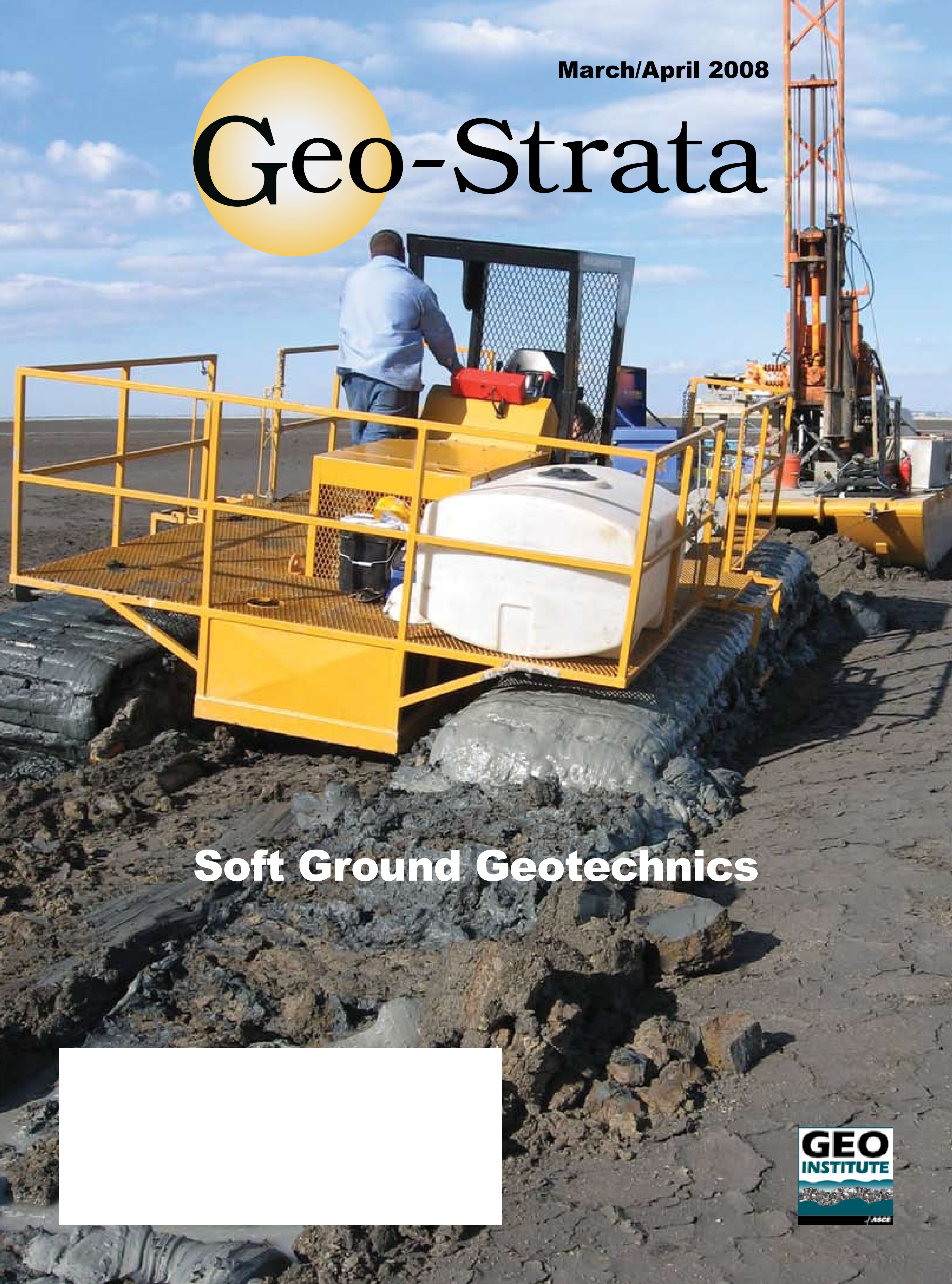
March/April 2008

Geo-Strata



Soft Ground Geotechnics

GEO INSTITUTE

Geo-Strata
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Features

Departments

On the cover: Tracked marsh buggy pulling a pontoon mounted BK-51 drill rig in the U.S. Army Corps of Engineers' Craney Island Dredge Disposal and Management Area. Photo by Anna K. M. Best, S&ME, Inc.

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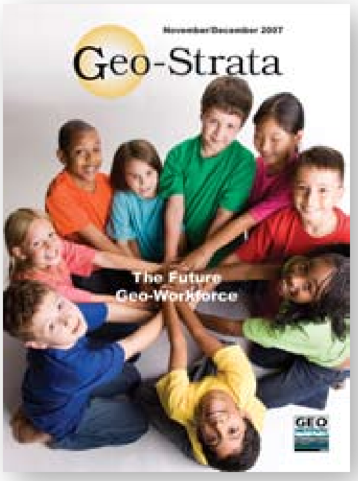
Letters to the Editor

November/December 2007



I recently read "The Global Engineering Challenge." One particular aspect intrigues me and prompted me to write. In the area of "why SME students leave those fields of study," the overwhelming reason included the poor quality of teaching and getting help with academic problems. After nearly 30 years in various aspects of the civil engineering construction profession, and having hired, mentored, and yes, terminated young professionals, I have found that nearly all of them are well-versed in the theory and academic side of engineering, but have little or no understanding of the practical side and how their academic education fits in the real world. I find it disconcerting that the vast majority of academic institutions seem to resist the hiring of seasoned professionals (unless they have a Ph.D.) to augment the academic professionals and require senior level students to take classes taught by experienced professionals where real world examples (good and bad) can be presented and how they are handled. The lack of quality report writing and logical approach (by some young engineers) to understanding field problems is worrisome to the profession. I've heard and read all the responses by the academic world as to why older engineers without advanced degrees may not be suitable in the academic world, but it seems that the lost productive time once the new engineer is in industry could be reduced if the teaching institutions would bring in outside professionals to tell and instruct students what they will really experience in the working world. It's not the technical side I refer to, but the personal interactions within a working group, the required field notes, the long hours, and the rewards of sticking it out that need to be explained. I had the opportunity to conduct some of these sessions with the ASCE student body at the U.S. Military Academy at West Point several years ago and it was not only rewarding for me but the response from the instructors and students was very positive. It comes down to the fact that advanced degrees do not necessarily mean good teaching capabilities. I realize I may have a myopic viewpoint, but 30 years of experience has yet to sway my thinking.

David A. Edwards, P.E.
Project Manager
O'Brien & Gere
East Syracuse, NY

I just finished reading Dr. Laefer's article on Geo-Diversity. I thought the article was well written and I really enjoyed it. Our company has, in recent years, implemented some of the items she mentioned in the article with very positive effects.

Raymond L. (Levi) Denton II, P.E.
Geotechnical Department Manager
Fort Collins, CO

COMING IN
May/June 2008 *Geo-Strata*

Condition Assessments

2008 ASCE/G-I MEMBERSHIP RENEWAL TIME

It's time to renew your ASCE and/or Geo-Institute membership. You should have already received your 2008 renewal notice. If you haven't, please call ASCE Customer Service at 1.800.548.2723.

ASCE/G-I MEMEBERS CAN RENEW:

- online at *https://www.asce.org/lib/redirect/?redcode=mbren.*
- By phone at 1.800.548.2723, or
- By mail at 1801 Alexander Bell Drive, Reston, VA 20191

If renewing online, please check your profile information to make any changes to your member record. G-I only members can renew by mail, or by fax at 703.295.6351 G-I only student members must also renew your free membership.

President's Letter
Art Hoffman, P.E., M.ASCE

Dear G-I Member,

Ten years ago, the G-I created the Sections and Branches Committee. We invited section and branch geotechnical (GT) group chairs or representatives to join us at our inaugural Geo-Logan conference for dinner and discussions. Then, as now, our goals were to:

- establish communication with the local groups,
- understand the goals and needs of the local groups, and
- work to find ways for the G-I to help the local groups.

These types of meetings were held at G-I national meetings for several years.

Our efforts didn't end there. For the past 10 years, along with the other Institutes, we have been meeting with section and branch leaders at Zone Leadership meetings around the country. At these meetings, we talk about the Institutes and how we can work with local groups.

The G-I has been reaching out to the local GT groups because we believe that great opportunities exist for us all to combine resources for the benefit of all of our members. We're pretty sure that the local groups could benefit from some of the things that the G-I can provide (like advertisement of local or regional geo-conferences and meetings) and we are confident that the G-I can use the help of local GT groups to identify members to serve on G-I Task Forces and Committees.

But, here's what's frustrating. After years of reaching out and trying to make connections, too many local section and branch leaders aren't even aware that the Institutes are accessible and eager to work with them. I believe that there is a general lack of understanding on the part of the local GT groups about the G-I's relevance to them. I also know that the Board of Governors hasn't yet figured out exactly what the local groups want from the G-I and how we can best serve them and their local members.

I consider these shortcomings to be mainly the responsibility of the G-I. We haven't yet found a successful method of establishing strong ties and channels of communication with the local groups. That's where it needs to start. Unless we know each other and talk to each other, we won't find out how to help each other.

There have already been contacts made and relationships developed with a few sections and branches. Four local geotechnical groups have even chosen to associate with the G-I by becoming official Geo-Institute Local Chapters and establishing a G-I presence in their area. They are:

- The Delaware Valley Geo-Institute Chapter,
- The Geo-Institute Chapter of the Maryland Section,
- The Geo-Institute Chapter of the Pittsburgh Section, and
- The Boston Geo-Institute Chapter.

We're glad to be associated with these groups and to be providing services (like posting local chapter newsletters and advertising on the G-I web site) to them. Several members also are active in national G-I activities.

What good can come of a formal relationship between your local geotechnical group and the G-I? I can think of a few things. From the G-I's perspective:

- The national committee chairs, governors and G-I staff would get to know active, committed local geotechnical leaders.
- The G-I would have a better chance of talking to local leaders and understanding their goals and needs. This would help us to find ways to help or support local geotechnical groups.
- National opportunities on G-I committees and Task Forces would be shared with the local leaders and interested local members could become involved at a national level.
- The G-I's brand would reach farther out to the members of ASCE, public officials, and to the general public.

But this isn't really about how relationships would help the G-I, it's really more about how a relationship would benefit your local geotechnical group, such as:

- advertising your local geotechnical conference or short course regionally and nationally;
- providing technical and logistical assistance if your local

group is attempting to influence relevant local public policy issues;

- creating a G-I e-mail address for your chapter; and

- possible increased participation by geologists and other geo-professionals in your area.

Some people have been hesitant to approach the G-I for fear of losing autonomy or for fear of a financial cost. I can assure you that existing local arrangements on financing and administration between the section or branch and the current local geotechnical group will remain essentially intact. The G-I is not interested in becoming involved with local governance or finances. I believe that the current G-I chapter leaders would confirm this if you spoke to them.

The process required to develop a formal relationship is easy—only four steps:

1. Get organized locally.

2. Submit initial information for G-I review.

3. After getting feedback from the G-I, prepare a specific Institute Chapter proposal.

4. Secure written approval from the governing boards of the G-I and the Section or Branch.

You can find the four-step process and more information about becoming a G-I Local Chapter on the G-I website at http://content.geoinstitute.org/groups/index.html or by contacting Linda Bayer at lbayer@asce.org.

Until we get to know more about each other, we won't really know how we can help each other. Please consider encouraging your local geotechnical group to become a G-I local chapter.

Art Hoffmann, Jr., P.E.
President, Geo-Institute of ASCE

Shady Lane

Note: This poem is intended to refer to a hypothetical project. Any references to real roads are coincidental.

There once was a street called Shady Lane
Whose soil lost most of its strength when it rained.
Its residents were happy
Though their pavements were crappy
And took a long time to drain.

Then developers came by one day.
They said, "Take all these front yards away!"
We're widening the road
Grubbs, get in work mode!
You'll see that our subgrade's Grade A."

The drillers came onto the site
With their split spoons and auger flights.
Their results added up
To prescribed undercut
To the borrow pit owner's delight.

Then came machines with their rollers and tracks
Compacting to 98% max
"You won't require repair,"
The superintendent declared,
"This new road won't see any cracks!"

When all of the work was complete
Residents gazed at their shiny new street
Saying, "It has the same name
But it sure ain't a Lane,
And they've made all the Shade obsolete!"

Mary C. Nodine, E.I.T., is a geotechnical poet and a staff engineer with Grubbs, Hoskyn, Barton and Wyatt, Inc. in Little Rock, AR. She can be reached at: mnodine@grubbsengineers.com

Geo-Strata is interested in hearing from you. Please send your comments on this poem to *geo-strata@asce.org.*

Filler

From the Editorial Board

Somehow it always seems when it is my turn to prepare the message from the Geo-Strata editorial board, the topic of the issue makes me wax nostalgic about observations from the early days of my career in Geotechnical Engineering. The theme for this issue, "Soft Ground Geotechnics," falls into that same position. Maybe it's my age and over 30 years in the business that makes me look back, but in this case I can point to the fact that my interest in soft ground and dealing with it was key to my attraction to Geotechnical Engineering. My first course in soils as an undergraduate included coverage of soft soils, but I think it was the course field trip to a major four-story-deep excavation for a downtown San Francisco high-rise deep into San Francisco Bay Mud that really caught my attention. The field discussion by the project manager covering the geotechnical investigations and design emphasized the issues related to the pile foundations being installed, the excavation support used, and the structural aspects of the building substructure to deal with the soft clay material. Soon thereafter, on a summer job as a driller's helper working on a USGS drill rig, I got plenty more firsthand experience with San Francisco Bay Mud and soft ground. That included mud in my hair, on my face, and even getting a taste of it from time to time. I can attest it is not a culinary treat. No matter the taste of the mud, by then I was hooked on Geotechnical Engineering and the challenges of work with soft ground.

In the more than 30 years since I got to enjoy Bay Mud taste treats, dealing with soft ground has come a long way and significant advances have certainly occurred. However, our profession still doesn't always deal with this more difficult aspect of geotechnical practice. Charles Ladd kicks off the topic with a commentary that looks at the long-used practice of precompression using surcharging and highlights some errors he still often sees in the use of this technique. These include issues with field investigation techniques, poor quality lab testing, incorrect stability analyses, and insufficient field instrumentation that can add up to poor practice.

Sand vertical drains to speed up consolidation of soft soils were first used about 80 years ago, and wick drains came along shortly thereafter. Since then, wick drains have evolved and are commonly used in many projects. Martin Taube provides an excellent article on wick drains entitled "Prefabricated Vertical Drains—The Squeeze is On" that covers the concept behind the drains, their applications, installation, and site considerations.

Highways are increasingly congested all over the United States, and new highways or existing highway widening projects to enhance capacity and ease congestion often require new or widened embankments on soft ground. Traditional techniques that have worked in the past may take too much time or cost too much. In "Embankments On Soft Ground? Don't Stress It," Silas Nichols discusses how today, requirements to build faster, better and for less money, have pushed engineers to explore "out of the box" solutions. One of those solutions is super-lightweight fill such as geofoam. Silas provides a discussion on what geofoam is and some of its advantages. He also covers some of the obstacles to geofoam use in transportation projects.

Landfills are often sited in areas when ground conditions are poor and not favorable for other types of use, and this is true for the 20+ year old Cherry Island Landfill near Wilmington, Delaware which had only a few years of remaining storage unless steps could be taken to overcome stability problems caused by soft foundation soil. In "Design Considerations for Expansion of an Existing Landfill over Extremely Compressible Soils," David Espinoza, Carlos Lazarte, and Michael Houlihan describe some clever design measures they conceived to extend the life of the landfill until about 2025.

As Chuck Ladd notes in his commentary, he sees misapplication of field investigation laboratory testing techniques at soft ground sites that can add up to poor practice. Some useful guidelines are offered by Aaron Zdinak, Richard Simon, Jesse Darden, and Joseph Clarke in their article, "An Approach to Characterizing Overland, Soft Soil Sites," who have used the approach for the design of transportation and flood control projects in the coastal plain of the mid-Atlantic, where they often encounter and are challenged by deep, soft, cohesive soil deposits.

Rounding out the articles on soft ground, John Volk and David Shiells discuss techniques used for dealing with soft ground for construction of an interchange for the Woodrow Wilson Bridge in their article "Rebuilding the Route 1 Interchange: Ground Improvement on the Woodrow Wilson Bridge Reconstruction Project. This article covers the geotechnical conditions encountered, ground improvement techniques applied, and the instrumentation and observational approach used.

Discussion of the application of the observational method provides a perfect segue to our ~~fourth~~ article in this issue—a Geo-Classic reprint of Richard Goodman's article "Karl Terzaghi's Legacy in Geotechnical Engineering. This article was originally printed in the October 2002 issue of Geo-Strata and provides an excellent overview of the man generally considered the father of modern geotechnical engineering. Key facets of his manner of geotechnical practice provide excellent reminders to all of us who practice this profession.

Finally, in our second issue of the political year of 2008, the GeoCurmudgeon returns to The Little Blue Engineer, who finds out more about politics in Tinytown and takes action. Reading this, and the previous GeoCurmudgeon that introduced the Little Blue Engineer, lead me to pull out my tattered copy of The Little Engine That Could. It was the one children's book my parents chose to save and present to me to read to my daughter when I became a parent. I admit it was one of my favorites way back then, but there I go getting nostalgic again.

This message was prepared by Editorial Board member Jeff Dunn.

Commentary: Soft Ground Geotechnics

By Charles C. Ladd, Sc.D., P.E., Hon. M.ASCE

This commentary discusses construction that loads the surface of saturated cohesive soils located on land or in shallow water. For such projects, a *soft ground* condition exists whenever the applied load produces a final effective stress profile that significantly exceeds the preconsolidation (yield) stress (σ'_p) of the foundation soil. This stress condition, rather than the stiffness of the soil per se, means that the foundation soil has low undrained shear strength, relative to the imposed shear stresses, and high compressibility. For these reasons, construction of buildings, storage tanks, embankments, etc. on soft ground poses two major geotechnical design issues: potential foundation instability due to undrained shear during loading, and excessive long-term consolidation and creep settlements.

Expensive solutions include excavation and replacement of the soft soil, a deep foundation system such as piles or stone columns, chemical treatment such as deep soil mixing, or decreasing the applied load using lightweight materials rather than fill. In contrast, with proper planning, *the precompression* option can provide significant cost savings. This technique consolidates the foundation soil by applying a *preload* (via fill, water, or vacuum) prior to placing or completing the structural load, thereby increasing the soil strength and reducing post-construction settlements. *Surcharging* denotes preloading in excess of the final load. Other design components may include:

- vertical drains, usually low-cost wick drains, to greatly accelerate the rate of consolidation;
- stability berms and geotextile reinforcement (within granular fill), and loading in stages to improve stability; and
- surcharging to decrease the preloading time or to over consolidate the soil (especially with vertical drains), which reduces long-term post-construction settlements by decreasing the rate of secondary compression (C_α).

The geotechnical services required for precompression are far more comprehensive and challenging than those needed for the more expensive solutions. These services entail a more thorough site investigation to define the stratigraphy and the relevant stiffness-strength-consolidation-creep properties, followed by detailed analyses of foundation stability and of settlements during and after construction. Deformation analyses to assess the effects of construction on adjacent facilities also may be necessary. Moreover, Peck's Observational Method is mandatory because of uncertainties in foundation stability, the rate of consolidation, and the amounts of settlement and lateral deformation. It also serves as an effective form of risk management. The extra cost for the investigation, design, and monitoring services is small, however, compared to the likely savings in construction costs.

Significant geotechnical advances in the state of the art (SOA) have occurred since Stan Johnson's classic 1970 ASCE papers on precompression and vertical drains. These include the piezocone for soil profiling, radiography to assess sample quality, automated laboratory consolidation and shear testing, computer programs for stability and consolidation-deformation analyses, and more versatile and robust field instrumentation. We also have a better understanding of clay behavior, prime examples being the relationship between undrained strength and stress history, and Mesri's "constant C_α/C_c" concept. But has precompression practice kept up with the SOA? My experience indicates sometimes yes, but more generally no. All too often, I see:

- highly-scattered and misleading lab data resulting from poor-quality samples and inappropriate testing such as UU and CIU triaxial test programs (unknown and unsafe errors, respectively), doubling the load in oedometer tests (ill defined σ'_p), and no tests to measure the reduction in C_α with the level of surcharging;
- reliance on piezocone data to obtain s_u and σ'_p using *universal* correlations (large scatter makes unreliable), plus inaccurate values of corrected tip resistance (penetration pore pressures are too low due to desaturation of the filter element);
- "effective stress" stability analyses using measured pore pressures during staged construction—the resultant factor of safety is much too high because such analyses inherently assume a slow, *drained* failure of the foundation clay; and
- too little field instrumentation and incorrect evaluation methods. For example, the surcharge removal decision is based only on surface settlements (unknown consolidation stress profile) and the Asaoka technique is applied to consolidation data with vertical drainage only (derived rate and degree of consolidation (U) much too high when *in situ* U is less than 50%).

So what causes poor practice? Certainly, one cause is clients who select a low bid based on an inadequate scope of work, and another is the adverse conditions in some countries that greatly inhibit proper site investigation and monitoring programs. But in general, I blame the geotechnical "ignorance" of practitioners who do not know what should be done and do not appreciate the extent to which sloppy engineering can adversely affect the outcome. These engineers often start with a poor formal education (too many universities reward research, not practice) and then do little to become informed of the SOA.

Nevertheless, even engineers well-versed with SOA precompression designs may encounter surprises. I list three uncertainties.

1. Does secondary compression (creep) occur only after the end-of-primary (EOP) consolidation (Hypothesis A), or does it also occur during dissipation of excess pore pressures (Hypothesis B)? Although U.S. practitioners, including myself, typically assume Hypothesis A, some field evidence (mainly from test fills on the highlystructured Champlain clay of eastern Canada) supports Hypothesis B, which predicts much larger EOP settlements for thick clay deposits with long consolidation periods.

2. Does the "smear zone" concept work for the design of wick drain spacings? This concept predicts faster consolidation rates at closer spacings, whereas field data indicate that spacings less than about 1.5 m can do more harm than good.

3. Are widely-used commercial computer programs based on the Modified Cam Clay (MCC) model of clay behavior adequate for deformation-time and stability analyses? I think not. The MCC model ignores small-strain linearity and undrained strength anisotropy that more recent models incorporate.

My first precompression project 40 years ago involved an interstate highway exchange with five bridges on highly-sensitive clay in Portsmouth, NH. The design included a test embankment loaded to failure, vertical sand drains, staged construction with stability berms, surcharge fills, and extensive field instrumentation. The clay turned out to be far more compressible and susceptible to undrained creep than I had assumed. This unexpected behavior would have caused serious stability problems if the Dutch "jet bailer" sand drains (their first use in the U.S.) had not provided much faster consolidation rates than those selected for design. I was lucky. Soft ground geotechnics is fun to practice, but can be humbling.

Charles C. Ladd is the Edmund K. Turner Professor of Civil and Environmental Engineering, Emeritus, at MIT, where he taught courses in advanced soil mechanics, soil behavior, and foundation engineering, and was director of the Center for Scientific Excellence in Offshore Engineering. Professor Ladd remains active as a geotechnical consultant and is working on his first textbook, Construction on Soft Ground: Site Characterization, Design and Performance Monitoring, to be co-authored with Professor Don J. DeGroot of the University of Massachusetts, Amherst and forthcoming from ASCE Press. Ladd can be reached at: ccladd@mit.edu.

Geo-Strata is interested in hearing from you. Please send your comments on this commentary to *geo-strata@asce.org*.

Prefabricated Vertical Drains— The Squeeze Is On

By Martin G. Taube, P.E., M.ASCE

Slim. Sleek. Flexible. Durable. Reliable. Prefabricated Vertical (PV) drains may be light in weight but they deliver a heavy blow to slow-draining soils. PV drains, also known as wick drains in the U.S. and band drains in other parts of the world, can provide a low-cost, practical, and effective means of expediting consolidation settlement in fine-grained soils.

Pre-loading, or surcharging, is a time-tested, effective method for increasing the strength of soft soils by applying a temporary load to the ground that exerts stress similar, or slightly greater, than the anticipated stress from the proposed structure. Pore water pressure and settlement are monitored to ensure that the surcharge fill can be safely placed and that the desired percentage of settlement has occurred before the surcharge is removed. With slow-draining soils, the pre-loading process can take years or decades. Wick drains can reduce the pre-loading time from several years to a few months; they are intended to expedite settlement rather than reduce it.

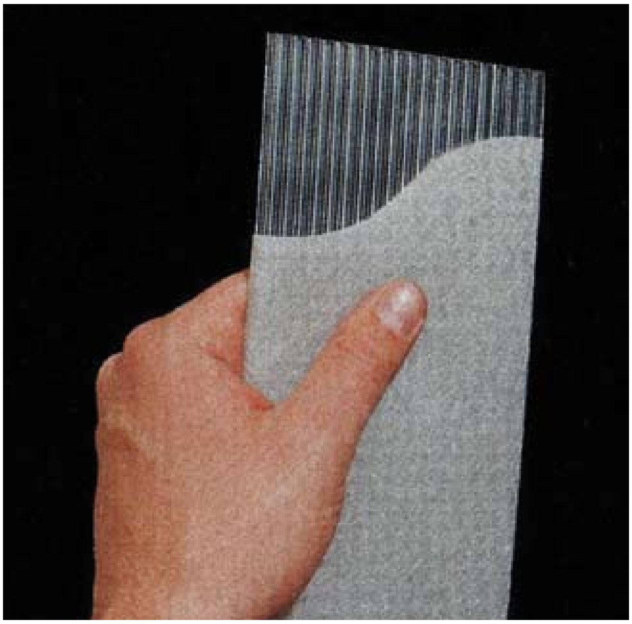


Figure 1. Wick drain material.

The Vertical Drain Concept

The duration of the pre-load period is controlled by soil consolidation characteristics, pore water travel distance, and surcharge height. Consolidation characteristics of soil particles are challenging to enhance and there are practical and safety limitations for surcharge height. Without vertical drains, the pore water travel distance is taken to be equal to either the thickness or one-half of the thickness of the strata undergoing consolidation. With properly-designed vertical drains, pore water will flow laterally to the closest drain rather than vertically to the underlying or overlying drainage layer and the drainage distance is significantly reduced. For example, if drains spaced 5 feet apart on a triangular grid pattern are installed through a 100-foot-thick layer that has no bottom drainage, travel distance is reduced by a factor of approximately 30.

In the 1920s, a technique for installing sand drains was patented in the U.S. Shortly thereafter, the first wick drains, consisting of layers of cardboard, were developed in Sweden. Cardboard wick drains, and subsequently paper-wrapped plastic drains, were installed outside of the U.S. through the 1970s. Introduced in the U.S. in the mid- to late-1970s, entirely plastic PV drains had become durable, reliable, and inexpensive, and could be installed very quickly as compared to sand drains. By the mid-1980s, PV drains had significantly replaced sand drains, which have been rendered almost obsolete in the U.S.

A variety of drain types are available in the U.S., the most common of which consists of a polypropylene core wrapped in a spun-bond polypropylene fabric. These highly durable drains are designed to resist rotting, tearing, clogging, cracking, and chemical degradation. The light-weight drains are approximately 4 inches wide by 1/8-inch thick. Drain discharge capacity varies with the amount of head that is applied, but typically ranges from approximately 1.5 to 2.5 gallons per minute. The flow of water into the core increases as fill is placed and pore water pressure in the slow-draining layer increases. Pore water pressure dissipates as the layer drains and the water is conveyed through the wick drain. The term "wick drain" can be misleading, as the flow through the drain primarily results from the increase in pore water pressure rather than capillary action.

Wick Drain Applications

Today, surcharges with wick drains are widely used for warehouses, storage tanks, residential and retail structures, roadways, airport runways, industrial facilities, port and marine construction, and MSE walls. When wick drains are used to expedite consolidation for soft ground underlying fills and earthen features such as berms, dikes, levees, and embankments, the goal is to allow for the feature to be constructed and put into service as quickly as possible. In particular, vertical drains serve to accelerate construction and reduce both the time and magnitude of post-construction settlement. They may also allow for construction of higher fills and steeper slopes because of the rapid strength increase in the treated soils.

In addition to expediting settlement for fills and preloads, wick drains have been used to reduce potential down drag on piles, to increase storage capacity for future landfills and waste containment sites, and for collection and extraction of floating product and contaminated groundwater.

Wick drains are commonly used for large, aboveground storage tanks, ranging in diameter from 100 feet to 350 feet, with product heights of up to 40 feet. Wick drains can be installed prior to a conventional soil surcharge, or, in some cases, the soil surcharge is foregone and the wick drains are installed after the ring wall but prior to tank construction. When installed without the soil surcharge, the pre-loading takes place as the tank hydro-test is performed. Once the desired amount of consolidation is achieved, the tank can be re-leveled, if necessary, and put in service.

Soils suitable for wick drains include clays, silts, organic layers, peat, clayey and silty sands, dredge spoils, and wastes such as mine tailings and industrial sludges. The scale of wick drain applications can range from a few hundred to

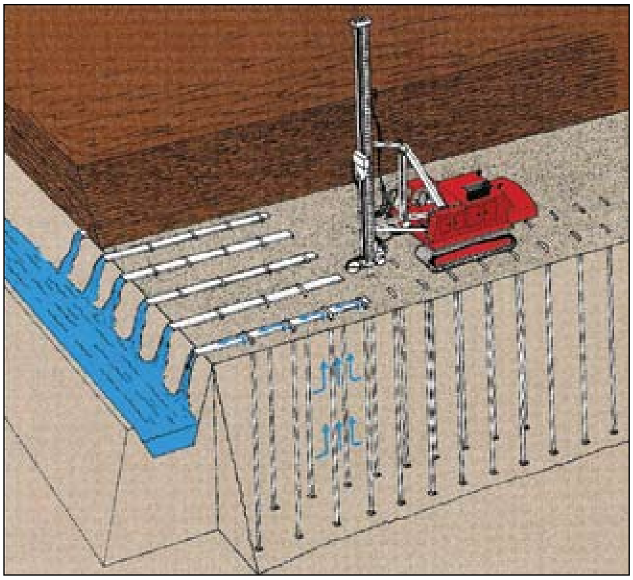


Figure 2. Wick Drains with horizontal strip drains to convey water.

In addition to expediting settlement for fills and preloads, wick drains have been used to reduce potential down drag on piles, to increase storage capacity for future landfills and waste containment sites, and for collection and extraction of floating product and contaminated groundwater.

several million linear feet. Recently, near Atlantic City, NJ, approximately 65,000 wick drains were installed to treat soft, compressible organic layers to depths of 40 feet for the construction of 134 townhouse units and surrounding grounds, resulting in approximately 3—4 feet of settlement.

The effects of a soil surcharge can be replicated or enhanced by applying a vacuum to a vertical drain to draw the water from slow-draining layers. This technique, known as Menard Vacuum™ Consolidation, relies on the establishment of a vacuum created under an airtight sealed liner system. The vacuum creates an isotropic state of stress in the soils which replicates the effect of a 12-ft.-high soil surcharge. Recently, in Camau, Vietnam, the Menard Vacuum™ Consolidation system was used to improve 1.7 million square feet of soft clay for the construction of a power plant. The soft clay was up to 55 feet thick and the induced settlement was between 6.5 and 10 feet.

Installation

Following the initial set up and feeding of the wick drain material, the drains are installed by pushing a hollow, steel mandrel, typically rectangular or rhombic in section, into the ground. The mandrel houses the wick material and protects it from damage as the mandrel is inserted into the ground to the termination depth. At the base of the mandrel, the wick material is looped through an anchor which holds the drain securely in place as the mandrel is extracted. Once the mandrel has been extracted from the ground, the wick drain is cut and the next drain is installed. In some sites, production rates greater than one drain per minute can be achieved.

Wick drain installation units are typically powered and supported by large crawler excavators or by cranes, depending on the depth of the drain and weight of the installation unit. Pull down is typically accomplished by heavy chain, cable, or gear systems. Depending on the subsurface conditions, the mandrel may be vibrated or statically pushed into the ground. The mandrel cross-sectional area is typically 10—12 square inches.

Wick drain center-to-center spacing is usually in the range of 3—8 feet. The drains are typically laid out in a triangular

(continued on page 16)

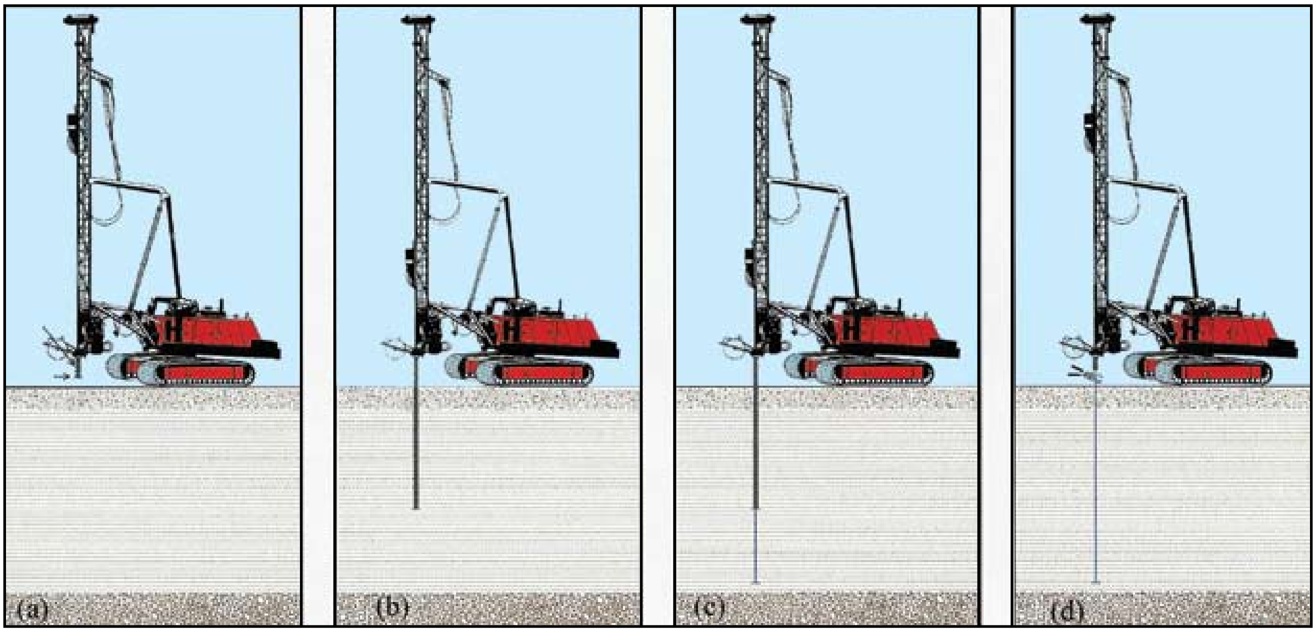


Figure 3. Wick drain installation process: (a) installation equipment; (b) driving mandrel; (c) extracting mandrel; and (d) cutting drain.

(continued from page 14)

grid pattern, less commonly in square grids, and, occasionally, in rectangular or irregular grid patterns. The majority of applications are between 15 and 120 feet deep; however, drains have been installed to depths over 150 feet.

Site Considerations

Tall masts, heavy equipment, and soft ground are a combination that necessitates special site preparation considerations. In most cases, the installation of a 12- to 24-inch thick sand or stone platform will provide sufficient traction and support for the wick drain installation equipment. Where the ground is especially soft, geotextile fabric or geo-grid is installed prior to the placement of the granular platform.

It is necessary to provide a drainage layer that is of adequate thickness and gradation to receive the flow of water conveyed through the wick drains. Ideally, the granular working platform can be designed to double as the drainage blanket. Horizontal strip drains may be used in lieu of the sand blanket if the existing ground can provide a well-draining, stable working surface.

For safety reasons, the site should be as flat as possible with minimal pitch to effect positive drainage; it may be possible to install wick drains on gentle slopes. The designer should consider topographic features such as hills and slopes, and also be cognizant of the presence of overhead power lines and buried utilities when designing a wick drain treatment program. With special modifications, battered and low headroom drains can be installed to help overcome site constraints. Where hard layers are present, drilling or augering can be used to loosen the ground to allow for wick drain installation.

The designer should consider topographic features such as hills and slopes, and also be cognizant of the presence of overhead power lines and buried utilities when designing a wick drain treatment program. With special modifications, battered and low headroom drains can be installed to help overcome site constraints.

A Cost Effective Ground Improvement Technique

With installation costs under 50¢ per linear foot for larger projects, the cost for wick drains can be less than 25¢ per square foot of improved ground. In the U.S., the technology is now widely accepted and proven to provide expedient, low-cost treatment of soft, compressible soils. ❍

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Embankments on Soft Ground? Don't Stress It

By Silas C. Nichols, P.E., M. ASCE

Figure 1. Massachusetts Central Artery/Tunnel embankment fill.

"Get in, get out, stay out" is a mantra that transportation officials have been pushing for several years. To reduce the amount of congestion on America's highways and to replace aging infrastructure, the philosophy is simple—build sustainable transportation facilities faster and more economically.

Some of the statistics reported by the Federal Highway Administration (FHWA) regarding congestion on the nation's highways are startling. Between 1982 and 2002, highway vehicle miles traveled increased 79 percent, while lane miles only increased 3 percent. In 2003, over 39,000 miles of highways in the United States had peak period congestion, and of these, over 6,800 miles were in rural areas.

To help alleviate this growing congestion problem, capacity on highways and major roads must be expanded, where appropriate, to better serve the traveling public. In many circumstances, however, roadway embankment widening or new alignments will require construction over soft or loose soils that are incapable of supporting increased loads.

Geotechnical construction on soft ground is a problem that has long challenged transportation engineers. Strategies have traditionally included ground improvement techniques for managing settlement and strength gain through staged construction, accelerating consolidation of soft clay layers, bypassing the soft soils by founding the embankment on more suitable soils, or reducing the load on the underlying soils.

Today, the demands to build faster, as well as better and more cost effectively, have pushed engineers to explore "out of the box" solutions. One of the solutions that the FHWA is deploying for accelerating construction of U.S. highway embankments on soft ground is the use of super-lightweight fills such as expanded polystyrene (EPS) geofoam.

Figure 2. Massachusetts Central Artery/Tunnel block placement.

What is Geofoam?

Geofoam is a generic name for any cellular material used for geotechnical applications. Block-molded, EPS is a plant-manufactured, lightweight, rigid foam plastic that has been used around the world as a super-lightweight fill material for more than 30 years. At a unit weight of 1-2 pounds per cubic foot (pcf), EPS geofoam—referred to as geofoam from here on—is up to 100 times less dense than most normal soils and significantly less dense than other fill alternatives.

As a lightweight fill in U.S. highway construction, popular applications for geofoam have included rapid embankment construction over soft ground, protection of underground structures, reduction of lateral load on walls and bridge abutments, and the remediation of slope or embankment failures. Additional geotechnical applications have included insulation in cold regions construction, levee construction, and non-structural site-grading.

Geofoam has been used successfully in highway projects all over the United States, including some very high profile projects such as the I-15 Reconstruction Project in Salt Lake City, UT; the Central Artery/Tunnel (Big Dig) Project in Boston, MA; and the I-95/Route 1 Interchange (Woodrow Wilson Bridge Replacement), in Alexandria, VA. In these instances, geofoam was selected as a lightweight fill to rapidly construct embankments over soft clays in order to meet tight construction schedules and eliminate the need for other time-consuming construction methods.

Figure 3. VA Route 1 over I-95 embankment fill.

Benefits to the Transportation Industry

Obviously, geofoam is only one of several lightweight fill options available to geotechnical engineers for reducing load on soft foundation soils. Materials such as flyash, blast furnace slag, boiler slag, tire shreds, wood fibers, expanded clay or shale, and foamed concretes have been, and will continue to be, successful lightweight fill alternatives in U.S. highway construction. The primary benefit of geofoam to transportation engineers, relative to other lightweight fills, is in the speed of installation. In schedule-driven or urban applications, the ability to construct embankments rapidly—without the need for staged construction or heavy construction equipment—is extremely attractive to transportation engineers. In addition, as a super-lightweight fill, geofoam has a unit weight several times less than the next-lightest fill alternatives commonly used in highway applications. Other benefits to the transportation community include:

- blocks can be placed in poor weather, which allows for quick repairs or construction without worry about the effects of Mother Nature;
- blocks are placed by hand and can be easily cut and trimmed either in the factory or on site to fit the geometry of the fill;
- geofoam exerts little-to-no lateral load, making it a good solution for fill behind retaining structures; and
- blocks are essentially inert, once in place. EPS will not react with anything naturally occurring in the ground.

Although the FHWA supports geofoam as an innovative and market-ready solution for U.S. highway construction, it is by no means a miracle material or the best solution for all lightweight fill needs. In fact, for most highway projects, engineers will find that the benefits of geofoam will not offset the cost effectiveness of other suitable lightweight fills. However, geofoam is an attractive super-lightweight fill alternative that should be considered in situations where it is both feasible and appropriate.

Some Obstacles to Widespread Use in Transportation

Despite the recent popularity of geofoam in roadway applications, continued acceptance and widespread deployment on U.S. highway projects requires that some significant obstacles and barriers be addressed. As a geotechnical solution for highway projects, State Departments of Transportation (DOTs) have encountered numerous issues in design and construction.

Table 1. Typical lightweight fills used in roadway embankments.

Lightweight Fill Type	Unit Weight (pcf)	Approx. Cost ($/c.y.)
Wood Fiber	35-60	9-15
Blast Furnace Slag	70-95	6-15
Fly Ash	70-90	11-16
Boiler Slag	65-110	2-3
Expanded Clay or Shale	35-65	30-42
Shredded Tires	35-55	15-23
Foamed Concrete	20-50	40-70
EPS Geofoam	1-2	100-140

Source: **FHWA-NHI-06-019**

Three major issues that have been recurring on recent DOT projects are (1) confusion and misunderstanding regarding the available material's standards, (2) high material costs, and (3) problems with quality control and quality assurance.

Currently, there are two material standards that are being specified for highway projects covering block-molded EPS for use in fill applications. In 2002, ASTM D 6817, *Standard Specification for Rigid Cellular Polystyrene Geofoam*, was approved as a material standard specification for rigid cellular polystyrene geofoam. The standard evolved from a method of practice document developed by the Geofoam Research Center at Syracuse University for a slope stabilization project in upstate New York. The research effort was jointly supported by the FHWA's New York Division and the American Plastics Council, Inc.

In 2004, the National Cooperative Highway Research Program (NCHRP) published Report 529, *Guideline and Recommended Standard for Geofoam Applications in Highway Embankments*, which summarized a comprehensive research project on the use of geofoam in roadway applications involving embankments and approach fills on soft ground. The document produced a guideline specification for the use of EPS geofoam in roadway applications that has been included in FHWA publications as a recommended design and construction standard.

Both the NCHRP guideline specification and the ASTM material standard have been beneficially applied to geofoam projects in roadway fill and other applications. The primary

Table 2. Material designations and properties comparison.

NCHRP 24-11 Material Designation	ASTM D6817 Material Designation	Min.Block Density—Test Sample (pcf)	NCHRP Elastic Limit Stress (psi)	ASTM Elastic Limit Stress (psi)
EPS 40	EPS 15	0.90	5.8	3.6
EPS 50	EPS 19	1.15	7.2	5.8
EPS 70	EPS 22	1.35	10.1	7.3
EPS 100	EPS 29	1.80	14.5	10.9

difference between the two material standards is the "unit weight to compressive strength" relationships for block designations. There is long-standing industrial acknowledgment that EPS unit weight could be reliably indexed to the elastic limit stress—measured as the compressive stress at 1% strain—of the material. However, there is currently disagreement within the industry as to what elastic limit stress can be practically achieved for a given block unit weight, and what that relationship means with respect to the performance of the blocks in a specific fill application.

Interpreting the performance requirements for geofoam in highway embankment applications has proven challenging for molders who have traditionally just targeted a minimum block unit weight in molding their product. Unlike most non-structural fill applications, highway embankment fills demand that all specific minimum performance requirements for the material be simultaneously satisfied—not just that the required minimum block unit weight is met. This issue has led many to believe that one standard is better or worse (ASTM sets lower performance levels at a given block unit weight), or that the standards should be adjusted so that the material properties are the same. Although alignment of the two standards to present the same information is preferred, it is clear that

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there is an immediate need to better educate stakeholders on the basis, benefits, and limitations of both standards for structural and non-structural fill applications.

Material costs have long been an issue with owners considering geofoam for highway projects. Not only is the cost of geofoam very high relative to other lightweight fill alternatives, but the bid prices that highway projects have been getting nationally are extremely variable and difficult to estimate. Blame can be placed in several areas, but the primary influences have been the raw material sources (polystyrene is an oil derivative), location of project relative to supplier, mold efficiency, and contractor/owner experience in bidding and constructing geofoam projects.

Finally, consistency in manufacturing and construction quality control and assurance has been identified as both a growth constraint in the molder community and an implementation barrier by owners. The dominant issues in this area pertain to the type and frequency of conformance testing, and whether it is reflective of the performance of the blocks in the field. There have also been some questions regarding block and construction tolerances and their effect on the final product.

Conclusion

As the FHWA and its transportation partners continue to look for ways to improve the nation's infrastructure, more emphasis will be placed on research and technology transfer efforts to mainstream ground improvement technologies for construction in soft ground into routine practice. In highway embankment applications, EPS geofoam has been a versatile and successful lightweight fill solution. The industry can expect that in addition to situations where any stress added to soft soil is unacceptable, super-lightweight fill solutions like block-molded geofoam will also find a place, particularly where projects are heavily schedule-driven. As everyone is aware, time is money, so get in, get out, and stay out. ❍

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Rebuilding the Route Interchange: Ground Improvement on the Woodrow Wilson Bridge Project

By John C. Volk, P.E., M.ASCE, and David P. Shiells, P.E., M.ASCE

Figure 1. Low density cementitous fill at west approach of Wilson Bridge abutment.

The Woodrow Wilson Bridge Reconstruction Project is a 12-year, $2.5 billion, 8-km-long project to replace the 1.6-km-long Woodrow Wilson Bridge over the Potomac River and to reconstruct four interchanges. This bridge is a critical link on the Interstate 95 corridor and a major commuter link between Northern Virginia and Maryland. The original six-lane bridge structure was constructed in the early 1960s and demolished in 2006. Designed to carry 75,000 vehicles a day, traffic across the bridge had grown to 200,000 vehicles per day by the late 1990's. Replacing it with a new 12-lane bridge requires reconstruction of four large interchanges, the VA Route 1 and Telegraph Road interchanges in Virginia, and the I-295 and MD Route 210 interchanges in Maryland, in order to accommodate new alignments and additional lanes.

Geotechnical Conditions

Increasing the number of lanes required widening embankments over relatively soft ground on both sides of the Potomac River. The Route 1 Interchange overlies very soft and highly compressible organic silts and clays, ranging in thickness from 3 m to 12 m. The organic silts and clays are highly plastic with organic contents typically in the range of 5 to 15 percent, and occasionally as high as 40 percent. A layer of fill 1-3 m thick typically overlies the soft soils, which are in turn underlain by a stratum of very dense sand and gravel, also 1-3 m thick. This sand and gravel layer is underlain to a significant depth by stiff-to-hard clay.Groundwater was generally observed at about 1 m below the ground surface.

The southern portion of the embankment widening was to be constructed over undisturbed ground adjacent to Cameron Run, a Potomac River tributary. As such, scour due to flood events was a major concern during design of the embankment in this area. The thick deposits of soft alluvial soils made the construction of 4–7 m-high highway embankments and retaining walls particularly challenging due to the potential for shear instability and excessive settlement.

Ground Improvement

The original construction of the highway embankments in the early 1960s utilized staged construction with sand drains to expedite the rate of consolidation and strength gain in the soft soils, combined with toe stability berms to increase shear stability and surcharges to reduce long-term settlements of the embankments.

The design team considered a number of ground improvement methods during the preliminary design stage, including wick drains (prefabricated vertical drains), toe stability berms, high-strength geotextiles, pile-supported embankments, stone columns, and deep soil mixing. Surcharging, staged construction, excavation and replacement, lightweight fill materials, and extending the bridge superstruc-

The embankments typically needed to be constructed in stages to allow the soft clay soils to consolidate and gain strength with time prior to subsequent loadings. The staged construction approach is limited, however, by the time required for the settlement of each stage of fill and by the requirement that adjacent structures or utilities be able to tolerate the vertical and lateral movements caused by large settlements of the embankments.

tures across the soft ground to minimize the extent of new embankment construction were also considered. The team quickly eliminated toe stability berms because of right-of-way and wetland restrictions, and also deemed excavation and replacement of the soft soils to be impractical due to the excavation depths required below the ground water table and the cost for disposal of the excavated materials.

In general, staged construction in conjunction with wick drains, high-strength geotextiles, and surcharges was deemed to be the least expensive ground improvement method for constructing the embankments over soft ground. The embankments typically needed to be constructed in stages to allow the soft clay soils to consolidate and gain strength with time prior to subsequent loadings. Wick drains increase the rate of consolidation of soft clays, while high-strength geotextiles serve as base reinforcement to increase the resistance to shear instability. Where practical, the embankments are often surcharged to overstress the soft clay soils and reduce the effects of secondary compression. However, the staged construction approach is limited by the time required for the settlement of each stage of fill. It is also limited by the requirement that adjacent structures or utilities be able to tolerate the vertical and lateral movements caused by large settlements of the embankments. Where feasible, the design team chose this ground improvement technology as the "method of choice" due to its proven track record, simplicity, and lower cost.

The primary uncertainty during design of the wick drains was the time required for the soft soils to consolidate. To refine their time estimate, a full-scale test embankment was constructed with triangular wick drain spacings of 1.2 m and 1.5 m. The results indicated that the time rate of consolidation was approximately 7-8 months per stage to achieve the end of primary consolidation using a 1.5 m triangular spacing of wick drains. Using the results of the test embankment, the design team was able to accurately estimate the required time for staged construction (number of stages and time for each stage).

The wick drain/high-strength geotextile/surcharge technology was applied to about 2 km of the new highway embankments. The embankments in the Route 1 Interchange were typically constructed in 2-3 stages, with each stage actually lasting 4-7 months. Surcharges were typically 2 m above final grade and settlements of 0.5 m to 0.8 m were measured during construction.

Lightweight fill materials, including geofoam, low-density cementitious fill, and expanded shale aggregate were used at selected locations to reduce stages of fill and to protect utilities from settlement. However, the lightweight fills were not utilized for the relatively low highway embankments adjacent to Cameron Run due to buoyancy and cost concerns. Approximately 23,000 m^3 of low-density cementitious fill (Figure 1) was placed on the western approach to the main bridge over the Potomac River and approximately 17,000 m3 of geofoam was placed at the north abutment of the Route 1 bridge over I-95.

The 1.5-km length of highway adjacent to Cameron Run was subject to 4-6 m of scour. This part of the roadway also traversed a number of pile-supported piers for Route 1 and other ramps, and these were judged unable to tolerate either the vertical and lateral deformations associated with the estimated 1-1.5 m settlements or the time associated with the staged construction technique. Thus, with lightweight fills having been previously eliminated due to buoyancy concerns, the design team turned toward deep mixing to strengthen the soft clays in order to support the highway embankment.

Deep mixing can be performed using two different methods: "wet" and "dry." The wet method is performed by mixing a cement grout with the *in-situ* soils by continuously injecting the grout through a large-diameter mixing auger (or augers) from the design depth up to the ground surface. The dry method is performed by pneumatically injecting a dry mixture of lime and cement under high pressure through a mixing paddle of specified diameter from the design depth to the ground surface.

The success of deep mixing is governed by several factors, including the amount of cement (or other binder), mixing speed, number of mixing blades, mixing duration, rate of penetration, rate of withdrawal, and shape and configuration of mixing blades.

To identify the mix design best suited for the site, a test embankment utilizing both wet and dry mixes was performed during the design phase. Initially, laboratory-mixed samples were tested in unconfined compression. The proposed design for the dry mix was 150 kg/m^3 of cement (no lime) with a target unconfined compressive strength of 550 kPa at 28 days. The proposed design for the wet mix was 300 kg/m^3 of residual cement with a target unconfined compressive strength of 1,380 kPa at 28 days.

The deep mix test embankment was constructed with single- and triple-auger 0.91 m-diameter wet mix elements

Figure 2. Deep soil mixing rig.

Figure 3. Pile-supported embankment pile caps.

and 0.81 m-diameter dry mix elements. Core samples were taken in the wet mix elements with triple-tube core barrel samples. The wet mix elements met the unconfined strength requirements of 1,380 kPa in 28 days. The dry mix elements met the strength requirements of 550 kPa for most of the column length except for a 1.5 m-thick zone. It is likely that the mixing energy was insufficient with the equipment used.

Based upon the results from the deep mix test embankment, the design team chose the wet mix method (Figure 2) for construction of the 1.5 km length of the I-95 embankment widening adjacent to Cameron Run. To improve lateral stability, a large portion of this alignment was designed with deep mixing buttresses (overlapping columns in a closed rectangular pattern) extending a distance of about 10 m from the toe of slope. The buttresses were generally designed using an area replacement ratio (the plan area of treated ground as a percentage of the total area) of 40 percent, compared to a 23 percent area replacement ratio utilized for settlement control on the interior of the embankment. Approximately 125,000 m of wet mix columns were installed to depths of 15 m to support embankments and mechanically stabilized earth (MSE) walls at the Route 1 Interchange. The performance specification for the wet mix was a target unconfined compressive strength of 1,100 kPa at 28 days.

The existing Route 1 bridge and ramp could not be demolished until late in the project when traffic had been shifted to the new ramps and bridges. The design team elected not to use deep mixing in the locations of the existing bridge structures due to the potential for conflicts with the pile foundations, the anticipated multiple mobilizations and a tight schedule. As an alternative, a piled embankment was designed and is presently being constructed. This design involves 0.3 m square precast concrete piles installed at 1.8 m centers, each having a 1.1 m square pile cap (Figure 3). A geotextile-reinforced crushed aggregate load transfer platform is placed above the caps to distribute the embankment loads.

Thick deposits of soft alluvial soils made the construction of highway embankments and retaining walls particularly challenging due to the potential for shear instability and excessive settlement.

Instrumentation

Extensive instrumentation has been installed on the embankments constructed over soft ground, including settlement platforms to measure vertical movements, inclinometers to measure lateral movements in the soft clay, magnetic extensometers to measure displacement with depth, piezometers to measure pore pressure, strain gages on the high-strength geotextiles, and pressure cells over the soil-cement columns. This instrumentation has been extremely helpful in adjusting the waiting periods between stages, adjusting stage heights of fill, and verifying the design.

Conclusions

The Woodrow Wilson Bridge Reconstruction Project has utilized a wide range of ground improvement technologies on the Virginia Route 1 Interchange. Soft soil, shallow groundwater, old foundations, utilities, and a tight work schedule,

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as well as both right-of-way and wetland restrictions, have all impacted the types of ground improvement used at the site. Wick drains, high-strength geotextiles, surcharging, staged construction, deep soil mixing, lightweight fill materials, and precast concrete piles have all been used at the site.

This project underlines the value of test embankments in reducing uncertainties during design and construction over soft ground. The design team used test embankments to determine the time required for staged construction, to identify the mix design best suited for deep soil mixing at the site, and to verify feasibility. The ground improvement technologies utilized were determined based upon considerations of technical feasibility, cost, schedule, and constructability evaluations. The design team also used the observational approach with extensive field instrumentation to adjust the original design to meet the schedule and save costs for the owner during construction.

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Karl Terzaghi's Legacy in Geotechnical Engineering

By Richard E. Goodman, M.ASCE

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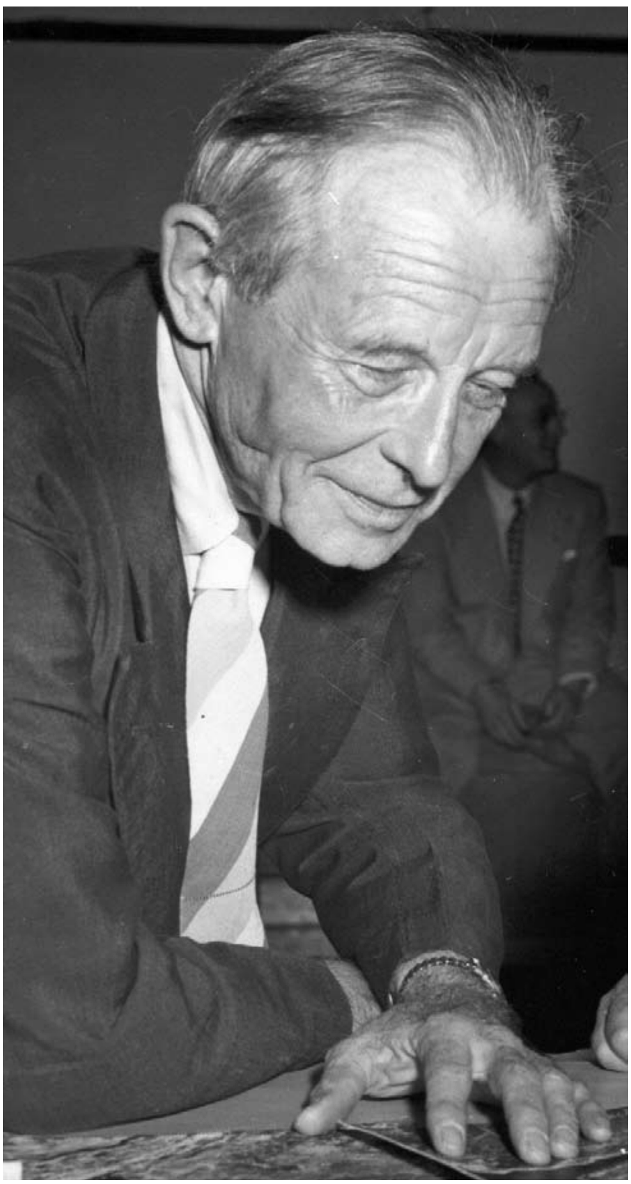

Figure 1. Karl Terzaghi

Karl Terzaghi (1883-1963) was the first to elaborate a comprehensive mechanics of soils with his publication of Erdbaumechanik in 1925. His recognition and formulation of the effective stress principle and its influence on settlement analysis, strength, permeability, and erosion of soils was his most prodigious contribution. But Terzaghi also pioneered a great range of methods and procedures for investigation, analysis, testing, instrumentation, and practice that defined much of the field we currently know as geotechnical engineering.

Among Terzaghi's publications, reports, and lectures, one finds seminal contributions across a wide terrain, including:

- classification methods for soils and rocks;
- capillary phenomena in soils;
- the theory and documentation of consolidation and settlement;
- piping and its prevention;
- design and construction of earth, rock, and concrete dams on all kinds of foundations;
- anchorage for suspension bridges in soils;
- field and laboratory measurement of pore pressures and soil properties;
- use of flow nets in two and three dimensions;
- design of drainage wells and tunnels;
- design to avoid scour of river and waterfront structures;
- earth pressure variations on walls and bulkheads;
- engineering in terrain underlain by permafrost;
- pile foundations;

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- soil improvement by compaction, pile-driving, grouting, and incorporation of geotextiles;

- soil and rock tunneling;

- engineering geology;

- sinkhole formation and collapse;

- regional subsidence due to oil-field operations; and

- landslides.

He was the great professor of geotechnical engineering of his day, with regular appointments first in Istanbul, then at MIT, Vienna, and Harvard, as well as courses of lectures in Berlin, Texas, and Illinois. Through his voluminous correspondence with engineers and scientists, his lifelong devotion to publishing both research findings and practical experiences, his numerous public lectures, and his authorship of clear and complete procedures in many engineering reports, Terzaghi disseminated advances in soils engineering that influenced the entire civil engineering world.

Ironically, although he was a great educator, Terzaghi grew to entertain a suspicion of formal education, which he thought had the capacity to obscure observation of new phenomena. He reserved his greatest admiration for "self-made men" who learned from their open eyes and minds.

Terzaghi's Personality and Interests

In reviewing this range of accomplishments and his domination of the field, it is interesting to examine Terzaghi's background and interests as well as his philosophy and methods of working. His upbringing and education combined Austrian rigor and military training and a passion for observation of natural science and the contemplative beauty of nature. His attractions ranged widely: construction, geology, mathematics, philosophy and ethics, architecture, flowers, swimming, conversation, travel, literature, music, art, people, and writing.

He was certainly a remarkable listener, as well as a reader and an observer. He was also an exceptionally faithful diarist and prolific correspondent, and through his correspondence he revealed a penchant for classifying almost everything in his experience: people, ideas, objects, and, of course, rocks and soils. Terzaghi could be a severe critic, especially of

Figure 1. Karl Terzaghi

those who tended to be blinded by their own theories, or worse, those utterly devoid of theories. He accused some of hiding inarticulately behind a pensive exterior.

Terzaghi's goals, which were set like sails to drive his life, changed dramatically at about age 43 (1926). As a younger man, he had striven to formulate a rational analytical or empirical methodology, properly embracing geological constraints, for designing works founded on soils (and, to a lesser extent, rocks). But as a mature man, having achieved his first target, he pursued the practice of engineering passionately to test and temper the emerging methods by physical realities.

In this he became increasingly concerned with the difficulty of knowing enough of a site's morphology and properties to determine a design solution before construction had started. This worry committed him ever further to the observation of soil and structural response throughout the construction period in order to inform a constant updating of the designs, transforming him into a proponent and practitioner (with coworker Ralph Peck) of "the observational method." Thus, despite Terzaghi's considerable achievement in advancing the theory of soil mechanics, he repeatedly counseled the profession to stay connected with the behavior of actual soil in engineering practice.

Terzaghi's Pragmatic Philosophy and Method

As his own method of accomplishment became formed, Karl Terzaghi expressed his personal beliefs about the practice of engineering to others. The key components included the following points:

- Take on only what one's own competence allows him or her to handle personally. Terzaghi had such confidence in his own core resources as to seek out the most challenging (some would say "adventurous") projects.

- Assume the worst configuration of properties and boundary conditions consistent with data from site investigations.

- Follow through on every angle and every subtask.

- Don't oversimplify the site model, its properties, or its response.

- Take responsibility as an engineer, even beyond the specifics of one's own specific assignment.

- Learn continuously from experience, personal and vicarious, and publish meaningful experiences for the betterment of the profession.

These items from Terzaghi's personal creed colored his attitude as an engineering consultant, the methods he adopted in working with others to solve engineering problems, and the way he wrote his own engineering reports. The following describes some key facets of his system.

1. He reported relevant case histories, from his own experience or about which he had learned either from conversations with engineers or reading, both of which he pursued diligently.

2. In the beginning, and throughout the course of a job, Terzaghi demanded a great deal of data and was usually persistent in obtaining most of the specifics he needed. He often questioned the results of prior soil investigations, sometimes rejecting their conclusions outright and beginning anew.

3. He generally tried to unravel a site's geological history, then used it to develop a list of questions that the investigations should attempt to address. He applied this history, and geological logic, to infer a foundation's geometric and material properties.

4. In investigating failures, he tried to obtain old records, photos, and eyewitness accounts and worked to identify and resolve inconsistencies among these data.

5. In writing his reports, he chose his words so as to make his thought

processes visible, being careful to expose the logic that led to certain simplifications and/or correlations with observations.

6. His calculations were tempered by judgments concerning imperfections in sampling and testing, and variability in the morphology and properties of different layers.

7. He tried to develop and explain simplified procedures orapparatus that the client could adopt to carry out the recommendations without undue inconvenience.

8. When criticizing previous work, he was courteous and careful to explain the nature of his disagreement, yet firm in his resolve.

9. He reviewed any specific design with a checklist of possible defects related to the interaction of geological and engineering factors and then meticulously examined each, point by point. He then computed or judged the capacity of the design to overcome the specific obstacles and, if warranted suggested refinements or reworkings in the design, which were accompanied by detailed sketches and drawings as well as pertinent case histories.

10. In completing a study, he tried to cover all the essential bases—engineering geology, geotechnical engineering, structural engineering, sometimes even hydraulics—so as not to leave the client hanging by overspecialization.

11. He used hydrologic measurements, from weirs to piezometers, together with analysis to compare the response of homogeneous materials with that of the actual site. Anomalies thus identified focused the investigations on critical locations.

12. He attached as much interest to the construction procedures as to the design itself, with full expectation that the design would be appropriately modified during construction as the true conditions were unveiled through observations and measurements.

13. He insisted on obtaining, and often helped recruit, highly qualified people to conduct the sensitive construction jobs, whether engineering measurement, excavation supervision, or tunnel foreman, and he argued for the employment of engineering geologists.

14. He invariably required measurements to be made on the site, with sufficient lead time to establish behavior before, during, and after construction. He warned of the implications of not making the required measurements.

15. He provided very definite and explicit recommendations in a way that was immediately useful to his clients. He stated his recommendations convincingly, some times almost threateningly, warning the reader in the sternest absolute terms that the difference between success and failure, safety and catastrophe, resided in absolute adherence to his word.

16. He was always conscious of the need to be efficient, if not optimal, in approach to excavation and design of any work within the constraints of assured safety. He often recommended staged design, awaiting the results of measurements, in order to avoid overdesign.

17. He was entirely committed to sticking with a project to its completion, even in the face of changes in management such that he no longer had a client to fund his involvement.

18. He was consistently aware of his ethical responsibility as an engineer and did not hesitate to indicate problems in a part of a job even if it lay outside his specific charge.

Karl Terzaghi was a remarkable man and an impassioned engineer. As he himself put it, "All the modest achievements which I have to my credit can be described by a simple formula… Guided by common sense and casual observations, I recognized weak points in traditional procedures and tried to make them less weak. Sometimes I failed, but usually I succeeded." ❍

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Filler

Design Considerations for Expansion of an Existing Landfill Over Extremely Compressible Soils

By R. David Espinoza, Ph.D., P.E., M.ASCE, Carlos A. Lazarte, Ph.D., P.E., M.ASCE and Michael F. Houlihan, P.E., M.ASCE

Figure 1. Cherry Island Landfill, Wilmington, DE.

The Cherry Island Landfill (CIL), located at the confluence of the Delaware and Christina Rivers near Wilmington, Delaware, was built over an area that was partly reclaimed from the Delaware River and was used for many years as a dredge disposal site for the U.S Army Corps of Engineers (USACE). As a result of the dredging practices, the subsurface characteristics at the CIL site consist of very soft and extremely compressible materials with undrained shear strengths varying from 200 pounds per square foot (psf) to 1000 psf and thickness ranging from 60 to 100 ft. The site, owned by the Delaware Solid Waste Authority (DSWA), has a total area of about 240 acres and has served for disposal of municipal solid waste (MSW) since 1985. Stability analyses indicate that the capacity of the landfill is limited unless further measures are taken to strengthen the subsoils. To increase the existing capacity of the CIL facility, DSWA solicited a design that would provide at least 22 years of disposal capacity beyond 2002.

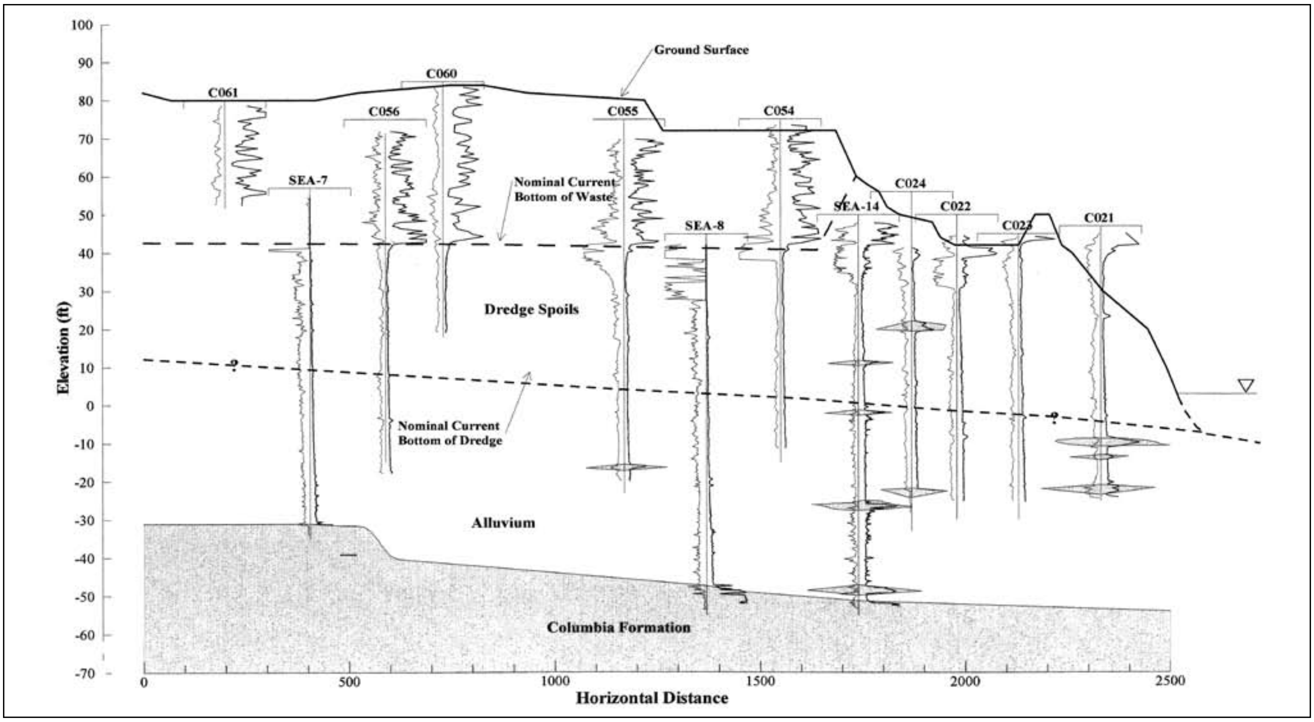

Figure 2. Cross-section through Cherry Island Landfill.

Subsurface Conditions

Dredge materials were placed by the USACE at the site from an elevation of approximately 0 ft-mean sea level (msl) to a maximum elevation of 40 ft-msl, resulting in the soil immediately below the CIL being comprised mostly of soft silts. Under the dredge layer lies an approximately 45-ft.-thick alluvium deposit with similar characteristics to the overlying soft dredge deposit. Under the alluvial deposit lies a 40-50-ft.-thick deposit of medium-to-coarse, medium-dense-to-dense sand (the Columbia Formation), followed by a consolidated clay deposit and weathered bedrock. The key stratigraphic features considered in the design of the vertical expansion of the CIL were: (1) the existing overlying MSW landfill; (2) the strength, compressibility, and thickness of the dredge/alluvium deposit; and (3) the presence of the highly permeable Columbia Formation underlying the soft alluvium and dredge deposits.

Because of the subsurface conditions, the current landfill layout consists of an approximately 8Horizontal:1Vertical

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(8H:1V) composite final cover grade and a maximum elevation of 172 ft.-msl. Because of the soft foundation conditions, additional airspace could not be obtained by increasing the landfill sideslopes without compromising the overall stability of the CIL. Therefore, special design considerations were required to allow for the vertical expansion of the facility.

Foundation Improvement Design

To better understand these design considerations, DSWA undertook a feasibility study to evaluate the most cost-effective foundation improvement alternative that would allow expansion of the CIL with an appropriate factor of safety against slope instability. The selected alternative consisted of installing prefabricated vertical drains (PVDs) to allow relatively rapid consolidation of the saturated dredge deposit and construction of an 8,000-ft.-long, 60-ft.-high mechanically stabilized earth (MSE) berm. The low shear strength and high compressibility characteristics of the soft dredge deposit and the underlying soft alluvium imposed a number of technical challenges on the design of the MSE wall. In addition, special design considerations were required to ensure that the existing landfill features such as the leachate transmission system (LTS), landfill gas (LFG) management system, and the stormwater management (SWM) system would continue to operate during and after the foundation improvements.

The perimeter MSE berm was designed to provide a counterweight at the toe of the landfill. PVDs were designed to quickly convey water from the dredge/alluvium deposits to the underlying sand deposit, thus allowing the dredge/alluvium to dissipate excess pore water pressures generated by the existing waste placement during berm construction and subsequent waste placement. The PVD spacing controls the rate of pore water pressure dissipation, which in turn determines the speed of MSE berm construction and subsequent waste placement. The horizontal extent of PVDs controls the global stability of the landfill. To design the PVD spacing and horizontal extent with high reliability, a theoretical pore pressure dissipation model was developed and a pilot test program was implemented to verify the model and evaluate the actual pore pressure dissipation rates for different PVD spacing. Based on the model and the pilot test, a 5 ft. PVD spacing was selected.

Because the MSE berm is a critical component of the stability of the CIL, a comprehensive slope stability analysis was undertaken. This included checking the temporary landfill configurations during filling, the final closed landfill configuration, and the staged construction of the MSE berm for every 10-ft. lift. The dredge/alluvium shear strength properties used in the analysis were based on their drainage characteristics during loading. Three distinct zones were identified: (1) the partially consolidated undrained area under the landfill zone; (2) the drained area in the PVD zone; and (3) the consolidated undrained area in the river zone. Based on these analyses, the size of the MSE berm (i.e., height and width) and the area with PVDs were calculated. At some locations, to allow pore pressure generated due to shear stresses, the PVD extended 100 ft. beyond the toe of the MSE berm. Based on the results of the stability analyses, the MSE berm was designed to have a maximum slope of 1H:12V and a maximum height of 60 ft., and the width of the PVD area was calculated to vary from 200 to 275 ft.. The MSE reinforcement consisted of high-strength (i.e., 50,000 lb/ft) geotextile and 5,000 lb/ft geogrid.

Because of the soft foundation conditions, the MSE berm will be constructed in stages. The results of the design and pilot test indicate that a 10-ft. lift can be safely placed approximately every three months. The construction of the MSE berm is monitored along 17 sections. The data from the proposed monitoring instruments (i.e., piezometers, inclinometers, settlement plates, and survey monuments) at each monitoring section is recorded and evaluated as frequently as daily during construction to provide up-to-date information on the stability of the MSE berm. Although large settlements of the MSE berm are expected (i.e., approximately 14 ft.), the structural flexibility of the MSE berm and its facing will allow these settlements to take place without compromising the integrity of the MSE wall. However, special design considerations are required for rigid structures that will go through the MSE berm, such as the SMW culverts and LTS pipes.

Stormwater Runoff

The CIL stormwater management system will transmit runoff from the landfill cover to various discharge points into the Delaware and Christina Rivers. The MSE berm design introduced three design challenges for the stormwater management system. The first challenge was how to effectively transmit stormwater runoff from the crest to the base of the MSE berm without compromising the stability of the berm. Second, how to counteract the effects of the differential settlement predicted between the face of the berm and the stormwater discharge locations. And third, how to route runoff past existing wetlands located along the northern side of the landfill. These three challenges

Figure 3. Stormwater managment outlet through MSE wall at Cherry Island Landfill.

were overcome through an innovative stormwater design.

The SWM design consists of discharging the surface runoff at multiple discharge points. A discharge point consists of a vertical drop structure from the top to the base of the MSE berm with a horizontal culvert through the MSE berm. Because differential settlements through the horizontal culvert were anticipated to be significant, specific soil-structure interaction analysis using settlements along the axis of the outlet culvert were conducted. These settlements were used for analysis of reinforced concrete pipe joint deflection and the corresponding reinforced concrete cradle.

Because the proposed MSE berm will be built around the perimeter of the existing landfill and over existing collection manholes, the existing LTS will be buried by the MSE berm. In order to continue collecting leachate, the existing manholes would have to be either extended vertically, connected laterally to a series of manholes located outside the MSE berm, or connected laterally to a series of manholes located within the MSE berm. After considering the advantages and limitations of each alternative, the third alternative (Figure 3) was selected. This option consists of connecting the existing manholes to new manholes located on the MSE berm. To reduce the influence of the large expected settlements, the new manholes will be connected to the existing manholes after construction of the MSE berm by means of directional drilling techniques. The main advantage of this alternative is that both the existing and the proposed manholes will settle at the same time, thus reducing the effect of differential settlement.

Summary

The foundation improvements at the CIL started in September 2006. Currently, approximately 6 million linear feet of PVD have been installed and the first two 10-ft. lifts have been placed around the entire facility. Construction of the MSE berm is expected to conclude in the spring of 2010. ❍

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An Approach to Characterizing Overland, Soft Soil Sites

By Aaron L. Zdinak, P.E., Richard M. Simon, P.E., Ph.D., Jesse N. Darden, P.E., and Joseph A. Clarke, P.E.

Deep, soft cohesive soil deposits are a frequent challenge for the design of transportation and flood control projects. In the Coastal Plain of the mid-Atlantic United States, projects are often located near water where young alluvial and marine deposits yield thickly bedded, normally consolidated, cohesive soils that often have measurable organic content. These cohesive soils are commonly interbedded with sands and non-plastic silts of varying relative density/consistency. As a result, measurement of shear strength and compressibility of soft cohesive soils is a primary challenge associated with projects in these locales.

Despite the complex subsurface geologic conditions at these sites, many subsurface characterization programs are developed by focusing on the collection of new data utilizing only conventional Standard Penetration Test (SPT) borings and basic laboratory tests. This approach, however, is inadequate for complex soft soil sites where a more robust approach is necessary. Experience suggests that an integrated approach focused on critical geotechnical design issues, historic geotechnical and performance data, and the acquisition of new geotechnical data (using a variety of methods in concert) is well suited to support projects founded on these challenging sites.

Critical Geotechnical Design Issues

Understanding the critical geotechnical design issues of a particular project helps focus the efforts of a subsurface characterization program. By identifying the design issues at the beginning of a characterization program, the types of explorations and tests to be conducted can be identified and evaluated specifically for application to the project.

For example, if large magnitudes of settlement have no impact on the proposed construction, there is little value in developing a subsurface exploration program targeting collection of samples for consolidation testing. Likewise, if stability of embankments is the critical design challenge, collection of disturbed samples for index testing will not meet the project needs. By understanding (and documenting) the design issues impacting a project, the selection of applicable exploration techniques and supporting laboratory tests becomes logical and efficient.

Existing Historic Data and Performance

A geotechnical data management system is essential for the successful characterization of complex subsurface conditions, allows efficient access to historical and new exploration data, and saves time and money. Geotechnical software programs are commonly used throughout the geotechnical profession to input the various types of geotechnical data. For many programs, the resulting relational database is fully customizable with respect to presenting exploration records and geotechnical laboratory testing results.

Virgin exploration programs and large projects in complex geologic settings are often exclusive of one another. Identifying previous explorations completed at a soft soil site can often facilitate development of better-defined and focused supplemental sampling programs, particularly if the data are already in database format (which can be imported into geotechnical software). If not already in database format, it is often useful to enter basic stratigraphic and laboratory test information into the software prior to planning the exploration event.

Once the type, quality, and distribution of the existing data are determined, they can be plotted in a number of useful manners to illustrate where data gaps may exist. The use of symbols and colors helps visualize specific pieces of data (e.g., exploration locations yielding high quality, reliable data may be represented with a green target, poor quality locations with a red target), allowing quicker determination of where additional data collection may be required. Viewing of this type of spatial data permits efficient layout of a new/supplemental exploration program.

Another important element of the characterization process is to take full advantage of existing performance information. If an existing facility occupies the site, recognizing past performance issues will allow better targeting of the required geotechnical information. For instance, if embankments adjacent to a roadway widening project are exhibiting signs of frequent slope instability, a properly-focused subsurface exploration program should target collection of data directly applicable to evaluating and designing for embankment stability. Utilizing the performance data of the existing or surrounding facilities near the project site often yields valuable information with respect to which long-term performance issues represent critical design issues warranting further exploration.

Collection of New or Additional Geotechnical Data

Once new or additional exploration locations on the project site are identified, applicable exploration techniques can be selected. In the past 10 years, exploration techniques including SPT borings; thin-wall, fixed piston tube sampling (3-inch- and 5-inch- diameter); electric piezocone penetrometer with pore pressure measurements (CPTu) soundings; flat dilatometer (DMT) soundings; and field vane shear testing (FVS) have been successfully used to collect subsurface information at soft soil sites.

To complement field investigations, a full suite of laboratory tests have also been used successfully. Laboratory tests include:

- index property determination (grain-size distribution, Atterberg limits, moisture content, etc.) for general classification purposes and to correlate to various geotechnical design parameters associated with long- and short-term shear strength parameters and compression/consolidation behavior;
- unconsolidated, undrained (UU) triaxial compression tests for determination of undrained shear strength;
- isotropically consolidated, undrained (ICU) triaxial compression tests for determination of undrained and drained shear strengths; and
- step-loaded and constant-rate-of-strain one-dimensional consolidation tests for the determination of compression and consolidation parameters.

Integrating the field investigations with a complementary laboratory test program leads to a more accurate model of subsurface conditions, which in turn results in more efficient designs following the characterization process.

Limitations of Exploration Methods

Every *in situ* and laboratory method has limitations which must be considered when selecting particular techniques. Although each test has a specific set of limitations, using these methods interactively allows one method to complement the shortcomings of another.

SPT and Direct Push Samples. SPT and direct push samplers yield grossly disturbed samples that are suitable only for visual/manual and laboratory index testing, and the SPT

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blow counts are only a rough indicator of soil strength. The methods are economical, readily obtainable, and provide a tangible sample to evaluate local soil type variability.

Thin-wall Tube Samples. Thin-wall tube samples produce a less-disturbed, but not undisturbed, sample of cohesive soil. The samples are time-consuming and more costly to obtain, but the resulting specimens are often suitable for laboratory shear strength and compressibility testing that can yield engineering properties representative of the soil *in situ*. Tube sampling is highly dependent on driller skill and experience, and the tube samples must be shipped carefully to avoid vibration and jarring to avoid excessive soil disturbance in the tube.

CPTu Test Soundings. CPT_u test soundings are economical to perform; they provide a nearly continuous log of the soil profile including correlation to soil classification, a measure of permeability, shear strength, and an economical method to measure pore pressure at various depths through the profile. The CPT_u is one of the best methods to assess vertical and lateral soil variability. Limitations of the CPT_u are that the undrained shear strength must be derived from the CPT_u tip and sleeve resistance by correlation to other strength measures and must be calibrated locally to yield design parameters.

DMT Test Soundings. DMT test soundings require a stabilized drill hole through dense granular or very-stiff–to–hard cohesive soils. Gravelly soils may rip the membrane. The method imparts a horizontal compression stress on the soil that might not correspond to the state of stress leading to failure in the field.

Field Vane Shear Tests. Field vane shear (FVS) tests require a stabilized drill hole through granular or stiff soils but can be advanced vertically through soft, cohesive soils. FVS test results can be approximately correlated to *in situ* shear strength based on published data related to soil plasticity from published studies. But anisotropy, soil structure, stress history, and other types of site-specific factors may influence the accuracy of FVS tests for strength measurements. The state of stress in the FVS test is not well-defined. The shear surface in a FVS test is vertical, whereas the larger portion of the shear surface in the field is typically horizontal.

Index Property Correlation. Correlating shear strength and compressibility parameters from index properties using

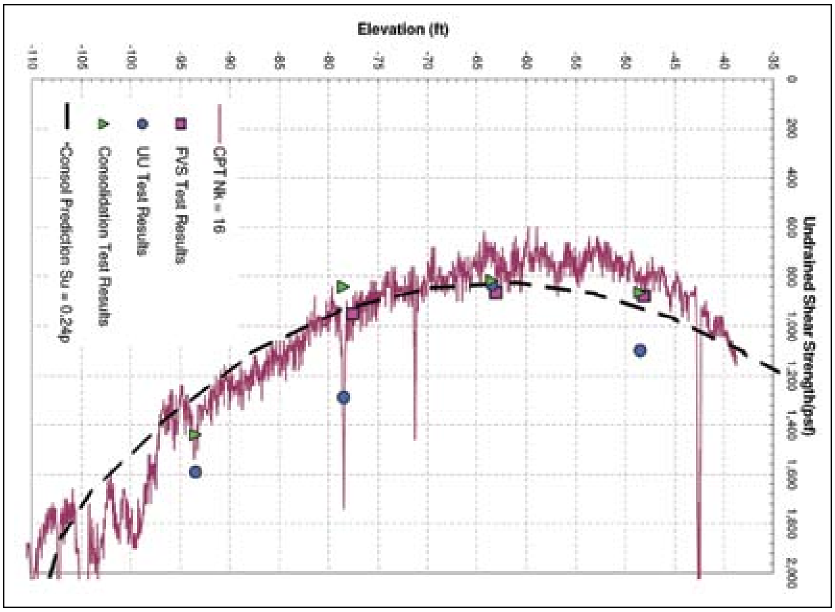

Figure 1. Summary of shear strength profile.

general, industry-wide correlations may result in overly conservative or aggressive results. Index property correlation should be based on specific site correlation to the results of shear strength and compressibility testing. They are suitable for determining if other test results fall within general data trends.

UU Tests. UU tests are economical but exceptionally sensitive to sample disturbance. Sample disturbance tends to reduce the measured shear strengths; however, experience indicates that by shearing the samples in the laboratory at higher strain rates than occur under field loading, the effects of limited sample disturbance may be offset. Differences in stress orientation, strain rate to failure, and clay anisotropy can raise or lower measured UU strength in the laboratory in relation to *in situ* strength.

ICU Tests. ICU tests will often overestimate soft soil strength, depending on the pre-shear consolidation pressure, due to reduction of void ratio from the as-sampled state. They are most useful to determine normalized soil properties by consolidating to a desired confining pressure and overconsolidation ratio higher than the maximum past pressure measured by careful laboratory consolidation tests. Interpretation of total stress strength parameters from ICU tests must not be based on the total stress circle representation offset from the effective stress failure circles by the test specific backpressure.

One-Dimensional Consolidation Tests. One-dimensional consolidation tests are susceptible to disturbance and require engineering judgment in their interpretation. The small sample volume is greatly influenced by heterogeneity with a specimen, and may not accurately reflect large scale impacts of existing in situ conditions, such as thin sand layers or three-dimensional drainage.

Graphical Summaries of Data to Support Design

Once data are collected and available, the designer must be able to comprehend data trends and the entirety of the data set. Clear, concise graphics are one of the best ways to present data for future integration into design efforts. A goal of all graphical presentations should be clarity and completeness. Figure 1 illustrates an example of combining data from several sources to produce a composite graphic.

The plot illustrated in Figure 1 shows the variation of undrained shear strength versus elevation. Within the plot, data from two field exploration methods (CPT_u and FVS), two laboratory testing techniques (UU triaxial and step-loaded consolidation testing with $s_u/p'_o = 0.24$), and a computer model trend (based on $s_u/p'_o = 0.24$) are presented. The calibration process can be streamlined by viewing multiple test results and modeling efforts on a single plot. Deviations in the data trends become more evident when the results are plotted together.

Summary

Experience characterizing overland, soft soil sites for large engineering projects indicates that a robust approach is essential to develop soil design parameters sufficiently reliable to permit economical design. Because of the vast amount of data generated during explorations for these challenging sites, all geotechnical data (exploration and laboratory test results) should be managed in an electronic database. Graphical representation of data in a clear, concise manner greatly improves the designer's ability to evaluate data trends and quality, and compare it directly to the results obtained by independent exploration methods. ❍

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GeoCurmudgeon

By John P. Bachner

It took a week to count the votes. And another week to count them again, because just one vote separated the loser from the winner: the Little Blue Engineer.

"Can you do your very best to preserve and protect the public's health, safety, and welfare?" the judge asked the Little Blue Engineer at the swearing-in.

"I think I can," said the Little Blue Engineer. And to do just that, he spoke to the Village Council. "My friends," he said, "we need to check our infrastructure. We need to know what needs to be fixed. We need an engineering firm to rely on."

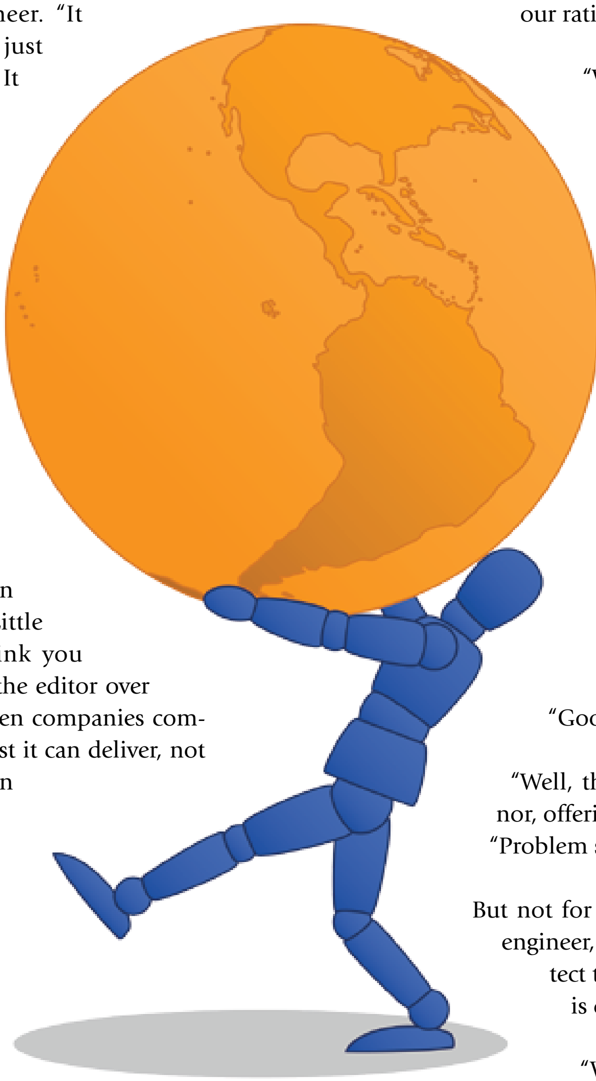
"We agree," said the Village Council. "Put out a call for bids."

"No," said the Little Blue Engineer. "It makes no sense to select a firm just because it gives us a cheap price. It will have to give us cheap service, too, and that's something we really can't afford. I know how much a good firm will charge for a good service. And we all know that the best quality delivers the best value. Let's select a firm based on its qualifications, as long as it asks for a reasonable fee."

And the Village Council agreed.

"MAYOR LETS NO-BID CONTRACT," was the headline in the Tinytown Gazette. And the Little Blue Engineer was upset. "I think you may not understand," he said to the editor over lunch. And he explained that, when companies compete on quality, each offers the best it can deliver, not the least it can live with. "And when we select the services together, we'll get exactly what we want," said the Little Blue Engineer. "No frills. Just excellence, and all for a reasonable price."

"I get it," said the editor. "But can you explain it to the people?"



"I think I can," said the Little Blue Engineer. "But only if you help."

And the editor did, in an editorial she wrote called, "Quality Just Makes Sense…and Saves Dollars."

But then came the bad news. "The Tinytown Bridge is in terrible shape," said the engineering firm Tinytown retained. "It's been neglected for years. You need a new one. Fast." So the Little Blue Engineer called on the governor. "Governor," he said, "the Tinytown Bridge is almost ready to collapse. We need help."

The governor turned to his state director of transportation. "How bad is it?" the governor asked. "Well," said the state director of transportation, "According to our rating system, it's SSDRC."

"What does that mean?" asked the governor.

"Seriously structurally deficient and ready to collapse."

"And what do you propose doing about that?" asked the governor.

"Change the rating system," said the state director of transportation. "We don't want people to be alarmed. So what used to be SSDRC will now be GBNSP."

"And what does that mean?" asked the governor.

"Good but needs some paint."

"Well, there you have it," said the governor, offering the Little Blue Engineer a cigar. "Problem solved."

But not for the Little Blue Engineer. "I'm an engineer," he said. "I took an oath to protect the public's safety, and that bridge is dangerous."

"Well, you can't make us spend

money we don't have," said the governor, puffing on his cigar. "I think I can," said the Little Blue Engineer, and back he went to Tinytown, and made a lot of calls.

And guess what: Two weeks later, when the governor looked out his window to see what all the shouting was about, there were 200 engineers parading around the governor's mansion, holding signs. "Safe Bridges, Not Safe Words," the signs said, and people were surprised. "Engineers never rock the boat," they said. "This must be serious." And you know what? The Little Blue Engineer was on television all over the state, telling people the truth: "The governor doesn't want people to be alarmed because the governor doesn't want people to know what a bad job the government's been doing. People should be alarmed. Maybe then they'd demand better infrastructure. And not just better bridges. Better roads, too. And better water and sewer systems."

Well, as you might have guessed, Tinytown got its new bridge, designed by an engineering firm selected for its integrity, experience, and ingenuity. Which is why the new bridge won so many national awards.

"Do you think you could tell the Tinytown story on national TV?" a television producer asked.

"I think I can," said the Little Blue Engineer. And he did, letting people know that "the quality of design is so good, our bridge was actually less expensive to build, and will be less expensive to maintain. And that will give us some extra money to help us improve our roads, and make our water and sewer systems safer, too. That makes Tinytown a better place to live, and that helps us grow. With more growth we have more revenue, and that helps us improve our schools and public services. We're even able to start design on a new home for the

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Geo-Institute News

GeoCongress 2008
Annual Congress of the Geo-Institute of ASCE
March 9-12, 2008
New Orleans, LA
www.geocongress.org

On Site and Daily Registration is Available.

Limited time? Join us just for the day. Review the online program and then pick your day. The Congress features discussions on current trends on the role of geoengineers and geoscientists in protecting and preserving our environment and will highlight the expansive and interdisciplinary nature of geoenvironmental issues. This G-I annual Congress will have numerous activities, including oral and poster presentations of technical papers, panel discussions and debates, a student paper competition, hardware/software and equipment demonstrations, exhibits, and field trips. There will be Short Courses, networking events, a multi-faceted student program, and a post-conference volunteer work day in New Orleans, as well as a tour of New Orleans.

Geo-Strata Magazine Now Online

Geo-Strata magazine is now available online. ASCE/G-I and G-I-only members can now access issues from 2005 through today via the G-I web site at www.geoinstitute.org. This is in addition to the hard-copy magazine that members receive. Previous issues will be added in the future. So, grab your ASCE/G-I member number and log onto the G-I's new "Members Only" portion of the G-I web site from the G-I homepage at: *www.geoinstitute.org*. Just click on "Members Only."

Shrink-Swell Soils Short Course
March 13, 2008
8:30 a.m.-5 p.m.
Marina Village Conference Center
San Diego, CA
http://content.geoinstitute.org/events/events.html

Dr. Jean-Louis Briaud, G-I vice-president, Texas A&M professor, and holder of the Buchanan Chair, is the renowned instructor for this special full-day G-I Short Course hosted by **the** ASCE San Diego Section Geotechnical Group.

Geotechnical Earthquake Engineering and Soil Dynamics IV (GEESD IV) Conference
May 18-22, 2008
Sacramento Convention Center and Sheraton Grand Sacramento
Sacramento, CA
www.geesd.org

Exhibitors. Reach a Unique Audience.
http://content.asce.org/conferences/geesd08/exhibits.html

Join us at GEESD IV which will bring together the broad community of geo-professionals working on earthquake engineering and soil dynamics problems. It will be a comprehensive decennial examination of our technical disciplines. The coverage will be diverse, including case histories and practice-oriented papers, recent research findings, innovative technologies, and the emerging arts across many of our disciplines. Professional engineers, researchers, specialty contractors, regulators, educators, and students will interact across a broad range of technical sessions, tutorials, short courses, discussions, and equipment demonstrations.

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Please become involved in the leadership of the Geo-Institute. The G-I's Nominations and Elections Committee is soliciting nominations for one seat on the Board of Governors. Each nominee must be a member in good standing of the G-I for at least one year prior to the election, and must be willing to serve on the Board for three years beginning in October 2008. Candidates should:

- have demonstrated leadership talent in the G-I or another professional organization like the G-I;
- have significant past involvement in G-I activities (e.g., been an active committee or subcommittee chair); and
- contribute to the G-I's goal of diversity (in career, practice areas, geography, gender, and ethnicity).

Nominations must be received by March 28, 2008, to news of upcoming events, calls for papers and abstracts, and news from the G-I, G-I chapters, local geotechnical groups, and ASCE. Subscribe at *www.geoinstitute.org.*

Have You Answered the Question-of-the-Month?

The Geo-Institute of ASCE wants members' opinions on a variety of subject matters to better assess your needs and priorities. Take a minute or two and log-in to the *Question-of-the-Month* from the Members Only page of the G-I web site.

11th Multidisciplinary Conference on Sinkholes and the Engineering Impacts of Karst™
September 22-26, 2008
Tallahassee, FL
www.asce.org/conferences/karst2008

This conference is the single most important international professional meeting concentrating on the practical application of karst science. You will participate in 3 days of plenary and technical sessions, enjoy social events, choose among 4 Short Courses, and can take an outstanding 8-hour field trip.

How will you benefit? You can:

- receive practical information to expand your knowledge;
- have the chance to decipher case studies;
- study practical applications relevant to your work;
- enjoy lots of opportunities to net work; and
- receive Professional Development Hours (PDHs).

be considered. Send nomination letters and the nominee's resume to the NEC, Geo-Institute of ASCE, 1801 Alexander Bell Drive, Reston, VA 20191; Fax 703-295-6351; E-mail ltighe@asce.org. Visit *www.geoinstitute.org* for detailed information.

Introducing *Geo-On-The-Go*

Geo-on-the-Go is the new G-I news feed. Subscribe today to be notified when the G-I website is updated with

Become a Sponsor
Contact Adele Dicken, at *adicken@asce.org*, or 703.295.6028

Become an Exhibitor
Contact Jeff Sandersen at *jsandersen@asce.org*, or 703.295.6107

IFCEE '09
March 15-19, 2009
Buena Vista Palace Resort
Orlando, FL
www.ifcee09.org/i4a/pages/index.cfm?pageid=1

Call For Abstracts and Proposals

This call includes abstracts, session and/or debate proposals, panel discussions, short courses, and hardware/software demonstration proposals. For information: *www.ifcee09.org/i4a/pages/index.cfm?pageid=3278*

The Geo-Institute, the International Association of Foundation Drilling (ADSC), and the Pile Driving Contractors Association (PDCA) are joining together to present a spectacular and comprehensive congress dedicated to the latest technological advances in the foundation and earth retention industries. Building on the highly successful 2004 Geo-Support Conference and Equipment Exposition in Orlando, FL, the IFCEE '09 will provide the most current technical information by bringing together industry leading organizations. This event will provide an opportunity for American and worldwide engineers, foundation contractors, equipment manufacturers, suppliers of tools and services, and researchers within the industry to interact. The extensive outdoor equipment exposition and indoor exhibit displays will provide an opportunity to examine the various machines and tools used in foundation construction.

The expanded technical program of IFCEE '09 will include:

- foundation design for extreme events;
- construction economic outlook;
- reliability issues;
- quality control and quality assurance;
- monitoring and testing of foundations;
- earth retention;
- ground modification;
- case histories; and
- rebuilding infrastructure…. plus, more.

For information, contact: Mohamad H. Hussein, conference chairman at: *MHGRL@pile.com*.

OPALs to Honor G-I Member

The OPALs, ASCE's annual black-tie event held in the Washington, D.C. area, brings together the most recognizable names in civil engineering. On April 30, 2008, ASCE will honor the remarkable achievements of civil engineers over the past year by awarding five lifetime achievement awards, the Outstanding Civil Engineering Achievement (OCEA) for the year's most outstanding project, the Henry L. Michel Award for Industry Advancement of Research, and the Charles Pankow Award for Innovation. This year, the Geo-Institute is proud to honor one of its own members, **Clyde N. Baker, Jr.,** P.E., Hon.M.ASCE, as the 2008 OPAL winner in the Design category.

Over the past 50 years, Mr. Baker has served as the geotechnical engineer on the major portion of high rise construction built in Chicago. He has also served as geotechnical engineer or consultant on seven of the 16 tallest buildings in the world, including the three tallest in Chicago – Sears, Hancock, and Amoco—and the current three tallest buildings in the world—the Petronas Towers in Kuala Lumpur, Malaysia and 101 Financial Center in Taipei, Taiwan.

Mr. Baker continues to share his knowledge and experience with his peers through numerous conference and university lectures, technical articles, papers, and publications. He is the recipient of the Deep Foundation Institute's Distinguished Service Award, the ADSC Outstanding Service Award, ASCE's Thomas A. Middlebrooks and Martin S. Kapp awards, and of three Meritorious Publication awards from Structural Engineers Association of Illinois (SEAOI), including the "History of Chicago Building Foundations 1948 to 1998." He is also the author of "The Drilled Shaft Inspectors' Manual," sponsored jointly by the Deep Foundation Institute and the International Association of Foundation Drilling.

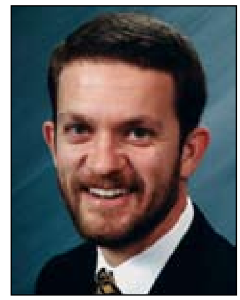
Mr. Baker is past president of the Structural Engineers Association of Illinois and the Chicago Chapter of the Illinois Society of Professional Engineers. He served as chairman of the Geotechnical Engineering Division of ASCE, is a past editor of the Geotechnical Engineering Journal, and is a past chairman of the American Concrete Institute Committee 336 on Footings, Mats, and Drilled Piers. He also is a member of the National Academy of Engineering and was the recipient of the G-I's Ralph B. Peck Award in 2000.

Mr. Baker is a past chairman of **STS Consultants, Ltd.**, a 550-person consulting engineering firm headquartered in Vernon Hills, IL and currently serves as senior principal engineer and senior vice president.

Read the Final G-I Trends Report

Download the Groundbreaking Final Report and review G-I Actions from the Geo-Institute's December 2007 Workshop on Trends Affecting the Geo-Community. at *http://content.geoinstitute.org/files/pdf/FinalTrendsWorkshopReport.pdf*

Members in the News


Daniel R. Boles

Daniel R. Boles, P.E., manager of the Tri-Cities branch of **S&ME, Inc.**, was named 2007-2008 Executive of the Year by the Tri-Cities Chapter of the International Association of Administrative Professionals. Boles has managed the branch since 2005, and previously managed the firm's Asheville, NC branch. He joined S&ME in 1999 with seven years of previous experience. Boles was selected for his leadership ability, human relations skills, professional achievements, and participation in various civic and professional organizations. He will be a speaker at the chapter's 2008-2009 Executive of the Year event next year (the 50th anniversary of the award program). He is the third S&ME manager receiving this honor in the last 15 years.

Mike Cowell, P.E., president of GeoStructures, announced that the company's revenue increased 57 percent last year as compared to the level in 2006 because the cost-saving and lower-risk benefits of its site-improvement products are becoming more important to builders and building owners. Leading the growth was the company's signature Geopier® product, followed by Impact Piers® and Rapid Impact Compaction (RIC), all of which reinforce or stiffen the soil to increase bearing capacity and control settlement for low- to mid-rise structures. These construction methods are an alternative to the traditional support systems of pilings and drilled shafts, and the lengthy process of over-excavating sites with weak soils and replacing them with controlled, compacted select fill.

Chester J. Drash

Chester J. Drash, P.E., a seniorprincipal with Terracon Consultants, Inc. and a member of the G-I's Codes & Standards Council, was elected to the Terracon Board of Directors. Mr. Drash also serves as a senior vice president and division manager overseeing seven of Terracon's Texas offices. He has over 30 years of experience in the engineering consulting industry with expertise in design and construction of structure foundations soft soils and expansive clay soils, as well as in value engineering studies and forensic engineering studies on structure foundations. He is also an active member in numerous professional and civic organizations including the Texas Society of Professional Engineers, San Antonio Economic Development Council, and Greater San Antonio Chamber of Commerce.

Dr. Conrad Felice, Ph.D., P.E., P.Eng., president/CEO of Lachel Felice & Associates, was appointed chairman of the Modeling Techniques in Geomechanics Committee by the Transportation Research Board (TRB) Executive Committee. The committee works together to develop research problem statements in their area of interest, and review and recommend papers for publication as well as for presentation at TRB Annual meeting. Dr. Felice has over 28 years of experience in delivering project and program management; construction engineering analysis and design; and construction claim avoidance and resolution services on engineering projects including tunnels, pipeline crossings, forensic analysis, earthquake engineering, and seismic risk evaluations. He has extensive experience on projects evaluating the dynamic response of earth structures and analyzing site liquefaction potential and ground response under earthquake and explosive loads.

Jesús Emilio Gómez, Ph.D., P.E., was recently promoted to principal of **Schnabel Engineering, Inc.,** Glen Allen, VA. Dr. Gómez has over 22 years of design and construction experience in geotechnical projects in the U.S., South America, Europe, and the Caribbean, and currently leads the Geostructural Group for Schnabel. Dr. Gómez has provided design and supervision of geotechnical specialty work, such as micropile design, grouting, temporary and permanent shoring, and deep foundations of many types and degrees of difficulty. His projects have included stability analysis and design of roadway embankments and rock slopes; earth retaining structures including multi-anchored systems and tied-back diaphragm walls; deep foundations for highway bridges and high-rise construction; and underpinning of existing structures. In addition, Dr. Gómez has experience in soil-improvement techniques for mitigation of liquefaction hazards and settlement reduction. He also received the 2004 Shamsher Prakash award for Excellence in Practice.

Jesús Emilio Gómez

Anderson
(third page horiz.)


Allen Minks

Allen G. Minks, P.E joined Geopier Foundation Company, Inc. as chief engineer-Development in the St. Louis, MO office. Minks has more than 24 years experience in the engineering field and holds bachelors and masters of science degrees in geotechnical engineering from the University of Missouri at Rolla. His most recent position was as chief engineer with SCI Engineering in St. Charles, MO. He is actively involved with ASCE and currently serves as the St. Louis Section ASCE president. Contact him at: *allenminks@geopier.com*.

Shana Opdyke, P.E., a sales engineer with design-build contractor GeoStructures, achieved accreditation for Leadership in Energy and Environmental Design (LEED), part of the Green Building Rating System™ that encourages adoption of sustainable building and development practices. Opdyke joins an influential group of engineers, architects, general contractors, and others in the real estate and construction industries who have demonstrated a thorough understanding of green building design practices and principles of the LEED rating system. They have experience working with multiple design disciplines, knowledge of LEED life cycle costs and benefits, and expertise in the documentation process for LEED-certified projects.

"Having been involved with the construction of hundreds of buildings supported on Rammed Aggregate Piers™, our 10-plus year history in providing LEED-qualified Geopier elements has resulted in savings to owners and benefits to the environment," says **Michael Cowell, P.E.,** president of GeoStructures. "Shana's knowledge of how to apply LEED-accepted tools and performance criteria at the ground-improvement and wall-construction level of a project means site owners have a head start on obtaining the credits they need to have a completely LEED-certified building."

Geotechnic
(third page horiz.)

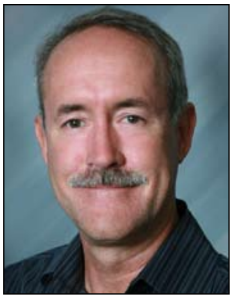
G-I Organizational Member News

Brayman is Low Bidder on Bridge Rehabilitation Work

Brayman Construction Corporation is the low bidder for rehabilitation work on the 62nd Street Bridge located on SR 8, and the Perrysville Avenue Bridge located on SR 19, Allegheny County, PA. Work includes the replacement or refacing of precast parapets, deck joint replacement, deteriorated concrete repairs, painting, and other miscellaneous work. The project is scheduled to begin in February 2008 and to be completed by November 2008.

DBM Contractors, Inc. Hires New Personnel to Open Northern California Office

DBM Contractors hired David Bolton to open its new Northern California regional office in San Jose. Bolton brings 30 years of Northern California experience in the specialty geotechnical construction industry to his new position. As operations manager, he is responsible for the overall operations of the new region and is currently developing and bidding public and private work in the area. Prior to joining DBM, Bolton worked with Case Pacific Company of Hayward and Malcolm Drilling and Soil Engineering Construction of San Francisco. He brings both local geotechnical construction industry experience and a strong working knowledge of the region's client base and ground conditions that will certainly impact DBM's success in this area.


David Bolton

Fugro Acquires William Lettis & Associates, Inc. (WLA)

Fugro recently acquired William Lettis & Associates, Inc. (WLA), an earth science consulting company specializing in earthquake hazard assessment and engineering geology for the power industry, government agencies, the oil and gas industry, and the water and infrastructure markets. Founded in 1990, WLA operates globally from offices in California, Colorado, Texas, and Georgia. This acquisition will broaden Fugro's geotechnical consultancy and geohazards practices, and the combined service offering will bring added value to both firm's clients.

Tensar Corporation Acquires Geopier Global Corporation Common Stock.

The Tensar Corporation acquired all of Geopier Global Corporation (Global) common stock in December 2007. Global is the exclusive provider of Intermediate Foundation® solutions throughout Europe and Asia and operates in similar fashion to the Geopier Foundation Company (GFC) providing soil reinforcement solutions to the U.S., Canada, Mexico, Central and South America markets. The acquisition should help expand GFC's scope and scale. A new company, Geopier Foundation GmbH, will be created and headquartered in Germany, with the operations of Global being transferred into the new entity.

Golder Associates Named on 2007 Hot Firms List

Management consulting and research firm Zweig White Information Services identified **Golder Associates** Inc. as #83 of the 200 fastest-growing U.S. architecture, engineering, and environmental (a/e/c) consulting firms for its annual ranking, The Zweig Letter Hot Firm List. This annual list features the design and environmental firms that have outperformed the economy and competitors to become industry leaders. Golder's success in the a/e/c industry comes primarily from the expansion of Golder's existing engineering and environmental services in waste management, mining, oil and gas, transportation, water resources, manufacturing, and other major market sectors.

The Green Choice

Insulfoam's web site at *http://www.insulfoam.com/homeowners/page.aspx?nid=28* features the document "The Green Choice in Rigid Foam Insulation" in which Insulfoam answers questions on why Insulfoam Expanded Polystyrene (EPS) Rigid Insulation is, and has always been, a green building product.

Trigon to Become Part of Kleinfelder

Kleinfelder and **Trigon Engineering Consultants,** Inc are entering the final stages of acquisition negotiation. The transaction close date is targeted for March 28, 2008 following a due diligence process, respective board approvals, and integration planning that will involve employees from each firm. "Kleinfelder is pleased to expand our business with a company that has an outstanding reputation as a thriving, profitable operation," said Gerry Salontai, P.E., president and CEO, The Kleinfelder Group, Inc. "As an employee-owned company, we are very conscientious about the firms we acquire. Trigon's geographic location, unique skill set, and reputation for outstanding service is what made Trigon attractive to Kleinfelder. We are eager to expand on the solid relationships Trigon has built with its clients and employees."

Greenville, S.C.-Based Engineering Firm Changes Name

Ground Engineering Solutions (GES) officially changed its name to **Terracon Consultants, Inc.** following one year of operating as a wholly-owned subsidiary of Terracon. GES is a leading provider of geotechnical, environmental, and construction materials services for public and private sector clients in the Greenville metropolitan area. Firm principals include **James G. Kahle, P.E.** and **Rex T. Brown, P.E.**. GES was established in 1992 and joined the Terracon group of companies in 2006. GES currently has 18 staff members and has been serving the development market since 1994.

Terra Offers Firms $1,000 to Attend Meeting

Terra Insurance Company will pay $1,000 to each of its insured firms that sends at least one representative to the Spring (annual) Meeting of ASFE/The Best People on Earth. The meeting is in San Juan, Puerto Rico, April 10-12, 2008, at the Intercontinental San Juan hotel. Terra will conduct a shareholders meeting at the same facility on Friday, April 11.According to Terra president and CEO David L. Coduto, "we're delighted to be in a position to offer this incentive, because it reflects the fact that Terra, unlike most of its competitors, has just completed another great year." Although Terra has not yet formally announced its 2007 performance, Coduto said that, as of September 30, 2007, Terra's stock value achieved its 78th consecutive quarterly record high. He commented, "We've done that well because the frequency of our claims has never been lower, and that's something we owe to the outstanding quality of the services our owner/insureds provide, and to the effectiveness of their risk management practices. They're entitled to reap the benefits of their success, by having the value of their shares grow and by taking advantage of this incentive." For information: www.terrarrg.com, or Terra Insurance Company, 2 Fifer Avenue/Suite 100, Corte Madera, CA 94925; or tel. 1.800.872.0077 (in CA, 415.927.2901); or-mail *terra@terrarrg.com.*

URS Appoints New Washington Division President

Thomas H. Zarges was appointed president of the Washington Division of the **URS Corporation.** Mr. Zarges, who formerly served as the Division's senior executive vice president for Operations, has over 35 years of experience in global engineering and construction. He joined Washington Group in 1991 as president of Power and Industrial/Manufacturing. He later served as president of the company's Engineering/Construction and Industrial/Process business units. Earlier in his career, Mr. Zarges served with United Engineers & Constructors, a predecessor firm to Washington Group, for 20 years.

Allied Organizations

AGI and AGIF Establish Teacher Award

The American Geological Institute (AGI) and the AGI Foundation announced the creation of the Edward C. Roy, Jr. Award for Excellence in Earth Science Teaching. This annual award recognizes one classroom teacher from kindergarten to eighth grade for his or her leadership and innovation in earth science education. The winner receives $2,500 and an additional grant of $1,000 to enable the recipient to attend an AGI member society conference. The award is named in honor of Dr. Edward C. Roy, Jr., who was a strong and dedicated supporter of earth science education. For information: *http://www.agiweb.org/education/awards/ed-roy/*.

Industry News

Have You Read FastTIMES?

The Environmental and Engineering Geophysical Society (EEGS) now offers FastTIMES, news for the near-surface geophysical sciences. It is available for download as a low- and high-resolution .pdf document (viewable with the free Acrobat Reader) from the EEGS website at *www.eegs.org/fasttimes/latest_issue.cfm*. It is best to download the document and view it outside of a web browser. Send your comments, suggestions, and content for the next issue to the editorial team—Jeff Paine (*jeff.paine@beg.utexas.edu*), Roger Young (*ryoung@ou.edu*), or Brad Isbell (*bisbell@hgiworld.com*).

GeoStructures Named to SmartCEO's Future 50 List

Design-build contractor GeoStructures was selected as a member of the Future 50, a ranking of the top companies in the Greater Washington D.C. area compiled by *SmartCEO* magazine. Much of the company's growth is attributed to its value proposition of alleviating risk associated with new site development. Especially in the highly developed Greater Washington region where few prime sites are left, the marginal sites and roadway projects where much of the construction is taking place have soil conditions that can affect developers' budgets and the performance of the structures. GeoStructures's offerings in ground improvement and sound and retaining walls have kept construction projects on schedule and within budget.

GeoConcepts Promotes Eaton King

GeoConcepts. a woman/minority owned business that provides professional geotechnical engineering, hydrogeologic, and environmental consulting services to private and public sector clients, recently promoted Eaton King to the role of construction services manager in its Ashburn, VA office. Mr. King manages the daily operations of GeoConcepts' field technicians, and coordinates field paperwork with the project managers. He holds several certifications from the Washington Area Council of Engineering Laboratories (WACEL) and offers specialized experience related to post-tensioning.

Upcoming Events

Visit: *www.geoinstitute.org/events.html* for links to these and other upcoming events:

Geotechnical Earthquake Engineering and Soil Dynamics IV (GEESD IV)
May 18-21, 2008
Sheraton Grand Sacramento & Sacramento Convention Center
Sacramento, CA

11th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst™
Ramada Inn & Conference Center
September 22-26, 2008
Tallahassee, FL

GeoCurmudgeon

(continued from page 51)

Tinytown Mightymites."
People from all over the country liked what the Little Blue Engineer had to say. They even told their children to think about engineering for a career. And more engineers began to think about running for public office. And before you could say Karl Terzaghi, more and more towns and cities elected engineers to lead. There were even a few engineers trying to become governors and Congressmen. And talk of something more. But as for the people of Tinytown, they all lived happily ever after.

Wow, Dad. That was really a great story.

Well, thank you, Tommy.

Dad?

Yes.

Do you think it could ever come true?

I don't know, son. I'd like to think so.

You know what, Dad?

What, Tommy?

I want to be an engineer when I grow up.

That would be great, son.... Do you think you can go to sleep now?

I think I can.

Geo-Strata is interested in hearing from you. Please send your comments on this column to *geo-strata@asce.org*.