Predicting the soil-water characteristics of mine soils

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ABSTRACT: The soil-water characteristic curve for unsaturated mine soils (i.e., waste rock, and tailing) is a key parameter for predicting net infiltration in the design of soil caps, potential seepage from waste rock stockpiles, and the migration of potential seepage to groundwater. To expedite preliminary engineering analysis and design, computer programs are used to predict the soil-water characteristic curve based on particle size distribution. Observations of recent testing indicate that the theoretical models currently employed by these programs are accurate for uniform mine soils (i.e., tailing), but are not accurate for well-graded mine soils such as waste rock. Further research has shown that a combined theoretical/knowledge-based approach provides a more accurate prediction of the soil-water characteristic curve for mine soils such as waste rock.

1 INTRODUCTION

Hydrologic studies at mine sites frequently involve the simulation of water flow through unsaturated tailing and waste rock. For example, as illustrated on Figure 1, the components of a hydrologic study for a waste rock stockpile may include the analysis and design of soil caps, predicting potential seepage from the base of a stockpile and/or predicting the migration time of potential seepage to an underlying aquifer. The soil-water characteristic curve (SWCC), which defines the soil's ability to store and release water, plays a fundamental role in the hydrologic study of these components, and therefore, accurate and defensible quantification of the SWCC is important.

The duration for laboratory testing to measure the SWCC can range from several weeks to several months for typical mine soils. Feasibility studies and preliminary analysis and design projects at mine sites can be subject to deliverable times that therefore preclude laboratory measurement of the SWCC. Due to the lengthy testing times, computer programs based on theoretical models are sometimes used to predict the SWCC using the readily measured particle size curve (i.e., Gupta and Larson 1979). The most recent approach to predicting the SWCC combines theoretical models with a knowledge-based systems approach (Fredlund 1996). This combined approach allows the user to calibrate theoretical predictions to available laboratory SWCC data as a means of improving the accuracy of the theoretical prediction. This paper evaluates the theoretical and the combined theoretical/knowledge-based approach for predicting the SWCC of mine soils.

2 BACKGROUND

The soil-water characteristic curve (SWCC) defines a soil's ability to store and release water. A typical SWCC takes the form shown on Figure 2 and is illustrated by the relation between volumetric water content and soil matric suction. The volumetric water content at zero matric suction corresponds to the porosity of the soil, which represents the total volume of water that the soil can store. The change in water content divided by the change in soil matric suction (i.e., the slope of the curve) represents the storage potential. Therefore, the steeper curve over a specific range of soil matric suctions, the greater the water storage potential. The soil matric suction which corresponds to the initial draining of the soil pores (i.e., the first transition from flat to steep) is referred to as the air entry value. The water content at which the SWCC begins to flatten after the air entry value is called the residual water content. At zero water content the soil matric suction is approximately 1,000,000 kPa (Fredlund et al. 1994). This dry condition is achieved by oven drying the soil.

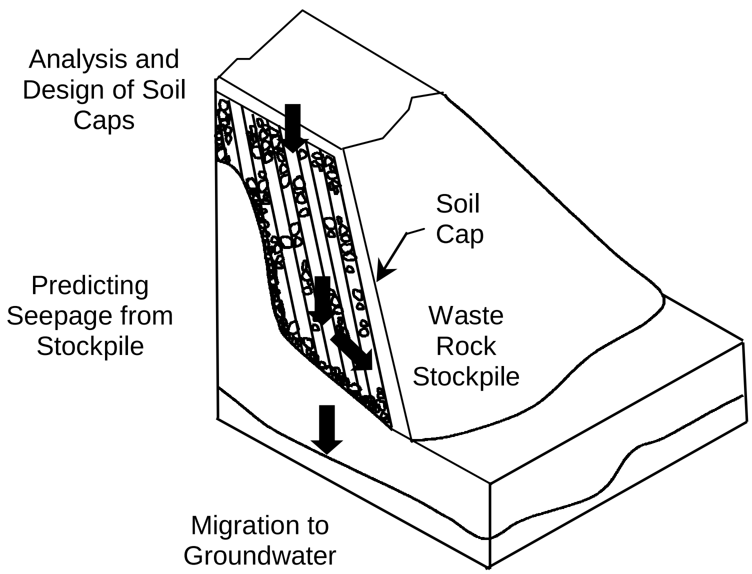

Figure 1. Schematic of a waste rock facility showing hydrologic conditions.

Methods to predict the SWCC using the particle size distribution have developed over the years. The earliest methods for predicting the SWCC from the particle size distribution were statistically based. The statistical models employ regression analyses on large data sets to predict the water content at specific matric suction values (i.e., Salter et al. 1966; Gupta and Larson 1979). Theoretical models were developed later and are based on the soil's pore-size distribution (which is determined from the particle size distribution). In this model, the particle size distribution is divided into a number of uniform particle sizes, and starting at the smallest particle size, a SWCC is estimated for each particle size and then summed to develop the

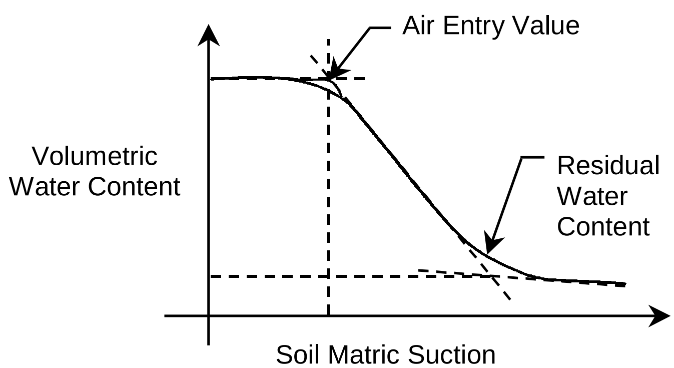

Figure 2. Components of a soil-water characteristic curve.

complete SWCC. Models that incorporate theoretical models include TheHyProS (Tarnawski and Wagner 1991), SOILPARA (Scientific Software Group 1998) and SOILVISION (SoilVision Systems Ltd. 1997).

The latest method for predicting the SWCC from the particle size distribution combines the theoretical model with a knowledge-based system (Fredlund 1996). The computer program SOILVISION (SoilVision Systems Ltd. 1997) combines the theoretical model with a knowledge-based system consisting of a data-base of soils (each with a measured particle size distribution and SWCC) and a quantitative means for calibrating theoretical predictions to a laboratory measured SWCC. Such versatility allows the accuracy of the prediction to be improved as more soils of a specific type are incorporated into the data-base for a given project.

3 PREDICTING SOIL-WATER CHARACTERISTIC CURVES OF MINE SOILS

The SWCC for three mine soils (i.e., two tailing samples and one waste rock sample) was predicted from the particle size distribution (Figure 3) using the theoretical method described in Section 2. The particle size distributions of the three mine soils are shown on Figure 3. The tailing samples have a relatively uniform particle size distribution (i.e., a narrow range of different particle sizes), whereas, the waste rock sample is well-graded (i.e., a wide range of particle sizes). The particle size distribution of this waste rock sample is slightly atypical due to its weathered condition; however, the well-graded particle size distribution is typical of many waste rock materials (Herasymuik 1996).

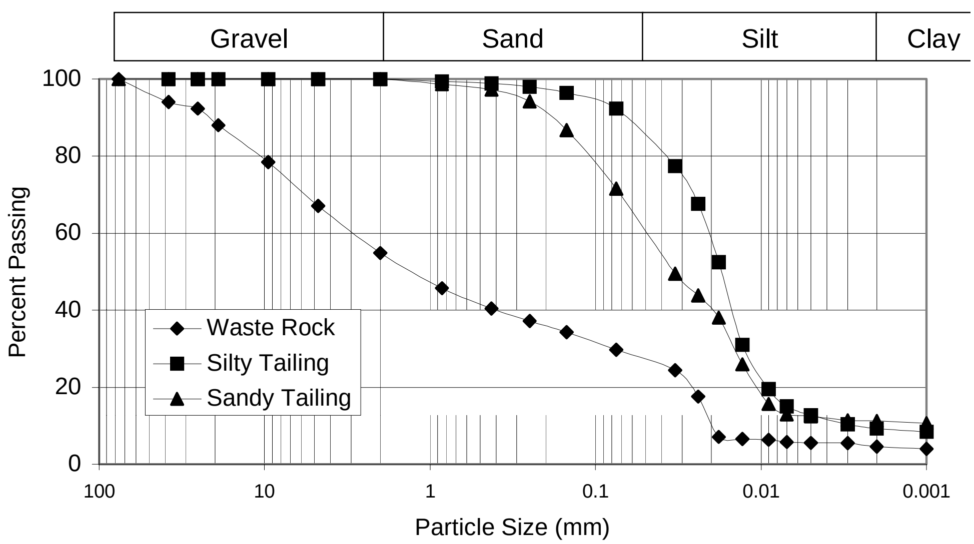

Figure 3. Particle size distribution of three mine soils.

The SWCC for each mine soil was predicted using the theoretical method employed in the SOILVISION model. The results of the predictions and the comparison to the laboratory measured SWCC for each mine soil is shown on Figure 4. As indicated on Figure 4, the predicted SWCC for the uniform tailing samples compared well to the measured SWCCs. In contrast, the SWCC for the waste rock was under-predicted.

The combined theoretical and knowledge-based approach capability of the SOILVISION model was used to improve the original prediction of the SWCC. A waste rock sample from the SOILVISION soil data-base having a similar particle size distribution to the waste rock sample shown on Figure 3 was identified by data query. The SWCC for this waste rock was already predicted and calibrated by adjusting the packing porosity parameter (theoretical prediction parameter) until the predicted SWCC matched the laboratory measured SWCC. The calibrated packing porosity for the data-base waste rock was used to predict the SWCC for the waste rock shown on Figure 3. This theoretical/knowledge-based prediction compared well to the laboratory measured SWCC (Figure 5), an obvious improvement from the prediction made using the theoretical prediction alone.

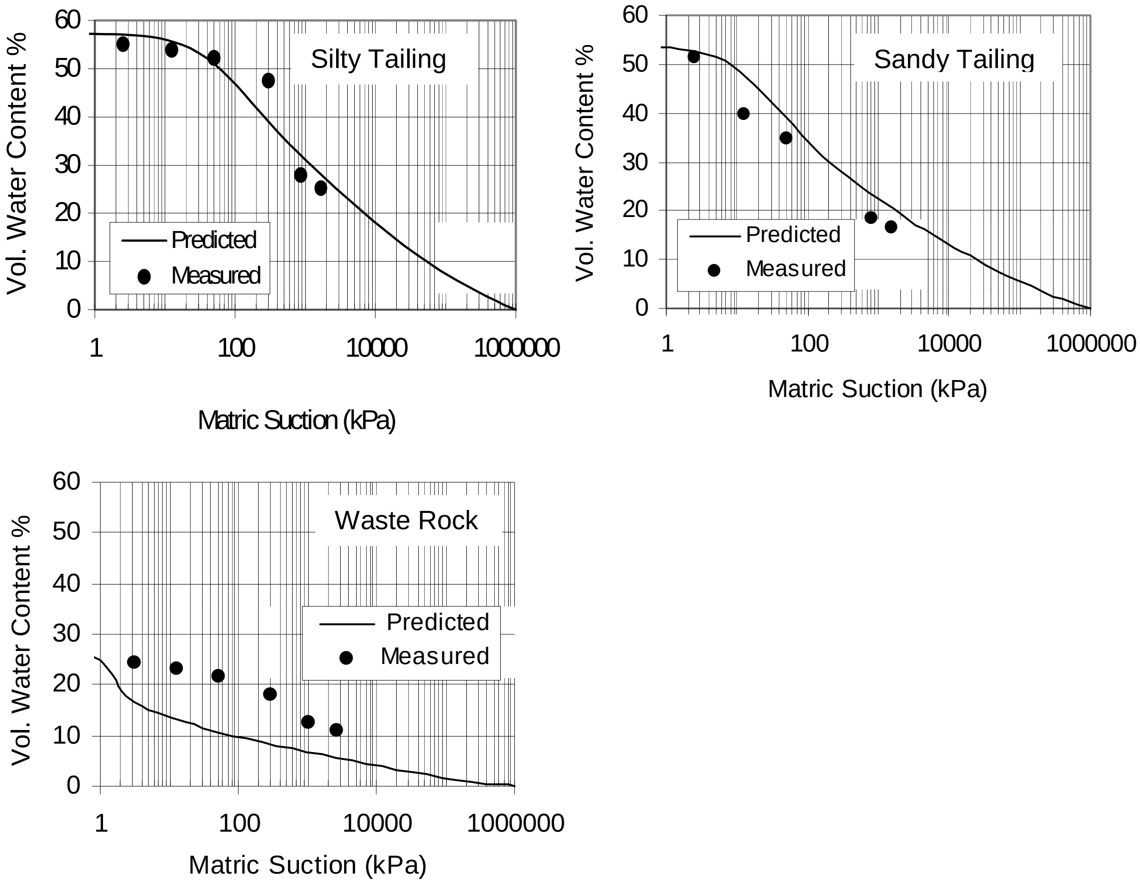

Figure 4. Predicted soil-water characteristic curves for three mine soils using the theoretical method.

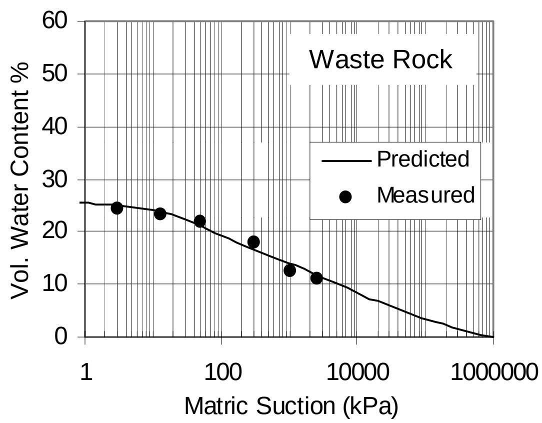

Figure 5. Predicted soil-water characteristic curve for the waste rock material using the combined theoretical and knowledge-based method.

4 DISCUSSION

The relatively poor comparison between predicted and laboratory measured SWCC for the waste rock sample and the good comparison for the tailing samples is due primarily to the shape of the particle size distribution. The tailing samples have uniform particle size distributions (i.e., predominantly sand or silt), whereas the waste rock sample has a very well-graded particle size distribution that includes clay, silt, sand and gravel size particles.

There are other factors (i.e., density) that should be taken into consideration when predicting the SWCC from the particle size distribution. Studies conducted by Veyera and Martin (1983) and Swanson and Barbour (1991) showed that density affects the shape of the SWCC for fine grained soils, while coarse grained soils such as sands are relatively unaffected by changes in density. Therefore, any mine soils that contain a fine grained fraction, such as all three mine soils shown in Figure 3, are susceptible to the effects of density. The combined theoretical/knowledge-based prediction demonstrated in Section 3 is particularly well suited to deal with these effects (provided that a sufficient data base of soils has been compiled to describe these effects).

5 CONCLUSIONS

The examples presented in this paper indicate that theoretical methods for predicting the SWCC using the particle size distribution are most accurate for mine soils exhibiting a uniform particle size distribution (i.e., tailing) and least accurate for mine soils exhibiting a well-graded particle size distribution (i.e., waste rock). Inaccurate SWCC data can translate into inaccurate hydrologic predictions such as prediction of net infiltration for the analysis and design of soil caps, predicting potential seepage from the base of stockpiles and predicting the migration time of potential seepage to an underlying aquifer.

Predictions for the SWCC of well-graded mine soils such as waste rock may be improved using a combined theoretical/knowledge-based approach. When SWCC data for similar soils is available to calibrate predictions, the combined theoretical/knowledge-based method can provide accurate predictions of the SWCC for mine soils for both well-graded and uniform mine soils for use in preliminary analysis and design.

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