Indirect Procedures to Determine Unsaturated Soil Property Functions

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ABSTRACT

The implementation of unsaturated soil mechanics into engineering practice comes at a time when the geotechnical engineer is accepting a new soil mechanics paradigm. Computers and numerical modeling play a dominant role in responding to ‘What if --- ?’ scenarios to engineering problems. For many problems involving unsaturated soils, it is necessary to be able to input approximate unsaturated soil property functions into the numerical model. For many problems, these functions can be approximated from either a knowledge of the soil-water characteristic curve or the grain size distribution of the soils involved. Databases of previous test data, along with a knowledge-based system becomes an important part of determining the necessary input soil property functions This implementation procedure deviates somewhat from historical classical soil mechanics procedures but has proven to be an acceptable procedure for engineering practice.

RÉSUMÉ

L’implantation des mécaniques de sols insaturés en pratique d’ingénierie se produit lorsque l’ingénierie géotechnique accepte un nouveau paradigme en sols mécaniques. Les ordinateurs et les modèles numériques jouent un rôle dominant dans les problèmes d’ingénierie en répondant au scénario “Qu’est-ce qui arriverait si?” Pour plusieurs problèmes impliquant des sols insaturés, il est nécessaire d’être capable d’introduire des fonctions approximatives des propriétés du sol insaturé au modèle numérique. Pour plusieurs problèmes, ces fonctions peuvent être estimées a partir de connaissance de la courbe caractérisque eau-sol ou de la distribution en grosseur de grains des sols impliqués. Les données de base de tests précédents de même que les systèmes de connaissance de base deviennent un facteur important dans la détermination des données nécessaires pour les fonctions des propriétés du sol. Cette procédure d’implantation dévie en quelque sorte des procédures historiques et classiques de mécaniques du sol mais s’avère cependant être une procédure acceptable pour la pratique en ingénierie.

INTRODUCTION

The characterization of unsaturated soil behavior in terms of two independent stress state variables appears to be generally accepted as evidenced from the proceedings of the First International Conference on Unsaturated Soils, Paris, France (1995). Theories have been formulated for the classic areas of i) seepage, ii) shear strength, and iii) volume change, for unsaturated soils (Fredlund, 1979). Constitutive relationships have been proposed for the classic areas of soil mechanics for saturated and unsaturated soils and in each case the soil properties become soil property functions.

The soil-water characteristic curve (relationship between water content and suction) has become of great value in estimating unsaturated soil property functions. The characterization of seepage, for example, in terms of a hydraulic head gradient and a coefficient of permeability function appears to be generally accepted (Fredlund, 1995). Figure 1 illustrates the relationship between the soil-water characteristic curve and the coefficient of permeability function for the unsaturated portion of the soil profile. The use of nonlinear soil property functions for analyzing unsaturated soils problems appears to be gaining general acceptance. This paper primarily addresses indirect procedures that can be used to estimate unsaturated soil property functions for use in the numerical modelling of saturated/unsaturated soil systems in engineering practice.

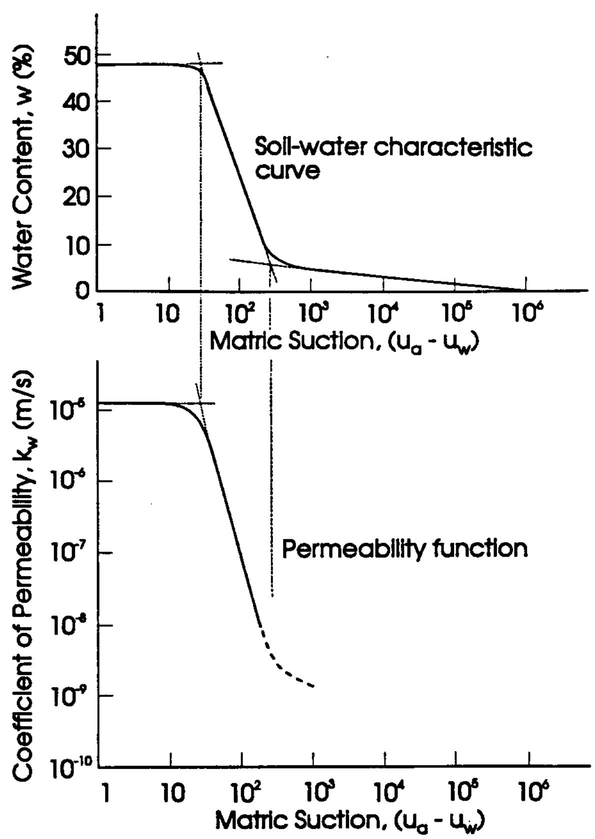

FIGURE 1 Visualization of the relationship between the coefficient of permeability function and the soil-water characteristic curve.

PROPERTIES OF THE SOIL-WATER CHARACTERISTIC CURVE

The behavior of unsaturated soils (i.e., unsaturated soil property functions) are strongly related to the pore size geometry and the pore size distribution. The soil-water characteristic curve becomes a dominant relationship for understanding unsaturated soil behavior. The soil-water characteristic curve defines the degree of saturation corresponding to a particular suction in the soil and becomes a measure of the pore size distribution of the soil. Figure 2 shows the general features of the desorption and adsorption branches of a soil-water characteristic curve. An equation proposed by Fredlund and Xing (1994) to empirically best-fit the soil-water characteristic curve is as follows:

$$\theta_w = C(u_a - u_w)\frac{\theta_s}{\left\{\ln\left[e + \left((u_a - u_w)/a_f\right)^{n_f}\right]\right\}^{m_f}} \qquad [1]$$

where: θ_w = volumetric water content, θ_s = volumetric water content at saturation, e = 2.718…...., (u_a - u_w) = soil suction, a_f = soil parameter approximating the air entry of the soil, n_f = soil parameter related to the rate of desaturation, m_f = soil parameter related to residual water content conditions, C(u_a- u_w) = correction factor to ensure that the function goes through 1,000,000 kPa of suction at zero water content.

The soil-water characteristic curve can be used to compute approximate soil property functions for unsaturated soils. Examples are the coefficient of permeability function, the coefficient of water volume change function and the shear strength function (Fredlund, 1995). While it is relatively easy to measure the soil-water characteristic curve in the laboratory, it is still quite costly and the test has not found its way into most conventional soils laboratories. For this reason, an examination should be made of the possibility of using grain size distribution classification test data for the prediction of the soil-water characteristic curve.

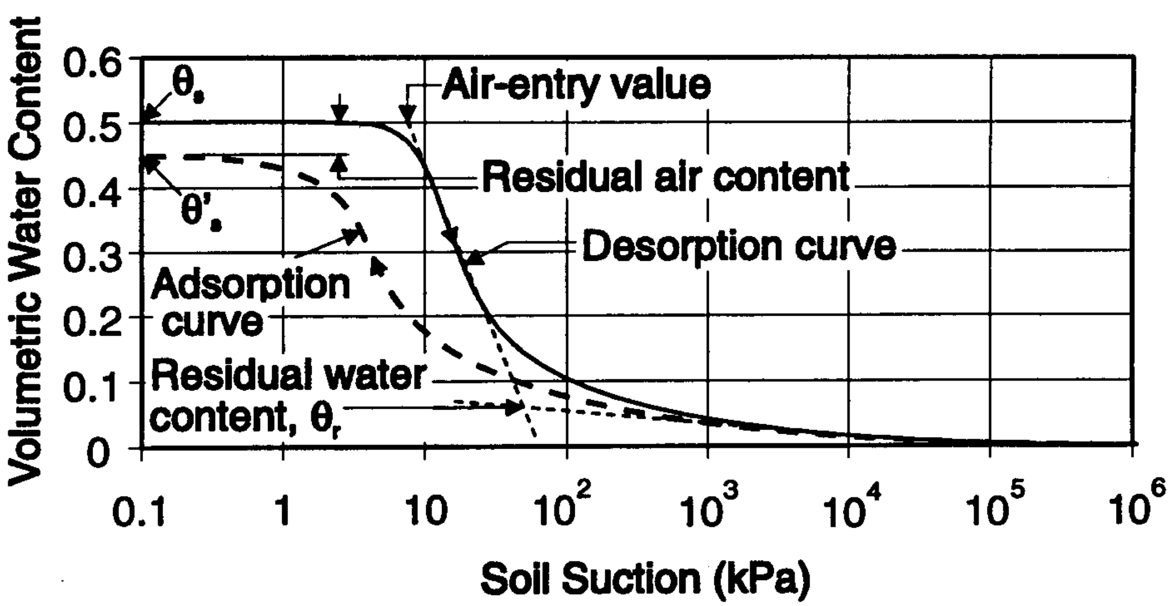

FIGURE 2 Definition of variables associated with the soil-water characteristic curve.

APPROACHES TO OBTAIN UNSATURATED SOIL PROPERTY FUNCTIONS

Several approaches can be taken towards the determination of unsaturated soil property functions (Fig. 3). The term, **unsaturated soil property functions,** refers to such relationships as: 1.) coefficient of permeability versus soil suction, 2.) water storage variable versus soil suction, and 3.) shear strength versus soil suction. Laboratory tests can be used as a direct measure of the required unsaturated soil property. For example, a (modified) direct shear test can be used to measure the relationship between matric suction and shear strength. These tests can be costly and the necessary equipment may not be available. Therefore, it may be sufficient to revert to an indirect laboratory test involving the measurement of the soil-water characteristic curve for the soil. The soil-water characteristic curve can then be used in conjunction with the saturated shear strength properties of the soil, to predict the relationship between shear strength and matric suction. Some accuracy will likely be lost in reverting to this approach; however, the trade-off between accuracy and cost may be acceptable for many engineering projects.

Figure 3 also shows the possibility of using a classification test for the prediction of the desired unsaturated soil property function. A classification test such as a grain size analysis is used to estimate the soil-water characteristic curve which in turn is used to determine the unsaturated soil property function. A theoretical curve could be fitted through the data from a grain size analysis (Fig. 4). The theoretical grain size curve is then used for predicting the soil-water characteristic curve. A comparison of the predicted soil-water characteristic curve with experimental data is shown in Fig. 5. While there may be a further reduction in the accuracy of the predicted unsaturated soil property function, the engineer must assess whether or not the approximated soil function is satisfactory for the analyses which must be performed.

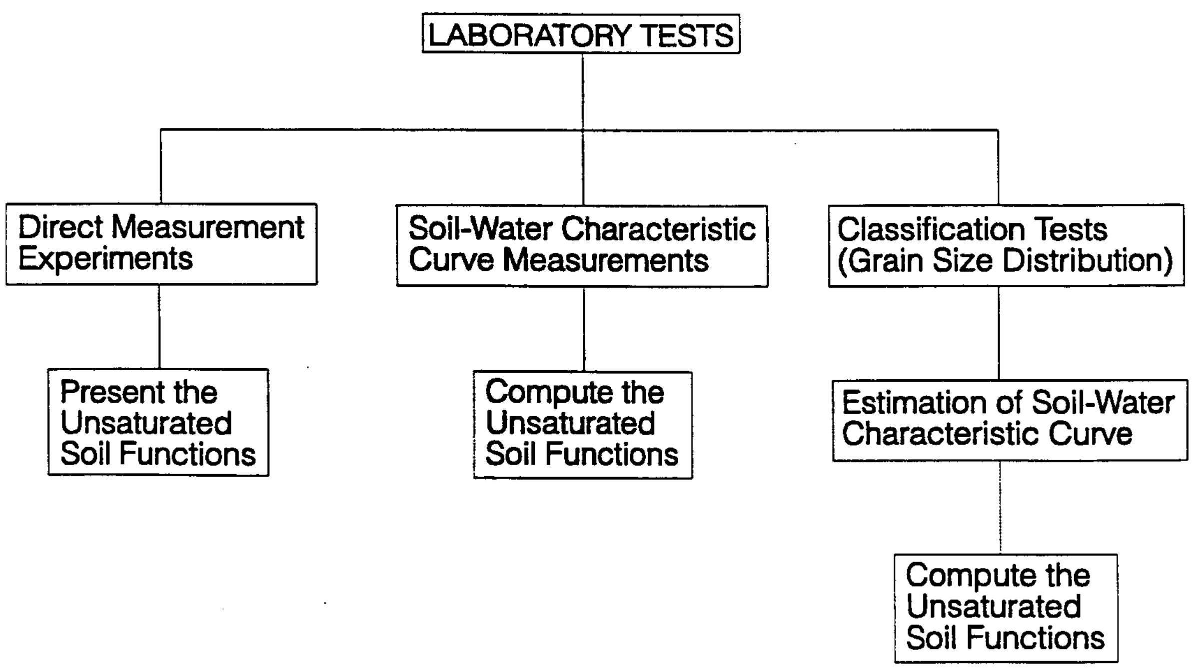

FIGURE 3 Approaches that can be used in the laboratory to determine the unsaturated soil properties.

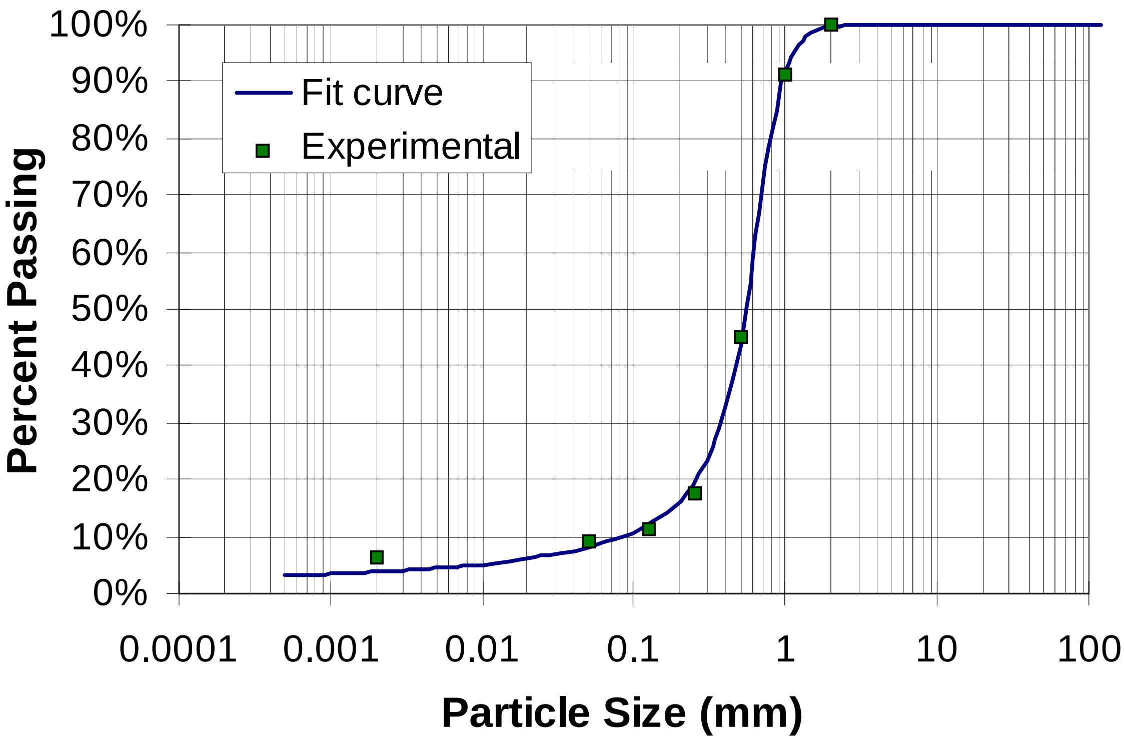

FIGURE 4 Grain-size distribution curve fit for a sand (#10720).

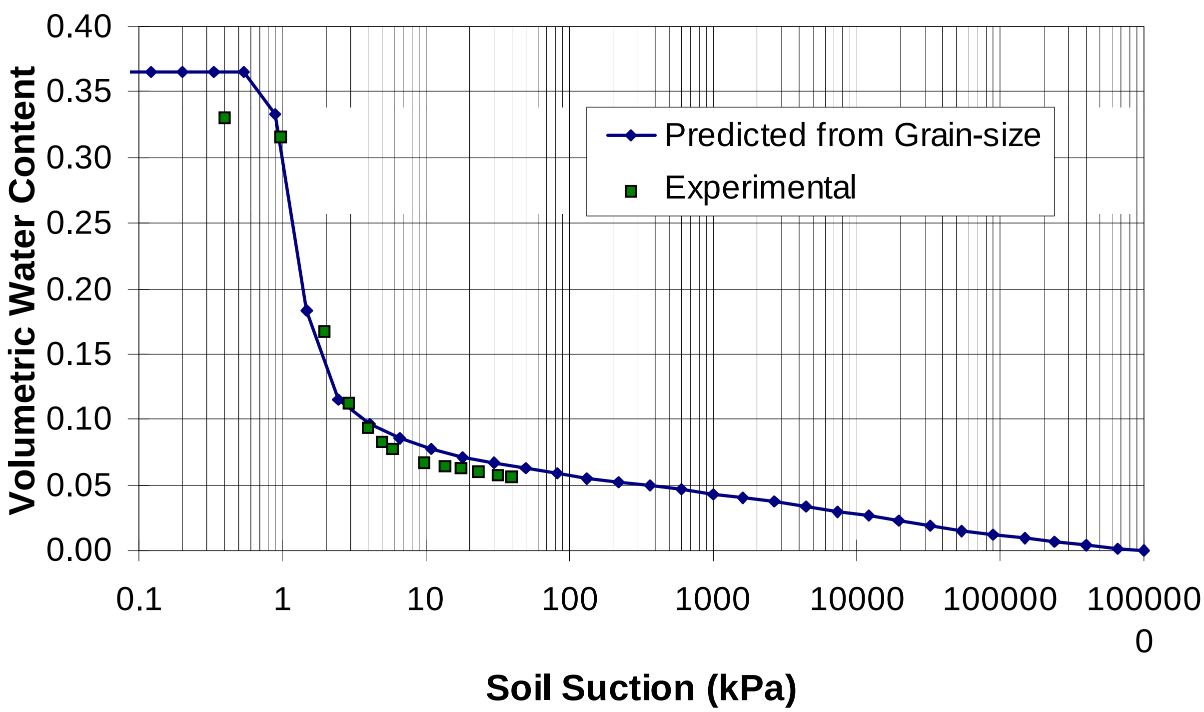

FIGURE 5 Comparison between experimental and predicted soil-water characteristic curves for sand #10720.

Figure 6 illustrates how one of several approaches can be used to determine the unsaturated soil property functions when using the classification and/or soil-water characteristic curve in conjunction with a knowledge-based system, to compute the unsaturated soil property functions. Plausible procedures can best be viewed within the context of a database of soil-water characteristic curve information and a knowledge-based system. Ongoing use is made of data accumulated from other laboratory studies. The first suggested procedure involves matching measured soil-water characteristic curves with soil-water characteristic curves already in the database. The measured soil-water characteristic curves can be either used to compute unsaturated soil property functions or can be used to select unsaturated soil property functions already in the database.

The second suggested procedure involves matching measured classification properties (i.e., grain size curves) with classification properties already in the database. Once one or more similar soils have been found, corresponding soil-water characteristic curves can be retrieved from the database. These soil-water characteristic curves data can be used to compute suitable unsaturated soil property functions or existing unsaturated soil property functions can be retrieved from the database.

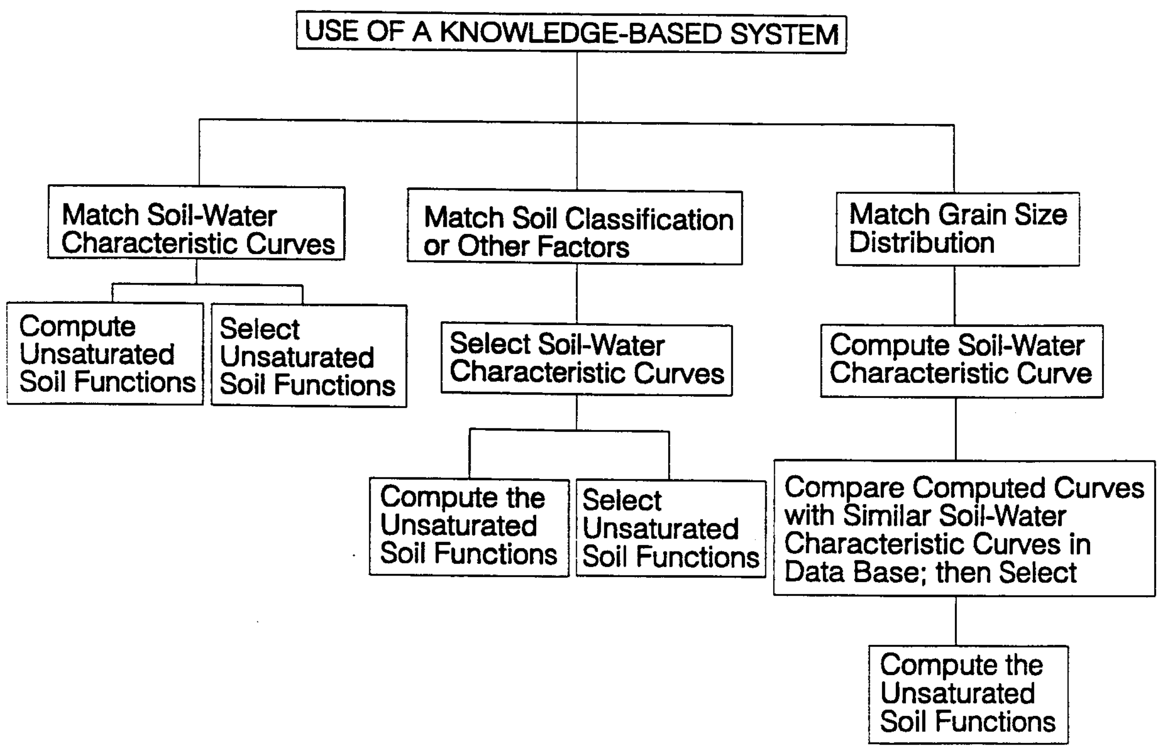

FIGURE 6 Approaches that can be used to determine the unsaturated soil property functions when using classification tests and a data base.

The third suggested procedure involves working directly with the measured grain size curve. There may also be some value in comparing the grain size curve to grain size curves in the database. Soil-water characteristic curves can then be computed and compared to soil-water characteristic curves in the database. A decision must be made regarding a reasonable soil-water characteristic curve and then the unsaturated soil property functions can be computed. Each of the above suggested procedures becomes increasingly less precise.

ANALYTICAL CHARACTERIZATION OF THE GRAIN SIZE DISTRIBUTION CURVE

The mathematical equation form that is used for describing the soil-water characteristic curve can also be used for fitting the grain size curve. One of several equation forms could be used; however, reference will only be made Eq. [1] since it has the ability to independently characterize the two extremes of the function. As such, the portion describing the coarse fraction can be different in character from that describing the fine fraction. Three parameters and a correction factor are used to define the mathematical function. The meaning of the parameters can be described in relation to the soil-water characteristic curve but these parameters need to be redefined with respect to the grain size curve.

$$P = C(d_r)\frac{100}{\left\{\ln\left[e + \left((d)/a_s\right)^{n_s}\right]\right\}^{m_s}} \qquad \textbf{[2]}$$

where: P = percent passing, 100 = represents 100 percent passing, e = 2.718….., d = diameter of the particles in mm, a_s = parameter approximating the large particle in the distribution, n_s = parameter related to the uniformity of the particle size distribution and is similar to the uniformity coefficient, C_u , m_s = parameter related to residual particle sizes, C(d_r) = correction factor to ensure that the function goes through a lower limit particle diameter (e.g., 0.00001 mm).

The grain size curve parameters, (i.e., a_s, n_s and m_s) can be obtained by performing best-fit studies on existing databases. Figure 7 shows several grain size curves for soil ranging from fine to coarse and from well-graded to poorly graded. Each of the grain size curves was best-fit with the above Eq. [2] along with the appropriate grain size curve parameters. These grain size parameters are useful when attempting to perform a search for similar soils in an existing database. The grain size curve parameters allow the grain size distribution of a soil to be represented as a continuous mathematical function for further analysis. The grain size curve can provide valuable information on the pore size distribution of the soil. This is true only to a degree, and the volume-mass properties as well as a "packing factor" must be taken into consideration (Fredlund et al, 1977).

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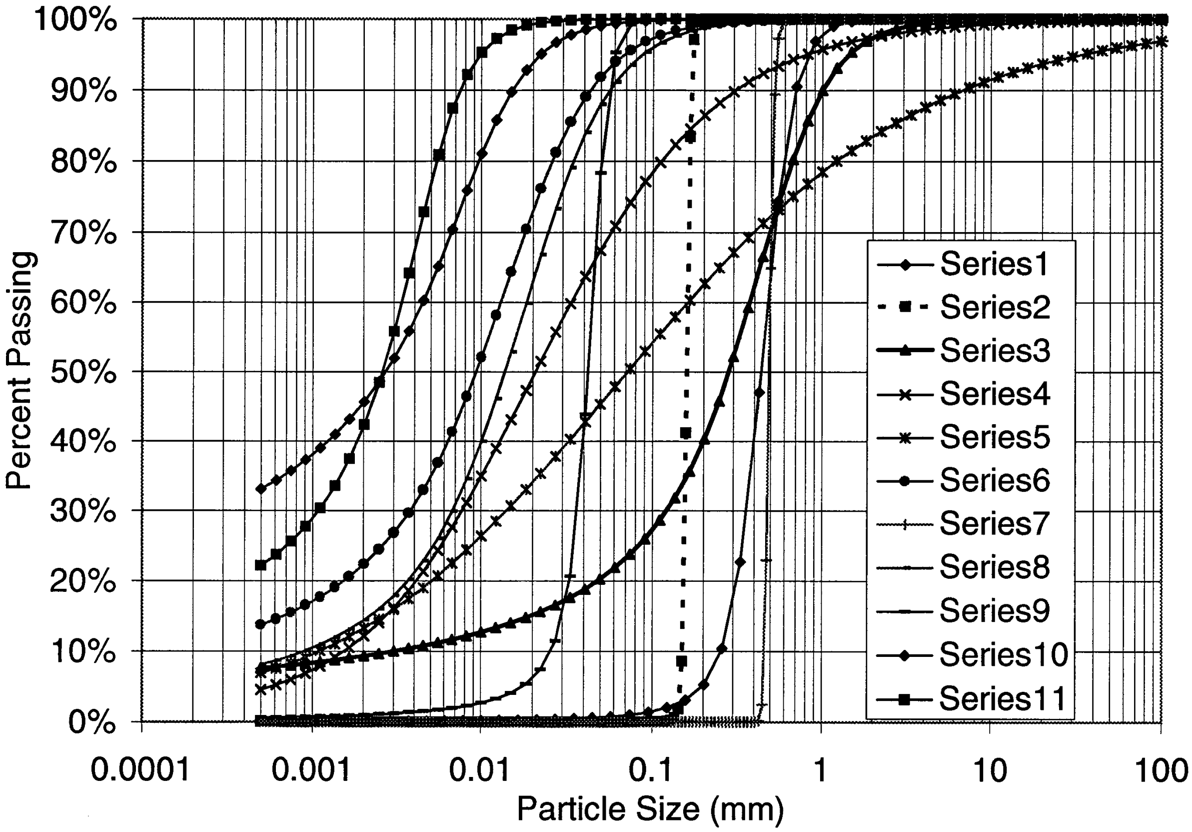

FIGURE 7 Theoretically fitted grain size curves for 11 soils.

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