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ABSTRACT

A small-scale centrifuge was used to obtain water content versus suction data for two relatively incompressible soils. The centrifuge was utilized to increase gradients within the specimen to assist in the drainage of water from the soil pores, thus decreasing the amount of time required to obtained equilibrium conditions within the soil over currently used methods of unsaturated soils testing. To obtain the centrifuge testing data, a specially designed soil specimen holder was fabricated. The results from the centrifuge testing were compared to existing soil-water characteristic curve data obtained using conventional unsaturated soil testing equipment (i.e., Pressure Plate). The "closeness of fit" of the centrifuge results in comparison to data obtained from other methods confirms the accuracy and suitability of the centrifuge-based method.

RÉSUMÉ

Une centrifuge a été utilisée à petite échelle pour obtenir des données de contenu en eau versus succion pour deux sols relativement incompressibles. La centrifuge a été utilisée pour augmenter les gradients dans les échantillons de façon à aider l'écoulement de l'eau des pores du sol tout en diminuant le temps requis pour obtenir les conditions d'équilibre dans le sol comparé aux méthodes couramment utilisées pour tester les sols insaturés. Pour obtenir les données testant la centrifuge, un support spécialement conçu pour les échantillons de sol a été fabriqué. Les résultats des tests de centrifuge ont été comparés aux données existantes de la courbe caractéristique eau-sol obtenues en utilisant l'équipement conventionnel testant le sol insaturé (i.e., Plaque de pression). La similarité des résultants de centrifuge comparés aux données obtenues avec les autres méthodes confirme la précision et l'acceptation de la méthode basée sur la centrifuge.

INTRODUCTION

The use of the principles of unsaturated soil mechanics, in both research and industry, has gained a much wider acceptance. Traditional saturated soil mechanics theories fall short in their ability to provide satisfactory and rigorous solutions for many geotechnical problems. The primary deterrent to the application of unsaturated soils analyses in design is the need to obtain reasonable unsaturated soil parameters. The most valuable information required for conducting unsaturated soils analyses is the soil-water characteristic curve. The soil-water characteristic curve is a plot of water content (i.e., volumetric water content, gravimetric water content or degree of saturation) versus soil suction. This curve provides insight into the storage capacity of the soil, as well as the hydraulic conductivity and void size distribution of the material. Depending upon the type of material being investigated, and the accuracy of the data required, the time necessary to obtain data from pressure plate type methods of testing can be prohibitive. By developing a centrifuge-based soil-water characteristic curve test, the potential exists for the collection of accurate water content versus suction data in a shorter period of time.

THEORY

To obtain water content versus soil suction data from a centrifuge test the relationships between the induced suction within the centrifuge, the centrifugal radius, the angular velocity of the centrifuge and the density of the pore fluid must be known. Such a relationship was developed by Gardner (1937). The equation is as follows:

$$\psi_1 = \frac{\rho\omega^2}{2}\left(r_2^2 - r_1^2\right) \qquad [1]$$

where:

ψ_1 = suction at a point within the centrifuged soil specimen, r_1 from the center of rotation,

ρ = density of the pore water fluid,

ω = angular velocity,

r_2 = centrifugal radius to a constant elevation free water surface,

r_1 = centrifugal radius to a point within the centrifuged soil specimen.

Using Eq. 1, and knowing the above variables, the suction at any point within a soil specimen being tested in a centrifuge, can be determined. By combining water content results collected from the soil specimen being centrifuged with the computed soil suction values, a soil-water characteristic curve can be obtained.

The pore fluid is driven from the soil specimen by the gravity force gradient created by the centrifuge when spinning. The increased gravity force acts in opposition to the capillary forces acting within the soil matrix causing drainage to occur wherever the capillary forces within the soil are exceeded. Drainage will continue to occur from the soil pores until the gravity force created by the centrifuge equals the capillary forces within the soil for a constant centrifugal speed. Equilibrium conditions have been reached when there is no further drainage of water.

LABORATORY PROGRAM

The laboratory program embraces the selection of an appropriate centrifuge, the design of the specimen holder and the testing of two suitable soil types.

Centrifuge Apparatus

The centrifuge used for testing during the laboratory program was the Beckman Model J6-HC Centrifuge. This apparatus is classified as a small-scale medical centrifuge and has a maximum centrifugal radius of twenty-five cm. The Model J6-HC is equipped with a refrigeration unit which allows for the control of the temperature of the centrifuge chamber. Additionally, with the as equipped Beckman Model JS-4.2 Swinging Bucket Windscreen Equipped Rotor, the Beckman Model J6-HC Centrifuge has a maximum speed of 4200 revolutions per minute (i.e., rpm) and is capable of carrying a maximum of six specimens.

Centrifuge Soil Specimen Holder

For the laboratory program a soil specimen holder was developed that created the conditions defined by Eq. 1 and that could be placed into the centrifuge for testing. This holder is shown in Figs. 1 and 2. The holder consists of five soil specimen rings, a drainage plate and a reservoir cup as indicated in Fig. 1. This holder maintains a constant elevation, free water surface within the drainage plate which has a known centrifugal radius, r_2, which is then used in Eq. 1. The configuration of the holder allows for a maximum of five water content versus suction determinations to be made from a single test specimen.

A high flow, low air entry, porous, ceramic stone is used in the drainage plate to act as a filter medium to prevent the movement of soil contained within the soil specimen rings down into the free water surface reservoir. The water which drains from the soil contained in the soil specimen rings during testing, travels through the porous ceramic stone into the constant elevation free water surface reservoir. The maintenance of a constant elevation within the constant elevation free water surface reservoir is accomplished through the inclusion of eight overflow ports equally spaced around the perimeter of the drainage plate. Upon leaving the constant elevation free water surface reservoir, the water is allowed to enter the reservoir cup at the base of the soil specimen holder through a series of drainage ports and channels which connect the overflow ports to the reservoir cup.

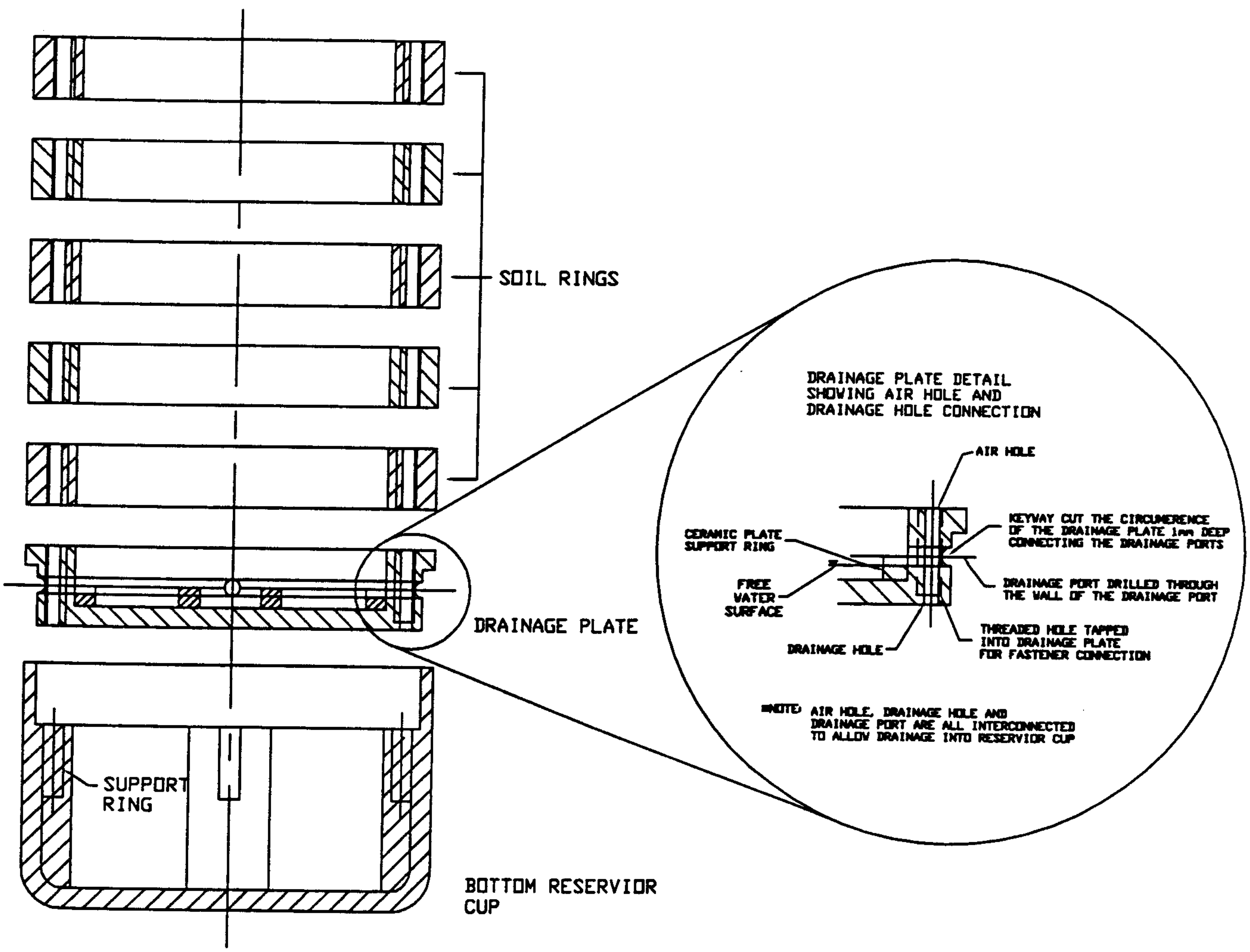

Figure 1. Centrifuge Soil Specimen Holder Cross-Section

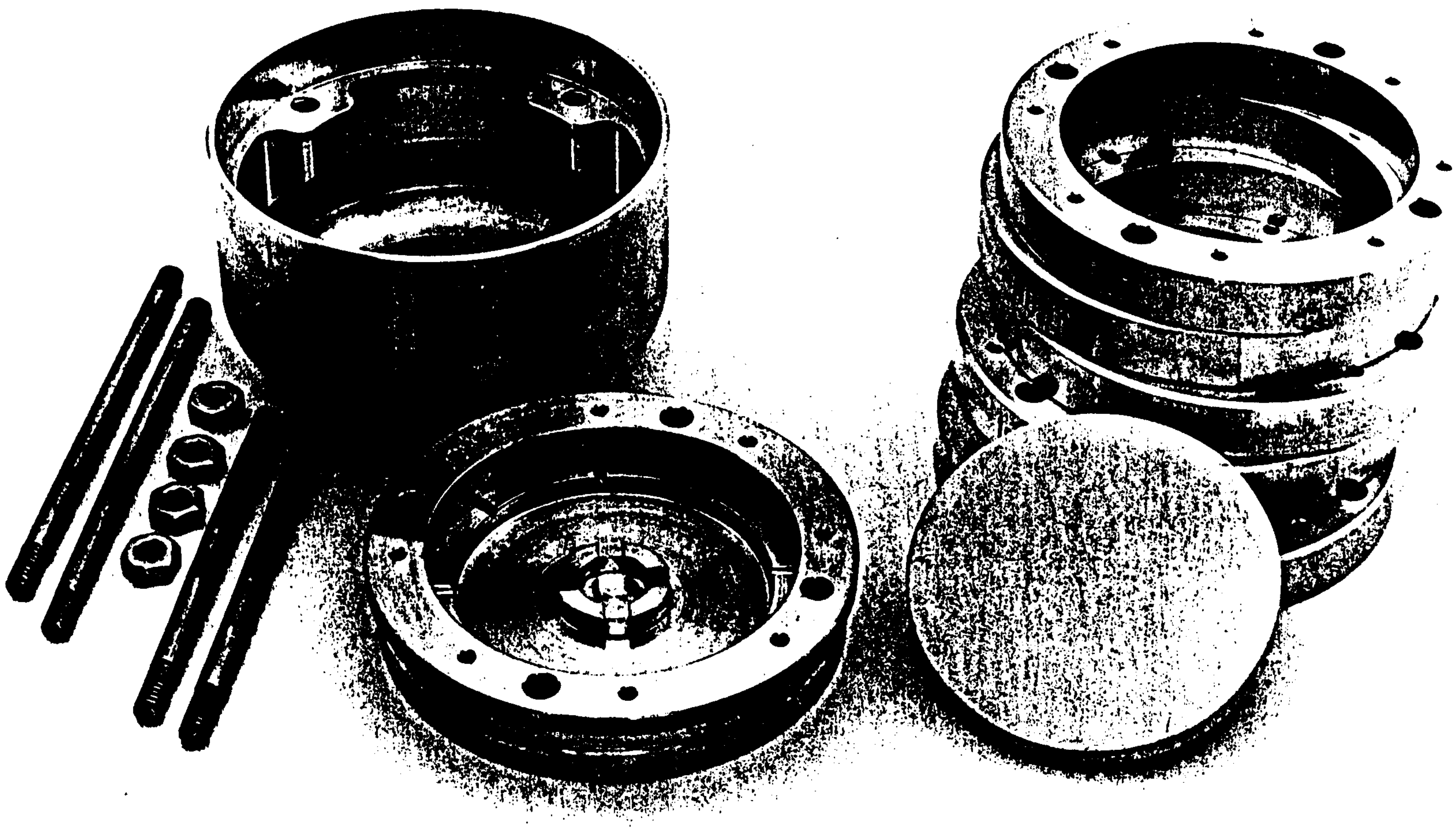

Figure 2. Centrifuge Soil Specimen Holder

Soils Tested

Two incompressible soils were tested using the centrifuge apparatus and centrifuge soil specimen holder. The soils tested were Beaver Creek sand, a fine to medium grained dune sand with less than five percent silt and clay size particles, and a Processed Silt (i.e., a natural silt that has been mechanically altered to remove the clay and sand sized fractions from the soil). The grain-size curve for these soils are shown in Fig. 3. Both of these soils had been extensively tested at the University of Saskatchewan, resulting in the availability of laboratory data that could be used for comparison purposes with the centrifuge-based results. For the centrifuge testing, both of these soils were placed into the centrifuge soil specimen holders in a slurried form, resulting in a completely saturated sample at the start of centrifuging.

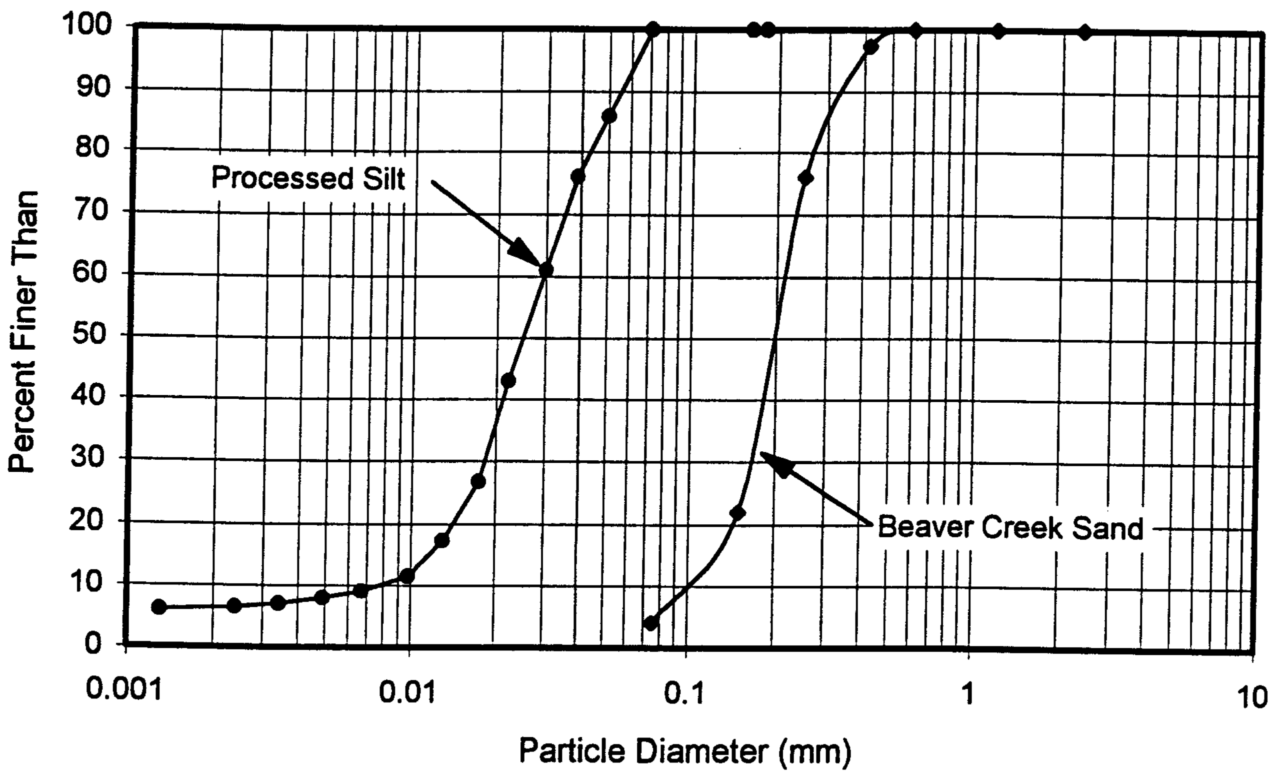

Figure 3. Grain-size Curves for Beaver Creek Sand and Processed Silt.

Testing Results

Several individual centrifuge tests must be combined in order to cover a large suction range on a complete soil-water characteristic curve. The results of the centrifuge testing on the Beaver Creek sand are shown in Fig. 4 along with the comparison data obtained by Rahardjo (1990) and Bruch (1993). The results of three separate centrifuge tests were combined to obtain the complete centrifuge curve. Figure 4 shows that the centrifuge-based test cannot produce water content versus suction data below a minimum suction of 1.5 kPa. This is due to limitations of the centrifuge and the soil specimen holder.

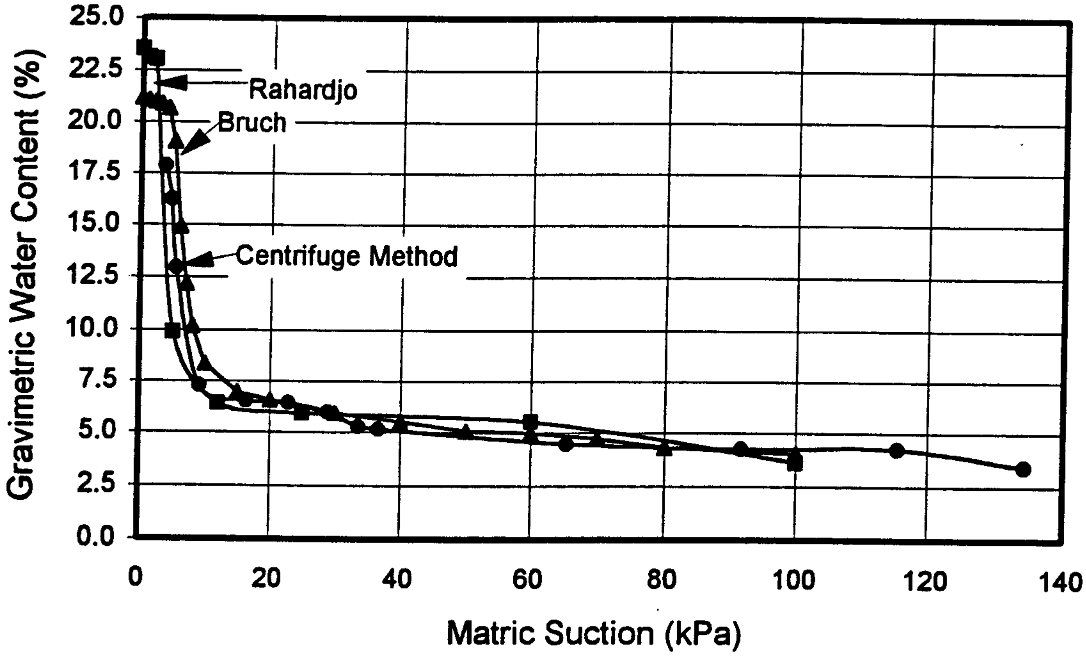

Figure 4. Centrifuge Soil-Water Characteristic Curve for Beaver Creek Sand shown with comparison data from Rahardjo (1990) and Bruch (1993).

The centrifuge results are of a similar magnitude and trend to the data obtained by Rahardjo (1990) and Bruch (1993), indicating the accuracy and acceptability of the centrifuge-based soil-water characteristic curve testing method for this type of material. Using the centrifuge-based testing method, a centrifuge-based soil-water characteristic curve for Beaver Creek sand like the curve shown in Figure 4 can be obtained in a time of two days which includes a twenty four hour period for water content determinations. A similar curve, such as those obtained by Rahardjo (1990) and Bruch (1993), obtained using the Pressure plate and Tempe cell apparatuses shown in Fig. 4, would require a minimum of one to two weeks.

The centrifuge-based testing results for the Processed Silt are shown in Fig. 5 along with comparison data obtained by Bruch (1993). Some separation exists between the two curves with the general shape and trends of the data being similar. It must be noted that no water content data was obtainable between the suctions of 10 and 40 kPa due to the critical speed range of the Beckman Model J6-HC Centrifuge. It is over this suction range that the centrifuge curve is shown as a dashed line, indicating the absence of data. Additionally, no comparison data was obtained for suction points in excess of 100 kPa. Using the centrifuge method, a complete soil-water characteristic curve for the Processed Silt can be obtained in three to four days. Obtaining water content versus suction data using more conventional methods would require a testing period of two to four weeks to produce the same curve, depending upon the number of data points collected.

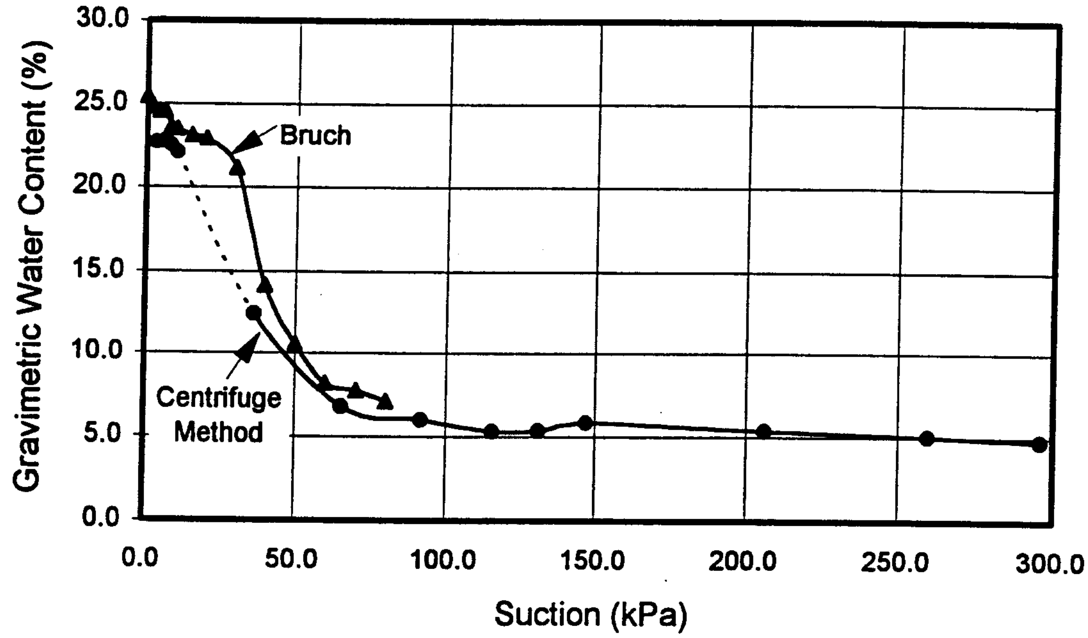

Figure 5. Centrifuge Soil-Water Characteristic Curve for Processed Silt shown with comparison data from Bruch (1993).

DISCUSSION

The results obtained by the centrifuge-based method for obtaining soil-water characteristic curve data on incompressible soils correlate favourably with existing data for the same soils. Refinements and possible alterations to the centrifuge testing method are still required in order to make this method of obtaining water content versus suction data more highly reliable and accurate over a wider range of soils. However, the potential exists for this method to be a useful tool for obtaining the necessary data in the application of unsaturated soil mechanics principles to geotechnical problems.

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