The Golden Canyon at Death Valley National Park

ΕΛΛΗΝΙΚΗ
ΕΠΙΣΤΗΜΟΝΙΚΗ
ΕΤΑΙΡΕΙΑ
ΕΔΑΦΟΜΗΧΑΝΙΚΗΣ
& ΓΕΩΤΕΧΝΙΚΗΣ
ΜΗΧΑΝΙΚΗΣ

Τα Νέα της Ε Ε Ε Ε Γ Μ

137β

Αρ. 137β – ΑΠΡΙΛΙΟΣ 2020

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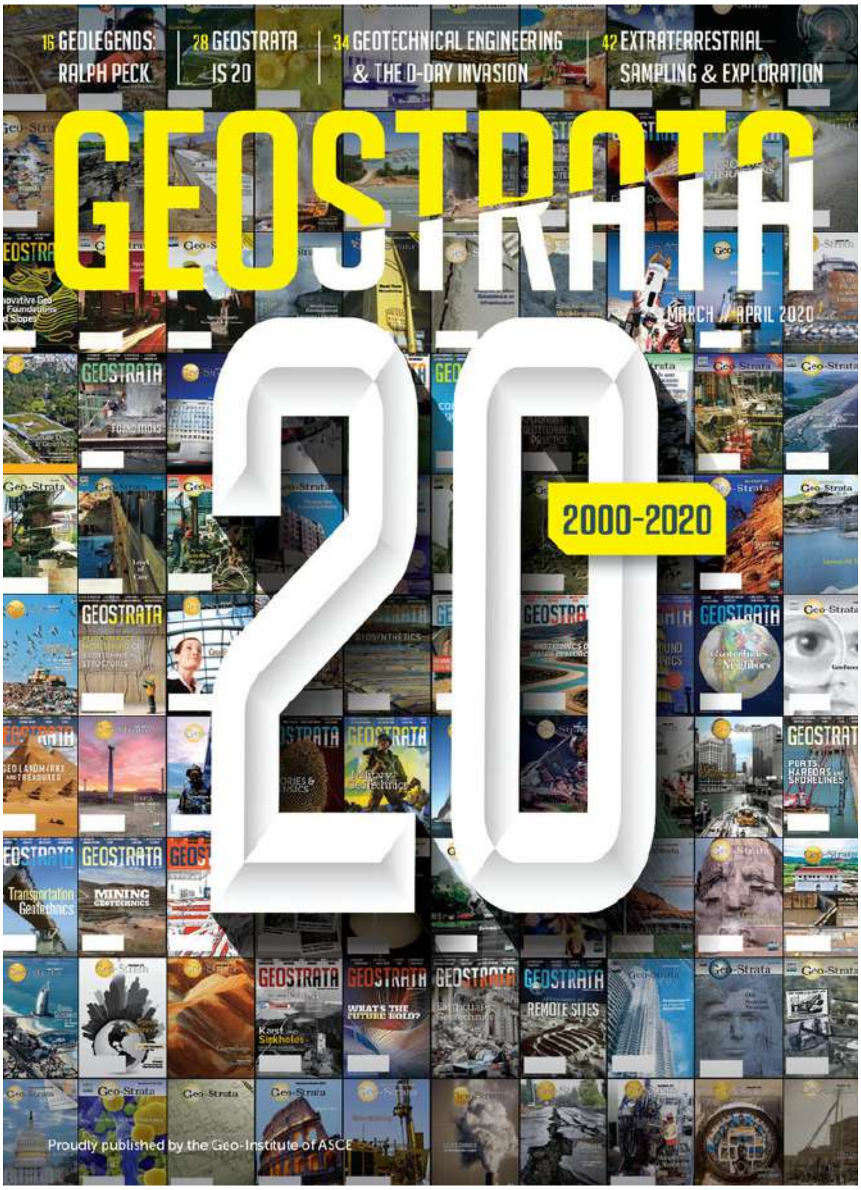


Αφιέρωμα στο GEOSTRATA

Π Ε Ρ Ι Ε Χ Ο Μ Ε Ν Α

Το τεύχος αυτό του περιοδικού περιέχει δημοσιεύματα από το επετειακό τεύχος (20 χρόνια από την πρώτη έκδοσή του) του περιοδικού του GeoInstitute της American Society of Civil Engineers. Μπορείτε να βρείτε το τεύχος αυτό στον ιστότοπο https://www.readgeo.com/geostrata/mar_apr_2020/

Σεισμός 5,3 ρίχτερ ταρακούνησε το Ζάγκρεμπ κόβοντας το ηλεκτρικό ρεύμα σε αρκετές περιοχές και προκαλώντας κάποιες υλικές ζημιές. Όσο για το εικονιζόμενο έργο ανήκει στην καλλιτέχνη Ivona και έχει τον τίτλο «Broken heart».

(Αιμιλία Καλογεράκη / φωτογραφήματα / Η ΚΑΘΗΜΕΡΙΝΗ, 25.03.2020, https://www.kathimerini.gr/1070755/gallery/multimedia/fwtografia/fwtografhmata)

Ο Dr. Thomas B. Jefferson (Dean of Engineering and Technology, Southern Illinois University at Carbondale), είπε:

“**Ένας καλός μηχανικός πρέπει να είναι έξυπνος και τεμπέλης. Έξυπνος για να βρίσκει τη λύση σε ένα πρόβλημα και τεμπέλης για να βρίσκει την απλή και εύκολη λύση**”......

(από τον Νίκο Μαρσέλλο, Πολιτικό Μηχανικό ΕΜΠ)

From the Editorial Board

Twenty years ago, I welcomed readers to the first issue of *Geo-Strata*, and with this issue I have the honor of welcoming you to the 20th anniversary issue of the magazine, now called *GEOSTRATA*. So after publishing 110 issues, we're using this milestone to not only reflect a bit on the past, but to stretch your imagination by listening to a voice from long ago, learning about the geotechnics behind two well-known milestone events, and discovering other interesting stories and features as highlighted below.

What's Inside?

My article, "Did You Know? — *GEOSTRATA* is 20," offers a snapshot of the magazine's history. How did this publication get started? What's happened during the past decade, and what's ahead?

Many have sought the sage advice of Professor James Mitchell, and *GEOSTRATA* has been no exception over the years. In this issue's commentary, Mitchell offers his insights about geotechnology's role in improving life on planet Earth in "Geotechnics in Addressing Engineering Grand Challenges." He describes how mankind's needs for access to clean water, economical solar energy, carbon sequestration, and urban infrastructure improvement will require significant geotechnical inputs if these problems are to be addressed successfully.

We've been fortunate to publish GeoLegend interviews of more than 40 of the most well recognized and respected people in our profession, but we never interviewed legendary soil mechanics pioneer Ralph Peck, who died two years before the series began. However, we were fortunate to learn about interviews with Peck that were conducted by University of New Mexico professor Fernando Moreu when he was a graduate student at the University of Illinois in the early 2000s. Working with Moreu, we converted his full interview into a memorable GeoLegend article. In it, Peck shares recollections of working with Terzaghi on the Chicago subway and writing their classic text, *Soil Mechanics in Engineering Practice*. His statement "I don't do jobs that I can't visit" should become a lasting reminder to all of us when we're pressed to do something we shouldn't.

World War II dramatically touched virtually all developed regions of the world and the people then living on the planet. There are many stories about the war that only just today are coming to light, and we have one for this anniversary issue. In "Soil Sampling at Sword Beach in Normandy, France, 1943," William Lawson describes the exploits of a pair of brave and gallant British commandos who secretly landed on the beaches around Luc-sur-Mer, France, on New Year's Eve in 1943. Their goal was to learn whether invasion landing craft could maneuver on the beaches' soils — information that proved invaluable five months later on D-Day.

Everyone has those "Do you remember where you were when?" events during their lifetime. One of mine is the first manned moon landing on July 20, 1969. At that time, a great curiosity of the geo-community was the composition and resistance of the lunar soils. In "Big Steps for Mankind," Zachary Mank, Robert Mueller, Marika Santagata, and Kris Zacny recount what was learned during the Apollo explorations, and how that experience was advanced during subsequent explorations of the lunar and Martian landscapes. It's a most interesting recounting.

In their article, "Best Practices for Geotechnical Site Characterization," Don DeGroot and Jason DeJong ask, "Have we regressed from decades past?" While there's been extensive advancement of tools and procedures in recent decades, the authors believe there's been some backsliding, possibly due to a lack of knowledge in how to conduct a reliable site-characterization program, and an underappreciation of the extent to which a poorly conducted program can adversely affect the project design, performance, and cost. They describe an integrated site characterization that folds the site investigation phase into a more comprehensive and holistic assessment of site conditions as a solution.

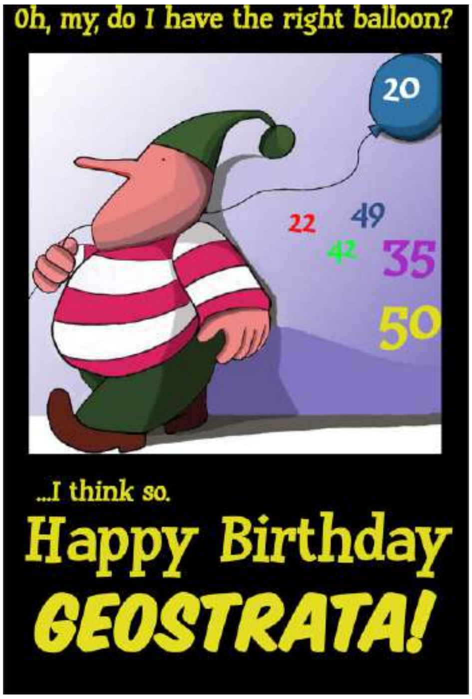
While we live in a 3D world, geoprofessionals have been trained to think and create in 2D because, until recently, tools just weren't available to do anything else. But times are a-changing. In "Creating Art and Reducing Project Risk with 3D Modeling," Michael Webster and Jennie Byron describe how they have used 3D modeling to help decision making, reduce project risk, and control costs, while revolutionizing client presentation and community engagement. And the outputs can be beautiful besides.

Michael Greenfield has worked at the forefront of recent advances in earthquake geotechnics. In his "What's New in Geo?" article, entitled "Handling Uncertainty in Geotechnical Earthquake Engineering," Greenfield describes how empirical predictive modeling for earthquake impacts has advanced so it's now possible to aggregate the uncertainties in shaking intensity, structural response, and damage into a single, decision-based, design metric of risk that's simple to communicate to stakeholders and can quantify the cost benefits of reducing uncertainty.

Back in 2007, we learned about a young geotechnical engineer's interest in writing poems for *GEOSTRATA*. We published Mary Nodine's first poem, "Blue Clay Blues," in the January/February 2008 issue. In this anniversary issue, we reprise both "Blue Clay Blues," and her July/August 2010 poem, "Lament of an Ancient Embankment Dam." So what was initially a simple inquiry from a reader has now grown into a collection of more than 60 poems and is one of *GEOSTRATA*'s most popular features.

GEOSTRATA's editor-in-chief, **JAMES L. WITHIAM, PhD, PE, D.GE, M.ASCE.**

GeoCartoon



ΑΡΘΡΑ

Geotechnics in Addressing Engineering Grand Challenges

James K. Mitchell, Sc.D., CE, GE, D.GE (Ret.), NAE, NAS, Dist.M.ASCE

I'm honored to have been asked to contribute this commentary for the 20th anniversary issue of GEOSTRATA, now the outstanding news and information publication of our profession

The Growth of Geotechnical Engineering

When I began my first course in soil mechanics as a third-year undergraduate student in civil engineering just over 70 years ago, we learned about soil description and classification, soil compaction, compressibility and settlement analysis, shear strength and stability analysis, permeability, and seepage analysis. My second course, taken the next semester, was foundation engineering. We learned about bearing capacity, lateral pressure and retaining walls, and the design of shallow and deep foundations. Upon graduation, we became members of the Soil Mechanics and Foundation Engineering Division of ASCE.

The last half of the 20th century brought many changes and expansions in the scope and depth of important and new subdisciplines that now collectively comprise what we call Geotechnical Engineering. Many of these developments are included in the Table 1.

By the end of the 20th century, new graduate programs had been established at colleges and universities, engineering practice had evolved to encompass many private firms and public agencies, and new specialty construction companies had entered the market. This growth is not surprising, given that virtually all of humankind's activities occur on, in, or with the earth, and that many of our most-needed resources (e.g., water, oil and gas, mineral ores) come from the earth, not to mention that the earth itself provides the most important and abundant construction materials available today.

Geotechnical Engineering in the New Millennium

At the dawn of the 21st century, the National Research Council of the National Academies of Sciences, Engineering, and Medicine commissioned a study leading to the 2006 report, *Geological and Geotechnical Engineering in the New Millennium — Opportunities for Research and Technological Innovation*. This report called for new technologies and tools in several areas: biogeotechnology, nanotechnology, sensors and sensing systems, geophysical methods, remote sensing, and information and cyberinfrastructure. In the first two decades of the 21st century, substantial advances have been made in all these areas.

Biogeotechnical engineering has already become a new subdiscipline of geotechnical engineering. Additional important developments have included considerations of sustainability and resilience; adoption of LRFD and performance-based design methods, adaptive management of major projects, new sensing and monitoring systems, Geotechtools (geotechtools.geoinstitute.org) for ground improvement technology information and selection, application of new numerical computational platforms such as the Discrete Element and Material Point Methods, consideration of risk and reliability considerations in hazard-mitigation projects, and increased use of artificial intelligence and machine learning.

Grand Challenges for Engineering

An international committee of technological leaders was tasked by the U.S. National Academy of Engineering to identify "Grand Challenges for Engineering in the 21st Century for improving life on planet Earth" (engineeringchallenges.org/challenges.aspx). Announced in 2008, the committee's 14 game-changing goals are now under study worldwide:

1. Provide access to clean water
2. Prevent nuclear terror
3. Engineer better medicine
4. Advance health informatics
5. Make solar energy economical
6. Develop carbon sequestration methods
7. Secure cyberspace
8. Reverse-engineer the brain
9. Manage the nitrogen cycle
10. Provide energy from fusion
11. Restore and improve urban infrastructure
12. Engineer the tools of scientific discovery
13. Enhance virtual reality
14. Advance personalized learning

The committee suggested these Grand Challenges fall into four cross-cutting themes of sustainability, health, security, and joy of living.

The Role of Geotechnology

Four of these challenges — access to clean water, economical solar energy, carbon sequestration, and urban infrastructure improvement — will require significant geotechnical inputs if they are to be addressed successfully. Interestingly, climate change was not specifically included as one of the 14 Grand Challenges. However, it's included indirectly, owing to the potential impacts of climate change on clean water, carbon sequestration, urban infrastructure, and managing the nitrogen cycle.

These problems require multidisciplinary and interdisciplinary approaches for their solution, drawing on the physical, biological, computational, and social sciences, as well as inputs from other branches of engineering. Life cycle sustainability analysis and resilience considerations must be components of new solutions.

Almost all the traditional topics within geotechnical and geological engineering must be drawn upon in addressing these challenges. The following areas will be of special importance:

- Site characterization
- Sensors and sensing systems
- Erosion and scour
- Seepage and groundwater flow
- Coupled flows
- Thermal properties and heat storage and flows
- Partly saturated soils
- Waste isolation and containment
- Embankments and levees
- Ground modification and improvement
- Rock mechanics
- Underground space

- Injection and grouting
- Modeling of complex geotechnical phenomena and systems

Geotechnical engineers also face some overarching issues that must be addressed. Among them are: 1) the need for better methods for detailed subsurface characterization and "seeing into the earth;" 2) improved understanding of fine-grained soil behavior under different biogeochemical conditions; 3) better understanding and quantification of time- and temperature-dependent changes in engineering properties of geomaterials; 4) improved ability to expand and use geotechnical "big data" sets, especially for site characterization; 5) the need to account for nonstationarity in magnitude-frequency relationships caused by climate change that are used for uncertainty and risk assessments; 6) incorporation of sustainability and resilience into our solutions; and 7) assuring environmental protection and enhancement. To maximize our contributions, it's imperative that we get involved in studies and projects at the outset and play proactive roles in anticipating future events as opposed to simply reacting to what's already happened.

JAMES K. MITCHELL, Sc.D, CE, GE, D.GE (Ret.), NAE, NAS, Dist.M.ASCE, is University Distinguished Professor, Emeritus, in the Department of Civil and Environmental Engineering at Virginia Tech. Prior to joining VT in 1994, he was on the CEE faculty at the University of California, Berkeley, for 35 years. His primary research and consulting interests have included soil behavior, soil stabilization and ground improvement, lunar soils, geoenvironmental engineering, and geotechnical earthquake engineering. He may be contacted at *jkm@vt.edu*

Did You Know? Geostrata Is 20

By James L. Withiam, PhD, PE, D.GE, M.ASCE

Spring 2000 was the first issue of Geo-Strata (now GEO-STRATA). That issue included articles on academic-industry partnerships, implementing innovative technology, marketing advice from "The Old Rainmaker," a conversation with geo-leader Wayne Clough, and a story about the then-ongoing reconstruction of I-15 in Utah.

We were also fortunate to have Ralph Peck "Look into the Future" in the magazine's inaugural issue. In his commentary, Peck told us:

- Geotechs should contribute to the design and construction of almost every civil engineering project, but the profession must guard against becoming just a routine service.
- With attorneys lurking everywhere, the profession must take proactive steps to mitigate and manage risks it faces.
- The number and expertise of specialty geotechnical contractors will proliferate.
- Computerization of geotechnical design and construction will become more pervasive, but their reasoned use will be essential.
- Geotechs will increasingly involve their clients in what they are doing and why.

After the first issue, *GEOSTRATA* would, in two back-to-back issues in 2006, publish two more contributions from Peck before his passing in 2008. In the March/April 2006 issue (p. 12), Peck applauded the use of case histories for teaching and training purposes in a commentary titled, "The Value of Hindsight." In it, he wrote "…the use of case histories of failures as a means for improving knowledge… has been one of the distinguishing characteristics of geotechnical engineering." Then, in the May/June 2006 issue (pp. 12-14), Peck offered "Advice to a Young Engineer," in which he shared wisdom he had learned from Karl Terzaghi. Those pearls are:

- If you blunder, be the first to discover and announce it. If someone else beats you to it, smile and say thank you.
- Be critical of your own concepts and skeptical toward those of others.
- When you commit an idea to print, emphasize every controversial aspect of your thesis that you can perceive.
- You can learn anything from anyone.

I mention these three contributions from *GEOSTRATA*'s initial years not only because they offered great insights from one of our profession's giants, but they lent legitimacy to a fledgling endeavor and helped encourage others to share their experiences in it. More importantly, however, if you're a younger reader, or a longtime reader who doesn't remember reading Peck's magazine contributions at the time, I recommend you track them down to take in their lessons.

GEOSTRATA: An Idea That Became a Magazine

GEOSTRATA's birth, formation, and first 10 years were highlighted in "*Geo-Strata:* A Decade of Delivery" (March/ April 2010, pp. 19-22). From the Geo-Institute's beginning, its Board of Governors believed the G-I needed a practice-oriented magazine to serve its predominately practice-oriented membership. The Board assigned an eight-person Task Force the responsibility of sorting through the details of the magazine's business operations during start-up within a general framework established by the Board. Among the many jobs facing the Task Force was to establish the magazine's objectives, identify actions for meeting them, and select an appropriate name. While the details of selecting the magazine's name are lost to history, *GEOSTRATA* is a definite brand of the G-I. More importantly, it has become the valued member benefit the G-I's founders envisioned more than 20 years ago.

Editorial control of the magazine's content is the responsibility of *GEOSTRATA* Editorial Board. The Editorial Board identifies and selects issue themes, article content, and authors, leads authors through the article development and review process, and assures that article milestones and production schedules are met. The review of issue proofs prior to publication is handled by *GEOSTRATA*'s editor-in-chief and content coordinator.

For two decades, the Editorial Board has been blessed to have had an engaged and committed group of geoprofessionals who represent the diverse backgrounds and interests of the G-I members. Equally important to *GEOSTRATA*'s success has been the oversight, creativity, and diligence of the magazine's content coordinators (CC), who edit author drafts, coordinate with the graphic designer, and rigorously review issue proofs. Interacting with more than a dozen persons at any given time, the CC's job is something analogous to a cat herder, so patience with firmness is a must. During *GEOSTRATA*'s two decades of existence, only two people have filled this important role: Kristie C. Kehoe (2005–2007; and 2013–Present) and Suzanne Davenport (2007–2013). My thanks to them both.

Communicating news and developing a revenue stream were original goals for *GEOSTRATA*. Compiling news has been the responsibility of G-I staff, who keep our readers updated on industry, company, and ASCE announcements. As for revenue, we are proud to say we have developed a loyal and longlasting core of advertisers who have helped sustain improvements and growth of the magazine. This summary of *GEOSTRATA*'s history over the last two decades would not be complete without a shout-out to former ASCE staff Linda Bayer, Diane Vance, and Sean Richardson, who all worked hard in their respective jobs to grow our magazine into the fine publication that it has become today.

What's Been Happening?

The past decade has brought about several improvements in *GEOSTRATA*'s content and look. Here are a few of them.

Lessons Learned from GeoLegends

The GeoLegend interview series was launched with the magazine's July/August 2010 issue. The series was the outcome of discussions between leaders of the G-I Graduate Student Organization and then G-I president, Jean-Louis Briaud. The articles provide an opportunity for graduate students to interview a distinguished academic or practitioner in geotechnical engineering and prepare an article suitable for publication in *GEOSTRATA*. We initially envisioned publishing two to three interviews per year, or about one every other issue. But students have enthusiastically embraced the opportunity of being part of the GeoLegend series such that with this issue, a total of 43 interview articles have been published. And the 43rd article is a true GeoLegend: Ralph B. Peck. The article is based on interviews that the author, Fernando Moreu, conducted with Peck when he was a graduate student at the University of Illinois between 2002 and 2004.

GeoPoet

GEOSTRATA's November/December 2018 issue chronicled the musings of the magazine's GeoPoet, Mary Nodine. Beginning with her first poem, "Blue Clay Blues" in the January/February 2008 issue, more than 60 entertaining poems have been published. A few of her more popular and cleverly titled poems have included "A Pile's Journey," "Battle of the Sieves," "A Sand Cone's Last Stand," "Soil Is for Poets," and "Deliberations for a Small Structure in an Unfortunate Location." We've published contributions from a handful of other geopoets through the years, and encourage any of our current readers with an interest to contact us.

What's New in Geo?

This article series was launched in the May/June 2015 issue with the goal of providing readers with a broad perspective of recent developments in research and practice that could foretell the future of our profession. Editor Mike McGuire is responsible for identifying article topics and authors for them. Jim Mitchell authored the first article in the series with a big-picture overview of what's on the horizon in geo. Since then, articles have covered earthquake geotechnics, numerical modeling, unmanned aerial vehicles, deep mixing, remote sensing, and biogeotechnics.

Did You Know?

With the July/August 2017 issue, we launched this new article type that's dedicated to little-known facts about our profession. While we've published just a few of these articles, we revisited a paper from the late 1960s that most readers have probably never seen. It's about the uselessness of using elephants to compact fill. Amazingly, we tracked down the paper's author, and he agreed to update his paper 50 years after its original publication date. Hopefully our readers can alert us to other prospects for Did You Know?

GeoCartoons

Except for cartoons created by a geotechnical engineer that we published in early issues, we made no effort to regularly include a cartoon. About three years ago, however, we began tapping into online sources where we found stock cartoons that were a good topical fit for each issue. Based on email feedback, these cartoons have solicited reader interest and enjoyment.

Magazine Redesign

GEOSTRATA has undergone several redesigns over time to enhance its appeal to readers and support the articles and news items in each issue. The most recent and dramatic redesign was published in the September/October 2014 issue on *Performance Monitoring of Geotechnical Structures*. The redesign included a more informative and aesthetically pleasing cover and table of contents. The pages became perfect-bound for a more sophisticated look, and the paper stock became whiter to make the magazine easier to read. We began stretching eye-catching graphics across the spreads introducing each feature article, incorporated more modern illustrations, and where possible, added more white space. These changes were driven by the creative efforts of G-I staff working with the magazine's graphic designer, Thor Design.

What's Ahead?

From this summary of what's been happening, you can see that *GEOSTRATA*'s team has been busy adding new content and redesigning the magazine's layout to help encourage reader interest and engagement. During the editors' annual meeting at Geo-Congress 2020 in February, we discussed what worked and what didn't over the past year, planned issue themes for 2021, and shared ideas for new content. Other topics of discussion included establishing a platform and guidelines for guest geocartoons, and the need for a comprehensive reader survey. We will also set aside a page or two in CoreBits to publish news from G-I student chapters.

Of course our face-to-face editor's meetings offer us time to float and discuss ideas for the future. One plan we will pursue is new and improved online delivery of *GEOSTRATA* to improve its access to those who don't receive or don't prefer receiving a hard-copy of the magazine. We realize that readers have different delivery preferences, so we will strive to meet them. We hope you will share your impressions and ideas to help us deliver a magazine that meets your needs today and into the future.

A Note from G-I Director Brad Keelor: Our modest editor-in-chief has done a great job of summarizing two decades about *GEOSTRATA*, but he never gave himself the credit he's due. Jim Withiam has been the driving force behind this publication since its very first planning meeting. He's the one who knows everybody in the geotechnical world and uses those connections to locate potential authors. He plans issues months in advance and is constantly considering new ideas and directions for the magazine. It's no exaggeration to say that without Jim, our fine publication would never have made it this far. On behalf of the G-I staff, the G-I Board of Governors, and our many readers, we thank you, Jim, for your tireless and unending efforts.

Lessons Learned from GeoLegends

Ralph B. Peck, PhD, PE, NAE, Hon.M.ASCE

By Fernando Moreu, PhD, PE, M.ASCE

Q: Professor Peck, how do you normally solve problems?

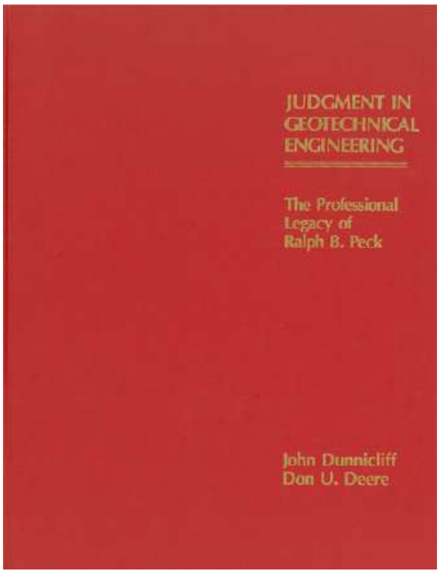
I don't think I have a formal procedure or a set way of approaching a problem. It actually depends quite often on how the problem is presented to *me*. You naturally try to find out as much as you can about the job from the initial source. Sometimes it's a potential client who is describing a job to you, or sometimes somebody has a problem and describes it. And you begin to form a judgment as to what's going on as soon as you begin to get this information. You develop questions in your mind as to what might or might not have happened. In professional jobs, almost always, you're going to go and actually see the job so you have an idea of its size, its importance, its implications, and particularly, the geotechnics and local phisiography, the geology, and so on. As this information accumulates, you get a concept of what the project may involve, and that concept is what you might begin to call "judgment." You'll see how it's related to other jobs that you might have done or other knowledge that you might have picked up. I would say that judgment is what you do with this total amount of information you get.

Q: What is "engineering judgment"?

I've always felt that a really good engineer has had enough experience to get a feel for what's the best course of action. You can make calculations and formal analyses as a matter of course, but those analyses don't solve the problems. I think they do provide insight *into* the problem. And you find that you reach a conclusion about what to do on the basis of all kinds of information that you have about a problem, not just calculations. That feeling you have about a job, I suppose, is what you call judgment. It's not necessarily a straightforward process of starting at a certain point and going through a line of reasoning and coming out with a conclusion. It's the process of bringing together anything that might bear on the problem, including experiences that you have had with something that might be similar or even might *not* be similar, and reaching a decision as to what to do on the basis of that background. That's what I call "judgment."

Q: So judgment only develops with experience?

Well, it certainly is improved and increased by experience, and I guess if you want to include experience to be life in general, you can observe what is going on in the world, what's normal and what's a little abnormal, what's usual, what's unusual, and even though it isn't a technical problem, that constitutes part of your judgment. It's a process by which you decide what to think or what to do without necessarily — or perhaps without at all — making calculations.



Do you have the book *Judgment in Geotechnical Engineering?* John Dunnicliff and Don Deere are its editors, the authors you might say. It's a selection of talks and papers, a biography of me, and so on. This book also has a paper that I wrote that's a story of the manuscript preceding the writing of *Soil Mechanics in Engineering Practice*. If you're interested in how the book developed, it describes the struggles we had, which lasted a good five or six years.

Rion-Antirion cable-stayed bridge crossing the Gulf of Corinth in Greece

Q: Is "engineering judgment" compatible with the use of computers?

Computers can save a lot of drudgery. They can solve problems quickly that we could hardly solve in the past. But I still don't think one should put a problem immediately on a computer without first making some kind of a rough estimate as to what's likely to happen or what the answer should be. If you can't do that, I don't really think you have any business trying to do it on the computer. If you don't have a sense of what the answer ought to be, you're at the mercy of this machine that can make big mistakes faster than any other way. I'm not against computers by any means, but I'm against using them blindly. I'm against using programs if you don't really understand what's in them. If people don't have enough judgment, enough sense of proportion about what the answer ought to be, then they can be misled by the computers — and misled badly.

Q: What's your biggest satisfaction as an engineer?

I like civil engineering as a profession because it produces things that make our civilization work. I like the thought of leaving behind a real dam, real structures, something of this sort. As to which job might have been the most satisfying, that would be hard to answer. Some were subway jobs. I think the Washington D.C. Metro was perhaps the most interesting one along those lines, although the San Francisco Bay Area's Rapid Transit System also was quite a challenge. I think my favorite area of working has been on earth dams, especially the James Bay project in Canada, which harnesses the power from an area about a third of the size of the state of Wyoming. It's a big area, with some 300 dams and dikes, all going through four big powerhouses. That project lasted almost 25 years. The first dams were built in about 1970, and the last of the dams was finished in about 1995.

I'm not against computers by any means, but I'm against using them blindly.

Q: What are your most recent projects?

Well, two of them were featured in 2001 and 2002 issues of *Civil Engineering*. First, there's the Rion-Antirion Bridge in Greece, which I've lectured on at the geotechnical seminar at the University of Illinois. The other is the Saluda Dam in Columbia, SC, which is an old, semi-hydraulic fill dam. The city of Columbia has grown around it, and it's now being strengthened and partially replaced because of the possibility of an earthquake. On the East Coast of the U.S., there didn't used to be much concern about earthquakes, but after there was a big one in Charleston, SC, seismologists decided that another quake like that would be felt in Columbia, and so this dam needs refurbishing.

RCC buck-up dam with rockfill berms constructed downstream of Saluda Dam in Columbia. This dam will retain a failure of the existing dam in the event of its liquefaction after an earthquake.

To fix the dam, the decision was made to build an RCC [roller-compacted concrete] dam. There's just room enough to get it in between the existing dam, which is an earth dam, and the powerhouse. It requires cutting away during construction a bit of the existing dam, and — this is the tricky part — be sure you don't cause a failure while you're cutting this away to get room to build the new one.

Q: Have you visited the dam?

Oh, yes. I don't do jobs that I can't visit. That's part of the judgment building.

Open cut for Chicago Subway construction.

Q: What new challenges will the civil engineering profession face over the next 50 years?

Well, that's really an unanswerable question. The reason I say this is that when I look back over the history of, say, structural engineering, which is what I started out to do, there have been so many changes that have totally altered the way we look at jobs. Say 150 years ago, about all civil engineers could do was use statics. And then there came indeterminate structures, and somebody invented slope deflection. Everybody was learning to use that new method, which required solving a lot of simultaneous equations, and that was hardly practical at the time. Then Hardy Cross came along with moment distribution and revolutionized the way you look at it. And then the computer came along, so it was no longer difficult to solve all these simultaneous equations. Moment distribution is almost unknown now, yet it had some real advantages. None of those was foreseen in advance, and I feel much the same way about geotechnical work. I think "geotechnics," as a sub-discipline, will be pretty much absorbed into the general practice of civil engineering and structural engineering again, but there may be some revolutions that we don't appreciate now that will come along and change things. So I'm sure there will be changes. I'm not sure exactly what they'll be, but they're likely to be pretty exciting.

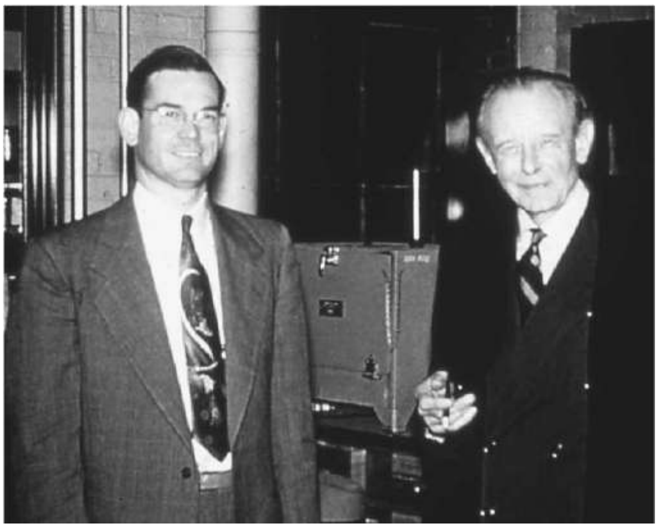
I don't do jobs that I can't visit.

Q: What advice do you have for the next generation of civil engineers?

Make the most of educational opportunities, and then after you graduate, don't be afraid to take advantage of opportunities that come along that may not be exactly what you had in mind to start with. If everybody did exactly what they were trained for, there wouldn't be any advancement. Certainly my career was totally changed by a subway experience with Terzaghi, which wasn't planned at all. If I had missed that, my life would have been totally different.

Q: How and where did you first meet Professor Terzaghi?

Karl Terzaghi was a professor at the Technical Institute in Vienna for several years after working with Professor Arthur Casagrande when he was at MIT during the late 1920s to the early 1930s. In 1938, Terzaghi left Vienna and came to Harvard as Hitler's control of Central Europe was growing. He tried to stay in Vienna until the end of the semester, but decided he'd better leave. He didn't have a job; he just left everything behind and left the country. Professor Casagrande, by then at Harvard, helped Terzaghi come to the U.S. and gave him an office. I met him because somebody said he was writing a book at the time, and one of the instructors at Harvard told me that Professor Terzaghi wanted to put grain size distribution in statistical terms. He wasn't sure of the English words for some of these definitions, and I helped him for about three quarters of an hour because I had been sitting in on a course in statistics. He just wrote down the formula for standard deviation, I told him what we call things in English, and that was it.



Ralph Peck with Karl Terzaghi

About three weeks later, Terzaghi got an appointment to be a consultant on the Chicago Subway, and he had promised to provide a man of his choosing to do the work. He didn't really expect to get the job, so when he got it, he realized he didn't have a man. I was at Harvard, not working for a degree like everybody else, so I could leave at a moment's notice — and actually my wife and I moved out to Chicago about three days after he got the job. And then of course he worked very closely as a consultant on the Chicago Subway for a long time, and that's where we really got acquainted. I was essentially his representative on the job. Initially, he came about once a month and stayed maybe a week, and then we carried on the work that he left behind. And I'd write him every day, telling him what was going on.

Ralph Peck with Thomas Thornburn and Walter Hanson

Q: What was Terzaghi like as an engineer and as a man?

He was a superb engineer. In soil mechanics, the area that he was interested in, he recognized that everything we do has a geological aspect. He didn't really try to invent soil mechanics. He tried to figure out how one could apply geology to civil engineering problems. This led him into the fundamental things that we now call soil mechanics. But he always approached a job first as a geological study and what does that imply with respect to the construction that is planned. Surprisingly, Terzaghi was not a theoretical man; he didn't really like theory. He developed theories and tried to explain things in a theoretical basis, and the theory of consolidation was certainly a great advance, but he never considered himself a theoretician. He was trying to solve practical problems, and if that involved discovering how consolidation worked to solve the problem, that's what he did.

While I only knew him the last third of his life, he was totally dedicated to his work. He was a very intense person, and he couldn't quite understand why other people didn't work as hard as he did. Even his wife, Ruth, in a letter after Karl died, made a comment to this effect. So, professionally, that would describe him. Most people regarded him as very stern, but I don't think that's right. He was really a very kindly person. He didn't mind if you made a mistake, but you had better only make a mistake once [Professor Peck smiles]. He disciplined himself so much that he expected other people to be equally motivated, but it was fun to work with him. He was so full of ideas, and in discussions, you felt like you were helping to create those ideas. He was very inspiring.

Ralph Peck while a student at RPI; circa 1931

Q: What's the story behind Soil Mechanics in Engineering Practice?

Well, technically, the contents are essentially Terzaghi's. After all, he established soil mechanics with his book *Erdbaumechanik*, in German, which was written many years before this book was written. He wrote that during and just after World War I, after he had made the fundamental experiments, the studies that led to the theory of consolidation, the concept of effective stress, and the things of this sort that are essential to the understanding of the subject. And several times he started to write books. *Erdbaumechanik* covered much of the basic theory of soil mechanics and the experiments that he used to verify the theory, but it was not a comprehensive book about what we now call soil mechanics in general. He wrote several manuscripts trying to develop the book, but they didn't quite work out. He abandoned them at times. Then he decided to write *Theoretical Soil Mechanics* with the idea that if he set down the theory, then he could devote a book to practice.

Practice was what he was interested in. He wanted to get the theory out of the way, you might say. He started to do that, and shortly after, he came over to the U.S. during World War II. I was in Chicago then. One of Terzaghi's very good friends was Al Cummings, who was the Raymond Concrete Pile Company's representative in Chicago. When we started to work on the subway in Chicago, any time Terzaghi would be in town we'd all get together with Cummings and just have conversations. As Terzaghi developed the manuscript that he wrote for *Theoretical Soil Mechanics*, he sent it to Cummings to review. Cummings handed it to me to also review, and pretty soon Terzaghi was sending it to both of us. And we spent the better part of a year critiquing that manuscript. Terzaghi revised large parts of it many times, actually. That would have been about 1939, `40, `41… finally appearing as *Theoretical Soil Mechanics* in 1943, I think. That was the book that gave the theoretical basis for *Soil Mechanics in Engineering Practice*.

Q: Was Theoretical Soil Mechanics the first theoretical book in soil mechanics?

It was the first comprehensive one. There were other books, including other authors who wrote about pieces of soil mechanics. Terzaghi himself had written on consolidation, for example, with Fröhlich, who was one of his colleagues and former students in Vienna. But he hadn't written a book that set down most of what was available at the time from the theories that you would use. Ed Hamilton, the president of John Wiley and Sons, and Terzaghi were very good friends, and Hamilton encouraged Terzaghi to write the book. Hamilton wanted to be able to publish, through Wiley, a broader textbook for applications. He talked to me a little bit about writing a textbook, and I said no; I wasn't equipped to do that yet, anyway. Partly out of these conversations, I think Hamilton helped to persuade Terzaghi to write *Soil Mechanics in Engineering Practice*. It was to be an undergraduate book with some editorial help, you might say, from me. Eventually it turned out to be a much more cooperative venture in the sense that I was writing parts of it clearly enough to satisfy Terzaghi. The organization he had for the book could stand some improvement, so eventually it became a pretty strong collaboration rather than senior and junior author.

Q: What's the story behind your textbook *Foundation Engineering*?

It grew out of the courses that I taught here at Illinois. I had developed a course in foundation engineering and was teaching it pretty much by myself. The first two people I began to share these courses with were Professors Tom Thornburn and Herb Ireland. Walt Hanson returned from service in the Navy during World War II. He was a structural engineer and interested in teaching the foundations course. While spending a summer working with me on consulting jobs shortly after he came back, he began to understand the soil mechanics part of foundation design. Hanson was the first person the administration would let teach the foundation course who seemed to be a combination of somebody that knew some soil mechanics *and* knew some structures. Walt picked up the soil mechanics side; he already had the structures side. He was the first person, besides myself, to teach the undergraduate foundations course. Thornburn was actually the first person that we engaged after I came here to teach in our group. Tom was essentially a "surficial" soil man. His initial interests were in highways and geology, but he soon began to teach the soil mechanics courses, too. The three of us put together some class notes, which became handouts, and eventually a textbook.

Q: How did each of *Foundation Engineering's* authors contribute to its writing?

It grew out of our class notes. Part D, the structural aspects, was primarily Walt Hanson's responsibility. Part A, the soil properties, was a combination of Tom Thornburn and myself. Part B, the theory, was just extracted from *Soil Mechanics in Engineering Practice*. Part C, "Selection of Foundation Type and Basis for Design," was pretty much mine, I think, but we all worked together and cooperated on it.

Fernando Moreu conducting the interview with Ralph Peck in 2003

Q: What skills do you believe are the most important for your students to obtain from your courses?

I think the characteristic that I most tried to develop in the students probably didn't come out until they took a graduate-level case history course. That course is designed to get the students to assemble the information they had studied previously and learn how to apply it to a real job. Because foundation design isn't straightforward… it requires you to size the situation geologically, understand what the soil properties are, know how the building will be used and how long you expect it to be in service, etc. You really only learn how to apply this knowledge by getting exposed to a variety of real problems, and the closest you can approximate the real problems in an academic setting is a course in case histories that deals with real problems.

But instead of just presenting the existing case histories, we tried to expose students to the situation at the beginning of the job and get them to ask questions as to what you would find out next. That approach had certain advantages; one is that students are encouraged to discuss the project among themselves, and, in the process, learn more than they could from lectures. That's what real engineers do on real jobs: they take the existing evidence, draw conclusions from it, and decide what else you need to know, get that, and progressively come to an appropriate answer for the job. That's what I tried to do in the foundation course.

I sent the students out to look at construction that was going on locally or on campus. We usually had a building under construction somewhere. There was one building — I guess it still exists in Urbana — that actually was a theater at one time, but a fire had caused the building to collapse. They rebuilt much of the building above the debris, so it settled quite extensively. My students would go look at it to see if they could figure out what happened. Of course, after a while, they talked to each other and knew what happened, but initially they would try to figure out what happened not knowing that it was a foundation problem, and try to deduce what was going on.

Q: How did college prepare you for consulting work?

I went to a rather unusual school: Rensselaer Polytechnic Institute (RPI). Actually, it's the oldest school of science and engineering in an English-speaking country. Established in 1824, it's not as old as the École Nationale des Ponts et Chaussées in Paris, but its graduates built many of the great structures of the last hundred years or so, such as the Brooklyn Bridge. And they had a whole host of distinguished alumni. I was there for seven years, starting as an undergraduate. One of the things I learned there was nontechnical, but it was a product of the educational system. The policy was that every student recited in every class — every day. Our courses were not a semester long; they were half a semester long, so they went at a fast place. And we were quizzed at the blackboard every day, and then two days a week we'd have a lecture. The other three days we'd be quizzed orally. It was very intense, but I liked it… that was a good system for me. It taught all of us to think on our feet and that you have to have answers.

Q: What should the relationship be between universities and the civil engineering profession?

I would like to see the universities continue the kind of research and advanced thinking and development that they are doing now, but temper it by keeping in close touch with practice, so that the research doesn't get too divorced, as it tends to do sometimes, from practice. There will always be, and should be, some people who are "dreamers," or out ahead thinking of things that might be done. But if all university faculty were doing research, they would be out of touch with practice, and wouldn't be serving a good purpose.

Q: What's your greatest satisfaction as a person?

In my case, it's hard to separate profession from the person because I do get, and always did get, a lot of satisfaction out of my profession, and I very much liked teaching. I liked the interaction with the students, and I was always particularly interested that the students see what professional life is like, so that occupied a lot of my effort. I don't have many hobbies. The field trips associated with jobs took me to a lot of countries. I like to travel. I think probably my greatest satisfaction other than actually working on jobs has been working with young people getting ready for jobs.

Q: Of the books you usually read, engineering or otherwise, which do you like the most?

There are lots of them! Of the more recent books, I certainly like books by David McCullough, like *The Path Between the Seas*, about the Panama Canal, *and The Great Bridge*, about the Brooklyn Bridge and its builders, John Roebling, and his son Washington. And the interesting thing is that McCullough is not an engineer; he just got interested in engineering projects. I think it's still true that he's the only non-engineer to be an honorary member of ASCE based on his books and doing so much for civil engineering. And because my father was a railroad engineer, I like railroads and books about them, of course. There are a number of fairly popular ones about railroads by a fellow of the name of Beebe and by Clegg. I like these books partly because several of them are about railroading and the Rockies, which is what my father was doing where I grew up. As a graduate student, when I was taking engineering, my outside reading wasn't exactly philosophy, but I did enjoy astronomy, origins of the universe, and the development of the universe. I read those books as fast as I could get them.

Q: How would you like to be remembered?

I don't worry too much about how I'll be remembered. To put it broadly, I'd like to be remembered primarily as an engineer who tried to pass that on to his students.

The author thanks Julie Rivera, PE, SE, for her help in editing this interview.

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Soil Sampling at Sword Beach in Normandy, France, 1943

How Geotechnical Engineering Influenced the D-Day Invasion

By William D. Lawson, PhD, PE, M.ASCE

Into the jaws of death. A Coast Guard-manned LCVP from the USS Samuel Chase disembarks troops of Company E, 16th Infantry, 1st Infantry Division, on the morning of June 6, 1944, at Omaha Beach

When the World paused last summer to remember the 75th anniversary of D-Day, many of us were gripped by stories, both heroic and horrific, told about the Allied invasion of Normandy's beaches. One of these stories, effectively dramatized in Steven Spielberg's 1998 Academy-award winning film, *Saving Private Ryan*, had to do with the return of a U.S. Army private to his mother, an Iowa farm wife who had already lost three sons to the war. The factual narrative that provided inspiration for *Saving Private Ryan* is documented in historian Stephen Ambrose's (1994) definitive account, *D-Day June 6, 1944: The Climactic Battle of World War II.*

Historical and Geographical Context

Operation Overlord, the Allied invasion of German-occupied France in June 1944, required the transport of 175,000 fighting men and their equipment across 60 to 100 miles of open water, overnight, to land on a hostile shore against intense opposition. The massive array of equipment included 50,000 vehicles of all types, ranging from motorcycles, to tanks and armored bulldozers. Churchill called it "the most difficult and complicated operation ever to take place." Commanders on both sides recognized it as a winner-take-all battle. In Hitler's words: "The destruction of the enemy's landing is the sole decisive factor in the whole conduct of the war and hence in its final results."

Planning for Operation Overlord commenced in March 1943. The Allied objective was to land, penetrate German defenses, and secure a lodgment in an area suitable for reinforcement and expansion… but where? There were critical tactical requirements that had to be afforded by any potential landing site (Figure 1):

- The site had to be within range of Allied fighter planes based in the United Kingdom.
- There had to be at least one major port close at hand, but unlike the Pas-de-Calais coast in northern France, where the English Channel is narrowest (and therefore the Germans expected an invasion), the site could not be well defended.
- The beaches for the landing site had to be suitable for prolonged unloading operations and have exits for vehicles and adequate road networks behind them for rapid, massive deployment inland.

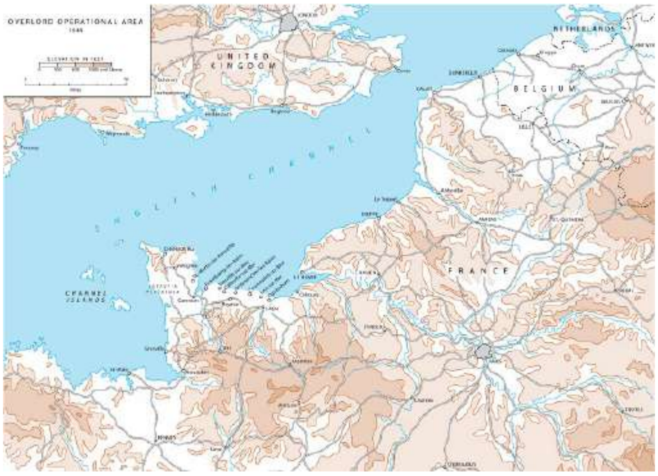

Figure 1. Overlord operational area. The shortest and perhaps, expected, invasion route was from Dover to the Pas de Calais region of France, a distance of 25 miles. However the Calvados coast of Normandy (actual D-Day invasion site) located south of Portsmouth, is over 100 miles across the English Channel

Much less known, yet equally dramatic, Ambrose's book also relates a tale of special interest to the geotechnical engineering community. It's the story of how the success of the D-Day invasion, and therefore the outcome of World War II — and by implication, the fate of democracy, if not the course of modern history — directly depended on soil-bearing analyses to establish whether the beaches of Normandy would support the heavy vehicles and landing equipment needed for the invasion. This issue could not have been addressed without soil sampling. So, with no protection from German forces other than stealth and the cover of darkness, a team of commandos from the British Royal Navy deployed to perform the crucial soil-sampling operation. This case study tells their remarkable story.

A process of elimination narrowed the choice down to the Calvados coast of Normandy (Figure 2). In addition to satisfying the tactical requirements, this site also had the strategic advantage of being as close as possible to Germany's industrial heartland, the Rhine-Ruhr region, which was the ultimate objective for the invasion.

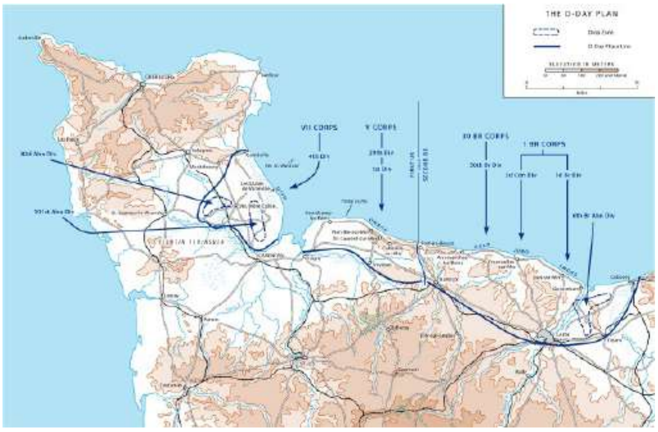

Figure 2. The D-Day plan. Invasion beaches along the Calvados coast of Normandy, British an Canadian Forces (Second British Army) were responsible for the eastern sector, including Sword, Juno, and Gold beaches. United States forces (First U. S. Army) were responsible for the Omaha and Utah beaches

With the potential site identified, the British began to collect intelligence about the French coast. Information included some ten million pictures and postcards provided by British families who had taken pre-war vacations in France. Aerial reconnaissance photographs were put together into panoramic photos, and information on tides, currents, and topography was obtained from old guidebooks. The French Resistance supplied information on beach obstacles, strong points, and other items of interest.

The Crucial Question

Despite all this information about the Calvados coast of Normandy, the Allied command still did not know the answer to one key question:

Would the beaches west of the mouth of the Orne River support DUKWs [amphibious vehicles], tanks, bulldozers, and trucks? There was reason to fear that they would not, because British geographers and geologists reported that there had been considerable erosion of the coastline over the past two millennia. The original port at Calvados, the old Roman port, had been two kilometers out from the 20th century shoreline. The French Resistance managed to smuggle four volumes of geological maps out of Paris, one in Latin that had been created by the Romans, who had surveyed their entire empire for a report on fuel sources. The survey indicated that the Romans had gathered peat from the extensive reserves on the Calvados coast. If there were boggy peat fields under a thin layer of sand on the current coast, it would not hold tanks and trucks (Ambrose 1994).

Soil failure, or in the vernacular of the day, inadequate *bearing capacity*, would strand vehicles, expose troops, and otherwise cause the landing parties to be pinned down under enemy fire. The only way to find out whether the soil was strong enough was to obtain samples, a task for British Special Operations forces.

Combined Operations Pilotage Parties

Since 1941, the British Royal Navy had recognized the importance of detailed beach reconnaissance surveys prior to amphibious operations; namely, beach invasions. Such operations required the cooperation of naval and military personnel for their respective tasks. Naval personnel would take soundings and obtain detailed pilotage information such as sailing directions, approach courses for the run-in, bearings, landing marks, coastal silhouettes, and related offshore reconnaissance. Military personnel would perform onshore reconnaissance to obtain details of the texture of the beach, beach exits, gradients, defenses, etc.

Figure 3. The X-craft midget submarine HMS EXTANT undergoing sea trials at Holy Loch, a World War II submarine base in the Firth of Clyde, Scotland, c. 1943. The COPP-1 team used the X-craft submarine to perform covert reconnaissance surveys of Normandy beaches prior to D-Day.

Each team, known as a Combined Operations Beach Reconnaissance and Assault Pilotage Party (COPP), had a Royal Engineers captain, commando-trained. All team members required combined operations training, including stalking and unarmed combat, in case of enemy defender interference. The officer in command of the team had to be a Royal Navy navigator or hydrographer. Physical hardening, toughening, and endurance training were essential.

COPPists deployed in a variety of craft, including canoes, two-man folding boats known as *folbots*, the X-craft midget submarine (Figure 3), and other small craft. Each naval beach reconnaissance officer to swim ashore wore a swimsuit designed to give him positive buoyancy and to protect him from the cold, abrasions, and fish stings. The suits (Figure 4) were made of rubberized fabric, had tight-fitting cuffs, ankles, and hood, and embodied a life-jacket inflated by mouth. They looked like grey rubber frogman's suits, but without the fin flippers. Leather patches protected elbows and knees.

Figure 4. COPP operational attire (drawing). One-piece overalls-styled protective suit with fitted hood and external pockets, worn by COPP-1 team members.

The officers did not swim unencumbered: they carried arms — a .45 Colt pistol with ammunition and a fighting knife. COPPists also carried equipment: a sounding lead and line, beach gradient reel, wrist watch in waterproof container, underwater writing tablet, a Chinagraph pencil for marking porcelain or other hard glazed surfaces, an army oil-immersed prismatic compass, and two waterproofed flashlights for homing on their launch craft. They also would carry survival and evasion equipment: copper acetate fish scares, 24-hour emergency rations, and a brandy flask. In addition, military officers would carry an auger for taking beach samples, rubber sleeves to store the samples in, and a bandolier designed to receive and hold the samples in the order taken.

Commando Soil Sampling Operations: New Year's Eve, 1943

The No. 1 Combined Operations Pilotage Party (COPP-1) was commissioned to gather pre-invasion military intelligence on the beaches along the Calvados coast of Normandy. The landing party consisted of Major Logan Scott-Bowden of the Royal Engineers (Figure 5) and Sergeant Bruce Ogden-Smith (Figure 6) of the Special Boat Section of the Royal Marines. Lieutenant Commander Nigel Willmott, founder of Combined Operations, was in command.

Figure 5. Major General Logan Scott-Bowden, CBE, DSO, MC and Bar (1902-2014). Commander, British Royal Engineers, and Commando Combined Operations Beach Reconnaissance and Assault Pilotage Parties.

Figure 6. Sergeant Bruce Ogden-Smith, DCM, MM (1918-1986). Special Boat Section, British Royal Marines, and Commando Combined Operations Beach Reconnaissance and Assault Pilotage Parties.

Part of Scott-Bowden's and Ogden-Smith's training for this mission involved instruction by scientists in how to collect soil samples. The soil-sampling equipment consisted of 10-in.-long tubes with phosphorescent numbers on their caps, and an 18-in.-long auger that was pushed fully into the sand and given one-half turn. When pulled up, it produced a 10-in.-long core sample from the lower end. Among the scientists giving the training was Professor John D. Bernal of Cambridge University, chief scientific officer to the chief of combined operations. Professor Bernal was one of the scientists who had expressed anxiety about the bearing capacity of the Calvados beaches. He had the ear of Professor Frederick Lindemann, nicknamed "the Prof," who was Prime Minister Churchill's scientific advisor.

On New Year's Eve 1943, with the expectation that the Germans would be busy celebrating, the COPP-1 team set out in motor torpedo boats to reconnoiter the area around Luc-sur-Mer, the eastern end of the Calvados coast. They transferred to a hydrographical survey craft and moved closer to shore before Major Scott-Bowden and Sergeant Ogden-Smith went over the side into the frigid water, armed with pistols, daggers, wrist compasses, waterproof flashlights, and sample tubes, to make the 400-yd swim to shore. The swim was strenuous, and the strong cross-currents swept them three-quarters of a mile east of the target area. They were also less than happy to be forced to land under the glare of a lighthouse beam, rotating every 65 seconds. According to Ambrose (1994):

They came in on a rising tide at the seaside village of Luc-sur-Mer on the beach later given the code name Sword. They could hear singing from the German garrison. They crawled ashore, walked inland a bit, went flat when the beam from the lighthouse swept over the beach, walked some more. They made sure to stay below the high-water mark so that their tracks would be wiped out by the tide before morning. They stuck their tubes into the sand, gathering samples and noting the location of each on underwater writing tablets they wore on their arms.

Major Scott-Bowden and Sergeant Ogden-Smith filled their bandoliers with tube samples of wet sand, taken according to the required pattern. Then, after examining a potentially dangerous area of exposed peat that had stood out clearly on aerial photographs, they went out into the surf to return to their recovery craft. Being so heavily laden, and with the force of the breakers impairing their mobility, Scott-Bowden and Ogden-Smith had much difficulty getting out to sea. By timing it right and by hard swimming, they eventually made it on the third try. However, during their struggle to get out through the breakers, they lost their auger and a fighting knife. Luckily, they were out beyond the low tide line, where it was felt the items would become buried in the sand, so the secrecy of the mission was not compromised.

Three weeks later, this time deployed from the X-20 midget submarine, Scott-Bowden and Ogden-Smith performed periscope reconnaissance and more onshore military reconnaissance near Vierville and along the Omaha Beach area. Two scale models of the landing beaches were prepared using all the information gathered.

Bearing Capacity Analysis

Notwithstanding the drama of the beach reconnaissance and soil sampling operations — feats of bravery for which the King invested Major Scott- Bowden, Sergeant Ogden-Smith, and Lieutenant Commander Clogstoun-Willmott with military honors — today's student of soil mechanics might wonder: "How much could be learned from an 18-in.-long auger and 10-in.- long tube sample of beach sand?"

Recall that the primary concern of the Allied Command was whether peat and soft clay existed on the beaches. Stated another way, was there enough cover sand on top of the clay and peat to support armored invasion equipment, especially the heavy, single-axle trucks and trailers?

The minimum depth of sand that analysts were seeking to confirm was 14 in. This particular depth derived from the experiences of Sir Malcolm Campbell, a British racing motorist who held the world land speed record during the 1920s and 1930s and who was viewed as the leading authority on such matters. Racing at locations including Daytona Beach and Bonneville Salt Flats, Sir Campbell had worked out that a minimum thickness of 14 in. of compacted beach sand was necessary to support his race vehicle. In fact, Sir Campbell used a spring-loaded, impact-type device, something like a steel pogo stick, to confirm the required sand thickness prior to racing. The device was noisy and could not be used by COPPists in stealth-type operations, hence, their use of augers.

Reports differ with regard to the evaluation of the beach samples. One source states that the samples revealed that large portions of the beach were underlain by soft blue clay, a problem for which the invasion planners devised countermeasures consisting of wire-reinforced canvas matting to support the armored trucks and tanks. However, another source states that "the samples showed that the sand could bear the necessary weight." Either way, in addition to the field measurements of beach sand thickness, in late-January 1944, Major Scott-Bowden was called to the Supreme Headquarters Allied Expeditionary Force to describe his reconnaissance and answer questions. It was this interview that ultimately settled the matter.

Field Load Test by Horse Cart?

Arriving at Supreme Headquarters, the 23-year-old major found himself facing Admiral Bertram Ramsay (the British naval commander-in-chief), Lieutenant General Omar Bradley (the principal American ground commander), as well as five more British admirals, five more American admirals, and four more generals. They peppered him with questions for about an hour. As Trenowden (1995) described in *Stealthily by Night: The COPPists Clandestine Beach Reconnaissance and Operations in World War II*, General Bradley, in particular, was interested in what Scott-Bowden had to say:

General Bradley took Scott-Bowden back to the large-scale map and pressed him for answers to many questions, mostly related to getting tanks from the beach onto the ridge above. Scott-Bowden was able to say that he'd seen two Percheron horses, in tandem, pulling a small cart up the slope from a construction site; so the track should be suitable for light tanks.

Apparently this was enough. When General Eisenhower and his team arrived in London, they accepted the plan. The D-Day invasion would be conducted on the Calvados coast of Normandy. And the rest, as they say, is history!

Author's Note: Upon completion of his interrogation at Supreme Headquarters, Major Scott-Bowden told General Bradley that COPP's other duty was assisting in assault pilotage and that he hoped they would be allowed to do that on D-Day. Bradley replied that he would see what he could do. Scott-Bowden ultimately got his wish. He was present on D-Day to assist in piloting in the American troops to Omaha Beach, as was Ogden-Smith. Among the thousands of soldiers who landed on Normandy's beaches that day — with Allied casualties totalling more than 10,000 killed, wounded, or missing (Figure 7) — they were the only two who had been there since the war began.

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Figure 7. Normandy American Cemetery, Collevile-sur-Mer, France. Inscription in Visitor Center: *"If ever proof were needed that we fought for a cause and not for conquest, it could be found in these cemeteries. Here was our only conquest: all we asked … was enough … soil in which to bury our gallant dead."* – General Mark W. Clark.

Big Steps for Mankind

Extraterrestrial Sampling and Exploration 50 Years after Apollo 11

By Zachary Mank, Robert Mueller, M.ASCE, Marika Santagata, PhD, M.ASCE, and Kris Zacny, PhD

Between June 1966 and January 1968, four Surveyor missions successfully landed on the Moon, collecting invaluable scientific data required to support the coming manned Apollo missions. Central to the goals of the program was obtaining data on the compatibility of the Apollo design with the conditions encountered on the lunar surface. Before these missions, the physical and mechanical properties of the lunar regolith (unconsolidated rocky material covering bedrock) could only be inferred from photographs, landing data, and boulder track recordings. Based on the controlled bearing, impact, and trenching tests performed remotely from Earth using the Soil Mechanics Surface Sampler (SMSS) deployed by Surveyor 3 and Surveyor 7, the first set of geotechnical parameters became available from which a lunar regolith model could be developed. These missions marked the start of geotechnical exploration beyond Earth.

Geotechnics of the Apollo Era

Exploration of the lunar surface continued during the Apollo era (1969-1972) helped develop the knowledge needed to plan future lunar surface activities, and soil mechanics studies were part of all of the Apollo missions. The Apollo 11 mission that landed the first human on the Moon also returned the first rock and regolith samples, and provided the very first penetrometer data. During subsequent missions, surface samples were collected, and, starting with Apollo 15, the battery-operated Apollo Lunar Surface drill allowed sampling of 2-4-cm-diameter cores as deep as 3 m into the lunar regolith. Between 1969 and 1972, approximately 382 kg of lunar rocks and soil from six different exploration sites were returned to Earth, providing a new understanding of the history and composition of the Moon and the first data on the physical and mineralogical characteristics of the surficial lunar deposits.

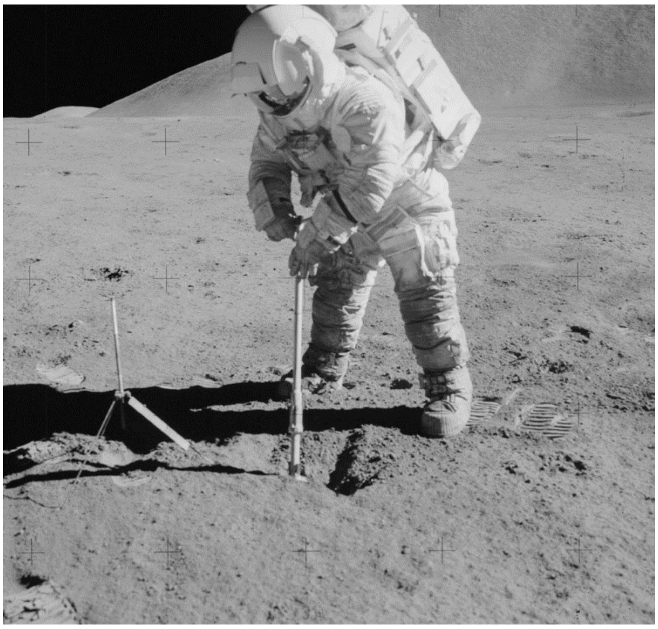

Figure 1. An Apollo 15 astronaut conducts a test with a hand-actuated Self-Recording Penetrometer (SRP).

The Apollo 14-16 missions also included a program of in-situ penetration tests to probe the geotechnical properties of the lunar regolith at depth. Apollo 14 astronauts used the Apollo Simple Penetrometer to conduct 2-point penetration tests, while the Self-Recording Penetrometer (SRP) was used by Apollo 15 and 16 astronauts for 17 tests at 3 sites in 2 regions of the Moon (Figure 1). The SRP (Figure 2a), the only device unique to Apollo's Soil Mechanics Experiment, used 12.8- or 20.3-mm diameter cones and provided continuous force versus penetration depth records that were inscribed on a recording drum. The maximum depth of exploration of 76 cm reached by the SRP was ultimately limited by the maximum reaction force provided by the weight of an astronaut.

Additional geotechnical data on the subsurface properties of the lunar regolith were collected during the Soviet Lunokhod 1 and 2 missions using a cone-vane penetrometer (Figure 2b) — a tool formed by a 5-cm-diameter, 60° conical indenter equipped with two vertical vanes, that could measure the penetration resistance as well as the shear strength mobilized during rotation of the vane. While limited to a depth of 10 cm, the cone-vane penetrometer was used between 1970 and 1973 to obtain data at approximately 1,000 locations on the lunar surface.

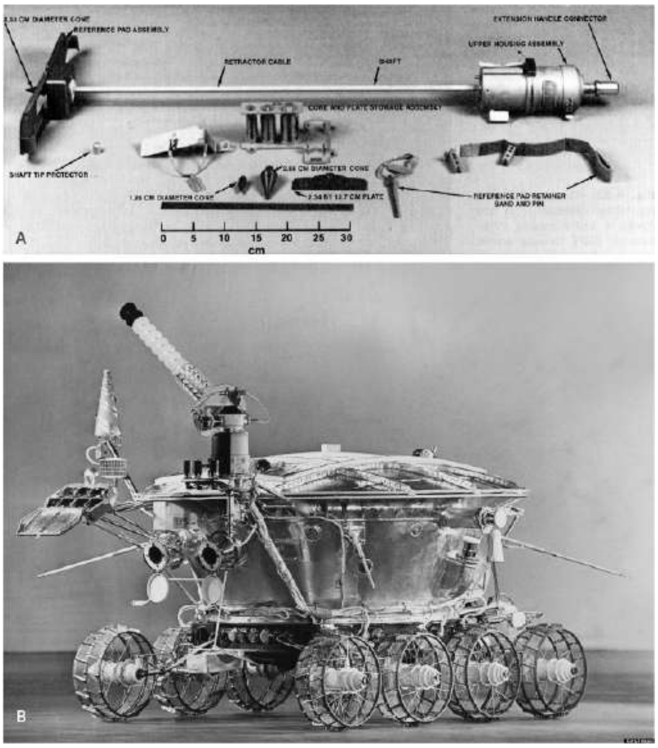

Figure 2. Geotechnical instruments used to record in-situ data on the surface of the Moon. A) Hand-actuated Self-recording Penetrometer (SRP) used on the Apollo 15 and 16 missions. B) Lunokhod robotic cone-vane penetrometer.

Collectively, the penetrometer data from the Apollo and Lunokhod missions provided the first view into the composition and variation of the properties of the lunar subsurface with depth, showed evidence of spatial variability at and between the sites investigated, and allowed refinement of the existing lunar regolith model.

The successes of the Surveyor and Apollo programs emboldened humanity to continue to push technical limits by exploring more distant planetary bodies, but, no matter the destination, the approach remained the same: data begets data. Similar to the way Surveyor paved the way for Apollo, the successes of precursor orbiter programs like Mariner and Pioneer enabled the design of more complex follow-ups to Mars and Venus. The twin Viking landers that reached the surface of Mars in 1976 were the first to collect geotechnical data on the red planet from a series of trenching studies executed by a robotic arm and scoop. They were also — perhaps more importantly — the first missions to use chemical analyses by onboard instrumentation to look for biomarkers on another planet. They proved that the threshold of geotechnical knowledge had been reached to make soft-landing on our most scientifically interesting neighbor achievable, and this new capability foreshadowed the life-detection emphasis of most future missions. The closing of the Space Race shortly thereafter, though, meant that Viking 2 was the last NASA mission to touch non-Earth ground for two decades and the last time a dedicated geotechnical instrument was deployed on another planetary body until 2018.

The Focus on In-situ Resource Utilization

The accomplishments of the Apollo program were impressive. However, as the space race drew to a close, political motivation and public opinion shifted to other priorities, even questioning the rationale for exploration. This has led to a transition in sources of investment for space exploration. Over time, commercial technology has advanced, building on the capabilities that NASA's scientists and engineers had pioneered, and placing more capabilities at the hands of modern explorers.

In the current era, more exploration missions have been to Mars than any other single destination in the solar system. The focus of these missions, for the most part, has been increasingly sophisticated attempts at chemical analysis and life detection. The technology designed to land the payloads has matured, and, as a result, knowledge of the greater environment has taken the back seat.

But the rejuvenated interest — both public and private — in manned exploration that has swelled in the past few years indicates that another period of breakthrough innovation is on the horizon (Figure 3), one that will again enable great leaps forward in planetary geotechnical exploration. Now that technology has caught up to the point where sustained human presence in such hostile environments might actually be feasible, the only part of the equation that still needs to be solved is how to reduce the mass of consumables like water, oxygen, and building materials that will need to be brought along as unwanted heavy cargo. As a result, this new era will be defined by the ability to put resources that are already at these destinations to use. In much the same way that the Apollo missions were enabled by the Surveyor program, these new missions will be enabled by a series of precursor prospecting missions to understand what's really possible.

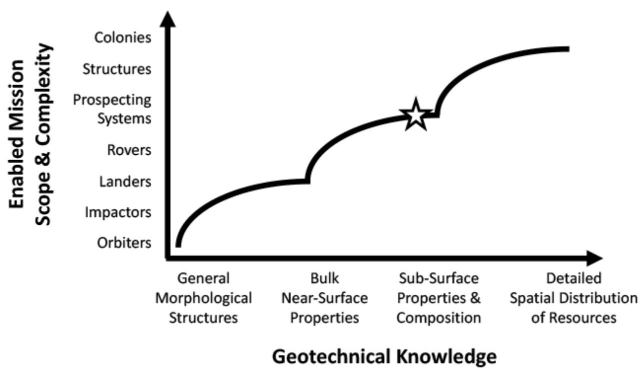

Figure 3. Plateau-breakthrough relationship between geotechnical knowledge and enabled mission scope.

In-situ resource utilization (ISRU) in general exists in two broad, but sometimes related, areas of emphasis. The first is water ice and oxygen extraction from regolith silicates. Accessible ice is often a major driver of landing site selection for notional manned missions because of the many uses of water: in unmodified form it can be used for agriculture or human consumption, and space radiation shielding, or it can be electrolyzed into oxygen that can be breathed or used for propellant, and hydrogen for use in fuel cells. Orbital mapping has done some of the work of locating water already on both the Moon and Mars, but an accurate understanding of the accessibility of that water is necessary.

The second major area for ISRU broadly centers on construction, excavation, and mining. Construction can be further divided into two major subtopics: improved surfaces (landing pads, roads, and foundations) and building materials. The former requires extensive knowledge of deeper subsurface properties than have been characterized so far. The latter has much broader open questions surrounding how plentiful possible substrate materials are at a site of interest and whether they require a consumable binder, what kind of radiation shielding available materials could provide, and how compatible the materials are with processes like 3D printing to make manufacturing in space a reality. Geotechnical exploration will likely play a critical role in answering all these questions.

Advancements in Exploration Technology

The "tool box" of available resources for geotechnical exploration has significantly expanded since the Apollo era. It's been driven by advances in sensing, instrumentation, robotics, data storage, and analysis technologies. Today's technologies permit access to remote sites, are deployable in harsh environments, allow sampling and characterization of an increasingly broad range of geomaterials, facilitate remote data collection, and provide the multiphysics data required to address emerging problems in the geo-environmental and energy fields. For example, cone penetrometer technology has made great strides since the Apollo era. Today, the toolbox routinely combines collection of penetration parameters with shear wave propagation measurements, and its capabilities have been further expanded with special sampling probes and a range of sensors for chemical characterization of the subsurface. On other fronts, work in offshore geotechnics has demonstrated that geotechnical measurements can be reliably obtained in harsh environments. Additionally, experience with materials such as hydrate-bearing sediments has demonstrated the ability to sample complex geomaterials while carefully preserving their in-situ state. Developed on our home planet, these are all capabilities that facilitate geotechnical exploration beyond Earth.

Despite these developments, implementation of any terrestrial technology on distant planetary bodies remains challenged by a number of factors. They include the need to integrate tools in robotic platforms and conduct tests remotely, with communication delays limiting the ability to deal with unpredictable occurrences, and, depending on the terrain, difficulties in gaining access to the desired testing locations. Moreover, the need for systems to be mass-optimized for flight comes at the cost of limitations on power and on reaction forces, which limits penetration depth. Additional impediments derive from concerns about sample contamination, and, especially under very low gravity conditions, from challenges with handling and management of particulates. Finally, with the cost of currently planned unmanned missions to Mars exceeding $2B, deployment of any technology millions of miles away from Earth leaves no margin for error.

Over the past decade, the capabilities to simulate increasingly complex geotechnical problems, both at the continuum and discrete level, have also significantly improved. In-situ measurements of geotechnical properties are also critical to validating these models for extraterrestrial conditions, a process that, to date, has been challenged by the limited available data, the uncertainty associated with testing regolith simulants, and the difficulties in replicating reduced gravity and little to no atmospheric pressure conditions within the constraints (small-scale and short-duration) of reduced gravity flights.

Overall, these "challenges" actually represent new opportunities for the geotechnical profession. We now have a robust set of "known unknowns" that can inform ongoing research and development agendas. While some questions are technical, others pertain to policy, ecosystem creation, and the economics to support the development of required solutions. Progress is being made on several of these fronts through both government and private industry initiatives.

Advancements in Instrumentation

On the planetary geotechnical instrumentation side, an instrument currently in development is the Honeybee Stinger system (Figure 4), which is designed as a rover-mounted payload with a mass of only 8.6 kg. The Stinger combines the Apollo Self-Recording Penetrometer and Lunokhod's integrated cone-vane approaches for measuring shear strength, while addressing the shortcomings of the original designs. Its probe tip, designed after the cone of a cone penetrometer, allows for continuous measurement of penetration resistance as it is robotically pushed into the ground. A shear vane initially housed inside the cone tip can be deployed at any depth to conduct a shear test (Figure 5), and subsequently retracted for further cone penetration up to depths of 100 cm. These measurements will allow characterization of the overburden mechanical properties required to drive the design of the wheels and excavation systems. As part of its development, Stinger has been tested in various lunar and Martian simulants, as well as in the Atacama Desert in Chile — a NASA-favorite Mars analogue site for its infrequent rainfall.

Figure 4. Honeybee Robotics instruments TREIDENT and Stinger mounted side-by-side on the NASA-ARC KREX-2 Rover in the Chilean Atacama Desert.

Another instrument focuses on the water-ice prospecting side of ISRU. Deemed "The Regolith and Ice Drill for Exploring New Terrains," or TRIDENT for short, the system is essentially a hammer drill with a 1-m-long bit that is designed to sample lunar regolith that may be laden with water. It augers cuttings to the surface, where MSolo, a mass spectrometer, can measure the volatiles that naturally sublimate when exposed to vacuum. By drilling in "bites," a depth resolution of 10 cm or less can be achieved. The drilling load records and an integrated in-bit temperature sensor provide additional data with depth. The combination of these measurements will directly feed into future mission planning, enabling the technology development that will harvest the trapped water in some of the first true ISRU applications. TRIDENT has been intensively tested for cryogenic-vacuum operation and shock and vibration survivability, as well as in nonlunar environments like the Atacama Desert and Devon Island, Canada. The TRIDENT-MSolo pairing is currently slated to go to the Moon in 2022 as a part of the NASA VIPER mission.

Figure 5. Stinger cone with deployable vanes for near-surface and deep penetration.

Beyond evaluation instruments, research is also focusing on technologies that can work with resources already available in space. This is one of the areas of emphasis of the Swamp Works labs at NASA Kennedy Space Center, where the RASSOR Excavator (Figure 6) has been developed and tested in the facility's Regolith Bin, which houses over 91 Mg of fine volcanic rock, an analogue for the Mars surface. Even without detailed knowledge of the geotechnical properties, it can be predicted that excavation on another planetary body will be difficult because of the increase in density with depth and the limited reaction forces in reduced gravity. To this end, RASSOR rethinks digging by relying on the continuous action of blades mounted on counterrotating bucket drums. This design achieves near-zero reaction forces, enabling loading, hauling, and dumping of space regolith under low-gravity conditions. RASSOR is designed to navigate steep slopes and rough terrain, right and flip itself when stuck, and its symmetrical design allows it to operate in reverse and recover from overturning.

Figure 6. Regolith Advanced Surface Systems Operations Robot (RASSOR) Excavator.

Research on tool-regolith interaction is being pursued also at NASA's SLOPE Lab, where researchers are working to develop more universal solutions to trafficability. Key to any extraterrestrial exploration operation is mobility and specialized technology, like the cleverly designed Superelastic Tires (fabricated from shape memory alloys), which are robust for driving over sharp rocks on the Moon and Mars. The tires can function on low shear-strength ground at the cold temperatures of deep space, which may, in some cases, avoid the need to improve the surface before traversing poor ground.

Challenges like those experienced in driving the mole at depth into Mars' subsurface during the recent Mars InSight mission demonstrate that soil mechanics and geotechnical engineering still play a critical role in supporting deep space exploration. And while questions remain regarding our collective ability to address the questions before us, rarely has there been a grander mission to motivate the geotechnical community.

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Best Practices For Geotechnical Site Characterization

HAVE WE REGRESSED FROM DECADES PAST?

By Don J. DeGroot, ScD, PE, M.ASCE, and Jason T. DeJong, PhD, M.ASCE

The objective of a geotechnical site-characterization program is to determine soil and rock stratigraphy, in-situ pore water pressure conditions, and soil and rock properties for analysis and design of geotechnical engineering infrastructure. It is best conducted using an integrated approach that combines various geo-disciplines to describe, evaluate, and determine expected site characteristics. The extensive advancement of tools and procedures in recent decades provides an opportunity to execute effective and thorough site-characterization programs routinely in practice. Yet, this is often not the case, and some may argue that today's state-of-practice has regressed in recent decades. While contractual structures and budget restrictions may contribute to this lower level and quality of characterization, the technical knowledge and pragmatic strategies available are not always implemented.

Integrated site characterization includes effective application of site investigation and laboratory testing, and skilled interpretation of field and laboratory test data to idealize a site for analysis and design.

An essential part of any site-characterization program is the site investigation, defined as the practice (equipment, methods) of acquiring relevant information to characterize site conditions that may impact a proposed project. It's been 70 years since Hvorslev published *Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes* (Figure 1). Even today, this publication remains an excellent summary of the consequences of sample disturbance and the source of still-valid recommendations for good drilling and sampling practice. Since that time, research and industry developments have produced advances in site investigation tools and procedures, especially the use of geophysical and in-situ testing methods.

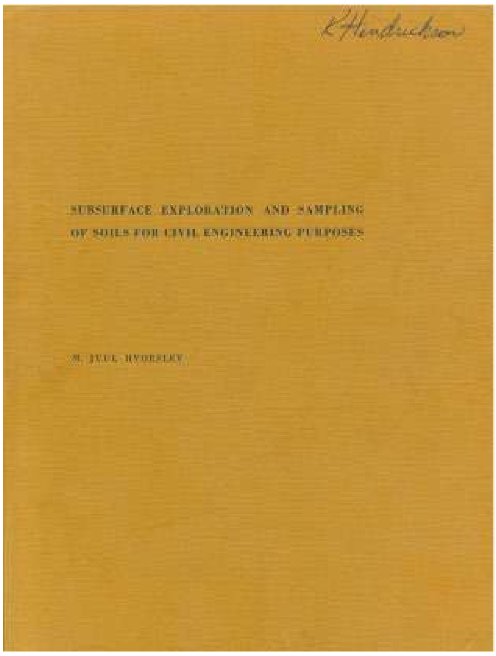

Figure 1. Hvoeslev's *Subsurface Exploration and Sampling of soils for Civil Engineering Purposes*.

Likewise, the central importance of the role of geology in geosystem performance was also established early on and became engrained in routine practice; the depositional and formational processes were central and guiding factors in site-characterization programs. In his classic text, *Fundamentals of Soil Mechanics*, Taylor stated that "… every soil investigation should include adequate investigation of all geologic features that have bearing on the problem." Similarly, Terzaghi and Peck, in *Soil Mechanics in Engineering Practice*, stated that "… the first step in any subsoil exploration should always be an investigation of the general geologic character of the site. The more clearly the geology of the site is understood, the more efficiently can the program for soil exploration be laid out."

Integrated Site Characterization

Integrated site characterization folds the site investigation phase into a more comprehensive and holistic assessment of site conditions. It's not just drilling, sampling, and analyzing the results of that field work. An integrated approach begins with desk study and continues through construction (Figure 2). Creation of a geologic model is an essential early component, where the site investigation program is just one part of the characterization process. Inductive reasoning, scenario assessment, and site idealization phases are salient features of the process outlined in Figure 1 that are often not explicitly considered in practice.

Emphasis on detailed analysis before mobilizing for the site investigation enables prioritization, efficiency, and possibly reduced costs. The process has the potential to transform the site investigation phase from one of discovery (often without strategic planning), to verification and/or filling in gaps in site knowledge and understanding. Overall, it's an iterative process as new information is generated and provides a structured framework for systematic sensitivity studies during analysis and design.

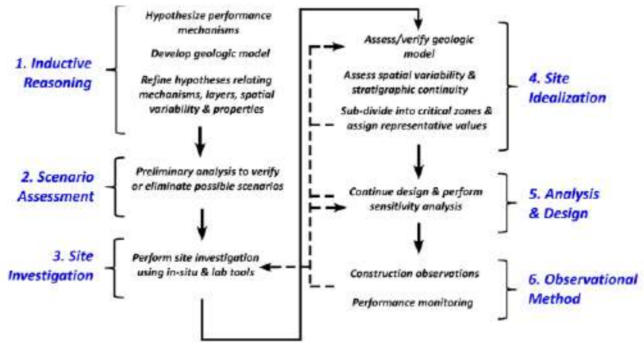

Figure 2. systematic methodology for integrated site characterization (from DeJong, et al. 2019, *Soil Dynamics and Earthquake Engineering*).

For high-value and/or high-risk projects, integrated site characterization often involves multiple geo-specialists, such as geoscientists, geophysicists, geostatisticians, and geotechnical engineers, ideally working as an integrated team from project start to finish. In the offshore energy sector, a primary outcome of an integrated site-characterization program is referred to as the project Ground Model. The Ground Model is a synthesized database of all collected and interpreted qualitative and quantitative information based on a site's geology, geomorphology, stratigraphy, soil properties, geohazards, and anthropogenic features. The Ground Model is thereafter used to create the Design Basis, which includes profiles of recommended soil parameters, typically with a statistical assessment of the data, such as best estimate, lower and upper bound estimates, and so on.

Poor Site-Characterization Practice

Across the full spectrum of project size, value, and risk, examples of poor practice are evident even though best practice methods are well established and often involve just a modest amount of extra time and cost over what's perceived as the "good enough" solution. Significant examples include:

- Insufficient consideration of site geology
- Deviation from well-established tooling and procedural guidelines for conducting in-situ and laboratory tests
- Lack of borehole stabilization, e.g., drilling mud
- Lack of fixed piston for undisturbed tube sampling in softer soils
- Over-reliance on low-quality strength index testing conducted on poor-quality samples

These characterization practices, and others, have direct consequences on design parameter accuracy and project costs (Figure 3). Their importance is often magnified when inadequate or erroneous implementation of fundamental soil behavior principles is used to evaluate the reasonableness of measured soil properties in the context of a site geologic model.

What are the root causes that can lead to a compromised quality in site characterization? One factor is the education and training of the current and future geotechnical workforce. For example, how many civil engineering undergraduate programs offer engineering geology as a senior elective course? How many graduate programs require a minimum of one geology course? How many offer hands-on courses in geophysics, drilling, and in-situ and laboratory testing? Of course most geotechnical engineers will not become field or laboratory technicians. Instead, they'll become managers or designers using the data generated by these services. But as with many professions, it would benefit geotechnical engineeers greatly and enhance the level of practice if they had direct experience with the field and laboratory methods used to acquire those data. Industry must also play a role in better training through internal mentoring of new and existing staff and support of professional development activities.

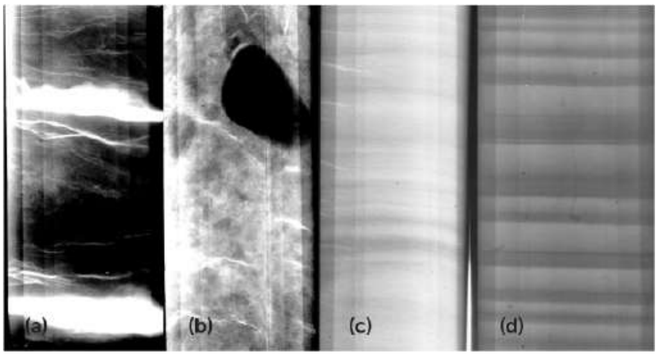

Figure 3. Examples of x-rayed soils in thin-walled tube samplers; (a) and (b) show significant disturbance for samples taken without a fixed piston sampler (white = voids) that would be noticed by an experienced technician upon extrusion. (c) shows more subtle disturbance that might not be observed upon extrusion. (d) shows a good quality, fixed-piston sampler of varved clay, with no visible distortion of varves at sample-tube interface.

Another contributing factor is the decades-long trend of firms closing in-house field and laboratory testing operations to cut costs. These decisions have resulted in loss of the traditionally close, in-house relationship among engineers and field and laboratory technicians that added significant value to a company's work quality and client services. Today, the engineer is often the client for these externally supplied services, and there can be some loss of control over sampling, testing, and reporting processes. To manage this business structure, it's important to develop and enforce detailed method statements for how field and laboratory services must be performed and to contract with well-qualified drilling contractors and laboratories, even when higher quality comes at a slightly higher cost. Simply referencing a test type in accordance to a standard is often insufficient because there's too much leeway in many standards.

It's recognized that the use of empirical correlations and more "conservative design" has a role in practice for smaller-value and lower-risk projects. In such instances, site investigation budgets accepted by clients are often severely limited, a condition that has been exacerbated by the increasing trend of competitive bidding for geotechnical engineering services. Commoditizing these services requires stronger reliance on past experience that must include performance confirmation of previously constructed facilities in the same geologic units.

Planning a Site Investigation Program Planning the site investigation phase of an integrated site-characterization program seeks to use the best attributes of geophysical, borehole drilling, and in-situ and laboratory testing. Geophysical testing is valuable for identifying stratigraphic units, the continuity of units, or lack of, between in-situ soundings and boreholes, and can provide insight into the geologic history of a site. Geophysical testing is an essential element of site-characterization practice for projects of large spatial extent, such as pipelines, bridges, earthen dams, and offshore wind farms.

In-situ testing, particularly the seismic piezocone, can be an efficient means of detailing subtle changes with depth of soil units. It's much more cost effective compared to drilling with associated laboratory testing in evaluating spatial variability of soil behavioral response across a site. The disadvantage of most in-situ test measurements is the need to use universal empirical, rather than site-specific, correlations to estimate soil mechanical properties for design.

Advanced laboratory testing (e.g., 1D consolidation, triaxial, and direct simple shear) provides the advantage of well-controlled boundary conditions and direct measurement of soil mechanical behavior. However, the usefulness of these best practice tests strongly depends on obtaining high-quality samples for fine-grained soils or the efficacy of reconstitution methods for coarse-grained soils.

In many cases, the site-characterization strategy can place greater emphasis on geophysical methods and in-situ testing, while requiring fewer high-quality boreholes, and uses best practice methods to collect good-quality undisturbed samples, particularly for fine-grained soils. Side-by-side boreholes and in-situ test soundings enable development of site-specific empirical correlations from the advanced laboratory test results. This approach follows the advice of Terzaghi and Peck and was reiterated by Peck in his paper, "Use and Abuse of Settlement Analysis" (*GSP 40*). Peck noted that for reasonably well-defined soil profiles, careful, undisturbed sampling and laboratory testing is warranted, especially if the design concept has a significant potential for settlement and stability problems. In contrast, for ill-defined soil profiles with heterogeneous layers, more emphasis should be placed on in-situ testing to locate more critical soil layers and for more limited collection of undisturbed samples for laboratory testing.

Drilling and Soil Sampling

Sample disturbance is the most significant issue affecting the quality and reliability of advanced laboratory test data for fine-grained soils (Figure 4). Sample disturbance causes changes in the natural soil state and structure; as a result, key design parameters such as compressibility, yield stress, and shear strength are adversely influenced by sample disturbance. Rotary drilling with a weighted drilling mud and a fixed piston sampler, preferably with a modified tube to enhance sample quality, is the recommended method for collecting undisturbed, thin-walled tube samples (e.g., Shelby) of fine-grained soils. For stiff to very stiff clays and clayey silts, Denison or Pitcher samplers and/or rotary coring methods should be considered.

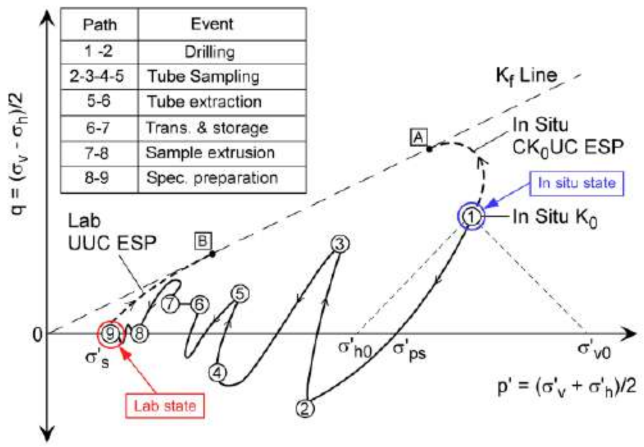

Figure 4. Hypothetical effective-stress path during tube sampling and specimen preparation of centerline element of low OCR clay (after Ladd and DeGroot, 2003, *Proc. 12th Pan. Conf. SMGE*).

Undisturbed sampling of coarse-grained soils typically requires use of impractical ground-freezing methods. Therefore, in-situ testing remains the preferred approach for characterizing the mechanical properties of these soils. Recent developments in sonic sampling have enhanced the characterization of gravelly soils. Intermediate soils, which are defined as silts, silty clays, clayey silt, and silty sands, among others, remain a challenge. Depending on plasticity, clay content and depositional environment and post-deposition processes, such soils can exhibit transitional behavior, with some properties being clay-like and others being sand-like. As a result, appropriate methods must be assessed on a project- and site-specific basis.

In-Situ Testing

The standard penetration test (SPT) remains the defacto in-situ test used in the U.S. for obtaining disturbed soil samples and a measure of penetration resistance. Despite ASTM standards, significant variations still exist in how the test is conducted (Figure 5). For projects where SPT blow counts are used directly to estimate soil properties, evaluate liquefaction susceptibility, and perform design calculations, additional controls should be implemented, including use of a calibrated automatic hammer, rotary drilling with a weighted mud, and a side or upwards discharge bit. In gravelly soils, the instrumented Becker penetration test may be preferred.

Figure 5. SPT exploration using a portable tripod. Do you recognize the drilling supervisor?

The seismic piezocone is an excellent tool for soil profiling because it can rapidly provide detailed subsurface information and estimates of soil properties via empirical correlations. Careful attention must be paid to the quality of the instrumentation and complete saturation of the pore pressure element. When possible, it's preferable to modify universal piezocone correlations to site and geologic unit-specific correlations by leveraging good-quality reference laboratory data.

Laboratory Testing

Laboratory testing of clay should stem from a carefully designed program that explicitly accounts for soil behavior issues relevant to a particular design concept, including the in-situ effective stress state, stress history, anisotropy, and loading-rate effects. This requires use of consolidated shear tests, such as triaxial and direct simple shear. Furthermore, the test program should include a strategy for mitigating the potential effects of sample disturbance.

The stress (or geologic) history of fine-grained soils can be established through 1D consolidation tests conducted on good-quality samples (Figure 6). The constant rate of strain (CRS) test is preferred over the traditional incremental loading (IL) consolidation test because it provides continuous, effective stress-strain-coefficient of consolidation data. Sample quality for low to medium overconsolidation ratio (OCR) clays can be readily evaluated from CRS or IL data, and also from consolidated triaxial and direct simple shear test data, using the volumetric-based measure of sample quality.

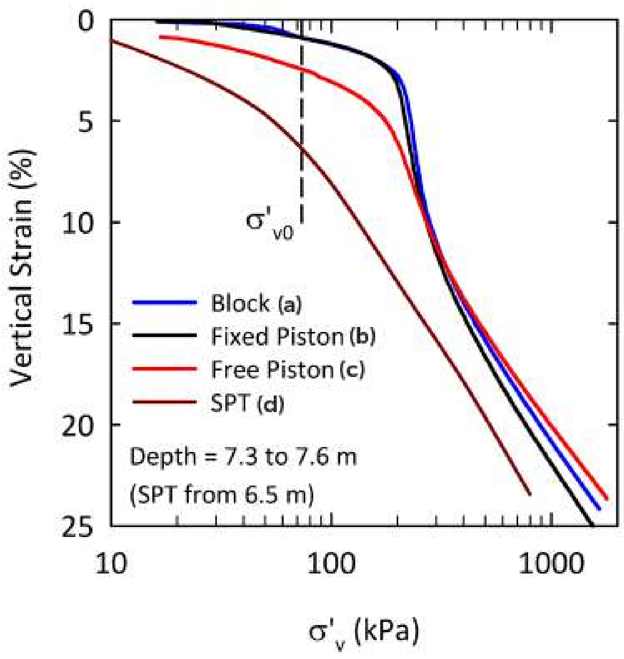

Figure 6. Constant rate of strain (CRS) consolidation tests on samples of Boston blue clay: (a) Sherbrooke block sample, (b) fixed piston 3-in.-diameter Shelby tube sample with bottom 1 cm of tube cut to produce zero inside clearance, and the outside of the cut edge was sharpened, (c) free piston 3-in.-diameter Shelby tube sample, and (d) 3-in.-diameter SPT sample.

Strength index tests like the unconfined compression test (UCT) are popular in practice because they are relatively quick and inexpensive to conduct. However, UCT tests are conducted on specimens of unknown effective stress, a sampling of induced and unknown OCR, and an unknown state of effective stress at failure. The test uses fast shear rates and measures only strength with the major principal stress in the vertical direction. As such, the "accuracy" of project-specific UCT data for design depends upon fortuitous compensating errors, and the actual degree of this compensation is typically unknown. Significant scatter in UCT data, even within a specific geologic unit, is often observed.

Site Idealization

Data synthesis is another site-characterization task for which knowledge of site geology is an important factor. The current in-situ state and behavior of a soil deposit is determined by the depositional environment and post-depositional processes, and, where relevant, anthropogenic factors. The qualitative geologic model is translated to a quantitative soil mechanics proxy by use of the preconsolidation (or vertical yield) stress for fine-grained soils, and via density or relative density for coarse-grained soils. This translation is valuable in assessing the reasonableness of measured or estimated soil parameters along the gradient of contractive behavior (loose, coarse-grained and low OCR fine-grained soils) to dilative behavior (dense, coarse-grained and high OCR fine-grained soils). Furthermore, evaluation of shear strength data within a normalized soil parameter framework is also valuable in assessing the reasonableness of measured values.

Why it Matters?

Best practice recommendations for conducting an integrated site-characterization program are well established. While there's no question that such practices increase the reliability of derived soil parameters and allow for more reliable and cost-effective design, best practices are not always used, and practice may have actually regressed over the past several decades. The intent of this article, therefore, has been to highlight best practices and their benefits.

Practitioners are encouraged to always consider the important role that geology plays as part of a comprehensive site characterization, and remain proactive in leveraging recent advances to improve geotechnical engineering practice. Promoting awareness with clients and other professionals about the value and importance of high-quality site characterization can help raise the quality of geotechnical practice. The wider adoption and appreciation for the best practice techniques described herein can be realized through refined engineering curricula, continued professional practice education, and well-informed communication with clients.

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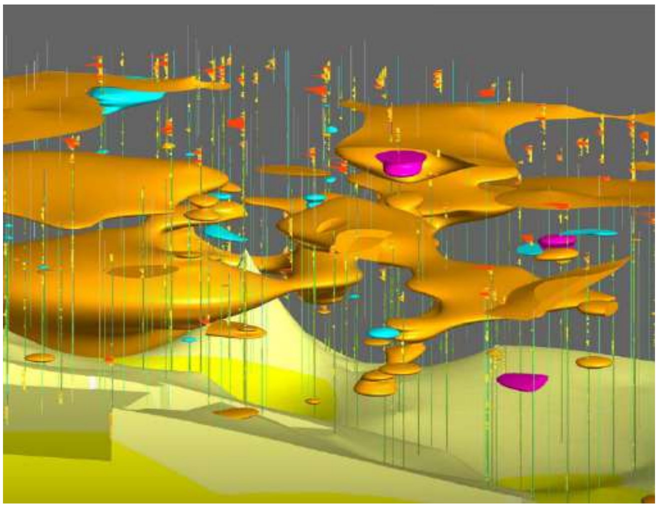
Creating Art AND Reducing Project Risk WITH 3D Modeling

Digital Insights Unearth Hidden Landscapes

By Michael Webster, FGS, MIEAust, and Jennie Byron, ADGIS



Humans have always lived in three-dimensional space, with senses that evolved for a 3D environment. So, it's perfectly natural that people can more quickly, easily, and fully understand something when it's represented in a mode that suits human sensory perception. This is why advances in 3D modeling and associated 3D technologies are game changers for engineers, geologists, scientists, architects, designers, and other professionals — and for the stakeholders who want to understand the world around them and the projects that affect them.

3D Modeling Becomes Art

For a recent project in Melbourne, Australia, the art of 3D modeling and printing was embraced to present a detailed visualization of the terrain underneath a vacant parcel of land within the city's vibrant arts precinct. In this case, the "dark art" of geology was transformed into an actual art project in collaboration with Testing Grounds, an experimental arts space that operates on the site (Figure 1).

Figure 1. Testing Grounds in Melbourne, Australia, is a temporary space for creative practices.

At an early state of the site's development, Golder was engaged to undertake geotechnical investigations and to assess Testing Grounds for future development. The firm had been undertaking geotechnical investigations in the area since 1969, so the data obtained during the recent investigations were added to an extensive set of historical borehole information. The area had a history of difficult ground conditions, with over 60 ft of normally consolidated clays, multiple paleochannels, and lava flows, all encountered at or near the 200-ft by 160-ft site.

Author Michael Webster adopted the latest digital engineering tools to develop 3D models and present the geology as part of an onsite art exhibition: "Turning Digital Geology into Art: An Underground Journey into Melbourne's Arts Precinct." The main model was 3D-printed and featured in the exhibition along with geological core samples, multimedia, and other items providing geological information about the site. A local artist and fashion designer created an exhibit in the space and throughout the site, demonstrating how geological data can be interpreted artistically.

The 3D model (Figure 2) presented the geological history of the arts precinct from as much as 3.5 million years ago. The geology is complex, with volcanic activity and changes in sea levels and river courses exacting their impact over millions of years. The 3D ground model had an unusual level of detail, and resulted in a dynamic, engaging, and artistic public educational resource. Each component, or layer, of the complex geology was separately printed in a different colour so it could be readily seen, handled, manipulated, and explored — allowing exhibit visitors to "hold the world in their hands."

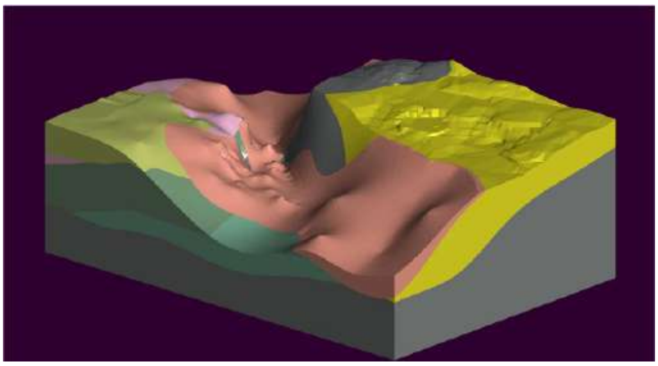


Figure 2. Cut-away view of 3D geological model, showing depositional contact in paleochannel deposit.

The Testing Grounds exhibition offered a way to creatively showcase the convergence of geology, technology, and technical excellence. Based on this experience, we believe applying 3D modeling to client projects can deliver real-world results that are as practical as they are beautiful.

More Than a Pretty Picture

Embracing 3D modeling isn't simply about having fun with new "toys" or about creating "pretty pictures" to show a client (although the process can be enjoyable, and the outputs can be aesthetically pleasing!). While 3D modeling is certainly revolutionizing client presentation and community engagement, there's also more to be gained from developments in 3D modeling, 3D printing, and virtual reality across the entire project lifecycle. The rich potential of 3D modeling can be harnessed to increase accuracy and efficiency, reduce time and labor, and enhance communication and decision-making — all leading to major reductions in a project's level of risk.

Data have traditionally been viewed in 2D forms, as tables, cross-sections, spreadsheets, or reports. However, interpreting and presenting data in 2D requires a huge investment of time and effort, particularly when presenting data in various scales and cross-sections. Managing a complex project and proliferating 2D drawings rapidly becomes inefficient and unworkable. Also, information is "projected" onto the section from varying distances. Information from further away can distort interpretation, create inaccuracies, and increase project risk.

The technical specialist who embraces 3D will not only save time and effort, but can also gain a greatly enhanced insight into the project, which will reduce risk from professional, construction, and operational perspectives. A 3D view (Figure 3) increases the chance of exposing inconsistencies or contradictions, inaccurate interpretations, and missed opportunities. It can reveal — far more effectively than in 2D methods — where data may not yet be adequately robust, detailed, or comprehensive, and where more fieldwork may be needed.

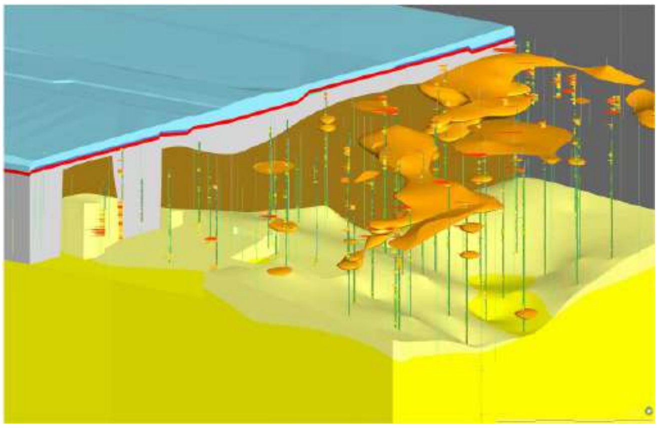


Figure 3. The rich potential of 3D modeling can be harnessed to communicate ground risks and guide decision-making.

With increased awareness of the areas of uncertainty, more work can be done to gather new information and increase understanding. As new data and information come to light, the 3D model can be updated and re-interpreted without having to go back to the drawing board and create new documentation from scratch.

The flexibility and responsiveness of 3D models also allows alternative scenarios to be tested. It's possible to quickly see how the model responds to different inputs and parameters, not only in terms of the immediate location or timeframe, but also from the broader perspective of flow-on effects and consequences. Multiple iterations with different inputs will offer further insights, assisting the specialist's decision-making process and helping to reduce risk.

The 3D model can also help reinforce or verify a specialist's interpretation, much like getting a second or third opinion. By providing this reinforcement, the model helps reduces risk and increases confidence in the specialist's interpretation and solution.

Whether represented onscreen or translated into physical outputs, 3D models open a new world of communication and engagement with clients and stakeholders. When a 3D model is communicated effectively, it "puts everything in perspective." Finally, everyone involved in or affected by the project can clearly "see" what the detailed technical drawings, charts, and graphs are showing. Furthermore, the project team and client can interact with the model and collaborate more effectively to test options, explore the impacts of changes, and understand the areas of uncertainty and corresponding risk.

Viewing the World Digitally

Given that geology is the study of the real, tangible, physical world — of surfaces, shapes, and materials — 3D is the ideal mode for engaging with geological information.

Geology is sometimes described as a "dark art." Each project's landscape is different, complex, often large, and mostly unseen. Geologists must make interpretations and draw inferences based on a limited amount of different types of information. Despite an extensive testing regime, they may only have seen as little as one-thousandth of one percent of the geological volume present at a site — and they must make important decisions based on that. A 3D model brings the dark art to light, revealing what the data are portraying and demonstrating where knowledge gaps remain.

Building a geological model takes a lot of data, which need to be digitized and incorporated into the 3D space (Figure 4). This data may include geological information, borehole sampling results, cone penetration tests, analytical results, field observations, geophysical data, construction records, survey information, and Lidar and aerial imagery. The next step is construction of a series of geological surfaces in 3D space to define the different geological units in the model. Any additional data gathered from the site exploration can be mapped quickly, on site or in the office, and incorporated into the dynamic model.

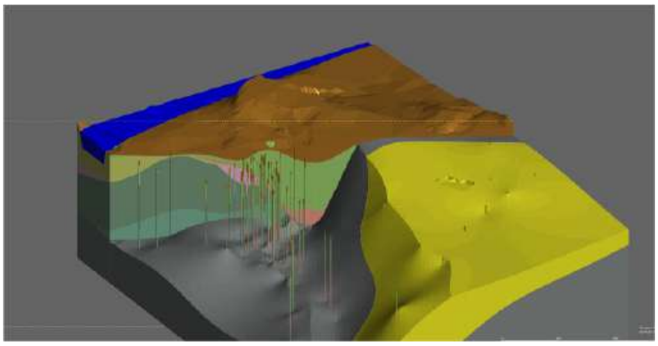


Figure 4. Cut-away section of Testing Grounds' 3D geological model showing test bore locations.

Once the data are visualized in the 3D environment, they can be further manipulated and presented in different formats, such as onscreen walk-throughs, virtual reality demonstrations, or 3D-printed physical models. These approaches can help to effectively communicate complex geological concepts for different audiences.

In a geological context, capturing and exhibiting a ground model enables a better understanding of the ground and subsurface conditions — much of which is not otherwise "seen" or intuitively understood. The model generates a holistic picture of the ground conditions, indicating the geology, areas of risks and unknowns, and areas requiring further attention.

When infrastructure is incorporated into the 3D model as shown in Figure 5, the position and relationship of these features to the ground can be studied, which leads to safer and more efficient design. Sometimes infrastructure maps are localized and may not provide the correct location or the full extent of water mains, sewer lines, gas lines, and so on. Incorporating these data into the model helps to point out high-risk areas, so that designs can be modified to avoid conflicts in locations with abundant or complex infrastructure.

Ultimately, the purpose of a model is to enable clients and project teams to make more-informed decisions to manage risk — and this is increasingly important as infrastructure projects become bigger and more complex. For example, digitally "excavating" a basement located in complex geology allows for greater understanding of construction risks for all members of a project team. It also provides information to designers about potential opportunities to optimize the design, such as avoiding problematic foundation conditions or identifying critical load cases for designing the excavation support system.

Figure 5. Visualization of a pond design.

A 3D model could be a great tool for decision makers when assessing different options for the route of new subsurface infrastructure. The 3D model offers a rapid and easily communicated picture of the risks and opportunities associated with each route — putting the options into a much clearer perspective.

Reducing Risks in Landfill Projects

Co-author Jennie Byron employed 3D modeling to reduce risk and improve outcomes in a landfill expansion project in New England. Landfill projects include a range of risks that can be mitigated using 3D modeling.

Common challenges in landfill projects include protecting groundwater through proper drainage, restricting uncontrolled run-off and, most importantly, ensuring that significant groundwater resources are not jeopardized by the landfill. Understanding subsurface conditions through 3D modeling can help to identify potential groundwater risk pathways if a release from the landfill were to occur.

For the landfill expansion project, 3D modeling (Figure 6) provided preliminary insights into the subsurface conditions through drilling, core logging, sampling, groundwater monitoring, and field observations. The model iterations enabled the project manager and team to see another side to their data, while helping to reinforce their geologic and hydrogeologic understanding of the project site and surrounding area.

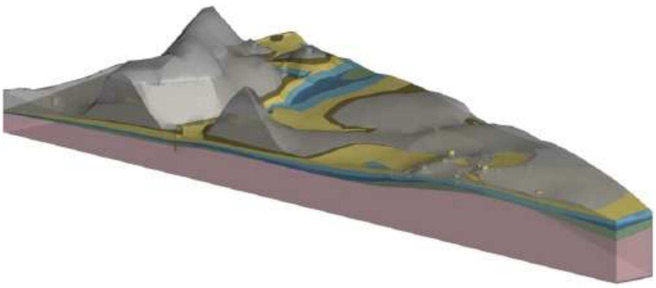


Figure 6. 3D modeling of subsurface conditions beneath a landfill assists with identifying potential groundwater risks pathways.

Cross-sections were generated, providing a static and dynamic view of interpolated surfaces and geology. Sometimes these models remained "behind the scenes," but their input was invaluable for providing a fresh perspective on existing and newer data.

Another general challenge for landfills, as for many projects across engineering and design disciplines, is addressing community concerns about visual impacts. Visual impact assessments (VIA) are a game-changer in this arena. A VIA is artwork itself, and can provide an unparalleled view of how a design will look in the real world.

The VIA includes 3D vantage points showing lines of sight and potential obstructions or impacts on views from residential or commercial areas. This makes it possible to clearly demonstrate options to the public at the design stage and shows the community how much care is being taken to achieve the optimum design. Taking the community along on the journey and building social acceptance early will reduce risks to the project's progress and add to its potential for success.

Getting 3D in Perspective

As with any technology or technique, getting good results from 3D depends on using it well and wisely. This requires specialized skill sets and software, as well as good data and a clear, shared understanding of the level of confidence or ambiguity in the model. The inputs need to be accurate for the model to be reliable and robust. As more data become available, or as conditions change, the model will need to be updated. An inaccurate or outdated model could cause more problems than it solves.

That said, under the right conditions, 3D modeling offers an unprecedented level of processing power translated into a form that human minds can easily interpret. With the increased perspective and clarity gained through 3D, project teams are likely to communicate key information more effectively and make better decisions. Those decisions influence risk, revenue, cost, efficiency, and productivity, and they determine the success of projects and businesses.

Ultimately, for geologists, engineers, and related professions, 3D modeling is part of a broader toolkit, but it isn't necessaryly the right solution for every problem. However, there's an opportunity to get better results across infrastructure and geotechnical projects, particularly if project teams can see beyond the most obvious value of 3D modeling as a presentation tool, and look to embrace its power and scope for design, decision-making, and risk reduction. There is much to be gained by becoming more digitally enabled to see the biggest and clearest picture in this complex and rapidly transforming world.

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Handling Uncertainty In Geotechnical Earthquake Engineering

We Don't Know Everything about Earthquakes, but That's Okay

By Michael W. Greenfield, PhD, PE, M.ASCE

Probability of liquefaction ground damage along the banks of the Willamette River in Portland, OR, following a Cascadia Subduction Zone earthquake

We don't know as much about earthquakes as we would like. Large earthquakes that truly test the limits of our designs are, thankfully, rare events. But over the past decades of research, engineers are beginning to understand what they don't know, how much they don't know, what they will probably never know, and where they should focus their efforts. Geotechnical engineers are embracing uncertainty to design a built environment with more predictable and reliable performance following a range of uncertain earthquake hazards.

History of Predictive Modeling for Earthquake Impacts

Soil is difficult enough to study when it *isn't* moving, so observing and characterizing the behavior of soil when it's subject to dynamic shaking can be very difficult. Engineers often rely on empirical observations from past earthquakes. Starting with a high-quality dataset is a key to developing robust design methods. A critical breakthrough occurred in the 1970s and 1980s, as professors Seed, Idriss, and Arango developed a method to predict soil liquefaction using empirical observations from past earthquakes. They took binary (yes/no) observations of liquefaction and used estimates of the intensity of shaking to infer the dynamic stresses that triggered liquefaction in the soil. They then developed curves that separated the liquefaction case histories from the non-liquefaction case histories. Such an approach provided engineers with a framework to rigorously incorporate past observations to understand how soils might behave during future earthquakes.

In the 1990s and early 2000s, researchers at Berkeley further advanced the empirical liquefaction prediction framework to account for the uncertainty in each case history. The resulting models provided an estimate of the probability of liquefaction, directly quantifying the uncertainty of the predictions. Such a novel approach allowed engineers to make design decisions while accounting for the uncertainty in ground shaking and subsurface conditions.

Earthquake engineers now accept the inherent uncertainty of earthquake hazards. Probabilistic predictions based on empirical data have become a cornerstone of modern geotechnical earthquake engineering. The dynamic behavior of walls, basements, foundations, dams, bridges, pipelines, docks, and other geotechnical structures can be highly uncertain. Each design has its own unique geologic setting, subsurface conditions, and dynamic behavior. All of these attributes contribute to the overall uncertainty of the system. Coupling the system uncertainty with the uncertainty in earthquake ground motions can lead to a wide range of possible outcomes.

The simplest approach to designing structures to withstand earthquakes is to distinguish and understand why certain systems performed well during an earthquake while others performed poorly. Engineers' reliance on historical performance data thus underscores the need for well-documented case histories. However, any dataset of empirical observations could not possibly account for all of the potential earthquake sources, paths, and site effects; subsurface conditions and groundwater configurations; dynamic soil and foundation behavior possibilities; and other random uncertainties. So many uncertainties require probabilistic considerations. Fortunately, engineers can now design for uncertain events through a combination of remarkable increases in the amount of empirical data, modern computational modeling, advanced statistical tools and analyses, and performance-based engineering.

Advances in Empirical Data Gathering and Sharing

A significant step forward is the Natural Hazards Reconnaissance Facility in Seattle, WA, known as the RAPID facility, which officially opened in September 2018. The RAPID facility's mission is to collect sensitive data after a natural disaster and facilitate database development. With an array of drones (Figure 1), Lidar instruments, geophysical sensors, and other field tools, the RAPID facility can help reconnaissance teams collect vast amounts of data very quickly. Dr. Jake Dafni, the operations manager at the RAPID facility, is on the front lines gathering more data to better understand earthquakes. In a recent interview, Dafni explained, "In the past, people used to go out with notebooks and cameras to collect data. Now, we're able to map entire faults with three-dimensional scanning in the course of a couple of days after an earthquake." Reconnaissance data and products produced by teams supported by the RAPID facility are publicly available and in a consistent format. Researchers can then use RAPID's comprehensive datasets to develop new prediction methods and tools. "Now we have the ability to look at impacts on a regional scale, rather than a point-by-point basis," Dafni continued.

Figure 1. A RAPID facility employee conducts drone-based imaging after a natural disaster.

The data-first approach adopted by the RAPID facility has proven to be very successful in past projects. For example, since 2003, the number of strong-motion records of engineering significance has increased at least 50-times, thanks in part to projects like the Next Generation Attenuation (NGA) West-2, NGA East, and Japan's KiK-net databases (Figure 2). These databases have made it possible to develop new ground-motion models to predict earthquake shaking intensity while quantifying the uncertainty in shaking intensity. With the increase in data, researchers have started laying the framework to develop region-specific predictive models.

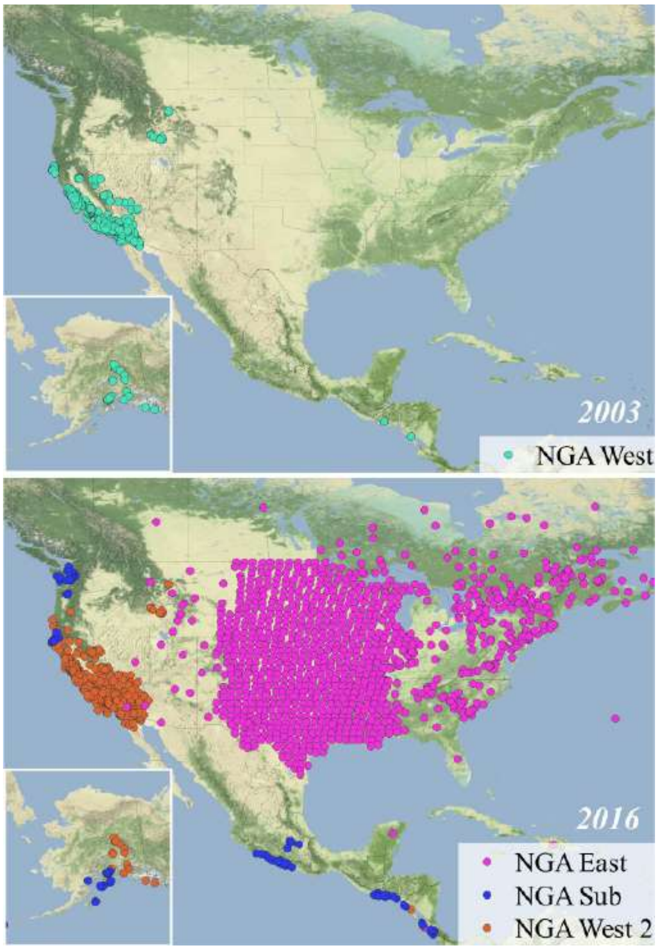

Figure 2. Recording stations with at least one record of engineering significance have exploded in the U.S. since the NGA West project in 2003.

In 2018, the NGA Project began releasing subduction-zone-specific ground-motion recordings (NGA-Sub). Researchers at the Pacific Earthquake Engineering Research Center then used these records to develop specific models to estimate the shaking intensity from a potential Cascadia Subduction Zone (CSZ) magnitude 9.0 earthquake off the coast of Oregon and Washington. Even though large CSZ interface ruptures have never been directly recorded, the Cascadia model uses data from Central and South America, Japan, New Zealand, and Taiwan to estimate the potential intensity of ground shaking in the Pacific Northwest. Of course additional data are still needed before strong conclusions about a potential CSZ rupture can be made, but the potential benefits of the region-specific models are clear. The standard deviation of predicted peak ground acceleration due to random variability could be reduced by 30 to 40 percent with additional data. Such advances are only possible by leveraging large, comprehensive datasets.

The success of the NGA programs and other data-driven efforts has inspired many new projects aimed at collecting high-quality empirical data from past earthquakes. The Next Generation Liquefaction (NGL) project seeks to develop an open-source global database of liquefaction case histories, building off of the original dataset developed by Seed, Idriss, and Arango in the 1970s. Due to recent reconnaissance efforts, the number of liquefaction observations has increased from 35 to over 250, greatly improving the applicability of new liquefaction models. However, the number of case histories is still relatively small compared to the number of potential sources of variation. Individual case histories, therefore, can greatly leverage the empirical model. Even small differences in the interpretations of key case histories can cause very significant differences in predictive models. One of the NGL project's missions is to standardize liquefaction case histories with rigorous data collection, processing, and multiple stages of peer review. Many independent research teams are contributing to the NGL database, so carefully cataloging all observations into a searchable, standardized, and open-source database is necessary to build consensus among model developers. The database is online as of 2019 (*nextgenerationliquefaction.org*), and more case histories are being collected, processed, reviewed, and uploaded on a regular basis. The NGL project will soon be moving toward a new phase of model development, augmenting the existing case history data with supporting studies to better understand the dynamic behavior and interaction of soils and pore water.

Computational Advances in Predictive Modeling

Even as the body of earthquake observations grows, gaps in the data exist, especially for rare or infrequently occurring events. Most of the empirical earthquake data has been collected over the past 50 years, a time frame that's too short to observe many of the most powerful earthquakes. Fortunately, recent computational advancements can now simulate the propagation of earthquakes waves at unprecedented scales. These modeling efforts can help fill in the data gaps for low-probability, high-intensity earthquakes. The M9 project at the University of Washington in Seattle has simulated dozens of CSZ ruptures with high-resolution output spanning from California to British Columbia (Figure 3). Each simulation provides a physics-based representation of a possible CSZ rupture. Certain aspects of fault ruptures — like the hypocenter location, patterns, and timing of the fault slip, and locations of high-stress drop asperities on the fault — cannot be predicted using current technology. However, through a combination of simulations with different rupture mechanics, engineers can represent a range of possible ground motions while accounting for the region-specific paths through which seismic waves must travel. These physics-based models can then supplement the available empirical data and help improve hazard estimates for specific regions.

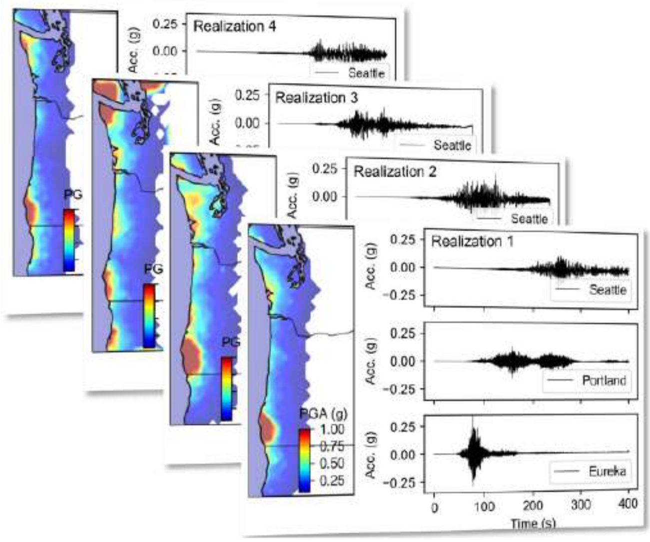

Figure 3. Dozens of Cascadia Subduction Zone simulations from the M9 project provide a range of possible ground motions.

Considering Uncertainty for Future Predictions

Engineers need more than just a large pool of data to help design reliable and resilient systems. Following the recent increases in data and advancements in computational analyses, the next step toward a reliable built environment is to use available data to predict the possible consequences of an earthquake. Probabilistic analyses with consideration of the uncertainty can then be used to assess if the current data is sufficient or if additional data needs to be collected.

For example, many cities maintain a large dataset of subsurface soil borings. These borings can be used with geospatial analyses to quantify the uncertainty between investigation locations. One popular geospatial tool called "kriging" uses probability distributions to interpolate between boring locations. Kriging assumes that measured data points are just part of a larger probability distribution. At a sample location, the kriging probability distribution has its lowest variance and is the least fuzzy. At locations far from any measurement points, the kriging probability distribution has very high variance and is the most fuzzy. Multiple geotechnical measurements, like groundwater depth, soil classification, and penetration resistance, can be analyzed using kriging to calculate probabilistic outputs. A recent study in Portland, OR, used kriging geospatial analyses with hundreds of borings to calculate the 3D probability of liquefaction over an area spanning 175 square miles. Such probabilistic regional hazard studies show not only where high-hazard locations exist, but also quantify the level of confidence (Figure 4). Engineers and stakeholders can use probabilistic results from regional seismic hazard studies to determine if the hazards are acceptably low, if additional data needs to be collected, or if mitigation should be pursued.

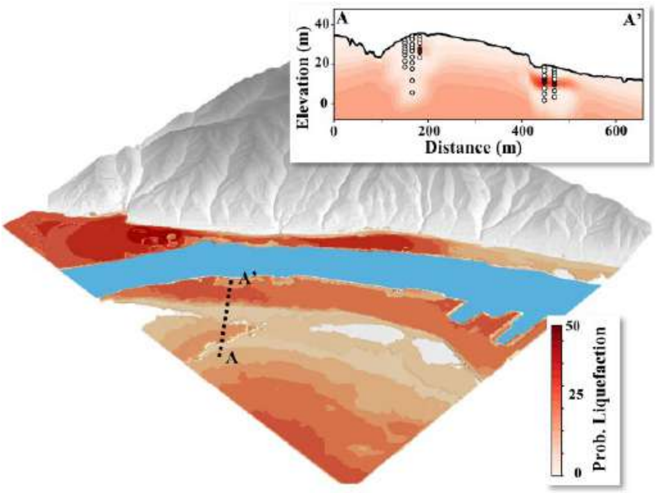

Figure 4. A large dataset of borings in Portland, OR, helps to quantify the uncertainty in liquefaction-triggering potential throughout a large area. The inset shows the probability of liquefaction versus depth along Section A-A' with five different borings identified.

Performance-Based Engineering

Ultimately, the purpose of understanding the level of uncertainty surrounding the consequences of earthquakes is to develop designs that are not only robust for "The Big One," but are also reliable and can recover quickly following a range of potential earthquakes. Embracing uncertainty, in the form of probabilistic seismic-hazard analysis (PSHA), has long been a pillar of earthquake engineering. PSHA cleverly accounts for the uncertainty in earthquake models, magnitude, rupture distance, and ground motions, combining many unknowns into a single probability of shaking intensity over a specific time period. PSHA has been implemented in a prescriptive manner into national design codes, which are generally tailored toward protecting basic life safety.

However, there's a growing desire among owners, insurers, government officials, and the public to design buildings and infrastructure to meet performance objectives, like minimizing economic loss or maintaining operation after an earthquake. Possible performance objectives may require buildings and the supporting infrastructure to be operational following frequent, modest shaking events, repairable after very strong shaking events, and stable so nothing collapses after extreme events. Each of these events and consequences could have a significant amount of uncertainty, making performance-based design challenging. The Pacific Earthquake Engineering Research Center has developed a performance-based earthquake engineering framework to account for the various hazards and performance outcomes. Performance-based earthquake engineering aggregates uncertainties in shaking intensity, structural response, and damage using an approach similar to PSHA. The results are a single decision-based design metric of losses, such as annualized cost or downtime. Such loss metrics are simple to communicate to stakeholders and can quantify the cost benefits of reducing uncertainty.

Fully implementing the performance-based engineering methodology, however, requires tools to evaluate the uncertain effects of ground movement and forces on structural systems. For example, estimates of building losses are conditional upon the probability of building damage versus ground settlement. These calculations build on top of probabilistic geotechnical analyses, requiring geotechnical engineers to fully understand the potential sources of uncertainty and how they may be translated into structural systems. So once again, engineers are relying on empirical data from past earthquakes to understand the uncertainties in structural response, damage, and loss.

Back at the RAPID facility, Dafni is busy preparing to deploy tools to document the next natural disaster. He knows that empirical data fuels probabilistic modeling efforts that ultimately become the tools engineers need to design the built environment for uncertain events. Through data collection, modeling, probabilistic analyses, and performance-based engineering, geotechnical engineers are working to make the built environment more reliable and recover more quickly after earthquakes. Although the design methodologies are new, the roots of these empirically based methods trace back to the 1970s, when geotechnical engineers began to understand the uncertainty surrounding earthquakes. With the rapid increases in available data and technology, engineers will likely continue to use data-driven empirical methods to understand uncertain events like earthquakes for the foreseeable future.

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In Memoriam

Robert M. Koerner, PhD, PE, D.GE, NAE, Dist.M.ASCE (1933-2019)

With great sadness and heavy hearts, the family of Robert (Bob) M. Koerner announced his death on December 1, 2019. He was the loving husband of Pauline (Paula) W. Koerner, and the father of Michael R. Koerner (wife Mary), George R. Koerner (wife Jamie), and Pauline Koerner Limberg (husband Douglas), and the grandfather of six children.

Bob was born on December 2, 1933, in Philadelphia, PA, to his immigrant parents, Michael and Cecilia Koerner. He grew up in Lansdowne, PA, and attended parochial school before entering college. He received a bachelor's and master's degree in civil engineering from Drexel University in 1956 and 1963, respectively, and a PhD in civil engineering from Duke University in 1968.

After receiving his undergraduate degree, Bob began his career in construction. He worked on a number of noteworthy projects in Philadelphia, New York City, and Wilmington, DE. He married Paula in 1959, and then transitioned into consulting with Dames and Moore out of NYC. After three near-fatal work-related accidents, Paula convinced Bob that she didn't want to raise their three young children as a widow, so he needed to find a safer career. Bob loved his first chance at teaching night school at PMC (now Widener University), so he committed to a career path in education by moving his family to North Carolina for his PhD at Duke University.

After completing his doctorate in 1968, Bob and Paula moved back to Philadelphia, where he joined the Civil Engineering Department at Drexel University. His initial research was on deep foundations, acoustic emission monitoring of soil deformations, and nondestructive testing to locate below-ground structures and objects. In the late 1970s, he began research in the fledgling field of polymers used in construction. In 1980, he co-authored the first textbook on geosynthetics, *Construction and Geotechnical Engineering Using Synthetic Fabrics*, and, as he once said, the "phone never stopped ringing."

With his full and complete focus on geosynthetics, Bob eventually became renowned in the field worldwide, and is known for over 750 publications, ranging from books, to journal papers, to symposia and conference proceedings, as well as reports and miscellaneous articles. His most notable publication is probably the textbook *Designing with Geosynthetics*, which he regularly updated to the 6th edition.

As his 65-page resume aptly documents, Bob simply never stopped writing. For *GEOSTRATA*, he authored a commentary titled "Geosynthetics: Past, Present, and Future" for the July/August 2013 issue. He was also the subject of a GeoLegend student interview published in the magazine's September/October 2014 issue.

Bob supported the growing industry of geosynthetic education and research by founding the Geosynthetic Research Institute (GRI) in 1986. He managed GRI at Drexel University until 1998, when he moved it off-campus to its present location near the Philadelphia International Airport. GRI was, and is, tremendously successful. Federal, state, and private research expeditures have exceeded expectations, and a consortium of organizations was formed from the outset that continues to the present.

In 1991, Bob formed and incorporated the Geosynthetic Institute (GSI) to develop and transfer knowledge, assess and critique geosynthetics, and provide services to its member organizations. Bylaws, a Board of Advisors, annual conferences, specific-focus group meetings, and related activities followed in succession and continue to the present. Today, 73 organizations, representing agencies, owners, consultants, testing laboratories, resin producers, geosynthetics manufacturers of all types, and installers, support GSI.

Bob was elected into the National Academy of Engineering in 1998. He has proudly served the local, national, and international engineering community for over 50 years. At his core, Bob was a teacher. He was always networking with people, sharing his latest insights, rehearsing lectures to himself if he was running alone, or laughing and talking when with others through thousands of training miles. (Bob completed 25 marathons and over 200 shorter races.) He taught in lectures, classrooms, businesses, conferences, on the street, in his home, and even on the beach. His latest recorded sessions geared for Internet education affectionately earned him the title "Webinar Bob."

Bob could get a group of strangers conversing with each other faster than anyone. He loved to put forward a question, and then manage the conversation to draw each person out to voice their opinion. These interactions made those he met better, smarter, more inquisitive, more articulate, and more thoughtful. Bob had this particular impact on everyone.

Bob's GeoLegend interview article closed with a question about what advice he would give to a young engineer. He replied: "There are intrinsic values in attaining one's full mental potential, and one does not usually get the chance to turn time back on itself. Go for it, and the sooner the better!" Those words reinforce that, "at his core, Bob was a teacher," and those who met and worked with him were the benefactors.

GeoPoem

By Mary C. Nodine, PE, M.ASCE

Blue Clay Blues

South of the Mason-Dixon Line
As I work in the Natural State I find
Lignite, marl and weathered rock
A different soil in every block!

(And every foot, to my despair,
As I log carefully every layer.)
Expansive clay, elastic silt…
The variety on which this state is built
Blows me away — and yet, I'm torn.
I know my heart will always mourn
For the beauty of those perfect grains
Beneath a city south of Maine
That comprise the hallowed, smooth, blue-gray
Matrix of our Boston Clay.

It's overconsolidated just so,
With plasticity that's brilliantly low,
Supporting friction piles with ease
(And little chance of unwanted heave).
Ah! To recover two feet in spoon after spoon
Is enough to make any engineer swoon
For the first 50 feet. And then, I daresay,
She might wish to find a sand seam in the clay,
Or even reflect on her time in the fill….
But by then, perhaps she has hit glacial till.

Originally published in the January/February 2008 issue of GEOSTRATA as the first-ever GeoPoem.

Lament of an Ancient Embankment Dam

For over a century I've stood,
High in the mountains,
surrounded by woods,
Overlooking this city whose water supply I protect,
keeping all downstream neighborhoods dry.

But you're not impressed that I've lasted so long;
Survived eighty-two drawdowns and still stand so strong.
All you can see is the puddles of seepage
Downstream of my toe, indicating some leakage
Through soil compacted with wheels pulled by horses!
A hundred long years of constant seepage forces
Caused piping — it's minor — what do you expect?
I was built with no core and no grain size spec.

Safe in your office, with a bit of reflection,
You'll boil me down to a flat 2-D section
With colors horrendous — red, yellow and purple —
Then presume I would fail in a perfect circle!

That shadow of a dam on your computer screen
May look pretty, but it's much too clean.
Your complex analysis outputs so much data
But can't capture the intricacies of my strata.
You'll lose subtle lenses of varied grain sizes,
The gentle undulations as my downstream slope rises.
You ignore my concrete face 'cause it has a few cracks;
But I'm steadfast, still holding this reservoir back.

So, make me compliant — design what you will.
Bring in your fanciest well-graded fill.
But as you plan for my future, all that I ask
Is a little respect for the success of my past.

Originally published in the July/August 2010 issue of GEO-STRATA.

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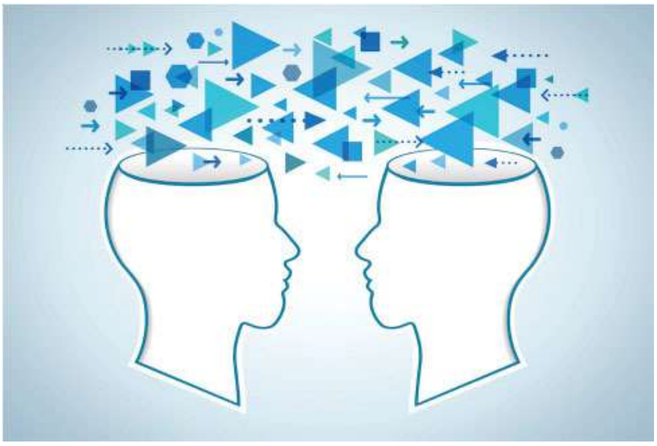
Board of Governors Update



Breaking Barriers to Innovate

The word "innovation" has shifted from being an anathema, defined before the early American settlement as a derogatory synonym for rebellion, revolt, and heresy, to a welcomed and desired process that brings together various novel ideas in a way that positively affects our society.

The Board of Governors (BoG) of the Geo-Institute (G-I) supports innovation through various technical activities that plant the seeds for new views and ideas to solve geo-problems. The BoG agrees that diversity is a key driver of innovation and supports diversity in the geoprofession, not only because it's part of our obligation to G-I members, but also because more and different solutions will be created when we break barriers that limit who can participate in solving the problems that society faces.

The BoG, in line with ASCE's Canon 8, has been actively conveying a message — that resonates particularly with the G-I's younger generation of members — to organizations and firm owners that engineering innovation is a critical factor to growth and competitiveness, which can be the essential by-product of a diverse workplace.

At the time of this publication, the BoG has met during the 2020 Geo-Congress in Minneapolis, MN, February 25-28. Part of this meeting and conversations with members during the event were devoted to discussing the various ways with which the G-I provides a safe, inclusive environment that fosters diversity of people and ideas. Ongoing efforts will be enhanced to ensure that all G-I members know that they have a voice, a broad range of opportunities, and will receive credit for their contributions to ideas and projects. Exciting details of these efforts will be discussed in future issues.

G-I Board of Governors

…

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(συμμετοχή Ελλήνων Γεωτεχνικών Μηχανικών)

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GEOSTRATA

Geo-Forensics — Lessons Learned from Failures

As I See It: Geo-Forensics — What We Learn from Failures
By J. David Rogers

Learning from Pile Driving Failures
By Dan Brown

Response to a Massive Runway Slope Failure
By Allen Cadden, Philip Shull, Gary Brill, and Michael Senior

In the Wake of the Mount Polley Mine Tailings Breach
By Harvey McLeod

In-Service Performance of Rockfall Barrier Foundations
By David J. Scarpato, Peter C. Ingraham, Robert P. Group, and Tim C. Shevlin

Highway Embankment Failure on Soft Clay
By Timothy D. Stark, Perry J. Ricciardi, and Ryan D. Sisk

Did You Know? Analyze Before You Test
By Tony Saada

Lessons Learned from GeoLegends: Raymond Krizek
By Karam Jaradat and Seyed Zeinali

ΕΚΤΕΛΕΣΤΙΚΗ ΕΠΙΤΡΟΠΗ ΕΕΕΕΓΜ (2019 – 2022)

ΕΕΕΕΓΜ

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