From practice to theory in geotechnical engineering
De la pratique à la théorie dans l'ingénierie de geotechnical

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ABSTRACT

Teaching geotechnical engineering started with experience in building theories of soil behavior. As theories were tested in the field and better instruments became available for the measurement of soil properties both in the laboratory and the field, the wealth of knowledge increased. Theory benefited practice and practice perfected theory. However, teaching soil mechanics has not deviated much from learning theories with the fresh engineer left to relearn the practical aspects over the years. This has produced a wealth of experience that has not been fed back to training the next generation of engineers. This paper calls practicing engineers to invest in teaching the next generation of geotechnical engineers.

RÉSUMÉ

L'enseignement geotechnical commencé comme une expérience dans la construction des théories de conduite de sol. Comme les théories ont été évaluées dans les instruments de terrain et meilleurs est devenu disponible pour la mesure de propriétés de sol tant dans le laboratoire que le champ, la richesse de connaissance a augmenté. La théorie a profité à la pratique et à la pratique perfected la théorie. Pourtant, l'enseignement de la mécanique de sol n'a pas dévié beaucoup d'apprendre des théories avec l'ingénieur frais quitté pour réapprendre les aspects pratiques au cours des ans. Cela a produit une richesse d'expérience qui n'a pas été nourrie en arrière à l'entraînement de la génération suivante d'ingénieurs. Ces appels en papier pratiquant des ingénieurs pour investir dans l'enseignement de la génération suivante d'ingénieurs de geotechnical.

Keywords : Geotechnical, teaching, practice, research, theory

1 INTRODUCTION

Teaching geotechnical engineering, also referred to formerly as soil mechanics, forms an essential part of a civil engineer's training. Many undergraduate curricula provide about one semester of geotechnical engineering in four years of civil engineering education. To practice as a geotechnical engineer, one must have a graduate level education in the field. Much discussion has gone in to evaluating what type of curriculum best provides the student with the tools necessary to practice. What value does research have in supplementing practice as more challenges are faced in the field? This paper traces the history of teaching and practice of geotechnical engineering and examines some of the current trends. It concludes that training in geotechnical engineering should be a blend of theory, practice and research and recommends that practicing engineers take an active part in the academic community.

2 A NEW LOOK AT THE OLD SCINECE

Since Coulomb introduced the concept of active and passive earth pressures in 1773 to the Academy of Science in Paris, understanding the engineering behavior of soil has become a science from being an art of building. This young branch of civil engineering, though practiced for over ten millennia, attracted many inquisitive minds that saw sand and clay as interesting materials to study. What began in Istanbul as an application of structural engineering principles soil has grown into a science by itself. The earlier part of the twentieth century defined and refined the understanding of soil behavior. Teaching of geotechnical engineering had progressed from theory to practice in less than 20 years. Problems linking theory and practical applications led to research both in the laboratory and in the field. As the lessons learned were passed on from one generation of engineers to another, teaching geotechnical engineering has taken up new challenges. This paper emphasizes the need for the transfer of knowledge from practicing engineers to engineering students.

3 NEW IDEAS FOR A NEW SCIENCE

Casagrande, Bjerrum and Skempton contributed to the understanding of soils as an engineering material as much as Terzaghi and Peck did. The early days of the study of soil mechanics launched a series of concepts, measurements and theories that had to be put to the test in the field. Just as much as Newton had to test his theory of orbital motion by inventing calculus, the pioneers in soil mechanics were inventing methods to prove their theories. Unknowns were filled in with constants in their equations. These engineers tested their concepts in the field by designing foundations, dams, structures and then checking their theories by measuring settlements, pore pressures and earth pressures. Some theories worked, but in others some parameters had to be changed and new theories came forth. All of these changes were being passed on to the second and third generation of soil engineers who gained exposure for their science in the larger context of civil engineering practice. Construction of tall buildings, the interstate highway system, building canals and waterfront structures challenged the soil engineers to come up with solutions to problems that did not exist until then. The science of soil mechanics grew from ideas to a scientific method in a short span of about 30 years from the 1920s to the 1950s. In the following 50 years geotechnical engineering research progressed so far that a time has come to question whether the simple theories of our text books are valid. When Schofield (2001) talked about "Paste Mechanics" in

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Istanbul where it all began with Terzaghi, he quoted Bjerrum to conclude ""Universities should not teach soil mechanics; they should teach mechanics."

4 TEACHING SOIL MECHANICS

The Pioneers: Theory for Practice

Perhaps the earliest compendium of ideas of how soil mechanics should be taught or understood came from Taylor's "Fundamentals of Soil Mechanics" (1948) and was counter balanced by Terzaghi and Peck who published their "Soil Mechanics in Engineering Practice" in 1948 with a purpose of taking the early concepts and discoveries into practice. Engineers in training at that time were given not only a tool but also a commission to apply their skills to the new science, which they did. Where there was no clear theory, one was developed. In this atmosphere teaching soil mechanics theories were tested, often by procedures newly developed that have changed little in 50 years. The classic "Standard Penetration Test" is an example of working with the currently available and rather than the best available. This was also the golden age of nation building in the USA and a new age of rebuilding in Europe. It was fertile ground for soil mechanics to grow as a science. Construction of tall buildings like the Empire State Building; construction of the Golden Gate Bridge; building dams and canals are just a few of the examples where soil mechanics provided the answers that until then was left much to empirical formulae and thumb-rules.

Second Generation teachers: Theory to Practice

Soil engineering teachers in the 1950s and 1960s were the ones who welcomed graduate students from all over the world who came to the institutions where the pioneers worked. Studies on expansive soils, residual soils and application of new field testing techniques added to better understanding and formulating widely applicable theories. One of the greatest opportunities this generation of soil engineers had was the ability to bring their practice into the classroom and send their students out to practice their research findings, all around the world. It is perhaps at this stage that soil mechanics went from "theory to practice." This was also the age of beginning of the space age and we collected samples from the moon. Gathering voluminous data was possible with the help of State Transportation Boards, Bureau of Reclamation, the Army Corps of Engineers and Engineering Experiment Stations set up at most major university centers. Premier research institutions like Danish, Swedish and Norwegian Geotechnical Institutes experimented with bold techniques and theories that their own unique environments challenged them to face. Research came out of the laboratory to practicing engineers. Measurement of in-situ soil properties became a better science with a wider acceptance of cone penetrometer test and pressuremeter test.

The Research Generation: Practice to Research

Teaching soil mechanics to civil engineers thus became an essential part of the graduate curriculum in almost every engineering school. Through the 1970s and 1980s engineers from practice got back to school to refine and define their skills. Practice called for research to gain better understanding and more research benefited practice. Recognition of the need to improve the correlation between theory, laboratory tests and estimating field conditions more accurately, new field measuring techniques were developed. In-situ measurement of soil properties with large-scale tests, pile load tests, cone penetrometer, pressuremeter and dilatometer became routine. The information fed from the field measurements required further refinement of laboratory tests. Simulation of actual field conditions in the laboratory became the source of many a doctoral thesis.

Teaching soil mechanics to the third and fourth generation of soil engineers was a good mix of theory and practice. This was also the beginning of the computer age and the new technology was available to soil engineers. There was a period of knowledge explosion with the availability of greater computing power, application of numerical methods, test methods such as centrifuges, strain gauges, electronic measurement of in-situ behavior of structures, soils and soil-structure interaction and mathematical refinement of theories. Teaching soil mechanics was a matter of more research, more software and more refinement of calculation. Somewhere in this period, the theory and practice of soil mechanics and foundation engineering earned the name Geotechnical Engineering. Geotechnical engineers also leaned towards environmental engineering creating a new world of opportunities.

The Next Generation: Virtual Geotechnical Engineering

When the Nanyang Technological Institute (now University) took its first batch of freshmen in 1984, the goal was to prepare "practice oriented engineers." Following a challenge thrown to practicing engineers to get back to the university to teach, this writer was invited to practice what he preached. This was a great opportunity to take an empty building and 200 students and start building a world class institution from there. One of the key elements of instruction was a 10-week in-house training where the students designed and built their own structures under the supervision of the faculty and a six-month industry training where the students worked with an engineering firm, again under faculty supervision. This not only opened up a channel of communication between the school and the practitioners, it also put students in a real world where they knew what they were learning, and more importantly, why. The university attracted expert talent from around the world who contributed their expertise not only to the school but to the nation of Singapore that had just started building a mass rapid transit system and many other signature projects.

Prof. Begnt Broms with NTI students learning about the Weight Sounding test, routinely used in Sweden.

At that time in a piece written by this author for the student magazine about the future of soil mechanics made a rather sarcastic remark about virtual world soil mechanics teaching in the year 2004 where the student simulates soil behavior on a computer with no real soil sample! Haque (2001) made this writer's vision reality with "Interactive simulation and visualization in a soil mechanics laboratory!"

This is where geotechnical engineering teaching has arrived in a little over half a century. Teaching fundamental soil mechanics today involves an understanding of the theory, manipulation of software that take many variables in to account, instrumentation that constantly monitors performance and in some cases even automatically corrects and equipment that can install complex designs precisely. What could a student learn that would be sufficient to practice the art of geotechnical engineering?

The frontiers for geotechnical engineering practice keep growing way beyond elastic theory and consolidation theory! The science has stepped out beyond mechanics in to geotextiles, geo-environmental engineering, geo-hydrology and geo-thermal engineering. So what and how do we teach?

5 TEACHING CONCEPTS

We have seen three aspects of teaching geotechnical engineering – theory, practice and research. No longer could we choose two out of the three, but should have a balance of all three. The virtual learning of soil behavior with all theory though simulated practice does not replace the experience of standing behind a shield tunneling machine. Years of experience in pile driving cannot substitute hours of calculating the effect of liquefaction on an offshore mooring.

Geotechnical engineering is for graduate study

Teachers have found the need for a balance between theory, practice and research essential in training the well balanced geotechnical engineer. ASCE policy statement 465 recommended that teaching geotechnical engineering belonged to graduate level educational curriculum. Townsend (2005) agrees with the ASCE policy that geotechnical engineering and writing in *Geostrata* he recommends three areas that need rethinking – attracting more talent in to geotechnical engineering study, research oriented toward practice and bringing experienced engineers to teach.

Nehdi (2001) argues generally that the "hard hat down in the ditch" image of civil engineers needs to change to attract more students in to civil engineering. This applies especially to geotechnical engineers and unfortunately, the image of a geotechnical needs to change. In total contrast to this, Haque (2001) goes to the other extreme with virtual soil mechanics and computer simulation. Java simulation gives the visual image to 21st century students the way toothpicks did to the 20th century students – same visualization but a different medium! But it proves the point that theory must replicate reality.

McDowell (2001) took a different approach. He gave a "real-life problem" and let the students learn by solving the problem with the given tools. He concludes by this method students learned the fundamentals of critical state soil mechanics, gaining a high level of cognitive ability.

At least one teacher, Kumar (2004), spoke of the need to teach geotechnical engineering at the undergraduate level, from a practice point of view.

The learning triangle

The premise of this paper comes down to this simple formula for teaching geotechnical engineering. With an ever-expanding body of knowledge and experience, there must be a rational method of preparing the students for not just what exists today, but what unknowns will come in the future. As a product of the 1970s the writer's own generation of geotechnical engineers received training from the scholars-teachers who had listened to the first generation pioneers and we started our careers with computer aided design. We got the best of the past and future and had the unique privilege of passing on a blend of experience and expertise to the next generation. Now we owe to the next generation to pass on the experience and learn from their expertise. In his own practice the writer has depended on the academic expertise of young engineers who can run computer simulations – provided they know what they expect to achieve in practical terms. Years of experience of the mature engineer who might not remember the difference between Taylor's text book and Taylor series will provide the parameters for the model so that the younger engineer can produce a rational result. Otherwise the GIGO concept of computer science prevails.

This attitude must trickle down to the graduate schools. Unfortunately universities place sole emphasis on an "earned" Ph. D. in recruiting teachers. The example of Nanyang Technological University cited earlier shows the value of practicing engineers returning to teach. No consulting engineer will take time out of his or her work to teach, except as a guest lecturer for an hour or two. This promotes little educational value as it does not have the same value as mentoring. Many large engineering firms have adopted a program of mentoring to keep their younger engineers motivated, productive and loyal.

Author with NTI students installing an inclinometer.

We need a change in the thinking among school administrators as Townsend (2004) points out to get practicing engineers to take a one year "sabbatical." Experienced teachers communicate fundamental concepts better than fresh doctorates.

Practicing engineers will benefit from the exposure to academic institutions and the research environment if they get involved with younger minds that have the technology but lack the technique. Of course we do realize that not every good engineer is a good teacher! But experience can build a better teacher of a good engineer,

6 CONCLUSION

Teaching of geotechnical engineering has come a full circle from teaching theoretical concepts to teaching practical applications. A balance between theory, research and practice could only come from teachers and practitioners crossing each other's boundaries and working in the other's domain. Universities should tap talent from the practitioners, just as much as doctors and lawyers do and researchers must be fed problems from the industry that need new solutions. Universities could provide the virtual learning environment and equipment that only academic institutions could afford, and practicing geotechnical engineering could reduce risk significantly by investing in research, including theoretical research. Knowing that their educational experience has practical application provides the much needed motivation to attract the best talent to the study of geotechnical engineering.

REFERENCES

Haque, M., Interactive Animation and Visualization in a Virtual Soil Mechanics Laboratory, 2001, 31th ASEE/IEEE Frontiers in Education Conference, October 10 - 13, 2001 Reno, NV, pp. T1C 5-9.

Kumar, S., Teaching Geotechnical Engineering using Professional Practice, 2004, International Conference on Engineering Education October 16-21, 2004, Gainesville, Florida

McDowell, G. R, A Student-centred Learning Approach to

Teaching Soil Mechanics, 2001, International Journal of Engineering Education. Vol. 17, No. 3, pp. 255-260, 2001

Nehdi, M., Crisis of Civil Engineering Education in Information Technology Age: Analysis and Prospects, 2001, 31th ASEE/IEEE Frontiers in Education Conference, October 10 - 13, 2001 Reno, NV, pp. T2B 20-29.

Schofield, A., Re-appraisal of Terzaghi's soil Mechanics, (A draft of an invited Special Lecture at the International Society of Soil Mechanics and Geotechnical Engineering Conference in Istanbul August 2001). www2.eng.cam.ac.uk/~ans/TR316.pdf

Taylor, D. T., Fundamentals of Soil Mechanics, 1948, John Wiley & Sons, New York, NY

Terzaghi, K.V. and Peck, R. B., 1948, Soil Mechanics in Engineering Practice

Townsend, F.C., Challenges Facing Graduate Education in Geotechnical Engineering, 2004, ASCE Geostrata, Summer 2004, pp.21-24