope access. Previous studies of recreational climbing and industrial rope access accidents have established baseline statistics that can be referenced against the few geohazard related accidents that have occurred. Ideally a rope training program would universally incorporate accident history to improve training methods and contingency planning for rescues, but knowledge of accidents and standards is not centrally shared.

For geohazard professionals, the review and enforcement of on-rope work is inconsistently applied by different jurisdictions and regulatory agencies. Differing standards of practice are reported by standardization councils, creating confusion and inconsistent performance evaluations based on the regulator's knowledge. Few standard operating procedures exist that are specific to geohazard specialists. Continued development of geohazard rope methods will enhance the entire industry and improve credibility when dealing with regulatory agencies or industrial rope access groups.

The Federal Highway Administration does not explicitly endorse any particular rope use method and cannot be expected to develop practicing methods for the rope work industry. Where FHWA does take a leading role is ensuring that all contracted rope practitioners follow the selected standard of practice stated in their submittal for projects under Federal jurisdiction. This approach led to the development of a new "Slope Scaling" specification to ensure geohazard mitigation work is performed using a documented and transparent program. The application of this new specification combined with continued monitoring of reported rope accidents will hopefully identify common factors leading up to those accidents, thereby doing what can be done to improve site safety on all Federal projects using geohazard rope professionals.

NOTES

30 ROCK STABILIZATION AT POMPEYS PILLAR NATIONAL MONUMENT: THE USE OF NUMERICAL MODELING TO ANALYZE RISK OF FAILURE

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ABSTRACT

Pompeys Pillar National Monument (PPNM) is a 200-foot-high sandstone outcrop containing hundreds of prehistoric and historic features, including William Clark's signature, scribed into the sandstone rock in 1806. Located 30 miles east of Billings, Montana, Pompeys Pillar is a heavily visited attraction with 30,000 visitors each year. The Bureau of Land Management (BLM), which manages the site, has identified that the sandstone and shale outcrop, which contains William Clark's signature (herein referred to as the Signature Block), is vulnerable to erosion. Itasca was retained by the BLM to assess the stability of the Signature Block and to evaluate remedial measures.

A sequence of mixed shales and siltstones with interbedded sandstone layers lie underneath the sandstone unit containing William Clark's signature. The condition and higher weathering rate of the shale and siltstone layers could impact the support to the overlying sandstone blocks.

A site investigation and laboratory testing provided valuable insight into the jointing and bedding, siltstone condition, and rock strength. High-resolution scans, drone-based videography, and photogrammetry of the pillar were previously collected to establish the model geometry. During the site investigation, preliminary instrumentation was installed. Next, a 3D geometry model of the critical areas was developed for a stability assessment. This assessment was performed using Itasca's 3DEC discrete element software. To assess shale erosion in the simulations, increasing amounts of shale and siltstone were removed from the model and block stability was assessed at each stage. Based on the modeling results, along with BLM feedback, remediation recommendations were provided by Itasca.

NOTES

31 PADDEN CREEK I-5 STREAM CROSSING TIERED HYBRID RETAINING WALL

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ABSTRACT

To comply with a federal injunction requiring corrected fish barriers, the Washington State Department of Transportation (WSDOT) had to replace the undersized Padden Creek crossing at Interstate 5 (I-5) near Bellingham, Washington. With a new stream alignment 30 to 40 feet below the interstate grade, the project would require significant disruptive excavation—and an estimated 400 traffic impact days for I-5.

GeoEngineers designed an innovative two-tiered wall system to enable accelerated top- down construction, ultimately decreasing the total number of traffic impact days on I-5 to 225 and allowing the entire southbound bridge to be built in just 37 days. The wall system consisted of a Geosynthetic Reinforced Soil Integrated Bridge Structure (GRS-IBS) to support the bridge itself and a lower soldier pile and ground anchor wall to support excavation to stream grade. This approach accelerated construction significantly and allowed project contractor Granite Construction to use a top-down construction methodology instead of more traditional bottom-up sequencing.

With this approach, the permanent lower soldier pile and ground anchor wall could be constructed as excavation progressed down while providing lateral support for the upper GRS-IBS system. Thanks to this clever strategy, contractors could wait to excavate the bulk of the new stream channel (more than 30,000 cubic yards of material) until after the new bridges were already built and I-5 traffic was in its permanent alignment.

NOTES

32 THE ERODIBILITY INDEX IN WASHINGTON STATE'S INTERMEDIATE GEOMATERIALS: THE NEED FOR A PRACTICAL TOOL.

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ABSTRACT

WSDOT's Fish Passage project is replacing hundreds of culverts that are barriers to fish migration. However, most of these crossings also impeded the flow of sediment and water, as well as fish. The associated disruption in geomorphic processes typically results in upstream sediment deposition and a downstream scour pool, causing the crossing to serve as a sediment trap and a grade control structure. The design of the replacement structures must account for future conditions that aim to reestablish geomorphic continuity. This often requires wider structures with open bottoms and deeper foundations to accommodate potential vertical scour. Because many of these crossings occur in the Puget Sound lowlands, they are often underlain by and/or founded on glacial sediments. Many of the available methods utilized to determine scour for the design of water crossings do not adequately address the erosion-resistant properties of common geomaterials found in Washington State, like weathered bedrock or glacial till. Termed Intermediate Geomaterials (IGMs), these materials can be more resistant to erosion than granular sediment. Without methods to assess the erosion resistant properties of these materials, designs are often forced to make conservative assumptions resulting in deeper foundations and increased project costs. The Erodibility Index Method (EI) is applied around the world for similar purposes. The EI is a geomechanical index method used to assess the likelihood of scour of any earth material by flowing water. This paper presents several WSDOT Fish Passage projects in the context of the Erodibility Index threshold and suggests potential future applications.

NOTES

33 ACCELERATING THE TRANSITION TO DIGITAL DELIVERABLES

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ABSTRACT

No one denies the digital age is here. Data is being generated and transferred faster than many of us are prepared to speak. In fact, some estimate that 3.5 quintillion bytes of digital data is created every day.

Within the Civil Industry, the scale of projects in infrastructure are getting larger. Organizations are being required to do more with less. Going digital seems to be the only way an organization can keep up with bigger projects, more projects, and shorter project timelines. The benefits of BIM and digital delivery to help with these industry shifts are well documented and understood.

The transportation industry National organization such as Federal Highways Administration (FHWA), American Associations of State Highways and Transportation Officials (AASHTO) and the Transportation Research Board (TRB) are providing resources to help DOTs and other organizations adopt digital delivery.

Several DOTs are piloting digital delivery programs. There is a huge opportunity to embrace cloud connected technology to ensure subsurface data is an integral part of digital delivery initiatives. Software used needs to take in to account the unique needs and requirements of the subsurface investigation, evaluation of a site, design of structures, and maintenance of those structures.

This paper will review previous, current, and emerging technologies that are driving organizations to adopt digital delivery. It will also examine issues that are keeping subsurface data from being fully integrated into the digital delivery models, and how these issues are being addressed within the industry now.

NOTES

34 MULTI-SCALE MULTI-SEASON LAND-BASED EROSION MODELING AND MONITORING FOR INFRASTRUCTURE MANAGEMENT

New England Transportation Consortium Research Project 19-2

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ABSTRACT

Soil erosion and slope instability issues are a major concern for New England state Departments of Transportation (DOT), roadway planners, and designers, impacting the cost to maintain transportation networks and other critical infrastructure. Effective screening tools used for modeling, monitoring, and forecasting erosion can aid in assessing erosion and slope failure susceptibility, which is critical for regional operations and planning.

GZA developed a screening-level tool to identify roadways vulnerability to erosion and slope failures based on a number of factors, using the latest GIS Enterprise technology. The work is being performed in collaboration with the New England Transportation Consortium (NETC). The project objective was to develop a multi-scale, multi-season land-based erosion and landslide modeling and monitoring toolkit for infrastructure management for all the New England states (including Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut).

The prototype Esri ArcGIS toolkit was developed for the MaineDOT based on Maine's state-wide GIS data such as topography, land use, surficial geology, and roadway system inventory. Various environmental parameters were considered as risk factors for roadways, including proximity to surface water body, proximity to the 100-year floodplain, and slope geometric information.

A large set of slope stability simulations were assembled to capture key geotechnical parameters including soil type, material strength, and groundwater depth. This set formed the basis of a "Response Function" that was used to interpolate to all the grid cells in the study area. The end deliverables of this project, i.e., the Esri GIS web viewer, included multiple risk analysis data layers for users to interact with and identify high, medium, and low hazard areas, for screening, analysis, and planning purposes for the Maine DOT.

The innovative approach developed for this project is applicable to other states or even regions and adaptable for future improvements such as inclusion of climate change considerations.

NOTES

35 INTEGRATING FIELD DATA WITH PHYSICS ENGINE SIMULATIONS OF FRAGMENTAL ROCKFALLS

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ABSTRACT

Rockfall numerical models are used to evaluate and plan highway scaling and slope protection projects. The simulation tools have been upgraded in recent years to include simulation of fragment shape, the protection provided by forests, and to consider three-dimensional geometry of slopes. The work reported in this paper is focused on the ultimate goal of developing fragmental rockfalls using physics engines.

To facilitate this objective, 193 videos of rockfall events initiated during slope maintenance were analyzed to create a database. This video data provides critical information on fragmentation, if it occurs, by capturing shape data and the full trajectory of the rockfall and any fragments produced. The variables considered cover slope and rockfall geology, shape and size are tracked alongside vegetation, and the occurrence of fragmentation. This has enabled analysis on the potential effects of geology and shape on the occurrence of fragmentation and the shape of fragments subsequently produced.

Based on initial analysis of the data, several trends are apparent. Rock type and slope material both appear to affect whether fragmentation occurs or not while a rockfall is moving down slope. Rockfalls with a compact initial shape fragment less often compared to differently shaped rockfalls. The initial rockfall shapes also have an effect on the shape of fragments produced. The three major rock types each have preferred rockfall and fragment shapes.

In the future, we will be using this database to identify events for rockfall trajectory calibration and fragmentation model development. The scope of this model will also be expanded as more varied data is added to the database, which may change or reinforce existing trends. We intend to share the database with the research community once we obtain a more broadly representative sample size of usable data.

NOTES

36 EMERGENCY RESPONSE AND CURES FOR KARST ON CHEMICAL ROAD

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ABSTRACT

A section of Chemical Road in Plymouth Township, Pennsylvania, had been experiencing subsidence due to karst geology since August 2020. On February 28, 2021, a sinkhole in the roadway closed the I-476 northbound off-ramp lane onto eastbound Chemical Road. Additional sinkholes were observed in the creek adjacent to the embankment slope supporting the road, and ongoing subsidence created a hazardous condition. Due to safety concerns from the progressive sinkhole activity, PennDOT closed the road and initiated an emergency project. Working closely together, the project team developed an expedited design that included grouting and sinkhole plugging treatment to reduce the risk of future subsidence. The design and construction of the repair had to be completed by the end of 2021 to reopen the road and restore public safety and mobility in the Plymouth Meeting area.

The design team performed geophysical and test boring explorations and produced bid documents for PennDOT review within one month of closing the roadway. Subsequently, the project was advertised a month later. Due to the schedule and complex nature of karst, collaboration during construction was critical. The project also involved several challenges with right-of-way, environmental, utilities, and hydrology/hydraulics issues. The team worked together to reopen the roadway in mid-December 2021. This schedule would not have been possible without effective and consistent communication among the team members. This paper describes the challenges presented by the project and how they were addressed by the team to meet the goal of restoring the roadway as quickly as possible.

NOTES

37 A COMPREHENSIVE APPROACH TO ROCK SLOPE DESIGN SOLUTIONS ALONG NC-88 IN ASHE COUNTY, NORTH CAROLINA

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ABSTRACT

In early 2023, HDR performed detailed surveys of multiple rock slopes along 3 miles of NC-88 in support of realignment efforts of a critical highway corridor between Warrensville and Smethport in Ashe County, North Carolina. The project alignment is physiographically situated in North Carolina's Eastern Blue Ridge Province. The local lithology generally consists of amphibolite, biotite gneiss, and mica schist of the Ashe Metamorphic Suite / Tallulah Falls Formation (Neoproterozoic). The proposed project involves multiple rock cuts to support widening and realigning NC-88, with some cuts exceeding 200 feet in height. Design complexities include difficult terrain, limited sight distances, increased traffic, rockfall hazards, and limited right-of-way access.

HDR executed a comprehensive approach to rock slope design, which included inspecting and geohazard scoring of existing rock cuts using the Unstable Slope Management Program (USMP) method and detailed geologic mapping of over 1,100 discontinuities on existing rock cuts. At a critical section of the project, seismic refraction and MASW surveys were performed, and an angled bore was advanced to 132.5 feet in depth to collect rock core and inspect subsurface discontinuities with optical/acoustic televiewing.

Collected data was used to inform global and subglobal (rockfall) stability analyses for each proposed cut, which revealed a high likelihood of planar and wedge failures at some of the most significant cuts. Preliminary design solutions, estimated quantities, long-term maintenance considerations, and right-of-way impacts customized for each proposed cut were then presented to NCDOT.

NOTES

38 A HYBRID DESIGN APPROACH FOR SURFACE STABILIZATION OF SOIL SLOPES USING STEEL WIRE MESH: TOWARDS A DEFORMATION BASED DESIGN

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ABSTRACT

Anchored (or pinned) wire mesh, commonly employed as passive stabilizing systems for potentially unstable slopes in granular soil or highly fragmented weak rock, are composite structures consisting of wire mesh, steel plates and reinforcing bars/ties. Their stabilizing action is determined by the complex interaction of such elements with the underlying unstable layer, depending on the geometry of the slope, the stabilizing intervention, mechanical properties of the soil and mesh, and the intensity and time variability of applied loads (especially environmental loads, e.g. seasonal water table variations). Standard design approaches are often based on an Ultimate Limit State hypothesis (ULS), assuming the full mobilization of both the ultimate soil resistance and the ultimate tensile force in the wire mesh. Such hypothesis can potentially lead to an unsafe design, especially when passive stabilizing systems are considered, since the stabilizing action is mobilized only upon the activation of soil displacement.

In the present paper, based on recent advances in design methods for slope stabilizing systems, an advanced "hybrid" method is presented combining an ULS analysis of the unstable slope with a Serviceability Limit State analysis (SLS) for the wire mesh. This hybrid method allows the designer to easily and consistently estimate the affect of soil displacement on the factor of safety of the slope, thus proving the efficacy of the wire mesh to reduce soil displacement and allow the influence of both its strength and stiffness to be determined.

NOTES

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