March 2004
Volume 22, Number 2

Current Events

Collaborative research

By David Elton, Ph.D.

Atlanta was the site of the most recent United States University Council on Geo-technical Education and Research (USUCGER) workshop, held 1–3 October 2003 at the Omni CNN. Over 80 geo-technical engineering professors from around the nation met to discuss geotechnical education and research issues. The conference, hosted by Auburn University Civil Engineering associate professor David Elton, was funded by the National Science Foundation (NSF).

Speakers

Speakers from industry, government and academia discussed the future of engineering. Georgia Tech President Dr. Wayne Clough spoke on research funding issues. He explained his vision for the profession and industry, suggesting many new fertile areas for research. Dr. Carlos Santamarina shared ideas on being more productive—grasping new ideas from other fields and translating them into workable programs and processes.

Chris Reseigh, president of Parsons Brinkerhof, a leader in the industry, stated the needs of the profession from thepracticing engineer's standpoint. Efficiency and innovation, combined with a more widespread education of geo-technical engineers, are crucial to properly addressing new markets. Rehabilitation work, rather than new construction, has become the focus of many firms. Risk reduction is an ever-growing concern.

Several speakers addressed research issues. Dr. Rick Fragaszy, head of geotechnical and geoenvironmental research at NSF, spoke on interdisciplinary research. Many NSF programs involve a variety of constituencies in research—in particular, faculty at predominantly undergraduate institutions (PUIs).

Dr. Stokoe provided valuable insights into a variety of funding mechanisms, with a particular emphasis on the equipment sites affiliated with the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). He presented a detailed overview of the NEES equipment site affiliated with the University of Texas at Austin, which has developed three mobile vibratory sources, a mobile data acquisition network, and a field local area network to communicate with NEES.

Dr. Leahy presented a summary of the primary sources of funding for geotechnical academics, impacts of civil engineering on the United States economy, and a summary of the motivations of the industrial client. Leahy suggested methods for optimizing academic/practitioner interaction.

Dr. Bachus presented detailed information on the industry perspective in relation to the interests of academics. He emphasized the need for the geo-technical profession to embrace new and emerging technologies, encourage cross-disciplinary cooperation, and improve site characterization in order to enhance the community's predictive capabilities.

The balance of industry, academic and government made the program most useful.

Award

Dr. Deborah Goodings, University of Maryland, received the USUCGER Distinguished Service Award from USU-CGER president Jean-Louis Briaud. Goodings' selfless service and vision for the organization were recognized.

Breakout sessions

Attendees participated heavily in the first day's many breakout sessions on technical topics, including natural hazards mitigation, soil improvement, geoenvironments, earthquake engineering, site characterization and geophysical methods, geosynthetics, unsaturated soils, experimental simulations, and numerical simulations. Research ideas were generated and new areas of cooperation explored.

New focus, new committees

Two new USUCGER committees were formed—Education and Research. The committees set agendas, elected chairs, and worked out terms of reference. These meetings were particularly lively and well-attended. Dr. Beena Sukumaran, Rowan University, was elected education committee chair, while Dr. Dennis Hiltunen, Penn State University, was elected research committee chair. Both committees welcome additional members.

Dr. Elton, Workshop Chair, noted that the Workshop's focus on new, young faculty was very effective, allowing them to participate fully and form many working relationships.

PUIs

The workshop invited many engineering professors from PUIs. These professors learned much about research collaboration and left with a new excitement and understanding about research at small schools, and how to work with big research institutions.

Dr. Jean-Louis Briaud expressed his pleasure: "We met our goals of furthering research and education, and involving new faculty in the exciting work of geotechnical engineering. We did a lot to generate new ideas and new focus for geo-technical engineering."

The workshop closed with an elegant dinner at Atlanta's Fernbank Museum, where Georgia Tech faculty hosted participants to a very pleasant evening of collegiality.

Review: Landfill design short course

By Laurie Honnigford

The PVC Geomembrane Institute (PGI) sponsored a short course titled "Specifying with PVC Geomembranes" on 10 November 2003 at the Empire State Convention Center in Albany, N.Y. The course was moderated by Robert Phaneuf, Section Chief, New York Department of Conservation.

Formulation and manufacturing of PVC geomembranes was covered by Patrick Diebel, Canadian General-Tower Ltd. Diebel also discussed the use of the PGI 1103 Specification and the ASTM methods used for geomembrane testing.

Dr. Timothy D. Stark, University of Illinois at Urbana-Champaign, presented information on geosynthetic interface strengths and the slope stability of landfill covers. Stark also discussed the fabrication and field installation aspects of working with PVC geomembranes. He stressed that one of the major advantages of using PVC is that approximately 80 percent of all seaming is done in a factory under controlled conditions. Eliminating 80 percent of field-welded seams leads to better seam quality and generally faster installation time. Stark also discussed the benefits of air-channel testing PVC geomembranes, including the visual inspection of the inflated seam.

A hands-on welding demonstration, led by Chris Bonnet from Plastic Welding Technologies (PWT), was held at the end of the course. The hands-on demonstration showed dual-track wedge welding and the air channel testing of PVC geomembrane seams. Air channel testing involves sealing one end of the seam, filling the channel with air pressure, and, using an air gauge, measuring the ability of the seam to hold the pressure. Any voids in the seam are easily detected by a loss in air pressure. This is another step in ensuring quality field seams in PVC geomembrane installations.

This seminar was attended by more than 70 people. Stark reported positive feedback from attendees who "were able to better understand what is required to design, specify, and construct with PVC geomembranes."

For more information, contact PVC Geomembrane Institute, 2215 Newark Civil Engineering Lab, 205 N. Mathews Ave., Urbana, IL 61801; +(1) 217/333-3929, fax +(1) 217/244-2839, e-mail pgi-tp@uiuc.edu, Web site www.pvcgeomembrane.com.

GeoQuebec 2004 and durable geosynthetics

The Eastern Quebec region of the Canadian Geotechnical Society (CGS) will host the 57th Canadian Geotechnical Conference, 23–27 October in Quebec City.

The conference will again be co-hosted by the International Association of Hydrogeologists–Canadian National Chapter (IAH-CNC). The theme is "Geo-engineering for society and its environment." (For a review of the 56th gathering, which took place in Winnipeg, Manitoba, October 2003, see the Checking In column in the January/February 2004 issue of *GFR*. The Winnipeg conference, "Two Rivers," included technical papers from the North American Geosynthetics Society.) GeoQuebec 2004 marks the fifth joint gathering of the CGS/IAH-CNC conference.

A special session on performance-related geosynthetic durability has been added. Geosynthetic topics for discussion may include, but are not limited to:

• Designing for aggressive chemical environments

- UV resistance
- Long-term designs in earth retaining structures
- Long-term designs in environmental applications
- Responsibility of professional engineers regarding design
- Case studies

For more information, contact Eric Blond, Sageos, Geosynthetics Tech Center, 3000 Boulle, Saint-Hyacinthe, PQ, Canada; +(1) 450/771-4608, fax +(1) 450/778-3901, e-mail ericb@sageos.ca, Web site www.geoquebec2004.org.

ECTC board members

By Laurie Honnigford

The Erosion Control Technology Council (ECTC) announces its newly elected officers for 2004–2005.

- Chairman: Tim Lancaster, North American Green
- Vice-chairman: Deron Austin, SI Geosolutions
- Treasurer: Mark Myrowich, ErosionControlBlanket.com

Also, two at-large board members were selected: Tony Johnson, American Excelsior Co.; and Kevin Spittle, Profile Products LLC.

Laurie Honnigford continues to serve as ECTC Executive Director.

ECTC is a non-profit group committed to advancing the use of rolled erosion control materials by providing education and leadership in the industry. ECTC assists engineers, designers and other interested individuals or organizations in the proper application of products, and establishes standards for testing and performance.

For more information, contact Laurie Honnigford, ECTC Executive Director, P.O. Box 18012, St. Paul, MN 55118; +(1) 651/554-1895, e-mail laurie@ectc.org, Web site www.ectc.org.

IAGI board members

By Laurie Honnigford

The International Association of Geosynthetic Installers (IAGI) announces its 2004–2005 Board of Directors:

- Carl Apicella, American Environmental Group LTD
- Brian McKeown, Clean Air and Water Services
- “Demo” Dave McLaury, DEMTECH Services Inc.
- President: John K. “Robbie” Robinson, Engineered Textile Products

• First vice president: Dennis O’Brien, MPC Containment Systems Inc.
• Second vice president: Lee Taylor, Taylor Geosynthetics
• Treasurer: Anne Steacy, Poly-Flex Construction
• William Steinke, Steel Dragon Enterprise Co. Ltd.

Robert Haddox, PLS Construction Services Inc., will continue to serve on the Board as Immediate Past President.

IAGI strives to provide a forum for geosynthetic installers to advance installation and construction techniques as well as to strengthen the knowledge, image and communication within the industry.

For more information, contact Laurie Honnigford, IAGI Executive Director, P.O. Box 18012, St. Paul, MN 55118; +(1) 651/554-1895, e-mail laurie@ectc.org, Web site www.iagi.org.

Designer’s Forum volume available

By Christopher Kelsey, Editor

Since 1997, *GFR* magazine has featured the Designer’s Forum column. The series has been the magazine’s most consistently published and requested section. Throughout, the articles have been moderated by—and generally co-authored, if not solely authored by—Greg Richardson, Ph.D., P.E., of the North Carolina-based firm G.N. Richardson and Associates (www.gnra.com).

GFR’s *Designer’s Forum 1997–2003* collects 50 of the columns. The contributers represent a variety of engineering segments (e.g., civil, mechanical, hydrotechnical) and geosynthetic specialists (e.g., consultants, manufacturers, installers and other professionals with considerable site or lab experience).

Geosynthetic engineering has become a vital part of civil and environmental designs over the past two decades. We’ve seen an extraordinary rise in the number of engineers and contractors actively incorporating polymeric materials in their projects. Rapid acceptance does not equal understanding, though. This is true in most fields, but it can be quite costly in engineering. We protect our profession, our clients, and our communities through smart designs.

As such, the Designer’s Forum’s synthesis of field-based expertise and design vision is an essential resource.

The volume has been broken into various application- and material-based sections:

• Covers and Caps
• Drainage
• Geosynthetic Clay Liners
• Geotextile Tubes

• Landfills
• Miscellaneous (e.g., tank lining, gas transmission in geocomposite systems, interface shear strength)
• Roadways
• Surface Impoundment

For more information, please contact Barbara Connett, IFAI Bookstore, 1801 County Rd. B West, Roseville, MN 55113-4061; +(1) 651/225-6913, fax +(1) 651/631-9334, e-mail bjconnett@ifai.com, Web site www.bookstore.ifai.com. GFR

GFR Engineering Solutions for Roads, Soil, Water and Waste

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Postscript of GRI-17 Conference

By Robert M. Koerner, P.E., director of GSI

GRI-17 is now in the past. From what we've heard, it was quite successful. Being in Las Vegas didn't hurt at all! We had over 200 participants who heard 22 papers and could follow along in the 346-page proceedings. The two-day event held on 15–16 December 2003 at the Flamingo Hotel had two focused sessions (waste properties and geotextile tubes) and two open sessions (each on individual geosynthetic topics).

Waste properties

The waste property session heard Kevin McKeon (co-author Paul Whitty) of Earth Tech illustrate the factor-of-safety sensitivity using varying waste properties, followed by Allen Marr (GeoTesting Express) and Michael Yako's (GEI Consultants) paper on their recent survey of waste properties in the United States. This was followed by Michael Ruetten, William Butler and John Trast's (STS Consultants) paper. It focused on the atypical properties of paper mill sludge and ash—pretty wild materials! Neil Dixon of Loughborough University and Russell Jones of Golder (United Kingdom) then counterpointed the Yako-Marr paper on waste properties reported from Europe and Asia. Lastly, Ed Kavazanjian (consultant) focused completely on field measurements of waste properties. The take-home message from the session is that laboratory and small-scale testing is very questionable with a heterogeneous material like municipal solid waste. The group then formed a panel for questions from the audience. The issue of knowing where and when liquids are involved was emphasized. The advent of wet landfilling, as in bioreactor landfills, was nicely brought into perspective by a number of speakers.

Geotextile tubes

The geotextile tube session opened with Chris Lawson (TC Nicolon), who nicely reviewed geotextile bags, containers and tubes. His presentation set the stage for the subsequent speakers. Doug Gaffney (Hart Crowser Co.) and Deron Austin (SI Geosolutions) presented a number of intricate case histories involving geotextile tubes. Their adaptability to line and grade was clearly evident. Cheryl Pollock of the U.S. Army Corps of Engineers (co-authors William Curtis and Neil McLellan) reported on a 2003 workshop wherein the industry was challenged in a number of respects. This is required reading for those involved in this aspect of geosynthetics. George Koerner of the Geosynthetic Institute (GSI) presented hanging bag test results of three case studies using four different geotextiles at each site. The result is that apparent opening size (AOS) is not relevant for dewatering projects compared to the hanging bag test which is very useful. Gerald Hauske, along with Dan Heilman, of Shiner Moseley Inc. went into a number of clever and innovative repair and maintenance techniques.

The subsequent panel session was excellent. Clearly, geotextile tube applications subdivide between coastal tubes (with granular soil infills) and dewatering tubes (with fine silts, clays and sludge-like wastes).

The former must deal with external forces leading to stability issues; the latter must deal with internal filter cakes clogging the fabric, thereby inhibiting dewatering.

Open discussion

The two open sessions contained twelve presentations. They were all well-presented and informative, and generated questions from the audience. Ron Frobel (consultant) began with confined animal feed operations (CAFOs). The subject of animal waste containment was eye-opening to say the least. Jim Olsta of CETCO described an interesting contaminated disposal site's containment using a GCL. Rich Thiel (co-author Mark Smith) of Vector Engineering gave an excellent overview of geomembranes beneath heap leach pads; the pads are huge! Generally without a geotextile cushion, the geomembrane selection is critical. Nathan Ivy (co-author Boyd Ramsey) of GSE nicely illustrated that a typical geomembrane roll must successfully pass more than 2000 tests! This was complimented by Jim Nobert of Poly-America who very accurately reviewed the history of the development of the GRI-GM13 specification on HDPE geomembranes. Jorge Zornberg (with student Christine Weber) of the University of Texas at Austin gave insight into geosynthetic needs in hydraulic engineering. Clearly, water will be in short supply in many areas of the world during this century.

The open sessions continued with Rick Varuso (and co-author John Grieshaber) of the New Orleans Corp of Engineers, who delivered a paper on geotextile/geogrid reinforced levees. Note that rock in this area is about 2000 ft. beneath the ground surface. Above it are very soft soils—quite a challenge. Sam Allen of TRI nicely laid out the idiosyncrasies of the stepped isothermal method (SIM). The method is now an ASTM standard. Dov Leshchinsky of the University of Delaware presented his computer code adaptation of reinforced wall internal stability when insufficient space, e.g., a rock outcrop, is available for full geosynthetic reinforcement. It is not an uncommon situation. The external stability must be handled by rock anchors, or equivalent. Co-authors are graduate students Yuhui Hu and Jie Han of Widener University. Grace Hsuan of Drexel University, with graduate student Mengjia Li, presented their research results on combined elevated temperature and high pressure effects on oxidation degradation of HDPE geogrids. The predicted time for depletion of the antioxidants at 7˚ C is over 100 years. A combined presentation by Ian and Elizabeth Peggs (I-Corp and geosynthetica.net, respectively) focused on risk assessment and insurance issues for waste containment systems. This important issue can profit well if the proper QA/QC and current best practices are utilized. Without a doubt, such quality instruments are available. The will to use them might result in lower insurance rates, and vice versa. Finally, Bob Denis of Solmax closed the conference with his presentation: "The Twilight Zone." It was a splendid capstone illustrating the anomalies of the geomembrane industry along with the requisite research needs in the geomembrane area. Every conference organizer should have a Bob Denis presentation to conclude with!

Proceedings

The conference proceedings are available at cost from the Geosynthetic Institute. For more information, contact Marilyn Ashley, Geosynthetic Institute, 475 Kedron Ave., Folsom, PA 19033; +1 610/522-8440, fax +1 610/522-8441, e-mail mashley@dca.net, Web site www.geosynthetic-institute.org.

GRI-18 and Geo-Frontiers

GRI-18 will be incorporated into the Geo-Frontier's Conference in Austin, Texas in January 2005. GFR

Editor's note: Updates regardings the Geo-Frontiers congress are available online at www.geosynthetica.net, www.gmanow.com, and www.asce.org.

See GFR *March 2004 for general information on Geo-Frontiers, and look for more columns in 2004.*

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Phytoremediation: an interdisciplinary approach

By Christopher Kelsey, Editor

Phytoremediation—the use of plants to either remove pollutants from the environment or render them less harmful—is a promising field. A number of plants are capable of drawing toxic materials from soils, and various trees have been found to cleanse soils through a natural rhizofiltration process (filtering through root systems). Some research suggests that rhizofiltration methods can be supported, in turn, by microbial activity: engineered micro-organisms that also feed on soil contaminants could live on the tree's root system. These technologies, while still in their infancy and in need of far greater study, present us with an exciting option for remediation projects. However, phytotechnologies cannot succeed on their own. The immediate and long-term limitations are apparent; but the promise is real. For it to work, other disciplines must gain a basic knowledge of phytoremediation's challenges, and bring their expertise to the table.

With geosynthetics

Geosynthetic materials provide many solutions for the sustainability concerns that govern current project designs. Depleted groundwater reserves, frequent droughts, and fears of contamination from aging industrial, mining, military and waste disposal operations have brought professionals from many engineering segments together. Their common concerns have blurred the lines between geotechnical, hydrotechnical, geosynthetic, environmental and civil practice.

Geosynthetics, as part of an interdisciplinary approach to remediation, can benefit (and benefit from) phytotechnologies in numerous applications, such as:

• *Landfill leachate collection systems.* Landfill runoff generally contains a wide range of potential threats to groundwater. It is not uncommon to find unacceptably high levels of organic carbon, nitrogen, chloride and iron, or even more toxic runoff such as pesticides, solvents and heavy metals. Leachate collection systems (**Photo 1**), using a combination of geosynthetic materials, can control runoff. If the runoff is stored, perhaps in a lined lagoon, it may be used to partially irrigate special growth zones in which trees capable of sequestering the contaminants have been planted. Landfill designers might set aside sections of a site for copses of trees bred for phytoextraction.

Photo 1. *Contaminated runoff from landfills can be collected and reused as irrigation for tree farms developed specifically to cleanse the site-specific runoff.*

• *Erosion control*. Rolled erosion control products (RECPs), including seeded blankets and turf reinforcement mats (TRMs), are used to mitigate soil loss from rain and water flow. Depending on project needs and and a suitable climate, contaminant-absorbing plants may be incorporated into an RECP's growth matrix.

• *Green roofs.* Lining systems used for containment and drainage control at common civil engineering sites are now used, in modified forms, for green roofs. Phytoremediative plants can be easily incorporated into these designs.

The application list is long. Phytotechnologies can contribute, in general, wherever designs incorporate vegetation. As some plants have been found to ingest cadmium, mercury, zinc, copper or even nitrogen-based explosives, the list of potential sites, current or post-closure operations, is quite long.

***Photo 2**. As municipalities redevelop former industrial sites, phytoremediative plants, supported by geosynthetic containment and stability designs, can help not only repair soils but improve a community's understanding of environmental risks and cleanup strategies.*

Concerns and limitations

A number of questions surround the practical viability of phytotechnologies in remediation and other engineering fields; most notably, cost. Plants and trees are "solar-powered," so the possibility of a continually renewable, photosynthetically driven source for processing contaminants is attractive; but phytotechnologies are not and will not necessarily be cheap. This is the first thing a designer, site owner, regulator, or anyone else involved in a project must understand. There are research and development costs. Thale cress has been used in trials to sequester arsenic, but it does not thrive in an arsenic-contaminated environment like genetically modified thale cress. Special strains must be created.

While new strains might absorb arsenic, mercury or zinc, they won't necessarily convert contaminants into a harmless, self-releasing form. (That is a different level of very difficult engineering.) The plant may need to be harvested so that the partially processed arsenic can be taken care of. Harvesting and processing these plants may be more expensive than general soil excavation and containment.

Other concerns include:

• The biomass of many metal-absorbing plants is not great enough to contribute an economically supportable remediation venture.

• Soils often immobilize metal contaminants (hence, the common response to excavate large swatches of soil). Phytotechnologies cannot yet overcome this.

• Though various deep-rooted trees can draw chlorinated hydrocarbons, the trees take up too much land.

• Regulators will be hesitant to accept the use of genetically modified organisms to enhance root systems.

• Sterile plants would alleviate some concerns about introducing unusual species into an ecosystem (without knowing the full impact), but, as noted before, the harvesting and processing cost may be too great.

• Plants that only partially breakdown a contaminant might actually release worse by-products into the environment. A thorough understanding of how each plant uses sequestered material is needed before any plant can be used.

• Plants should not be used in areas accessible to foraging animals.

The bottom line

Phytoremediation cannot exist as an unsupported approach to environmental cleanup. Mining runoff, landfill leachate, and general industrial operations produce pollution that is too challenging for both conventional and engineered plant life. However, current designs can incorporate more phytotechnologies, if only beginning with the lowest tier. This will assist research in a new field and support common remediation site goals.

Christopher Kelsey is editor of GFR*.*

GFR Engineering Solutions for Roads, Soil, Water and Waste

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Design software for soft soils

Software is not a substitution for experience, but it improves the design process.

by Dov Leshchinsky

Constructing embankments over soft soil is always challenging. First, the foundation soil relevant properties need to be identified. This is as much of an art (i.e., experience) as it is science. For example, was the soil profile including sand seams properly characterized? Was the soil shear strength correctly interpreted? Are the field/lab coefficients to calculate settlement representative? Second, a design needs to be carried out in which the foundation's settlement and strength are estimated at any time. This allows for a construction rate or staged construction that implements such measures as prefabricated vertical drains (PVDs, or "wick drains") to accelerate consolidation or for use of lightweight fill material (e.g., geofoam) to reduce the induced stress in the foundation. While determining the relevant data is the most critical element in the design process, the calculations of stresses and settlements are tedious—often leading to short cuts (i.e., assess only one or two case scenarios), and resulting in overly expensive construction.

It is important to note that design software is not a substitute for experience; however, it can be an excellent tool to reduce the tedium and increase productivity while producing an optimal construction based on a rational approach. Program FoSSA, the subject of this article, is such a tool.

Software overview

Settlement in a foundation soil is a reaction to stresses induced by embankment loading. FoSSA calculates the stress distribution under an embankment, which may have a rather complex geometry, followed by: the elastic (immediate) settlement; the consolidation settlement (including excess porewater pressure and settlement during the consolidation process); accelerated consolidation settlement due to PVDs (triangular and square installation patterns); secondary settlement; and undrained shear strength distribution within consolidating layers. The program can deal with a foundation profile comprising up to fifty, complex-geometry layers (consolidating or not), and up to 25 layers in an embankment (e.g., representing alternating layers of geofoam and soil, or just simulating staged construction).

The distribution of the induced stress is calculated based on a numerical integration of the basic Boussinesq equation. The elastic settlement is based on a numerical integration of Hooke's equations. Consolidation settlement (1-D) solves Terzaghi's differential equation using a finite difference scheme at any prescribed time and for any initial excess porewater distribution. The PVD design follows Rixner et al., "Prefabricated Vertical Drains, Vol. I: Engineering Guidelines" (1986), which is a practical modification of Barron's solution developed for vertical sand drains. The undrained shear strength calculations during consolidation follow Ladd's "Stability Evaluation during Staged Construction" (1991). The various theories are linked in a consistent manner to produce designs that are compatible with existing practice. It can be used with field data to back-calculate the basic consolidation parameters (i.e., calibrate the parameters using field data obtained during field monitoring; useful in an observational approach).

Example

General

Stresses in soil increase due to external loading (e.g., embankment construction) or internal loading (e.g., lowering of ground water table). The soil response to an increase in stress is a decrease in its voids, resulting in settlement. If the soil is saturated, any decrease in the volume of voids can occur only if water, an "incompressible" material, is simultaneously expelled—thus, allowing such reduction. The water in the void carries the initial stress increase. (Hence, it is a pore water pressure in excess of hydrostatic or equilibrium.) This excess pore water pressure causes the flow of water; the flow rate depends on the opening size of the interconnected voids. If this size is large (e.g., gravel, sand), the water flow will be nearly instant. However, if the soil is made of fine particles such as clay, the water flow is a slow process.

The term "consolidation" refers to the settlement process associated with the reduction of the volume of voids in saturated fine-grained soils. Consolidation occurs in response to increasing stress; it represents a transitional phenomenon in which excess pore water pressure dissipates simultaneously with the development of settlement. Consolidation is considered complete when the excess pore water pressure returns to hydrostatic (static equilibrium). This complex process is described mathematically by a differential equation; typically, it is Terzaghi's 1-D equation. Its solution is very meaningful, from a practical standpoint, since it enables us to predict both the rate at which consolidation settlement will occur and soil stresses; and, thus, the soil shear strength at any time. Unfortunately, this equation cannot be solved in a closed-from solution. Some non-dimensional charts with the solution exist. However, such charts are limited to a few loading cases. Moreover, its application is cumbersome. Computers can solve this equation quickly—taking the tedium out of the prediction (or design) process. The user needs to be a good engineer, but not a mathematician.

Problem

To demonstrate the power of a computerized process, consider the problem shown in **Figure 1**. A soft clay layer, varying in thickness between 10 and 15 m, is contained between two sand layers. Obviously, the sand is much more pervious than the clay; thus, it can easily drain the water that is "squeezed" out of the clay layer as it consolidates. (Hence, the clay drains at both its boundaries.)

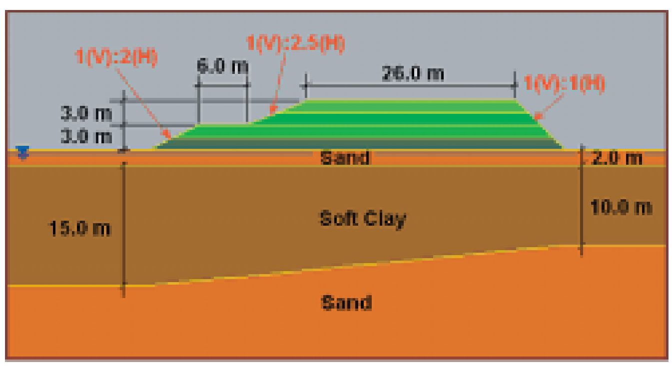

Figure 1. *Example problem: Profile of foundation and embankment geometry.*

Now, an embankment with the geometry shown in **Figure 1** is to be constructed. It is 6 m high. Its left side slopes are 1V:2H and 1V:2.5H. It includes a setback of 6 m at mid-height. The right side slope is rather steep, 1V:1H, and is very likely reinforced with layers of geosynthetics (outside the scope of this article). The flatter slopes and the setback would produce smaller increases of stress than the steeper slope. However, the settlement of the deformable clay is also proportional to its thickness. Hence, it makes sense to use different geometries on either side of the embankment to obtain a settlement that is closer to symmetry across the base.

Note that there are four distinct embankment layers, each 1.5 m high. We'll use this distinction to indicate the option of staged construction. As mentioned earlier, the program allows for up to 25 embankment layers to simulate more involved staged construction schemes. In our example problem, however, we'll keep the problem simple yet instructive.

Stress increase

To find the consolidation reaction of the foundation to the embankment loading, the increase in vertical stress is sought. The basic equation of Boussinesq (linear elasticity) is integrated to yield the stress increase in any relevant zone of the problem. The Boussinesq equation is frequently used in geotechnical engineering (especially for stress distribution under footing) because, generally, it yields reasonable results without the need to carry out a complex numerical analysis. Furthermore, the induced vertical stress is independent of the material elastic properties, a very attractive feature when dealing with messy soil mass below. **Figure 2** shows the distribution of vertical stress increases due to the load exerted by the completed embankment. Notice that the highest stress is under the crest. Also, stresses under the first left side slope and the setback are relatively small—a consequence of geometry, and a designer's choice when attempting to get approximately symmetrical settlement in response to loading.

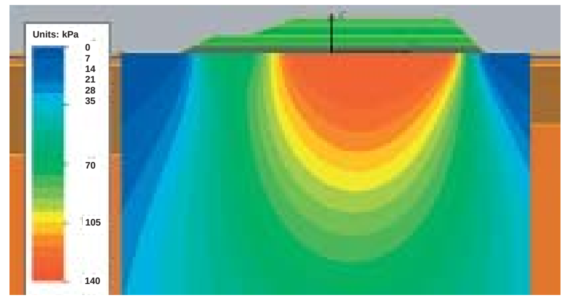

***Figure 2**. Vertical stress increase due to embankment loading.*

Ultimate settlement

Once the increase in stress is known, the consolidation settlement can be computed. **Figure 3** shows the input data needed for these computations. It allows the user to invoke the consolidation computation for any desired layer. The user needs to specify whether the clay drains at the top, bottom or both ends; in our case, it involves both boundaries, since sand augments the clay layer. The compression index and the initial void ratio dictate the ultimate consolidation settlement; the consolidation coefficient, *Cv*, dictates the rate of consolidation.

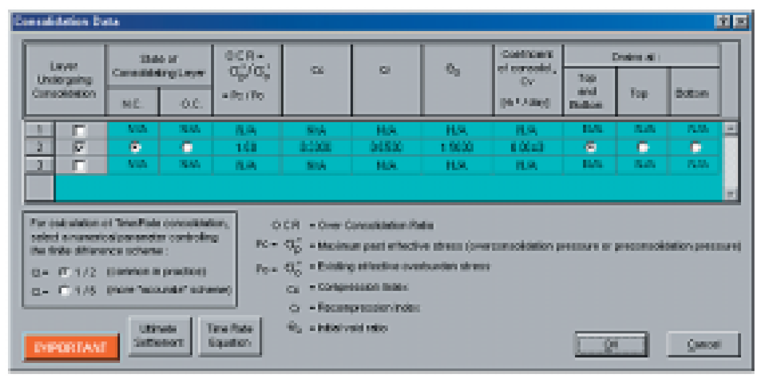

***Figure 3**. Input parameters for computing consolidation.*

Figure 4 shows the ultimate consolidation settlement (i.e., the settlement at the end of the consolidation process when all excess pore water pressure has dissipated). The distribution shown in the figure is plotted in an exaggerated scale. The deepest drawn bar represents an ultimate settlement of 0.52 m. Notice that on the left side of the lower embankment the settlement is about the same as on the right side while the clay layers are 50% thicker.

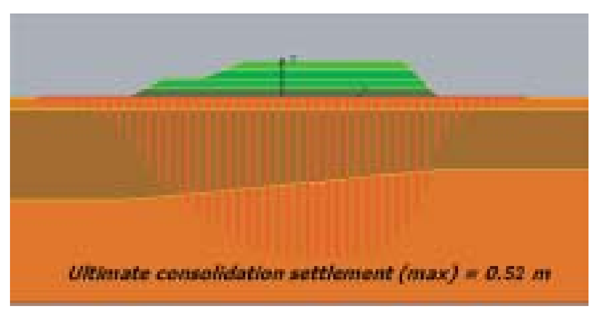

***Figure 4.** The distribution of ultimate consolidation settlement.*

Conventional case

To calculate the time rate consolidation, a vertical section through the consolidating layer is selected. **Figure 5** is for a section through which the maximum ultimate settlement of 0.52 m is predicted. The program user can easily select several parallel sections to obtain a spatial perspective of the consolidation process. **Figure 5** shows the distribution of excess pore water pressure, *Ue*, versus time, *t*; it is a solution of the Terzaghi 1-D equation. The formal terminology for *Ue* curves, each at a different time, is *isochrones*. FoSSA generates isochrones based on a user's specified average degree of consolidation, *U*, which is a function of the excess pore water distribution, *Ue*. Hence, for a specified value of *U*, the program solves Terzaghi's equation by time increments in order to find the corresponding *Ue* and its associated *U* until such cumulative time that the computed *U* is the same as the target value.

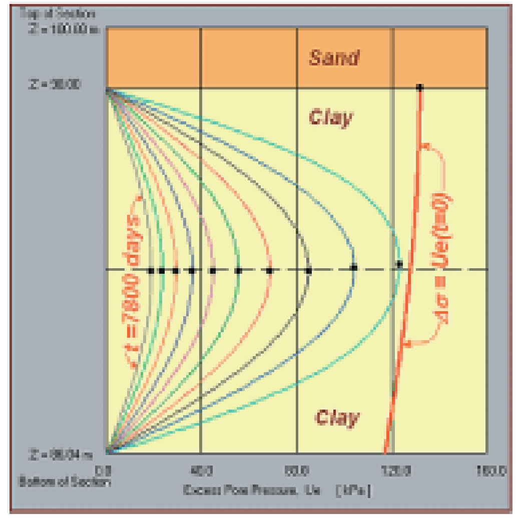

***Figure 5**. The dissipation of excess pore water pressure along a vertical cross section through the consolidating clay layer.*

Figure 5 was generated for a specified target average degree of consolidation: of *U* = 90%. The program found that it will take about 7,800 days to reach a consolidation average of 90%. The thick red line on the right represents the initial conditions (at time *t* = 0, immediately after load application). It is equal to the Boussinesq vertical stress distribution initially carried entirely by the pore water as an excess pressure. Shown next are 10 curves (isochrones), each at a different time—the first curve (turquoise color) is at about 780 days after load application; the second is at about 1,560 days; and the curves continue in increments of 780 days until the last one at 7,800 days, which produces *U* = 90%.

Notice that the excess pore water pressure drops quickly to zero at the draining boundaries. However, the maximum *Ue* (marked by a thick black bullet) quickly shifts to the center of the clay layer. That is, the dissipation of excess pore water pressure will be slowest near the center of the doubly drained clay layer, since the water flow path needed to enable such dissipation is the longest.

The distribution of excess pore water pressure, *Ue*, serves to calculate the average degree of consolidation, *U*, and subsequently the settlement, *Sc*, at any time during the process. It should be noted that in a strict mathematical sense, it will take infinite time for *U* to reach 100% (i.e., as *Ue* dissipates, the flow rate of water through the interconnected voids decreases). It is quite common in geotechnical engineering to consider *U* = 90% as a practical limit that is "close enough" to complete (100%) consolidation.

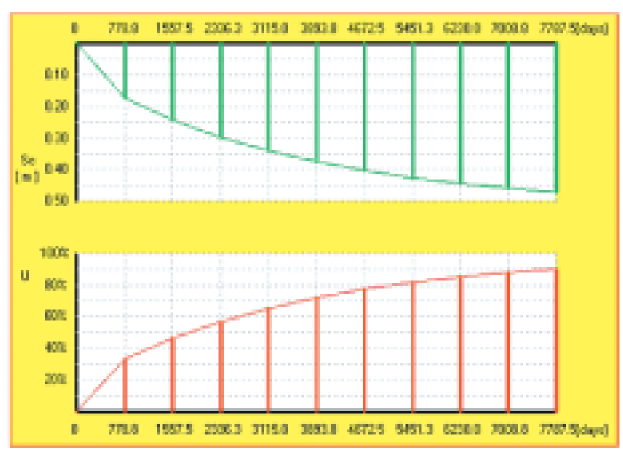

***Figure 6**. Settlement, Sc, and average degree of consolidation,* U*, versus time.*

Figure 6 was generated following the results in **Figure 5**. One sees that *U* rapidly increases; at 90% it reaches an asymptote (i.e., the increase in *U* versus increase in time increments becomes smaller). The respective settlement, *Sc*, is directly proportional to *U*. It should be pointed out that a field measurement of settlement is quite simple. Hence, the validity of results can be ascertained. Quite often the rate of consolidation is faster than predicted. This is mainly due to the existence of thin sand seams, which facilitate drainage, within the consolidating clay layer. Using field data, a designer can re-assess the computations by “calibrating” the input data to produce, she hopes, a more reliable prediction for the next time increment (i.e., observational methods); and, thus, adjust construction activities.

The distribution of *Ue*, **Figure 5**, makes it possible to assess the average actual soil stress (i.e., effective stress). That is, *Ue* dissipates the intergranular stress increase proportionally. (The stresses induced by the embankment, carried initially by the water, are gradually transferred to the soil solid particles.) This is accompanied by a decrease in the volume of the voids (hence, settlement) and an increase in the shear strength of the foundation soil. **Figure 7** shows such an increase. Initially ($t = 0$), the shear strength distribution is linear. (See thick red line.) As consolidation proceeds, the strength increases rapidly and reaches its full consolidated value at the boundaries. The heavy black dot shows that the lowest strength is slightly above the center of the clay; however, with time it shifts upward, signifying the same trend as at $t = 0$. The location of the lowest strength would depend on *Ue* and the specified initial distribution of strength.

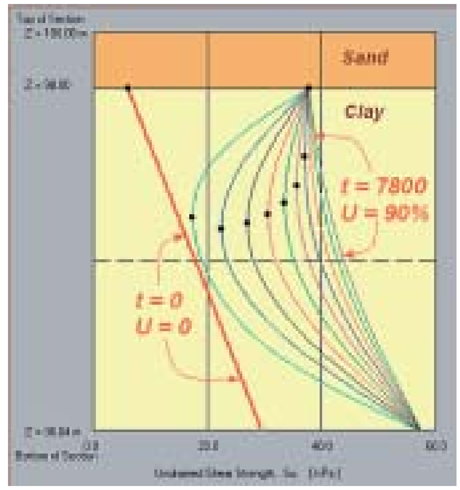

Figure 7*. Shear strength distribution versus time.*

Knowledge of the shear strength is extremely important in the design of embankments over soft soil. It enables the designer to assess the stability against deep-seated failure versus time (and not only settlement as implied by basic consolidation calculations). In fact, the main motivation for staged construction is to allow the foundation soil to gain sufficient strength before adding another layer of soil. FoSSA enables a designer to estimate the shear strength gained after each loading stage and thus estimate the needed time lag of ceased construction until the next soil layer can be placed so as to maintain a sufficient margin of safety against collapse.

Stability analysis was not conducted in this example problem. It is possible that analysis of that sort will lead towards staged construction to ensure constructability.

Prefabricated vertical drains (PVDs)

The computed results show that it will take about 21 years for the foundation soil to consolidate. If the embankment carries a structure (e.g., highway), it requires continued maintenance (and resources) as the consolidation settlement develops. The use of PVDs (wick drains) can be very effective in accelerating the consolidation process. Such drains can shorten the drainage path of water squeezed out; in addition to vertical flow, water now can drain horizontally to the PVD and

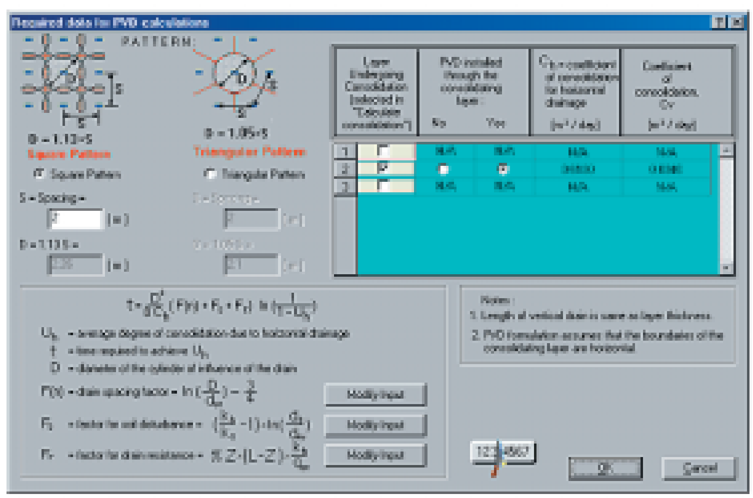

Figure 8*. PVD data is entered.*

move quickly outside the clay layer. The design challenge is to determine the spacing (and pattern) of the PVD installation, so excess pore water pressure dissipates quickly. **Figure 8** shows the input data required by the software. It includes *Ch*, the coefficient of consolidation in the horizontal direction, signifying the horizontal permeability of the clay. Depending on the clay formation, *Ch* can be larger by an order of magnitude as compared with its vertical counterpart, *Cv*. The user can select between triangular and square pattern as well as spacing. Specific parameters related to the effectiveness of a particular PVD can be entered. (The information is provided by fabricators, typically.)

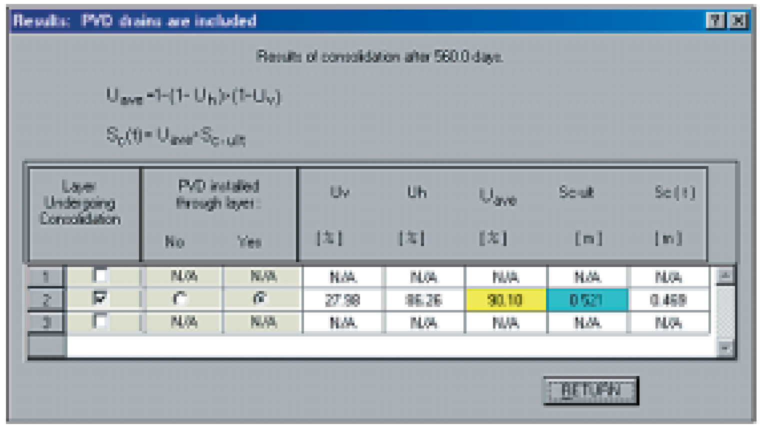

Figure 9. Effects of PVDs.

For the data in **Figure 8**, the program calculated the time required to attain a 90% consolidation. **Figure 9** shows that this can be attained within 560 days, about 14 times faster than without PVDs. Clearly, the economics of using PVDs can be rationally assessed. Furthermore, FoSSA allows for quick optimization of the PVDs layout. The effectiveness of PVDs can also be assessed in a staged construction scenario.

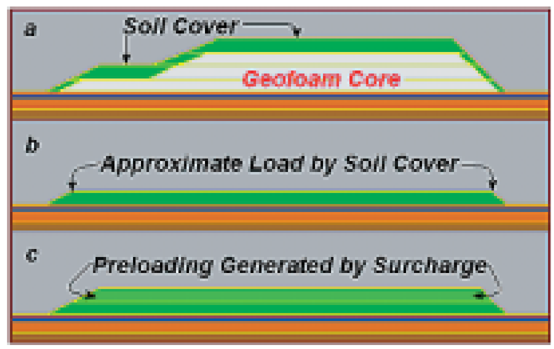

***Figure 10**. Use of lightweight fill: a. geofoam core; b. settlement due to cover material; and c. preloading to facilitate consolidation settlement.*

Lightweight fill

The effect of the PVDs was evaluated last, and demonstrated a significant decrease in consolidation time. However, the case with soft soil is often related to insufficient stability to low shear strength. One way to increase stability is to use high-strength geotextile reinforcement at the foundation interface. Another one is to conduct staged construction, placing predetermined layers of soil until sufficient strength gain is generated to allow the placement of the next layer. Often, base reinforcement combined with staged construction and PVDs is used. Alternatively, the load that produces settlement and possible instability can be reduced by using lightweight fill (e.g., geofoam, foamed concrete). Geofoam has negligible weight (relative to soil) and is easy to work with. It has to be protected, however, by a layer of soil. Hence, let us examine the case shown in **Figure 10**. We wish the final installation to be as shown in **Figure 10a**: geofoam core protected by a soil cover. The soil cover will generate some settlement. **Figure 10b** shows a simulation of this cover as used in the program to assess settlement. (Actually, the exact section shown in **Figure 10a** can be replicated by software; however, the simplification in **Figure 10b** is easier to follow and is, from a practical standpoint, valid). PVDs as specified in **Figure 8** are used in combination with the geofoam.

Figure 11a shows that after 560 days, the settlement due to the soil cover only will reach 90% consolidation. Note that the consolidation rate is the same as in **Figure 9** where the full embankment height was used. However, for the entire embankment the ultimate settlement was 0.52 m whereas for only the cover soil it is 0.19 m (**Figure 11a**).

If a settlement of 0.17 m over a period of 560 days is not acceptable, the following construction scheme (**Figure 10c**) is possible: in addition to the cover material, place another layer of soil to preload the clay (i.e., by design, over-consolidate the clay prior to actual construction); once the consolidation settlement reaches the ultimate value which would have been generated by the cover soil alone, the preloading layer can be removed (and, perhaps, used to construct the embankment at locations where preloading is not needed); the cover soil is then removed, the geofoam placed, and the cover soil replaced on top. Looking at the results in **Figure 11b**, one sees that a settlement of 0.19 m is generated within 200 days by preloading. Hence, at this stage, the scheme shown in **Figure 10a** can be built with near zero settlement and a high level of stability.

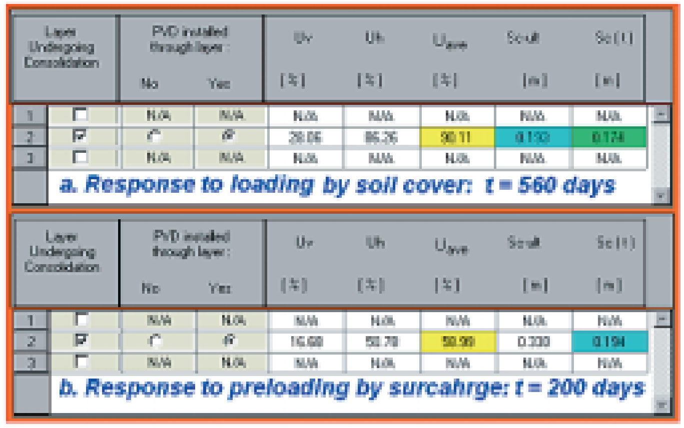

***Figure 11**. Settlement in the geofoam case: a. without preloading; b. with preloading.*

The construction scheme using the geofoam, in this example, is not more involved than the conventional case with PVDs (considering the placement of preloads and replacement of cover). In fact, it shortens the construction time to one "season" and, contrary to the case without the preloading, produces nearly zero settlement right at the end of construction. This has clear economical implications and can be compared against the cost associated with the use of geofoam.

Concluding remarks

Construction over soft soil is concerned with two major aspects of performance: stability and settlement. Both increase with time after the end of construction. There are several potential designs, of course. Checking the many options can be a cumbersome process, but software can facilitate the selection of the most suitable, sound, geotechnical solution. It is a valuable tool for designers, one we should embrace; but we must never lose site of the fact that design software is not a substitute for knowledge and experience.

Dov Leshchinsky is Professor of Civil Engineering, University of Delaware, and a partner in ADAMA Engineering. FoSSA was developed by ADAMA (www.GeoPrograms.com).

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GFR

March 2004
Volume 22, Number 2

Maximum interface shear strength

A case history from the Visalia Landfill.

By Damon Brown, CEG and Bill Urchik, P.E.

The existing 127-acre Visalia Landfill, Tulare County, California, has been in operation for over 50 years and predates the requirements of the federal Resource Conservation and Recovery Act (RCRA) Subtitle D, Part 40. The landfill does not have a liner or leachate collection system. It is scheduled to close within the next two years.

The County of Tulare has permitted a second Waste Management Unit (WMU) to be compliant with current Subtitle D requirements. Both the new and existing WMUs are located on 631 acres owned by the County. The new landfill (WMU-2) will occupy a 115-acre footprint with an allowable waste height in excess of 300 ft. WMU-2 will have approximately 17,100,000 yd.^{3} (13,070,000 m^3) of airspace and will be built in ten phases over the next 30 years. The subject of this paper is the design and construction of the first phase of WMU-2. The section in question is approximately 16 acres (6.5 ha).

The liner system

Design of the liner system was undertaken by EBA Engineering. It is permitted to accept a peak of 2,000 tons of refuse per day. The Visalia landfill accepts waste from only within the county, including six exclusive refuse hauler areas, unincorporated areas, and the cities of Visalia, Woodlake and Dinuba.

***Photo 1**. Arial photo of Visalia WMU-2 under construction.*

The state of California requires a Subtitle D composite liner system, consisting of a minimum 60 mil HDPE geomembrane underlain by two feet of compacted clay with a maximum hydraulic conductivity of 1 x 10^{-7} cm/sec. The absence of both a local source of low-permeability material and high quality drain rock, along with the associated high cost of importing these materials, dictated the use of a geosynthetic clay liner (GCL) and a geocomposite drain in the base liner design.

The original liner system consisted of the following components, from top to bottom:

- A 2 ft. thick protective operations soil layer
- A geocomposite drainage layer comprising the blanket leachate collection and removal system (LCRS) and consisting of a 5.7 mm (0.225 in.) thick HDPE geonet core heat-bonded to a geotextile filter fabric
- A double-sided textured 60-mil high-density polyethylene (HDPE) geomembrane
- A nonwoven, needlepunch-reinforced geosynthetic clay liner (GCL)
- A prepared subgrade

Calculations were performed to demonstrate the equivalency of a GCL to two feet of compacted. Data were provided to demonstrate that the GCL is compatible with the constituents in the Visalia Landfill municipal solid waste (MSW) leachate.

Regulation changes

Recent changes in the interpretation of the state's water code led the State Regional Water Quality Control Board to require double composite liners for new landfills and lateral expansions of existing landfills in California's Central Valley Region.

Subsequently, the liner system was redesigned to be a double composite system. The second composite liner system was incorporated with a 1 ft. thick soil separation layer. The primary function of the soil separation layer was to decouple the two liner systems and eliminate a weak interface between the systems. Additionally, this enhanced the constructability of the liner. **Figure 1** shows a cross-section of the final liner system design.

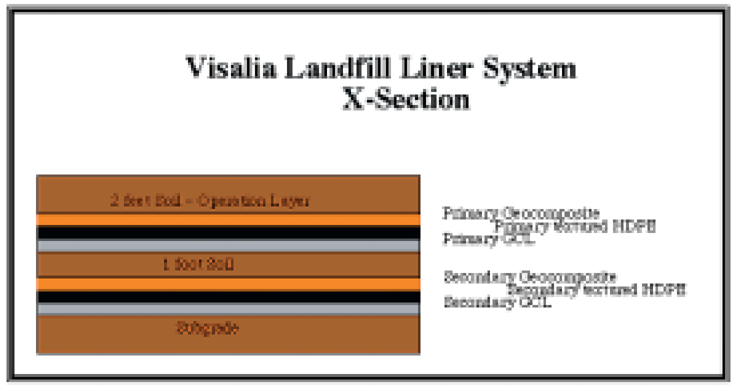

***Figure 1**. X-Section of Visalia liner system.*

Interface shear strength

Of primary concern were the interface shear strength requirements between the individual components of the liner system. Static and dynamic slope stability analyses were performed. They resulted in a minimum post-peak friction angle requirement of 17˚ between any liner component. The post peak interface shear measurements were made at two inches of horizontal displacement.

***Photo 2.** Textured HDPE being installed over GCL with the use of a slip sheet.*

The peak internal friction angle of the GCL alone was required to be a minimum of 25 degrees when sheared at a normal load of 18,000 psf, representing the expected maximum stress on the liner when WMU-2 is filled. The GCL was also required to have a minimum peel strength of 30 lb., per ASTM D 4632, to enhance longterm creep performance and further guard against internal failure of the GCL. (See "Comparison" sidebar.) While some papers indicate there may be a correlation between GCL peel strength and GCL internal shear strength under large normal loads (Mackey and Von Maubeuge 1999), more investigation is required to accurately define the potential correlation.

During the design phase, several "unconstrained" direct shear tests were performed on the entire liner system, meaning that components of the geosynthetic liner system were placed in the shear box apparatus without fixation to the upper half of the shear device. This technique allows the shearing plane to occur at the weakest interface between any of the components, including within the GCL, if lacking internal shear reinforcement. Interface shear testing of GCLs under large normal stress conditions representative of landfill liners can drive internal failure of the GCL if it does not possess adequate strength. This internal failure phenomenon was observed during the qualification testing of a particular GCL under consideration for this project. For this reason, interface shear testing is always recommended during the design phase of a project, especially when high normal and shear loads are expected.

***Photo 3**. The demand for higher waste heaps continues to fuel liner system design innovation.*

Specifications for the textured HDPE did not require a minimum asperity height, nor were there requirements for special texturing. The quality of texturing was considered a performance specification, so as to not limit manufacturers. However, all HDPE supplied to the project was required to be representative of the textured HDPE used in the contractor submittal testing. It should be noted that while there is evidence suggesting an association between maximum asperity height and peak interface shear strength, there is no strong correlation between asperity height and post-peak interface shear strength, particularly at high normal stresses. The authors did, however, observe that HDPE geomembrane sheet possessing a subjective overall higher degree of texturing (not simply a large asperity height) consistently produced higher post-peak interface strengths.

Ivy (2003) published test data showing the peak interface friction between textured HDPE and bi-planar geocomposite increasing from 24˚ to 29˚ as the textured HDPE asperity height increased from 11 mils to 31 mils. That is an increase in friction angle of over 20%. Furthermore, the large displacement friction angle of the interface with the greater asperity height geomembrane also increased over 20%. While this suggests that using a textured geomembrane with greater asperity height may increase interface shear friction angles, other geomembrane properties may be adversely affected, as mentioned by Ivy. It is evident that more investigation into this association is required.

Testing

Direct shear test parameters consisted of the following:

• The geocomposite, HDPE geomembrane, and GCL were used along with representative samples of site soils that had been remolded to 90% relative compaction at optimum moisture content per ASTM D1557.

• The GCL was allowed to hydrate under zero confining stress for 24 hours. The full normal load was applied to the specimen and consolidated for an additional 24 hours. This is believed to result in conservative shear strength test data, as the GCL is unlikely to fully hydrate under zero confining stress in the field. Should the GCL hydrate under zero confining stress in the field, further inspection and construction quality control/construction quality assurance (CQC/CQA) procedures would be required to ensure the integrity and shear strength of the GCL.

• The interface between the geonet composite and HDPE geomembrane was sprayed with water immediately prior to testing.

• The test was conducted at a shear rate of 0.04 in./min until a minimum displacement of 2 in.

The GCL (BentomatDN) did not experience internal failure during the interface shear testing program. It was accepted for use in the composite liner for the Visalia Landfill.

Interface shear testing of other liner system components were conducted by the contractor in accordance with specific testing criteria presented in the project specifications. EBA Engineering performed additional CQA interface testing for each lot of geosynthetics supplied for the project. This resulted in three additional testing programs being conducted, confirming that the materials delivered to the site achieved the interface shear requirements of the liner components.

Photo 4. *Thorough testing by manufacturers during product development and CQA personnel in the project design phase helped make the Visalia Landfill project, with its geosynthetic mix, a success.*

At the conclusion of the testing program, it was found that only one combination of GCL and geomembrane achieved the internal and interface shear strength requirements for this project. Interestingly, these materials were supplied from two separate manufacturers, each of whom committed to supplying products which were optimized for shear strength. This project is an excellent example of how geosynthetic shear testing was conducted in the design phase prior to the bidding process of the project to validate design parameters. The ultimate responsibility however, is left to the manufacturer of the geosynthetic products to produce a product (if possible) to meet the particular specification.

Conclusion

Liner installation began in late July 2003, and concluded in early November 2003. Particular attention was paid to minimize the amount of wrinkling in the HDPE in an effort to reduce potential pathways for leakage. This also created more opportunity for maximizing the interface shear characteristics of the HDPE/GCL interface.

This phase of the Visalia landfill expansion required specific geosynthetic products to meet an extremely difficult specification to assure stability of WMU-2. Standard products were simply not capable of meeting the specification. Engineers are perhaps becoming complacent with the term “site specific.” While some design properties are more or less universal, most landfill liner designs do indeed have very unique and specific requirements as well. Manufacturers must understand the requirements of their customers and must continue to refine their geosynthetic products to meet these requirements. Likewise, designers need to understand the limitations of these products and must realize that special products may come at a premium. The Visalia landfill expansion was perhaps a unique example of how a designer and a team of manufacturers worked closely together to create an effective solution for a client. As more and more landfills are being permitted to be higher with more refuse being deposited in each cell, the attention on stability of these cells is paramount. Shear strength specifications are becoming more difficult to meet, requiring “special” geosynthetic solutions for these projects.

Acknowledgements
The authors wish to thank and acknowledge the cooperation of Jeff Monaco and the Tulare County Resource Management Agency for allowing the use of their case history in this paper. GFR

Damon Brown, CEG, works for EBA Engineering, Santa Rosa, Calif.

Bill Urchik is a project engineer for CETCO, Arlington Heights, Ill.

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Comparison of peel specifications per ASTM D4632 and ASTM D6496
It is becoming more common for engineers to specify GCLs possessing peel strength greater than the industry standard certified value of 15 lb., per ASTM D 4632, especially for landfill bottom liners expecting large normal stresses. However, a new ASTM peel strength method (D 6496) for GCLs has been implemented. Designers should be aware that the new test method involves different testing and reporting procedures and therefore yields different test results when compared to ASTM D 4632. If the new peel method had been specified for this project, the required peel strength would have been 5.03lb./in. This is equivalent to the ASTM D 4632 value of 30 lbs as originally specified.

Standard GCL Peel Value	*High GCL Peel Value*
ASTM 4632 – 15lb.	ASTM D 4632 –30 lb.
ASTM 6496 – 2.5lb./in.	ASTMD6496–5.03lb./in.

Project Information
Owner: Tulare County, Calif.
Design engineer: Damon Brown, EBA Engineering, Santa Rosa, Calif.
Installer: D&E Construction, Visalia, Calif.
GCL: Bentomat DN from CETCO, Arlington Heights, Ill.
Geosynthetic shear testing laboratory: SGI Testing Services, Norcross Ga.

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Support systems in New Zealand

Making roads safer for expanding populations.

By Moninder (Witty) Bindra, MTech, MBA, MASCE

Transit New Zealand (TNZ) constructed a new $14.2 million, 5.5 km long section of State Highway 2 (SH2) between Kaitoke and Te Marua, just north of Upper Hutt in New Zealand. At the time the project went to tender, 92 crashes had been reported along this section of highway over a five-year period. Two of the crashes resulted in fatalities and 26 involved injuries.

The stretch of road is a key route the Wairarapa: over 5,000 vehicles use it daily; and overall traffic is expected to increase by 3.6% per year. The client wanted a design that maximized motorist safety.

Project partners

Opus International Consultants Ltd.'s design involved various civil works, including installing drainage, clearing topsoil and shifting ground material from hilly areas into hollows to provide a consistent new road in the naturally hilly terrain. In some areas the contractors excavated to 25 m below the existing surface and moving this ground material into low troughs to build up the land. In total, 580,000 m^3 (758,600 $yd.^3$) of soil was moved. Of the total volume, 360,000 m^3 (470,900 $yd.^3$) was used on the project; the remaining 220,000 m^3 (287,700 $yd.^3$) was taken off site. Higgins Contractors Ltd. were the main contractors. Rick Goodman and Sons Ltd. undertook the extensive earthworks. Though standard earthmoving gears were used—scrapers, excavators, dumpers, large-capacity road trucks—the site presented many interesting challenges to the roadwork crews. One gully section was not only exceptionally deep but too close to twin storage lakes to be contained by a retaining wall. A 40 m two-span bridge was built to solve this problem.

Soil solutions

The geology of the site was such that the realignment passed through a variety of soil types. They ranged from gravel to greywacke to, at the northern end of the realignment, fine clay-based silt. The silt contained a high water content. It required extended drying and consolidation to ensure it could safely carry a four-lane highway.

***Photo 1**. Placement of geogrids.*

The simplest solution was to excavate the original material and replace it with a better quality soil; but that was economically feasible only close to the surface. In deep fill areas, various methods were required to improve soft subgrades.

Nonwoven geotextiles—Syntex from SI Geosolutions—were installed to ensure that the ground was well-drained of excess moisture. They provided the new road with a stable base. In total, 60,000m^2 (71,760 $yd.^2$) were supplied by Permathene Ltd.

The geotextile is a needlepunched staple fibre polypropylene geotextile with high resistance to degradation and creep. The advantages of polypropylene for this site included good chemical resistance and the fact that polypropylene doesn't absorb water.

Wick drains, inserted into the underlying material, provided further support. The wick drains were drilled through the geotextile to a depth of about 4 m, spaced at 1.5 m intervals. A common stabalizing method involved putting down a geotextile blanket and overlaying it with up to 250 mm of drainage aggregate. Tones of rock and earth were then placed over the drainage blanket. The weight of this material forced water up through the wick drains, out horizontally through the drainage blanket, and away from the area.

***Photo 2**. A combination of geogrids and wick drains improved the stability of site soils, creating a safer stretch of road.*

Following installation, the area was left undisturbed for three months to give the ground time to consolidate sufficiently. Over that period, the site was monitored constantly so a decision could be made as to when to move to the next stage.

Geogrid support

To boost the subgrade's load bearing capacity, 26,000 m^2 (31,100 $yd.^2$) of biaxial geogrids were installed. The geogrids were placed on the weak subgrade and covered with good soil. Like the geotextile material, the geogrids were manufactured from polypropylene. They had an engineering grade high molecular weight and with carbon black, a combination that met the site's need for materials with high tensile strength, excellent shearing resistance with soft soils, and outstanding durability against microbial activities and chemicals (e.g., acids, alkalis and salts).

Conclusion

SH2 is safer. It will be able to handle the expected increase in traffic volume. The extensive use of geogrids and nonwoven geotextiles on this highway realignment highlights how designs that utilize material combinations succeed—benefitting clients not only in performance but in reduced cost.

Acknowledgments

The author wishes to acknowledge the exhaustive testing the products undergo. They are manufactured at an ISO 9000 facility, and are tested and inspected in quality control laboratories accredited by the Geosynthetic Accreditation Institute's Laboratory Accreditation Program (GAI-LAP).

Project Information

Design: Opus International Consultants Ltd., New Zealand
General Contractor: Higgins Contractors Ltd., New Zealand
Sub Contractor: Rick Goodman and Sons Ltd., New Zealand
Geosynthetic Supplier: Permathene Ltd., New Zealand
Geotextile: Syntex 801 Nonwoven from SI Geosolutions, USA
Geogrid: Etsong 2020 from Qingdao Etsong Geogrids Co. Ltd, China

Moninder (Witty) Bindra, MTech, MBA, MASCE, is a general manager with Permathene Ltd., Avondale, New Zealand. Permathene is an ISO 9001 and ISO 14001 certified supplier, and a corporate member of the International Geosynthetics Society (IGS) and the International Erosion Control Association (IECA).

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Geosynthetics in the city

Editor's note: In the March 2003 issue of GFR*, we highlighted a few projects that created public spaces: sports stadiums with geosynthetic turf support, multi-liner systems in northern ponds, polymeric materials that protected park trails from ATV damage.The following projects demonstrate two more common public designs that incorporate geosynthetics: out of sight, but not out of the designer's mind.—CK*

Mission Street

By Bruce N. Wright

A computer study of the sun's daily path shaped this intimate park in downtown San Francisco. Underneath, geotextiles help direct stormwater runoff and control root growth. Every urban park fights for its piece of the sun. Some are doomed by historical circumstance to grabbing solar rays vicariously from reflections off of surrounding office towers; but some, such as 560 Mission Street, San Francisco, are lucky to get direct access to Sol's warm embrace. A narrow slot between tall buildings on three sides, 560 Mission has a favorable southern exposure that inspired landscape architects Hart Howerton to hang their design upon the few hours of direct sunlight the park receives each day.

Photo 1*. Specifications called for a root barrier sheet, a prefabricated drainage course, and filter fabric to ensure proper conditions for the bamboo grove.*

The small park—0.2 ha (0.5 acre)—is an urban public plaza in the burgeoning South of Market district in downtown San Francisco, located next to a 31-story office tower, a seven-story office building and on top of a parking garage. The east side of the project posed a particular challenge because a seven-story blank wall dominated the space. The solution was to paint the wall an intense red and place a tall grove of bamboo next to a cascading series of terraces that provide seating in the sunniest parts of the plaza. In addition to the bamboo grove—which is bisected by a gently sloping pedestrian ramp—a small field of Japanese maples (to mark the seasons with changing foliage) presides over a collection of movable chairs and tables. At street's edge, a reflecting pool with a kinetic sculpture attracts passersby.

To provide sufficient soil depth above the parking garage for the lawn and bamboo elements of the landscaping, Hart Howerton built up the terraces from 330 mm to 1m depth for the length of the red wall and installed filter fabric to ensure controlled drainage off the site and into the city's storm sewer system. The design won a 2003 Design Merit Award from the American Society of Landscape Architects (ASLA).

Project data
Landscape architect: Hart Howerton

Design architect: Cesar Pelli & Assoc.

Architect of record: Kendall/Heaton Assoc.

Geotextile: 14ONC/Filterweave 401 from Mirafi

***Photos 2 & 3**. (Left) Fabrics control drainage between the park and a parking garage directly beneath it. (Right) A kinetic sculpture and water feature draw pedestrians.*

901 Cherry Offices for Gap Inc.

By Barbara K. Hower

In 1994, a small number of design firms participated in a design competition for The Gap's new corporate campus in San Bruno, California. The campus is located on a sloped, wooded 4.8 ha (12 acre) parcel in the hills above San Francisco International Airport. Cherry and Bayhill avenues bound the site to the east and south and a freeway off-ramp from Interstate 380 to the west and north. Although The Gap was interested in environmental design concepts, its primary goal was to create a great place to work.

The 17,550 m^2 (188,900 $ft.^2$) project consists of a two-story building that steps up the sloping site and includes office and conference space organized around three atria. A commons located at the building entry contains a conference facility, dining cafe, and health center with swimming pool, and outdoor areas include terraces, a large plaza, and a series of gardens on the sloping site.

The new Gap campus is located in a part of San Bruno once part of an oak savannah ecosystem. Because the last remaining vestiges of this ecosystem were on site, the design team decided to mimic the savannah on top of the building. The green roof was designed as continuous, undulating grassland covering most of the site, with large openings cut into it for the oak grove.

Winner of the competition and design team leader for the master plan was William McDonough + Partners/ The design team included Gensler & Associates, executive architect and interior design architect; Hargreaves & Associates, landscape architect; Ove Arup & Partners, structural and mechanical, electrical and plumbing engineers; William Wilson and Associates, construction manager; Swinerton, general contractor; and Paul Kephardt, native grassland specialist.

Some cost benefits:

• Aesthetic enhancement: The green roof creates engaging surroundings and visual environments for employees, and the native grasses and plants reflect the local foothills in color and texture, while attracting birds and butterflies.

• Acoustic insulation: The green roof serves as an acoustical dampener. The roof mitigates the sounds of adjacent freeway off-ramps and the flight path of San Francisco International Airport.

• Thermal insulation: The soils and insulation within the green roof system lower the cost of cooling and heating the building. Ove Arup estimated that the thermal mass of the roof would modify the building's rate of temperature change and result in significant energy savings.

• Extended durability of membrane: The waterproofing membrane is protected from ultra-violet degradations, mechanical puncture, and thermal shock, which extends its life expectancy significantly beyond that of a conventional roof membrane.

• Local environmental impact: The green roof modifies the local micro-climate, affecting temperature and humidity, while creating oxygen and counteracting some of the carbon dioxide produced by the building.

• Storm water retention: The average annual rainfall in San Bruno is approximately 76cm, which equals approximately 1.9 million liters of water absorbed by the 6,300 m^2 (67,810 $ft.^2$) roof.

The project received a Green Roof Award of Excellence in the New Extensive roof category at the First Annual Green Roof Infrastructure Conference.

Green solutions

Green roofs are green space on top of a human-made structure. A green roof generally mimics typical soil strata, except the plants are not planted in the ground but in a green roof system. Modular roofing systems consist of drainage layers, filter cloth, growing media, and plants that are prepared in movable, interlocking grids.

Photo 4. *Green architecture designs merge geotechnical and roofing technologies.*

Green roofs are fast becoming a mainstream technology. The current way that buildings are designed, constructed, used, and demolished cause many problems in our communities. Statistics published by the United States Green Building Council show that commercial and residential buildings in the United States account for 65% of total electricity consumption, 36% total primary energy use, 30% of the total greenhouse gas emission, and 124 million tons of waste generated. And urban areas are growing at a rate of 3% per year.

The market for green roofs is, so to speak, "ripe." Green roofs help restore a city's stripped vegetation.

GFR

Barbara K. Hower, based in Chicago, is a contributing editor of Fabric Architecture.

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Agricultural applications for geosynthetics

Editor's note: Selections from the GMA Educational Series are reprinted here by permission.

Some of the earliest geosynthetic specifications in the United States were directed at the use of pond linings for agricultural water preservation. These early application concerns included the lining of ditches, agriculture farm ponds and water harvesting catchments in arid regions. Today, the applications range widely from covered and uncovered ditch linings and ponds to geosynthetic linings that protect groundwater, soils and surface waters from animal waste.

Photo 1. *Animal waste lagoons produce toxic emissions (e.g., ammonia and hydrogen sulfide). Geosynthetic cover systems can contain emissions, and in conjunction with methane conversion equipment produce power for heating structures—barns, houses—and water. Excess power can be sold to local grids.*

The use of geosynthetics, and in particular geomembranes, on the farm has come a long way and has grown significantly in recent years, especially with more stringent federal and state legislation. Also, environmental public awareness has increased due to programs developed by the U.S. Department of Agriculture/Natural Resources Conservation Service (NRCS) and U.S. Environmental Protection Agency (U.S. EPA).

Containment as a requirement

As water becomes more scarce—thus, costly—providing a barrier against high rates of water seepage loss will become a requirement in more than just arid and semiarid regions. In addition to water conservation, wastewater containment is an essential component in protecting water and air from pollution caused by animal waste. Containment with a reliable, time-proven method is a requirement, not just an option, due to recently enacted environmental legislation.

Whatever the reason for containment, geosynthetics provide a reliable, cost-effective, better-performing alternative to traditional compacted soil and clay liners. Traditional soil approaches provide less in seepage control and are highly variable in quality; and they may not be acceptable for design and regulatory compliance. Although geomembranes are the primary type of geosynthetics used as a barrier or cover system, other types of geosynthetics are used in conjunction with geomembranes, such as geotextiles, geocomposites, geonets, geosynthetic clay liners (GCLs) and geopipe. In addition, coated fabrics and geocomposites are being used strictly for odor control on large waste lagoons.

CAFOs and legislation

The National Pollutant Discharge Elimination System (NPDES) and permit regulations for large Confined

Animal Feeding Operations (CAFOs) was issued by the U.S. EPA as a final ruling and became effective in April 2003. This federally mandated ruling will ensure that CAFOs take action in managing animal waste, which includes the lining of waste lagoons. The U.S. EPA estimates that the new regulations will affect 15,500 of the largest livestock operations. This means that all CAFO waste lagoons and evaporation ponds must be lined and many must be covered for odor control. Smaller farm operations will be affected, too.

***Photo 2**. Geosynthetic clay liner was installed at this farm in Minnesota.*

Animal waste lagoons

Animal waste lagoons have long been under-engineered and currently contribute to the pollution of ground and surface waters. To control waste seepage, the NRCS allows compacted earth linings and geosynthetics. However, with the growing concern over pollution and federal legislation, the use of geosynthetics has increased rapidly. In particular, exposed geomembranes, geomembranes with soil cover, and geosynthetic clay liners with soil cover have been used. In addition, geotextile and geonet composites are used for protection and gas transmission. Many of the large CAFO operations use concrete containment channels and holding pits directly under or close to the barn or animal housing structure where continuous wash down and flushing of the waste occurs. These areas are lined with geomembranes to prevent seepage contamination.

Odor control covers

A growing number of scientists and public health officials have traced a variety of health problems to the vast amounts of concentrated animal waste, which emits toxic gases such as hydrogen sulfide and ammonia. Odor control covers can be a low cost geomembrane or coated fabric; or, they can be a more expensive engineered floating cover system, depending on the design and criticality of the containment. Both scrim-reinforced and non-reinforced geomembranes and geocomposites are being used extensively in the control of odors and greenhouse gas emissions on the farm.

Water conveyance

In addition to controlling environmental contamination by providing a barrier, geosynthetics, and most notably geomembranes, have been used for decades in preserving clean water for on-farm use. The conveyance of water in ditches, laterals and main canals for delivery to crops is as common as on-farm water storage tanks and ponds. However, frequent drought conditions in many parts of the United States have depleted water supplies and increased irrigation costs. Seepage loss in water conveyance channels can approach 50 percent. Seepage loss of valuable water can be eliminated with the use of geosynthetic lining systems. Soil-covered and exposed geomembranes are used extensively in the lining of both new and old canals that require rehabilitation. Old, cracked, concrete-lined canals have lost their effectiveness over the years and are being replaced or repaired. One viable method for repair of old concrete is to provide an exposed geomembrane lining system over the concrete. This method not only saves valuable water, but saves money as well. New construction with concrete also requires a geomembrane under the concrete to prevent seepage loss once the concrete has cracked. Water conveyance systems use other geosynthetics in conjunction with geomembranes such as protection geotextiles, geocomposites and geogrids.

***Photo 3**. With water loss exceeding replenishment, irrigation districts are turning to canal liners. Geomembranes, either on their own or combined with concrete linings, perform extremely well.*

Stock water containment

Water containment in ponds and concrete tanks for on-farm use is just as important as water conveyance in that seepage and loss of valuable water should be minimized, especially for remote ponds and tanks. Soil-covered geomembranes and GCLs are used for the construction of new or the rehabilitation of old ponds. Exposed geomembranes are used to reline old stock water concrete containments or tanks.

Anaerobic digesters

Anaerobic digesters are used to rapidly decompose animal waste in a controlled environment; thus, allowing the recovery and use of methane-rich low Btu biogas. Biogas is used to fuel combined heat and power (CHP) generators that produce on-farm electricity, providing heat and hot water for barns, washing operations, and domestic use. (Excess power can be sold to local grids.) Also, they are a viable method of waste management due to the fact that both bottom-lining systems (described above) and flexible-cover systems are used. With every digester constructed, geosynthetics are used to either line the anaerobic lagoon or cover the lagoon for collection of biogas. According to the U.S. EPA AgStar digest, the number of operating digesters has increased by more than 30 percent in the last two years. Greater federal funding has become available for farm installations. Exposed geomembranes are used to line the lagoons in combination with geotextiles and geonet composites depending on the design. The most frequent type of cover system is composed of a reinforced geomembrane that is designed for gas inflation pressure, wind resistance, rainwater collection and access. The geomembrane cover systems for anaerobic digesters are engineered covers due to the fact that they must resist considerable stress and provide an effective service life.

For more information

Contact the Geosynthetic Materials Association, 1801 County Rd. B W.; Roseville, MN 55113-4061; +1 651/225-6942, fax +1 651/631-9334, e-mail dfhalloran@ifai.com, Web site www.gmanow.com. GFR

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Getting involved in North America

Editor's note: Future columns will detail groups outside of North America.

Often, successful engineers, contractors and academics belong to professional societies, associations or institutes. Activity has its rewards. Membership, whether individual or corporate, provides business links, education, chances to develop standards, research support, market studies, general community, etc. Of course, not all groups present opportunities for involved membership. A two-person consultancy will probably not join a manufacturing group such as the Geosynthetic Materials Association (GMA). However, disparities of immediate specialty should not prevent one from investigating other groups. There are benefits to knowing what other specialists are doing.

For example, phytoremediation is rarely part of a geosynthetic or geotechnical discussion. (See article on page 14, *GFR* March 2004.) It's rarely discussed outside of phytoremediation circles, for that matter. Some of its proponents even fear that broader engineering firms, if they get involved, will hamper the development of phytoremediative technologies; but if you research who is at work in that field, what concerns they're focusing on, what benefits they foresee—all of it expands your options. Manufacturers and distributors of seeded erosion blankets can incorporate metal-absorbing plants into vegetated products; designers can build them into a project (e.g., rhizofiltration with a leachate collection system) and find the right company to produce it; construction quality assurance (CQA) specialists and installers can develop appropriate site protocols, etc. In short, a larger view opens opportunities, even if you intend to keep your practice relatively specialized (or relatively general).

The geosynthetic community offers many professional resources to assist your work. Get to know these groups. They offer short courses, publish material to support your project bids, affect regulation, improve project teams. They speak to professional chapters, develop joint work efforts, train personnel, host conferences. Even if you are not eligible to join a certain society or association, or their work is just too far outside your direct interests, you might develop a solid professional connection still.

The following list contains only a handful of the many important groups in the geosynthetic engineering field. Visit their Web sites. Contact them to find out more about ways you can work together.—*CK*

Geosynthetic Materials Association (GMA)
www.gmanow.com
GMA represents a number of geosynthetic manufacturers. With its focus and task groups—e.g., the Water Management Task Groups—it produces educational literature, develops seminars, and assists designers and construction professionals in locating the right project material.

Canadian Geotechnical Society (CGS)
www.cgs.ca
CGS is an independent non-profit society that encompasses a wide spectrum of scientific and engineering disciplines within the geo field. See page 10 of *GFR* March 2004 for information regarding GeoQuebec 2004.

Erosion Control Technology Council (ECTC)
www.ectc.org
Members of ECTC are leading the way in standardizing rolled erosion control products (RECP) and providing specification assistance in this growing field. ECTC's work is vital to mitigating runoff and stainability concerns in many civil engineering projects.

Geosynthetic Institute (GSI)
www.geosynthetic-institute.org
GSI has been a major force in the geosynthetics arena. (A GSI column appears regularly in *GFR*'s pages.) Its interests in research, testing and education have helped refine materials and bridge gaps between competing standards organizations. See page 12 of *GFR* March 2004 for more information.

Geosynthetica.net
www.geosynthetica.net
This free, online-only resource publishes news and technical documents relevant to work with geosynthetics. Geosynthetica.net also provides marketing services for its underwriters.

International Association of Geosynthetic Installers (IAGI)
www.iagi.org
IAGI's members are well-trained in properly handling and installing geosynthetic materials on job sites. This is vital to a project's success—especially from a liability standpoint. IAGI has developed a number of influential programs, including a very sound HDPE welding certification program. It is also contributing vital site-experience insight to electrical leak location discussions.

North American Geosynthetics Society (NAGS)
www.nagsigs.org
NAGS is part of the International Geosynthetics Society (IGS). Its members are involved in most segments of civil engineering. They frequently author papers, provide instruction, and guide research and testing.

PVC Geomembrane Institute (PGI)
http://pgi-tp.ce.uiuc.edu
Through its education and research efforts, the PGI advances the use of PVC geomembranes. See page 10 of *GFR* March 2004 for a review of a PGI short course. GFR