MICRO VERSUS MACRO GEOTECHNICAL ENGINEERING

Ronald F. Reed, P.E.
rreed@reed-engineering.com
Reed Engineering Group, Ltd.
2424 Stutz, Suite 400
Dallas, Texas 75235
214-350-5600

Abstract

Scaling concepts, theories, and equations from the micro to macro arena is common throughout the engineering disciplines. An example is equations for stress and strain of steel which are readily scalable from the micro to macro setting.

However, geotechnical engineers have to deal with natural materials which are rarely isotropic and virtually never uniform on a macro scale. Application of concepts and theories that are developed strictly on a micro scale are difficult to expand to the macro scale, and can lead to gross errors regarding behavior of soil deposits.

Three cases are provided which illustrate the difficulty of applying micro concepts in the macro scale; shear strength in rock, chemical injection for stabilization of expansive soils, and permeability.

Introduction

Evaluation of engineering principals, and or the performance of structures using scaled models, is common throughout engineering practice. Engineering studies of both fluid dynamics and air flow across an airplane wing or even modeling buildings is routine.

In the field of geotechnical engineering, the materials that are dealt with are rarely uniform, with in-situ materials being even more non-uniform than fills. Qualifications to almost all of the geotechnical applications include that the material is "uniform and isotropic". Although natural materials are neither "uniform nor isotropic", successful application of geotechnical engineering principals is possible, provided sufficient uniformity within the material being evaluated makes that particular application valid.

However, application of micro concepts to macro situations can result in significant deviations to the expected outcome. This paper presents three examples where micro analysis is not considered to be applicable to the macro condition. The purpose of these examples is to stimulate conceptual thinking, and awaken research to the macro environment.

Example 1, Slope Stability

Analysis of rock stability is at the upper end of the analysis spectrum, but engineering geologists typically think in terms of defects, not shear strength. As part of their analytical toolbox, engineering geologists have the principal of stereographic projection, which allows for surveying, modeling and analysis of discontinuities. An example of a stereographic projection is provided in Figure 1. (Its use is beyond the scope of both this paper and the writer.)

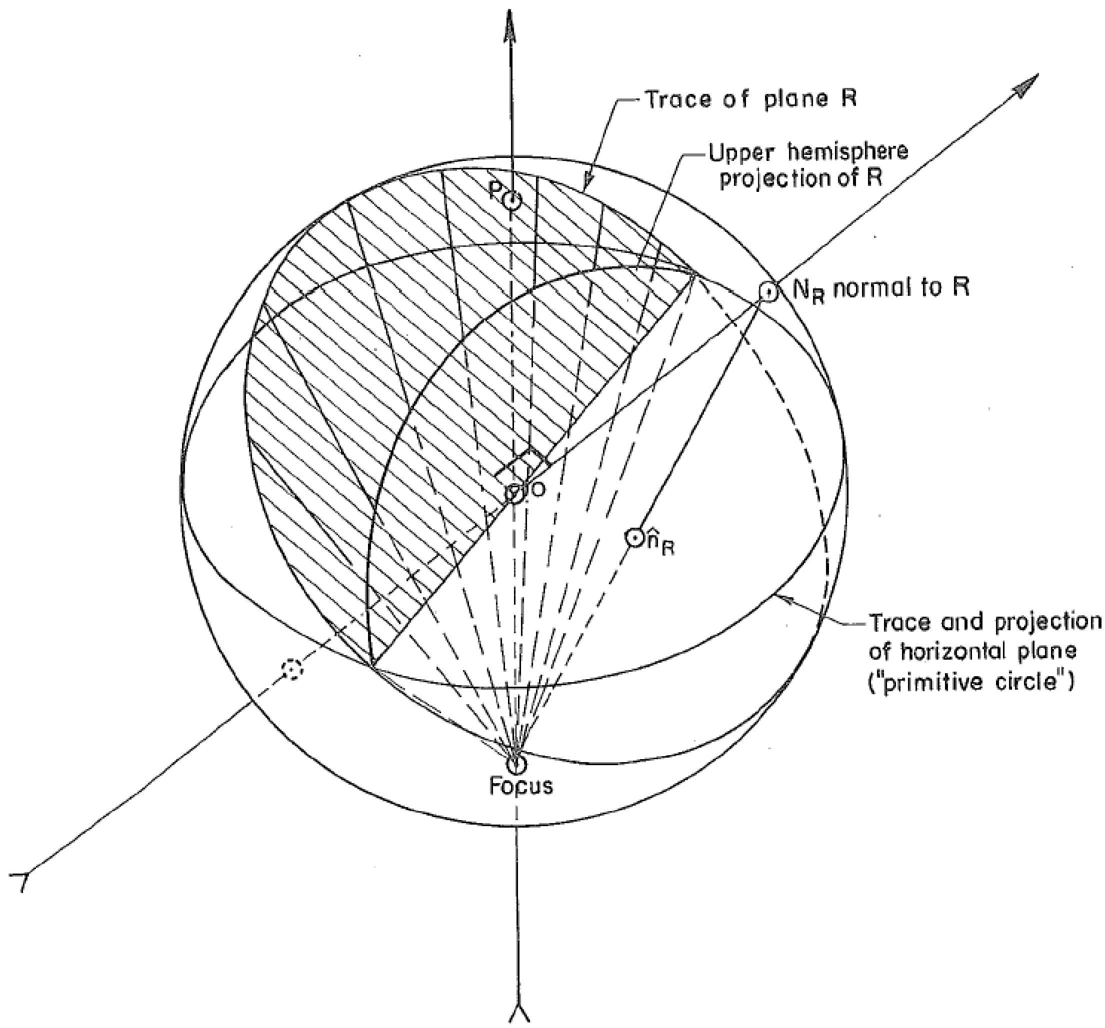

Figure 1. Stereographic Projection. From Richard E. Goodman, "Methods of Geological Engineering".

Geotechnical engineers do not always think in terms of discontinuities, but in terms of shear strength. This is unfortunate since slope stability in unsaturated materials is just as likely to be associated with discontinuities as with shear strength. The analysis procedure becomes even more complicated when one considers that shear strength in an unsaturated soil is currently undefined, since the contribution of suction (negative pore pressure) to the strength component cannot be reliability measured.

However, the presence of discontinuities cannot be completely ignored. A cut section within extremely weathered shale is shown in Photograph 1. The discontinuities are readily apparent. Analysis of slope stability within materials of this type using a rotational failure would be meaningless, even though a "factor of safety" could be calculated by any conventional or finite element slope stability program. Any meaningful analysis must account for the impact of discontinuities, i.e., the macro condition.

Photograph 1. Cut section within Eagle Ford Shale

Some of the newer computer programs such as CLARA and GSlope have the ability to model discontinuities and their effect on slope stability. This modification to the traditional rotational analysis is an example of recognition that the macro condition may control certain engineering situations.

Example 2. Chemical Injection

The use of pressure injection technology of various chemicals to stabilize unsaturated expansive soils has been promoted within North Texas since the mid to late 1960's. Initially lime was used as the chemical of choice. Within the last 10 to 15 years various proprietary chemicals, generally potassium based, have been touted for their ability to "stabilize" the in-situ clay.

The micro scale is typically used to evaluate the effectiveness of chemical injection. Frequently small samples are mixed with various quantities of chemical and then tested for swell. This is a reasonable approach until the percent of chemical is applied to the macro scale.

A local North Texas high school student, Parker Spradley, evaluated the effectiveness of reduction in the potential for swell of a chemical by performing swell tests on samples with various percent chemical. Although the testing was not as complete as would be performed in a university setting, her test results illustrate the concept of micro to macro scale.

A large sample of clay was uniformly blended then divided into 15 sub-samples. Three samples were tested in a raw condition using three different methods of compaction and swell procedures. The remaining 12 samples were mixed with 1, 2.5, 5 and 10 percent of potassium chloride by dry weight. Three separate swell tests where then performed on the mixture. Test results are shown in Figure 2.

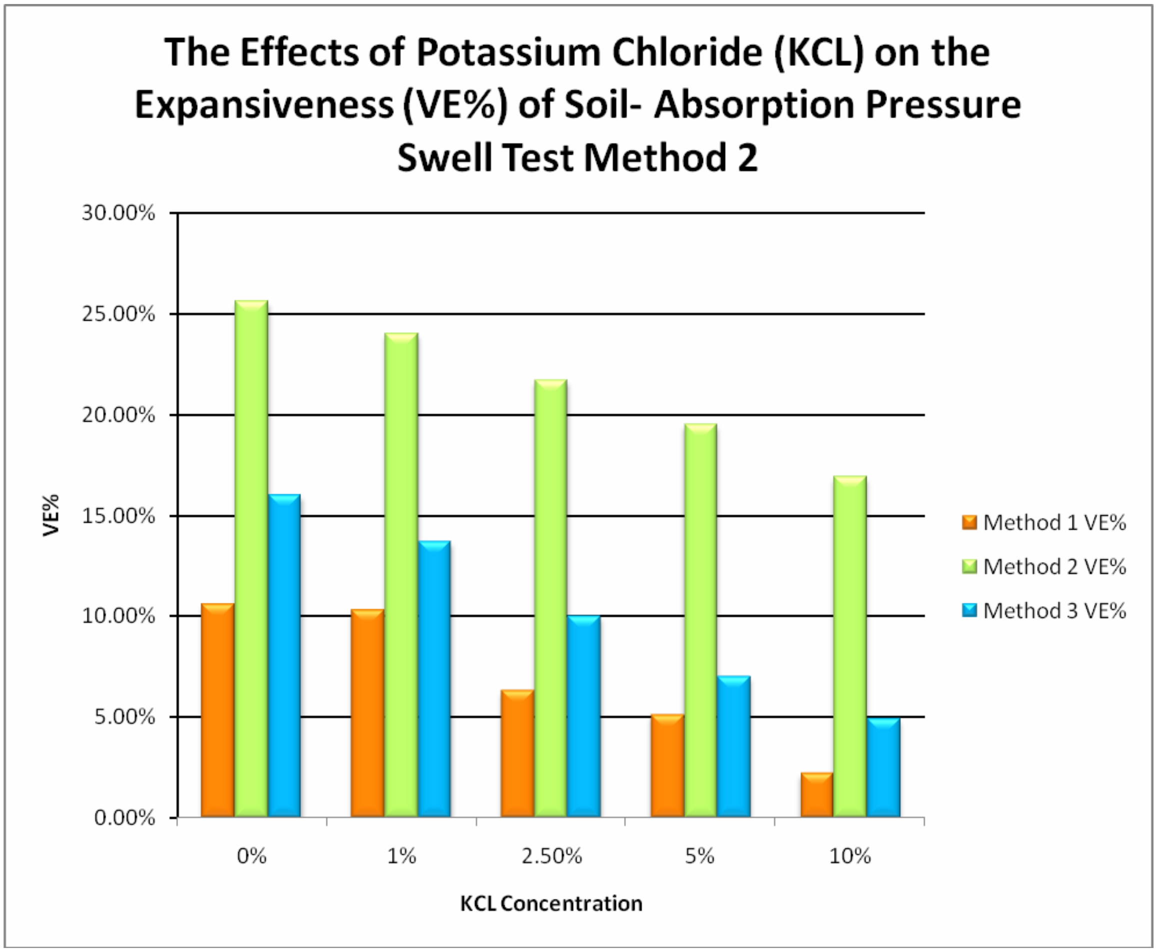

Figure 2. Percent Swell versus Percent Potassium Chloride from Spradley.

Although it would have been more complete to have additional information such as change in plasticity and suction with the additional of the chemical, Figure 2 is a valid illustration of the effect of potassium chloride on clay. Ten percent of the chemical reduced the swell by 65% to 100%, dependent upon the test method.

However, this is on the micro scale. To achieve 10% by dry weight on the macro scale to a depth of 10 feet via the injection method, using a dry unit weight of 90 pcf for the clay, would require injecting 90 pounds of chemical per square foot of area. Obviously, this is unachievable via the injection procedure.

Example 3 – Permeability

The third example of micro versus macro analysis involves measurement and use of permeability or hydraulic conductivity in unsaturated soils.

In Fredlund and Rahardjo, “Soil Mechanics for Unsaturated Soils”, permeability is inversely related to the matric suction, i.e., as the matric suction increases, the soil sample becomes less permeable. This same concept is shown in “Unsaturated Soil Mechanics” by Lu and Likos.

From a micro perspective, this is logical because as the matric suction increases, the soil particles are drawn closer together, thus making smaller “channels” for fluid flow. A plot of permeability versus matric suction is shown in Figure 3.

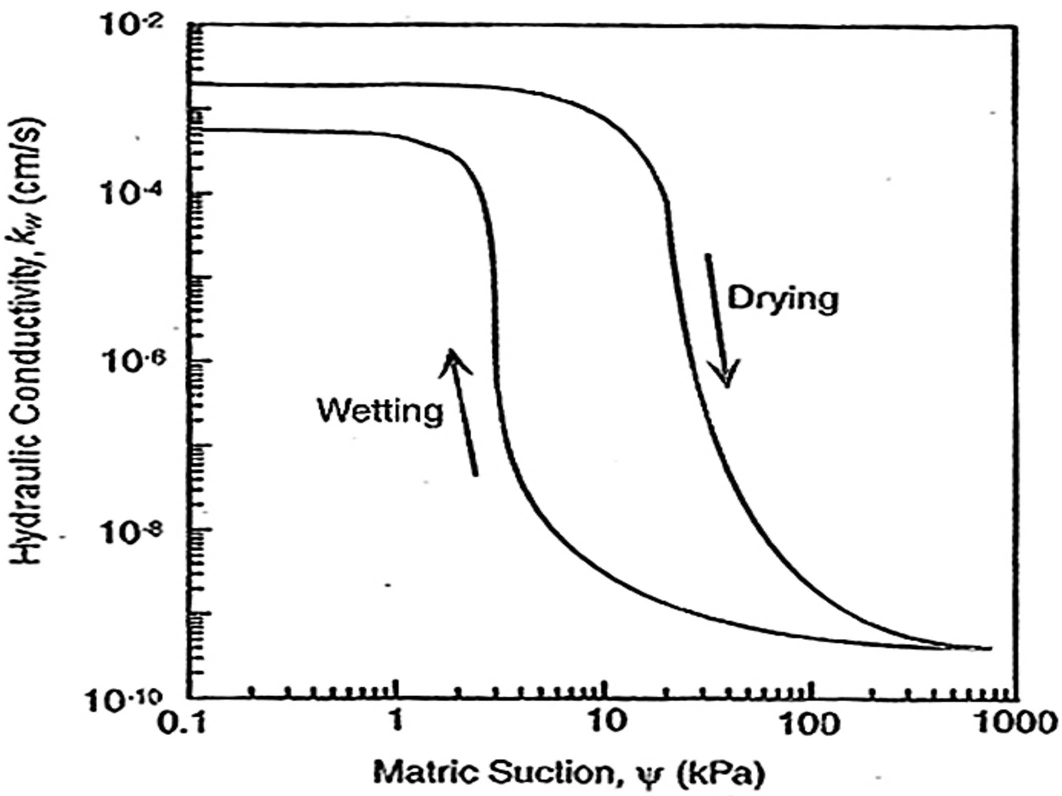

Figure 3. Permeability versus Matric Suction. From “Unsaturated Soil Mechanics” by Lu and Likos.

This concept has been integrated into a finite element program by Soilvision Systems, Ltd., “SVFLUX”. The program analyzes flow within saturated to unsaturated soils. Input parameters include permeability versus suction curves similar to that shown in Figure 3.

For fill, such as a newly constructed dam or levee, this permeability function is reasonable. In other words, it would appear that extension of the micro concept of permeability to the macro condition would be correct for cases where analysis of fill not subject to seasonal moisture change is performed.

However, for natural clays or fill subject to seasonal changes, an increase in matric suction causes the clay to shrink. Since shrinkage is three dimensional, shrinkage cracks develop. For an unsaturated soil subject to seasonal moisture or geologic drying, the macro permeability would be controlled by the discontinuities or shrinkage cracks, not by the micro permeability of a small lab sample.

The concept that permeability decreases upon saturation is discussed by Day (“Hydraulic Conductivity of a Desiccated Clay Upon Wetting”, *Environmental and Engineering Geoscience*, Vo. III, No.2). Day’s graph of hydraulic conductivity versus swell is shown in Figure 4. Figure 4 illustrates that as a soil swells the permeability decreases. Since swelling is a result of reduction in matric suction, it can be inferred that as matric suction is decreased, permeability is decreased. This conclusion is directly opposed to the hypothesis presented in the Fredlund & Rehardjo and the Lu & Likos publications.

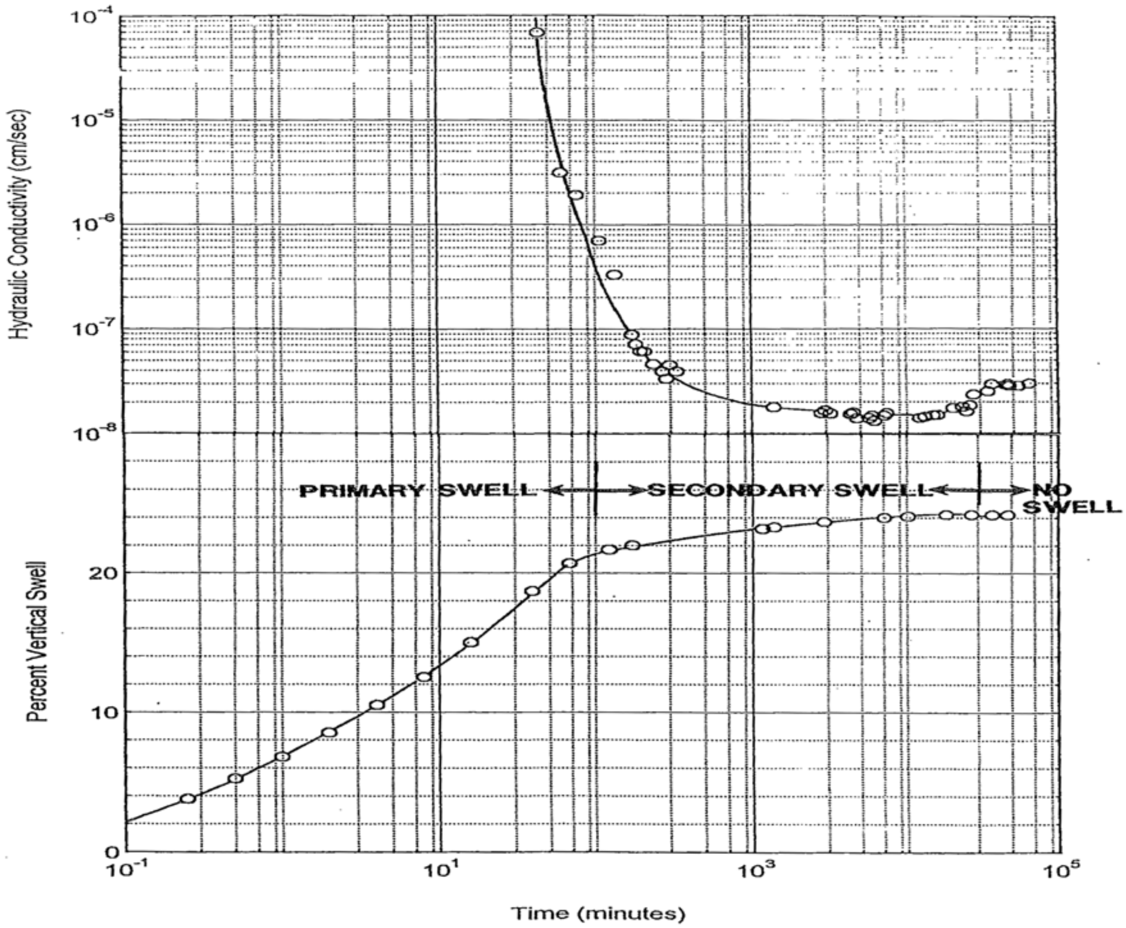

Figure 4. Plot of Hydraulic conductivity versus Time from Day, “Hydraulic Conductivity of a Desiccated Clay Upon Wetting”, *Environmental and Engineering Geoscience*, Vo. III, No. 2.

Obviously, the correct relationship between permeability and suction pressure would be required in any analysis of a naturally deposited unsaturated soil, or for that matter, any fill that has undergone seasonal moisture change. Without the correct permeability function any seepage analysis, no matter how elaborate the program, is meaningless.

Conclusions

Geotechnical analysis and design requires a firm scientific and engineering foundation coupled with considerable judgment. One of the critical elements includes evaluation if concepts developed on the micro scale fit the macro condition encountered in geologic settings.