

“The Past and Future of Computing in Geotechnical Engineering:  
The Inside-out View”

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**(TITLE SLIDE)**

Welcome to Atlanta! It is a pleasure to have the 2006 Geo Congress here, and we are proud to have Dr. David Frost from the Georgia Tech faculty chairing the organizing committee.

I would also like to extend a warm welcome on behalf of Georgia Tech. Our Atlanta campus is a stone’s throw away from the Hyatt Regency, and we would be honored if you found time to pay us a visit. Lots of exciting things are underway there, including endeavors in both geotechnical engineering and high-performance computing, as well as a number of other fields ranging from nanomedicine and biomedical engineering to photonics.

As president of Georgia Tech, my time, like that of any university president, is consumed with fund-raising, trying to keep alumni happy about athletic programs, uplifting the always flagging faculty morale, working with our outstanding elected representatives, and bird-dogging administrative issues. But the good news is that I have had the opportunity from time to time to act as a civil engineer as we built over \$1 billion worth of facilities over the past decade and transformed our campus. Unfortunately, opportunities like this one to visit with my fellow geotechnical engineers are rare. So it is an honor to be with you today and I want to thank you for inviting me.

This afternoon I want to offer you the opportunity to take a break from the nitty-gritty of sessions on user interfaces and numerical modeling and analysis techniques, and explore from a 30,000 foot level the opportunities that are arriving at our doorstep from the rapidly evolving world of information technology, high capacity networking and high-performance computing.

Ever since Karl Terzaghi began shaping the field of geotechnical engineering in the 1920s, our work has been characterized by periodic bursts of creativity driven by new methods, tools, and technologies. And as we look back over that history, it is clear that in many cases geotechnical engineering has been impacted in positive ways by new technology that has spilled over from other specialties. This conference focuses on the advances for geotechnical engineers derived through applications of information and computing technology. These advances have proven significant, but I would suggest

that we are on the verge of something much more profound in the near future, if, IF, we are ready to take the initiative and grasp it.

Before we look ahead, we need to heed the advice of Winston Churchill who once said, "The farther backward you can look, the farther forward you are likely to see." So I'd like to begin by taking a look backward at the growth of information and computing technology within geotechnical engineering. It is somewhat disarming to find that in this process I have to admit how old I am since the history of the introduction of computing and information technology in our field largely parallels own career.

### **(SLIDE #2: SLIDE RULES AND BIG COMPUTERS)**

When I first arrived at Georgia Tech as a freshman back when the earth was cooling, one of the first classes I took was how to use a slide rule. Looking back, I now realize that this process was more significant than just learning how to use this remarkable tool. As we sat in a classroom with a giant slide rule hanging at the front and watched the professor slide various pieces around in a way to get real answers, this not only was a learning experience, it also served as a means of inducting us into the fraternity of engineering. Much like the secret handshake of a social fraternity, the ability to pull out your slide rule and whip out answers placed you among a special group of cognoscenti who stood above the unwashed masses who had no idea how a slide rule worked. Since in today's world everybody knows how to use a computer, we have lost a little something in the process.

Even though I was a freshman a long time ago, I want to emphasize that I am not so old that there were no computers were around. Even in the 1950's there were computers, but they were room-sized, filled with vacuum tubes, and could be operated only by experts who apparently had to wear ties to work.

### **(SLIDE #3: MECHANICAL, ELECTRONIC CALCULATORS)**

While slide rules ruled, a rival loomed on the horizon – the calculator – devices which at first were mechanical. Since the transistor had not been invented the calculators we used were large, cumbersome, and powered by hand. You rolled a wheel or turned a crank on the side. Some of these devices had, at least for me, a peculiarly satisfying touch in that when you got your answer, a little bell would ring. I often wish my computer would do this.

As my junior year approached, the first battery-powered calculators appeared on the market. These devices had an instant appeal to engineering students, but colleges everywhere discouraged their use. The obvious reason was because the batteries required frequent recharging, and no classroom had enough outlets to accommodate

their use in class. Also, there lurked in the minds of faculty in those days the notion that if these new-fangled gadgets were allowed to replace the slide rule and the rigor of mental mathematical gymnastics, students' brains would turn to mush.

#### **(SLIDE #4: PUNCH CARDS)**

With the advent of transistors, computers became more powerful and useful. When I was a Ph.D. student at Berkeley, these new fangled devices allowed complex tools like the finite element method to be used for the first time, and geotechnical engineering was fertile ground for it. I wrote my computer programs on punch cards, and dutifully rode on my bicycle to and from the computing center at all hours of the day and night with them strapped in a flip top box on the rack at the back of my bike. After all these years I still have a recurring nightmare about a time when I was riding my bike back from the computing center, euphoric from my first successful run with my 2000 card finite element program. My euphoria was enhanced by seeing a lovely girl waving at me. Unfortunately, I suddenly realized she was not waving, but signaling me, and I discovered to my horror that my card box had flipped open. Looking back up the hill I saw about 1500 of my prized punch cards strewn out behind me and my life flashed before my eyes. Somehow I recovered most of them, but it took two weeks to get them ordered right and have another meaningful run.

#### **(SLIDE #5: FINITE ELEMENT ANALYSIS OF WALLS)**

With the rapid improvement of software and hardware, tools like the finite element method could be used explore the relationship between forces and deformations. We re-examined our understanding of the fundamentals of soil-structure interaction, the conditions leading up to slope failure, and how seepage interacted with movements.

#### **(SLIDE #6 – U-FRAME LOCK)**

We could for the first time analyze complex systems like U-frame locks that relied on soil structure interaction for its stability. This topic formed the basis for my PhD thesis. My work was enhanced because of the advent of new forms of instrumentation that documented field behavior which allowed us to begin to calibrate our models and improve them.

#### **(SLIDE #7 – URBAN EXCAVATION SUPPORT SYSTEM)**

Soon after, others, including myself, began to study flexible support walls for urban excavations where movements were as critical to performance as was overall stability. In this case, a critical mass of field performance monitoring data became available, which enabled us to develop useful charts that allowed for the first time a true deformation-based design approach to such support systems.

### **(SLIDE #8 – DESIGN CHART)**

Wall components and spacing of supports could be selected specifically to control movements within expected limits. For the first time spacing of supports was shown to be a critical parameter in movement control. Many of my colleagues at that time used the finite element method to explore a range of other issues in creative ways to enhance our design tools for other problems.

### **(SLIDE #9: DESK TOP COMPUTERS)**

With the growth of the power of desktop computing, geotechnical engineers adapted powerful analytical tools so they could be used in consulting firms, not just universities. The advent of the engineering workstation in the mid-1980s made it possible to do three-dimensional design without a supercomputer. By 1990, 3-D graphics were coming to personal computers.

### **(SLIDE #10: SUPER COMPUTERS)**

Even as the desktop computer was getting all the attention in the 1980s as the new kid on the block, mainframe vector supercomputers continued to advance in power and complexity. However, these exotic first generation supercomputers were extremely expensive, and the market was limited to the national labs and a handful of the largest research universities.

There were also problems that went beyond the capabilities of these exotic machines. Fast though they were, they still did not have the horsepower to cope with complex questions like forecasting the weather, accurately predicting response during earthquakes, or behavior at the particulate level.

We first noticed something new was up when Sandia National Labs announced in 1991 that “massively parallel computers” could do the work of a single supercomputer. Unlike vector supercomputers, which processed a large group of data all at once in a single processor, massively parallel computing employed a large number of microprocessors simultaneously to nibble their way through a problem. By 1995, the commercial parallel processing market had topped \$1 billion and Cray Computers, the world’s leader in traditional supercomputers, and filed for bankruptcy. However, parallel processing configurations also had their limitations. They were great at crunching large data sets, but large problems that required sequential calculations were often out of their reach.

The turn of the 21<sup>st</sup> century heralded a return to supercomputing, with a surge in supercomputer power that even exceeded Moore’s famous law that the speed of computing doubles every 18 months or so. This development was highlighted when

Japan announced in 2002 that it had built the world's most powerful supercomputer, the Earth Simulator. The U.S., among other nations, was stunned to find they had fallen behind, as much from complacency as anything else. There were warning signs for the U.S. government that our parallel processing systems were failing to deliver what we needed, both for national security and for science and technology leadership. Thus was launched an international competition to build the next-generation world's fastest computer.

**(SLIDE #11 – QUOTE)**

The ability of these new supercomputers to complete trillions of computations per second enables them to embrace calculations of incredible complexity and manipulate gigantic databases with ease. They are also essential to the modeling and simulation that is increasingly characteristic of scientific research. Way back in the 1991 edition of *Advances in Computers*, Thomas DeFanti and Maxine Brown wrote, "Much of modern science can no longer be communicated in print; DNA sequences, molecular models, medical imaging scans, brain images, simulated flights through a terrain, simulations of fluid flow, and so on, all need to be expressed and taught visually."

This new generation of supercomputers is being used to model the behavior of virtually anything that is too big, too tiny, too far away, or too dangerous to deal with in person – from exploding stars to individual atoms, from earthquakes to disease outbreaks.

**(SLIDE #12: RAZOR, NANOMEDICINE)**

High-performance computing is essential in emerging new interdisciplinary fields. The recent mapping of the human genome, for example, created a massive database that is about three terabytes in size – the equivalent of about 150 million pages if someone were to print it out. As a result, the new field of bioinformatics has emerged, bringing together biological and biochemical knowledge with skills in computing and mathematics to manage, process, and learn from complex data.

Georgia Tech just opened its Center for the Study of Systems Biology, which features an IBM supercomputer that is the 41<sup>st</sup> fastest computer in the world. It is capable of performing more than 8.5 trillion calculations per second, and it will use data from the sequencing of the human genome to study how living systems interact with one another.

**(SLIDE #13: BLUE GENE)**

The new generation supercomputers uses widely different architectures, and it is not clear at this stage which technology will ultimately emerge as the strongest. In the United States, the Department of Energy is taking the lead in developing high

performance computing centers through their network of national labs, and you will hear more about this from another speaker. After a recent competition, the Oak Ridge National Lab was selected as site where the most powerful computer in the world after Blue Gene will be developed. NSF is also in game through its National Centers for Supercomputing. These centers are being re-competed as this conference is being held.

Although the need for supercomputing power is becoming more widespread, it is not possible for universities or companies to provide science and engineering researchers with their own personal supercomputers. It is not even possible for every university that wants one to have one. A cooperative approach among universities, the federal government, and private industry is essential to developing appropriate supercomputer capabilities and making maximum strategic use of the resources they offer.

So, university researchers across the nation compete for awards from the Department of Energy that are made not in dollars but in the currency of millions of hours of time on its supercomputers. But to maximize the potential of these centers, they need to offer access, and this calls for a new generation computer network that can match the speed and power of the new generation of supercomputers.

**(SLIDE #14: NATIONAL LAMBDA RAIL)**

This next-generation network is the National LambdaRail, which is an initiative by a consortium of twenty leading research universities, including Georgia Tech, that joined forces to create what is essentially a third-generation high-capacity Internet devoted exclusively to research. The consortium saw a window of opportunity in the overbuilding of fiber-optic infrastructure that resulted when the deregulation of telecommunications allowed too many companies to compete for the same customers. So the National LambdaRail was able to purchase dark network capacity at bargain rates. This network allows a researcher to reserve for exclusive use a given system capacity for a fixed period of time, avoiding the need to compete with hundreds of users who simultaneously might want to use the system, as is the case for Internet II.

This combination of a growing supercomputing capacity and the National LambdaRail network which connects it to researchers is offering remarkable new opportunities for engineers and scientists. No longer does your particular university or company have to wait years for the technology to migrate downwards; it is available for the pioneers right now.

**(SLIDE #15: DOE GOALS)**

To better appreciate the lay of the land, it is useful to take a look at the goals of DOE for advanced research that will use high performance computing. As you can see, DOE

anticipates a range of problems that can be fruitfully addressed by the new generation computers. While no geotechnical applications per se are mentioned, a several of those listed have relevance to our field and I will suggest subsequently there are many more.

**(SLIDE #16: PROTEIN FOLDING)**

Probably nowhere else is the potential for impact on our society as large as in nanomedicine and molecular mapping. As we continue to seek to use the breakthrough mapping of the human genome, our growing understanding of phenomena like protein folding and what causes each action to occur in its own way at its own time, will lead to the possibility of predictive and personalized medicine. This will allow us to anticipate disease and prevent it rather than wait for disease to silently establish its base in our bodies and then deal with its perverse consequences.

So, where does geotechnical engineering fit into this picture? The answer to that question is that in the past we have found ways to use each new generation of computing power, and once again we need to explore the opportunities offered by the new generation systems that are coming into use. For starters we should re-visit fundamental problems we set aside in the past because they were beyond the reach of the state of the art of the time. Let me provide some examples.

**(SLIDE #17: WATER MOLECULES)**

One is gaining new insights to the true interactions between our multiphase soil systems consisting of water, air, clay minerals and organics, by simulating the molecular make up of the respective components.

**(SLIDE #18: NANOTECH)**

We can approach the behavior of each element from its basic nano structure by considering the full 3-D perspective. My Georgia Tech colleague, Carlos Santamarina, will speak to this type of possibility later in the conference.

At the macroscale, we can learn how soil deposits mobilize strength in some areas while others lose strength and drop to residual levels. We can visualize sequentially how different construction processes induce deformations in complex three dimensional environments.

**(SLIDE #19: CLINCH RIVER STRATIGRAPHY)**

More powerful Geographic Information Systems will allow us to visualize topographic, geologic and geotechnical information in 3-D formats. This technology will open new doors as analytical and artificial intelligence modules are linked to GIS information bases.

**(SLIDE #20: SEISMIC REFRACTION PROFILES)**

Much of the recent radical increase in oil productivity in old oil fields has derived from the increasingly sophisticated information gained from new forms of GIS systems. These have potential applications for geotechnical engineers.

**(SLIDE #21: FOUR PARAMETER CONE)**

High performance computing has the potential to optimize our growing capability to use multi-parameter field tests like the five parameter cone tests. With more powerful computing and networks, it will be possible to process the information being signaled from field tests and place it in its geographical context in real time for engineers waiting to begin design work back in the office.

**(SLIDE #22: MUNI METRO TUNNELS)**

During construction of tunnels we need to use high performance computing to be able to utilize results of instrumentation and observations at the face of the tunnel, fed in an integrated fashion, to fine tune information so movements can be controlled. During the late 1990s, I was fortunate to chair the consulting board that designed the Muni Metro turnaround facility in San Francisco. We were boring a tunnel under Market Street, which was dicey work for several reasons. First, this area of the city was originally in San Francisco Bay and had been filled in with junk fills in the late 1800s. What lay below the surface of the ground was a jumbled mixture of soils and rocks with sunken ships embedded here and there. Even though we did all we could to understand the subsurface conditions, we were never quite sure what we might encounter.

At the surface level we hoped to limit movements to under 3 inches. We had conscientiously used technology in design to control movements, such as grouting of the face. We had instrumentation in place and asked for rapid turnaround of information from the face. But we knew we could not entirely prevent problems, because the information could not be processed AND shared fast enough. Under Market Street we encountered the remains of an old ship, lost ground occurred, and settlements of up to seven inches occurred at the street level. If we had had better IT systems in place we could have handled this problem in real time.

**(SLIDE #23: HIGHWAY CONSTRUCTION)**

Advances in high-performance computing can also broaden the ways in which we can create systematic information to sharpen our ability to adjust our design to local conditions. Artificial intelligence systems, for example, have the potential to become an important addition to our computing resources in areas where geotechnical engineers are called upon to exercise their professional judgment.

Along these lines a computer model called FORESALT has been developed in Scotland to forecast the in situ moisture condition value – or MCV – of a site. The model combines ground investigation soil suction with a database of meteorological records to generate a projected MCV for each week of the year. It demonstrates the weather patterns that the site must be prepared to handle as well as the likely periods of the year when the soil is in an acceptable state for earth moving. FORESALT was tested with a 56-week trial full-scale field exercise in Scotland, where it is now being used for highway construction. It helps to set the construction schedule as well as determine the likely types and quantities of imported fill materials that will be needed for the roadbed.

I have used FORESALT and the other illustrations to this point in my presentation to show how high performance computing can open doors for geotechnical engineering. We need to pursue all of these. However, I am now going to suggest we should build on this technology to reach beyond traditional directions and broaden the perspective and the horizons of the geotechnical engineer.

**(SLIDE #24: KATRINA OVER NEW ORLEANS)**

I developed my thoughts about this during my on-going involvement as the chair of a committee of the National Academy of Engineering and the National Research Council related to the dramatic events that occurred in the New Orleans region as a result of Hurricane Katrina. We report to the US Department of Defense. Our charge is to review and evaluate the substantial effort that the Army Corps of Engineers and ASCE have underway in assessing and upgrading the performance of hurricane and flood protection infrastructure. This committee has sixteen members, a number of whom are highly qualified geotechnical experts, including Tom O'Rourke, John Christian, Andrew Whittle, and Delon Hampton.

**(SLIDE #25: LANDSAT VIEW)**

If you look at this land-sat photograph of the New Orleans region, it is easy to see that the landscape in the area is a complex of lakes, rivers, land, and swamps. The low-lying developed land is nominally protected from the effects of hurricanes by 284 miles of levees and floodwalls. Engineers proposed a plan for protection of the areas in 1965, and suggested it could be built within ten years for \$75 million.

**(SLIDE #26: HURRICANE TRACK)**

Forty years and \$800 million later, the system was not finished, and it was overwhelmed by Hurricane Katrina as it moved to the east of New Orleans. Most of the

press coverage has focused on the behavior of I-walls that were placed on top of several of the urban levees;

**(SLIDE #27: 17<sup>th</sup> STREET CANAL)**

Shown here is the 17<sup>th</sup> Street canal with its levees and I-walls before the hurricane hit. Lake Pontchartrain is in the background at the top of the picture.

**(SLIDE #28: LEVEE BREACH)**

Near Lake Pontchartrain, the east side of the I-wall on the 17<sup>th</sup> Street levees failed, as did three other sections along other urban levees. The resulting flooding of the city was extensive in the Lakeside and Ninth Ward neighborhoods, causing massive damage and disruption.

**(SLIDE #29: LEVEE REPAIRED)**

These I-walls were not overtopped but failed due to the loading caused by storm surges that were driven in from Lake Pontchartrain. Storm surge effects on the I-walls also were induced from the south through the access provided by the Mississippi Gulf River Outlet (Mr. Go).

**(SLIDE #30: OVERTOPPING OF LEVEES)**

But less reported were the instances of massive overtopping of the levee system that occurred to the east of the city from storm surges that originated in Lake Borgne as the hurricane tracked north. Considering the larger picture it is apparent that the overtopping of the system was extensive. Taken together, the overtopping and the failure of the I-walls led to a large scale failure of the hurricane protection system.

**(SLIDE # 31: NEW ORLEANS MAP)**

There are many reasons for the failure of the system, among them technical issues, gaps the levees created by infrastructure like roads, political intrusion into the engineering process, societal choices, and legal issues. Be that as it may, the Corps of Engineers is now faced with the daunting task of coming up with a plan and a design to not only to repair the levees, but to add to the capacity of the system. And this has to be done not in 40 years, but in perhaps as little as three years.

At the first meeting of the Committee on Regional New Orleans Hurricane Protection Projects, as we are called, we were briefed on the progress of the Corps team, and we were duly impressed by the extent of the work done. Those who were assessing the wave and water action presented a comprehensive computer model that simulated what had happened to the entire ecosystem during Hurricane Katrina. They could effectively demonstrate how the storm surge had moved through the network of

waterways during different times, and where the water went when levels were breached or overflowed. It was all there before us.

Although the geotechnical engineers had accomplished a great deal, they did not have the tools that would allow the level of presentation shown by the water experts. Those of us with geotechnical backgrounds felt right at home listening to them, because the techniques were largely the same ones we were familiar with from the 80's and 90's. Yet, this was also disconcerting since it suggested too little new technology was being implemented to help create a full understanding of the issues facing the designers. There also was very little shown that could be used to relate to the public, and in this case, the public has a need and desire to understand outcomes even in the interim stages of the work. This led us to recommend in our first report that the Corps look to newer means to explain their efforts, such as GIS technology, which could help organize the massive data base that is developing for this very challenging project.

#### **(SLIDE #32: NEW YORK GROUND ZERO)**

An example of how GIS has helped in understanding and analyzing the issues related to Ground Zero in New York City is shown here from work by my colleague David Frost. An interactive GIS model was used to store vast amounts of information about each building around Ground Zero and to allow access by a simple click on the image of the buildings. Shown here is documentation in a spread sheet about the building and any pictures of the damage. Imagine if we had this available for New Orleans and with a simple mouse click on any location on a site map we could see the type of damage and learn how the floodwaters arrived and through what failure mode.

But it also begs the question – why do geotechnical engineers not have in place a comprehensive geosystems approach to analysis, design, and information display? The traditional geotechnical approach to planning and design of a system consists of breaking it into parts using a section-by-section approach and then considering each section as a separate unit. I would suggest this not only is a less than optimum approach, it also limits the professional status of geotechnical engineers. I worry that this shortcoming will be intensified when we examine findings from the studies underway of the I-wall failures in New Orleans. We run a risk that these failures will dominate our discussion of the hurricane protection issues and divert us from the larger lessons. But will we as geotechnical engineers learn anything fundamentally new from these studies? Will we change anything about our field from this knowledge? Or, will this debate, as interesting as it may be, focus us inward, away for the larger design challenges and our need to serve the public interest. I suspect if we do not think in broader terms, we will continue to find ourselves following a lead dog and watching scenery that will never change.

**(SLIDE #33: WEBSTER)**

I would suggest that geotechnical engineers need to be in a position to understand how systems as a whole work together in order to appreciate how to make judgments about design for individual pieces of it. In an excellent paper to be presented to this conference by Allen Marr, he will make the valid argument that geotechnical engineers need to learn to use the growing power of computing tools to help them understand the context for design issues so they can better exercise their judgment. As we say here in the south, amen, brother, amen. In other words, in the future geotechnical engineers need to learn to consider more than geotechnical conditions if they are to be in a position to best use their abilities and serve the needs of the public. And if this is to be done, high performance computing technology will underpin it.

Assessing the soundness and performance of a network of elements to protect New Orleans and its residents is a task that calls for a systems approach. It begs the question – why aren't geotechnical engineers doing this now and where is a course in geosystems in our professional education programs? This in turn leads to another question – if we had a well established geosystems approach to projects, could not geotechnical engineers take a lead role in making critical choices and not simply being in a position of responding to directions from administrators?

**(SLIDE # 34: GEOSYSTEMS LIST)**

My proposal for geosystems engineering would involve consideration of:

1. The historical, societal, legal, and public policy framework for our profession, our work and any particular project.
2. Methods to effectively communicate to external stakeholders.
3. The factors that drive the decisions that have to be made for a project.
4. Economic and market issues.
5. Expectations of stakeholders and who the stakeholders are.
6. All pertinent geotechnical and geologic issues.
7. The potential design choices and reasons for choosing one over the other.
8. Alternative scenarios for potential outcomes.
9. Advanced computing and information technology to allow designers optimum use of data bases and visualization techniques.

I am sure others have better ideas and can shape them into a more useful framework, but these can serve as starting point. By taking the initiative in adapting high performance computing tools to create a geosystems approach to problems and projects, we can deal with stakeholders from a higher level of decision making authority. We can insure that our judgment is best applied, because we will have

established the full context for our approaches. This, in turn, will help elevate the role of the geotechnical engineer in the design hierarchy since others will look to us for the context for design.

In conclusion, this somewhat winding presentation has taken us down a garden lane of memories regarding the use of computing and information in geotechnical engineering. What I hope was accomplished in this journey was to remind you that geotechnical engineering has done well when it was on top of new developments and sought to rapidly take advantage of them. I also sought to inform you about the emerging new opportunities from high performance computing and high capacity networks. At this point, I do not see the evidence that geotechnical engineers are at the forefront in the use of these remarkable tools.

My remarks cited some of the possibilities that could come from using high performance computing. While many of these would build in sequential fashion on our past, one stands out as a new direction. I would argue that new computing tools can help to expand our role as geotechnical engineers if we are willing to integrate new simulation and testing tools, broad databases, visualization technology, and real-time monitoring into our practice and use them to drive decision-based structures. By putting geotechnical engineering into a broader geosystems context, we open opportunities to not only collaborate with others in related fields, but to better position ourselves for a leadership role. Ladies and gentlemen, I encourage you to think big.