Unsaturated Soil Mechanics: Who Needs It?

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The responsibility for the scope of geotechnical engineering lies strongly in the hands of geotechnical engineers with a vision for the discipline. These engineers will need to come from consulting practices, the construction industry, government agencies and universities.

If there is a lack of vision established for civil engineering, geotechnical engineering and geo-environmental engineering, the scope of these areas will gradually shrink. A particular area of practice will become routine, empirical, and slowly drift towards the use of codes and guidelines. Codes and guidelines are not to be viewed as negative, but need to be accompanied with a progressive vision that will, at the same time, broaden the scope and improve the way in which engineering is done. Also, new approaches and techniques need to be continually forthcoming for civil engineering.

Professor Ishihara, President of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE), opened the Asian Unsaturated Soil Mechanics conference in May, 2000, and made reference to the rapidly growing interest and activity in the area of unsaturated soil mechanics. It was pointed out that the TC6 subcommittee on unsaturated soils was a very active committee within ISSMGE.

In the opening address to the same conference, graphs and pie-charts showed statistics to illustrate the recent increase in the number of research publications related to the unsaturated soil mechanics area. It was shown that there has been an overall increase in unsaturated soils' research, and that the largest increase has occurred in the Asian region and in Brazil. A recent, major research grant application submitted to the National Science Foundation of America made the case for increased funding to the unsaturated soils area by pointing out that much of geotechnical engineering pertains to the unsaturated portion of the soils profile. At the same time, this subject has received little attention in the curricula of universities.

Soil mechanics is a relatively young science dating back to the mid-1930's. The first International Conference on Soil Mechanics and Foundation Engineering (1936) had a significant number of research papers on compacted and unsaturated soils with negative porewater pressures. Following international conferences quickly directed most of the research attention towards the behavior of saturated soils. There was the realization that unsaturated soil problems were more complex than those in saturated soil mechanics. The stress state variables required for unsaturated soil behavior were not known and the apparent complex and highly non-linear character of the analyses presented unique challenges. For example, Terzaghi's simulation of the capillary rise phenomena revealed that the coefficient of permeability of the unsaturated soil was highly non-linear. The partial differential equation describing flow through an unsaturated soil proved to be non-linear, in addition to a non-linear function for the coefficient of permeability. In the absence of a means to efficiently solve this type of equation, as well as other non-linear equations, a science for unsaturated soil mechanics was slow to emerge.

In the mid-1960's, attention was given to a number of so-called problematic soils for which the classical theories of saturated soil did not produce satisfactory solutions. One such problematic soil was the swelling or expansive soils that were found in most countries of the world. The magnitude of damage attributed to expansive soils was enormous, rivaling that of all other natural disasters put together. A series of international conferences were commenced in 1965, and repeated at approximately four years intervals. It was reported that expansive soils' problems resulted in losses in excess of 2.3 billion dollars annually in the United States alone. A more accurate analysis resulted in this number being upgraded to 7 billion dollars annually in the U.S.A. And the list of countries reporting serious expansive soils' problems kept growing. Certainly there was a growing awareness with time, but unfortunately there was little emphasis on the formulation of a scientific basis for understanding expansive soil behavior. There was a concern, but it was not sufficient to bring forth the emergence of unsaturated soil mechanics.

In the mid-1970's, there was a renewed realization that human beings had a responsibility to be good stewards of the environment. Developed and developing countries alike felt the new responsibility towards the environment. Generally, it was the chemicals left near or on the ground surface that later found their way through the unsaturated soil zone, into the groundwater. Major emphasis was directed towards a program for the sustainability of our planet's resources. The most important commodity for the sustainability of the environment was in the protection of the fresh groundwater supply.

When addressing geoenvironmental problems, it was extremely important to understand the contaminant transport mechanism. This mechanism was described in terms of a partial differential equation that had a form somewhat similar to the consolidation equation for saturated soils. Geotechnical engineers were well poised for the challenge of solving contaminant transport problems. In addressing the geoenvironmental issues, the primary need was to quantify the coefficient of permeability and the storage capacity of unsaturated soils near to the ground surface. Groundwater hydrologists responded to the need to simultaneously model both the saturated and the unsaturated portions of the soil profile. Estimation techniques were proposed to characterize the unsaturated soil properties. The estimation technique made use of the *saturated* soil properties along with the soil-water characteristic curve for the soil. This procedure ushered in a new way of implementing unsaturated soil mechanics into general geotechnical engineering. The new approach involved the use of indirectly estimated unsaturated soil parameters and prepared the way for the implementation of modeling procedures for other areas of classical soil mechanics (e.g., shear strength and volume change).

Figure 1. Near ground surface, engineered structures, such as this protected slope in Hong Kong, become unstable in response to extreme changes in moisture flux boundary conditions.

Environmental problems were not only observed to initiate at the ground surface, but it was the ground surface moisture flux condition that formed an important boundary condition for modeling engineering problems. This led to the development of soil-atmospheric models as part of solving geotechnical problems. It was primarily the solution for the "actual" evaporative flux that provided the necessary boundary condition for solving near-ground-surface problems. In particular, one significant area of engineering to emerge was that of the design of cover systems for the management of waste facilities. It was necessary to quantify the climatic conditions such that the cover system could operate as a "store and release" system or as an oxygen barrier in the case of mitigating acid mine drainage problems. Moisture flux boundary conditions had historically been omitted from classic soil mechanics where the concentration was on specifying heads or zero flux. The evaluation of moisture flux boundary conditions applies to saturated and unsaturated soil conditions, but has mainly found its home within unsaturated soil mechanics. In general it is the moisture flux boundary condition that provides the "trigger" mechanism associated with a hazard. The study of the stability of initially unsaturated slopes often ignores negative pore-water pressure changes but at the same time it is the response to ground surface moisture fluxes that produces the instability (See Fig. 1).

The basic theories for understanding unsaturated soil mechanics began to become clearer in the 1960's and 1970's. At the same time, the power of the digital computer brought engineering solutions of non-linear partial differential equations to the desktop of the engineer. Digital computing power doubled every one and a half years, and the increased computational capability meant that solutions were available for new saturated-unsaturated soils formulations.

The pressure to address geoenvironmental problems, along with the power of the digital computer, brought in a new paradigm for characterizing unsaturated soil properties. Unsaturated soil properties were consistently observed to take the form of functions rather than constants. These unsaturated soil property functions were estimated from the saturated soil properties and the soil-water characteristic curve. This procedure did not provide a rigorous assessment of the soil properties, but did provide soil property functions of sufficient accuracy for many geotechnical problems. This does not have the appearance of being a perfect solution but it was far superior to the past procedures where the unsaturated zone was not even taken into consideration in the solution. Parametric type studies allowed the solution to be tested for its sensitivity to the input soil parameters.

Database technologies brought another dimension to the estimation of unsaturated soil property functions. Soil-water characteristic curves have been measured in large numbers, in many parts of the world. These curves provide an indication of the relationship between the water content of a soil and soil suction, and as such provide important information leading towards the implementation of unsaturated soil mechanics. Knowledge-based systems can be utilized to assist in "mining" past laboratory test results for reasonable estimates of unsaturated soil property functions. Once again, the procedures were approximate and further research is required to differentiate between soils that are initially slurried, compacted or naturally structured.

It is not necessary to live in an arid or semi-arid climatic part of the world (like 60% of the world's population), in order to have a need for unsaturated soil mechanics. Rather, unsaturated soil mechanics has taken on the character of a more general soil mechanics, and saturated soil behavior as a special case. Moisture flux boundary conditions are observed to "trigger" many of our soil mechanics concerns. These concerns range from the instability of a slope to the protection of hazardous wastes. Expansive soils and collapsing soils are generally a problem when the water content of the soil is changed. This change often comes about as a result of a change in the ground surface moisture flux. And there are many other problems such as stability concerns related to earthfill dams that are driven primarily by increased pore-water pressures resulting from the moisture flux at ground surface.

There is need for an ever-increasing vision for the future for geotechnical engineering. One of the recent topics to receive considerable attention is that of hazard management and risk assessment. The geotechnical engineer has much to contribute in this area by bringing together the knowledge of surface hydrologists and geotechnical engineers. Many of the hazards of particular concern are initiated near to the ground surface. Excessive rainfall over a long period of time leads to near-saturation of the upper portion of the soil profile. These unsaturated soils are like a reservoir that can be characterized by the soil-water characteristic curve. Real-time simulations can provide a warning system that becomes part of a hazard management system.

It is the role of researchers in any particular area of engineering, to not only research existing problems but to also attempt to broaden the scope of the types of problems that can be addressed. This is part of our responsibility as researchers and practicing engineers alike.

Unsaturated soil mechanics may have more to do with the ground surface moisture flux conditions than it has to do with the thickness of the unsaturated soil zone. As a result, the scope of geotechnical problems that engineers can address is quite extensive. It is the responsibility of geotechnical engineers to embrace as wide a scope of practical problems as possible, to best fulfill our responsibility to society and our profession. Unsaturated soil mechanics is a frontier that has received much attention in the past few years. Possibly there are other frontiers that also need to be addressed and brought within the scope of geotechnical engineering.

And so, who needs unsaturated soil mechanics? Every geotechnical engineer needs to be aware of the role played by the portion of the soil with negative pore-water pressures (i.e., generally the portion above the water table). Many of the present solutions in unsaturated soil mechanics are quite approximate and much more research is required. At the same time, there is much that can be done to improve our solutions in geotechnical engineering through the application of unsaturated soil mechanics.

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