Standing Committees of the Geotechnical Engineering Section (AFS00)
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Geotechnical Engineering Section and Committees' Contributions to 100 Years of Transportation

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AFS00 - GEOTECHNICAL ENGINEERING SECTION

Prior to 2016, AFS00 section's name was Soil Mechanics and was comprised of nine technical committees. During 2015-16, Design and Construction Group undertook a major strategic review of its committees and structure. As a part of that undertaking, significant changes were made to the AFS00 section, such as a new name for the section and reductions in the number of committees within the section from 9 to 7. The new section name is "Geotechnical Engineering." However, scope of the section was not reduced but resulted in a more detailed scope.

Geotechnical Engineering section is primarily concerned with all matters related to the design and construction of infrastructure on all types of ground conditions, which often need some sort of compaction and stabilization by various means; need foundations of different types; and employ subsurface drainage conditions to mitigate soil failures. In summary, geotechnical engineering section applications is centered on the understanding of soil behavior in natural and man-made environmental and loading conditions; stability of earth and rock embankments; foundations of different types to support bridges, walls, and embankments; soil improvement techniques; drainage conditions within the geomaterials, natural and constructed earth slopes, bases and ballast courses; and many others.

Currently, the section has the following seven committees and one joint committee with AFP00 (Geological and Geoenvironmental Section):

AFS10 – Transportation of Earthworks
AFS20 – Geotechnical Instrumentation and Modeling (Consolidation of AFS20 and AFS50)
AFS30 – Foundation of Bridges and Other Structures
AFS40 – Subsurface Soil-Structure Interaction
AFS60 – Subsurface Drainage
AFS70 - Geosynthetics
AFS80 - Stabilization of Geomaterials and Recycled Materials (Consolidation of AFS80 and AFS90)
AFP00 and AFS00 Joint Subcommittee on Geotechnical Asset Management

As a part of this Centennial Paper, each committee has provided a short summary of past contributions, current activities and future plans. The following sections summarize each committee's contributions.

AFS00 COMMITTEES' CENTENNIAL PAPER CONTRIBUTIONS

The following sections cover each committee's history, original scope and current scope along with their centennial paper contributions.

AFS10: Transportation Earthworks Committee

Contributors: Jie Han, Surya, S.C. Congress, Robert Gladstone, James Brennan

History:

- Established in 1970 as Embankments and Earth Slopes Committee (A2K02) under Soil Mechanics Section in Design and Construction of Transportation Facilities Group
- In 1985, changed to Transportation Earthworks Committee (A2K02) In 2002, under Soil Mechanics Section in Design and Construction of Transportation Facilities Group (comment: sentence starting with "In 2002" does not make sense – suggest delete it)
- In 2004, changed to Transportation Earthworks Committee (AFS10) under Soil Mechanics Section in Design and Construction Group

Scope in 1987

This committee is concerned with the design, methods of construction, and behavior of embankments, embankment foundations, and natural and constructed earth slopes employed in transportation facilities.

Current Scope (2015)

This committee is concerned with all matters related to the design, construction and performance of transportation earthworks including soil, rock and geomaterial structures, natural and constructed earth slopes, mechanically stabilized earth slopes and walls, and their foundations. This committee focuses on the identification and advancement of technologies for effective earthwork engineering.

Past

Earthwork primarily involves sequential tasks, such as excavation, transportation, spreading and compaction, which need heavy mechanical equipment and repetitive processes. When weak ground is encountered, it often needs to be improved before earthwork. In the past 100 years, many important advances have been made in earthworks in terms of equipment, QC/QA, materials, and applications. It is almost impossible to provide a complete summary of these advances; however, this paper highlights the following advances as examples.

Soil excavation was completely manual prior to the invention of machines that had enhanced the efficiency and eased the earthwork construction. In 1933, B.F. Berry improved manually-operated older cutting machines into tapered outer face, which eliminates a number of troubles and uncertainties involved in older machines. In 1953, the excavating machine with a hydraulic system was developed. Later on many new machines were developed, such as track excavator, wheeled excavator, backhoe excavator, bulldozer, dragline excavator, and trenchers. Even before the Roman Empire, building of embankments involved manual compaction of soil. In

1830, roller compactors drawn by horses were first introduced in France. The United States, motivated by the use of animals by England to compact earthen dams in 1820, invented sheepfoot rollers in 1906. With the advent of internal combustion engines in 1876, earthwork community had witnessed a significant increase in the roller capacity that facilitated for the ease in construction activities. Since the World War II, there were many advancements in the compaction techniques including the vibratory compaction. The development of intelligent compaction started in Europe in late 1970s and was introduced in the US in the early 2000s. The intelligent compaction (IC) technology includes vibratory rollers equipped with the real-time Global Positioning System (GPS), roller-integrated measurement system, feedback controls, and on-board real-time display of all IC measurements.

A study conducted in the early 1900s highlighted the role of degree of compaction in road failures. Road failures due to non-uniform compaction triggered the development of standard Proctor compaction curves for compaction specification and the California Bearing Ratio for pavement design during 1920s and early 1930s. The pavement damage caused by landing of the B-19 bomber in 1941 led to the development of the modified Proctor compaction test by the Army Corps of Engineers to enhance compaction of pavement subgrade. Nuclear density and moisture devices were developed in the early 1950s and provide quick means to accurate measure soil density and moisture content of compacted fill in field earthworks.

Earthworks have increasingly taken place on weak ground, which often requires ground improvement. Many ground improvement technologies have been developed in the past century. For example, the American engineer, D.J. Moran, first proposed a sand drain technology for ground improvement of deep soft deposits in 1925. The California Division of Highways, Materials and Research Department conducted laboratory and field tests using this sand drain technology in 1933. In the late 1930s, W. Kjellman in Sweden developed the technology of prefabricated band-shaped vertical drains made of a cardboard core and a paper filter jacket, which was later replaced with nonwoven geotextile. Nowadays prefabricated vertical drains (PVDs) have been widely used in the world for ground improvement. L. Menard devised and developed the dynamic compaction technology to densify loose soil to a greater depth in the 1960s. Several column technologies were developed from 1930s to 1960s including but not limited to stone columns, deep mixed columns, and vibro-concrete columns. Recent developments include rammed aggregate columns and rigid inclusions. Column-supported embankments have been increasingly used in the United States for highways on weak ground since 1990s. Early applications of soil nail walls in North America were for temporary excavation support in Vancouver, B.C and Washington, D.C. in the late1960s and early 1970s.

Present and Future

In the early 1980s, instruments were developed by the earthworks and foundations division of the Transport and Road Research Laboratory in the US for measuring settlement, pore water pressure, and total pressures in soil masses. Intelligent compaction methods can monitor the construction process through sensor measurements, thus making QC/QA much user-friendly than before. Past practice estimated the volume of soil used in embankment construction by survey and different mathematical methods.

In addition to natural soil and rock used as fill materials for earthworks, man-made materials have been used to improve natural material properties or replace natural materials. Steel strips or meshes have been placed inside granular fill to form mechanically stabilized earth (MSE) following the invention by Henri Vidal in France in 1963. The first MSE wall built using this technology in the US was on Route 39, California in the early 1970s. This MSE technology has been commonly used the US for earth retaining structures including bridge abutments. Even though fabric was used in the roadway construction in South Carolina as early as in 1926, geosynthetics have become important materials for earthworks after Dr. J.P. Giroud coined the term “geosynthetic” in 1977. The early uses of geosynthetics included geotextiles as separators and filters and geomembranes as liners. Dr. F.B Mercer invented geogrids in the late 1970s, which were introduced to North America in 1982 for soil reinforcement or stabilization of slopes, embankments, walls, and roads. FHWA promoted the use of the Geosynthetic Reinforced Soil–Integrated Bridge System (GRS–IBS) since 2010. Wicking geotextile was used to mitigate freeze-thaw problems of granular bases in Alaska in 2010. Expanded polystyrene (EPS) geofoam, a lightweight material, was first used in embankments to reduce settlement in Norway in 1972 and on Highway 60 in Colorado the US in 1989. The largest geofoam project in the United States was on Interstate 15 in Salt Lake City, Utah from 1997 to 2001. Recently, lightweight foamed concrete has been increasingly used as a backfill material for earthworks.

The great efforts of FHWA through the Office of Research and Development on disseminating the technical information to highway agencies and practitioners have contributed to the widespread use of soil nail walls today. The second Strategic Highway Research Program (SHRP 2) developed the online GeoTech Tools in 2010, which provides geotechnology selection guidance and engineering tools for embankment, ground improvement, and pavement support applications.

Future

With rapid development of new technologies and materials, the future of earthworks may include but is not limited to the use of:

- Smart construction equipment (e.g., fully-autonomous, remote control dozers; GPS/Global Navigation Satellite System (GNSS) controlled excavators) and robots
- Unmanned aerial platforms or drones and smart sensors for QC/QA during and after placement of fills, assessment of time-related construction changes, and real-time monitoring of earth structure performance, and estimations of earthwork volume and mass (see Figure 1)
- Artificial intelligence (AI) technology including big data and machine learning for earthworks
- Smart materials for earthworks
- Real-time monitoring, network data acquisition, and control during the ground improvement process
- Geophysical or non-destructive technologies to evaluate conditions and remaining life of existing or unknown earth structures
- Technologies and materials to minimize climatic effects
- Bio-stabilization of natural soil and fill in earthworks

Figure 1: UAV System for Transportation Infrastructure Assessments

AFS 20: Geotechnical Instrumentation and Modeling Committee
Contributors: Soheil Nazarian, Derrick Dassenbrock, Lee Petersen, Brian Collins, Scott Anderson

History

- Established in 1970 as Soil and Rock Instrumentation Committee (A2K01) under Soil Mechanics Section in Design and Construction of Transportation Facilities Group
- In 2004, changed to Soil and Rock Instrumentation Committee (AFS20) under Soil Mechanics Section in Design and Construction Group
- In 2015, AFS20 (Soil and Rock Instrumentation Committee) was merged with AFS50 (Modeling for Design, Construction, and Management of Geosystems Committee and AFS50 was sunset) to form a new committee, Geotechnical Instrumentation and Modeling (AFS20) under Soil Mechanics Section in Design and Construction Group

Scope in 1987

This committee is concerned with in situ and laboratory instrumental systems (excluding nuclear) for static and dynamic measurements such as stress, strain, displacement, temperature, moisture, pore pressure, and density states within soil samples, earth masses, layered systems, and interacting structures. It will concentrate on installation, calibration, and operational techniques; performance capabilities and requirements; data interpretation; and system limitations. Instrumentation applications shall include both soil and rock.

Scope (2015) - AFS20: Geotechnical Instrumentation and Modeling

This committee is concerned with instrumentation, monitoring, and modeling encompassing physical, numerical, and geospatial aspects of soil, rock and geosystems to obtain information for use in design, construction, performance assessment, risk analyses and asset management of transportation infrastructure.

History/Background

The Geotechnical Instrumentation and Modeling (AFS20) Committee was formed in 2015 by merging the Soil and Rock Instrumentation Committee and the Modeling for Design, Construction, and Management of Geosystems Committee, both with long history since their inception in the 1970s. The original mission of the Soil and Rock Instrumentation committee was focused on installation, calibration, and operational techniques; data interpretation; and system limitations of the in situ and laboratory instrumental systems (see Figure 2). The Modeling for Design, Construction, and Management of Geosystems Committee was concerned with the theory and mechanics of the behavior of earth masses and layered systems and experimental studies to test the validity of existing theories under field conditions. Given the complementary aspects of instrumentation and modeling, the merging of the two committees made perfect sense.

Figure 2: (a) A manual groundwater assesment using a weighted tape in a borehole piezometer; (b) a settlement plate to measure settlement in a field of prefabricated vertical drains; (c) and a series of rebar strainmeters attached to a centralizer bar before being placed in a concrete filled steel shell pile to measure strain distribution.

The current primary mission of AFS20 is physical measurement, numerical modeling, performance and risk assessment, and subsequent decision analysis of geosystem behavior.

State of the Practice

Geomaterials have complex behavior, which is influenced by previous history of deformation, age, composition, structure, stress state, water, and other factors. Because of the complex nature of these materials, laboratory and field testing of their behavior is standard practice in the profession. One of the components of the observational method, proposed by Karl Terzaghi, is measurement and evaluation of actual field conditions. From a simple measuring tape, to the most sophisticated synthetic aperture radar systems, measurement has been and will continue to be of significant importance in evaluating the performance of geotechnical systems such that new construction or maintenance can be performed safely and cost effectively.

The goal of this committee is to support and advocate for the development and application of instrumentation and modeling in the geotechnical community for the following reasons:

- In-situ, lab testing, geophysical, and remote sensing measurements are important for the assessment of soil properties or soil behavior for use in design and construction.
- New systems of measurement can provide improved quality, economy, or previously unobtainable spatial or temporal information.
- Numerical models provide a valuable tool for efficiently testing and assessing conditions which would be expensive or time consuming to test and measure in the field or create as full or scaled physical models at test facilities.
- Numerical models, calibrated with field measurements, can simulate real-world situations with confidence and provide the basis for robust parametric studies.
- Numerical models can be used to optimize designs and construction operations enhancing project value; companion monitoring programs can be used to evaluate and validate performance.

AFS20 cannot accomplish its goal unless it actively collaborates with other committees in the geosystem areas to formulate and solve their instrumentation and numerical modeling needs. The most significant innovations in the last 50 years in instrumentation can be summarized in the following items:

- The development and improvement of electronic, digital, and fiber optic sensors and sensor networks.
- Automation and computer control of laboratory testing systems.
- Development of affordable automated field data acquisition systems; wireless sensor networks; and associated communications systems for data reporting
- Data presentation, management, and visualization platforms
- Availability of affordable and disposable sensors for distributed measuring systems
- Incorporation of remote sensing such as RADAR, LIDAR, InSAR and satellite imaging in the monitoring of geosystems

Similarly, the most significant innovations in modeling can be summarized in the following items:

- Improved understanding of geomaterial behavior, and constitutive models that better represent the behavior (Figure 3)
- Development of discrete and distinct element methods that permit representing soil and rock materials as discontinuous materials
- Combining both geotechnical materials and structural materials in the same model, with realistic behavior for both.
- Dramatic improvements in the user interfaces of modeling software allowing for more intuitive operations and less computer code-driven programming.

These innovations have also generated some current challenges. The major challenge related to instrumentation is managing the massive amount of data in a manner that can provide useful, organized, conclusive, and actionable information. The major challenge in modeling, despite the availability of parallel and cloud computing, is the ever-increasing desire for simulating more sophisticated problems with increasing complexity. A related challenge in creating sophisticated models is accurately representing complex soil behaviors in heterogenous, and sometimes highly spatially variable, subsurface conditions.

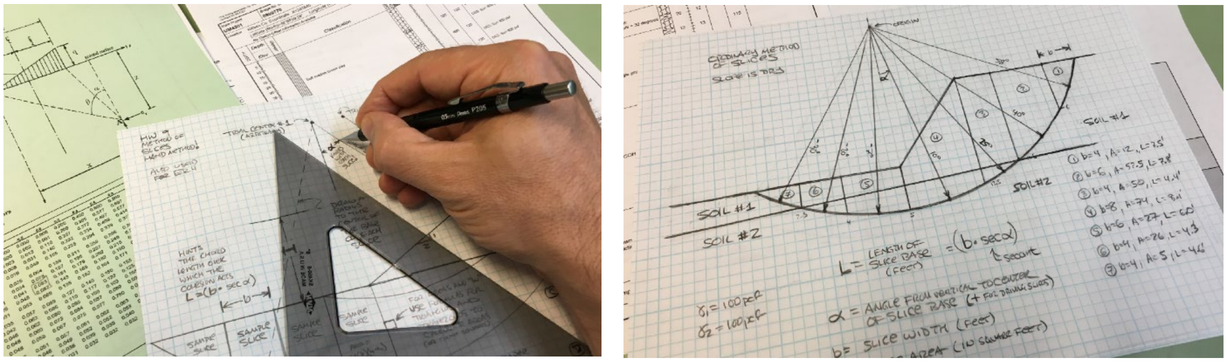

Figure 3: (a) Setting up a slope stability problem by hand (b) the finished slip surface evaluated by hand for one case using a simplified Ordinary Method of Slices evaluation.

Emerging Solutions

The industry and academia have made significant strides in improving the quality and volume of field measurements and associated numerical modeling; innovations in these disciplines are progressing at a rapid pace. To take advantage of the current momentum, investment should be made in the following emerging areas:

- Developing and in incorporating data science for civil transportation infrastructure applications to better manage the quantity and quality of field and laboratory data.
- Developing platforms for data exchange so that the engineering community can more readily take advantage of the increasing availability of site investigation and performance information
- Incorporating machine learning and artificial intelligence for developing empirical models
- Encouraging the development of technologies for smart structures with built in sensors to allow real time monitoring of the health of geosystems
- Advancing visualization by promoting augmented reality where objects in the real-world are "augmented" by computer-generated information (measurements) from on-line monitoring systems or numerical models (Figure 4)
- Improving contact sensors and incorporating remote sensing technologies using UAS and satellites.

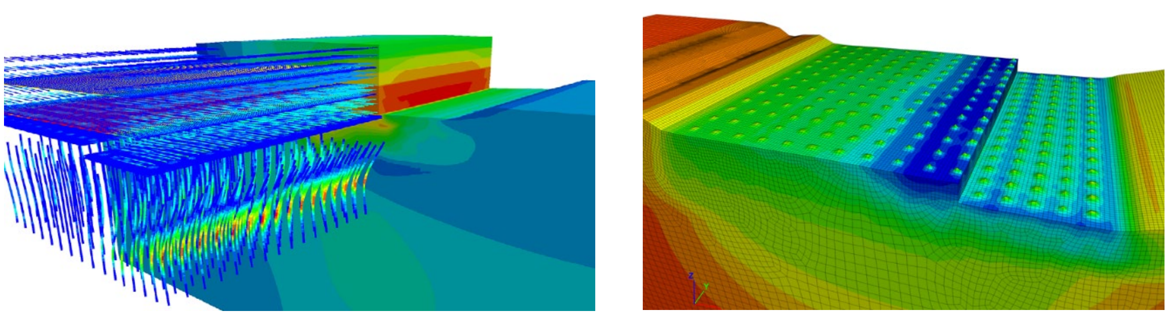

Figure 4: (a) Computer model of a column supported embankment (b) colum supports

AFS30: Foundation of Bridges and Other Structures Committee
Contributors: Ken Fishman, Antonio Marinucci, Brent Robinson, Sharid Amiri, Gerald Verbeek, Vern Schaefer, Victor Aguilar Vidal, Allen Cadden

History

- Established in 1970 as Foundation of Bridges and Other Structures Committee (A2K03) under Soil Mechanics Section in Design and Construction of Transportation Facilities Group
- In 2004, changed to Foundation of Bridges and Other Structures Committee (AFS30) under Soil Mechanics Section in Design and Construction Group

Scope in 1987
This committee is concerned with the behavior and stability of foundation soils supporting bridges, retaining walls, box culverts, buildings, overhead signs and other transportation structures; and with earth pressures exerted against these structures and against temporary structures used in construction.

Scope (2015)
This committee is concerned with the local and global behavior, stability, and interaction of structural foundations, and their supporting materials, for permanent and temporary transportation structures (bridges, retaining walls, box culverts, buildings, overhead signs, and other transportation structures).

Introduction and History
Advancements in the design and construction of foundations for bridges and other structures over the past century have involved innovations, developments and enhancements for foundation systems; design and analysis; testing for integrity and verification of foundation capacity; considerations of loadings and conditions from extreme events including earthquakes, severe storms, and ship collisions; and sustainable designs that consider durability and foundation reuse. All of these advancements led to the need for better information and techniques for site investigation and characterization of subsurface site conditions, nondestructive testing and use of robust advanced numerical models, full scale field testing and advanced experimental techniques such as centrifuge modeling, and use of geophysical testing and electronic devices for probing and obtaining more complete data to describe the subsurface.

The famous 7-mile bridge along the Overseas Highway in the Florida Keys shown in the photo below (Figure 5) is a good example of how innovations, developments, enhancements and advancements have affected the design and construction of bridge foundations over the last century. The photo shows the older, obsolete structure that was the original construction and the newer structure in the foreground. The older structure was built 1909 - 1912 under the direction of Henry Flager and Clarence S. Coe as part of the Overseas Railroad. The structure was taken over by the US government in 1935 when it was refurbished for automobile use. The current bridge was built circa 1978 - 1982.

Figure 5: Florida Keys Bridge

Looking at these structures side-by-side one can observe improvements in bridge design and construction that affected the types of foundation systems and needs for improvements in design and construction:

1. Use of precast, post-tensioned concrete girders in the superstructure allowed longer spans for the newer bridge and reduced the number of piers in the water by half, resulting in significant savings. Compared to the original structure this increased the loads that must be carried by the foundation system. The need to carry larger loads lead to innovations in foundation design including use of drilled shafts, the need to consider the group behavior of pile foundations, and the need to resist uplift loadings from extreme events.
2. The new piers are not as massive and act more as beam-columns which required considerations of more eccentric and complex loadings on the bridge foundation system. Design of the foundations was facilitated by improvements in analysis for soil/rock structure interaction and consideration of lateral resistance for deep foundation elements.
3. The newer bridge is better designed to withstand extreme event loadings including hurricanes. The newer bridge survived Hurricane Irma (2017) intact, although the older structure sustained damage from several previous hurricanes.

Present

The following sections describe specific innovations, developments, enhancements and advancements related to design, construction and testing of foundation systems.

Drilled Shafts

During its growth and development, the deep foundations industry evolved and transformed from relying on manually intensive, hand-excavated boreholes and caissons to technology assisted machine-excavated bored piles (or drilled shafts). Moreover, the bored pile industry has benefitted from and integrated advancements and enhancements into practice by borrowing and adapting technology and applications from the oil & gas industry and from the water well drilling industry.

Similar to many other techniques, the development and growth of the drilled shaft foundation marketplace were driven by the advancements in construction methods and equipment technology, where the design approaches followed much later. Prior to the 1970s, designs were typically performed using one of three approaches: (1) theoretically-based elastic solutions using discrete elements, which evolved from general geotechnical engineering problems and then adapted to drilled shafts, (2) numerical solutions using discrete pile and soil elements, and (3) empirical and semi-theoretical methods, based on correlating full-scale field testing with theoretical approaches. From the 1960s through the 1990s, extensive research (e.g., full-scale field experiments, small-scale experiments, numerical modeling, and reliability-based evaluation) was sponsored by the Federal Highway Administration and the Electrical Power Research Institute (EPRI) to improve the design, construction procedures, performance, quality protocol and evaluation, and reliability of drilled shaft foundations.

During the 1990s, almost simultaneously, bored piles were being designed to support greater loads, while the quantity of bored piles to support these increased loads decreased. Designs incorporating single, large diameter bored piles (i.e., monoshafts) have increased in use and, as such, overdue explicit attention to quality and integrity became important.

Micropiles

Small diameter elements were introduced following World War II by Dr. Fernando Lizzi as a means to repair war damaged Europe with lightly loaded elements that would reinforce the foundation system rather than transferring load to a discrete high capacity element. In the United States, the cost of materials and labor significantly changed this model. Using equipment traditionally used for anchor installation, contractors began reinforcing bridge structures first with lightly loaded elements but shortly thereafter they began leaving steel casing in the ground and taking advantage of the structural benefit.

Micropiles in the United States emerged as an innovative system to reinforce structures with high capacity piles installed in some of the most difficult access and subsurface conditions. Over the past 30 years, the development of hydraulic drills and advancements in reliability in tooling has expanded this market. Further, hollow bar elements as reinforcing has emerged as a tool for many contractors (small and large) to enter this market and provide ready solutions to difficult conditions. Now with the ability to drill through nearly any ground conditions, in the most restricted conditions without significantly impacting traffic flow has made this technology an attractive solution for retrofits and new construction.

QA/QC & Foundation Testing

Over the past 100 years, deep foundations have evolved from manually excavated shafts or driven timber or steel piles installed to either refusal blow counts or blow counts estimated by a dynamic formula. Application of the one-dimensional wave equation to pile driving allowed engineers and contractors to better size impact or vibratory hammers and estimate driving resistance through simulation. Field control during installation of driven piles has evolved from end of drive or fulllength records of blow count to real time measurement and calculation of driving stresses, delivered energy from the hammer, pile integrity and geotechnical resistance to driving.

Quality control of drilled shafts, auger cast piles and micropiles has evolved considerably from recording concrete volumes placed in an excavation by number of trucks or pump strokes. Before concrete is poured, mechanical or sonic calipers and bottom cleanliness devices are inserted into drilled shaft excavations. Grout pumps are commonly instrumented with flow meters to monitor grout volume placed with depth. Once concrete has been placed and starts to cure, structural integrity can be evaluated by thermal, sonic or radiation sensors. Stress wave-based methods using light impacts applied on or near the pile top are also occasionally used for quality control.

Post installation, top down static load tests can be more sophisticated, with an array of instrumentation deployed below the ground surface to determine geotechnical resistance distribution and pile movements due to compressive, tensile, lateral or torsional loads. Bi-directional static tests are applied from within the shaft, and do not require additional above ground reaction frames or kentledge. Dynamic load tests, with load durations of tens to hundreds of milliseconds, are also now commonly used in conjunction with numerical models to calculate static and dynamic resistance. These dynamic tests replace static load tests or allow for wider coverage of testing across a site. Load testing databases of well documented site investigation and construction case histories provided for the refinement of design methodologies, as well as initial and regional calibration of load resistance factor design for all types of shallow and deep foundations.

Additional measurements across a site can help to mitigate potential damage to other assets due to the effects of foundation installation. Models, monitoring devices and countermeasures for construction vibration have been developed and are commonly deployed. Ground movements in soils prone to settlement, heaving, or collapse are monitored to prevent damage to existing structures. Above ground and underwater noise can also be measured to mitigate quality of life or environmental impacts.

Design - Site Characterization

Site characterization has evolved, and the technology has improved. The tools and methods have developed over the past century. The tools vary from the SPT (Standard Penetration Test), CPT (Cone Penetration Test), to Geophysical Methods of Testing, and beyond. Today there are well over 150 different types of in-situ probes, field methods and gadgets available for the purpose of geotechnical site investigation and site characterization. (Mayne, 2012). Wash borings were introduced in 1870s with Boston Transit Commission on Subway construction. Until 1902 wash borings were the dominant methods for subsurface exploration. In 1902, the practice of driving samples retrieving dry samples began. The sampling standardizing process began in 1926, by collecting blow count data using 22-inch samplers with 140 lbs donut weights falling 30 inches. The 1930's contributed to the continuous improvement of drive samplers. In 1947, Karl Terzaghi coined the term Standard Penetration Test (SPT) to describe the correlations over the previous 20 years. In the late 1950's, the Los Angeles office of Dames and Moore began employing 3-inch diameter drive samplers, which recovered a 2.4-inch diameter sample. The SPT procedure was adopted as ASTM Test D1586 in 1958.

An alternative to SPT is the so-called Cone Penetration Test (CPT), which got started in the first half of the 1930s when in The Netherlands Pieter, Barentsen developed the first internationally recognized cone model: the Dutch Cone. Initially these (mechanical) cones that just measured the tip resistance were pushed in the ground using hand-operated pushers, until hydraulic pushing rigs were introduced in the late 1950. Another major milestone was the introduction of the Friction Jacket Cone in 1965, when Begemann improved the Dutch Cone by adding an extra sliding shaft for measuring the sleeve friction, resulting in a cone that is also known as Begemann Cone. Then in the early 1970s, after a period of testing, failing and improving the electric cone penetrometers with strain gauged measuring bodies became more reliable and popular, and the electric cones, which measure tip resistance, sleeve friction and pore pressure, are now the standard cone type. The CPT procedure was adopted as ASTM test D3441 (for mechanical CPT) in 1974 and D5778 (for electrical CPT) in 1995.

Ground Improvement

Soil improvement has a long history in transportation, starting with mechanical and chemical stabilization of subgrade soils – both of which have been around for over 100 years. Over the past six decades significant new technologies and methods have been developed and implemented to assist the geotechnical specialist in providing cost-effective solutions for construction on marginal or difficult sites. The impetus for ground improvement has been both the increasing need to use marginal sites for new construction purposes and to mitigate risk of failure or of poor performance. Ground improvement technologies are geotechnical construction methods used to modify and improve poor and marginal soil and rock conditions to meet project requirements. Many of these technologies were developed by contractors and often the development occurred overseas and was brought to the United States.

To take advantage of these new developments, FHWA led the way with Demonstration Project No. 116, Ground Improvement Methods in 1999 (FHWA-SA-98-086). Technical summaries were presented on: grouting, vertical consolidation drains, soil mixing, stone columns, lightweight fill materials, vibrocompaction, deep dynamic compaction, soil nailing, mechanically stabilized earth walls, reinforced soil slopes, micropiles, and column supported embankments. Updates to these technical summaries have been presented in the reference manuals for the FHWA/NHI courses Ground Improvement Methods (FHWA NHI-06-019/020 - 2006) and Ground Modification Methods (FHWA NHI-16-027/028, also GEC 13 - 2016). These geotechnical construction techniques have also been included in the *GeoTechTools* system – a website of geo-construction information and technology selection guidance for project planning and development, project delivery, and improved infrastructure performance. All these developments mean that ground improvement has come of age and reached a high level of acceptance in the geotechnical community where it is now routinely considered on projects where poor or unstable soils are encountered.

Design Platforms

Once the building design and construction process began to formalize codes and requirements, a rational design philosophy based on the notion of allowable stresses (ASD) was developed (≈1920). In the ASD design, the uncertainties in the calculations of loads and resistances are accounted for using a global factor of safety. The underlying assumption in ASD philosophy is the elastic behavior of the materials. This assumption presented major inconsistencies in reinforced concrete design where sections are usually cracked under service loads. Thus, the strength-based design philosophy was developed by the concrete industry (≈1950-1970). The inclusion of uncertainties in a probabilistic manner to the load and resistance lead to what is called reliability analysis. The first reliability-based codes specification adopted in the US was the AISC 1986 for the design of steel structures, and then the AASHTO 1994 for the design of highway bridges. Due to their format, reliability-based codes are often called Load and Resistance Factor Design (LRFD). Here the design procedure includes load factors that account for uncertainties associated with the estimated design load, and the resistance factor that accounts for uncertainties related to the expected capacity of a structural member. The latest structural codes for steel, concrete, masonry, wood, and highway bridge specifications follow the LRFD philosophy.

A number of geotechnical designs are part of complex systems that include structural and geotechnical components. Thus, with the goal of maintaining consistency in the design of the structural and the geotechnical elements, the reliability-based design is increasingly becoming a need in geotechnical engineering. Although, considering how site-specific geotechnical conditions could be, sometimes it may be desirable to perform a direct reliability-based design for the specific problem rather than to rely on a generalized LRFD specification. There is a significant research effort ongoing in the area that has calibrated several LRFD procedures for shallow and deep foundation among other typical geotechnical designs. Nevertheless, the LRFD methodology has not become the standard in practice yet.

Future

Future areas that will be covered by this committee will include the use of UAVs or drones for bridge foundation assessments, which in turn can be used to collect performance data for asset management activities. Other advances will include developments in reliability-based designs including LRFD methods. This also relates to the design and testing of higher capacity, non-redundant foundation elements (e.g. large diameter pipe piles; pressure grouted drilled shafts); increased use of shallow foundations; better understanding of scour and effects from seismic loading and other extreme events on foundations.

AFS40: Subsurface Soil-Structure Interaction Committee

Contributors: Timothy Wood, Andrew Wells, Steven Folkman, Kevin White, Jim Goddard, Timothy McGrath, Michael G. Katona

History

- Established in 1970 as Subsurface Soil-Structure Interaction Committee (A2K04) under Soil Mechanics Section in Design and Construction of Transportation Facilities Group
- In 2004, changed to Subsurface Soil-Structure Interaction Committee (AFS40) under Soil Mechanics Section in Design and Construction Group

Scope in 1987

This committee is concerned with the analysis, design, and performance of buries structures that are associated with transportation facilities; emphasis is placed on the role of soil-structure interaction and relative stiffness in determining the response of the system due to some combination of static and dynamic loadings, including both impact and vibration.

Scope (2015)

This committee is concerned with the analysis, design, installation, and performance of underground conduits and buried structures, such as culverts, storm drains, and sanitary sewers, associated with transportation facilities. Emphasis is placed on the role of soil-structure interaction, including the effects of structural stiffness relative to the surrounding soil stiffness in determining the response of the system due to static, live, and dynamic load. The primary goal is improvement of the performance of buried structures.

Yesterday

For most of the public, culverts, storm sewers, sanitary sewers and drainage pipes are out of sight and out of mind. Though historically small span structures, buried structures play an integral role in the transportation, hydraulic, and environmental systems of the built environment. While the public may not have noticed, this industry has been growing, expanding, and innovating with the Transportation Research Board's Standing Committee on Subsurface Soil-Structure Interaction contributing for more than 50 years.

Through the tireless efforts of industry partners, departments of transportation, and academic research, the underground structures have undergone significant changes and diversification in materials, sizes, and shapes. Methods of analysis have developed from the early empirical and elastic methods of Marston and Spangler to complex finite element and finite-difference modeling and load resistance factored design. It is interesting to note that soil-structure interaction has its start in the work of Anson Marston from Iowa State University who was the first Chairman of the Highway Research Board and championed the field with the resounding cry of "Let's get Iowa out of the mud." Along the way, the nonlinear soil modeling of Selig, Duncan, and others have been coupled with complex computer modeling techniques developed by Katona to make routine the previously complex mathematics of soil-structure interaction. There has been significant advances in the design and codification of buried structures by McGrath amongst others. Many of these advances were documented in the seminal Transportation Research Circular Issue E-C230 published in 2018 (see Figure 6).

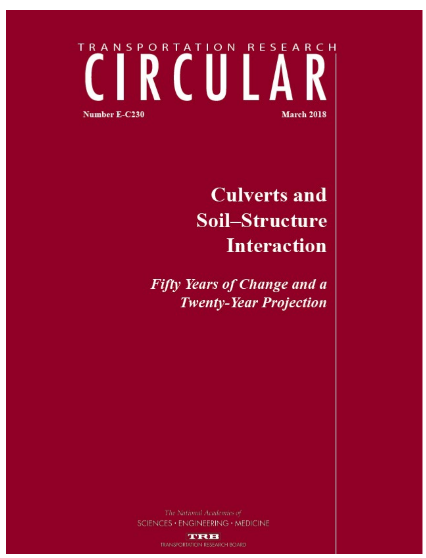

Figure 6. *Culverts and Soil–Structure Interaction: Fifty Years of Change and a Twenty-Year Projection: Presentations from the 93rd Annual Meeting of the Transportation Research Board*, Transportation Research Circular, Issue E-C230, 2018, http://onlinepubs.trb.org/onlinepubs/circulars/ec230.pdf

Today

The industry continues to push the boundaries of what can be accomplished with soil-structure interaction dependent structures ranging from small pipe to massive buried bridges with spans exceeding 75ft. In recent years, infrastructure owners have recognized the need to treat culverts and other buried structures as infrastructure assets, and TRB has issued a comprehensive inspection guide to give owners the tools necessary to do so. For a relatively small community, the sister TRB committees of AFS40 and AFF70 have maintained lively and active participation in Annual Meetings through workshops, lecture and poster sessions, and committee meetings. This interaction ensures that the marketplace continues to adapt and advance to meet the needs of the transportation community.

Tomorrow

As we stand on the shoulders of the giants who preceded us, we hope to see just a little bit farther. With our understanding firmly laid by the geotechnical and buried structure giants of the past, the field of subsurface soil-structure interaction will continue to meet the often-unseen and underappreciated needs of the traveling public. Already, the TRB committees are championing innovation in the field. Research and synthesis needs aimed at quantifying the already significant sustainability and resiliency of buried structures are being articulated within the committee. Buried bridges of all sizes will be at the center of meeting the transportation needs of future generations. Further, with growing concern about environmental threats, buried bridges will prove to be cost-effective and resilient solutions.

As progressive project delivery methods and value engineering continue to evolve, the opportunity for the use of large span culverts and buried bridges will continue to grow. For the past century, many have only considered culverts to be small structures, used to transport limited quantities of water. In the next century, the concept of a culvert will expand to include large span buried bridges as a common construction type rather than an exception to the rule.

The further development of soil-structure interaction predictions will require an increase in accuracy, precision, and reliability. This will require better classification of soil properties and the variations in those properties, as well as improved constitutive soil models to better represent soils. Furthermore, installation and construction methods will improve, increasing the effectiveness of construction inspection, and decreasing the sensitivity of buried structures to construction practices. Improvements in predictive capability and construction reliability will directly fuel shifts into reliability-based design methods; those based on rigorous statistical and physical models, not simply estimates from older allowable stress methods. The advent of computer-learning and artificial intelligence will help to further develop the expected properties of the soil-structure interaction system as well as provide real-time monitoring of in-service structures with the ability to address concerns long before they become problems.

Buried structures have served the public well for the last 100 years. The future remains bright for improved transportation systems built over the hidden blessings of buried structures.

AFS60: Subsurface Drainage Committee

Contributors: Habib Affan, Mohamed Elfino, Clark Graves, Jim Goddard

History

- Established in 1970 as Subsurface Drainage Committee (A2K06) under Soil Mechanics Section in Design and Construction of Transportation Facilities Group
- In 2004, changed to Subsurface Drainage Committee (AFS60) under Soil Mechanics Section in Design and Construction Group

Scope in 1987
This committee is concerned with the theory and behavior of subsurface water movement and the design and performance of subsurface drainage for transportation facilities. The scope includes water movement due to gravitation, capillary and thermal driving forces, percolation, seepage, erosion, piping, filtration and infiltration.

Scope (2015)
This committee is concerned with the sources, movement, and collection of subsurface water and its impact on the performance of transportation facilities. The committee is specifically concerned with innovative technologies and strategies that improve the subsurface drainage of pavements and related transportation facilities to attain long-term performance based on cost-effective design, construction, and maintenance.

History, Current State of Practice and Future
Road builders and geotechnical engineers have recognized for long time (since John L. McAdam 1820), the importance of keeping their facilities dry in order to obtain the expected performance. The increase in loading to transport more goods throughout the completed highway system in the US necessitated higher capacity of our highways, runways, and geotechnical structures. It is very clear that drier foundations will provide a structure that can withstand higher loadings.

Advancements in understanding the implementation of effective drainage resulted in exceptional performance of many structures. It all started with recognizing the sources of water that can enter a highway or an embankment, so the water removal can be achieved. Installing different varieties of drainage systems, such as deep edge-drains in cut areas of the highway especially when high ground water-table is present, has lowered the water table significantly and improved our pavement performance. In addition, several cross drains, shallow edge-drains were designed for our highways and runways. These developments required the cooperation and interaction among the geosynthetics, pipe industries, geotechnical, hydraulics, and pavement engineers. The resulted products included, but not limited to, the trench/pipe type drains, geocomposite for pavement, back of retaining walls, and draining embankments using wick-drains. Daylighting drainage layers, French drains, and pavement drainage layer (stabilized and non-stabilized) were also another contribution of effective drainage and part of the committee scope.

Another significant advancement the past century had witnessed in the drainage section is the progressive use of porous or permeable pavement. Although such pavements were first seen in Europe in 1800s, such pavement has only been implemented in the USA in the past 50 years. Permeable concrete is now used in numerous locations throughout the U.S. and its number of applications has recent grown significantly from driveways and sidewalks to commercial and multi-acre spaces. Benefits include both financial (lesser storm water management expense) and environmental (runoff elimination, groundwater recharge and others).

TRB's committee on subsurface drainage contributed to the development and/or the use of software to design drainage systems, such as "Drainage Requirements in Pavements" DRIP has proven to be an excellent tool. This is one of the very few software available to estimate a comprehensive drainage requirement for road. AFS60 provides technical assistance for this software and arranged a well-received webinar in 2018.

TRB's committee on subsurface drainage (AFS60) contributed significantly in the development, advancement and promotion of many of the above mentioned areas through research scoping, arranging meetings, workshop, webinars, synthesis etc. AFS60 has also collaborated with other committees and entities. In recent years, one of the Research Need Statements (RNS) developed by AFS60 has been selected for highly competitive NCHRP funding (01-59). AFS60 reviews paper related to drainage for the annual TRB event that had contributed to a number of practice ready papers.

In summation, the subsurface drainage committee has wide-spread interaction with both types of pavements (concrete and asphalt), geotechnical engineering structures such as embankments, earth dams, levees, and storage reservoirs as it is essential to have effective drainage to get the desired performance. AFS60 has been proudly a very active partner of the advancements in the drainage arena witnessed in the past century and will continue to explore new materials including novel geotextiles, geocomposites, and others as well as methods for enhancing drainage conditions around the transportation infrastructure.

AFS70: Geosynthetics Committee
Contributors: Jennifer Nicks

History

- Established in 1981 as Task Force on Engineering Fabrics, changed name to Geotextiles in 1988, and again in 1989 to Geosynthetics under the Soil Mechanics Section in the Design and Construction of Transportation Facilities Group.
- In 2004, changed to Geosynthetics Committee (AFS70) under Soil Mechanics Section in Design and Construction Group

Scope in 1987
This committee is concerned with the design, installation, and performance of engineering fabric systems (excluding vegetative fabrics) employed in transportation facilities. These concerns extend to fabric specifications, design methodologies, construction techniques, and long-term performance.

Scope (2019)
This committee is concerned with the analysis, design, installation, and performance of geosynthetics used in transportation facilities. These concerns extend to design considerations, material properties, geosynthetic effectiveness in terms of cost and performance, innovative or improved design and construction methodologies, and long-term performance.

Background
The Transportation Research Board (TRB)'s Standing Committee on Geosynthetics (AFS70) was officially formed in 1987 under the Soil Mechanics Section in the Design and Construction of Transportation Facilities Group. The roots of the committee stem from a Task Force on Engineering Fabrics, established in 1981, which primarily focused on geotextiles. Initial research needs identified by that Task Force included: (1) Use of Geotextiles Within the Pavement Structure; (2) Geotextiles in Reinforcing Applications; (3) Use of Geotextiles for Drainage and Filtration; (4) Railroad Applications of Geotextiles; and (5) Applications in Extreme Environments. Since then, the focus of the committee has broadened to include any geosynthetic product used in transportation facilities (e.g. geotextiles, geogrids, geomembranes, geocells, geocomposites, geofibers, and others).

Current Activities

The Geosynthetics Committee is now under the Geotechnical Engineering Section and the Design and Construction Group of TRB. Committee members represent federal and state agencies, academia, industry, and design firms with expertise and a strong background in geosynthetics. The Geosynthetics Committee has a dynamic and engaged membership, as evidenced by the large attendance at every meeting and the interest and activities of those members. Many members from the academic side are actively involved in current geosynthetic research projects, funded by both public and private entities. Representatives from industry are numerous and very helpful in bringing identified research topics to the group while they often fund needed studies in the field. Practitioners are bringing in their issues as research needs and they are implementing research results as design methods and construction specifications. Many groups and organizations are represented by the members of the committee (DOT's, AASHTO, ASTM, IFAI, GMA, NAGS, etc.), which means that the impact of the group is much wider than just within the membership or TRB.

Unlike many other topics within TRB, most applications of geosynthetics are outside of transportation. They are used as a roofing material, to line reservoirs and detention basins, and a myriad of other uses. Therefore, many technological advances develop elsewhere which need to be studied to bring them into the transportation field. Geosynthetics are generally the newest materials in the geotechnical field, and as such are finding the newest applications while identifying potential knowledge gaps. Recent work of the committee has focused largely on advancements in: (1) geosynthetic applications, design, installation, and testing (e.g. for pavements, railways, earth retaining structures, airfields, slopes, embankments, etc.); (2) geosynthetic specifications; (3) numerical modeling and analyses; and (5) geosynthetic reinforced soil integrated bridge systems. Considerable effort has been performed in these areas over the years, through papers, posters, lectern sessions, and workshops at the TRB Annual Meetings, in addition to webinars, circulars, and research products.

Future Forecast

With the advent of new or improved geosynthetic products and applications for enhanced drainage, reinforcement, separation, filtration, and stiffening, the Geosynthetics Committee will continue to remain relevant and have an increasing role in developing research needs and implementing technology transfer. Upcoming key efforts include the development and sponsorship of webinars related to erosion and sediment control, geosynthetic specifications, and best practices for pavement design using geosynthetics. Forums will also be established to deliberate and discuss new design methods for geosynthetic reinforced soil walls and abutments. Advancements in instrumentation and numerical modeling of rate-dependent geosynthetics is also a growing topic of interest to the committee.

Sustainability and resiliency continue to emerge as a major concern in many areas, including transportation, worldwide. Geosynthetics play a large role in these aspects of civil infrastructure, life-cycle-cost studies, and carbon foot print analysis. Future work by AFS70 aims to address the reuse, recycle and reengineering of materials; use of wastes in highway design, slope design and ecology topics; and Green road ratings knowledge. Quantifying the life-cycle cost benefits and asset management of geosynthetics in transportation infrastructure will also be pursued through research and development.

The future of geosynthetics is strong, with no end in sight. AFS70 is poised to help bridge the gap between research and practice through the active involvement of members and friends of the committee within TRB, other professional organizations, academia, and industry. For current and future announcements and other related information to the Geosynthetics Committee, please visit the AFS70 website at https://sites.google.com/view/afs70-geosynthetics/.

AFS 80: Stabilization of Geomaterials and Recycled Materials Committee
Contributors: Wayne Adaska, Will Carruth, Dave, Ta-Teh Chang, Robin Graves, Robert Parsons

History

- Established in 1970 as Compaction Committee, changed name to Soil Portland Cement Stabilization (A2J01) in 1987; changed name again in 1992 to Cementitious Stabilization Committee under Soil Mechanics Section in Design and Construction of Transportation Facilities Group.
- In 2004, changed to Cementitious Stabilization Committee (AFS80) under Soil Mechanics Section in Design and Construction Group
- In 2016, AFS80 (Cementitious Stabilization Committee) merged with AFS90 (Chemical, Mechanical, and Asphalt Stabilization Committee) and the new committee formed is Stabilization of Geomaterials and Recycled Materials Committee (AFS80) under Soil Mechanics Section in Design and Construction Group. AFS90 was sunset.

Scope in 1987
The scope of this committee shall encompass laboratory research and field investigative studies related to Portland cement stabilization of earth materials used in the construction and maintenance of transportation facilities in any component of the facility. The component items include backfills, shoulders, subgrades, bases, surface courses, and the aspects of material properties, mixtures, thickness design and evaluation, for all applicable modes of transportation.

Scope (2015)
The work of this committee is concerned with all aspects related to cementitious stabilization of materials used in the design, construction, maintenance, and rehabilitation of transportation infrastructure.

Scope (2016)
This committee is concerned with stabilization of materials in the design, construction, maintenance, preservation and rehabilitation of transportation infrastructure.

Past and Current State of Practice
Developments in the field of soil stabilization represent a major advance in the design for pavements, foundations, and other structures over the past century. Soils and other materials that were unusable due to inadequate strength, durability, or were susceptible to excessive volume change can be transformed into high-quality construction materials through the use of soil stabilization products and techniques. Through the decades, multiple TRB committees have focused on development of cementitious, chemical, and mechanical stabilization methods and assessing their benefits. AFS80, the Stabilization of Geomaterials and Recycled Materials

Committee, is the current home for collection and publication of information on soil stabilization. Some of the most impactful contributors to soil stabilization over the previous decades include:

Cement: For more than 100 years soil-cement has been an integral part of many pavements. As early as 1915, an enterprising paving contractor in Sarasota, Florida constructed what could be characterized as the first soil-cement pavement. Years later, in 1935 the first scientifically controlled use of soil-cement pavement was constructed by the South Carolina Highway Department for State Highway 41 near Johnsonville, South Carolina. Since these early beginnings, more than 250,000 miles (401,336 km) of equivalent 24-ft (7.5 m) wide cement-stabilized bases have been constructed throughout the United States. Within the last 15 years, major improvements with in-place mixing equipment has resulted in fast and effective mixing to depths greater than 18-in. (450 mm). In addition, a process known as full-depth reclamation (FDR) where the distressed bituminous pavement and base course is reclaimed with stabilizers such as cement has become a common practice.

The Transportation Research Board, and in particular the stabilization committees, have played an important role in disseminating information on the design, construction and performance of soil-cement as well as other stabilizers. Some of the Highway Research Boards bulletins from as far back as the early 1960's, such as HRB Bulletin 292 Soil Stabilization with Portland Cement have laid the ground work for future research and served as a resource in understanding engineering properties and construction principles that are still relevant today.

Lime: Stabilization of soils with lime has a long history dating back over 2000 years to Roman times, and is instrumental today in stabilization of plastic soils for foundations of highways, airports and building structures. Although lime stabilization has a long history, understanding of specific mechanisms of soil-lime interactions, engineering evaluation of soil property improvement, and proper design of mixtures are much more recent developments. TRB research publications in the 1950's and 1960's under the Committee on Lime and Lime-Fly Ash stabilization began the foundation for detailed technical knowledge within the field of lime stabilization. This culminated in the publication of TRB Circular 180 in 1976, which was later updated into State of the Art Report 5 in 1987. These documents detailed soil-lime reactions, treated soil properties, mixture design and construction processes, along with an extensive bibliography.

Following the publication of these pioneering documents, extensive additional research has been published by evolving TRB Committees within the broad field of soil stabilization. Subjects such as durability of lime stabilized soils, lime stabilization of soils containing sulfates, leaching and permanency of lime stabilization, and advanced engineering testing and design methods are examples of additional research areas. Some recent studies have focused on testing and evaluation of lime stabilized soils for incorporation into sophisticated mechanistic-empirical models used in pavement design. TRB Committee AFS80 on Stabilization of Geomaterials and Recycled Materials remains active today in advancing the field of lime stabilization through technical sessions, research publications and technology transfer.

Fly Ash: For more than a half century, fly ashes have been used for soil stabilization. Fly ashes have played key roles as pozzolans or fillers. In the case of fine-grained soils fly ashes can act as pozzolans. Fine-grained soils can have improved properties when treated with Class C self-cementing fly ash or with cement-fly ash or lime-fly ash mixtures. Fly ashes vary with source material and production source, and considerable research has been done on the variety of ashes and their relative benefits, including contributions to strength, stiffness, durability, and control of volume change.

Fibers: One of the first modern investigations using fibers for soil reinforcement was conducted by Vidal and published in the Highway Research Record in 1969. Since that time additional research has focused on using fibers both as a sole additive and in combination with other traditional stabilizers such as cement, lime, and fly ash. Although fibers can be expensive and difficult to mix in the field, the primary benefits provided by fiber inclusion are typically a modest increase in strength with a substantial increase in durability and toughness for a variety of soil types as reported by many research groups. These benefits have been utilized for a variety of applications including embankment stabilization, slope protection, and airfield and road construction.

Other Non-traditional Stabilizers: Many different types of non-traditional soil stabilization additives have been investigated as alternatives for more traditional materials such as portland cement and fly ash. These materials include polymer emulsions, enzymes, lignosulfonates, resins, and acids among others. Enzymes and multiple non-traditional stabilizers were studied by many researchers and practitioners and these are published in TRB records and CDROMs. Also, a Transportation Research Circulars published by this committee has provided recommendations for stabilizer selection and evaluation.

Future

New products and techniques continue to emerge. Research on byproducts, such as cement kiln dust and lime kiln dust, and recycled products that can be repurposed for soil stabilization continue to attract the attention of the committee. Research on biostabilization of soil is another area of great promise that the committee looks forward to sharing with the engineering community. As additional engineering constraints spur demand for new solutions that are more capable, more cost efficient, and more climate friendly, AFS80 looks forward to a second century of serving the engineering community through transfer of new knowledge about these technologies as it emerges.

Joint Subcommittee on Geotechnical Asset Management

Contributors: Scott Anderson and Darren Beckstrand

The centennial ends with the AFS section sharing a subcommittee with the AFP section on something called geotechnical asset management. This was most certainly far from the minds of the TRB community 100 years ago when the need for the research community was to devise safe and reliable means for construction, and ways to assure a consistent outcome. It is also true, however, that with the focus as it was, engineers at the time were recognizing what would become geotechnical asset management. They recognized that some means of earthwork construction and some earth materials could be more reliably depended upon to last a long time and were worth a premium. They also were driven by the pressing need to build a highway system. The National Highway System grew rapidly through the century and, with the focus on new highway, new structures, and new capacity, the practice evolved to one of 'build and forget'.

The TRB Geotechnical Asset Subcommittee is now formalizing and drawing attention to the understanding that few things last forever and are 'as solid as a rock', which is simply a convenient misconception. Elements of earthwork, like elements of steel, concrete and asphalt have a life span and the lifespan is influenced by the design, materials, construction, natural environment and loading. Now, at the end of the century, we have the need and ability to act upon this reality. The need is that we have built a large inventory of highway without specific thought or budgeting for how it will be maintained, and we have done such a good job that the public and the politicians that represent are little inclined to provide more money for a maintenance and preservation function they have never explicitly paid for before. That means that we have to be very smart about how we own and operate our infrastructure and the earthwork assets it is built upon.

Fortunately, the end of the first century of TRB finds us with exploding horizons on how to capture and manage data. It is not problematic to track the factors that influence longevity and performance of earth structures, whereas it would have been very costly and impractical even a few decades ago. Thus, we can meet the need effectively. The fact that we can do so is in large part due to the activities of the AFS and AFP sections at TRB and the activities of the volunteers dedicated to advancement. As the century draws to a close, data collection through new technologies, remote sensing and UAVs, for example, and the ways to visualize data, including mixed, augmented and virtual reality fill the meeting rooms and hallways.

The concept of lifecycle is not new in transportation any longer, and is even often talked about for geotechnical assets. Risk management has been a part of geotechnical highway practice for most if not all of the century, and now it is squarely a part of geotechnical asset management. The value of the concepts of management and preservation in a risk-based way is so evident that several TRB recognitions have been directed this way in recent years, including Section Paper Awards, K.B. Woods awards and the invitation to the Dialogue with Leaders.

FUTURE AND REMARKS

The 2015-16 Strategic Review by Design and Construction (DCG) group played a major part in the reorganization of Geotechnical Engineering section (formerly known as Soil Mechanics section). All nine original committees were reviewed and four of them were consolidated into two committees and the final outcome was that seven current committees were finally formed after the exercise. Each committee, as seen by their centenary paper input in the above sections, have contributed immensely to transportation communities in many areas:

- Research and developing practical solutions related to geotechnical engineering;
- Enhancing the life of the infrastructure;
- Novel materials including geosynthetics and chemical additives to strengthen the soils and foundations to earth structures
- Better design of foundations using LRFD design tools
- Risk based design concepts and performance based pavement and drainage designs
- New tools and instrumentation and integrating unmanned aerial vehicle platforms for infrastructure performance monitoring and asset management
- New modeling methods including numerical solutions that can be practically integrated with DOTs design practices;
- Life cycle cost studies along with sustainability and resiliency design and many others.

Significant technology transfer elements are also accomplished by the AFS00 committees as evidenced by the following:

- *TR News* articles;
- research payoff articles;
- news briefs;
- TRB workshops;
- best paper awards, including the KB Woods paper award;
- best practice paper awards and best of the session paper awards;

- articles in the *Transportation Research Record*;
- CD ROM publications;
- Problem statements for NCHRP syntheses;
- TRB webinars; and
- innovative practices that are expanded via TRB circulars.

The changes in the automated and connected transportation environment along with the use of autonomous systems are instrumental in the committees in exploring ways to integrate and design current and future transportation infrastructure with the new technologies. The growth and development of artificial intelligence and smart infrastructure solutions and monitoring have also opened up more geotechnical challenges and opportunities for Geotechnical Engineering section and committees. This is also promoting the collaboration outside the traditional group and committee structure.

The Geotechnical Engineering section and committees are confident that the next century will witness many more innovations and advancements in this dynamic growth of transportation sector and we hope future research, solutions and technology transfer practices from our section will be embraced and implemented by our stakeholders including transportation agencies, design and construction sectors, academic and research partners and others.

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