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CENTER FOR GEOTECHNICAL PRACTICE AND RESEARCH

The Future of Geotechnical Engineering

by

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and

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Report of a study performed by the Virginia Tech Center for Geotechnical Practice and Research

January 2013
CGPR #70

Center for
Geotechnical Practice and Research
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Preface

Future events can be divided into three categories:

1. All those things that you know will happen. For example: the sun will come up tomorrow, the other line always moves faster, and late flights will get later. Your life experiences tell you how to deal with these.

2. All those future events that you can influence in some way – you know, or think you know, where you want to go, or what you want to achieve.

3. All those things that are totally unpredictable. For example, you never know when you will be in the right place at the right time, or the wrong place at the wrong time. The best you can do in these situations is to be ready to take advantage of opportunities in the case of the former and to be sure your affairs are in order in the case of the latter.

This report has been prepared to address the future of geotechnical engineering. A review of the growth and development of many areas within this important discipline and an assessment of its present status provide a strong foundation for dealing confidently with Category 1 events. New understanding, technology developments of many types, and many important societal and environmental challenges should provide opportunities for geotechnical engineers to make important contributions to success in dealing with events in the second category. By being alert, perceptive, innovative, and proactive there will be opportunities make major contributions in dealing with geotechnical aspects of issues that arise from the first type of unknown events in Category 3, and to mitigate potential adverse effects from the second type.

SOME OF THE SCOPE OF GEOTECHNICAL ENGINEERING AND CONSTRUCTION

1. Laboratory testing - Minnesota Department of Transportation experimental testing apparatus for the resilient modulus of unbound pavement materials. From MN DOT (2012), From “What is Resilient Modulus?”, dot.state.mn.us/materials/mr/images/resilient-modulus.jpg, accessed November 10, 2012.

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3. Slope stability – Landslide in Colorado. From Colorado Geological Survey (2012), “Landslides in Colorado”, geosurvey.state.co.us/hazards/Landslides/PublishingImages/landslide.jpg, updated November 1, 2012.

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7. Geotechnic Frontiers – Apollo 15's Jim Irwin samples the lunar surface to help define its characteristics. From NASA (2012), "Soil Mechanics Experiment" nssdc.gsfc.nasa.gov/image/spacecraft/alsep_soil_mech.jpg, updated May 14.

8. Soil and site improvement – Jet grouting to stabilize I-90 near the superfund site Milltown Reservoir in Montana as a bypass channel is constructed during EPA remediation efforts. FromUSEPA (2008) "Milltown Reservoir OU Photos - I-90 bridge stabilization drilling", epa.gov/region8/images/I-90%20stablization_jet-grouting2%2006-12-07.jpg, updated June 8, 2012.

9. Environmental Geotechnics – Landfill liner. From Missouri Department of Natural Resources, (2012) "Missouri Solid Waste Management Law, 1972 to 2012", dnr.mo.gov/env/swmp/images/landfilllinera.JPG, accessed November 10, 2012.

10. Geotechnic Frontiers – Offshore drilling rig. FromCongressman Forbes (2012), "Expanding Offshore Drilling to Create Jobs and Enhance Energy Independence" forbes.house.gov/uploadedfiles/offshore_drilling_1.jpg, accessed November 10, 2012.

11. Tunneling – Tunnel portal and tunnel boring machine. From FHWA (2011), "Technical Manual for Design and Construction of Road Tunnels - Civil Elements", fhwa.dot.gov/bridge/tunnel/pubs/nhi09010/images/fig_14_02.gif, updated April 5.

12. Geotechnical earthquake analysis – Sand boil resulting from the liquefaction of sand in the Marina District of San Francisco during the Loma Prieta Earthquake of 1989. From USGS (1999), "Progress Toward a Safer Future Since the 1989 Loma Prieta Earthquake", http:\\pubs.usgs.gov/fs/1999/fs151-99/images/sandboil.jpg, published November 3.

13. Mechanically Stabilized Earth Structures - MSE Wall on Guadalupe Parkway, Route 87, by San Jose Airport. From Caltrans (2002), "MSE Wall on Guadalupe Parkway", dot.ca.gov/hq/esc/geotech/photos/west/p1010005.jpg, published July 25.

14. Earthwork and Excavation – An active, open excavation. From Arlington Virginia (2012), "Land Disturbance Activities and LDA Permit", arlingtonva.us/departments/EnvironmentalServices/dot/images/image81108.jpg, updated October 31.

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Acknowledgements

The authors acknowledge with appreciation the interest and input provided by the members of the Virginia Tech Center for Geotechnical Practice and Research. We thank George Filz and Mike Duncan for their review of the manuscript and helpful comments.

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1. INTRODUCTION

In 1950 the scope of soil mechanics and foundation engineering consisted of a relatively limited range of topics, as shown, for example, by the contents of the classic text by D.W. Taylor *Fundamentals of Soil Mechanics (1948),* which included:

Soil Classification
Capillarity, permeability and seepage
Stress analysis by elasticity
Consolidation and settlement analysis
Shear strength of sands and cohesive soils
Slope stability
Lateral pressures and retaining walls
Bearing capacity
Shallow and deep foundations

At that time there was but a handful of relatively small, newly formed consulting engineering firms that specialized in the practice of soil mechanics and foundation engineering. Bonaparte (2012) lists only six such firms, four of which were founded after 1940. National technical and professional societies supporting activities relating to soil mechanics and foundation engineering and providing opportunities for publication of research and technical papers were limited primarily to the American Society of Civil Engineers (ASCE), the American Society for Testing and Materials (ASTM), and the Highway Research Board, now the Transportation Research Board (TRB), with limited participation internationally in the International Society for Soil Mechanics and Foundation Engineering (ISSMFE), now the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). While courses in soil mechanics and foundation engineering were part of the undergraduate civil engineering curriculum at most universities, there were few strong graduate research programs available.

Developments and expansion of the field over the next 60 years have been great, as indicated by the decadal listing of major new areas of interest in Table 1. By the 1970's the scope of the field had broadened greatly, new sub-disciplines had emerged, and *Geotechnical Engineering* became universally adopted as the name of the field. During this period the number of students from undergraduate civil engineering and other earth science fields choosing geotechnical engineering as their area of specialization for graduate study mushroomed, many new firms, from small to large, entered the field, the practice of geotechnical engineering changed in significant ways, and new professional and technical organizations were formed as the field moved through adolescence into maturity.

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Table 1. Major new areas of study and developments in geotechnical engineering by decade from 1950 to 2010 (updated from Mitchell, 2006)

Decade	Major Developments and Areas of Emphasis
1950 - 1960	Slope stability, Shear strength, Soil fabric and structure, Causes of clay sensitivity, Compacted clay properties, Pavement design, Soil stabilization, Transient loading
1960 - 1970	Physico-chemical phenomena, Rock Mechanics, Computer applications, Finite element analyses, Soil-structure interaction, Soil dynamics, Liquefaction, Earth and rockfill dams, Pore pressure, Effective stress analysis, Offshore, cold regions, and lunar projects
1970 - 1980	Constitutive modeling, In-situ testing, Expansive soils, Soil dynamics, Centrifuge testing, Partly saturated soils, Geotechnical earthquake engineering, Underground construction
1980 - 1990	Groundwater and geohydrology, Geoenvironmental engineering, Geosynthetics, Earth reinforcement, Risk and reliability, Ground improvement
1990 - 2000	Waste containment, Site remediation, Seismic risk mitigation, Land reclamation, Infrastructure, Geophysical applications, Geographic information systems
2000 - 2010	Information technology applications, Sustainability, Improved ground treatment methods, Sensors, Data mining, Automated monitoring, Enhanced and extended applications of the observational method, Asset management

Geotechnical problems and the scope of geotechnical engineering have broadened to the point where geotechnology now draws on, or is a significant component of, several related disciplines. They include geology and engineering geology, rock mechanics, geophysics, geochemistry, geohydrology, seismology, civil engineering, mining and mineral engineering, and petroleum engineering.

New knowledge, new challenges, and new opportunities in a changing world stimulate inquiry into what will lie ahead and how to best prepare for it. Accordingly, members of the Virginia Tech Center for Geotechnical Practice and Research (CGPR) requested that a study be made of the Future of Geotechnical Engineering, and this report has been prepared to present the results of that study.

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The scope of this requested study is broad. A survey of the CGPR members at the 2012 annual meeting was made to help identify the topics of most interest. CGPR members were invited to make suggestions and provide useful bits of information concerning new and anticipated innovations in their various areas of expertise. The results of this survey, summarized in Appendix B, were helpful in shaping the sections and areas of emphasis in this report.

In the sections that follow, the present status of geotechnical engineering is summarized briefly, the importance of geotechnical solutions in addressing several important technical, societal and environmental problems is noted, some emerging trends are evaluated, and some implications for future teaching, research and professional practice are offered. The report draws extensively from, and builds upon, a recent comprehensive study of the status and new developments in geotechnical engineering published in 2006 by the National Research Council: *Geological and Geotechnical Engineering in the New Millennium - Opportunities for Research and Technological Innovation* (NRC, 2006).

2. **THE PRESENT STATUS OF GEOTECHNICAL ENGINEERING**

The range of problems and projects that now form a part of geotechnical engineering includes:

- Foundations for structures of all types
- Transportation infrastructure, including roads, airfields, railroads, pipelines, rivers and canals, ports and harbors, tunnels and subways
- Land reclamation
- Seismic safety and mitigation of seismic risk
- Resource recovery
- Energy
- Preservation and restoration of historic structures
- Waste disposal and waste containment structures
- Site remediation and environmental enhancement
- Soil and rock as construction materials
- Exploration and development in cold regions, the deep ocean, and space
- Natural hazard protection and risk reduction (landslides, tornadoes, hurricanes, earthquakes, tsunamis, expansive soils, floods)
- Sustainability

New materials and technologies, especially for earthwork construction, ground improvement, ground reinforcement, and waste containment applications, have been

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developed within the last one or two decades, and many of them are now used on almost a routine basis. Among them are:

- Many types of in-situ earth reinforcement and reinforced earthwork
- Deep soil mixing
- Jet grouting
- Compaction grouting
- Geosynthetics and geocomposites of many types for many purposes
- Micro-piles
- Very large diameter driven piles
- Micro-tunneling
- Bio-treatment of soils for environmental and ground improvement purposes
- Lightweight and foam fills
- New and improved geophysical methods for “seeing into the earth” for site characterization, property determination and monitoring purposes.

Geotechnical engineering and construction are now strongly influenced by factors such as the following, any and all of which can have major impacts on how the work is done:

- Public input and participation is greater than ever before
- Regulatory and legal issues have significant impact on what we can do and how we do it.
- Health and safety issues are very important
- Decisions are often made using the results of risk and decision analyses
- Design-build contracting is competing with design-bid-build contracting
- Struggling economies around the world have slowed some types of work
- Poorly defined goals and questionable benefit-cost ratios can work to the detriment of some projects.
- Automation, information technology and the cyber-infrastructure of the digital age are stimulating new approaches to interactive design, construction procedures, QA/QC, monitoring, and long-term evaluation of performance and condition; i.e., a digital age application of the observational method.

Educators in geotechnical engineering have always faced the daunting task of effectively teaching an engineering discipline involving materials and boundaries that usually are not well defined. Prior to about 1945, the burden was carried by one or two faculty members within college and university civil engineering programs who taught one or two courses in soil mechanics and foundation engineering. Most of these faculty members were not engaged in research. Things have changed, however, as virtually all civil engineering departments, both nationally and abroad, are requiring at least one

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course in geotechnical engineering, and are offering advanced courses in both their undergraduate and graduate programs. As a testament to this, in 2011 there were 126 universities listed as members of the United States Universities Council on Geotechnical Education and Research (USUCGER). There is strong competition in both attracting the best and brightest prospective graduate students and in obtaining extramural research support. Some geotechnical researchers have realigned their focus to study problems in or take advantage of newer and emerging disciplines, such as biogeochemical science, nanotechnology, and information technology, and many are working on interdisciplinary and multi-disciplinary projects, perhaps in some instances without first mastering the fundamentals of soil mechanics and geotechnical engineering.

Educators are teaching a much broader range of courses and are reaching more and more students. Paralleling the current trends in research, it is not uncommon to see courses offered in interdisciplinary subjects such as biogeochemical soil improvement. The widespread use of computers in the classroom and at home provides teachers with new tools. Instructors are having their students solve real world design problems with programs commonly used in practice. Virtual laboratory testing by computer is sometimes used to introduce students to laboratory testing; however, it is not likely that this can ever completely replace the value of hands-on testing of real soils and rocks. Helpful resources and papers are available en-masse in digital databases, and instructors can bolster a student's geotechnical library without ever leaving their desk. Continuing education in geotechnical engineering has never been easier for professionals. The availability of a wide range of online graduate courses is allowing students to finish degrees at their own convenience, not only strengthening their resume, but improving the state of practice as a whole. Downsides of this include no or only very limited direct contact with professors and daily interactions with other students studying the same material.

As will be discussed in more detail in a later section, private practice (the business of geotechnical engineering) has expanded greatly from only a few relatively small geotechnical engineering firms prior to World War II. Now there are several large to very large engineering firms, offering services from many disciplines, including geotechnics, that dominate the market for large projects. A larger number of small to medium size firms provide a broad range of geotechnical engineering, design and construction services. There are now many relatively small geotechnical engineering firms that offer unique and specialized services to the profession; e.g., grouting and ground improvement, risk analysis, forensic studies, deep foundations, ground freezing, dewatering, soil dynamics and earthquake engineering, and geosynthetics. Some of these smaller firms were started by individuals trying to bring innovation into practice.

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Professional societies, too, have changed considerably over the past few decades. From a few national organizations meant to protect, unite, and advance a profession riddled with uncertainty and liability, some societies have now become global entities. Organizations such as the ISSMGE, bring together geotechnical professionals from around the world to discuss and attempt to solve global issues, help uplift the profession, aid individuals in developing countries, and help inform them of new research/information across national borders. At home, organizations such as ASFE have also aligned themselves with a global perspective, calling for sustainability to be at the forefront of every design. These societies are also taking advantage of the digital age to increase their reach and accessibility. Never before has it been easier to view proceedings, both in written and electronic form, from a professional society's conference. Webinars now make a full range of technical and professional information available worldwide. Smart phone applications are now available so that conference participants can view information about speakers, attendees and topics, including presentation materials, right in the palm of their hands.

Against this backdrop, the great worldwide need for new infrastructure and energy resources and greater protection against natural disasters, all provided in a sustainable, economical and environmentally responsible manner, means that both the opportunities and challenges confronting the geotechnical engineering profession are greater now than ever before.

3. UPDATING THE NEW MILLENNIUM REPORT: THE PAST FIVE YEARS

The roles of geotechnical engineering in addressing societal needs were described by the Geotechnical Board of the National Research Council in its 1989 report, *Geotechnology: Its Impacts on Economic Growth, the Environment, and National Security* (NRC, 1989). Seven broad national issues were addressed:

1. Waste management
2. Infrastructure development and rehabilitation
3. Construction efficiency and innovation
4. National security
5. Resource discovery and recovery
6. Mitigation of national hazards, and
7. Frontier exploration and development.

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Recommended actions for advancing the roles of geotechnical engineering in better meeting each of these national needs were identified in the Geotechnical Board's report (NRC, 1989). Each of these actions was assessed in the New Millennium report (NRC, 2006) in terms of accomplishments, unresolved issues, and new opportunities. This assessment is summarized herein in Appendix A - Table A-1. The most important geotechnical engineering knowledge and technology needs included:

- Improved ability to "see into the Earth" and characterize the subsurface was cited as perhaps the most important need, irrespective of the problem or project.
- More reliable and accurate methods for sensing and monitoring.
- Improved data acquisition, processing and storage; inclusion of data into suitable information systems.
- Better understanding and prediction of the time-dependent and long-term behavior of constructed facilities and earth structures.
- Improved ability to characterize soil variability and the uncertainty in soil properties and their influence on the reliability of geosystems.
- How to deal with earth materials falling in the range between hard soils and soft rocks.
- Understanding biogeochemical processes in soils and rocks.
- Improved soil stabilization and ground improvement methods.
- Understanding and prediction of geomaterial behavior under extreme loading and environmental conditions.
- Development of subsurface databases and models.
- Innovative applications of new information technology and communication systems.

Advances in each of these areas will help geotechnical engineers better understand, manage, design and build, on, in, and with the earth, and will also lead to new and better strategies to protect and enhance the environment and mitigate the effects natural disasters (earthquakes, floods, landslides).

The New Millennium report (NRC, 2006) contains an in-depth description and analysis of several new and developing technologies and tools that have the potential to increase understanding of the properties and behavior of earth materials and to improve the practice of geotechnical engineering. They are: (1) Biotechnologies, (2) Nanotechnologies, (3) Sensors and Sensing System Technologies, (4) Geophysical Methods, (5) Remote Sensing, and (6) Information Technologies and Cyber Infrastructure. Table 3.5 in that report, reproduced here as Table 2, provides an assessment of each of these technologies and tools relative to advancing knowledge and practice in geotechnical engineering.

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Table 2.The Potential of New Technologies to Advance Knowledge and Practice in Geotechnical Engineering (from NRC, 2006)

Discipline	*Potential impact on Geotechnology*	*Timing*	*Required knowledge for geotechnical engineers*
Biotechnology	**High** • improved understanding of earth material behavior • new construction materials • applications for in situ ground remediation of contaminated soil and groundwater will increase • passive methods for ground stabilization may be possible • better resource recovery methods may develop	Mature concepts permit high impact in the short-term	• biology • geochemistry
Nanotech-nology	**Medium to low** • nanotechnology is a recognized part of soil technology • enhanced understanding based on more study of reactions at the nanoscale • new materials and methods • solutions looking for problems at this stage?	Field in early stages of development. Its full impact in geotechnology should be expected in the long term	• physics • chemistry
Sensors and sensing systems	**Medium to High** Depending on whether the promise of microelectromechanical systems is met, MEMS developers should be connected to geotechnical problem solvers • will require geotechnical engineers to increase their knowledge of electronics • proper integration can revolutionize laboratory measurement through non-invasive sensing • can make geophysical methods cheaper and more pervasive • integration of development work by other industries essential	Revolutionary developments in progress. Sensors already available and systems can have high-impact in the short term.	• electronics • signal processing • inversion math

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Table 2. Continued

Discipline	*Potential impact on Geotechnology*	*Timing*	*Required knowledge for geotechnical engineers*
Geophysical Methods	**High** • will require increasing the benefit cost ratio • non-invasive methods need more development • new data acquisition and processing methods enhance applicability • tomographic methods allow 3-D characterization	Revolutionary and mature tools available. Further emphasis on high-resolution near-surface characterization will have renewed impact in the mid-term	• electronics • signal processing • inversion math
Remote Sensing	**High** • ongoing, fruitful area for research and development • ground-truth observations remain a research issue • research could address the potential for real-time decision making	A new family of unprecedented tools will have significant impact on the short term	• signal processing • data management • computer science
Information technology	**High** • ongoing developments • provides a mechanism for collaboration • requires synergy among the computer science, engineering and science research communities for fruition • aspire to 4-D GIS for real-time decision making • development of self-referential smart geosystems with built-in information structures	Its critical role in sensing systems, geophysics and remote sensing will determine their high impact on the short-term. Smart infrastructure systems are already on the drawing board and under development. Existing geosensing and monitoring devices are available and ready for integration with these systems.	• data management • computer science

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In the seven years since the publication of the New Millennium report (NRC, 2006) research and development have continued in each of these areas, and increased incorporation of some new developments into engineering practice is becoming more widespread. A brief summary and assessment of some of these recent developments is presented in the following paragraphs.

Biotechnologies

The potential impact of work in this area was expected to be high. This prediction seems to be holding true. Two key application areas for biotechnology in geotechnical engineering were identified as remediation of contaminated ground and passive in situ soil improvement. Use of biotechnology as a contaminated and polluted ground remediation tool continues, with improvements in the methods ongoing. Bioremediation methods can vary greatly in terms of the biomechanisms utilized, target contaminants, species of microbe, method of introduction, and control measures. As an example, one method utilizes white rot fungus to biodegrade naphthalene in contaminated soils. White rot fungi degrade harmful chemicals through excretion of extracellular lignin-degrading enzymes. Utilization of fungi such as this is particularly economical as the fungi thrive on decaying wood, can degrade a number of harmful chemicals, and are derived from a natural source (Zebulun et al. 2012). A number of firms offer remediation treatment services such as this for cleanup of contaminated soil, water, and mine waste, and research continues to improve the methods. The transportation of microbes in the subsurface is being more accurately modeled to better determine their ultimate fate (Sharma et al. 2011).

Biogeogrouting, a method of injecting microbes and nutrients into the subsurface, is being used in loose granular soils to increase strength and stiffness. Introduced microbes are stimulated by nutrients and produce chemicals (e.g., urease) that catalyze chemical reactions leading to precipitation of calcium carbonate ($CaCO_3$) which in turn bonds the granular particles together, somewhat akin to traditional cementitious grouting methods. To reduce the high costs associated with introducing microbes to a subsurface, further research concerns the feasibility of similar techniques that utilize the native bacteria (Weaver et al. 2011). Biogeogrouting, and similar in situ ground improvement methods, have not yet been adopted into routine practice. With further development and improvement, however, these methods have the potential to be a sustainable alternative to traditional in-situ ground improvement methods.

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Nanotechnology

Nanotechnology is more difficult to analyze when considering its applications to geotechnical engineering. All geotechnical engineers are de facto nano-technologists, given their knowledge and understanding of small clay particle characterization and interactions. Accordingly, this study focused on engineered nano-scale devices and their uses in geotechnical applications. From this perspective nanotechnology has not yet proven to have much impact on the field, consistent with its low predicted influence in the New Millennium report. No firms appear to be offering services involving novel uses of nanotechnology in geotechnical design and exploration. Most recent research on nanotechnology relates to development and use of micro-sensors. The feasibility of utilizing inexpensive, wireless nano-sensors to monitor the temperature and moisture content of soils has been studied. Continued research is being performed to determine the life-cycle of these sensors, and their effectiveness in a range of soils types (e.g., Jacksona et al. 2008).

Sensors and Sensor Technologies

Sensors and sensor technologies were predicted to have medium impact on the field, but continued work in the area indicates a much higher impact. The instruments used for measuring movements, pressures, inclinations and other quantities, as well as the methods for collecting, transmitting, storing, processing, and displaying the information have undergone almost quantum jumps in speed, accuracy, reliability and ease of use.

Geotechnical applications of fiber optic sensors have become extensive; including use as replacements for more traditional instrumentation. Some applications include warning systems for landslides, strain gauges in stabilized earth systems and displacement monitoring devices for braced excavations (Mohamad et al. 2011). The development of wireless sensor systems (WSS) enables the remote and rapid collection of large volumes of data. WSS provide geotechnical engineers with a more controllable work site, allowing them to view in real time the effectiveness of their designs during and after construction, and to immediately locate any critical issues. WSS are also being utilized, at a smaller scale, in conjunction with dense sensor arrays for detailed analysis of a geostructure’s response to driving forces after construction. Applications such as these allow for a more thorough understanding of geostructure behavior than was previously possible.

Strain gauges located at multiple points in a geogrid layer help monitor the strain during the lifetime of geosynthetically reinforced structures. A novel application of this method is being developed that involves the construction of geosynthetics using electrically

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conductive filled polymers that exhibit strain-sensitive conductivity. With proper instrumentation, geosynthetics constructed out of this material can act not only as reinforcements but also as their own sensing system. Information concerning strain along a geosynthetic liner can be collected throughout the lifespan of the material, and at any location. Commercialization of strain-sensitive conductive geosynthetics may make monitoring of geosynthetically reinforced and lined earthen structures more attractive, economic and effective (Hatami et al. 2009).

Shape Acceleration Arrays (SAA) and Shape-Acceleration-Pore Pressure (SAPP) arrays (MeasurandGeotechnical.com) enable real-time measurement and display of ground movements, vibrations, and pore pressures. Such systems can be invaluable for such applications as monitoring performance, locating failure surfaces, control of excavations, and warning of impending failures.

Geophysical Methods

As some applications of geophysical methods became more well established, their impact on the field was expected to be high. Firms specializing in geophysical methods are offering services that include aerial investigations and terrestrial noninvasive subsurface investigations. Versatile Time Domain Electro-Magnetics, VTEM, is one such aerial investigatory method. The method utilizes an airborne vehicle, often a helicopter, to tow a suspended magnetometer and concentric transmitter and receiver loops. The method follows the basic principles of terrestrial time domain electro-magnetic investigations, however it can be applied continuously over a large territory. VTEM surveys are being utilized to effectively map shallow subsurface conditions and target deep mineral deposits. Terrestrial, noninvasive, subsurface investigations have been used for rapid identification of the locations of underground utilities in cluttered urban environments. Ground penetrating radar has emerged as a popular investigatory tool. As the name implies, the analysis involves the pulsing of radar into a subsurface, and the monitoring of the reflected waves. By calibrating the device for the subsurface of concern, features that are more resistant to penetration (ie. pipes) can be effectively located and mapped.

Research in applied geophysics has been identified by the ASCE GeoInstitute as of high importance, as illustrated by the recent establishment of a new technical committee on the subject. Current geophysical research efforts are focusing on coordination with traditional subsurface investigations. Investigations focus on applications that rapidly cover large areas of land before a more traditional investigation is performed. This allows identification of areas of concern early and more accurate direction of subsequent invasive subsurface investigations (Ali and Gul 2011). Other research

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focuses on the use of terrestrial LIDAR (Light Detection and Ranging) to survey geologic and ground surface features that may be inaccessible for use of more traditional methods. Accurate profiles of the features can be generated from the collected data and utilized in slope stability models (Collins and Sitar 2011) among other applications.

Seismic and shear wave methods have become widely used geotechnical applications of geophysical methods. The incorporation of sensors for shear wave velocity measurement into cone penetrometers along with the use of seismic piezocones is improving our ability to characterize the subsurface. This hybrid geophysical-geotechnical method allows for the collection of cone tip resistance, sleeve friction, porewater pressure, and downhole shear wave velocity data with depth. Seismic cone penetration tests (SCPTu) are being used to predict values of lateral earth pressure, locate the limits of undocumented existing foundations, and quantify soil characteristics such as unit weight, equivalent elastic moduli, and liquefaction potential (e.g., Mayne 2010).The current state of practice attempts to fit documented correlations to a subsurface of interest. However, many current correlations are site specific and not calibrated with multiple soil types. Continued work should be expected to enable development of more generic correlations.

Geophysical methods have met their predicted high impact, especially when they are used in combination with more established techniques. However, their suitability for application as stand-alone non-invasive subsurface characterization methods still requires further development.

Remote Sensing

Remote sensing methods can be useful for large scale preliminary surface investigations. Firms specializing in remote sensing are offering high resolution satellite imagery of project sites. The images allow engineers to better plan, design, and manage projects. Continued efforts in this field were expected to be extensive and, similarly to geophysical methods, this has been true, albeit apparently without any recent major breakthroughs.

New applications of remote sensing have included its usefulness as a disaster relief and investigatory tool. On January 12, 2010, Haiti was struck by a devastating earthquake. Over a million individuals were left displaced and/or injured, a quarter of a million were killed, and much of Port-au-Prince was left in ruins. Disaster relief efforts needed rapid deployment and implementation. In near real time, high resolution satellite imagery was collected. The images were combined and analyzed to assess damage, effectively

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deploy aid, and to identify any further immediate dangers. The lessons learned from the great success of utilizing remote sensing as a disaster relief tool will undoubtedly aid in responding to future events (Eguchi et al. 2011).

Information Technology and Cyber Infrastructure

As predicted, information technology (IT) has had a very high impact on many facets of geotechnical engineering. Advances in IT have allowed for ease of global communication and transfer of information; effectively shrinking the world. To geotechnical engineers, this means lessons learned in one corner of the globe can be quickly made available to all. In addition, detailed case studies, with vast amounts of collected data, and results of multi-method site investigations, with tools of ever increasing accuracy, are providing geotechnical engineers with a nearly overwhelming wealth of information. In fact the easy access to such vast amounts of information about most of the topics included in this report, the evaluation of its validity and importance, and deciding which of it should be included was one of the major challenges faced by the authors, and it provided an excellent example of the "information overload" problem.

Advanced data analysis methods, such as Artificial Neural Networks (ANN), are being investigated relative to their applicability for analysis, interpretation, and predictive value of large data sets.

Practicing engineers may begin to feel that all the advances in information collection and analysis may eventually leave them as useless artifacts. However, none of this information can replace the most important attribute of a successful geotechnical engineer: engineering judgment. Engineering judgment, the ability to analyze collected information, locate areas of importance, and understand and react to this information, while at the same time understanding its limitations, will always be essential to success in our profession. Thus, while advances in information technology will provide practicing engineers with more information, in the coming years we will see an increasing need for ever more competent engineers who are able to efficiently sift through this ever increasing mound of information and apply good engineering judgment to effectively utilize it (Marr 2006).

Recently, the global network of information has been made faster and larger, while access to it has been made easier. We live in the age of the smart phone. According to a Pew and American Life survey performed in January and February of 2012, nearly half (46%) of American adults are using smart phones (Smith 2012). Engineers are now doing faster and better in the palm of their hand what they had to do just 10 years ago in their homes or offices. As one example, an application is available that allows field

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engineers to enter observed soil characteristics into their phone and immediately estimate the bearing capacity of cast-in-place bored piles (hetGe, 2012). As with all such applications, however, it is incumbent upon the engineer to be sure of the validity of the methods and reasonableness of the results. The Army Corps of Engineers Engineer Research and Development Center Information Technology Lab (USACE-ERDC-ITL) has developed applications for smart phones in disaster response. During the 2011 Mississippi river flood, the ITL team effectively developed and utilized an app that acquired and collected GPS coordinates, date, and time of photos taken of sand boils. The information was saved to a website, allowing for almost real time assessments of trouble areas, and initiation of remedial measures. Further efforts will link the data to other information available in the area during acquisition, including, for example, the most nearby river gage reading. Being such an immediate success, Corps' engineers hope the application will aid in “decision making response efforts during floods or other natural disasters” (Klaus 2012).

4. CURRENT UNIVERSITY RESEARCH

Current research activities provide some indication of what topics the geotechnical engineering research community considers important, what areas and topics funding agencies consider important, and what some of the topics are that are likely to be important in the future. To assess what is being studied at the present time, a compilation and analysis was made in late 2011 of the topics both of interest to, and being researched by, 263 faculty members at 126 member universities of the U.S. Universities Council for Geotechnical Education and Research (USUCGER).

Available web pages for each of the USUCGER universities and geotechnical engineering faculty members, assumed to be up to date, were reviewed. Based on stated areas of research interest, c.v. information, and lists of recent (post 2006) publications, the different subjects being studied by each individual were listed and classified within a defined list of topics. In some cases this required a judgment call by the authors as to the most appropriate topic area within the final consolidated list of topics chosen to represent the total range of geotechnical research activity.

The resulting data were then organized into specific topic groupings within the technical committee structure of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The technical committees in ISSMGE are divided into three Topic Categories: Fundamentals (TC101-TC107), Applications (TC201-TC216) and Impact on Society (TC301-TC307), as listed in Tables 3, 4, and 5. Corresponding technical committees within the ASCE GeoInstitute are listed in the next column of each

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table. While both organizations have many committees covering comparable topic area**s**, there are several areas where the topic is covered by only one of them, as may be seen by the blank cells in the tables. The column headed by Research Topic restates or contains a more expanded listing of subjects within the topic. In addition there are several additional topics being studied by the USUCGER researchers in each Topic Category that do not fall within the committee structure of either ISSMGE or the GeoInstitute, and these are listed in the lower part of each table. These topics tend to be either highly specialized or recently emergent and in early stages of development.

The right column in each table indicates the number of USUCGER researchers studying each topic. Graphic display of the data in these tables illustrates the distribution of research emphasis among the category and topic areas**,** as shown in Figures 1, 2, 3, and 4. Figure 1 shows that there is approximately equal cumulative effort devoted to study of topics in the Fundamentals and Applications categories, with significantly less research effort on Societal Impacts, although Figure 4 shows that risk assessment and sustainability are of considerable current interest within this latter category.

It may be seen from Figure 2 that university research on the fundamentals of geotechnical engineering is dominated by studies of physical modeling in geotechnics, geomechanics from micro to macro, in-situ testing and site characterization, numerical methods in geomechanics, and strength and consolidation testing. Research in the applications category (Figure 3) is most intensive in the topic areas of geotechnical earthquake engineering, environmental geotechnics, transportation geotechnics, ground improvement, soil-structure interaction and retaining structures, slope stability and reinforcement, and deep foundations.

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Table 3. Geotechnical Engineering Fundamentals and Topic Interests of USUCGER Researchers

Topic Category	ISSMGE Committee		GeoInstitute Committee	Research Topic	Number of USUCGER Researchers Studying this Topic
Fundamentals	Laboratory Stress Strength Testing of Geomaterials	TC101		Laboratory Stress Strength Testing of Geomaterials (eg. Consolidation, Non Destructive Testing)	37
	Ground Property Characterization from In-Situ Tests	TC102		Ground Property Characterization from In-Situ Tests	53
	Numerical Methods in Geomechanics	TC103	Computational Geotechnics	Numerical Methods in Geomechanics (eg. Finite Element Method, Computational Geotechnics)	51
	Physical Modelling in Geotechnics	TC104	Soil Properties and Modeling	Physical Modeling in Geotechnics (General Soil Behavior/Mechanics/Dynamics, Large Scale Testing, Stochastic Geotechnics)	74
	Geo-Mechanics from Micro to Macro	TC105		Geo-Mechanics from Micro to Macro (eg. Constitutive Modeling, Elasticity Theory, Physico-Chemo-Geo Processes in Soils, Nanotechnology)	72
	Unsaturated Soils	TC106	Unsaturated Soils	Unsaturated Soil Mechanics/Testing	25
	Laterites and Lateritic Soils	TC107		Laterites and Lateritic Soils	0
			Engineering Geology & Site Characterization	Geologic Engineering & Site Characterization (Geomorphology)	5
			Geophysical Engineering	Geophysical Methods and Applications, Remote Sensing	31
			Rock Mechanics	Rock Mechanics	11
				Contaminant: Fate, Transport, Soil Interaction, Site&Soil Remediation	37
				Groundwater	7
				Theoretical Mechanics/Methods	11
				Special and Unique Soils (e.g., collapsible, expansive, organic, residual, volcanic)	21
				Biogeochemical Processes	16
				Field Monitoring of Geo-Structures	6

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Table 4.Geotechnical Engineering Applications and Topic Interests of USUCGER Researchers

Topic Category	ISSMGE Committee		GeoInstitute Committee	Research Topic	Number of USUCGER Researchers Studying this Topic
Applications	Geotechnical Aspects of Dykes and Levees, Shore Protection and Land Reclamation	TC201		Geotechnical Aspects of Dikes and Levees, Shore Protection and Land Reclamation	10
	Transportation Geotechnics	TC202	Pavements	Transportation Geotechnics, Pipelines, and Pavements	55
	Earthquake Geotechnical Engineering and Associated Problems	TC203	Earthquake Engineering & Soil Dynamics	Geotechnical Earthquake Engineering, Site Response, Liquefaction	84
	Underground Constructi on in Soft Ground	TC204	Underground Construction	Underground Constructi on (incl. Braced Excavations)	18
	Safety and serviceabilty in geotechnical design	TC205		Safety and Serviceabilty in geotechnical design (incl. Load and Resistance Factor Design (LRFD))	7
	Interactive Geotechnical Design	TC206		Interactive Geotechnical Design, Construction and Monitoring, Intelligent Geosystems	3
	Soil-Structure Interaction and Retaining Walls	TC207	Earth Retaining Structures	Soil Structure Interaction (incl. Earth Retaining Structures)	48
	Slope Stability in Engineering Practice	TC208		Slope Stability and Reinforcement	44
	Offshore Geotechnics	TC209		Offshore Geotechnics	13
	Dams and Embankments	TC210	Embankments, Dams and Slopes	Dams and Embankments	7
	Ground Improvement	TC211	Soil Improvement/Grouting	Ground Improvement (incl. Grouting)	51
	Deep Foundations	TC212	Deep Foundations	Deep Foundations	43
	Scour and Erosion	TC213	Geotechnics of Soil Erosion	Scour and Erosion (Tornado and Soil Interaction)	10
	Foundation Engineering for Difficult Soft Soil Conditions	TC214		Foundation Engineering for Difficult Soft Soil Conditions	0
	Environmental Geotechnics	TC215	Geoenvironmental Engineering	Environmental Geotechnics (incl. char. waste materials & containment systems)	56
	Frost Geotechnics	TC216		Frost Geotechnics	4
			Geosynthetics	Geosynthetics	32
			Shallow Foundations	Shallow Foundations (incl. Settlement)	14
				GIS Applications	6
				Drilling, Trenchless Techology	6
				Geofoam	5
				Information Technology	7
				Artificial Neural Network	6
				Geotechnical Processes in Petroleum Engineering	5

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Table 5. Geotechnical Engineering Impact on Society and Topic Interests of USUCGER Researchers

Topic Category	ISSMGE Committee		GeoInstitute Committee	Research Topic	Number of USUCGER Researchers Studying this Topic
Impact on Society	Preservation of Historic Sites	TC301		Preservation of Historic Sites	1
	Forensic Geotechnical Engineering	TC302		Forensic Geotechnical Engineering	1
	Coastal and River Disaster Mitigation and Rehabilitation	TC303		Coastal and River Disaster Mitigation and Rehabilitation	0
	Engineering Practice of Risk Assessment and Management	TC304	Risk Assessment and Management	Engineering Practice of Risk Assessment and Management (Probabalistic Methods)	27
	Geotechnical Infrastructure for Megacities and New Capitals	TC305		Geotechnical Infrastructure for Megacities and New Capitals	0
	Geo-Engineering Education	TC306		Geo-Engineering Education	10
	Dealing with sea level changes and subsidence	TC307		Dealing with sea level changes and subsidence	0
				Sustainability	31
				New Frontiers	4
				Infrastructure Rehabilitation	13

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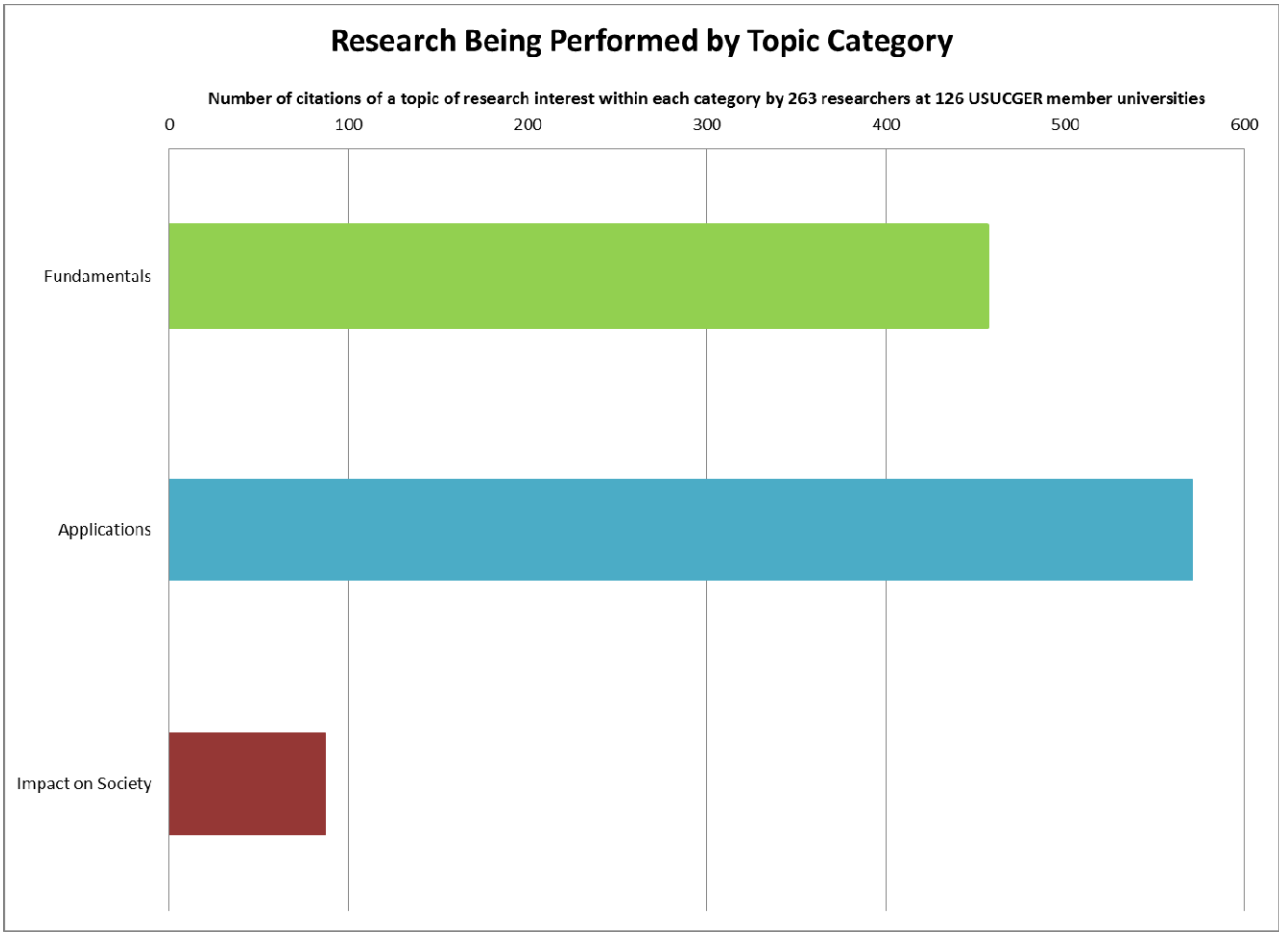

Figure 1: Focus of USUCGER Member University Research within the ISSMGE Defined Categories of Geotechnical Interest.

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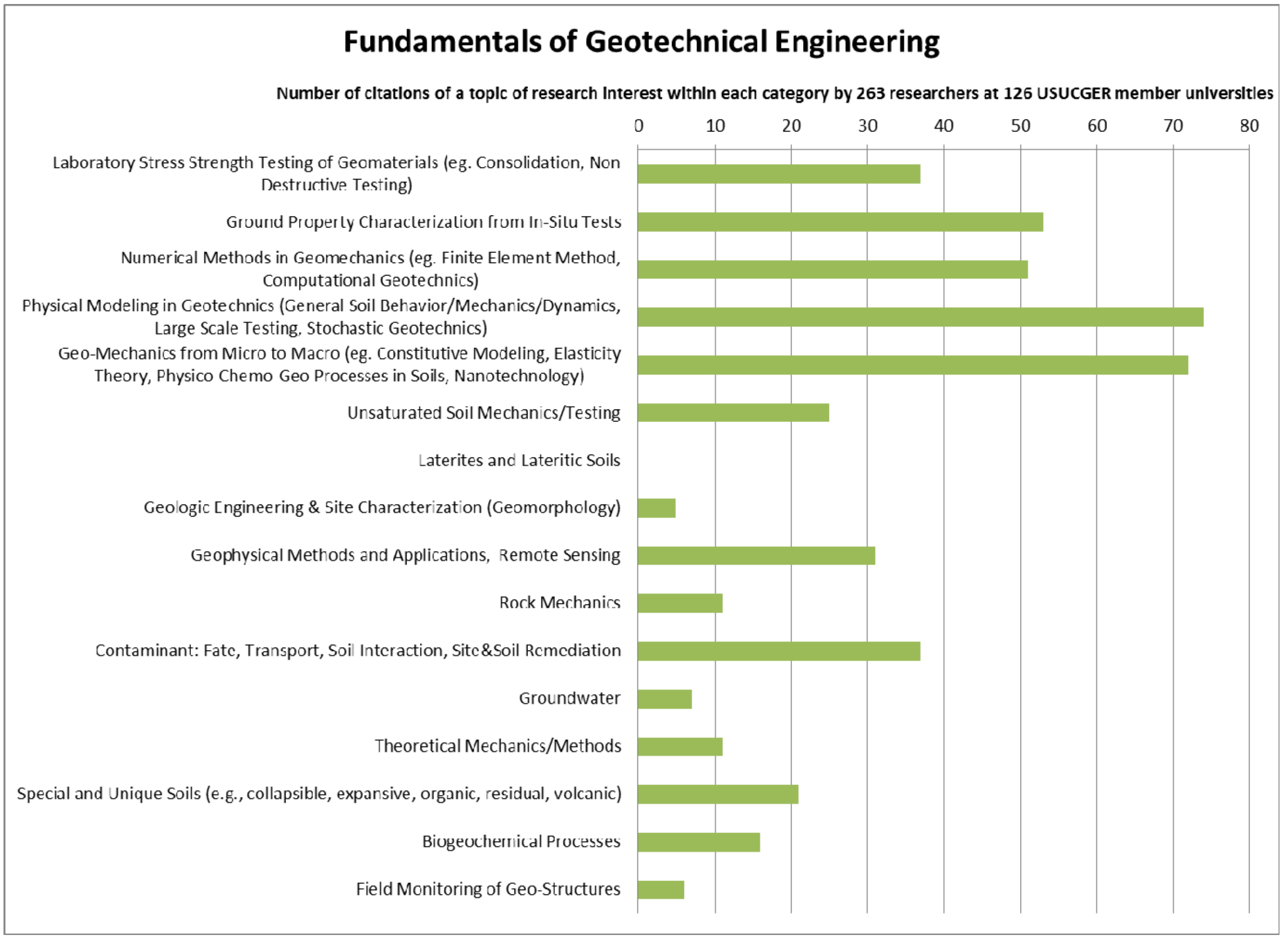

Figure 2: Focus of USUCGER Member University Research on Fundamentals of Geotechnical Engineering.

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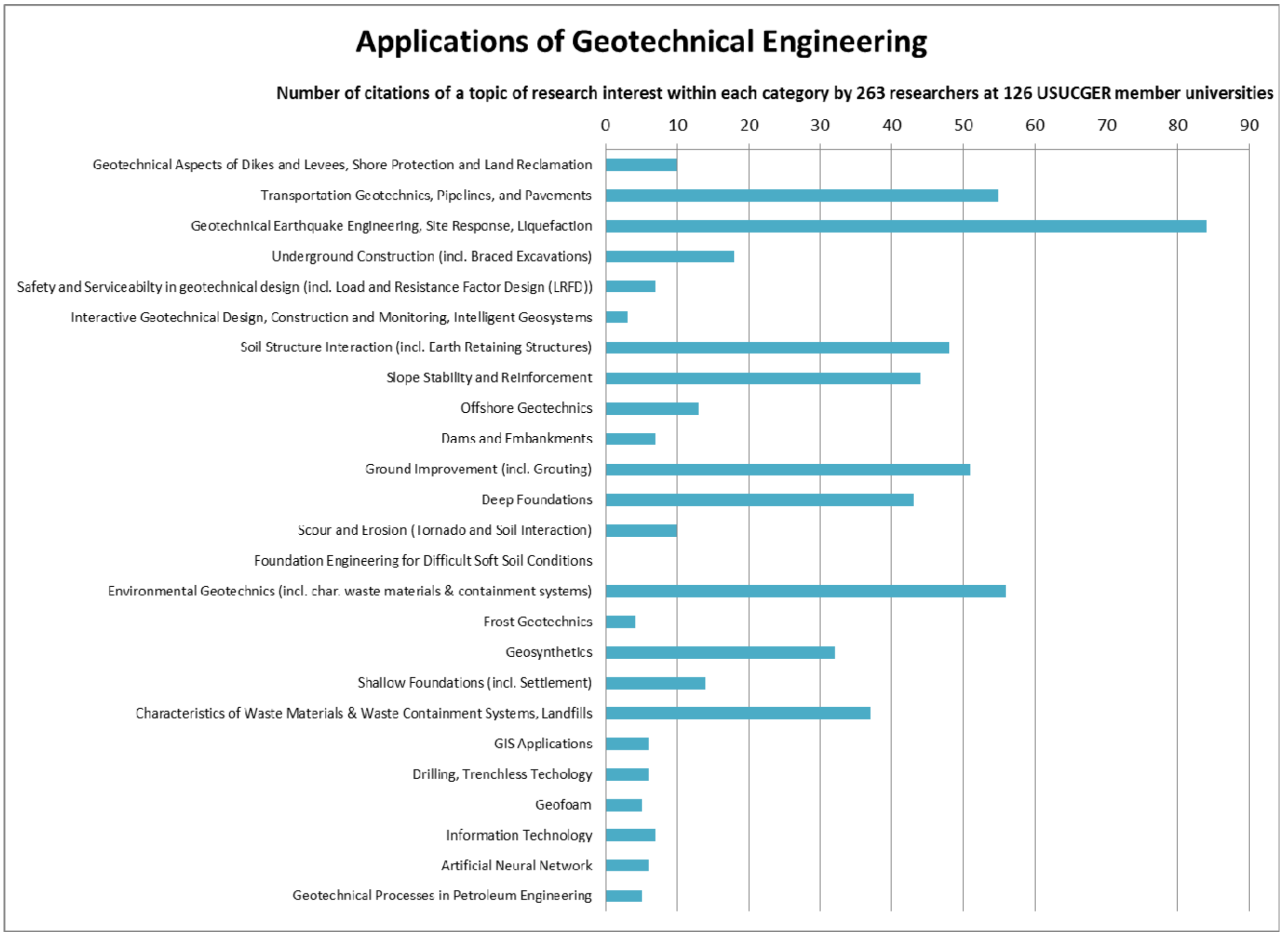

Figure 3 Focus of USUCGER Member University Research on Applications of Geotechnical Engineering.

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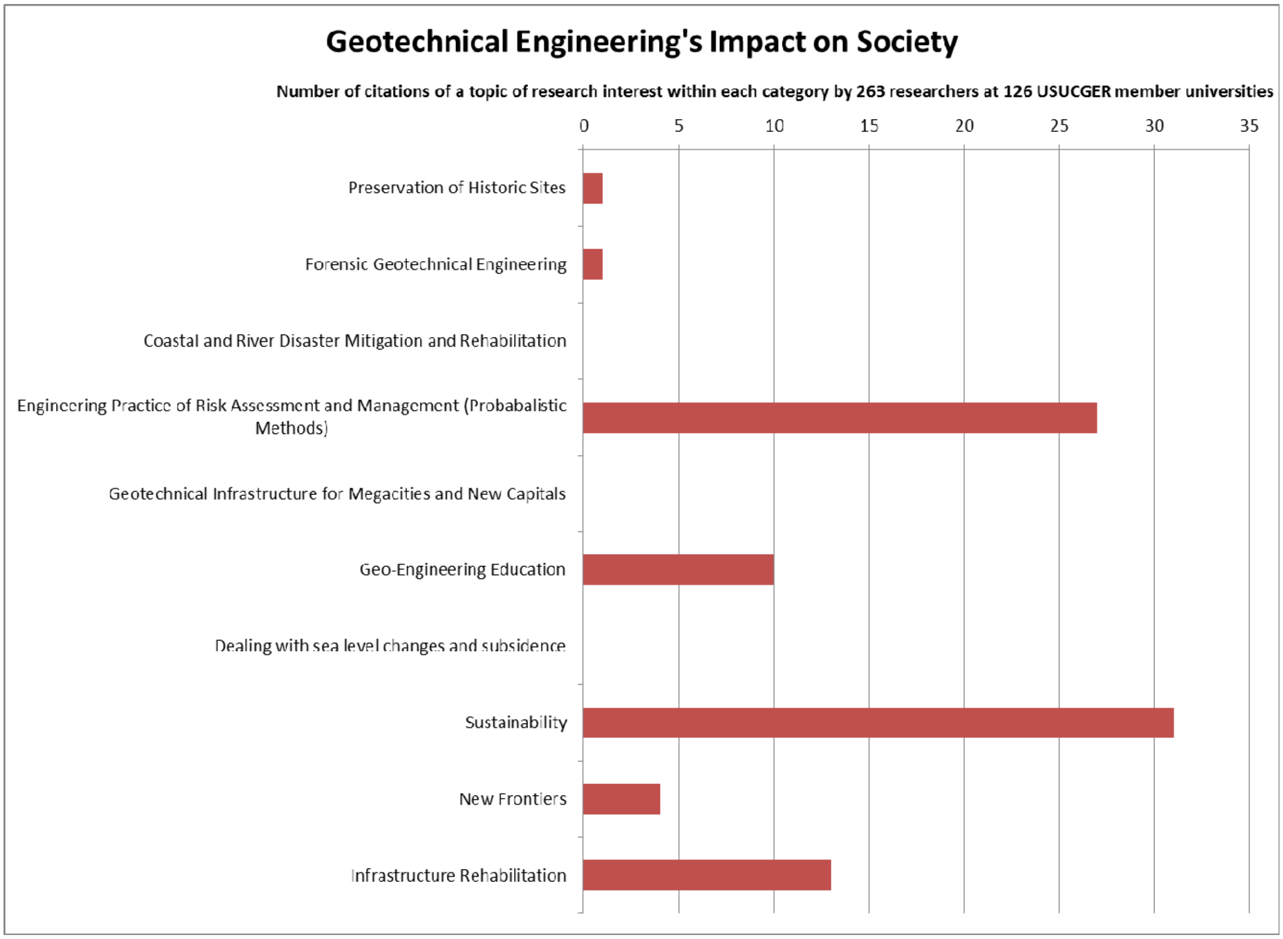

Figure 4: Focus of USUCGER Member University Research on Geotechnical Engineering's Impact on Society.

The New Millennium report (NRC, 2006), assessed in the previous section of this report, listed six new and developing technologies and tools considered to have the potential to increase understanding of the properties and behavior of earth materials and to improve the practice of geotechnical engineering in the years ahead: (1) Biotechnologies, (2) Nanotechnologies, (3) Sensors and Sensing System Technologies, (4) Geophysical Methods, (5) Remote Sensing, and (6) Information Technologies and Cyber Infrastructure. The USUCGER data on research interests and projects for the 263 faculty members were reviewed to determine the number of citations falling within these new technologies, with the results indicated in Table 6. The small numbers indicate that relatively few researchers have focused their efforts on direct study of the technology or tool itself. This does not mean, however, that these topics are not relevant. In fact, what does seem to be the case is that new developments in each of these areas by others is providing new tools, analysis, and computational methods that increase the capabilities

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of both geotechnical researchers and practitioners to do more things faster and better, and many of them are being rapidly incorporated into practice.

Table 6. Research interest in new technologies

New Technology or Tool	Number of citations as a research interest by 263 USUCGER researchers
Biotechnology	13
Nanotechnology	2*
Sensors and Sensing Systems	10
Geophysical Methods	10
Remote Sensing	6
Information Technologies and Cyber Infrastructure	10

*This small number indicates only those who listed nanotechnology as a specific topic of research interest. As virtually all geotechnical engineers and scientists deal with fine grained soils in some form, we are all practicing nanotechnologists.

Care must be taken in interpreting and assessing the information in the preceding tables and figures. They simply indicate what is currently being worked on within United States universities, and do not necessarily reflect the entire geotechnical research enterprise, either in the U.S. or worldwide. Additional research is carried out in private practice and by government laboratories. This research is likely to be more applied in nature than that at the universities**.** It is important to note that problems encountered in geotechnical practice are often good sources of topics (and financial support) for university researchers. Furthermore, the research interests and activities of the USUCGER faculty members are likely to be significantly influenced by the availability of extramural funding, so sponsoring agency priorities become major considerations as well.

The popularity of a research area is not necessarily a measure of potential future payoffs in either advancing knowledge or improving materials, designs, construction methods, sustainability, or environmental enhancement. The biggest advances many times come from one or two creative people with good ideas, insights and motivation working outside the box of traditional thinking (e.g., Bill Gates, Steve Jobs).

5. RESEARCH TRENDS

As a major funder of university research in geotechnical engineering, the Geomechanics, Geomaterials and Geotechnical Engineering Program of the National Science Foundation has a major impact on areas of emphasis and future directions. The NSF description of this program, updated October 26, 2011, is:

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The GTE program supports fundamental research on geotechnical engineering aspects of civil infrastructure, such as site characterization, foundations, earth retaining systems, underground construction, excavations, tunneling, and drilling. Also included in the program scope is research on geoenvironmental engineering; geotechnical engineering aspects of geothermal energy; life-cycle analysis of geostructures; geotechnical earthquake engineering that does not involve the use of George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) facilities; scour and erosion; and geohazards such as tsunamis, landslides, mudslides and debris flows. The program does not support research related to natural resource exploration or recovery. Emphasis is on issues of sustainability and resilience of civil infrastructure. Cross-disciplinary and international collaborations are encouraged.

Over the past several years the trends away from single to multi-investigator research teams has continued, as has also increased emphasis on multi-disciplinary and inter-disciplinary projects. These trends are likely to continue, as addressing today's problems and needs; e.g., energy, sustainability, infrastructure, hazard mitigation, environmental protection and enhancement, requires a range of scientific, technological, and economic and social inputs.

Real time participation of investigators from several locations in experiments and the testing of large models and systems are now possible as a result of advances in communication technologies, data sharing systems and new imaging methods. NSF's George E. Brown, Jr. *Network for Earthquake Engineering Simulation* (NEES) is a good example of where and how these new advances are being used. It can be expected that this type of research will continue to expand.

Although innovation in geotechnical engineering may have at times been hampered by risk aversion and fear of litigation, practitioners and the geotechnical construction industry appear to be quicker to try and to adopt new methods than in the past. One need only visit the exhibits areas that form a part of most conferences to see new materials and methods that provide innovative and better ways for doing things. The geotechnical construction industry is perhaps unique in that the contractors, as a result of their own research, introduce new technologies and improve existing ones. Examples include deep soil mixing, micro-piles, new earth reinforcement materials and schemes, and computer controlled equipment operation. Some of this work generates academic research topics, often focused on unraveling the fundamentals of how and why the technologies and methods work. Maintaining close ties between research and practice is an important element for future advancements in the geotechnical engineering profession.

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6. SUSTAINABILITY

Sustainable Development is the term used to describe combined environmental, social, and economic efforts to meet today's needs without depleting resources, damaging ecosystems, or compromising the needs of future generations. Two main goals of sustainability are 1) to enable people to meet basic needs and improve their quality of life, and 2) to ensure the natural resources and systems on which people depend are maintained and advanced for their use and for the use of future generations (Pearce et al., 2012). Much has already been written and debated about the subject; however, there is no denying the fact that the concepts and goals are now being incorporated directly or indirectly into most development, manufacturing, and construction projects, especially in the developed countries.

Three sustainability focus areas have important implications and applications for geotechnical engineering and construction: (1) helping to meet the ever-increasing need for energy resources, (2) reducing and minimizing energy consumption and (3) reducing and minimizing the generation of greenhouse gases, especially carbon dioxide. Most large new building and infrastructure construction projects are now undertaken with at least some attention being paid to energy required to produce the materials used and to do the work, and to the production of greenhouse gases, given that these quantities serve as proxies for consumption of (mostly non-renewable) energy resources and contributors to global warming. Rating systems such as LEED (Leadership in Energy and Environmental Design) developed by the U.S. Green Building Council, targets for net zero building energy systems and the like are increasingly used, as are goals for reducing, recycling, and reusing materials and construction elements (USGBC 2008). A solar power generation system for electricity generation to power a building is shown in Fig. 5.

In almost every issue of the daily *ASCE SmartBrief,* one or more news items is listed under the Sustainable Development heading. As an example, the item for October 12, 2012 was:

"Envision" -- a rating system aims for greener infrastructure
"Envision" is a sustainability rating system that covers all civil infrastructure, including bridges, roads, railways, pipelines, dams, airports, levees and public spaces. This rating tool aims to "initiate a systemic change to improve not only project performance, but the mindsets of designers, project owners, and decision-makers, to transform the way infrastructure is designed, built, and operated," writes Tim Psomas of the Institute for Sustainable Infrastructure.

A link is provided to a full article in "CE News", which makes the point that 'Envision," developed by the Institute for Sustainable Infrastructure (ISI) is intended to provide a sustainability rating for infrastructure comparable to that provided for buildings by LEED.

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“FORT CARSON, Colo. — The brigade and battalion headquarters building, 4th Brigade Combat Team, 4th Infantry Division, features an on-site solar array, which supplies approximately 62 percent of the building's electrical power needs.”
http://www.usace.army.mil/Media/Images.aspx?mgqs=21747
Figure 5. Solar Power for Electricity Generation

Many potential roles for geotechnical engineering in sustainable development of energy resources are described by Fragaszy, et al. (2011). Among them are development of geothermal energy, the use of underground space for energy storage, radioactive waste storage, energy recovery from methane hydrates, and underground carbon storage. Concurrently, exploration for additional sources of traditional hydrocarbon energy resources; i.e., coal, oil, and natural gas, continues both offshore and onshore, and the need for better methods for site characterization, mining, construction in hostile environments, safe recovery and transport of product, and environmental protection are greater than ever before as the U.S. strives for energy independence in the future.

Deep geothermal energy systems utilize deep hot spots such as hot dry rocks as sources of heat to produce steam and power generators. At a smaller, residential scale,

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it is possible to use shallow systems to heat and cool buildings. By sending a building's coolant through the ground during the summer, the collected heat is stored. In the winter time, heat can be collected from the ground to heat the building using the same system. Traditional methods for this energy storage and recovery utilize a network of twisting pipes; however, recent developments have included incorporating the process within structural foundation piles (Fragaszy et. al. 2011).

Renewable energy producers, such as wind mills and tidal turbines, produce energy intermittently. To make these systems more reliable, excess energy produced during a cycle could be stored underground, in caverns or porous rock, in the form of compressed air or pumped water. Energy would later be retrieved as needed during peak demand periods. Imaginative geotechnical engineering will be required to make such systems feasible, reliable, and economical.

Currently, most geotechnical design decisions are made primarily based on commercial savings without consideration of environmental emissions or energy consumption (Egan and Slocombe, 2010; Holt et al., 2010). However, methods for a more balanced, sustainable design selection process involving the environmental and societal dimensions of sustainability are being developed. (e.g., Parkin, et al, 2003; Jefferis, 2008; O'Riordan, 2012; Shillaber, et al. 2013). These methods take into account the embodied energy in the materials used, energy consumption and carbon emissions from the construction, and life cycle analysis in addition to monetary cost when making design selections. The results from these types of analyses should be considered in evaluating alternative methods and materials for foundations, ground improvement, and earthwork construction.

At the same time, there also is a realization that some existing infrastructure may be "unsustainable" as presently managed and operated. For example, it was concluded in a recent study that the U.S. Army Corps of Engineers' water projects are in this category (NRC, 2012). Maintaining the nation's locks, dams and levees at an acceptable operational level may require expanding revenues and strengthening partnerships among the private and public sectors. Geotechnical considerations are likely to be major components in the development of new approaches for dealing with maintenance and rehabilitation aspects.

7. IMPACTS OF THE DIGITAL AGE

Today's world is much different than what it was even two decades ago. Remarkable advances in electronics, computers and information technology have ushered in a new

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digital age and transformed the way we work and live. While computer size and cost have been exponentially decreasing, computer processing and storage have been exponentially increasing in power and speed. One example of this is given by Duncan (2013): *The IBM 7094 mainframe computer at Berkeley in 1966 was capable of performing 3.6 x 10^8 floating point calculations in an hour, ----, and cost the equivalent of $2,000 today. A laptop computer, available today for about $500, can perform the same number of floating point calculations in 0.11 seconds, at negligible cost.*

For some geotechnical engineers practicing in the new digital age, this technological revolution may be seen as a mixed blessing. Our field is complex, and technological advances have opened many doors and expanded understanding. Computations and iterations that used to take weeks to do using pencil, paper, and a slide rule can now be done in seconds with readily available programs and devices. Methods of analysis that once were computationally prohibitive are now used routinely. On the other side of the coin, however, the digital age has presented engineers with new challenges in how to select, evaluate, and use all of the new resources wisely, as well as the need to acquire at least some proficiency in areas outside of the more classical geotechnical engineering discipline. For good or bad, however, new and evolving technologies are influencing virtually every aspect of geotechnical design and construction.

Marr (2006) describes how the several stages in a geotechnical engineering project have been transformed by new computing tools. He divides geotechnical design into five stages: investigation, analysis, prediction, observation, and evaluation. The impact of digital technology on each stage is noted briefly below.

- A geotechnical investigation usually includes information and data from several sources. It may start by researching databases and analyzing previously performed work and investigations in the area. Then the subsurface investigation may make use of remote sensing methods, geophysical methods, seismic-piezocones and other in-situ testing devices along with sampling of various types. The data from these tests are then reduced, analyzed, and correlated with laboratory test results from samples. Virtually all of the data from these tests are processed and displayed digitally. Statistical methods may be applied to the results to better estimate the accuracy of results and quantify variability. While currently available programs make all of this work easier and faster and produce results that can be presented in new and more illustrative ways, their blind acceptance cannot be done without risk. They must pass the test of reasonableness, and only prior experience, knowledge of earth materials and their properties, and good judgment can insure that they do.

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- The controlling variables estimated from the investigation stage are next used in (ever less) simplified models of the design environment in the analysis stage of design. Spreadsheets and simple programs have become widespread and readily available throughout the geotechnical community. Numerical modeling, using tools such as the finite element method, has become common, and allows virtual recreation of the design environment. With such programs, geotechnical engineers are able to visually show the behavior of a geotechnical structure and its response to variations in geometric, property, and parameter values. The visual outputs of these models also aid in bridging the gap between engineer and client, while at the same time offering new insights to the analyzing engineer. Advances in processing speed and power now allow geotechnical engineers to utilize more complex models in their designs.

- Prediction is the objective of many geotechnical studies. How much settlement will there be and how long will it take? What will be the factor of safety after making these modifications? Can we do this without causing that? If this tailings dam fails, will the run-out flow move off the owner's property? Will this slope be stable in the event of a M7.5 earthquake? Ever faster, better, and more comprehensive analysis and numerical models and methods are being developed to help answer such questions.

- From breaking of ground to decades after construction, sensor networks can provide a wealth of information. Sensor data can be used to control construction equipment and many construction operations and for real time monitoring of a structure's integrity. Digital measurements can be incorporated into QA/QC activities. They can provide data essential to matching performance to prediction. Sensors can be used to trigger alarms when certain values exceed chosen thresholds. After construction is completed, measurement networks can remain in place, continuing to monitor the safety of the structure, decreasing risk, and providing additional information on performance.

- As long as the life cycle monitoring data of a structure is not lost in a data dump, competent engineers are able to continue to observe the performance of their designs. In the evaluation stage of geotechnical design, both the collected short term and long term information can be analyzed. Engineers who are aware of the accuracy of their work are able to grow and evolve, thereby improving their future designs and increasing their standard of practice. (Marr 2006)

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Research on simulations of whole systems, ranging from relatively small and simple geosystems to complex civil infrastructure systems, is now in progress that links analysis, design, prediction, construction, performance, and evaluation in real time. With appropriate feedback loops, designs and predictions can be updated, construction details can be adjusted, emerging risks can be identified, and schedules can be updated. None of this would be possible without the many important advances in measuring, imaging, modeling, and computing power made possible in the new digital age.

8. GEOTECHNICAL ENGINEERING PRACTICE (THE BUSINESS)

In a State-of-Practice paper *The Business of Geotechnical and Geoenvironmental Engineering*, prepared for the ASCE GeoInstitute's Geo-Congress 2012, Bonaparte (2012) details the history, the current state and the future of geotechnical engineering practice. Much of this section contains paraphrases from Bonaparte’s paper.

The practice of geotechnical engineering, as we recognize it today, began in the 1930s. Around this time, design solutions using soil mechanics and foundation design began to gain acceptance (by no means total), and soil and foundation engineers were investigating sites, performing laboratory tests and making recommendations based on the results. These engineers worked predominantly for small firms that were, in turn, subcontractors to larger engineering firms.

In the decades following World War II, the United States saw vast growth due to the post-war economic boom. This period was characterized by expansion of industry, infrastructure, and of residential and commercial construction. Geotechnical firms began to grow owing to the increasing need and demand for their services. New geo-technologies and specializations began to develop. As a result of increased liability and litigation and the need for better industry-wide standards of care, this period also saw the formation of the first business-oriented geotechnical engineering organization, the Associated Soil and Foundation Engineers (ASFE), now titled *ASFE: The Geoprofessional Business Association*.

Bonaparte (2012) continues by noting that from the 1980’s to the present time a number of additional factors have affected professional practice. The number of publications, journals and conferences specific to geotechnical engineering has increased greatly. Geotechnical engineers who utilize these forums to keep up to date with new developments, particularly those that are just beginning to be adopted into practice, stay ahead of the curve. These engineers become armed with an ever increasing geotechnical “tool box” of new means and methods. Firm specialization is common in

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today’s market, and this can in part be attributed to the wealth of new technologies. In addition, the increasing complexity of geotechnical projects and a need to carve a niche market in an ever increasingly competitive environment has fostered their growth. The U.S. Environmental Protection Agency, formed in 1970, had a huge impact on geotechnical practice. As new EPA regulations developed requiring implementation, many firms reorganized and expanded to provide services in the geo-environmental area. They began recruiting needed specialists in other relevant fields such as hydrogeology and environmental science, eventually redefining our practice to include geoenvironmental engineering along with geotechnical engineering.

The recent recession temporarily halted the growth of the engineering and consulting (E&C) industry. Nonetheless, E&C revenues today dwarf those seen 30 years ago. Increases in revenues can be attributed to increased number, size and complexity of projects. To handle the more complicated opportunities, many E&C firms have expanded to offer more diversified services. Geotechnical engineering services are now very often in-housed by these large firms. Recent years, however, have also seen a promotion of smaller, niche geotechnical firms. Government promotion of women and minority owned businesses is allowing these small firms to flourish as subcontractors to their much larger E&C counterparts.

Bonaparte (2012) notes that the competent operation and management of geotechnical engineering firms require several components, including a basic business model and a plan for how to allocate pre-tax, pre-bonus profits. Employee ownership in companies provides additional challenges, as does the transition of ownership over generations.

Mergers and acquisitions have been identified as a major shaping force in the E&C private sector. M&A have been increasing in part due to the complexity and size of the work being won. As the pace of M&A is expected to continue, firms must continually evaluate their long term plans relative to being acquired or acquiring other firms. With larger firms growing larger, and acquiring larger projects, smaller firms may see an opportunity to grow and fill the gaps left by an emerging super firm. Employees, too, must be aware of the possible changes associated with M&A, as they may positively or negatively impact their careers.

Bonaparte (2012) concluded his paper with several predictions about future directions and developments in the business of geotechnical engineering. Among them are the following:

- "Technical advances in geotechnical engineering and technology will continue at a fast pace. Geotechnical engineering businesses will find it challenging to keep pace

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with these advances, not only in their incorporation into practice but also in convincing clients of their effectiveness and positive benefit-cost ratio.

- The amount of work available to geotechnical engineers is expected to stay static, however the projects that engineers will be working on will change. Work will result from our current challenges associated with ageing infrastructure, resource shortages, and natural hazards.
- The size of projects, combined with the current practice of project owners preferring the responsibility for a project's execution to be placed with a single firm and the associated financial risk, will result in continued dominance of the very large firms with in-house geotechnical engineering capability.
- To compete with these very large firms, large firms will undertake aggressive merger and acquisition growth strategies.
- Firms too small to compete with the very large firms, even with aggressive growth strategies, will make themselves attractive to the very large prime contractors by offering services not provided by the prime contractors, such as drilling and testing.
- Many firms will see a shift in ownership and management as the baby boomers, or grey-haired engineers, begin to retire. To attempt to compensate for this loss of invaluable experience, firms will look to hire still active retirees, as consultants.
- To bring in the best and the brightest of the new generation, firms will need to develop effective recruiting strategies, fostering strong connections with universities and catering to the new standards of the younger generation.
- The new generation of workers, the "Millennial Generation", will have unique characteristics not seen before. The Millennials are the first generation to be born and raised in the digital age, and they use technology in nearly every facet of their daily lives. This generation is characterized as being outside the box thinkers and more concerned with the environmental impact of their decisions and hold sustainability paramount. This generation holds much promise, however, it remains to be seen how well this new generation performs as leaders and fills the shoes left by those retiring" (Bonaparte 2012).

9. RISK AND RELIABILITY

Geotechnical engineering and earthwork construction are inherently risky activities. Uncertainties and unknowns are ubiquitous to virtually every project. Traditionally, these uncertainties and unknowns have been accounted for through the use of factors of safety applied to limit equilibrium analyses, conservative designs and use of the observational method during construction. This reliance on safety factors has been changing in recent years as a result of the introduction of, for example, load and resistance factor design (LRFD), performance-based design, and risk analyses of various types.

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Risk; i.e., a consideration of the probability and consequences of failure, and reliability issues can be considered in three categories as they relate to geotechnical engineering:

1. Risks in doing the engineering and construction. Dealing with these risks properly is vital to the success of any project, for safety and protection of the public, and for the survival of the responsible engineering organization(s).
2. Hazards and risks arising from natural disasters (e.g., landslides, earthquakes and floods) and anthropogenic activities. Dealing with these events after they occur, and perhaps more importantly, mitigating their potential consequences before they occur, provide important project opportunities for the geotechnical community.
3. Use of risk-informed decision making for the prioritization of projects and allocation of resources.

Each of these types of risk is discussed briefly in the following paragraphs.

Geotechnical Engineering and Construction Risks

Given the nature and variability of earth materials and the impossibility of knowing all the details of the subsurface and groundwater conditions, as well as the uncertainties about loads of various types, environmental conditions, and land use now and in the future, every project involves many knowns, known unknowns, and unknown unknowns. Terzaghi, Casagrande, and Peck all recognized the importance of this type of risk and the difficulties in its reliable characterization. George Burke in a presentation during Geo Virginia 2012 stated that the three greatest risks of this type are associated with large loaded areas, resisting large forces, and stopping groundwater.

Casagrande (1964) noted that “Terzaghi’s great accomplishment was to replace in earthwork and foundation engineering the large conglomeration of great ‘unknown risks’ of the past in part by rational analyses which are based on the principles of soil mechanics that he developed, and in part by ‘calculated risks’ that we can estimate with the help of soil mechanics, and judgment.” Casagrande went further in stating that to initially assess calculated risk, one had to first determine the magnitude of the potential losses and the range of uncertainty present. If the range of uncertainty was small enough, it would be appropriate to account for the risk using a conventional factor of safety. If the range is large, however, use of numerical factors of safety is inappropriate and engineers must use their experience and judgment to assess the margin of safety.

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Peck (1969) expanded on Terzaghi's earlier "learn as you go" coupled with soil mechanics method by proposing what is now commonly referred to as the Observational Method, consisting of the following steps:

> “(a) Exploration sufficient to establish at least the general nature, pattern and properties of the deposits, but not necessarily in detail.
> (b) Assessment of the most probable conditions and the most unfavorable conceivable deviations from these conditions. In this assessment geology often plays a major role.
> (c) Establishment of the design based on a working hypothesis of behavior anticipated under the most probable conditions.
> (d) Selection of quantities to be observed as construction proceeds and calculation of their anticipated values on the basis of the working hypothesis.
> (e) Calculation of values of the same quantities under the most unfavorable conditions compatible with the available data concerning the subsurface conditions.
> (f) Selection in advance of a course of action or modification of design for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis.
> (g) Measurement of quantities to be observed and evaluation of actual conditions.
> (h) Modification of design to suit actual conditions.”

Whitman (1984) was among the first to introduce quantitative methods for computing geotechnical risk, and these methods have been expanded and applied to many problems and projects in different areas of geotechnical practice. By successfully identifying and, more importantly, communicating geotechnical risks before and throughout projects, geo-professionals can advise owners and contractors of possible problems and facilitate working together to arrive at innovative solutions.

An example of novel project risk mitigation that is gaining popularity is Active Risk Management, or ARM. As defined by Marr (2011), ARM is “a systematic process of identifying, analyzing, planning, monitoring and responding to project risk *over the life of the project*.” As designing for risk by considering only a worst case scenario is often ineffective, or not economic, Marr suggests, with ARM, to "…design for the most likely scenario based on an investigation of the underground conditions and potential hazards.” A preliminary risk assessment is then performed to determine what sources of uncertainty will dominate operational risks. These risks are then evaluated to see which can be mitigated, reduced, or avoided through design modifications, observations and remedial work. The assessment is continually updated and modified throughout construction, as new information becomes available (Marr 2011).

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Natural Disaster and Anthropogenic-Based Risks

Geotechnical hazards are increasing in frequency and severity. Population growth has driven people to settle in more geologically precarious regions, particularly in the third world. Many of these areas endure natural disasters (earthquakes, tsunamis, storms, landslides, etc.) at high frequency. In 2009 and 2010, over 300,000 fatalities occurred as a result of natural disasters. Data for the previous decade (1991-2000) showed that of the fatalities due to natural disasters, only 5% occurred in highly developed countries. Media coverage of the devastation resulting from natural disasters and greater global intolerance to loss of life have resulted in a demand for a change in disaster aid efforts. Disaster aid efforts concentrated primarily on after-disaster response have been deemed insufficient, and the focus has been steered to disaster mitigation. Due to global mandates for active risk mitigation in design, such as the UN-signed Hyogo Framework for Action 2005-2015, and domestic safety regulations, spearheaded by government agencies such as the US Army Corps of Engineers Risk Management Center, geotechnical engineers now find themselves incorporating the risk from a hazard event in the design of their structures (Lacasse and Nadim 2011).

Additional geotechnical and hydrological hazards and risks can be created as a result of human activities such as land reclamation and development, mining, construction of large waste and tailings storage facilities, atmospheric and temperature changes caused by human activities, and underground injection of waste fluids. Furthermore, reassessments of the resistance of existing aging infrastructure, especially dams and levees, to the potential damaging effects of earthquakes and floods often lead to a conclusion of inadequate margin of safety. In many cases part of the reason relates to increases in the Maximum Credible Earthquake and/or Maximum Probable Flood that may occur. This can result in the need for extensive retrofits, upgrades, or even complete replacement to assure safety in the future.

All of these things provide new challenges, opportunities and markets for geotechnical engineering services and construction projects that, in the authors' view, can only be expected to increase in the future. An illustration of recent geo-construction risk hurricane flood risk mitigation is given in Fig. 6.

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How the U.S. Army Corps of Engineers is reducing natural disaster risk in New Orleans. The Hurricane and Storm Damage Risk Reduction System is comprised of numerous features including levees, floodwalls, floodgates, surge barriers and pump stations."
http://www.usace.army.mil/Media/Images.aspx?mgqs=23119
Figure 6. An Example of Natural Disaster Risk Mitigation

Risk-Informed Decision Making

Existing infrastructure is aging, more and more facilities are in need of rehabilitation and upgrading, and the public is demanding more safety and economy in its public works, so the need for new and better structures and protections continues to escalate. All of this is happening during a period of economic stringency and flat or declining budgets. In an effort to carry out their missions most responsibly and to provide the biggest bang for the buck, a number of government agencies and other organizations are incorporating risk analyses into their decision making process, both for determination of which

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projects go forward and for establishing the priority under which they will be undertaken. At the national level, the United States Bureau of Reclamation (USBR) and the U.S. Army Corps of Engineers (USACE) are especially active in developing risk-based methods for dam and levee safety evaluations, usually where seismic and seepage conditions are of particular concern. The USACE recently established a Risk Management Center (RMC) in Denver, CO for this purpose.

Scott (2012) described the USACE approach to risk-based decision making, and it is summarized briefly below. Although different organizations may have their own risk guidelines, there are similarities. An annual failure probability of about 1 in 10,000 is often considered an acceptable upper bound for dam safety. Several methods for making quantitative risk assessments are available. They can be based on event trees, fault tress, loading hazard curves, structural response curves, relative frequency data, probabilistic analyses, subjective elicitation of probabilities and consequence models (Scott, 2012). All of these methods force a careful and in-depth examination of the factors that could lead to a failure and the associated probabilities of their occurrence.

When considering potential consequences of failure in terms of potential lives lost, a number less than about 0.001 lives per year is usually an acceptable guideline. It may be seen, therefore, that as the potential loss of life from a failure event goes up, the acceptable failure probability must go down if this criterion is to be satisfied. For example, if the potential loss of life is 10, then the failure probability should be less than 10^{-4}, whereas if it is 1000, the acceptable probability is reduced to 10^{-6}. Scott (2012) points out, however, that for failure probabilities less than 10^{-6} and potential loss of life greater than 1000, our ability to quantify risks becomes more uncertain. In this case, actions should be taken to ensure that the risk is as low as reasonably possible (ALARP).

Scott (2012) states that once the likelihood and consequences of a failure event have been determined, three situations can be addressed: "(1) whether the estimated risk justifies action, (2) if so, the urgency of taking action, and (3) the confidence in the estimates and whether additional information is likely to change the perception of the need and urgency to take action."

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10. GEO-CONSTRUCTION

The overall ASCE grade assigned to the existing infrastructure in the U.S. in 2009 was 'D', when it was estimated that it will take $2.2 trillion dollars and 5 years to raise the status to “good condition” (ASCE 2012). The 2013 ASCE Infrastructure Report Card is scheduled for release on March 19, 2013. Many additional industrial, energy-related, and commercial projects are now moving from the drawing boards to construction. All of this work should provide a major market for geotechnical construction of all types in the years ahead. Contractors will be competing with both domestic rivals and international newcomers for many of these projects.

Geotechnical contractors have a tool box of new technologies at their disposal. Recent advances in information technology, sensors, and sensor technologies enable the real time monitoring of equipment and geostructures during construction. To geotechnical contractors, this means that critical operational parameters can be monitored to remove uncertainty in their methods and help to ensure success in their work (Finno and Kern, 2012). Safety, paramount on every construction site, has also seen great improvement due to sensor technology. By programming a sensor network to notify project engineers and managers when parameters exceed critical values, work can be immediately stopped before the problem worsens. The real time monitoring of stability and safety allows engineers to revise designs to meet the newly acquired design parameters before critical failures occur.

In construction, time is everything. Contractor’s schedules are tight and each day saved is money earned. Advances in equipment allow geotechnical contractors to dig and build faster and more efficiently. Design-build contracts are often attractive to owners, especially with geotechnical projects, as all the risk associated with geotechnical uncertainty is now placed on a singular entity, and time and money can be saved by overlapping the design and building stages (Dwyre et. al, 2012).

To improve efficiency and reduce unexpected costs, camera networks are being implemented that track progress in three-dimensions and resource quantities on a site. The camera network arrays provide managers with real time knowledge of waste, materials and schedule progress. The real time knowledge of where personnel, excess material and equipment are located allows construction teams to quickly become aware of problem items that may cause a deviation from the critical path (Park et. al 2011).

As observed by the second author during a 2012 summer internship, many of the new trends in geotechnical construction are incorporated in the current work on the 2nd Avenue Subway project in Manhattan, NY. Currently the only subway line that runs

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along the East Side of Manhattan, the overtaxed Lexington Avenue line, handles about 1.3 million people every weekday - more people than the San Francisco, Chicago and Boston subway systems combined in a 24 hour period (Tingley, 2012). The 2nd Avenue subway line will share this load on an 8.5 mile long new line along the East Side that runs from 125th Street in Harlem to Hanover Square. The construction of the 2nd Avenue line is proposed to proceed in 4 phases (Metropolitan Transit Authority, 2012). The $325 million dollar contract for the first phase of the 96th street station involves the use of braced slurry walls and secant piles to excavate below 2nd Avenue to a depth of about 85 feet (E.E. Cruz, 2012). A number of sensor systems were utilized for quality control and quality assurance during the digging of the diaphragm walls. Digital inclinometers were located on the bucket of the excavating rig. As the bucket entered the excavation, the operator was able to review the verticality of the excavation through a blue-tooth connection, and at the end of shift, transfer the data to the engineer for final review. As construction was occurring within feet of existing foundations, damage to these structures was a concern. To lower this risk, a series of digital surveying stations were placed on the buildings along the proposed work. The stations rotated continually throughout the day, creating an array that wirelessly notified a monitoring engineer if building deformations exceeded allowable values.

Tuchman (2012) identified five critical issues in construction and proposed five ideas for advancing the construction industry over the next 10 years. These are listed in the Box below. Most of the challenges and opportunities that these encompass can be applied directly to geotechnical engineering and geo-construction.

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FIVE CRITICAL ISSUES AND FIVE GOOD IDEAS FOR THE NEXT 10 YEARS OF CONSTRUCTION

by Janice L. Tuchman, Editor-in-Chief, Engineering News-Record

The Vecellio Distinguished Lecture, October 5, 2012

The Critical Issues

1. *Americas Infrastructure is Aging and Ailing*
   -Earning a D on ASCE's infrastructure report card, every facet of America's infrastructure, from water to transportation, is in need of improvement.
2. *Global Forces Affect the Work of Design Firms*
   -Companies are being bought by international firms, non-domestic products are being utilized in design, and employees are practicing and collaborating internationally.
3. *Meeting the World's Needs Will Take More and More Energy*
   -Increasing energy demands coupled with emerging alternative energy producers is shifting the balance of what firms are designing and building.
4. *Design and Construction Practices Need to Help Achieve Sustainability*
   -Is our current approach to sustainability the right one?
5. *The Pace of Technology Advancement Is Accelerating*
   -Will we effectively be able to "keep up" and utilize the advances to improve construction practice?

The Good Ideas

1. *Accelerated Bridge Construction*
   -The construction of bridges is being greatly expedited by design-build contracts and the utilization of pre-fab bridges or bridge components. Why is this a good thing?
2. *Global Work Sharing*
   -Advances in computing power and information technology are allowing design firms to easily communicate and share work with their international offices, decreasing overhead and lowering engineering costs.
3. *Helping the (Power) Grid "Get Smart"*
   -By incorporating the technological advances that characterize the 21st century into our power grids, we will be able to create smart, decentralized grids that monitor usage, allow alternative energy providers to give and take to the grid, and are self-healing.
4. *Net Zero Sustainability*
   -Jeffrey Baker, of the Department of Energy and winner of the 2011 ENR Award of Excellence, designed and built the world's largest net-zero-energy-use building and has created a replicable model for the design and construction of similar structures.
5. *Imagining Construction's Future*
   -With technology advancing at such an astonishing pace, soon what we are able to do will truly be limited only by our imagination. To prepare for the unimaginable future, Intel has in place an open forum in which professionals contribute and share technically based science fiction short stories to spark creativity and innovation.

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11. GLOBALIZATION

Michael Sheehan, in his 2009 article, *Globalization: Conundrums and Paradoxes for Civil Engineering*, defines globalization as, "…a process of integration—on a worldwide scale—of markets, production, and distribution through the free flow of capital and labor." This commercial interconnectedness promotes a blurring of cultural barriers and a sense of interdependence. Hard territorial borders are no longer boundaries, as social space and business expand across and beyond them (Sheehan 2009).

To some engineers, for example, those who work internationally, the effects of globalization are apparent. Many domestic engineers, however, may not yet see the connection. Many domestic firms are owned by larger, international companies, and methods and materials used in design and construction are imported from foreign suppliers (Yates 2007). No practicing engineer is immune to the effects of globalization, and as such, it is helpful to understand its causes, as well as the opportunities and challenges it poses.

Geotechnical engineering today contains components developed all around the world. Charles-Augustin de Coulomb in France laid the path for how we describe soil strength and calculate lateral earth pressures. William John Macquorn Rankine, a Scottish civil engineer, later offered his own theory for earth pressure. Albert Mauritz Atterberg, a Swede, introduced new tests for soil classification, while Henry Darcy, a French engineer, revolutionized the way we look at fluid flow in porous media. Two of the most prominent figures of modern geotechnical methods, Karl Terzaghi and Arthur Casagrande, were Austrian-born, but later brought their talents to the United States. Advances in geotechnical technologies and tools have come from every corner of the globe. The multibillion dollar geosynthetics industry has developed from continuous research and development of materials and geotechnical applications from around the world. Earth reinforcement using inclusions is built upon the pioneering studies by Henri Vidal in France. The "Dutch cone test", now known as the cone penetration test (CPT), originated in the Netherlands. Other tests, including the vane shear test, pressuremeter and dilatometer originated in Sweden, France and Italy, respectively (Coduto 2001).

Advances in information and transportation technologies have caused our world to shrink. The 21st century is an age of unprecedented connectedness. Supply chains have grown longer and transportation more economical. New distant markets are opening up to international businesses. The internet and cyber infrastructure now allow data to rapidly circle the globe. Ideas and information can be shared across cultural and political boundaries, promoting international collaboration. Commerce is becoming

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digitized, with the transference of funds occurring as digital transactions; further facilitating international business (Sheehan 2009). Today's challenges are also encouraging globalization. Many of our important problems projects involve global considerations. Issues relating to sustainability, overpopulation, energy and other resources, climate change, and natural disasters affect us all.

Living in an interconnected world means changes in one corner will have an impact all over. This has been made painfully clear over the past few years during the great recession in the United States. In a talk at Columbia University in 2008, economist Nouriel Roubini stated, "…when the U.S. sneezes, the rest of the world catches the cold. This time around, the U.S. is not just going to sneeze; it's going to have a severe case of pneumonia…and therefore the transmission to other countries is going to be also very, very severe" (quoted in Gjelten 2008). All firms, regardless of size, are affected by the performance of the global economy. As a testament, before 2008, Fluor, the large, international and publically owned engineering company had a high stock price of around $100. After the crash in the US, the stock dropped to about $30 (Fluor 2012). The hardships felt globally as a result of unregulated, and irresponsible, business activities have encouraged some to move away from globalization. An animosity towards the global market, already present due to cultural elitism and fear of international competition, is growing (Sheehan 2009). However, this is probably only a bump in the road that is unlikely to stop or reverse the long-term trend towards increased international activity in design and construction.

Professionals practicing abroad can encounter some of this animosity, as well as other unique challenges. Language and cultural barriers, alien business practices, and a lack of legal support are some of the challenges to be expected (Marr 2006). Due to monetary constraints, engineers can find themselves as the sole physical representation of their firm while abroad. New tasks, or those that were delegated to others domestically, fall on the shoulder of the international engineer. International engineers must be business savvy and knowledgeable of political limitations (Cheah, Chen, and Chong 2005). Improved managerial skills are necessary, as well as an ability to adapt to changing standards and policies from job to job (Yates 2007).

Engineers need to prepare for these challenges, because many geotechnical engineering firms and contractors must become involved in the global market in some fashion to succeed. The global market can provide firms with a vast work force to select from for new employees. Specialized firms and contractors can find a bigger market for their services abroad. To lower overhead, the structure of larger firms can be reorganized to utilize global resources. Contractors are purchasing materials from foreign suppliers, at lower costs, to compete. As not all international goods are

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produced with the same regulations and standards as those domestically, care is needed in selecting and using them. However, by embracing globalization, while being cautious of its shortcomings and differences, many firms will be able to offer superior products at the most competitive price (Marr 2006).

As the walls continue to come down, we must also be careful to remain open-minded. If we assume our method is the best and others should aspire to be like us, opportunities for growth and improvement may be elusive. Dealing with heterogeneous materials is nothing new for geotechnical engineers. Successful geotechnical engineers understand the limitations of their calculations when dealing with high variability. This same heterogeneity is prevalent in people and other cultures. People are separated by "different races, ethnic groups, cultures, languages, values, religious understandings, and social, economic, and political systems" (Sheehan 2009). A successful engineer in the age of globalization understands both the limitations and opportunities when confronted with this variability, and will actively work to utilize them to best advantage.

12. TEACHING AND EDUCATION

Geotechnical engineering has benefitted tremendously by having outstanding educators to attract, teach, do pioneering research, and award degrees to the future leaders in the field. The future need remains, but just as the scope of the field has expanded, problems to be addressed have taken on new dimensions, and the digital age has transformed many aspects of practice and construction, engineering education is being impacted in many ways.

The United States Universities Council on Geotechnical Education and Research (USUCGER) was organized in 1985 to address concerns about dwindling federal support for geotechnical research. In subsequent years the scope of its activities was broadened to include the whole of geotechnical engineering education. The USUCGER mission statement is: "to provide advocacy for the continued development and expansion of high quality geomechanical, geotechnical and geo-environmental engineering research and education which will enhance the welfare of humankind and meet the needs of the nation." (USUCGER, 2012)

Welker (2012), in a keynote lecture for the ASCE GeoInstitute's 2012 Geo-Congress session on geotechnical engineering education, drew on a survey of USUCGER member faculty, along with more informal methods of analysis, to discuss the current state of geotechnical engineering education practice. Welker investigated educators' current complaints with their profession. Educators found difficulties attracting the best

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and brightest students to geotechnical engineering, were troubled by deteriorating geotechnical laboratory resources coupled with growing incoming class size, and were concerned by the disconnect with practitioners due to a loss of practice-focused faculty. Educators were also concerned with the decrease in number of credit hours required to attain a Bachelor of Science degree. The average credit hour requirement in 1920 was 151 vs. 130 today; yet engineering technical complexity has greatly increased. Emphasizing this disparity, in 1920 civil engineering required more years of formal education than many other prominent professions, including law and medicine. Today, the average law degree requires 7 years, medicine, 8, and civil engineering remains at 4 (Townsend 2005). Educators are concerned that their students will lose the technical skills required to be successful as their curricula become more professionally focused. They also see the need to include emerging, technically rich, and useful subjects such as risk assessment and load and resistance factor design (LRFD) in their curricula, (Welker 2012).

The ASCE acknowledges that a 4 year degree is currently “satisfactory” for entry-level civil engineers. However, in the recently proposed and accepted Policy Statement 465 (PS 465), the society argues that due to the rapid changes that characterize the 21st century, simply a 4 year degree is “becoming inadequate for the professional practice of civil engineering”. The policy “supports the attainment of a Body of Knowledge (BOK) for entry into the practice of civil engineering at the professional level.” ASCE defines the appropriate BOK as “(1) the fundamentals of math, science, and engineering science, (2) technical breadth, (3) breadth in the humanities and social sciences, (4) professional practice breadth, and (5) technical depth or specialization.” The policy proposes also that in addition to requiring a baccalaureate degree in civil engineering and the appropriate experience, entry-level engineers must fulfill their BOK through attaining a master’s degree or completing 30 graduate level credits before attaining licensure. (ASCE 2012). However, this latter recommendation has not gained universal acceptance and remains controversial throughout the engineering profession (Rubin and Tuchman, 2012).

Implementation of Policy Statement 465 should allow geotechnical engineering educators to reach more young professionals as they enroll in geotechnical engineering courses to meet their licensure requirements. By bringing baccalaureate graduates back into the classroom, educators will have new opportunities to attract the best and brightest to the geotechnical engineering field.

Advances in information technology have allowed for vast improvements in the quality of distance learning. It has never been easier for graduates to learn at their own pace, when and wherever is convenient for their schedules. Improvements in the digital

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classroom have allowed for a greater breadth of classes available to students not physically located near institutions with strong geotechnical engineering programs. Digitizing the classroom has allowed educators to cover more material, in greater clarity, and more quickly. Educators are more accessible to students, as well, and can even make their personal library of resources easily available to students through cloud services, the digitization of text, and other file sharing services. In the midst of all these changes, however, educators should be wary of unintentionally forming a disconnect between student and teacher and between student and student. Less personal contact with an educator can lead to a more passive attitude in students and lack of creative thinking. A case study approach can be useful in the technological classroom of today to foster effective implementation of new methods and solutions (Singh 2012).

An International Conference, Shaking the Foundations of Geo-Engineering Education, sponsored by ISSMGE’s Technical committee on Geo-Engineering Education, (TC 306), was held in Galway, Ireland in July 2012. A goal similar to what ASCE's Policy Statement 465 aims to achieve was discussed. One outcome is a listing, shown in the box below, of minimum competencies that geo-professionals should possess upon completion of an undergraduate degree and after five years of experience, including graduate study. This listing, currently out for review, draws heavily on the ideas presented by Atkinson (2012) in a keynote paper to this conference.

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WHAT SHOULD GEO-PROFESSIONALS BE ABLE TO DO?

ISSMGE Technical Committee TC 306 on Geo-Engineering Education met in Galway, Ireland in July 2012, sponsored an International Conference on Shaking the Foundations of Geo-engineering Education, and discussed what geotechnical engineering professionals should be able to do at different stages of their careers. By listing suggested required competencies, the committee hopes to help guide undergraduate and post-graduate curricula in geotechnical engineering. The following topics are proposed as comprising the “minimum competencies in geo-engineering expected by employers in the construction industry”. Presently (January 2013) this list is out for review and comment by geo-engineers, teachers and employers.

1 Undergraduate degree in civil engineering

1.1 Create spreadsheet calculations
1.2 Write a technical report
1.3 Describe soil and rock in engineering terms
1.4 By experiment determine the pore pressure in a sandcastle
1.5 Estimate φ’ for sand and undrained strength of clay from soil descriptions
1.6 Draw a simple flownet; calculate flow rate and pore pressure at any point in the flownet
1.7 Calculate limiting undrained slope height and limiting drained slope angle
1.8 Calculate slope stability in jointed rock
1.9 Calculate stability of retaining walls
1.10 Calculate bearing capacity and settlement of simple shallow foundations
1.11 Calculate capacity of a single pile
1.12 Determine a compaction curve

2 Undergraduate degree in geology

2.1 Write a technical report
2.2 Design and manage a ground investigation
2.3 Describe soils and rocks in geological terms
2.4 Create a geological model including geological history and groundwater

3 Geotechnical engineer (after 5 years, including graduate degree): everything in 1 plus

3.1 Do routine in situ and laboratory tests and interpret the results
3.2 Create a geotechnical model including design parameters
3,3 Perform and validate numerical analyses
3.4 Design simple foundations, slopes and walls
3.5 Design an embankment on soft ground
3.6 Design piled foundations
3.7 Design earthworks and pavements

4 Engineering geologist (after 5 years, including graduate degree): everything in 2 plus

4.1 Describe soil and rock in engineering terms
4.2 Do in situ and laboratory tests and report the data
4.3 Supervise ground investigations and prepare borehole and test pit logs
4.4 Assess aggregate resources
4.5 Select appropriate geo-construction methods

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13. SOME PREDICTIONS ABOUT THE FUTURE OF GEOTECHNICAL ENGINEERING

"Predictions are difficult - especially about the future"
(Neils Bohr).

Nonetheless, we conclude this report with some predictions about the future of geotechnical engineering. These predictions are listed without categorization, prioritization, probability of occurrence, or assessment of relative importance.

- The scope of problems and projects requiring geotechnical inputs for solution will continue to expand.
- Continuing advances and improvements in biotechnology, sensors and sensing systems, geophysical methods, remote sensing, and information technology will enable geotechnical engineers to work faster and smarter, and with more tools in their toolbox.
- Technological advances, if used wisely, will enable better insights and understanding of fundamental interrelationships, phenomena and processes that impact earth material and system behavior.
- The importance of sound engineering judgment in all aspects of geotechnical engineering projects will increase owing to the need to evaluate wisely all the information that can be obtained and brought to bear on a problem or project. Without it, unanticipated failures or other "geotechnical surprises" can be expected.
- The need for early identification and integration of geotechnical considerations into overall project definition, feasibility studies, planning, investigation, and design will increase. Structural, environmental and sustainability issues can and will be better addressed if the geo-perspective is brought to bear early in the project.
- Closer collaboration among engineers, specialty equipment developers and manufacturers and contractors will result in new design possibilities, easier constructability, reduced costs, and improved job-site safety.
- Sustainability considerations will play a more important role in selection of design alternatives and construction methods. Embodied energy, carbon releases and life cycle cost analyses will be among the factors considered.
- More geotechnical factors will be incorporated into LEED and Envision rating systems for buildings and infrastructure.

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- Risk and reliability considerations will play increased roles in selecting among alternative solutions, evaluating and managing uncertainty during construction, and dealing with natural disaster and anthropogenic-based risks.
- Geotechnical engineering will have very important and expanding roles in addressing energy needs and development of energy resources (both fossil fuels and renewable resources), infrastructure renewal and new construction, repair and new construction of dams and levees, recovery of natural resources, hazard identification, mitigation and recovery, and protection and enhancement of the environment.
- Sponsored research from the National Science Foundation will continue to emphasize multi-investigator studies, many of which are multi-disciplinary or inter-disciplinary in scope. Research support by other mission-oriented government agencies such as the Department of Energy, the Corps of Engineers, the Bureau of Reclamation, and the U.S. Geological Survey will be of narrower scope and more specific problem focused.
- Societal impacts will be given more consideration in the ranking of competitive research proposals.
- New and improved measuring methods, low-cost instrumentation, and data acquisition, processing, and display systems will enable more extensive life cycle monitoring of buildings, infrastructure systems, dams and other earthworks.
- Case histories that describe innovations, successes and difficulties associated with large civil engineering projects will continue to play a major role in defining new directions and advancing the profession.
- The businesses of geotechnical engineering will be challenged to keep pace and demonstrate that they are cost-effective and beneficial to their clients.
- A few very large firms with in-house geotechnical capabilities will continue to obtain the major portion of the very large projects. However, firms that are too small to compete with these large firms will be successful by providing specialty services not provided by the large firms, such as drilling and testing, risk analyses, instrumentation and monitoring, and geophysical services.
- There will be changes in ownership and management as the baby boomers retire. Mergers and acquisitions can be expected to continue. As the grey-haired experienced engineers retire, some may come back in consulting roles. At the same time, the "Millennials" will be entering the workforce, bringing with them digital skills, heightened environmental concerns and new forms of thinking.
- Geotechnical contractors will continue to develop innovative ways to improve their construction equipment and methods, reduce costs and increase profits. Speed, precision, and safety will reach unprecedented levels owing to advances in sensor, information, and control technologies. Dominant, innovative firms will aggressively acquire others that cannot keep pace, and use their size to compete

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with large, international firms on an increasing number of large infrastructure projects.

- Both the challenges and opportunities resulting from globalization of the engineering and construction industries will continue to influence the technology and impact the business of geotechnical engineering.
- Some changes in the traditional forms of civil and geotechnical engineering education are likely as a result of the tension created by decreasing unit requirements for the baccalaureate degree and the need to cover more material in the face of the need to prepare students with more knowledge and skills. New approaches and methods for teaching may result from both the digital age and from research by departments of engineering education now active at many universities. Distance learning and continuing education via the many seminars, webinars, and conferences that are now available will assume increased importance.
- The equivalent of a masters degree will continue to be necessary for most geotechnical engineers. In addition, continuing education throughout their careers, already a requirement for continued licensure in many states, will become a universal fact of life. Both the individual engineers and their employers must assume responsibility for meeting these needs, usually through self-study courses, attendance at short courses, conferences and workshops, and taking advantage of the wide range of webinars that are now widely available.
- In 2008 a committee of the National Academy of Engineering identified 14 *Grand Challenges for Engineering in the 21st Century*. Among them are problems involving energy conservation, resource protection, water use, food production and distribution, waste management, security and counterterrorism, communications, transportation, weather prediction and control, and sustainable development. Opportunities for geotechnical engineers and geotechnical engineering to make significant contributions to solving any and all of them are abundant.
- Finally, two additional sets of predictions are listed in the two boxes below. The first is comprised of prognostications made by four eminent colleagues in geotechnical engineering who participated in a panel discussion on -"Research, Teaching, and Practice Interrelationships in Geo-Engineering Development - Is the Past a Prologue to the Future?" held at the 2010 ASCE GeoInstitute Geo-Congress, GeoFlorida (Mitchell, 2010). The second, "Ten Certain Trends To Consider Now," was developed by the ASFE Emerging Issues and Trends Committee (ASFE, 2012).

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SOME PROGNOSTICATIONS ABOUT THE FUTURE
(By four Geotechnical Engineering Experts, as Reported in Mitchell, 2010)

Research Areas Likely to Yield High Payoffs

- Advanced field instrumentation and sensing technologies - wired/wireless sensor networks; fiber optic strain measurements; self-sensing materials; data processing, interpretation, presentation; improved seismic monitoring, smart phones (R. Bonaparte)
- Smart geosystems and adaptive management - monitoring and controlling deep excavation ground movements; natural hazard warning and mitigation systems; smart waste containment systems. (R. Bonaparte)
- Improved methods for rehabilitation of existing geo-infrastructure - dams and levees; structural foundations; waste containment systems (R. Bonaparte)
- New materials for sustainable geo-construction: bendable concrete, bio-mediated improved soils; advanced geosynthetics (geotubes, electrokinetics) (R. Bonaparte)
- Advances in site characterization with a focus on how to deal with difficult soils; e.g., large particles, clayey and silty sands, cemented soils, old soils, weathered rocks and residual soils. (R. Boulanger)
- Improved methods for imaging the subsurface. (R. Boulanger)

Major Societal-Scale Problems with Potential High-Payoff Contributions from Geotechnical Engineering

- Protection from extreme natural events - hurricanes, earthquakes, landslides (R. Bonaparte)
- Water resource management, protection, conveyance and storage (R. Bonaparte)
- Infrastructure revitalization and underground construction (R. Bonaparte)
- Sustainable/renewable energy (geothermal, wind, tidal, solar) (R. Bonaparte, C. Santamarina)
- Oil/gas exploration and development in extreme offshore environments (R. Bonaparte)
- Underground carbon sequestration (R. Bonaparte, C. Santamarina)
- Mitigation of climate impacts (R. Bonaparte)

Transformational Developments

- Advances in field measurements and instrumentation combined with modern modeling capabilities and rational treatment of uncertainty are improving understanding of geotechnical phenomena and transforming the ways major problems are attacked. (J. Christian)

TEN CERTAIN TRENDS TO CONSIDER NOW

(from ASFE, 2012)

ASFE's Emerging Issues and Trends Committee addressed the emerging trends most likely to affect the geoprofessional industry during what was termed the "Crystal Ball Workshop" in July 2011. The following list of "Ten 'Certain' Trends to Consider Now" is excerpted from ASFE Practice Alert Number 53 (ASFE, 2012) that reports the results of this workshop.

1. **Technology** will continue to change the way we work - ~~a~~ "bring your own device" and migrate to the "cloud" are examples of strategies that could be adopted to accelerate speed of communication and service delivery~~.~~.
2. **Technology** is "leveling the playing field" - firms must differentiate themselves to avoid commoditization as a result of looking like everybody else.
3. **The demographic shift** as 80 million "Baby Boomers" begin to retire and 80 million tech-savvy "Millennials" enter the workforce will cause social media to become fundamental business communication media.
4. **Water scarcity and related food shortages** could provide significant opportunities for firms with water-resources expertise.
5. **Climate change** may cause sea level rise, increases in the frequency and intensity of weather-related natural disasters, and adverse impacts on infrastructure, commerce and welfare.
6. **World energy demand** will be 50 percent greater than in 2011. The demand for alternative and renewable energy resources will increase as will that for enhanced recovery techniques for fossil fuels.
7. **Consolidation in the geoprofessional industry** will continue**.** Smaller firms will need to develop effective profitability, capitalization and ownership transition strategies.
8. **Firm sustainability** will become a growing challenge. Recession-caused downward fee pressure and profit squeeze are making it difficult for many firms to build the balance sheet needed for shareholder retirement.
9. **A "war for talent"** is brewing. Understanding the factors that motivate job satisfaction and employee engagement is critical.
10. **Purpose-driven organizations and corporate responsibility** will be effective in attracting and retaining talent. Younger employees of today are looking more for the "why" than for the "what".

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Appendix A

Table A-1. Unresolved Issues and New Opportunities for Geotechnical engineering (Table 2.2 from NRC, 2006)

NATIONAL NEEDS[1]	2004 STATUS AND CRITICAL ISSUES	UNRESOLVED ISSUES AND NEW OPPORTUNITIES
Waste Management and Environmental Protection	**Status:** Many new technologies have been implemented and more are under development. Risk-based corrective and action and monitored natural attenuation have provided significant savings in many cases. **Critical Issues:** Many challenging sites still need to be remediated, additional technological development is still needed, including development of appropriate waste containment and remediation technology for developing countries and technology for reduction/reuse/recycling of waste materials. Cleanup, restoration, and protection of wetlands, rivers, harbors, and other waterways has become an important consideration.	• Significant global environmental problems have emerged • Formal adoption of the observational method (adaptive management) for site remediation projects • Bio-engineering methods for in situ remediation and containment barriers • Long-term stewardship of waste landfills and contaminated sites • Consideration of wastes as “resources out of place", “cradle to cradle” management of wastes • Strategies and technologies for alternatives to landfilling • Carbon sequestration • Remediation of contaminated sediments • Regional databases and data models for environmental data • Advanced sensors and remote sensing • Urban surface water management; erosion and sediment control

[1] As defined by the Geotechnical Board (NRC, 1989)

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Table A-1 (continued)

NATIONAL NEEDS[2]	2004 STATUS AND CRITICAL ISSUES	UNRESOLVED ISSUES AND NEW OPPORTUNITIES
Infrastructure Development and Rehabilitation	**Status:** New materials and technologies have made significant inroads in practice. However, little progress has been made in clearing the backlog of infrastructure needs. Lifecycle cost analyses are more refined and sophisticated, but still not widely embraced for selection of preferred alternatives. Sustainability considerations are becoming more important. **Critical Issues:** Wider use of lifecycle cost analyses, including incorporation of sustainable development and other social values, improved modeling of environmental impacts of infrastructure development, rehabilitation of existing geo facilities, and enhanced durability of geo construction.	• More discriminating, penetrating and cost-effective methods for seeing through the ground • Better coordination between planners, designers, constructors, and users • Passive methods for ground improvement, including bio-stabilization • Regional databases and data models • Smart geosystems and adaptive management methods (using the Observational Method) • Biofilms for corrosion protection • Long-term durability of geosynthetic materials • Use of formal reliability and life-cycle cost analysis • Quantification and reduction of uncertainties
Construction Efficiency and Innovation.	**Status:** New project delivery methods (e.g., design/build) have had an impact on innovation and efficiency. Significant advances have been made with respect to new equipment and techniques for geotechnical construction, particularly with respect to ground improvement. More efficient means of underground construction remains a critical need and improved methods for site characterization remains one of the greatest needs in geotechnical engineering. **Critical Issues:** More efficient/economical and less disruptive underground construction and ground improvement, minimizing environmental impacts of construction activities.	• Improved site characterization • Remotely controlled, automated earthwork construction • Better matching of soil and rock conditions with equipment and methods • Use of adaptive management systems for application of the observational method • Many aspects of tunneling and underground construction methods, including materials handling, directional control, excavation, safety, ground support • Trenchless technologies • More energy and cost efficient ground improvement, including bio technologies • Easier handling and better improvement of wet and weak soils

[2] As defined by the Geotechnical Board (NRC, 1989)

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Table A-1 (continued)

NATIONAL NEEDS[3]	2004 STATUS AND CRITICAL ISSUES	UNRESOLVED ISSUES AND NEW OPPORTUNITIES
National Security:	**Status:** Homeland security has become a critical national need, focus has shifted from national to global. **Critical Issues:** Providing adequate, appropriate, and reliable civil infrastructure; securing civil infrastructure against internal and external threats; dependence on foreign oil; providing secure sources for strategic natural resources	• New and better methods for hardening sensitive and critical structures and infrastructure • Improved methods for threat detection, including detecting and locating underground intrusion and surface traffic • Appropriate energy, sanitation and water technologies for developing countries • Development of secure reserves of strategic resources
Resource Discovery and Recovery	**Status:** Sustainability concerns have moved to the forefront for energy and water resources development. **Critical Issues:** Providing necessary resources for sustainable development and national security and minimizing environmental impacts of resource recovery and use.	• More reliable, discriminating, penetrating methods for seeing into the earth • Optimization of energy resources • More sustainable resource recovery methods • Improved waste and tailings handling and disposal methods • Carbon sequestration • Groundwater recovery, protection, and recharge
Mitigation of Natural Hazards	**Status:** National and regional hazard maps (earthquake, flood, and landslide) have been developed and have been incorporated into zoning laws and land use planning in some areas. Formal geohazards risk assessment is becoming an integral part of many projects. However, many communities are still at risk and continued research is needed. **Critical Issues** Improved regional hazard monitoring, forecasting, communication, and land use planning; Appropriate hazard mitigation technology for developing countries.	• Less complicated and more easily understood risk and reliability assessment methods • Remote sensing for hazard forecasting and monitoring • Non-intrusive and passive methods for mitigation of geohazard risks to existing structures and facilities, including bio technologies 1. Land use planning and zoning to account for geohazards and their potential consequences 2. Appropriate technology to avoid major loss of life and property in the developing world

[3] As defined by the Geotechnical Board (NRC, 1989)

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Table A-1 (continued)

NATIONAL NEEDS[4]	2004 STATUS AND CRITICAL ISSUES	UNRESOLVED ISSUES AND NEW OPPORTUNITIES
Frontier Exploration and Development	**Status:** NSF, NASA, USGS, and oil companies are pursuing research in these areas. However, geotechnical engineers are often not involved in these ventures. **Critical Issues:** Exploration at the frontiers of the natural universe ultimately leading to new frontiers for natural resource recovery and human habitation.	• Fundamental knowledge and understanding • New sources of natural resources (long term) • New habitats (very long term)

[4] As defined by the Geotechnical Board (NRC, 1989)

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Appendix B

CGPR Member Survey

CGPR member interest in twelve topics (major markets, new tools and technologies, geotechnical research, digital impacts, sustainability, risk and reliability, geotechnical construction, globalization, business and practice, technical and professional societies, predicting the future, and geotechnical engineering education) was surveyed. In addition, individual CGPR members suggested that the study should also include discussions on the design-build environment, engineering geology, and anticipated future demands on geotechnical engineers. Of these topics, CGPR members indicated the highest interest in risk and reliability. Geotechnical research, geotechnical engineering education and geotechnical construction all also are of high interest. Perhaps surprisingly, globalization, sustainability, and predicting the future were indicated as topics of lesser interest/importance, with technical and professional societies being the least important. The overall results of the survey are listed in table B-1.

Table B-1: Results of the CGPR Member survey at the 2012 Annual Meeting. Numbers indicate the number of CGPR member organizations (VI/HI: Very interested, High Interest. MI/MI: Mildly interested, Medium interest. LI/LI: Little interest, Low interest.)

TOPIC	VI/HI	MI/MI	LI/LI
Major Markets: e.g., energy, infrastructure, sustainability, resources, natural disasters, etc.,	12	5	4
New Tools and Technologies; biotechnology, remote sensing, digital applications, etc.	11	10	2
Geotechnical Research	16	8	0
Digital Impacts	7	6	9
Sustainability	5	11	7
Risk and Reliability	18	5	1
Geotechnical Construction	15	7	1
Globalization	2	13	8
Business and Practice	7	11	5

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Technical & Professional Societies	1	14	8
Predicting the Future	5	13	5
Geotechnical Engineering Education	16	3	2
Design-Build Environment	1	0	0
Engineering Geology	1	0	0

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Appendix C

List of Technical and Professional Committees in Three Geotechnical Societies

(Additional information about the scope, mission, and membership of each committee is available on the web sites for each organization. In some cases publications are listed, some of them with links to direct access.)

1. **ISSMGE – International Society for Soil Mechanics and Geotechnical Engineering**
    a. Fundamentals
        i. Laboratory Stress Testing of Geomaterials – TC101
        ii. Ground property Characterization from In-situ Tests – TC102
        iii. Numerical Methods in Geomechanics – TC103
        iv. Physical Modeling in Geotechnics – TC104
        v. Geo-mechanics from Micro to Macro – TC105
        vi. Unsaturated Soils – TC106
        vii. Laterites and Lateritic Soils – TC107
    b. Applications
        i. Geotechnical Aspects of Dykes and Levees, Shore Protection and Land Reclamation – TC201
        ii. Transportation Geotechnics – TC202
        iii. Earthquake Geotechnical Engineering and Associated Problems – TC203
        iv. Underground Construction in Soft Ground – TC204
        v. Safety and Serviceability in Geotechnical Design – TC205
        vi. Interactive Geotechnical Design – TC206
        vii. Soil-Structure Interaction and Retaining Walls – TC207
        viii. Slope Stability in Engineering Practice – TC208
        ix. Offshore Geotechnics – TC209
        x. Dams and Embankments – TC210
        xi. Ground Improvement – TC211
        xii. Deep Foundations – TC212
        xiii. Scour and Erosion – TC213
        xiv. Foundation Engineering for Difficult Soft Soil Conditions – TC214
        xv. Environmental Geotechnics – TC215
        xvi. Frost Geotechnics – TC216
    c. Impact on Society
        i. Preservation of Historic Sites – TC301
        ii. Forensic Geotechnical Engineering – TC302
        iii. Coastal and River Disaster Mitigation and Rehabilitation – TC303

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iv. Engineering Practice of Risk Assessment and Management – TC304
v. Geotechnical Infrastructure for Megacities and New Capitals – TC305
vi. Geo-Engineering Education – TC306
vii. Dealing with sea level changes and subsidence – TC307"

("ISSSMGE Technical Committees – 2009 - 2013." ISSMGE - International Society for Soil Mechanics and Geotechnical Engineering, 2009. Web. 25 Sept. 2011. <http://www.issmge.org/web/page.aspx?refid=612>)

ASFE – The Geoprofessional Business Association – Committees and Task Forces

d. "Board of Directors
e. Advocates Assembly
f. Business Practice Committee
g. Bylaws Committee
h. Construction Materials Engineering and Testing Committee
i. Council of Fellows
j. Education Committee
k. Emerging Issues and Trends Committee
l. Environmental Committee
m. Executive Committee
n. External Relations Committee
o. Geotechnical Committee
p. Investment Advisory Committee
q. Leadership/Management Task Force
r. Legal Affairs Committee
s. Membership Committee
t. New Leaders' Committee
u. Nominating Committee
v. Peer Review Task Force
w. Program Committee"

("Committees and Task Forces." ASFE - The Geoprofessional Business Association. Web. 25 Sept. 2011. <https://netforum.avectra.com/eWeb/DynamicPage.aspx?Site=ASFE>)

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ASCE – American Society of Civil Engineers – Technical Groups & Institutes

x. Select Technical Groups for all of CEE

- i. “Technical Council on Cold Regions Engineering
- ii. Technical Council on Computing and Information Technology
- iii. Council on Disaster Risk Management
- iv. Energy Division
- v. Technical Council on Forensic Engineering
- vi. Geomatics Division
- vii. Technical Council on Lifeline Earthquake Engineering
- viii. Pipeline Division
- ix. Technical Council on Wind Engineering
- x. Technical Activities Committee “

ASCE – Geo-Institute – Technical Committees

- xi. “Computational Geotechnics
- xii. Grouting
- xiii. Deep Foundations
- xiv. Pavements
- xv. Earth Retaining Structures
- xvi. Risk Assessment and Management
- xvii. Earthquake Engineering & Soil Dynamics
- xviii. Rock Mechanics
- xix. Embankments, Dams and Slopes
- xx. Shallow Foundations
- xxi. Engineering Geology & Site Characterization
- xxii. Soil Improvement
- xxiii. Geoenvironmental Engineering   Soil Properties and Modeling
- xxiv. Geophysical Engineering
- xxv. Underground Construction
- xxvi. Geosynthetics
- xxvii. Unsaturated Soils
- xxviii. Geotechnics of Soil Erosion”

("Technical Committees." ASCE - Geo-Institute. Web. 25 Sept. 2011. <http://content.geoinstitute.org/MC/TechnicalCommittees.html>)