NORGES GEOTEKNISKE INSTITUTT
NORWEGIAN GEOTECHNICAL INSTITUTE

PUBLIKASJON NR. 207
PUBLICATION

Ralph B. Peck

Engineer
Educator
A Man of Judgement

Edited by Elmo DiBiagio and Kaare Flaate

Oslo 2000

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The Norwegian Connection

When Ralph B. Peck received the ASCE Norman Medal in 1943 for his paper "Earth Pressure Measurements in Open Cuts, Chicago Subway", Karl Terzaghi closed his tribute to him with the following words:

> *"I express the hope that Ralph may succeed where I have failed and that he may educate a generation of foundation engineers who retain their common sense and their sense of proportion*

The entire geotechnical community would agree that Ralph has been successful in this task. He educated not only one but several generations of foundation engineers. And with the new Peck Library, he will continue to do so.

Future generations may wonder why the Ralph B. Peck Library is to be found in Norway, together with the Terzaghi Library established at NGI in 1967. There is really an interweaving of many reasons, but the origin of Ralph Peck's Norwegian connection is no doubt the magnetism, close friendship and mutual professional respect that existed between him and NGI's first director Laurits Bjerrum. It is no coincidence that he was the first non-NGI person asked to give the Bjerrum Memorial Lecture in 1980.

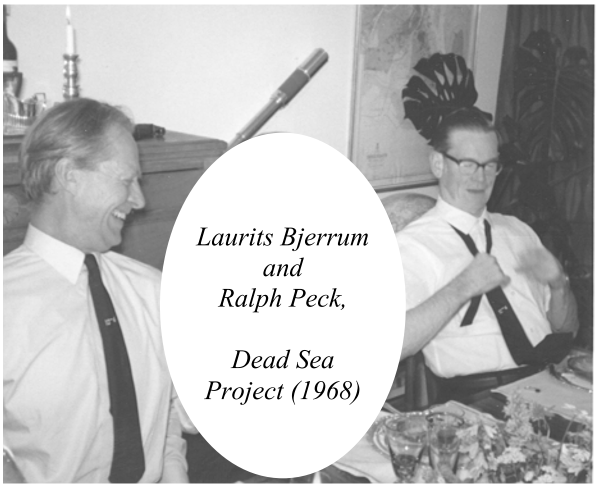
Terzaghi Library at NGI

Laurits Bjerrum at Stonehenge

Laurits Bjerrum and Ralph Peck first met in Zurich in 1953. Sir Alec Skempton introduced them to each other. At Bjerrum's invitation, Ralph stopped over in Oslo on his way home from the conference, where Laurits showed him the test pitting being done for the Oslo subway, the sliding that had occurred on one of the railroad lines, and building settlements in Drammen. He came again in October 1959 to lecture and give expert advice on the settlements of clay due to leakage of groundwater into jointed rock associated with the subway tunnel. The event was covered in detail over an entire page in *Aftenposten*, the main daily Norwegian newspaper.

The U.S. Corps of Engineers invited Laurits and Ralph in 1964 to act as consultants together on the landslides associated with the Alaska earthquake. The pair enjoyed each other's company and their technical work as a team so much that they decided to try to always have a joint consulting project together. The decision worked out well over the next 10 years. This included the Cannelton and Uniontown lock and dam construction failures on the Ohio River between Indiana and Kentucky, the dams in the James Bay project, and of course the epic Dead Sea dikes. At the time of Laurits' death, the two were to be involved in a consulting assignment on the leaning Tower of Pisa. Their last technical discussion was during a meeting in Montréal, on the liquefaction aspects under the base of gravity platforms in the North Sea and how the foundation sand had become so dense. Nowadays, the platform they discussed is known as the Ekofisk storage tank.

The Bjerrum-Peck cooperation was full of drama; it was an era of good times for soil engineering consultants. The pair participated in a series of extra-ordinary projects, all memorable. There were also good times at conferences, and while lecturing in each other's respective countries. Each meeting added to the ties between them.



Laurits Bjerrum and Ralph Peck, Dead Sea Project (1968)

Witness to the friendship between Laurits Bjerrum and Ralph Peck are two volumes of correspondence from May 7th 1952 until February 26th 1973, the last letter mailed by Laurits at the airport on his way to London. In this last letter, the Bjerrum and Peck families were planning a trip together in connection with the Moscow conference. The correspondence over 20 years presents a lively story of the development of two unique figures of our profession, on both the personal and professional level. Emerging from the correspondence is a genuine friendship and a desire to help each other in every way, even with details like choosing an appropriate wording for a key lecture. The geographical distance between them made no difference.

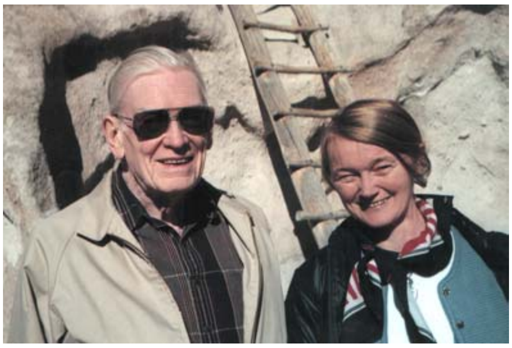
When Laurits died, Ralph wrote a personal tribute that since has gotten to be well known and often quoted. In this tribute, Ralph gave credit to Laurits for having made NGI the "Mecca of soil mechanics research and the finishing school of soil mechanics". It is a just return that someday NGI would be able to establish a Peck Library.

Ralph is the first to say that many events and coincidences contributed to developing a special relationship between him-self and NGI over the last 60 years. Coincidentally, the assistant to Laurits Bjerrum and Ralph Peck on the Dead Sea project was Kaare Høeg who was to succeed Laurits at the helm of NGI. Through con-sulting projects around the world with Laurits, joyful happenings with the Bjerrum family, consult-ing assignments with Kaare Høeg then and now, a long personal and professional friendship with the undersigned, and through the

Ralph and Marjorie Peck, Laurits and Gudrun Bjerrum and Alec and Nancy Skempton at Mexico International Conference in 1969. (Photograph is believed to have been taken by Harry Seed.)

careers of two of his doctoral students, Elmo DiBiagio and Kaare Flaate, who became closely connected to NGI's history, NGI has occupied a niche in Ralph Peck's personal and professional life. Fortunately, these events have drawn him close to NGI and made possible the establishment of this unique Library.

It is also fitting that Ralph Peck's works will be joined to those of his mentor, colleague, and friend, Karl Terzaghi. The Karl Terzaghi Library tells about the birth and growth of soil mechanics. The Ralph B. Peck Library tells about the practice of foundation engineering, and how one exceptional engineer exercised his art and science over a period of 60 years. It documents how a unique man could become an Engineer, Educator, and Man of Judgment *par excellence*.



Ralph B. Peck and Suzanne Lacasse at the Bandelier National Monument in New Mexico (1999)

We, at NGI, see it as a privilege and an honor to have been chosen to be the custodian of Ralph Peck's papers. We are fully aware that this privilege also involves a duty to all who will want to learn about Ralph Peck's work or about the unique engineer that Ralph Peck is. We pledge to do our outmost to preserve his papers for the generations of civil engineers to come and to give to the Library the setting such a precious collection of documents deserves. We are also aware that NGI is only the host and custodian. Our role is to ensure that the integrity of Ralph Peck's work is preserved for the future. The Library makes it possible for his work to be a reliable witness of how geotechnics became what it is today, and provides our profession with a guide for the future.

NGI in Oslo

Oslo, 25 April 2000

Suzanne Lacasse
Managing Director
NORWEGIAN GEOTECHNICAL INSTITUTE

A Profile of His Career

August 13, 1926

Ralph Peck

In checking up on the quality of work being done by pupils, I am very much pleased to see that the quality of your work is high and very uniform. This indicates that you should be successful in future work.

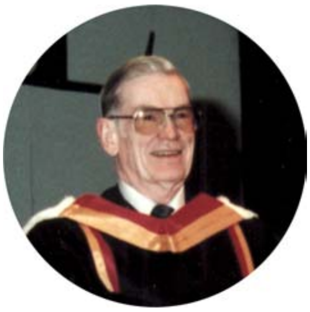
H. S. Philips
Principal
Aaron Grove Junior High School

The prediction quoted above, made by a Junior High School Principal to a young boy in 1926 was certainly correct. That 14-year old boy has since become one of the leaders in his profession and is known worldwide for his contributions to engineering and engineering education.

Ralph B. Peck, 1999

His advice has been sought on numerous major national and international projects including foundations, tunnels, dams, pipelines and airfields. His impact on the profession has been most significant because of his commitment to education in both his academic and professional engineering life. His teaching and research, in the 32 years at the University of Illinois, were directed toward integrating the theory and practice of geotechnical engineering – a task that he achieved and will be remembered for above all.

A brief review of his career is summarized on the following two pages. To keep within his field of expertise, geotechnical engineering, this information is presented in the form of a bore hole profile – something that he knows and has worked with throughout his career.



1987
Honorary Doctorate
Laval University

1973
Accepting
The Moles Award

1968
On the job
Dead Sea Dikes

Ralph B. Peck

Date and place of birth: June 23, 1912, Winnipeg Canada
Nationality: USA

Married to Marjorie Truby on June 14, 1937

Children: Nancy Jeanne Peck (Young) and James Leroy Peck

Education

Civil Engineering Degree, Rensselaer Polytechnic Institute (RPI), 1934

Thesis: An investigation of the stresses in short beams by the photoelastic method

Doctor of Civil Engineering Degree, Rensselaer Polytechnic Institute, 1937

Thesis: Stiffness of suspension bridges

Employment Record

Retired, self-employed consultant in geotechnical engineering, since 1974

Professor Emeritus, University of Illinois, 1974

Professor of Foundation Engineering, University of Illinois, 1948 to 1974

Department of Civil Engineering, University of Illinois, 1942

Assistant subway engineer for the city of Chicago, 1939 to 1942

Laboratory assistant to Arthur Casagrande, Harvard University, 1938/39

Structural detailer, American Bridge Company, 1937 to 1938

Honors

The Ralph B. Peck Award, established by the Geo-Institute (1999)

Inducted in RPI's Hall of Fame celebrating greatness, 1999

Honorary degree of Doctor of Science (1987), Laval University

Fellow of the American Academy of Arts and Sciences, 1975

Honorary member of the American Society of Civil Engineers (1975)

Honorary degree of Doctor of Engineering (1974), RPI

Elected Member of the National Academy of Engineering, 1965

Honorary member of the Japanese, Mexican and SE Asian Societies of Soil Mechanics

Professional Offices

President of the International Society of Soil Mechanics and Foundation Engineering, 1969 to 1973

Member of the Board of Directors of American Society of Civil Engineers, ASCE, 1962 to 1965

Chairman of the Executive Committee of the Soil Mechanics and Foundation Division, ASCE, 1957

Member of the Executive Committee of the Soil Mechanics and Foundation Division, ASCE, 1954 to 1957

Some Statistics (per March 2000)

Three books including two textbooks both classics in the field of geotechnical engineering, over 300,000 copies sold (per 1999)

> With K. Terzaghi and G. Mesri, *Soil Mechanics in Engineering Practice*, 3rd Edition
> With W.E. Hanson and T.H. Thornburn, *Foundation Engineering*
> With A. Casagrande, L. Bjerrum and A.W. Skempton, *From Theory to Practice in Soil Mechanics*

Two books about Ralph B. Peck

> *Judgment in Geotechnical Engineering*, by J. Dunnicliff and D.U. Deere
> *The Art and Science of Geotechnical Engineering*, Edited by E.J. Cording et al.

234 Technical papers

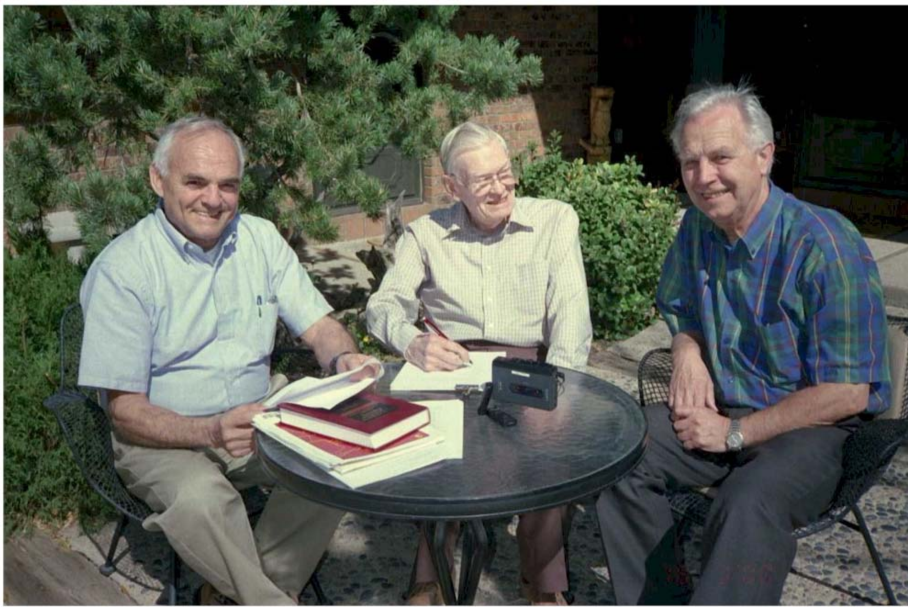
Over 5000 students attended his lectures at the University of Illinois

39 Doctoral graduate students

1045 Consulting projects during his 50-year professional career

In His Own Words

When it was decided to include a biography of Ralph in this publication, the planning committee realized immediately that there was only one person capable of doing this properly – Ralph himself. Thus, it was decided to arrange an interview in which he could tell his own story, a task that Ralph carried out with the same professional enthusiasm and expertise as all his endeavors. The following is a transcript of the interview, which took place at his home in Albuquerque, New Mexico, in March 2000.



Elmo DiBiagio and Kaare Flaate interviewing Ralph Peck

Q. *Where does your story start? We know a lot about your professional life and accomplishments, but we know very little about your background? Can you tell us a little about your early life?*

A. My parents grew up in what was then Dakota Territory, where my grandparents on my father's side homesteaded and supported themselves by farming. My grandfather was also an itinerant Sunday-school missionary. He traveled over 100,000 miles in Dakota by horseback, horse and buggy, and bicycle, and held camp meetings which led to establishing Sunday schools and churches in the Territory. My father, Orwin K. Peck, grew up in Mitchell, attended Dakota University which was located there, and received the degree of Bachelor of Arts. My mother's parents also lived in Mitchell. Her father, Oren T. Huyck, had an interest in a series of grain elevators in that part of the country. He was of Dutch extraction. I know very little about the origins of my other three grandparents, except that they probably came from Scotch-Irish and English ancestry.

My mother and father knew each other at an early age. They told of studying together in high school and when they both went to Dakota University. My father worked summers for a Scandinavian contractor by the name of Bjodstrup who built county highway bridges. When my father asked how he knew what size timbers to use, he didn't get a satisfactory answer, so my father decided to go to the University of Wisconsin, the closest major university, to study Civil Engineering. He graduated in 1907. My mother in the meantime went to the University of Minnesota and took a classical course. She taught in the Minneapolis schools for a year or two while my father was finishing at Wisconsin. She had hoped to go to Wellesley, but my grandfather died at that time and my grandmother couldn't afford to send her to an Eastern school.

My father, Orwin K. (O. K.) Peck, had some excellent and well-known teachers at Wisconsin, including F. E. Turneaure and Daniel W. Mead. He graduated in 1907, went to work for a steel fabricator in Minneapolis, and then as Bridge Designer for the Northern Pacific Railway. He and my mother were married in 1909 and moved to Winnipeg, Canada, where my father worked in the office of the Grand Trunk Pacific Railway, then being built from Winnipeg to the Pacific Ocean in British Columbia. This explains how I came to be born in Canada in 1912, but I was never a Canadian citizen because my parents registered me with the American Consul upon my birth. When the railroad job in Canada was finished, my father spent another year as the Resident Engineer on a bridge in Winnipeg, and then became Assistant Bridge Engineer of the Louisville and Nashville Railroad. We moved as a family to Louisville, Kentucky. My mother's mother, Grandmother Huyck, lived with my parents from the time of my Grandfather Huyck's death, and I turned out to be an only child, so my family during my youth consisted of my mother, father, and grandmother.

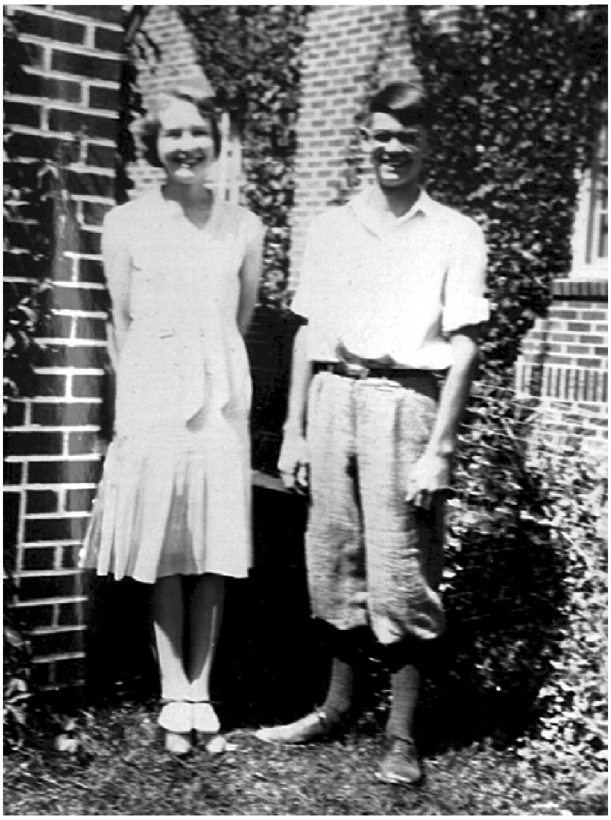
While we lived in Winnipeg, the great influenza epidemic of World War I occurred, and I was told later that I was one of the first in Winnipeg to contract of the disease. In any event, I was a sickly child for many years and my mother taught me at home until third grade. I had just started to school in Louisville when my father became Bridge Engineer of the Detroit, Toledo and Ironton Railroad, with headquarters in Detroit. There, in two years I went to two different schools. I was absent much of the time because of various childhood diseases. My father's job with the DT&I turned out not to be satisfactory, because Henry Ford bought the railroad and tried to operate it only as a way to transfer his automobiles onto the various railroads that the DT&I crossed. Dad could see no future under those circumstances, and we moved to Denver, Colorado, where he started a 36-year career as Bridge Engineer and, later, Engineer of Structures for the Denver and Rio Grande Western Railroad. This was a very interesting assignment, as the D&RGW, which was built to serve the mining industry, mostly in Colorado, had lines to practically all the mining camps in that state with extensions into New Mexico and Utah. During the years of my father's service the railroad was transformed from a local nearly bankrupt organization to one of the major transcontinental links.

Q. *When did you become interested in engineering?*

A. My father really liked his work and discussed it every night at the dinner table, where he not only told about what he did, but where I was required to tell what I had learned in school that particular day. There is no question that my father's interest in his job and those dinner-table conversations turned me toward Civil Engineering. In fact, after I got over the state of wanting to be a street-car conductor, I never had any idea of a profession other than engineering, particularly bridge engineering.

I spent a large part of the time through grade and junior high school at home, even in Denver, because I had the misfortune to get scarlet fever and diphtheria together when we first went to Detroit. This left me unable to participate much in very active sports. My teachers gave me home assignments while I was ill, but I also read a lot, including everything I could find about astronomy in the encyclopedia and other books. I thought at that time that astronomy might be a good profession, but it never quite took the place of engineering. By high-school time, I was able to go to school without much interruption due to illness. I had some really excellent teachers, played piano in the high school so-called symphony orchestra, and edited the student yearbook. I particularly liked the courses in geometry and physics.

Ralph and Marjorie, the day before Ralph left for RPI in 1930



The summer after I graduated from high school, Dad got me a job as a helper on a signal gang on the railroad. Most of the time I was digging ditches alongside the railroad track to install cables for a new signal system. It seemed very hard work, but by the end of the summer I came to enjoy it. Our gang lived out on the job in a work train with our own kitchen car and cook. The job started in the high mountains of Colorado and then moved to the Utah Desert. Eventually I came to enjoy the laborers, who appeared at first to be a rough lot, but I found that they were big-hearted and kindly.

Q. *What were your interests while growing up in Denver?*

A. Most of my activities centered around school and family. We had no family car, but my Dad and I took long walks, ten miles or so on a Sunday afternoon, usually a mile or so before bedtime. Dad had a deep bass voice, sang in the choir of the small church to which we belonged, and often played duets with me after I started taking piano lessons. At the church there was a small young people's group, usually about 3 girls and 7 boys, that was active for a number of years. One of the girls, two years younger than I, was Marjorie Truby. We were just two of the "gang" in those days, but by my senior year in high school we saw quite a bit of each other. After I went away to school at RPI we corresponded occasionally but with increasing frequency.

Q. *How did you happen to go to Rensselaer Polytechnic Institute?*

A. When I was a senior in high school, I sent away for catalogs to several of the leading engineering schools, including Wisconsin, Illinois, and M.I.T. One day Dad asked me why I didn't write to Troy. My response was, what's Troy? He said it was the oldest engineering school in the country, where he would liked to have gone if he could have afforded it. So I sent for their catalog. With the catalog came a small pamphlet, which I still have, showing examples of the works of their graduates - many of the great bridges of the era, such as the Brooklyn and Williamsburg Bridges over the East River in New York. That pamphlet sold me. Because Dad could get passes for me on the railroads between Denver and Troy made the choice possible. I never regretted it.

Q. *What was your first job and how did you like it?*

A. I graduated from RPI in 1934, almost at the bottom of the Great Depression. Fortunately, RPI granted me a fellowship for three years and I continued to the Doctorate. By 1937 the depression was nearly over, and the American Bridge Company had reinstituted its drafting school where budding structural engineers could learn the all-important practice of detailing structural elements. The school lasted about six weeks and after that I went to work in the drafting room of the bridge company. I worked on parts of such bridges as the Bronx Whitestone and the upper deck of the Henry Hudson Bridge in New York City. This was very good experience, but unfortunately the recession of 1937 came along and the bridge company ran out of work. Our whole group was suddenly unemployed. I wrote to Professor L. E. Grinter, with whom I had once corresponded, about the possibility of a teaching job and received a favorable response, except that he said he had no need for a structural engineer. However, if I would learn something about hydraulic engineering at the University of Iowa or something about soil mechanics at Harvard under Professor Casagrande, he would offer me a job. Not seeing anything more promising, I decided to try my hand at the new subject of soil mechanics. I wrote to Professor Casagrande who responded that the first semester was almost over and that it would probably be unwise for me to start until the next academic year. I decided to take my chances, and Professor Casagrande was kind enough to let me come. As it turned out, the staff at Harvard was constructing a new soil testing machine which required detailing a steel framework to hold all the equipment. I was asked if I could detail the steel work, since it was known that I had come from the American Bridge Company. I was happy to do so, took the drawings home, and came back the next morning with the pieces all detailed. My immediate boss at Harvard, Ralph Fadum, was a bit surprised, because I think everybody thought this was a job that should take two or three weeks. As a result of being able to do it rather quickly, I became an hourly employee. The following summer I ran consolidation tests on the new machine, six tests at a time, in connection with one of Dr. Casagrande's consulting projects. During the fall semester I became an assistant to Bill Shannon, who was running the lab, and did such things as clean up the glassware and lay out the equipment needed for the experiments in the laboratory by the graduate students.

While I was at Harvard, Professor Terzaghi returned to the United States after leaving his post in Vienna following Hitler's Anschluss. We saw very little of him, but we heard that he was writing a textbook. One day Ralph Fadum called me in and said that Dr. Terzaghi was working on a chapter in which he intended to express the characteristics of grain-size distribution by statistical parameters but was unsure that he knew the correct English words for some of the terms. Since I had been sitting in on Professor Gordon Fair's course on statistics, Ralph thought I might be able to discuss the subject with him. I made an appointment with Terzaghi and spent about 45 minutes with him. It was a very simple interview. Terzaghi simply wrote down the formulas for such a thing as the standard deviation and asked what we called it in English. The interview went satisfactorily, and I left feeling quite exhilarated, because I had experienced 45 pleasant minutes with the great Dr. Terzaghi. Somewhat later, since Terzaghi did not yet have employment in the United States, Professor Casagrande and Mr. A. E. Cummings, who was District Manager of the Raymond Concrete Pile Company in Chicago and a friend of Terzaghi, arranged for Terzaghi to come to Chicago and speak to the local section of the American Society of Civil Engineers. He chose for his subject "The Danger of Tunneling Beneath Large Cities Founded on Soft Clays". I think either Casagrande or Cummings had suggested this subject, because they knew the City of Chicago was undertaking a subway project.

Ralp and Marjorie with their children Nancy and Jim, 1947

Evidently Terzaghi scared the audience and soon found himself being sought as a consultant by both the State Street Property Owners Association and the City of Chicago's Department of Subways and Traction. He laid down certain requirements, including sampling in test borings by means of Shelby tubes, which Professor Casagrande had initiated in Boston, and setting up a laboratory under the direction of a man of Terzaghi's own choosing. He then returned to Harvard. Rumor has it that Professor Casagrande was quite annoyed because he thought Terzaghi's terms were too high and that he had lost the opportunity to get himself established. Terzaghi went back to writing his book, and nothing happened for about a week. Then he suddenly got a telegram from the City saying, "Your terms are accepted, please send your man". Actually Terzaghi didn't know any people to recommend; he had probably never thought about the matter. So he consulted Professor Casagrande and others and, fortunately for me, I got the job. I always felt that the reason I did was because I was the only one of the students in Professor Casagrande's course who was not working for a degree and who was perfectly free to leave at a moment's notice. In any event, within the week, Marjorie and I found ourselves sitting in the office of the Chief Engineer, Mr. Ralph Burke, of the Chicago Subway. This job was undoubtedly the turning point in my career.

Construction had already started on one of the station sections when I arrived in Chicago. At first I was busy setting up the laboratory, organizing the staff, and overseeing soil tests to describe the materials that would be encountered in other parts of the system. In the meantime, large settlements of the buildings and of the streets over the advancing tunnels were occurring. The contractors insisted that these settlements were purely coincidental and had nothing to do with the way they carried out the subway construction. Terzaghi, who visited the project very frequently, suggested that we try to measure movements of the ground around the tunnels by driving stakes into the ground on opposite sides of the tunnel as soon as the excavation passed a certain point and by measuring the convergence between the stakes. We did this, measured many other components of movement within the subway, compared the results to the settlements on the street surface, and were able to establish that the volume of the settlements of the street was roughly equal to that of the movements measured inside the tunnel. As a result, the contractors could no longer claim that their activities were not the cause of the movements, and they began to change details of the methods of excavation and support. This resulted in a considerable improvement in the behavior of the nearby structures and streets. Later, we began to measure the loads in the bracing systems of the open cuts and tunnels, and constructed test sections to determine the validity of methods of analyzing tunnel supports. All these activities took place with the support and guidance of Terzaghi, who visited the job frequently.

Part of my duties were to write Terzaghi every afternoon, detailing what the soil laboratory group was measuring, what the results were, and how the job was progressing. Whenever we conducted a set of measurements to determine the movements inside and outside the tunnel, a special report was prepared. Terzaghi examined each report, made almost daily comments by mail, and kept close track of the job with numerous visits. Near the end of the project, he summarized the data and prepared extensive memoranda in connection with the tunnels constructed by the liner plate method, by the shield method, and by open cutting.

Q. *How was it to work with K. Terzaghi?*

A. Working with Terzaghi was stimulating, demanding, and exhausting. He, himself, worked almost day and night and he expected those working with him to do the same. He simply took it as a matter of course that everyone was as interested in his own job as Terzaghi was. At the same time he was kindly and understanding, and always gave the feeling that whatever was being done was a new adventure. In those days, of course, soil mechanics was new, and almost any observation of behavior in the field provided previously unknown information. Almost anything was a new discovery, and Terzaghi made one feel excited about the advances in knowledge. He did not mind if we made a mistake, but he did not like to see the same mistake repeated. Although at this time he was preparing the manuscript of "Theoretical Soil Mechanics", he did not approach jobs from a theoretical point of view. In connection with the Chicago Subway, for example, he waited until the end of the job to prepare the memoranda that analyzed all the field observations, and only then did he write his theoretical papers.

Ralph with Karl Terzaghi at Lake Maracaibo, 1956

Terzaghi was intensely practical and enjoyed talking to the workmen on a job as much as or more than talking with the designers or executives. He was very willing, perhaps even eager, to change his mind when new information appeared. He was writing the manuscript for "Theoretical Soil Mechanics" during the time construction of the Chicago Subway, and he had asked Al Cummings to review various portions of the book as he prepared them. Since I was close to Al in those days, I became involved in the review process as well. One of the sections of the book dealt with the earth pressures against vertical circular shafts. Terzaghi had completed this section for shafts in sand on the basis of information available in the literature. He thought it would be useful to add a section on shafts in clay and developed a theory that was similar to that for sand. It was rather complicated, and both Al and I suggested that it might be out of place in the book. However, he decided to include it. On the subway job, we had to construct a circular shaft through the soft clays to a considerable depth and found it possible to measure the load in each of the circular rings that held the bracing in place. These results could be translated into equivalent pressures against the shaft. The results did not agree even remotely with those predicted by the theory Terzaghi had just developed. As soon as he saw thee results, he scrapped the theory entirely and wrote a small footnote for his book saying that a satisfactory theory was not yet available. He was as happy to discard an unsound theory that he had developed as he was to find a successful theory.

Near the end of the Chicago Subway Project, we began to prepare the manuscript for the book that became "Soil Mechanics in Engineering Practice". Completion of the book required seven years, and many times I think both of us wondered if we would ever succeed. Occasionally we became exasperated with each other; sometimes his criticisms were harsh, but they were always on a professional, not a personal, basis.

On the half dozen projects in which we cooperated after the Chicago Subway the arrangements were always similar. It was my job to organize the exploration, to set up and supervise the field observations, and to describe what was happening in connection with the construction or behavior of the facility. Terzaghi analyzed the results on a continuing basis, made recommendations to the client, and made further suggestions for observations that should be carried out. He compared the results with the predictions of theories, but as far as I am aware, never approached a problem on a purely theoretical basis. He attempted to let field observations determine what Nature had to say.

Ralph and Marjorie with their parents, Lester and Ethel Trudy,
Ethel and Orwin K. Peck, 1960

Q. *You have had more than one thousand consulting projects, big and small, during your professional career. What type of projects do you prefer to be engaged in?*

A. My first consulting projects occurred about 60 years ago. At that time, soil mechanics was quite new. There had been few applications, and most engineers were skeptical about its usefulness. Many of the early projects were simply to make recommendations for the design of foundations for buildings, retaining structures, and stabilization. I was interested in all of them, because every one provided new information, either about the behavior of different kinds of soils and structures, or about the applicability of soil mechanics. As time went by and soil mechanics became more widely used, the projects of interest became more complex. Eventually the projects that interested me most had to do with the construction problems of tunneling and the design and construction of earth dams. Most intriguing projects required discovering, perhaps over quite a period of time, the significant characteristics of the subsurface materials and the behavior of the structures during and after construction. Over the years it became increasingly apparent to me that the difference between success and failure resided not in the quality or quantity of theoretical studies, but in the success with which the fundamental properties of the geological materials had been evaluated originally or could be determined as a result of field observations during and even after construction.

Q. *What do you consider to be your most significant contribution to soil mechanics and foundation engineering?*

A. It has been my good fortune to have been able to pass on to a large number of students an approach to foundation engineering and subsurface problems; in effect, to allow Nature to speak for herself. With respect to construction and design problems, to me nothing is better practice than predicting and verifying how the subsurface materials will behave, and adjusting the design and construction procedures on the basis of the observations as a project proceeds.

Q. *Would you choose another profession or other studies today?*

A. I think I would still choose to be a civil engineer, because I like the idea of constructing facilities that are useful. In that broad framework, I doubt if I could make a more positive statement. When I was planning to be a bridge engineer, it would not have occurred to me to be interested in geotechnics because the subject hardly existed. The important thing is to be well prepared in a general area and willing to take advantage of and participate in new and perhaps unanticipated developments.

Q. *What advice would you give to an engineer starting a career today?*

A. To get a good academic background in whatever field of study is chosen, to try to select early jobs for their experience and potential, and to be prepared to take the risk of entering a newly developing aspect of one's chosen profession. I feel that good opportunities come along in everybody's life. Those who take advantage of one or more of these opportunities, even if in unconventional areas, are likely to be successful. Those who want to practice only what they have learned in school are almost sure to stagnate.

Q. *Considering your career as an educator, how did your position at the University of Illinois come about?*

A. While working on the Chicago Subway, I was invited to lecture occasionally at Illinois and later to visit the University every second week. The invitation came about, through two University of Illinois members of the original subway soil mechanics group, Sidney Berman and Chester Siess. When the Chicago Subway project closed down as a result of World War II and I was considering other employment, Professor Huntington, Head of the Civil Engineering Department, offered me a position. I asked Terzaghi what he thought about the proposition. His response, to my surprise, was negative. He said that I did not know enough to be a teacher; I should get more practical experience. I took his advice and accepted a position on a team to design and construct an ordnance plant in Ohio. The plant was not too far from a new steel facility that the

Republic Steel Corporation was building in Cleveland for the United States government as part of the war effort, and I could take time from the ordnance plant job to participate in the design and construction of its ore storage dock. This was a cooperative venture in which I could be his eyes and ears on the job during frequent visits and could organize and monitor the field observations required to ensure the stability of the facility. When the ordnance plant was finished, Terzaghi indicated that we might continue to cooperate in similar fashion on other jobs as time went by and that under these circumstances he would "permit" me to go to Illinois. When I transmitted this news to Professor Huntington, he was pleased at my interest but no longer had the money for the position that he had offered, but he could offer a part-time appointment. I was happy to accept. Professor Huntington was able, however, to persuade the Dean of the Graduate College who had some funds, to engage Terzaghi as a lecturer and research consultant, and to establish two half-time assistantships in the Graduate College to be called Terzaghi Assistantships. One reason that Dr. Terzaghi "permitted" me to go to Illinois was his former knowledge of the University. When Terzaghi was teaching at M.I.T., around 1928, Dean M. L. Enger of the College of Engineering had been Chairman of the ASCE Committee on Foundations and had invited Terzaghi to give a series of lectures at Illinois. Enger was still Dean at the time I went to Illinois and was enthusiastic about soil mechanics, whereas many other deans had not even heard of the subject. Terzaghi had been impressed by the nature of civil engineering research at the University of Illinois Engineering Experiment Station, where many of the structural projects dealt with measurements on very large-scale models or even full-sized structures. The emphasis was on behavior, not on theory. Theory was used as a means to predict behavior, was modified to agree with the results of experiments that indicated behavior, and was not regarded as an end in itself. Consequently, Terzaghi felt that this was an appropriate academic climate for growth in soil mechanics.

Q. *Was it "publish or perish" in those days?*

A. Certainly not to the extent that developed later. I think it is fair to say that the quality of publications, rather than the quantity, was then the factor that most impacted academic and professional advancement.

Q. *What is your preferred teaching style?*

A. Probably because I still regard geotechnics as a hands-on profession, I have always liked to teach by example and by the use of case histories. At first, when there were almost no textbooks in soil mechanics, my courses were built about lectures that involved case histories, but after "Soil Mechanics in Engineering Practice" was published I was somewhat at a loss for a semester or two, because the textbook seemed to pre-empt the development on a case history basis. It has always been my observation that students learn more from each other than they do from their professors, so I liked to give assignments that encouraged discussion of controversial points by the students. At the beginning of courses in foundation engineering, I customarily used a series of lantern slides, perhaps over a period of several weeks, illustrating the characteristics of real soil deposits under real geological conditions, and I tried to develop an understanding by the students of what one could or could not learn simply by making borings and soil tests. I strongly emphasized the variability of some types of soil deposits and how that might affect the impressions one got from a boring or testing program. I felt that this was absolutely fundamental to satisfactory practice of foundation engineering and other aspects of geotechnics. Only after the students developed a feel for this natural variability did I think they should be introduced to conceptual models, because by that time they would understand how different the models might be and usually were from the simple concepts on which they were based.

Q. *Was it difficult to combine teaching and consulting work considering all the travel involved in consulting work in your field.*

A. It was difficult, and it undoubtedly caused inconvenience to the students. Most of my courses were for graduate students who were better able to cope with changes in schedule. I think these students generally enjoyed the case history approach and were willing to put up with the inconvenience. They liked to find out what really happened. We were required by the University to report our consulting activities and to give an accounting of the relevance of the work to teaching or research.

Q. *Is engineering education going in the right direction today?*

A. The progress in engineering and in engineering education is not uniform; it tends to go in cycles. In my early days of teaching, soil mechanics was new and teachers in that field were in demand and generally in favor. Today the great advances are in computational skills and modeling of behavior of engineering structures. These advances are real and essential to the development of the profession. As with most advances, however, there is a downside. Many teachers, and consequently their students, come to think of the models as reality. This is dangerous and the danger is not always appreciated by the teaching profession. I think this is a passing phase and that emphasis will again move toward reality. In geotechnics the use of instrumentation and the observational method help considerably in keeping the subject close to reality.

Q. *As a family man, tell us something about your family and family activities.*

A. Marjorie and I were married the afternoon of the day on which I had received my doctorate at RPI. We had a very short honeymoon in the cottage of my favorite professor of structures, at one of the lakes in the area of Troy, New York, and then headed for the American Bridge Company near Pittsburgh. We got along quite well on the 75c per hour at the American Bridge Company, but we had to borrow from Marjorie's parents to go to Harvard to learn about soil mechanics. Fortunately, we could pay the money back almost immediately, because when I began to work for Professor Casagrande the rate was an attractive $1.00 per hour. When we moved to Chicago my salary was $300 per month, and we felt really rich. Our daughter, Nancy, was born while I was working on the subway. Our son, Jim, came along later, after we were located at the University of Illinois. My consulting activities left much of the task of bringing up the children to Marjorie, but Champaign-Urbana was a good community in which to raise a family, and we led an active social life. After living briefly in a house rented from one of the professors in the Department, we built our first house to a design that essentially reflected the character of a civil engineer. It was two-story, rectangular, very efficient, and quite unimaginative. Later Marjorie found a lot adjoining a country club; we engaged an architect with quite modern ideas and built a rather unusual structure. We also built a small summer place on a lake created by a dam about 30 miles from Urbana. It turned out to be a little too far from town to suit the activities of Nancy and Jim, but we did spend many summer weekends there and found it ideal for ice skating in the winter. Many of our summer vacations were spent in Denver where both sets of our parents lived.

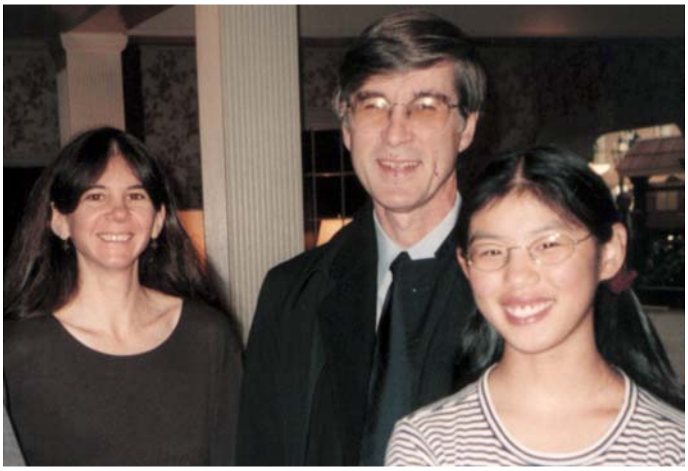
Ralph's daughter Nancy with husband Allen with some of their art work, 1999

Marjorie liked interior decorating and helped quite a number of the faculty wives with their houses. We belonged to a pot-luck and bridge dinner group that met about twice a month. Most of the members belonged to the Civil Engineering Department or to the Department of Theoretical and Applied Mechanics. I wasn't much of a bridge player and usually had the lowest score for an evening, but the wives tried to outdo each other with respect to the dinners and they were quite festive affairs. Many of our activities centered around the Congregational Church in Champaign, where the minister was known affectionately as the Chaplain of the Civil Engineering Department because of the large number of Department members who belonged to the church.

Nancy spent one year at the University of Illinois and then transferred to the University of Arizona where she studied geology. There she met her future husband, Allen Young. Allen had been an enlisted man in the Navy before he came to the University, so he graduated somewhat later than Nancy. In the meantime, Nancy worked for the Arizona Bureau of Mines. Allen returned to the Navy as an intelligence officer for 10 years, and he and Nancy moved around the country frequently. Unable to work during such short intervals, Nancy began to change her focus to art. While stationed for several years in Hawaii, they both developed their creative skills.

Ralph with Nancy's son Michael and his wife Michelle, 1999

After a number of moves, they settled in Albuquerque the year after Marjorie and I retired there. They have continued with their art, and Nancy is represented in a number of galleries, mostly in the West. Their son, Michael, a graduate of the California Culinary Institute, lives with his wife Michelle in San Francisco, California.



Ralph's son Jim with his wife Laurie and their daughter Maia, 1999

Jim attended De Pauw University in Indiana, where he became interested in Chinese studies. He continued these studies at Harvard during the years of the Vietnam War and made the acquaintance of many students from Mainland China. He became Asian Editor for Pantheon Press, and most recently is the Executive Director of a project known as "The Culture and Civilization of China", engaged in producing a series of books on various aspects of Chinese culture, authored by experts from China and elsewhere. His wife, Laurie, is a poet who writes under her maiden name, Laurie Scheck, and who teaches creative writing at Princeton University. They adopted Maia, in Beijing, when she was a very small baby. She now is a very accomplished teen-ager.

Marjorie died in 1996, after we had been married for 58 years. Fortunately, Nancy and Allen built a new house and studio in the same block as my home, where they can keep an eye on me.

Marjorie and Ralph on their 50th wedding anniversary

Recognition Where Recognition Is Due

Ralph B. Peck

For his development of the science and art of subsurface engineering, combining the contributions of the sciences of geology and soil mechanics with the practical art of foundation design.

Gerald R. Ford
President of the United States of America
September 18, 1975

The National Medal of Science

Awards

Ralph has received many distinguished awards during his career. The most important of these are listed below. To provide an insight into the appreciation that has been bestowed him by his professional peers and by society in general, a selection of the Citations that accompanied these awards are cited in their entirety.

The ASCE Norman Medal

1988 The Award of Merit, Consulting Engineers Council,

1988 The John Fritz Medal of ASCE, ASME, AIMME, AIChE, and IEEE,

1988 Rickey Medal of ASCE,

1986 Presidents' Award (ASCE),

1984 Distinguished Service Award of the Deep Foundations Institute,

1983 Golden Beaver Award,

1978 University of Illinois Alumni Award,

1976 Washington Award of the Western Society of Engineers,

1975 Selected as One of the Top U.S. Construction Men of the past 50 years (ASCE),

1974 National Medal of Science, awarded by President Gerald R. Ford,

1973 Outstanding Civilian Service Medal of the U.S. Army,

1973 The Moles Non-member Award,

1972 The National Society of Professional Engineers Award

1969 Karl Terzaghi Award (ASCE),

1965 Wellington Prize (ASCE),

1944 Norman Medal (ASCE),

Citations

The Karl Terzaghi Award (1969)

In recognition of his outstanding contributions to the literature, to teaching, and to the practice of soil mechanics and foundation engineering. In these activities he has been unusually successful in the application of the principles of soil mechanics and field observations of geological details to the definition of problems and their solutions. His early work on the design and construction of the Chicago Subway marked the beginning of a distinguished career. Significant papers described problems encountered in the construction of the subway, and in 1944 he received the Norman Medal from the ASCE for his paper on earth pressure measurements in open cuts. The textbook "Soil Mechanics in Engineering Practice" with Dr. Karl Terzaghi, exemplifies the highest level of application of soil mechanics principles to practical problems of foundation engineering.

The National Society of Professional Engineers Award (1972)

For his leadership in engineering as exemplified by his significant technical contributions; his standards of professional conduct in all his endeavors; his dedicated service to his professional and technical societies; his outstanding excellence as an engineering educator; and his untiring efforts to improve the society in which we live.

Department of the Army. The outstanding Civilian Service Medal (1973)

For noteworthy assistance to the Office, Chief of Engineers, as a consultant from July 1954 to December 1972. As an engineer, consultant, professor, author and authority in soil mechanics and foundation engineering, he contributed continuously and outstandingly to the advancement of knowledge and proficiency in the application of the principles of soil mechanics by the Corps. These efforts, and his sense of public responsibility enabled the Corps of Engineers to design and construct earthworks and pavements with a high degree of safety, economy, and reliability, and to accomplish its Civil Works mission in a more efficient manner.

Elected to the grade of Honorary Member, ASCE (1975)

For his outstanding career as an educator, researcher, problem-solver, and communicator; for his ability to perceive the problem and apply theoretical concepts to its practical solution; and for his innovative and inspirational instructional methods.

The Washington Award, Awarded by the Western Society of Engineers (1976)

For notable contribution to the Public Welfare thru Engineering and Science conferred in 1976 for eminent international leadership and pioneering contributions to soil mechanics and foundation engineering practice, education and research, and distinguished service to mankind.

University of Illinois Alumni Award (1978)

To Ralph Brazelton Peck, a distinguished foundation engineer, for his dedication and contributions to society as a teacher, author, and engineer.

Distinguished Service Award, Deep Foundation Institute (1984)

In recognition of his exceptional judgment in geotechnical problems and lifelong sharing of professional knowledge.

The John Fritz Medal (1988)

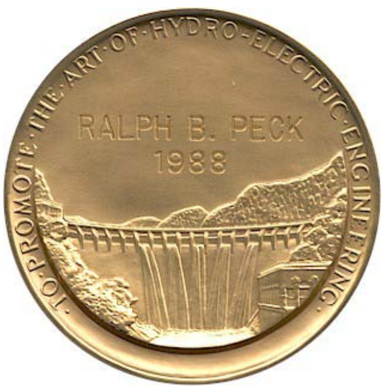
For pioneering contributions and outstanding leadership in the theory and practice of geotechnical engineering. His work has made possible deep and tall structures in soft soils around the world.

American Consulting Engineers Council, The 1988 Award of Merit

In Recognition of outstanding service as an engineering visionary innovator and educator whose research and creative designs have produced international legacy of benefit to all mankind. His dedication and notable achievements have brought increased recognition and distinction to the engineering profession.

Rensselaer Alumni Hall of Fame (1999)

An acclaimed international expert in the field of soil mechanics, he has helped to change the face of the Earth through his discoveries of the way soils work. Through his work on the Chicago subway in the early 1940s he emerged as one of the undisputed leaders in the development and practice of soil mechanics and foundation engineering. As a distinguished professor at the School of Engineering at the University of Illinois, he conducted field and laboratory research on stabilization of railroad beds and embankments, the mechanics of earth dams, the stability of retaining walls, and the settlement of foundations. He has served as a consultant for major foundation projects throughout the world, from the Trans-Alaska Pipeline, to rapid transit systems in Chicago, San Francisco, and Washington, to dams in Turkey and Greece, to the Dead Sea dykes in Israel.



The Rickey Medal of ASCE

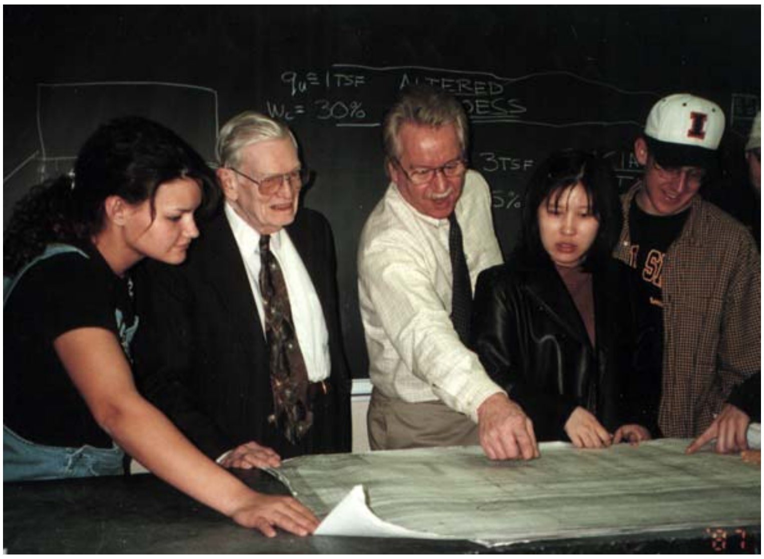
The Art of Subsurface Engineering

"The most fruitful research grows out of practical problems"

Ralph B. Peck

More than five thousands students have listened to Ralph's lectures during his more than three decades as a professor at the University of Illinois. The professor had a genuine interest in his students, always giving them first priority in a busy schedule. His teaching style was unique. Everyone who attended his courses experienced that it was never a one-way exchange of information. Almost without knowing how it happened, everybody got involved in discussing the theories and the problems that were the topic of the day. Ralph, the eminent professor, believed in the old saying: "You learn as long as you have students".

The most fortunate of his students went on to graduate school where a small group studied for their PhD, a task that can best be described as a joint effort between professor and student. His students enjoyed working with him in the combined effort to develop new knowledge in the field of soil mechanics. The appropriate lectures were presented in a wider perspective, which sometimes lead the students to play around with the titles of the required courses: Theoretical Soil Mechanics became known as the Philosophy of Soil Mechanics, and Foundation Engineering became The Art of Subsurface Engineering.



Ralph with P.A. Lenzini and students at University of Illinois

Professor Peck has been the advisor or co-advisor of 39 students who completed their Doctor of Philosophy in Engineering degree at the University of Illinois at Urbana-Champaign. Listed for each student are the date of his or her degree and the title of the thesis study.

Doctoral Students of Ralph B. Peck

Year	Name	Title of thesis
1945	Chang, Arthur C-C.	Engineering Properties of Chicago Subsoil
1945	Uyanik, Mehmet E.	Observed and Computed Settlements of Structures in Chicago
1946	Moretto, Oreste	An Investigation of the Effect of Certain Factors on the Strength and Compressibility of Clays
1949	Teng, Wayne C-Y.	Determination of Contact Pressure Against a Large Raft Foundation
1949	Zeevaert, Leonardo	An Investigation of the Engineering Characteristics of the Volcanic Lacustrine Clay Deposit beneath Mexico City
1951	Lee, Tien-Un	Earth Pressure Against Spill-Through Abutments
1951	Mostafa, M. Khalil	Actual Track Capacity of a Railroad Division (coadvisor; W. W. Hay)
1951	Wu, Tien-Hsing	An Analytical Study of Earth Pressure Measurements on Open Cuts, Chicago Subway
1952	Sabry, A. A. A.	Analysis of Field Observations on the Test Tunnel at Garrison Dam
1953	Ghanem, Mohamed P.	Bearing Capacity of Friction Piles in Deep Soft Clays
1955	Deere, Don U.	Engineering Properties of the Pleistocene and Recent Sediments of the San Juan Bay Area, Puerto Rico
1956	Ireland, Herbert O.	Settlement Due to Building Construction in Chicago
1956	Hay, William W.	The Effects of Weather upon Railroad Operation, Maintenance and Construction
1956	Nordlund, Reymond L.	The Bearing Capacity Failure of a Grain Elevator (coadvisor: D. U. Deere)
1959	Fry, Thomas S.	An Engineering Evaluation of Surficial Soils of Northeastern Illinois (coadvisor: T. H. Thomburn)
1960	Davisson, Melvin T.	Behavior of Flexible Vertical Piles Subjected to Moment, Shear, and Axial Load
1960	Misiaszek, Edward T.	Engineering Properties of Champaign-Urbana Subsoils
1960	Olson, Roy E.	Consolidation Characteristics of Calcium Illite
1960	Triandafilidis, George E.	Dynamic Bearing Capacity of Foundations
1961	Esrig, Melvin I.	The Load-Deflection Behavior of a Heavily Loaded Area in Cleveland, Ohio
1961	Kane, Harrison	Earth Pressures on Braced Excavations in Soft Clay, Oslo Subway (coadvisor H. O. Ireland)

Year	Name	Title of thesis
1961	Lacroix, Yves H.	Design and Construction of a Deep Cutoff (de facto advisor: K. Terzaghi)
1961	Wagner, John E.	Construction and Performance of the Grouted Cutoff, Rocky Reach Hydroelectric Power Project
1962	Gangopadhyay, Chitta R.	The Mode of Consolidation Initiated by Pile Driving in a Varved Clay
1962	Prakash, Shamsher	Behavior of Pile Groups Subjected to Lateral Loads (coadvisor M. T. Davisson)
1962	Raamot, Tonis	The Foundation Behavior of Ore Yards
1963	Chryssafopoulos, H. W.	Identification of Young Tills and Study of Some of Their Engineering Properties in the Greater Chicago Area
1963	Lamb, John H., Jr.	A Gelatin Model for Lateral Earth Pressures
1966	DiBiagio, Elmo L.	Stresses and Displacements around a Rectangular Excavation in an Elastic Medium
1966	Flaate, Kaare S.	Stresses and Movements in Connection with Braced Cuts in Sand and Clay
1967	Bazaraa, Abdel R. S. S.	Use of the Standard Penetration Test for Estimating Settlements of Shallow Foundations on Sand
1967	Salley, James R.	Tolerable Settlements of Power Plants and Turbine-Generator Bases
1968	Schindler, Larry	Design and Evaluation of a Device for Determining the One-Dimensional Compression Characteristics of Soils Subjected to Impulse-type Loads (co-advisor: H. D. Ireland)
1969	Chang, Yuan-Chun E.	Long-Term Consolidation Beneath the Test Fills at Väsby, Sweden
1969	Hagerty, Donald J.	Some Heave Phenomena Associated with Pile Driving
1969	Schmidt, Birger	Settlements and Ground Movements Associated with Tunnelling in Soil
1971	Palladino, Donald J.	Slope Failures in an Over-Consolidated Clay, Seattle, Washington
1973	Campbell, Joe D.	Pore Pressures and Volume Changes in Unsaturated Soils (coadvisor: R. E. O1son)
1976	Parker, Harvey W.	Field-Oriented Investigation of Conventional and Experimental Shotcrete for Tunnels

The Just One-Page Summary

If you can't reduce a difficult engineering problem
to just one 8 ½ x 11-inch sheet of paper,
you will probably never understand it

Ralph B. Peck

Throughout his academic and professional career Ralph has been a prolific writer and speaker. Through his writings, lectures and personal contacts he has demonstrated his communication skills. Anyone who has met Ralph in person or read his publications or listened to his lectures can not avoid taking note of his unique communication talents, not to mention his outstanding command of the English language.

He is indeed a true master in the art of communication. His ability to organize and transmit his thoughts in a clear, concise and logical manner to any audience, orally or in writing, is indeed one of his trademarks. Anyone who has seen him prepare an engineering report or a large block of text for a book or publication simply by speaking it into a dictating machine can not avoid being impressed and envious of his ability to do that.

Ralph has used his communication talents in moderation. His communications style is clear-cut, concise and to the point without a lot of extraneous information to fill up space or to clutter the minds of the readers or listening audience. The need for simplicity in communication is a philosophy that he passed on to and demanded of his students. For example, in one of the courses he taught at the University of Illinois, CE 484, he demonstrated problem solving by means of case histories that he had been involved in.

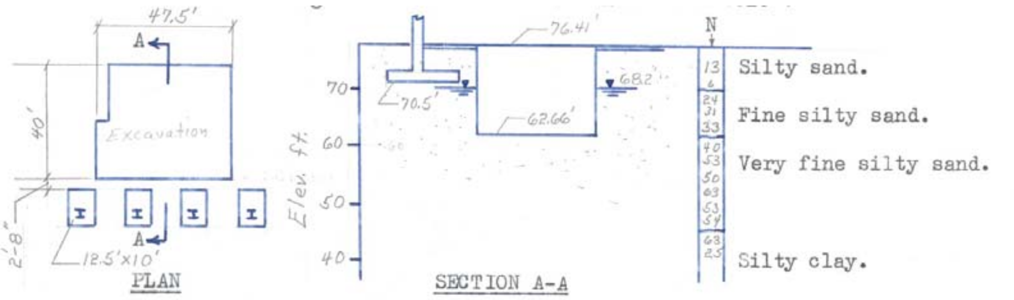
After the facts and details of a case history had been presented by Ralph, his students were required to analyze the project, identify the problems and discuss the approach taken to arrive at an acceptable solution to the problems and then prepare a summary. The only catch was that he insisted that the summary could not be more than one page long! He justified this requirement by saying that no project is so complex or so large that it can not be summarized on one sheet of 8-1/2 x 11-inch paper.

Not everyone could master the one-page summary at first. One student submitted a 20-page report on his first try, then his "absolute minimum" of 12 pages on the second try. His third attempt resulted in 4 pages to which Ralph commented: one page! For many of us, preparing those one-page summaries was the hardest part of that course, but in retrospect it was one of the best things he taught us – to be concise.

No.7. U.S. Navy Missle Launching Pad. Elmo DiBiagio

Description of Project. This project deals with an excavation made in 1958 for the specific purpose of installing a training missile launch pad inside the Gunners Mate Building at the Great Lakes Naval Training Station in Chicago.

Significant Problem. The exterior walls of the 231 by 241 ft Gunners Mate Building consist primarily of glass panels; the flat roof of the structure is supported entirely by roof trusses and columns located along the exterior building walls. These columns are supported by spread footings on sand at a depth of approximately five feet. The proposed excavation was to be made in the southeast corner of the building adjacent to two existing gun mounts and within 2 ft-8 in. of the line of spread footings that support the walls and roof columns. ≈ plan and cross section of the excavation as well as the general soil conditions are shown below.
The specific problem was to devise a means of carrying out the excavation without



damaging the building or disturbing the gun mounts. The major concern was to prevent settlements of the column footings and thereby avoid cracking of the exterior glass panels. Engineers at the Training Station estimated that footing settlements greater than 1/4 in. could not be tolerated.

Approach to the Problem. The Navy engineers had proposed a system consisting of steel sheeting embedded 16 ft below final excavation depth, timber braces in both directions at two levels and a well point installation between the footings and the sheeting. The cost of the project according to this scheme was $86,000.

Our Board of Consultants proposed two schemes for carrying out the excavation. The first of these utilized a well point dewatering system and a bracing system consisting of H-pile soldier beams, wooden lagging and three levels of struts. Soldier beams were selected instead of continuous sheeting because they would be easier to drive or jet and drive through the compact sand.

The second approach was based on the assumption that the well points could be eliminated and steel sheeting could be used to avoid loss of ground and subsequent settlement of the footings. This method required at least four feet of embedment of the sheeting below final grade in order to prevent a hydraulic heave of the bottom; dewatering was to be achieved by pumping from a sump in the center of the excavation. The major objection to this method was the uncertainty regarding the effects on the building of the shock and vibrations associated with driving the sheeting through the compact sand.

Solution. The procedure adopted for carrying out the excavation was as follows.

1. Vertical 8 in. soldier beams were driven on 5 ft centers around the periphery of the excavation. Jetting vas required.
2. The soil beneath the four adjacent footings was stabilized to a depth of 18 ft by chemical injections around the periphery of each footing (Cost $12,000).
3. One line of well points was installed along the outer edge of the footings. This location vas chosen because it would result in a more uniform draw- down and consequently more uniform settlements beneath the footings.
4. Top strut was positioned before excavation and installation of lagging began.

Evaluation. The excavation vas successfully made without breaking any of the glass panels in the building; however it was noted that at the completion of construction the footings were 7/8 in. higher than they were prior to the start of construction. The battle was w on but they lost the war because of poor field control.

Copy of one of those One-Page Summaries

No Job Without Its Lesson

"No theory can be considered satisfactory until it has been adequately checked by actual observations"

Ralph B. Peck

The products of our engineering profession are the results of numerous activities like teaching, research, planning, design and construction. Specialization is a necessity; however, this sometimes causes the various pieces to live their separate lives. A satisfactory result depends on the interrelation between all activities and the transfer of knowledge across the artificial borders. Ralph was aware of this problem at an early stage of his career and typically the textbook from 1948 by Terzaghi and Peck had the title: Soil Mechanics in Engineering Practice.

During his life-long career he has been actively engaged in bridging the gap between academia and the engineering practice. An important part of this effort constitutes of his consulting activity on a variety of projects within US as well as internationally. As a professor this was a two-way operation where he applied the latest research findings to the practical problems, and brought the field observations and field experience back to the university. The actual projects became part of the coursework and the students experienced the great benefit of this.

Three wise men, No, Yes and Maybe

1045 Consulting Projects

Starting in 1941, Ralph numbered his consulting jobs consecutively. The first one, Job 0, is dated July 1941. His report for that job has the title, "Engineering Report on Condition of Building at 1600 – 1616 Mechanic St., Chicago". Since then the job count has reached an impressive 1045, as of March 2000, see Figure 1. It is interesting to note that Job 0 had nothing to do with foundation engineering. It was, instead, a structural analysis of a warehouse in Chicago to evaluate the safety of the building under the loading conditions.

Ralph's Job Files comprise a large part of the Peck Library. To keep track of this vast amount of information, NGI has registered the pertinent information in a database. This database makes it easy to compile interesting statistics about his consulting projects. Figure 1, for example, shows the cumulative number of projects plotted as a function of time.

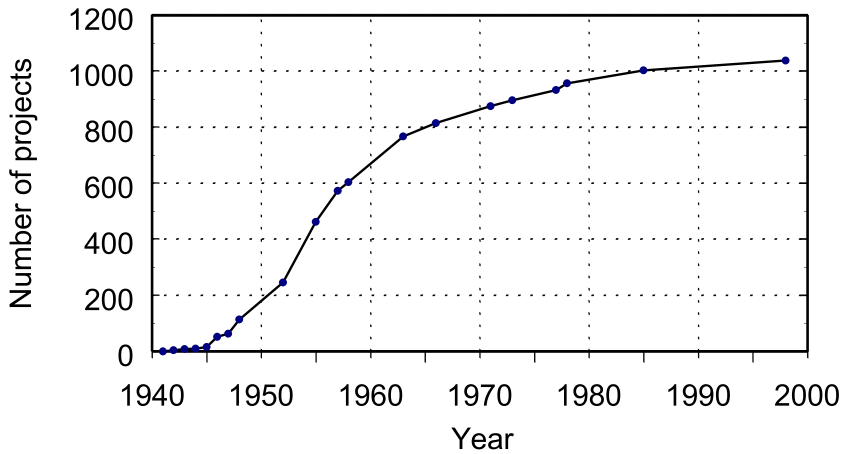


Figure 1. Ralph's consulting projects versus time

Of the 1045 projects, 137 of these were in foreign countries. Table I lists the 32 countries where he has worked and how many projects were carried out in each of them. Projects within the United States and its territories are summarized in Table II.

Table I. Projects in foreign countries

No. of Projects in each country	Country
76	Canada
9	Venezuela
4	Costa Rica, Mexico
3	Colombia, Dominican Republic, Greece, Israel
2	Brazil, British Guiana, , Ghana, Hong Kong, Liberia, Philippines, Turkey, Zambia
1	Argentina, Australia, Egypt, El Salvador, Equador, Haiti, India, Italy, Japan, Nigeria, Norway, Okinawa, Pakistan, Panama, Portugal, Sumatra

Table II. Projects in the United States.

No. of Projects in each state	State
301	Illinois
61	Ohio
42	New York
41	Indiana
31	Missouri
29	California, Michigan
28	Iowa
24	Wisconsin
21	New Jersey
17	District of Columbia
16	Washington
15	Kentucky
14	Kansas, Louisiana, Texas
10	North Dakota
9	Hawaii, Mississippi, Pennsylvania, Virginia
8	Minnesota
7	Maryland, Oklahoma
6	New Mexico, South Dakota, Utah, West Virginia
5	Alaska, Florida, Massachusetts
4	Nebraska, Wyoming
3	Arizona, Georgia, Idaho, Oregon
2	Nevada, North Carolina, South Carolina
1	Connecticut, Delaware, Maine

Ralph has grouped his consulting projects into different categories depending on their type and technical content. More than 20 categories were required to classify all of them. A bar chart showing the number of projects in the 20 principal categories is shown in Figure 2.

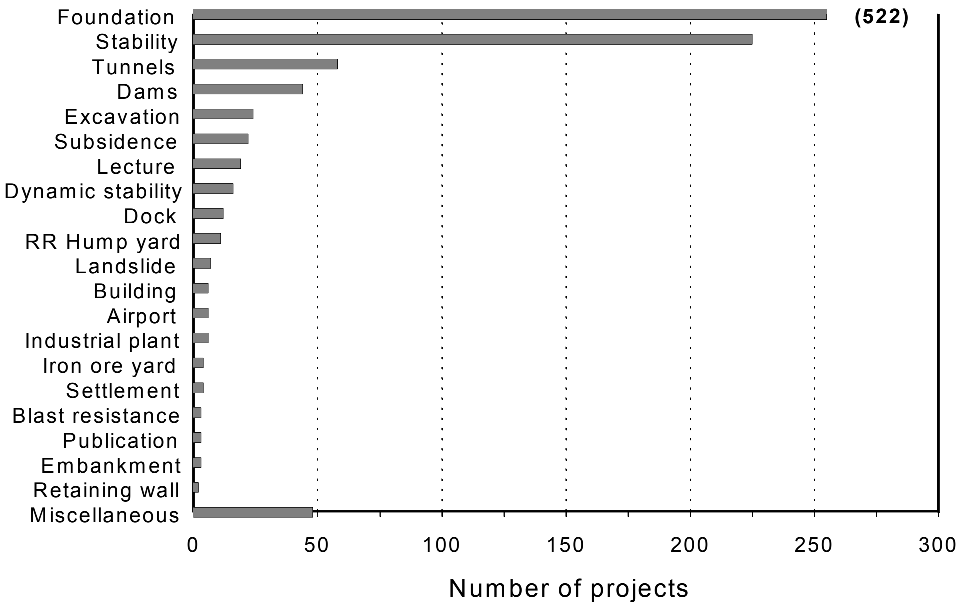


Figure 2. Number of projects in each category

If It's Important, Say Why

Ralph B. Peck's knowledge and communication skills have made him a much sought after key-note lecturer at national and international meetings and conferences. Many of his key lectures have come to be recognized as milestone contributions to the advancement of geotechnical engineering.

An abridged list of his key lectures follows. Two of these that indicate clearly his ability to organize information and communicate it to his audience are printed in their entirety. These two are marked with an asterisk (*) in the list.

Some Key lectures

Advantages and Limitations of the Observational Method in Applied Soil Mechanics. Ninth Rankine Lecture, *Geotechnique,* June 1969, 19, pp. 171-187.

Presidential Address, The Direction of Our Profession. *Proc. 8th Int. Conf SoiI Mech.,* Moscow (1973),4.1, pp. 156-159.

Soil Mechanics in Engineering Practice: The Story of a Manuscript, 1942- 1948. *Terzaghi Memorial Lectures,* Bogazici Univ., Istanbul (1973), pp. 50- 77.

The Selection of Soil Parameters for the Design of Foundations. 2nd Nabor Carrillo Lecture. Mexican Soc. for Soil Mech. (1975), 64 pp.

*On Being Your Own Engineer. *Civil Eng. Alumni Assoc. Newsletter,* Univ. of Ill., Urbana, Illinois, Fall 1976, pp. 4-5.

*The Last Sixty Years. Proc. 11th Int. Conf. Soil Mech., San Francisco (1985). Golden Jubilee Volume, pp. 123-133.

Pains of A New Profession in Soil Mechanics 1925-1940, *ASFE Annual Meeting, Boston, Mass., (1988).*

Six Decades of Subway Geo-Engineering: The Interplay of Theory and Practice, Geo. Engineering for Underground Facilities. *ASCE-GeoInstitute Geot. Spec. Publ. 90, (1999), 99 1-15.*

On being your own engineer[1]

Here at this University and in this Department that has trained so many outstanding civil engineers, you have achieved a standard of excellence that results in your recognition at this Honors Day ceremony. It gives me the greatest pleasure to congratulate you on these achievements. Here in your undergraduate career, you have become leaders in the pursuit of engineering knowledge, the first essential step in becoming a civil engineer. Excellence in undergraduate studies correlates highly with a successful engineering career in later years. I sincerely hope that the satisfaction of a successful career continues to be yours and that these honors and recognitions that you so rightfully receive today will be only the first of many satisfactions that will come to you in your practice of civil engineering.

Yet a successful undergraduate career is not always or inevitably followed by leadership in your profession. In a changing world, in a dynamic profession such as civil engineering, how can you be sure today that you will be among the leaders of your profession 20 or 30 years from now? How can you even be sure to pick the branch of civil engineering, the particular kind of work that you will actually like the best or have the most aptitude for? Do you dare leave these matters to chance, do you dare let nature simply take its course? Nobody can predict the future and nobody can guarantee success in the future. But there are, nevertheless, many positive things you can do to shape your own career. I should like to think about some of these with you today.

I believe every engineer, perhaps even while an undergraduate but certainly upon graduation, needs to form and follow his own plan for the development of his professional career. Perhaps it is an unpleasant thought, but 1 believe it is only realistic that nobody else is quite as interested in your career as you yourself should be. If you don't plan it yourself, it is quite possible that nobody will. On the other hand, there are too many factors, there are too many changes in a dynamic profession to permit laying out a fixed plan. The plan that you follow must be flexible and it must continually be evaluated.

To be sure, every career depends to some extent on chance, on the breaks, good or bad. But if you have followed a sound plan, you will be ready for the good breaks when they come. Those who feel they have never had favorable opportunities usually have not been ready and have not even recognized opportunities when they came.

Civil engineering projects don't exist in the classroom or in the office or in the laboratory. They exist out in the field, in society. They are the highways, the transit systems, the landslides to be corrected, the waste disposal plants to be constructed, the bridges, the airports; they have to be built by men and machines. In my view, nobody can be a good designer, a good researcher, a leader in the civil engineering profession unless he understands the methods and the problems of the builders. This understanding ought to be firsthand, and if you are going to get it, you have to plan for it. Without this experience in the field, your designs may be impractical, your research may be irrelevant, or your teaching may not prepare your students properly for their profession. There are several ways in which you can get construction experience. One is by being an engineer for a builder, for a contractor. Or on the other hand, you might be an inspector for a resident engineer for the designer or owner. It doesn't matter in what capacity you work, and it doesn't take a very long time to get worthwhile experience in the field, but sometime early in your career, you should plan to get it. Since the real projects are out there in the field, you will have to go where they are to get the construction experience, and you may have to put up with a little inconvenience in order to get it.

Real problems of civil engineering design include both concept and detail. In fact, details often make or break a project. A beautifully designed cantilever bridge in Vancouver Harbor collapsed during construction because a few stiffeners were omitted on the webs of some temporary supporting beams. Spectacular failures such as this don't always follow from neglected details, but poor design, poor engineering often do. I believe every civil engineer needs a personal knowledge of the details of his branch of civil engineering. If he's going to be a geotechnical engineer, for example, he needs to know among other things exactly how borings are made and samples taken under a variety of circumstances. If he's going to be a structural engineer, he needs to know how steel structures are actually fabricated and erected. He needs to know, in other words, the state of the commercial art that plays such a large part in his profession. He needs to know how things are customarily done so that he can tell whether, for example, a commercially available sampling tool will do the job at a modest competitive price or whether

[1] Publication No.161. Civil Eng. Alumni Assoc. Newsletter. Univ. Of Ill., Urbana, Illinois. Fall 1976, pp.4-5.

some unusual tool must be developed for the particular requirements of the job. So it seems to me that you should plan to get this sort of experience also: to spend some time on a drilling rig if you plan to be a geotechnical engineer; to work for a steel fabricator or in a design office if you intend to be a structural engineer.

How can you get this varied experience, these various components of civil engineering that are so dissimilar? I think, for the most part, you have to do it by choosing your jobs carefully and changing your job if and when it seems necessary. You may be lucky in your very first job and go to work for an organization that designs, that supervises construction, that makes its own laboratory tests, that supervises borings, and so on. If this should be true, you would be fortunate, but this is not usually the case. Even such an organization may tend to let you get stuck in one phase of their work, and you may have to persuade them from time to time to let you work in other parts of their activities. More likely you will have to change organizations, possibly even to move to another part of the country or of the world. Unfortunately you can't order the jobs that you want, when you want them, and where you want them. But you can look at every opportunity to see if it fits in your plan and to judge if the time is right to make a change. The breadth of experience so important in a civil engineer's background can't be obtained any other way than by a variety of jobs or a variety of activities within a given job. You owe it to yourself and to your career to see that you get this varied background. On the other hand, while you're getting this background, you ought to avoid being a job-hopper. Each of your employers will have an investment in you. At least for a while, when you start to work for him, he will not be getting his money's worth from you. You owe him a return on his investment, you owe him good work, and you owe staying with him a reasonable minimum time while you're getting that experience.

On my first real job, I had the good fortune to be working under Karl Terzaghi. He had a good many requirements, but one of the most important was that I should keep a notebook in which I should record not just what I had done that day, but what I had seen, what I had observed. When I went down into a tunnel heading, I should come back and sketch how the heading was being executed and how it was being braced. I soon discovered that very often, when I came back, I couldn't remember exactly what had gone on in the heading. I couldn't remember exactly how the bracing fit together. In other words, my eyes had seen what was going on, but my brain didn't really register. My powers of observation were poor. But as I continued to keep this notebook, I discovered that more and more I could remember what I had seen, and more and more my powers of observation developed. I recommend this to you as one way to make your experience more meaningful.

An investment of ten years or so after your degree, including perhaps graduate studies as well, in accordance with a carefully planned but flexible program, will go a long way toward assuring success in your engineering career. But there is another important aspect to be considered. Any worthwhile career is demanding. It makes demands on your time and effort, and also on your family. And there are other demands on your life besides your career. Your wife or your husband will have her or his own goals and even may also have a career in mind. The demands of others in your life and the fulfillment of their goals and careers will require cooperation, adjustment, give and take. Moves from one place to another will require leaving friends, will require that your children change schools. Tensions and conflicts are inevitable and compromise and reason are necessary. You and your partner will need the best possible understanding. Many a marriage has foundered on the career ambitions of one or both partners and, conversely, many a career has foundered on unreasonable or nonunderstanding social or financial demands of the partner. There is seldom a perfect solution to this problem, but there are many good solutions. The important thing is to face up to the problems early and to keep working on them. The best engineers, I think, have achieved a reasonable balance among their goals in life. Often they can truly say that their partner in life has also been their partner in their career.

Your generation has a most exciting prospect. Don 't believe for a minute the prophecies that technology has outlived its usefulness. You will have, fortunately, much more to consider than technology. You will need to be true conservationists, true ecologists in the positive sense. You will need to be involved in the social cost-benefit assessments of civil engineering work above and beyond the dollar cost-benefits. Progress in these directions will be the challenge and the great achievement of your generation, and it is an exciting prospect. But to succeed, you must be fully prepared, not poorer, but better grounded technically than your predecessors. In the next ten years, the choices you make and the experiences you get will be crucial. As Honor Students, you have taken the first necessary step with skill and distinction. All of us, your teachers, your parents, your husbands, wives, and friends wish you even greater success in the future. Indeed you *must* succeed, or this world will be a poorer place rather than a richer place in which to live.

The last sixty years[2]

THE FIRST MODERN DECADE

Erdbaumechanik was the book and Karl Terzaghi the personality that catapulted soil mechanics as a discipline into the consciousness of civil engineers. As Professors Kerisel and Skempton have so ably described, engineers in many countries had begun the development. Soil mechanics would have appeared inevitably without Terzaghi, but had it not been for the dynamic leadership of this unique world citizen, devoted with remarkable singleness of purpose to the development of his field, who can say what blind alleys and diversions might have marked our progress? Terzaghi possessed a strong sense of personal destiny. He had no doubt, as he reflected on his life in later years, that he would have made his mark whatever the times and circumstances, but he accepted that he had appeared at the right time and with the right background to make his contribution in what has become our profession. Not all fields have been so fortunate.

Much of what we consider modern soil mechanics was already known in the years 1926-1929. In late 1925, Terzaghi, with the encouragement of F.E. Schmitt, editor of Engineering News- Record, prepared a series of articles[*], "The Principles of Soil Mechanics", based largely on his research at Robert College. Although the articles were perhaps too scholarly and abstract for many practicing engineers, they brought the subject to the attention of a large audience. However, in two speeches, subsequently published, Terzaghi addressed the problems of the practitioner more directly. These speeches, "Modern Conceptions Concerning Foundation Engineering", delivered before the Boston Society of Civil Engineers in November 1925, and "The Science of Foundations", presented to the American Society of Civil Engineers in January 1927, elicited wide oral and written discussion. It is interesting to review his assessment of the accomplishments and problems of the subject at that time.

He stressed soil classification, particularly in terms of physical properties that differentiate sands from clays, and at the same time attempted to identify unifying principles that could account for the properties of both materials. The strength of sands he recognized as purely frictional. He understood the influence of excess pore pressure on shear strength and recognized the need for performing drained shear tests to determine what we now call the effective shear strength. He regarded the shearing resistance of clays, which at the time he simply termed "cohesion", as the product of capillary pressure and the tangent of the effective friction angle. Although conveniently measured as half the unconfined compressive strength, the "cohesion" of clays was thus no different in principle from the friction of sands. The large pore water tensions required to account for the high "cohesion" of some clays had, in Terzaghi's words, "never been suspected up to this time", and were not easily accepted by engineers who held the misconception that the tensile strength of water was limited to one atmosphere. The mechanism of shrinkage in clays, elegantly explained by capillarity, helped convince the doubters.

Terzaghi at this time emphasized three soil properties that he felt, when evaluated, would permit the solution of all practical problems of importance: the "cohesion" (and for sands the frictional resistance) as defined above; the "elastic" (actually the stress-deformation) properties; and the permeability. The phenomenon of consolidation was one manifestation of the "elastic" properties.

The News-Record articles highlighted Terzaghi's scientific investigations into the significant engineering properties of soils; they gave little insight into possible practical applications. The series closed, however, with a brief statement of three requirements for practical use of the knowledge - a statement that may be regarded as an early indication that Terzaghi's primary concern was with

[2] Proc. 11th Int. Conf. Soil Mech., San Francisco (1985). Golden Jubilee Volume, pp 123-133.

[*]To keep the text suitable for oral presentation at the Conference, references in the usual form have been omitted. However, in an effort to show in some detail the widespread participation of workers from many countries in the development of soil mechanics, an extensive series of notes, indicated by numbers in parentheses, is appended.

engineering. He expressed the belief that the new understanding of soil properties could not be beneficial without sound background in theory (what he then termed a theory of models), without a system of soil classification that would permit reliable correlation of case histories, and without the ability to visualize simplified but reliable analogs for representing the complex conditions and problems presented by Nature.

The limited practical applications that Terzaghi chose to present to the engineering profession at this time suggest that he sensed the potential of his work but that he had not yet systematically explored it. One such application, the settlement of foundations on clay, had attracted his attention in Istanbul and was of great interest to engineers in his new locale, Boston. In the first major public presentation of his work to engineers in that city he described not only the delay of settlement associated with consolidation, but also the influence on settlement of the width of the loaded area. He used the approximate proportionality of settlement to width at constant soil pressure to explain several striking examples of unexpectedly large settlements on deep clay deposits. At the same time he noted that the relation for other soils could be far different, and indicated that investigations at MIT would be directed heavily toward this subject. It seems evident that at this time (late 1925) procedures for forecasting total and differential settlements and the rate of their development were not yet ready for practical use.

Terzaghi recognized that a source of much frustration to engineers and owners alike was the misbehavior of foundations on piles and the related unreliability of the commonly used Engineering-News pile formula. Perhaps no contributions to foundation engineering elicited such vigorous responses from foundation engineers as his declarations and demonstrations that (1) no pile formula could possibly lead to correct results if the static and dynamic resistances to penetration were not the same; (2) these resistances could not possibly be the same in saturated plastic clays; (3) the Engineering-News formula was theoretically unsound; and (4) the settlement of a pile foundation would always be larger at a given load per pile than that of a single pile in a load test.

Of equal interest to Terzaghi were his explanation and quantification of the phenomena of underseepage and quicksand. This subject was of less concern, however, to most of his listeners than the behavior of building foundations and brought forth less discussion.

Having laid the foundations for the new engineering science by 1926 through a systematic series of theoretical and laboratory investigations, Terzaghi's work during the next decade took two directions. At MIT (1925-1929) and Vienna (1929-1938) he directed intense research in the laboratory, particularly toward the investigation of shearing resistance, including the monumental contributions of Casagrande and Albert, Jurgenson, Rendulic, and Hvorslev. In addition, he accepted a series of consulting assignments which gave him the opportunity not only to test the new science in practice, but to develop the techniques for its application. In 1928, for example, he undertook to investigate the settlement of a pulp and paper mill above a deep deposit of highly compressible clay overlain by granular materials. To compute the settlements of the various structures he found it necessary not only to perform consolidation tests, but also to determine the distribution of stresses in the subsoil. He did this by integrating Boussinesq's equation for pressures over rectangular areas. He then compared the computed settlements with those measured over a seven-year period and adjusted his forecast accordingly. In 1930 he developed his filter criteria in connection with the design of a rockfill dam in Algeria. Thus, because nearly every new assignment represented an opportunity for developing new approaches to old problems, he amassed the experience that permeated his discussions at the International Conference in 1936.

In this first decade of modern soil mechanics, when Terzaghi's research was coming to the attention of the profession and when many of his disciples as well as other independent workers were enthusiastically advancing the new engineering science, Terzaghi already realized the danger that the science would be mistaken for the art. Had it not been for his admonitions through the years, the direction of development of soil mechanics might easily have gone awry. His feelings, even as early as 1927, were expressed in his landmark paper, "The Science of Foundations".

> "Foundation problems, throughout, are of such character that a strictly theoretical mathematical treatment will always be Impossible. The only way to handle them efficiently consists of finding out, first, what has happened on preceding jobs of a similar character; next, the kind of soil on which the operations were performed; and, finally, why the

> operations have led to certain results. By systematically accumulating such knowledge, the empirical data being well defined by the results of adequate soil investigations, foundation engineering could be developed into a semi-empirical science . . . ."
>
> . . . "The bulk of the work - the systematic accumulation of empirical data - remains to be done."

THE FIRST INTERNATIONAL CONFERENCE

Although Terzaghi's influence was the single most pervasive element in the development of soil mechanics during the decade 1926-1936, remarkable activity was going on, often independently, throughout the world. Twenty-one countries were represented at the International Conference at Harvard in 1936, and the scope of the subjects considered and of the work described is impressive even today. Our Society owes an enormous debt to Arthur Casagrande for his conviction that the time was right for such a conference - a conviction not shared by Terzaghi before the event - and for Casagrande's efforts to organize it. A brief recapitulation of the topics reported in the Proceedings of the Conference indicates the breadth and modernity of the subject only a decade after Erdbaumechanik:

* Shear strength and effective stress (l); torsion tests (2).
* Undisturbed sampling (3), including impregnation of sands (4).
* In-situ testing, especially the Dutch cone (5).
* Centrifuge testing (6) and model relations.
* Significance of precompression in estimates of settlement (7).
* Widespread use and development of theory of consolidation (8).
* Recognition of and design based on secondary consolidation (9).
* Development of elastic stress distributions useful for solution of practical problems (10).
* Regional subsidence (11).
* Preloading for improving bearing capacity and reducing settlement (12); pore-pressure measurements for control (13); sand drains (14).
* Soil improvement: injection of emulsion (15), electro-osmosis (16).
* Settlement due to groundwater lowering (17).
* Design against damaging effects of swelling clays (18).
* Arching theory of earth pressures (19).
* Frost action (20).
* Soil dynamics; earthquakes (21), liquefaction in earthquakes (22), machine vibrations (23), wave equation for pile driving (24).
* Observational method (25).
* Instruction in soil mechanics; course content.

The list could easily be expanded. Even so, this catalog suggests not only the breadth of interest and accomplishment, but also the early recognition of subjects still of active interest to research workers and practitioners.

Not the least of the accomplishments of the Harvard Conference was the establishment of our Society. There were, regrettably, to be twelve years of world turmoil before the next conference, but at Rotterdam the Society resumed its role in the growth and development of soil mechanics.

THE FIRST QUARTER-CENTURY OF ISSMFE

From Harvard to Rotterdam (1936-1948)

During the years between the first and second International Conferences, soil mechanics rapidly took its place as an integral part of civil engineering. In almost every part of the world, the beneficiaries of training in the new subject found their skills in great demand on a number of challenging projects. Field observations on successful works and studies of failures on less successful ones were quickly reported in the literature and became common knowledge. Those who were fortunate enough to participate in this remarkable period experienced the excitement of discovery and partook in the growth of their profession to a degree unusual in the annals of engineering.

In May 1939 Terzaghi delivered the 45th James Forrest Lecture at the Institution of Civil Engineers. He entitled it, "Soil Mechanics - A New Chapter in Engineering Science". In contrast to his 1927 lecture on "The Science of Foundations", the James Forrest Lecture was pointed directly to the practitioner. In the few months before he delivered it, Terzaghi bad investigated the settlement of the Charity Hospital in New Orleans, for which he had carried out what today would be called a conventional settlement analysis; he was deeply involved in the Chicago Subway project; and he had investigated the failure of the earth dam at Chingford Reservoir in England, the assignment that led to the invitation for the lecture. He had just published his general wedge theory of earth pressure, based on the results of measurements of strut loads on the Berlin Subway. No longer was there any doubt of the broad utility of applied soil mechanics. Soon, he forecast, failures of underpinning operations or earth dams, excessive settlements of foundations, or subsidences due to groundwater lowering could no longer be classified as "acts of God".

To an audience today it may seem unwarranted to devote so much attention to the activities and thought of one man. There were indeed many other contributors to progress in soil mechanics in theory, in the laboratory, and in practice. Yet, few people during Terzaghi's lifetime would have disagreed that he was not only the guiding spirit in soil mechanics, but that he was the clearing house for research and application throughout the world. Within the next few years he would be engaged on projects on every continent save Australia and Antarctica. He would carry on an extensive correspondence with workers in all parts of the world, and through this correspondence he would disseminate information and influence the direction of research. Hence, even today, one can hardly improve on his contemporary assessments of the state of soil mechanics as expressed in his summary papers and presidential addresses.

By 1948 perhaps a dozen more or less comprehensive books, some representing significant contributions to the new subject, had appeared (26). Yet, they either presented aspects of particular interest to their authors or consisted of digests of the great outpouring of technical literature with little evaluation of its relevance. Many engineers and educators questioned whether soil mechanics qualified as a legitimate discipline. Hence, in the years between the First and Second Conferences, Terzaghi devoted much effort to organizing the subject formally. "Theoretical Soil Mechanics" appeared in 1943, and "Soil Mechanics in Engineering Practice" in 1948. The first of these books required a careful selection of only the most useful and pertinent theories from the multitude of theoretical studies that might be applied, rightly or wrongly, to earth materials. The second required a critical appraisal of every aspect of soil mechanics to judge whether or how it was actually of use in practice. These two books together with the thoughtful volume "Fundamentals of Soil mechanics" by Donald W. Taylor, which also appeared in 1948, helped bring the subject to a position of respectability in academic circles and usefulness among engineers everywhere.

From Rotterdam to Paris (1948-1961)

The Second International Conference at Rotterdam in 1948 resulted in seven volumes of Proceedings. The policy of the Organizing Committee was to present the full breadth of the subject, with little attempt at selection or editing. It was apparent that, with the increased interest in soil mechanics, such a policy would soon become unworkable. Hence, at Zurich, London, and Paris, only papers passing the scrutiny of the National Committees were accepted.

The year 1948 saw not only the Second International Conference, but the birth of Géotechnique, the International Journal of Soil Mechanics, an act of remarkable faith on the part of its founders R. Glossop and H.Q. Golder.

Whereas only about 200 persons had attended the First Conference at Harvard, nearly 600 were present at Rotterdam in 1948 and mare than 700 at Zurich in 1953. It was becoming apparent that technical discussions at such large gatherings were subject to severe limitations. Soon local conferences began to be organized, some dealing principally with problems in a limited area and others with specific technical subjects. Indeed, the Canadians had anticipated this need and held their first annual conference in 1946. The European Regional Conference on the Stability of Earth Slopes convened in 1954 in Stockholm and became the first of a series of European Regional Conferences held midway between the International Conferences. The First Australia-New Zealand Conference took place in 1952 on the subject of Shear Characteristics of Soils. The first Panamerican Conference was held in Mexico City in 1960. Similar developments occurred in Asia and Africa. These Regional Conferences, now under the aegis of the international Society, have themselves become major undertakings with large attendance. The growth of interest in soil mechanics has indeed been explosive.

Finally, to a considerable extent as a result of the interest of the Swedish National Society and the personal efforts of Arthur Casagrande during his Presidency of the International Society, an abstract service of the literature of our profession has been developed by the National Society of the Federal Republic of Germany.

STRENGTH OF SATURATED CLAYS - A CAPSULE REVIEW (1936-1961)

To trace the technical developments of soil mechanics and its applications during the last 60 years in a single lecture is manifestly impossible. Yet, to omit the story of the struggle for a clearer understanding of soil properties, theory, and application would be to leave out the heart of any history of our profession. I shall compromise by recounting briefly the manner in which our understanding developed between the conferences at Harvard and Paris concerning one single facet of the subject, the shearing resistance of saturated clays.

In his James Forrest Lecture (27), Terzaghi discussed the contributions of soil mechanics to the calculations of the stability of slopes. After considering slopes on cohesionless soils and the influence of pore pressures on the shearing resistance, he went an to say, "The determination of the shearing resistance of typical clays is far more difficult. The relation between the normal pressure and the shearing resistance is much more complicated than could have been anticipated 10 years ago, and even today our knowledge of this subject is still in a somewhat controversial state. The most important recent contribution was made in 1936 by Mr. M.J. Hvorslev".

Hvorslev's studies, carried out under Terzaghi's direction in Vienna, led to the conclusion that the shearing resistance of a saturated remolded clay is a function of the effective normal stress on the plane of failure and of the void ratio in the plane of failure at the moment of failure; this function appeared to be independent of the stress history of the sample. One portion of the shearing resistance, $p'\tan\phi_o$, a function of the effective normal stress, was considered to be the effective internal friction. A second portion, a function of the void ratio, was considered to be the effective cohesion. The value of ϕ_o was smaller than the corresponding angle of internal friction obtained from direct or triaxial tests and Coulomb's criterion. According to Hvorslev, however, it was in almost complete agreement with the angle calculated from the inclination of the failure planes in unconfined compression tests.

These elegant findings have withstood the test of time. Nevertheless, they were at first primarily of scientific interest, largely because the determination of the shearing resistance required a knowledge of the pore pressures in order to obtain the effective pressures, and there were no means of forecasting the pore pressures under field conditions.

Practice, however, had taken a different turn. As early as 1922 Wolmar Fellenius (28) had assumed that clays were purely cohesive materials for which the friction angle was zero and made stability calculations, confirmed by observation, on this basis. In 1941, Golder (29) carried out laboratory model tests to check the validity of the bearing capacity equation

$$q = (2 + \pi)c$$

in which c was taken as half the compressive strength, tantamount to assuming $\phi=0°$. The laboratory tests confirmed the bearing capacity formula. When Terzaghi made his initial analysis, also in 1941, of the results of the strutload measurements on open cuts in soft clays in Chicago (30), he assumed a friction angle of 17° in agreement with the consolidated-undrained values obtained in the laboratory. The analysis led to earth pressures, however, that did not agree with the observations. He then assumed the clay to be frictionless and reached good agreement. In 1942, Skempton (31) published the results of a favorable comparison of the failure load on an actual footing at Kippen in Scotland with that calculated on the basis of a bearing capacity factor for a cohesive material; that is, for $\phi=0°$. At about the same time, Cooling and Golder (32) analyzed the failure of Chingford Reservoir on the same assumption and found that the failure had indeed occurred at a factor of safety of about unity.

Thus, in the early 1940's, use of the so-called $\phi=0°$ concept was widespread and successful. Yet, to many workers it seemed more logical to base stability calculations on the results of consolidated-undrained tests that reflected the overburden stresses under which the materials had been consolidated in the ground. It was also troublesome that the failure surfaces, which should have been inclined at 45° to the direction of the major principal stress if $\phi=0°$, turned out In fact to be inclined at smaller angles indicative of frictional resistance.

This unsatisfactory state of affairs still prevailed at the time the manuscript for "Soil Mechanics in Engineering Practice" was being written. To explain the phenomenon, Terzaghi postulated a "quicksand" structure for clays. Before being subjected to construction loads, the gravity stresses in the clay were presumed to be carried from one silt grain to another, and the space between the silt grains was considered to be filled with a purely cohesive clay. Added loads would cause sufficient disturbance to transfer the stresses to the purely cohesive material.

"Soil Mechanics in Engineering Practice" went to the printers in mid-1947, just a year before the Rotterdam Conference. At Rotterdam, Skempton presented four remarkable papers (33, 34), two with Golder as a co-author (35, 36). In these papers, Skempton demonstrated empirically that the $\phi=0°$ approach was justified provided the clays were fully saturated and there was no water content change under the applied stresses. He also demonstrated theoretically that the angle of inclination of the failure planes should agree with that predicted by Hvorslev. Finally, he demonstrated by means of his lambda theory that the pore pressures in a triaxial test on saturated clay were a function of the ratio of the expansibility to the compressibility of the clay structure. Since a specimen loaded vertically tends not only to compress vertically but to expand laterally, the expansibility must be a significant factor during strain under constant volume. For many practical conditions the pore pressures would be equal to the applied vertical stresses. These milestone papers immediately legitimized and defined the range of validity of the $\phi=0°$ method of analysis, and they eliminated the necessity for the artificial concept postulated in "Soil Mechanics in Engineering Practice". Moreover, in 1950 Bishop and Eldin (37) showed that under appropriate conditions even a sand when completely saturated would exhibit a zero angle of shearing resistance with reference to total stresses. Finally, in 1954, Skempton (38) published his paper, "The Pore-Pressure Coefficients A and B". Here he extended the fundamental idea of relative compressibilities, embodied in his lambda theory, to unsaturated materials and made clear that the most efficient procedure for evaluating the pore-pressure coefficients was not by calculation based on the compressibility and expansibility, but by means of triaxial tests. In a companion paper, Bishop demonstrated use of the coefficients in analyzing the impervious fill of an earth dam during construction and during rapid drawdown. The procedure was further developed in the classical book, 'The Measurement of Soil Properties in the Triaxial Test", by Bishop and Henkel (39) in 1957.

The use of pore-pressure coefficients made effective-stress calculations practical for such engineering works as earth dams. Estimates of pore pressures based on the coefficients provided values to which measured pressures could be compared. This represented a considerable advance, and consequently the use of pore-pressure coefficients became widespread in England and Europe. In contrast, design of dams in the Americas tended to be based on the results of tests intended to duplicate field conditions. An assessment was usually made whether the field conditions would be represented most closely by undrained (Q), consolidated-undrained (R), or drained (S) triaxial teats. Particularly in the U. S. Army Corps of Engineers, to whom Arthur Casagrande was a long-time consultant and whose engineers were in considerable numbers his former students, it appeared mare practical and more expedient to attempt to duplicate field conditions of loading and drainage, and to use the corresponding apparent friction angle in analysis, than to forecast pore pressures and carry out explicit effective-stress calculations. Considerable research was done on both sides of the Atlantic, and the determination of shear strength and its use began to assume a parochial geographical character. This unfortunate state of affairs appeared to be leading to the development of two schools of thought, to the detriment of the advance of knowledge.

In recognition of this situation, the Soil Mechanics and Foundations Division of the American Society of Civil Engineers organized a Research Conference on Shear Strength of Cohesive Soils held at Boulder, Colorado, in June 1960. Papers were invited from organizations in the forefront of research. In contrast to preceding conferences, no limitation was placed on the length of the papers in order that the invitees could fully describe and discuss their work. In addition to contributions from organizations in the United States, four were solicited from other countries. These included Imperial College, the Norwegian Geotechnical Institute, the PFRA of Canada, and the National University of Mexico, and representatives of these organizations were invited to attend the conference. Unquestionably this conference, which provided ample time for formal and informal discussions and which brought to North America such European workers as Bishop and Bjerrum, cleared the air enormously. The papers themselves (40) remain a source of valuable information, but most importantly the conference brought a common denominator into shear strength research in the form of mutual understanding, if not complete agreement.

Terzaghi, unable to attend but having read the papers, assessed the situation in a letter to the participants (41): "In 1936 when the First International Conference on Soil Mechanics and Foundation Engineering convened at Harvard, the salient features of our present knowledge of the shear strength of cohesive soil were established and the differences between laboratory and field behavior of these soils were known in a general way. However, none among us who participated in that Conference suspected how much time and effort would be required to close the remaining gaps **. . .** The attempts to tackle these tasks now extend over almost a quarter of a century and they engaged the effort of scores of competent investigators on both sides of the Atlantic. Yet the papers submitted to the Conference leave no doubt that a considerable amount of research will still be required until we shall be able to say that the gaps in our knowledge are practically closed."

A KALEIDOSCOPE OF ADVANCES (1936-1961)

The foregoing sketch of the development of knowledge in one facet of a single small area of soil mechanics epitomizes that of our entire field. To attempt a similar synopsis of even a limited selection of other areas would exhaust our time and patience. We have not the time to trace the story of both the control and use of vibrations (42) as it developed in Germany, the soviet Union, the United States, and England. We cannot examine the understanding of the sensitivity (43) of certain glacio-marine clays as it developed in Sweden, Norway, England, and Canada. We cannot trace the development of techniques of subsurface exploration including airphoto interpretation (44), geophysics (45), or sampling to fit the requirements of soil conditions in different parts of the world (46), or the recognition of the merits and limitations of such in-situ devices as the Dutch cone penetrometer (47), the vane (48), or the pressuremeter (49). We can do no more than take note of the emergence of such concepts as critical state soil mechanics which have had great impact during the last quarter century (50). Nor can we summarize the vast worldwide assemblage of case histories by which the validity of our procedures has been judged, or the great engineering works that could hardly have been possible without the contributions of our science. Our failure to do justice to the historical development of soil mechanics between the Conferences at Harvard and Paris is largely a consequence of the enormity of the productivity of workers in our field during those 25 years.

In short, we may sum up where our profession stood in 1961:

* There had been vast improvements in our understanding of the properties and behavior of earth materials.
* Not only was soil mechanics widely applied in practice, but field verification of behavior was actively pursued.
* Soil mechanics was included in all civil engineering curricula, and its principles had become common practice.
* Numerous centers of activity in research and practice had sprung up around the world to meet local needs.
* Remarkable engineering works, probably not likely to have been possible without soil mechanics, had been accomplished.

By 1961, a quarter century after the first conference at Harvard, Skempton in his Presidential Address at Paris assessed our progress. Speaking broadly, he identified two great gains. First, he considered it "proved beyond all doubt that the engineering behavior of soils in practice can be analyzed in a rational manner". Second, he noted the wide acceptance of soil mechanics by the civil engineering profession and by the universities. At the same time, he could not help expressing the concern that young engineers fresh from these universities would, in the possession of their new knowledge, be tempted to carry out designs without developing an intimate knowledge of the sites and an appropriate understanding of soils and rocks.

THE LAST QUARTER CENTURY

Progress has continued along the traditional lines of development in the preceding quarter century and will doubtless continue to do so. By no means have all important questions concerning shear strength, compressibility, permeability, sampling, design, and instrumentation been answered. Instead of recounting progress along these traditional lines, it may be of greater interest to observe new trends and changes in the structure of soil mechanics and its applications.

As in many technical fields, perhaps the greatest changes in soil mechanics during the last quarter century have been associated with the development and adoption of the digital computer. Terzaghi had on many occasions said that if a theory was not simple, it was of little use in soil mechanics. There were two reasons for this statement. First, the properties of real soils and soil deposits are so complex that errors associated with their numerical evaluation overshadow errors introduced because of shortcomings of the theories. Second, the mathematical solutions of all but the simplest problems are so complex that numerical solutions can be obtained, if at all, only by an unreasonably great expenditure of time and effort. The computer, to a great extent, has eliminated the validity of the second reason. Laborious calculations, such as those associated with the flow of water through pervious soils under a variety of boundary conditions, with the stability of a slope of irregular shape on non-uniform soils, or with many soil-structure interaction problems, can be executed with great speed and accuracy by an untiring machine.

One-dimensional wave analysis of pile driving, to which the theory of longitudinal impact was adapted as early as 1938, remained little mare than a curiosity for 25 years. As soon as the computations could be made by computer, it became profitable to investigate the pertinent physical properties of piles, hammers, cushion blocks, and soils, whereupon dynamic pile-driving analysis took its place as an everyday working tool of designers and contractors alike.

The power of relaxation methods was demonstrated by the enthusiasm with which structural engineers adopted the moment distribution procedure of Hardy Cross after its publication in 1932. As generalized shortly thereafter by Southwell in the U. K., relaxation methods became recognized as a powerful tool for solving many types of problems that could be formulated by sets of simultaneous equations. By the early 1950's, computer-aided finite difference techniques were beginning to find application, and the techniques are still useful in a variety of problems in soil mechanics. By far the greatest activity, however, has been in the development and use of finite-element procedures. Their applications have been as broad as the field of theoretical and applied soil mechanics itself. The comparative ease with which numerical solutions can be obtained for problems with complex geometries and soil properties, the ability to take into account many types of non-linear properties, and the ease with which the results of field measurements can be inserted into solutions have all contributed to the widespread use of the procedures. Problems in soil dynamics, including those with variable dynamic input such as earthquake excitations, are almost routinely solved. What has aptly been termed a subculture devoted to numerical computation has grown up in our midst.

There is no doubt that finite-element methods have vastly extended the range of problems for which theoretical solutions can be obtained, and that our understanding of and insight into many practical problems has been enhanced. The need to rely on sometimes crude theoretical approximations, often not properly fitting the boundary conditions or other constraints of the problems, no longer exists.

Finite-element solutions, however, require as input numerical values of soil properties. A broader suite of properties is usually needed than was required for the simpler, more restricted theoretical solutions. Such suites of properties, the constitutive relationships, involve stress, strain, and time, and are greatly complicated by nonlinearity, strain softening, viscous behavior, and reversal or repetition of load. The initial in-situ stress conditions must also be postulated.

Earlier in this discussion we traced the struggle for understanding of one small aspect of the shearing resistance of cohesive soils during the 25 years after the Harvard Conference. Even that struggle is not yet ended, because many factors governing the shear strength of clays are not yet known. Yet, the constitutive relations are far more complex and presently much more poorly defined. Consequently, in finite-element solutions, assumptions must often be made in quantifying the constitutive relations, and the solutions are often sensitive to the assumptions. Since it is well known that the stress-strain-time characteristics of soils are influenced more by sampling disturbance than are the ultimate strengths, and since the constitutive relations embrace the stress-strain-time relationships, sampling and testing inevitably introduce uncertainties into the results. Thus, the ability to calculate has outstripped knowledge of the physical properties of the soils that is required to take full advantage of the calculations. To reduce the uncertainties, attention during recent years has increasingly been focused on in-situ testing and various indirect means of evaluating the constitutive relations.

The numerical calculation subculture, in its enthusiasm over its many early successes, has fostered the opinion that the observational or learn-as-you-go procedure is now outdated. Proponents of this view feel that predictions for even the mast complicated problems can be made reliably, and that design can be based confidently on these predictions. This view might be tenable were it not for the uncertainties associated with the constitutive relations and with the applicability of these relations to real geological conditions including the often undiscovered "minor geologic details" at specific sites. However, although much better predictions can often be made than heretofore, the complexity of the problems to which finite-element solutions are applied enhances the likelihood of departure from reality. It is no less essential now than in the past to utilize the predictions for forecasting significant quantities that can be measured in the field during and after construction in order to verify the validity of the assumptions that have been made.

When the finite-element methods have been used in this manner, and when they have been used as a basis for comparing theory and reality, they have vastly improved cur understanding of complex problems. Outstanding examples include studies of the influence of soil stiffness, wall stiffness, and spacing of struts or tie-backs on the deflection of excavation support systems, and forecasts of the development of pore pressures and the position of the phreatic surface in the earth cores of rockfill dams. Studies of the latter type, when combined with pore pressure observations, have provided needed insight into the actual permeability characteristics of the cores.

Uncertainties have always been an inherent part of soil mechanics and its applications: uncertainties with respect to the geology, the initial stress conditions, the numerical values of the soil properties, the loads. Since the treatment of uncertainties falls within the realm of probability, soil mechanics has in recent years also turned attention to probabilistic studies and to risk or reliability analyses.

Again, the availability of the computer has made practical some of the calculations required for such studies. Probabilistic and risk-assessment approaches do not imply fundamental changes in the structure or concepts of soil mechanics, but they constitute increasingly valuable aids toward making decisions regarding design and safety. How they will be incorporated most effectively into practice remains to be seen. Possibly, as in structural engineering, they may be taken into account as load factors and resistance factors.

Since the late 1950's, rock mechanics has undergone a development not unlike that experienced earlier by soil mechanics. At Paris, Skempton noted that there is no sharp boundary between soil mechanics and rock mechanics and proposed that the scope of our Society be enlarged to include both. As a practical matter, however, rock mechanics had already achieved recognition as an engineering science, and a sister International Society soon came into being. Similar activity took place in engineering geology. The three lines of endeavor became known collectively as geotechnics. The disciplines are, in fact, practically inseparable, and most practitioners are knowledgeable to greater or lesser extent in all three.

THE FUTURE

Fortunately it is not my task to look beyond the present. Perhaps I may be permitted, however, to take note of recent undesirable trends that could be discouraged to our advantage.

The observational method, surely one of the most powerful weapons in our arsenal, is becoming discredited by misuse. Tao often it is invoked by name but not by deed. Simply adopting a course of action and observing the consequences is not the observational method as it should be understood in applied soil mechanics. Among the essential but often overlooked elements are to make the most thorough subsurface investigations that are practicable, to establish the course of action on the basis of the most probable set of circumstances and to formulate, in advance, the actions to be taken if less favorable or even the most unfavorable conditions are actually encountered. These elements are often difficult to achieve, but the omission of any one of them reduces the observational method to an excuse for shoddy exploration or design, to dependence on good luck instead of good design. Unhappily, there are far too many instances in which poor design is disguised as the state of the art merely by characterizing it as an application of the observational method.

Sophisticated calculation is too often substituted for painstaking subsurface investigation. The ease or the fascination of carrying out calculations taking into account complex loadings, geometrics, and soil conditions leads many of us to believe that realistic results will somehow emerge even if vital subsurface characteristics are undetected, ignored, or oversimplified. Unwarranted comfort is often taken in the delusion that a range of assumed values, possibly all of which overlook a vital feature, guarantees that the correct result will be bracketed by the calculated ones. Not only does this practice lead to erroneous conclusions in specific instances, but it breeds a distaste for the painstaking field work that may be required to disclose and evaluate those subsurface features that will determine safety and performance.

Instrumentation, vital for obtaining quantitative answers to significant questions, is too often misused, especially in earth and rockfill dams. In some countries regulations concerning the safety of dams demand the incorporation of inclinometers, settlement indicators, and piezometers in the cores of virtually all new dams, but for what purpose? Not for research, because the patterns of deformation and pore-pressure development for ordinary geometrics and materials are now well known and can be predicted by calculation. Only under unusual circumstances can it be said that design assumptions in these regards require verification. Yet, installation of instruments, even under the best of circumstances, introduces inhomogeneities into the cores, and occasionally is the direct cause of such local defects as sinkholes. The potential weakness introduced by an installation should be balanced against the potential benefit from the observations. In contrast to those located in cores, piezometers in foundation materials near the downstream toes detect upward seepage pressures that cannot be predicted reliably, and can thus give timely warning if measures are needed to ensure safety. There is a danger that instrumentation may be discredited because of indiscriminate use.

Our profession may be well into the mature stage, ready to profit from refinements, or it may be on the verge of revolutionary developments comparable in impact to those of the 1920's; none of us can tell. Whichever direction we take, failure to address shortcomings such as these three will reduce cur potential to achieve the state so confidently predicted by Terzaghi that our failures will be of our own making, not acts of God.

NOTES

Notes 1-25 refer to the Proceedings of the Harvard Conference in 1936. The information is presented as Author, Country, Volume, and page.

1. Terzaghi, Austria, I, 54
2. Cooling, England, I, 37; Hvorslev, Austria, II, 125
3. Fehlmann, Switzerland, II, 98; Hanna, Egypt, I, 10
4. van Bruggen, Netherlands, I, 3
5. Barentsen, Netherlands, I, 7; Godskesen, Denmark, I, 311; Fellenius, Sweden, III, 65
6. Pokrovsky and Fedorov, USSR, I, 70
7. Tschebotarioff, Egypt, I, 33; Casagrande, USA, III, 60
8. Samsioe, Sweden, I, 41
9. Buisman, Netherlands, I, 103
10. Steinbrenner, Austria, II, 142; Gray, USA, II, 157; Burmister, USA, III, 71
11. Cuevas, Mexico, I, 294
12. Porter, USA, I, 229
13. Ringeling, Netherlands, I, 106
14. Porter, USA, I, 229
15. Pfeiffer, Netherlands, I, 263; Rodio, Italy, III, 215
16. Endell and Hoffmann, Germany, I, 273 (electrochemical hardening)
17. Brinkhorst, Netherlands, I, 115; Cuevas, Mexico, III, 233
18. Wooltorton, Burma, III, 242; Dawson, USA, I, 80
19. Terzaghi, Austria, I, 211
20. Beskow, Sweden, III, 173; Mackintosh, USA, II, 260
21. Converse, USA, I, 77
22. Casagrande, USA, III, 58
23. Barkan, USSR, II, 283
24. Kanschin and Plutalow, USSR, I, 169; Legget, reference to Granville et al, England, III, 142
25. Graftio, USSR, I, 284

The remaining notes amplify the text:

26. Among these books were:
    "Fundamentals of Dynamics of Soil Masses", N.M. Gersevanov, USSR, 1934
    "Fundamentals of Soil Mechanics", N.A. Tsytovich, USSR, 1934
    "Équilibre des Massifs a Frottement Interne", A. Caquot, France, 1934
    "Pressure Distribution in Foundation Construction", 0.K. Frölich, Austria, 1934
    "The Battle of Engineers against Soil and Water in Earthworks", A. Agatz and E. Schultze, Germany, 1936
    "Earth Pressure, Earth Resistance, and Load-Bearing capacity of Building Sites", H. Krey, Germany. First ed.1912, 5th ed. corrected and supplemented by J. Ehrenberg, 1936
    "Theory of Settlement of Clay Layers", K. Terzaghi and 0.K. Frölich, Austria, 1936
    "Fundamentals of the Mechanics of Frozen Ground", N.A. Tsytovich, and M.I. Sumgin, USSR, 1937
    "Engineering Properties of Soil", C.A. Hogentogler, USA, 1937
    "Soil Mechanics and Foundations", F.L. Plummer and S.M. Dore, USA, 1940
    "Soil Mechanics", D.P. Krynine, USA, 1941
    "Soil Mechanics", A.S.K. Buisman, Netherlands, 1941
    "Theoretical Principles of Soil Mechanics and their Practical Application", N.M. Gersevanov, USSR, 1948
    "The Mechanics of Engineering Soils", P.L. Capper and W.F. Cassie, UK, 1948
    "Substructure Analysis and Design", P. Anderson, USA, 1948

27. "Soil Mechanics - a New Chapter in Engineering Science", Inst. C. E. Jour. Vol. 12, No. 7, pp 106-142 (1939)
28. "Erdstatische Berechnungen", Berlin (1927)
29. "The Ultimate Bearing Pressure of Rectangular Footings", Inst. C. E. Jour. Vol. 17, p. 161 (1941)
30. Peck, R.B. (1943), "Earth-Pressure Measurements in Open Cuts, Chicago (Ill.) Subway", Trans. ASCE, Vol. 108, pp. 1008-1036
31. "An Investigation of the Bearing Capacity of a Soft Clay Soil", Inst. C. E. Jour. Vol. 18, pp. 307-321
32. "The Analysis of the Failure of an Earth Dam during Construction", Inst. C. E. Jour. Vol. 19, p. 38 (1942)
33. "A Study of the immediate Triaxial Test on Cohesive Soils", Proc. 2 Conf. Soil Mech., Rotterdam, Vol. 1, p. 192 (1948)

34. "The ϕ=0 Analysis of Stability and its Theoretical Basis", Proc. 2 Conf. Soil Mech., Rotterdam, Vol. 1, p. 72 (1948)
35. "The Angle of Shearing Resistance in Cohesive Soils for Tests at Constant Water Content", Proc. 2 Conf. Soil Mech., Rotterdam, Vol. 1, p. 185 (1948)
36. "Practical Examples of the ϕ=0 Analysis of Stability of Clays", Proc. 2 Conf. Soil Mech., Rotterdam, Vol. 2, p. 63 (1948)
37. "Undrained Triaxial Tests on Saturated Sands and their Significance in the General Theory of Shear Strength", Geot. Vol. 2, No. 1, p. 13 (1950)
38. Géot. Vol. 4, No. 4, p. 143 (1954)
39. Arnold, London (1957)
40. Proc. Research Conf. on Shear Strength of Cohesive Soils, ASCE, Boulder, June 1960
41. Ibid. p. 1117
42. In Germany the German Research Society for Soil Mechanics (DEGEBO) issued a series of publications starting in 1933 on many aspects of vibrations. Among the investigators were A. Hertwig, G. Fruh, and H. Lorenz. A massive effort in the USSR was marked by the publication of "Dynamics of Bases and Foundations" by D.D. Barkan (Maskstroiizdal, 1949), universally recognized as the classic work in this field

    Two publications are representative of developments in the USA: Crandall, F.J., Ground Vibrations due to Blasting and its Effect upon Structures", J. Boston Soc. C. E. April 1949, and Tschebotarioff, G.P., "Performance Records of Engine Foundations", ASTM Spec. Tech. Publ. 156, 1953. In the UK progress was indicated by Andrews, W.C. and J.H.A. Crockett, "Large Hammers and their Foundations", Struct. Eng. Oct. 1945, p. 453, and Crockett, J.H.A. and R.E.R. Hammond, "The Dynamic Principles of Machine Foundations and Ground", Inst. Mech. Eng. London, 1949

43. Significant publications included:

    Sweden: Odenstad, S. (1951), "The Landslide at Sköttorp", Proc. No. 4, Royal Swedish Geot. Inst.
    Jacobsson, B. (1952), "The Landslide at Surte", Proc. No. 5, Royal Swedish Geot. Inst.
    Kjellman, W. (1954), "Mechanism of Large Swedish Landslides. European Conf. Stability of Earth Slopes, Stockholm, Vol. 1, p. 75

    Norway: L. Bjerrum (1954), "Geotechnical Properties of Norwegian Marine Clays", Géot. 4:2:29
    L. Bjerrum (1955), "Stability of Natural Slopes in Quick Clays", Géot. 5:1:101
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    England: A.W. Skempton and R.D. Northey (1952), "The Sensitivity of Clays", Géot. 3:1:30

    Canada: Eden, W.J. and C.B. Crawford (1957), "Geotechnical Properties of Leda Clay in the Ottawa Area", Proc. 4th Conf. Soil Mech., London, vol. 1, p. 22
    Meyerhof, G.G. (1957), "The Mechanism of Flow Slides in Cohesive Soils", Géot. 7:1:41

44. For details of procedures in this period see:

    Lueder, D.R., "Aerial Photographic Interpretation; Principles and Applications", McGraw-Hill, N.Y., 462 pp. (1959)
    Colwell, R.N. (ed.), "Manual of Photographic Interpretation", Am. Soc. Photogrammetry, Wash. (1960)
    Belcher, D.J., L.E. Gregg, and K.B. Woods, "Distribution, Formation, and Engineering Characteristics of Soils", Purdue Univ. Eng. Bull. Research Series No. 87, Vol. 27 (1943)
45. Golder, H.Q. and L.G. Soderman, "Merits and Mistakes of Geophysics in Civil Engineering", Proc. 2nd Panamerican Conf. Soil Mech., Brazil, Vol. 1, pp. 513-531 (1963), gives brief practical evaluation of common geophysical methods in several countries during the 1950's
46. For example, the Swedish foil sampler (Kjellman, Kallstenius, and Liljedahl: Proc. Royal Swedish Geot. Inst. No. 1, 1950); Bishop's sand sampler (Géot. 1:2:125, 1948); and various piston samplers. The classic reference is Hvorslev, M.J., "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes", Waterways Exp. Sta. Bull. 36 (1948)
47. The history is recounted in Sanglerat, G., "Le Pénétromètre et la Reconnaissance des Sols", Paris, Dunod., pp. 230 (1965)
48. From its introduction (Carlson, 2nd Conf. Soil Mech. I, 265, 1948), the vane rapidly became the preeminent tool for in-situ investigation of the undrained strength of soft clays. Its implications have been the subject of numerous assessments in various parts of the world over more than a score of years, for instance L. Bjerrum, Frimann Clausen, C.J., and J.M. Duncan, "Earth Pressures on Flexible Structures - A State of the Art Report", Proc. 5th European Conf. Soil Mech., Madrid, Vol. 2. pp. 169-196 (1972)
49. This device, introduced about 1930 by Kögler and Scheidig, was developed into a practical instrument by L. Ménard as a student in France in 1956 and the USA in 1957. Since 1961 it has undergone a variety of improvements and has enjoyed wide use
50. The significance of the school of thought at Cambridge University first attracted general attention on publication of K.H. Roscoe, Schofield, A.N., and Wroth, C. P., "On the Yielding of Soils", Géot. 8:1:22 (1958)

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At the writer's request, Prof. M.V. Malyshev kindly submitted a detailed summary of the contributions of Soviet workers with an extensive bibliography. The writer has used the summary extensively in preparing the text and notes.

Influence of Non-technical Factors

"... non-technical problems were even more widespread and more serious than I had realized"

Ralph B. Peck

It is common to believe, in particular among university educated people, that knowledge is the same as competence. However, *competence is the sum of knowledge, skill and attitudes.*

Knowledge is the basis of any profession and knowledge dealing with technology is the trademark of engineering. The development of technology is a continuous process that makes possible new opportunities for improvements in the society in which we live and for the benefit of all mankind. Society expects that the engineer is professional and competent in his work, thus, the engineer must continuously update and renew his knowledge and use it in the best possible way.

But knowledge alone is not enough, it is equally important to posses the *practical skill required* for performing the job, a requirement that is primarily acquired over the years in a job situation. To illustrate this, one only needs to think of a carpenter who knows everything about the theory, but lacks practical training in his work.

Engineering products are important elements in our society, and in order to arrive at the best result for the common goal, we have to take the values that are the basis of our society into account. These values are reflected in *our attitude* towards the society, our clients and our colleagues. Our attitude strongly influences the solutions that we arrive at, for instance with respect to the environment. Ethical values are thus also an important part of our competence.

Dr. Peck has over the years, through lectures and publications, demonstrated the importance of the non-technical factors in engineering. One outstanding example of this is given in his contribution to the book "Embankment Dam Engineering: The Casagrande Volume", Wiley, New York (1973). Although exemplified with experience from dam engineering, it is a general account of the influence of non-technical factors on engineering works. This unique paper is presented below in its entirety.

Influence of nontechnical factors on the quality of embankment dams[3]

1. INTRODUCTION

In this chapter we examine some of the nontechnical causes of shortcomings in earth and rockfill dams. On many projects they are more numerous and more serious than the technical causes.

The shortcomings may infringe only slightly on the nominal factors of safety assigned to the structures. Yet in some instances they may lead to costly maintenance or even large-scale remedial measures. Hence, in spite of the many technical advances of the last several decades, there is still room for improvement in our practice.

Most of the shortcomings, in the writer's opinion, originate in the attitudes and actions of the persons most intimately concerned with the creation and completion of the project: the owner, designer, constructor, and technical consultant. It is our purpose here to describe as objectively as possible and to reflect upon some failings of members of each of these groups. We shall see that each group is indeed responsible for creating or aggravating certain problems that tend to impair the quality of the finished product. The following review of the attitudes and actions of each group may suggest ways in which our practice can be improved; no importance should be attached to the order in which the groups are discussed.

2. THE UNREALISTIC OWNER

The owner of a proposed dam quite justifiably regards the dam as no more than a means to an end. His real interest is in the production of power, the development of a water supply, the enhancement of a recreation area, or some other enterprise to which the dam is only a necessary adjunct. He cannot be expected to be an expert in the field of dams. Nevertheless, his actions may have a far-reaching effect on the quality of the finished dam and, indirectly, on the soundness of his enterprise.

Reasonably enough, the owner wishes to obtain his facility at minimum expense. Even at the very earliest stages, he needs estimates of cost in order to evaluate the feasibility of his enterprise and to arrange the financing. Preliminary estimates must be made at a time when there is a minimum of information. Whether the estimates are made by an engineer or by the owner on the basis of correlations with other projects for which he has information, an unrealistic owner has a predilection forever after to consider the lowest preliminary estimate as the cost of the dam. He is likely to discount the importance of the allowance for contingencies or even to ignore it completely. Consequently, if the cost of the structure seems to increase in succeeding estimates as further information is obtained, the owner is likely to regard all increases above the lowest preliminary estimate as money out of his pocket. If his financial resources are already strained, he is likely to feel that he has been misled by those who made the estimates. Thereafter, throughout design and construction, the cooperation between owner and designer is impeded because an element of distrust has been interjected. The designer may find it extremely difficult to persuade the owner of the necessity for any design feature that may increase the cost beyond the original minimum, very preliminary estimate.

The owner usually has invested months or years in developing the political framework for his project and in arranging the financial structure. When these tasks have finally been accomplished and he has the money and the authority to proceed, he is likely to feel that his interests would be served best if the construction were completed immediately. The time for exploration, design, and construction seems unprofitable and appears merely to delay his use of the facility. If the owner has made inadequate allowance for the time required for appropriate and necessary exploration and design, the finished product inevitably suffers. To some extent the designer can compensate for possible design deficiencies by increased conservatism, but at extra cost to the owner. If the owner fails to appreciate that the increase in cost is justified by the benefits of meeting the scheduled completion date, cooperation between the owner and the designer is likely to deteriorate still further.

[3] Publication No. 137. Embankment Dam Engineering: The Casagrande Volume, Wiley, New York (1973), pp. 201-208.

Many owners regard the cost of exploration as a waste. They see no tangible benefit from the time or money spent in drilling holes and performing other operations in the subsurface materials, particularly if the exploratory work is not located precisely within the bounds of the completed structure. Their legal staffs and purchasing agents fait to understand why the cost of the boring program cannot be established in advance. If their confidence in the designer is less than complete, they are likely to regard the progressive development of the exploratory program as an indication of indecision and incompetence on the part of the designer.

Once a job is under construction, especially if it has gotten off to a slow start, the owner sees his scheduled completion date approaching more and more rapidly and fears that construction will not be finished on time. He may then exert great pressure to expedite the work. Under these circumstances he may seriously hamper the effectiveness of the inspection forces who are attempting to safeguard the quality of the construction. When the inspectors find substandard work, the resident engineer may conclude that he should reject it. He may even consider it advisable to shut down the job until proper procedures are worked out. If, under pressure from the owner, it is decided that the delay cannot be risked, the contractor quickly appreciates the situation and the inspectors and the resident engineer lose effective control of the job. It is not uncommon in large projects for the owner to engage an engineer or a group of engineers to serve as his personal advisors on engineering matters, acting independently of the designers. The success of such an arrangement depends largely on the personalities and the method of operation of the two groups involved. Inherently, there is a question of ultimate responsibility and an opportunity for controversy. If the owner has appointed his advisors primarily because he has come to question the capabilities of his designers for some of the reasons just given, the controversial possibilities of the situation are increased and the design and construction may suffer because the ultimate responsibility is not clear.

Finally, an owner may feel that his designer and his engineering advisors have the obligation to apply to his project whatever knowledge they have derived from similar work, but he may be unwilling to make even the smallest expenditure on his own job to improve the state of knowledge. The quality of his own job may not be impaired because of this attitude, but that of future dams may surfer. To be sure, no owner should unwillingly or unknowingly find himself the sponsor of a research project. Happily, however, many owners see the merit of obtaining, preserving, and disseminating knowledge obtained on their projects. Such owners constitute almost the sole source of the advance in technical knowledge on full-scale structures, and they deserve substantial credit for their long-range views.

3. THE UNCERTAIN DESIGNER

The uncertain designer is likely to be one who has taken the job too cheaply. He may find that he cannot afford either the time or the money for adequate investigations; furthermore, he may have come to no proper understanding with the owner about the extent of the designer's control over the exploratory program or about the cost of the program.

The geological features at a site were placed there by nature and are part of the site. When the owner acquires the property, the geological features become his. On the assumption (unfortunately not always satisfied) that the designer carries out an exploratory program devised to obtain the essential information in the most economical manner, the cost of the program should ordinarily be borne directly by the owner. If the cost is part of the engineer's fee, it is likely that too little exploration will be done, or else that the owner will pay the engineer more than be deserves if subsurface conditions turn out to be simpler than anticipated.

Although the owner and his purchasing agent may dislike open-ended agreements, and although such agreements may be contrary to the owner's policy, many a designer's reputation and pocketbook would be in a better state today if he had insisted on control over the exploratory program, with the cost to be paid or reimbursed by the owner. The consequences of an inadequate exploratory program persist and are compounded throughout the construction period and possibly throughout the life of the facility. If a prospective designer is not sufficiently forceful or persuasive to establish a proper understanding concerning the exploratory work, all parties would be better off if he declined to participate in the project.

The uncertain designer may also be one who is willing to accept an assignment to design without the concomitant authority for supervision of construction. It may appear dogmatic to hold to the belief that no earth or rockfill dam should be supervised during construction by a different organization or group of people from the designers. However, inasmuch as field conditions always differ to some extent from those anticipated before construction, the design phase inevitably extends until the end of the construction period. If the construction supervisory forces are not intimately familiar with the bases for design, unanticipated field conditions may lead to serious blunders. Although it may not always be possible for the designer to insist upon construction supervision, be should consider seriously whether only the design half of the job is worth taking.

The uncertain designer may fortify himself with consultants. Yet be may act upon the advice of his consultants or rely implicitly upon their recommendations without actually having provided them with the opportunity for real study of the project. This matter will be discussed more completely in connection with consultants themselves.

The contract and specifications define the duties and authority of "the engineer" in supervising the construction. If the designer who writes these documents has no clear philosophy of the proper position of the engineer in his relationships with the owner on the one hand and with the constructor on the other, he is likely to produce unclear or contradictory documents, leaving too much or too little to the discretion of the engineer during construction.

4. THE UNFAIR DESIGNER

Unless a contractor has underbid the job or fails to conduct his work intelligently, he has the right to expect a profit. The designer should recognize this fact and should realize that the motivation for profit is uppermost in the thinking of most contractors. To assume otherwise, or to establish conditions that jeopardize the likelihood of a profit, is not only unrealistic but unfair.

With the thought that he is protecting the owner's interest, the designer may be unwilling to allocate risks and costs impartially. By various clauses of the specifications be may try to avoid payment to the contractor for necessary work actually performed.

Most designers would not recognize that their practice falls into this pattern. Yet many of the clauses in their specifications may contain disclaimers and provisions, borrowed from older specifications, which they have not subjected to close scrutiny and which have the effect of throwing more risk onto the contractor than the designer realizes.

The owner and the designer have, of course, the right to transfer substantial risk to the contractor, provided the existence and nature of the risk are clearly understood. It is likely that the bid prices will be higher than necessary under these circumstances, but the advantage of a fixed price may outweigh the possible saving. It is not the clearly stated risk that is the mark of an unfair designer; it is the obscure or hidden risk, of which even the designer may be unaware, that leads to controversy and hence to a reduction in quality of the work. The bidder who recognizes contract documents of this type is likely, if he gets the job, to be on the lookout for the first manifestation of what he regards as unfair treatment and to adopt an uncompromising attitude detrimental to the quality and progress of all the succeeding work.

5. THE OVERLY OPTIMISTIC DESIGNER

Perhaps bowing to pressure from the owner, the overly optimistic designer assumes that "this project" will be a normal one and therefore that the allowance for the contingencies can be reduced. After he studies the results of the exploratory program, he assumes that the subsurface conditions will correspond to the best ones compatible with the findings. If he has misjudged the character of the soil conditions or has committed any other oversights, he assumes that the contractor will be happy to take care of the deficiencies. He assumes, as we shall discuss later, that instrumentation will make up for deficiencies in design. He trusts that the weather will be at least normal during the construction period. He believes that his consultants can solve his problems on the basis of their superior general knowledge without really having to delve deeply into them.

If the subsurface conditions do involve unexpectedly unfavorable features, or if the working season is unusually short and wet, additional time may be needed to complete the job. The pressure to complete the work on schedule may lead to inferior workmanship under relaxed inspection, to the detriment of the final product. It may also lead to controversy with the contractor concerning payment for additional work; if the controversy becomes too acute, the job may be slowed still further. Compromises become inevitable between meeting the completion date and meeting the requirements for quality.

The designer needs to keep in mind that, in addition to the kinds of delay inherent in general construction work, some causes for delay are peculiar to dam construction. These include the uncertainties of flood frequencies and discharges, the difficulty of proving the suitability of borrow pits, the likelihood of encountering unfavorable subsurface conditions in the foundation and abutments, and the probabilities of unfavorable weather during construction. If the designer is too optimistic, the execution of the work is almost certain to be delayed or compromised

6. THE DESIGNER WHO MISUSES HIS CONSULTANTS

Boards of consultants and individual consultants are widely used during the design and construction of major earth and rockfill dams. The organization of the consulting activity may range between two extremes. On the one hand, the designer may keep to himself almost the complete design function and may utilize individual specialist consultants as he thinks desirable to give advice with respect to specific aspects of the project. At the other extreme, the designer or the owner may organize a board of consultants with the authority and responsibility of advising upon and reviewing all aspects of the project and of making joint recommendations on any and all aspects of the work. Depending on the circumstances, both arrangements have inherent difficulties and inherent advantages. Under any type of arrangement, however, the designer may misuse his consultants in such a manner that the project does not benefit fully from their services.

If individual specialist consultants are called in to discuss specific aspects of the project, the designer may choose to insulate the various consultants from each other. They may never meet as a board to discuss mutual interests or, indeed, even to discover whether they have ally areas of mutual concern. Yet, for example, the design of the diversion works cannot be completely divorced from design of the cofferdams. Without an interplay among the specialists in both areas, some matter of mutual concern may go unnoticed or may lead to conflicting design requirements at a later stage. It is preferable that the designer not keep his consultants in individual boxes, uncontaminated by interaction with any other consultants.

On the other hand, when boards of consultants are assembled, it is customary that they be briefed by the design group or by the construction forces on developments since the last meeting. The briefings by their very nature involve a condensation and selection of subject matter. By selecting what he considers to be most important, the designer may, quite unintentionally, impose his personal point of view on the information transmitted from him to the consultants. If he knowingly or unknowingly allows this to occur, he may prejudice the deliberations of the consultants and bias their opinions.

The designer may feel obliged to request from the board of consultants or from the individual consultants positive written recommendations after a brief study or a meeting. He may not, however, authorize or see the necessity for the detailed studies that may be necessary for a proper conclusion on the part of the consultants. Under these circumstances, the consultants have little choice but to be excessively conservative in their conclusions.

Finally, the designer often appears to expect the consultant to be on his side in controversies with the owner or the contractor. If the consultant has participated fully in all steps of the design and is equally responsible with the designer for the decisions under question, such an assumption may be justifiable. In most instances, however, the value of the consultant lies in his objectivity. For example, if a contractor's claim is valid, the consultant does the designer or the owner a far greater service by pointing out the validity of the claim than by attempting to contest it.

7. THE OVERLY BUSY CONSULTANT

Heavy demand for his services in connection with the design of dams, as an individual or as a member of a board, may exert subtle pressure on a consultant to spread his activities too thinly. Before he realizes it, he falls into a routine of attending one board meeting after another, with little preparation other than reading documents en route. As the routine becomes a way of life, the consultant degenerates into a mere transmitter of information from one job to another.

Similarly, the consultant often has inadequate contact with the job. His visits are brief and occasional; his information comes from reports and digests prepared by others. Yet many of the most significant features of the design and construction of an earth or rockfill dam depend upon details that must be seen to be appreciated. Indeed, significant details may be overlooked by people on the job who are less expert than the consultants. The consultant may conceivably be the only one who would notice a particular defect or shortcoming; if he fails to do so, the performance of the completed structure suffers.

The consultant who has inadequate contact with the job can expect to evaluate and make recommendations on only a fraction of the significant items that should command his attention. To the extent of his oversights, the consultant short-changes his client.

Some consultants may be satisfied to answer only the questions directed to them, whereas others may assume too much expertise and responsibility in areas about which their knowledge is actually limited. Either extreme is detrimental to the best interests of the job. The consultant must certainly relate events within his own field of expertise to the requirements of the project as a whole; therefore on some occasions he must range beyond the questions directly asked of him. However, if he unwisely gives advice in a field beyond his expert knowledge, and if his client accepts the advice in the belief that the consultant considers himself qualified, the consequences may be serious.

One of the accomplishments of a board of consultants is the arrival at a consensus even though the experts in the group have individually different backgrounds and experiences. Such a consensus, reached after thorough discussion, may lead to a better course of action than that which would have been recommended by any one of the members. Unfortunately, if the board is made up of overly busy consultants, it is difficult to find times at which the entire membership can assemble. The frequency of meetings may be reduced to the extent that the board's advice can no longer be timely, and critical, phases in design or construction may have to be passed without proper review or guidance. As an alternative, meetings of only part of the board or visits by single members may be substituted for full meetings. Differences of opinion among board members can then no longer be resolved by complete discussion and begin to appear in the reports and correspondence. The board no longer acts as a unit, the responsibility of the members becomes unclear, and the value of the board to the project diminishes.

8. THE DESIGNER INEXPERIENCED IN CONSTRUCTION

The designer of an earth or rockfill dam, if inexperienced in the building of such structures, fails to recognize the inherent difficulties of certain operations and is likely to establish unrealistic requirements in the specifications. For example, many unrealistic and unworkable clauses regarding the grading, lift thickness, and method of compaction of fill materials have been incorporated into contract documents merely because the writer had no personal experience with the difficulties of preventing segregation along the boundaries between filters and adjacent zones. A man who knows at first hand the very real practical problems of placing granular materials without segregation is likely to recommend very different dimensions, gradings, and construction techniques for filter zones than the man whose conceptions were derived exclusively from textbooks and laboratory reports.

The foregoing example is one of a multitude that might be listed and discussed. The benefits of construction experience are legion but they are rarely appreciated by designers, especially those who lack such experience.

9. THE ABUSER OF THE OBSERVATIONAL METHOD

One of the outstanding contributions of Karl Terzaghi to the art of foundation engineering and of the design and construction of dams is the observational method. By appropriate observations in the early stages of construction and during first or partial filling of the reservoir, reliable information can be obtained concerning the real subsurface conditions, as opposed to those that previously could only be deduced or assumed. Because of the added information, shortcomings in the design can be remedied before difficulties develop. It is no longer necessary to base every design on the most unfavorable conditions; a more economical design may be based on what appear to be the most probable conditions. Only if the observational data indicate the necessity for further expenditures need such expenditures be made.

The power of the observational method has been demonstrated in the last several decades. Inherent in the method, however, is the absolute necessity for devising, in advance, a positive means for solving any problem that may be disclosed by the results of the observations. If the observations should demonstrate that the least favorable conditions compatible with the results of the subsurface studies actually do prevail, the corresponding problems must be met with appropriate, previously anticipated solutions.

Unfortunately, the latter aspect of the observational method has often been overlooked. The designer may recognize that a difficult problem may arise under certain unfavorable conditions. He may defer thinking further about the problem by specifying instrumentation. He then may claim that he is invoking the observational method and that he will do what is necessary when the results become available. If he proceeds on that basis, without having evaluated the least favorable conditions and without a solution in the event one is required, he is postponing the day of decision until a time that may be too late. If a designer has not considered the various unfavorable situations that may develop, even his instrumentation and his observational program are likely to have no clear-cut objective, and the significant events may not even be observed.

The designer may, furthermore, have no personal experience with the various types of observational devices he intends to install. Inasmuch as many types of instrumentation are described in favorable terms in technical journals, the naive designer may feel assured that his duty is satisfied when he has specified the instruments. Unfortunately, almost all instrumentation for earth dams is difficult to install and is subject to malfunction. A designer who has not personally installed, observed, and attempted to interpret the results of various instruments is due for a rude shock when he finds himself depending on the results of the observations at a critical stage in the lifetime of his project.

Instrumentation is an accepted aspect of earth and rockfill dam construction today. Without it our knowledge would be inadequate indeed. Nevertheless, many instrumentation programs are planned without proper consideration of the nature and purpose of the information to be obtained. Moreover, it is often easier to obtain authorization for the installation of measuring devices than to make the readings or to analyze the data. All too often the observations are not even continued after the project is completed.

10. THE INEFFECTIVE INSPECTOR

The problems of inadequate inspection are by no means peculiar to earth and rockfill dams. The inspector is often the least experienced and lowest paid man on the job. The combination of a neophyte inspector and an experienced contractor, and its consequences with respect to the quality of the finished product, are well known. Unfortunately, inadequate inspection may have more serious effects where an earth dam is concerned than in most types of construction.

Of all the factors related to inspection that impair the quality and performance of a dam, possibly the most serious is the failure of the supervisor to back an inspector if he takes a firm stand against a contract violation. Even the inexperienced inspector may recognize that a certain construction operation does not lead to results that are in accordance with the contract documents. If he takes a strong stand and his superiors fail to support him, he will conclude that violations of the specifications are not considered serious, and any defects thereafter are likely to go unreported. If the contractor realizes that the job will not be shut down, he may not see any necessity for mending his ways.

Inspection and supervision are sometimes delegated to an outside agency or to a separate organizational division not associated with the designers. This practice almost always lowers the quality of a dam. If an inspector recognizes a problem that involves design, his finding must be subjected to thorough analysis before a decision can be made and acted on: it passes from the inspector to his chief, to the designer, sometimes to the consultant, and then back down the line to the field. Even in this electronic age several days are likely to be consumed during which the work in question may already be covered up or the construction schedule dislocated. Even the closest possible links between design and field supervision are none too close in connection with earth and rockfill dams. Additional organizational structure reduces the likelihood of appropriate and prompt solutions, even of day-to-day field problems.

11. THE LOOPHOLE CONTRACTOR

We have previously commented that the contractor has a right to a profit if he bid the job correctly and carried out the work satisfactorily. He has no right to expect a profit that he realizes solely on the basis of technicalities or loopholes in the contract. If all parties act in good faith, it is not usually difficult to reach an equitable adjustment of a controversial matter, even if the contract documents are imperfect. On the contrary, no contract is likely to be so perfect that loopholes cannot be found by the persistent searcher. If a contractor at the very outset looks at the job from the point of view of finding loopholes to exploit, he sets up antagonisms that influence the tone of the entire job. In a climate of antagonism between contractor and supervisory forces, quality and progress suffer.

It must be admitted that the loophole contractor may have acquired his undesirable traits in self-defense, through dealings with engineers whose contract documents were drawn so unfairly as to assure the contractor's financial discomfiture. The drawing of contract documents detrimental to the interests of the contractor, and the searching of contracts for loopholes by contractors even prior to bidding, are extreme and undesirable reactions to the same problem, that of failing to establish a just and fair arrangement for carrying out and paying for the work required.

12. THE FINANCIALLY SHAKY CONTRACTOR

The financially shaky contractor is likely to start the job with inadequate equipment and poor supervision. Predictably, be drops behind schedule almost at once. As the job gets further behind and the contractor sees more money being lost, be begins to cut corners and do increasingly shoddy work. As the shoddy work becomes evident, the inspector's efforts to require compliance reduce progress still further. The situation feeds on itself and becomes progressively worse.

Avoidance of the financially shaky contractor may be no simple matter, but success may be rewarded by a workmanlike job completed on time. Quite the opposite may come to pass if the contractor is not in a position to spend money to make money.

13. THE UNQUALIFIED CONTRACTOR

The degree of qualification of the contractor is reflected by his representative on the job, the superintendent. A poor superintendent is an insuperable obstacle to scheduled completion of a dam of high quality. The superintendent's personal characteristics may play a significant role in the nature of the final product. If be is too close to job details, if be puts too much faith in his organization chart, or if be cannot communicate effectively with the resident engineer, the job suffers.

The foremen are just as important as the superintendent. They are the men who must have the intimate know-how, and on whom all parties depend for the actual execution of the work. The importance of a staff of skilled foremen is especially great in the earliest stages of construction, when many of the most complex field problems arise.

14. CONCLUSION

The foregoing discussion is by no means definitive. The technical factors, purposely excluded from this chapter, are of course also of great importance. Incompetence at any level, whether technical or nontechnical, is reflected in decreased quality and security of the finished dam. There can be no substitute for technical competence in foreseeing and solving problems as they arise, because the safety of the dam is paramount. Yet neither can the nontechnical considerations discussed in this chapter be slighted without also courting disaster.

A failure of a dam is indeed a failure, whether caused by a slipshod inspector, an unclear contract document, or an erroneous stability analysis. Our concentration on investigating the properties of the materials of which dams are made, and on the technical analyses of the anticipated behavior, should be matched by attention to the nontechnical and human factors that are no less a part of this branch of engineering.

1983 Postscript

A number of engineers who read the paper asked me if I might have had one of their jobs in mind. Usually my answer was negative, but the reaction indicated that nontechnical problems were even more widespread and more serious than I had realized.

Words of Wisdom

Words of wisdom are generally old sayings developed by mankind over the years. These generally brief statements put things in place and provoke thoughts and reflections in our daily life. We find them in the works of philosophers and in the books of many writers. Although one does encounter new ones, they are often just old sayings reformulated for illustration in a special situation.

Dr. Peck's lectures and publications have as their trademark *quality of content in a condensed form*. These do not lend themselves easily to be taken apart and quoted out of context. In fact some of them are written in such a manner that you have to take everything or nothing. However, we yielded to the temptation to try to isolate and extract some of the important messages given in his literary works. So we took a journey through some of his publications looking for words of wisdom. Here is what we found.

We better listen; he has something to say!

On the Importance of Engineering

Our personal, individual attitudes toward engineering and toward society have potential impact on our country's future. However small that impact, each of us should try to make it for good.

~

Engineering is indeed a noble sport, and the legacy of good engineers is a better physical world for those who follow them.

~

Hence, we need never fear that our profession will become routine or dull. If it should, we can rest assured that we would not be practicing it properly.

On Communication

If it's important, say why!

~

If you can't reduce a difficult engineering problem to just one 8 ½ x 11-inch sheet of paper, you will probably never understand it. (Advice to his students).

~

Unhappily, far too much that we write is not worth reading. The prestige presumed to be associated with authorship results in great pressure to publish.

~

We should write with more discrimination.

On Education

Our practice falls short of our knowledge.

~

It would be a serious mistake to permit the subject of soil mechanics to be taught by individuals who do not possess an adequate background of field experience.

~

Why should there be such a discrepancy between our knowledge and our general practice? To some extent, I fear, because of too much specialization and too little appreciation of the interrelation of the various branches of civil engineering.

~

It is the opinion of the writer that the proper growth of soil mechanics has been seriously misdirected by the injection of an academic conception into the subject.

~

Unfortunately, with the present trend many students are led to believe that theory and laboratory testing constitute the whole of soil mechanics.

~

We should not neglect the aspects for which we have no theory while we over emphasize the significance of those for which we do.

On Research

The most fruitful research grows out of practical problems.

~

No theory can be considered satisfactory until it has been adequately checked by actual observations.

~

Professors and their protégés are often the worst offenders in devotion to research of minor consequence.

~

The academic climate encourages finding a subject for investigation that can be pursued at the desk or in the laboratory until all aspects have been exhausted. The subject is likely to be chosen more for convenience than for significance.

~

I see no reason to be ashamed of attempting to solve problems of importance to practitioners and I am convinced that the serious investigation of questions arising out of these problems will continue to promote studies of major consequence.

~

In soil mechanics, no evidence can be considered reasonably adequate until there is sufficient field experience to determine whether the phenomena observed in the laboratory are indeed the same as those that operate in the field.

~

In short, engineering science and engineering practice are not identical. Advances in science may temporarily appear to run counter to good practice. When this occurs, the implications should be evaluated carefully, but it should by no means be assumed that the latest scientific advancement is always in the right direction.

~

If something is discovered that does not agree with the hypothesis, rejoice! You can than really learn something new, You are on your way to an understanding of the problem.

~

Translating the findings of our research into simple concepts and procedures for the guidance of the practicing engineer is, in my opinion, a duty and worthy activity of our profession.

On Design

Simple calculations based on a range of variables are better than elaborate ones based on limited input.

~

We should be on guard not to ascribe to elaborate analytical routines a reliability they do not possess.

~

Construction deserves more attention in design. Our permanent structures are too often designed as if they come into existence without the necessity for being constructed.

~

Those who try to force Nature into the pattern by simplifying assumptions of theory will be courting disaster.

~

Designers and regulatory bodies tend to place increasingly reliance on analytical procedures of growing complexity and to discount judgement as a nonquantitive, undependable contributor to design.

~

The most successful practitioners of the art (-of engineering-) will maintain a healthy respect for the ability of Nature to produce surprises.

~

Sophisticated calculation is too often substituted for painstaking subsurface investigation. The ease or the fascination of carrying out calculations taking into account complex loadings, geometrics, and soil conditions leads many of us to believe that realistic results will somehow emerge even if vital subsurface characteristics are undetected, ignored, or oversimplified.

On Construction

A man who has been trained only in theory and in laboratory testing may be incapable of recognizing the significant problems in the field, and even if he recognizes them, may have no idea on how to cope with them.

~

I doubt if guidelines, regulations, or even the best of specifications can take the place of personal interaction between designers and field forces at this stage.

~

In my view, nobody can be a good designer, a good researcher, a leader in the civil engineering profession unless he understands the methods and the problems of the builder.

~

Reliance of precedent as a basis for extrapolation may certainly be dangerous, because significant differences among the precedents may not be appreciated.

On Observation and Instrumentation

Instrumentation is no substitute for adequate design.

~

What is often forgotten is that the observational method is an adjunct to design, not a substitute for it.

~

Indeed, in my judgement, the simplest measurements are always the best because they have the least possibility for error and the greatest likelihood of survival

~

An instrument too often overlooked in our technical world is a human eye connected to the brain of an intelligent human being.

~

We need to carry out a vast amount of observational work, but what we do should be done for a purpose and done well.

The observational method in practice.

Most of the shortcomings, in the writer's opinion, originate in the attitudes and actions of the persons most intimately concerned with the creation and completion of the project: the owner, designer, constructor, and technical consultant.

~

The observational method, surely one of the most powerful weapons in our arsenal, is becoming discredited by misuse. Too often it is invoked by name but not by deed.

~

Unhappily, there are far too many instances in which poor design is disguised as the state of the art merely by characterizing it as an application of the observational method.

~

Instrumentation, vital for obtaining quantitative answers to significant questions, is too often misused, especially in earth and rockfill dams.

~

There is a danger that instrumentation may be discredited because of indiscriminate use.

On Engineering Judgement

The successful practice of engineering requires a high degree of engineering judgement.

~

There is actually such a thing as engineering judgement and it is indispensable to the successful practice of engineering.

~

Yet a sense of proportion is one of the main facets of engineering judgement. Without it, an engineer cannot test the results of a calculation against reasonableness.

~

Unreasonable and unrealistic criteria grow out of lack of judgement, a lack of perspective as to the relative importance of things. Unfortunately, such criteria are not uncommon.

~

A good engineer has a feel for the appropriateness of his solution from the narrowest technical details to the broadest concepts of planning. His judgement tells him if each step is sound and if the whole enterprise is sound.

~

Theory and calculation are not substitute for judgement, but are the basis for sounder judgement.

~

Your real security will lie in your ability as engineers, which in turn will depend on the quality of your judgement.

~

Employment selected for experience, and the self-discipline of private study and cultivation of your powers of observation, must necessarily improve your judgement.

~

Finally, the writer would suggest that the consultant should be wary of making non-technical judgments. He is not a lawyer. He is often not called into a controversy until the battle lines are drawn. If he ventures out of his technical specialty, he may become unwillingly a pawn in the struggle.

~

As long as the myth persists that only what can be calculated constitutes engineering, engineers will lack incentive or opportunity to apply the best judgement to the crucial problems that cannot be solved by calculation.

~

Where has all the judgment gone? It has gone where the rewards of professional recognition and advancement are greatest – to the design office where the sheer beauty of analysis is often separated from reality. It has gone to the research institutions, into the fascinating effort to idealize the properties of real materials for purpose of analysis and into the solution of intricate problems of stress distribution and deformation of idealized materials. The incentive to make a professional reputation leads the best people in these directions.

This small selection of quotations listed above does not give full justice to neither the engineer, nor the professor nor the consultant that Ralph is. Thus, we would like to add to the list an additional few words of wisdom, written by another engineer, that do indeed portray the philosophy and image of Dr. Peck so very well.

"Knowing what
thou knowest not
is in a sense
omniscience."

Piet Hein
Danish poet and engineer

To Publish or Not to Publish

One should write with more discrimination

Ralph B. Peck

Ralph has always been concerned that others should benefit from the knowledge that he has acquired in his professional work. One result of this attitude is the 234 technical papers he has published (per March 2000), often in collaboration with other noted professionals. In addition he has frequently co-authored papers with his students, thus, helping them off to a good start in their own professional careers. A complete list of his publications has been included at the end of this publication. It is interesting to note that three of Ralph's early publications are co-authored with his father, O. K. Peck.

Figure 3 shows the number of professional publications he has contributed yearly between 1936 and 2000. On the average, Ralph has published something every three months ever since his first publication in 1936. His peak production year was 1973 with 13 publications. During his professional career there have been only 5 years where he has not publish anything.

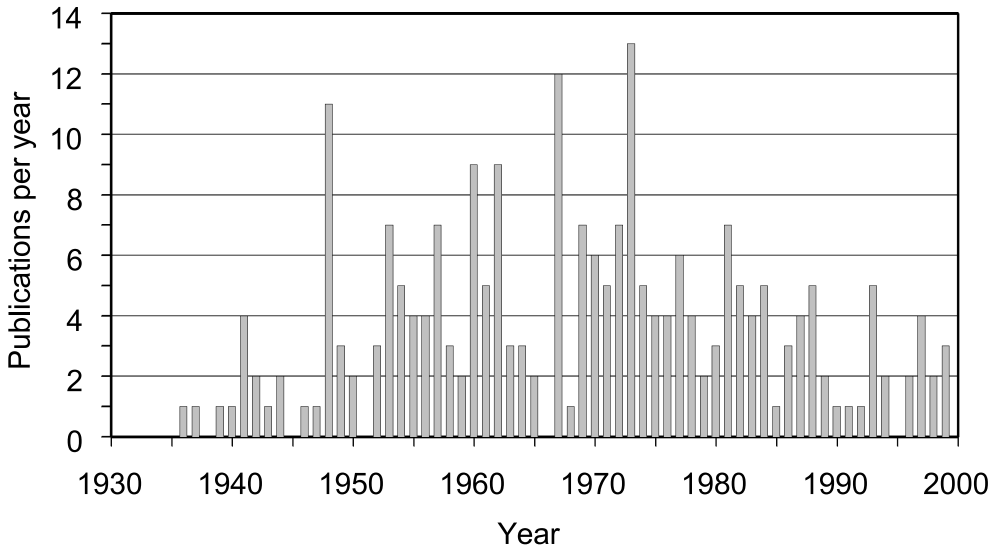

Figure 3. Number of publications per year for Ralph B. Peck

Ralph has always been a strong advocator of discussing papers that others have published, as a means of contributing to progress in our profession. Thus, it is not surprising that more than 40 of his publications are discussions of papers written by others.

In preparation for this publication, we asked Ralph to go through his bibliography and classified each publication according to subject matter. He grouped his publications into 15 different categories when he did this. The results of his evaluation are shown in Figure 4. It is interesting to note that approximately 20 percent of Ralph's publications deal with professional practice.

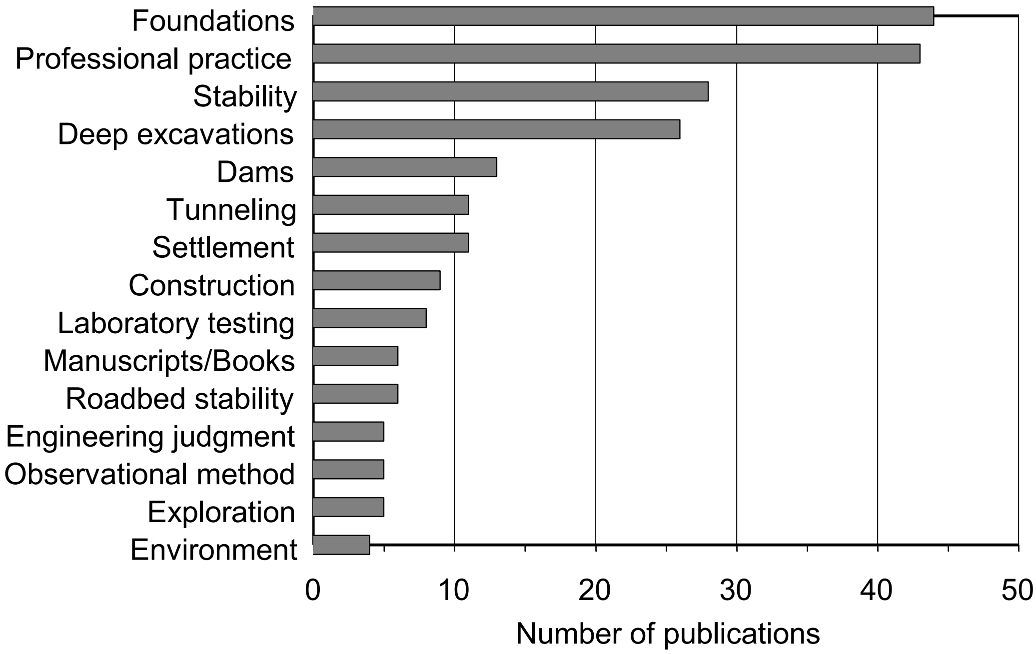

Figure 4. Subjects addressed in Ralph's publications

Ralph's papers are generally short and concise. This is clearly shown in the histogram in Figure 5. If textbooks and special reports are excluded, the average length of his publications is only about 8 pages.

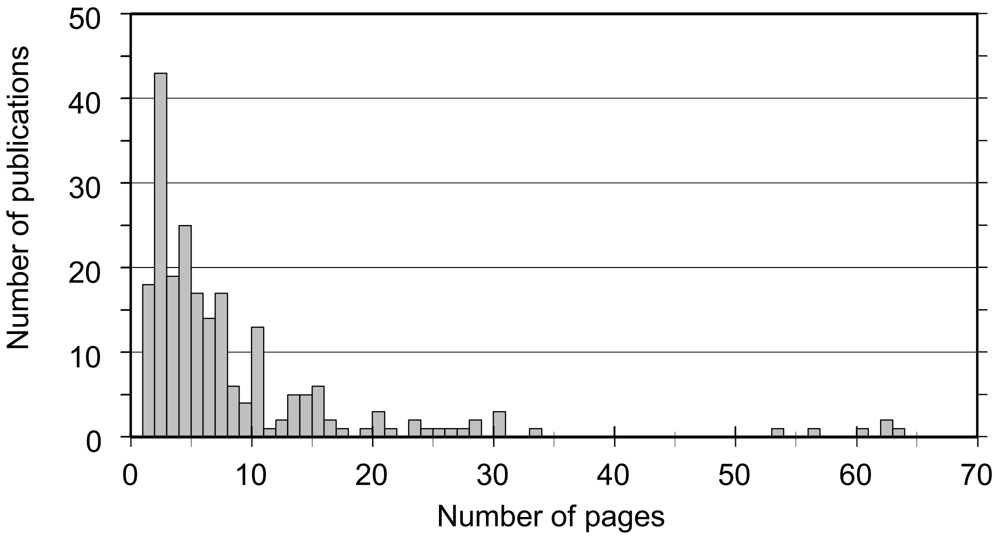

Figure 5. Histogram over the number of pages in Ralph's publications.

Details of the books Ralph has co-authored are given in Table III. The two textbooks *Soil Mechanics in Engineering Practice* and *Foundation Engineering*, both classics in their field, have sold more than 300,000 copies to date.

Peck, Hanson and Thornburn
The authors of "Foundation Engineering ".

Table III. Books co-authored by Ralph B. peck

Title	Edition	Year	Pages	Authors
Soil Mechanics in Engineering Practice	$1^{st.}$	1948	566	Terzaghi and Peck
	$2^{nd.}$	1967	729	Terzaghi and Peck
	3^{rd}	1996	549	Terzaghi, Peck and Mesri
Foundation Engineering	1^{st}	1953	410	Peck, Hanson and Thornburn
	2^{nd}	1974	514	Peck, Hanson and Thornburn
From Theory to Practice in Soil Mechanics		1960	425	Peck, Casagrande, Bjerrum and Skempton

Terzaghi, Peck and Mesri
The authors of "Soil Mechanics in Engineering Practice", 3^{rd} Edition.

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