A Simple Technique of Using Continuously Disturbed Line (CDL) as a Tool in the Estimation of Compacted Soils Behaviour

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ABSTRACT
This paper presents the results of a series of unsaturated compressibility tests using conventional consolidation and shear strength results from modified ring shear tests (MRST). Testing was conducted on both saturated and unsaturated soil specimens of Indian Head till. The results of the study suggest that the Critical State Line (CSL) is approximately equal to an Approximate Continuously Disturbed Line (CDL_a) which is estimated from the relationship of water content to matric suction for the compacted soil. The CSL appears to follow the compaction line at high matric suctions while remaining lower than the CSL at lower matric suction values. The intersection point of the CSL and the CDL_a lines correlates well with the point at which a single value of the microstructural water ratio e_{wm} can be calculated from the measured shear strength data at different matric suctions. The plot of void ratio to water content of the compaction curve provides a good indication of the threshold point along the shear strength envelope where matric suction contribution to the shear strength of the unsaturated soil is linear. The results indicate that there is a reasonably good agreement between the shear strength test results and the compaction/suction results for matric suctions higher than 100 kPa. This threshold point roughly corresponds to the air-entry value of the water content versus suction relationship derived from the MRST shear strength data.

RÉSUMÉ
Cet article présente les résultats d'une série d'essais de compressibilité sur un sol non-saturé en utilisant une consolidation conventionnelle ainsi que les résultats d'essais menés sur un appareil de cisaillement annulaire modifié (MRST). Plusieurs essais ont été effectués sur des échantillons saturés, aussi bien que non saturés, de till d'Indian Head. Les résultats de l'étude suggèrent que la ligne d'état critique (CSL) est approximativement égale à une ligne approximative de la ligne d'état continuellement perturbé (CDL_a) qui est estimée d'après la relation entre la teneur en eau et la succion matricielle du sol compacté. La CSL semble suivre la ligne de compaction aux plus hautes valeurs de succion matricielle, alors qu'elle demeure sous-jacente avec une pente plus faible à de plus basses valeurs de succion. Le point d'intersection de la CSL avec la CDL_a correspond avec le point où une valeur unique de l'indice d'eau de la microstructure, e_{wm}, peut être calculé à partir des résultats de cisaillement annulaire à différentes succions. Le tracé de l'indice des vides en fonction de la teneur en eau de la courbe de compactage donne une bonne indication du seuil le long de l'envelope de résistance au cisaillement où la contribution de la succion matricielle à la résistance au cisaillement du sol non-saturé est linéaire. Les résultats indiquent qu'il existe une bonne correspondance entre les résultat d'essai en cisaillement et les résultats de succion au compactage pour pour des succions matricielles supérieures à 100 kPa Ce seuil correspond à peu près à la pression d'entrée d'air dérivée d'après les résultats des essais MRST.

1 INTRODUCTION

Compacted unsaturated soils are used in the construction of many geotechnical and geo-environmental structures such as embankments, pavements and soil liners. Conventional soil mechanics cannot be extended in the interpretation of the mechanical behavior (i.e., shear strength and volume change) of compacted soils as they are typically in a state of unsaturated condition. Experimental determination of the hydro-mechanical properties of compacted unsaturated soils is time consuming and needs extensive equipment and specially trained personnel (Fredlund and Rahardjo 1993). Due to this reason, in recent years several simplified models were proposed in the literature to predict the shear strength and flow behavior of unsaturated soils using the Soil-Water Characteristic Curve (SWCC) and the saturated properties of the tested soil (for example, van Genuchten 1980, Fredlund et al. 1994, Vanapalli et al. 1996, Fredlund et al. 1996). The limitation of these models for predicting the compacted unsaturated soil behaviour is that they generally use the degree of saturation at a given matric suction to calculate the contribution of the matric suction without taking into account the influence of changes in pore-structure that arises due to the influence of the stress state variables and the shearing process. The SWCC is not a unique relationship for compacted soil and is dependent on several factors such as the initial compaction water content and density, the method of compaction, the clay chemistry and the stress state variables. All these parameters influence the soil fabric and the soil pore structure (Vanapalli et al. 1999). The presently available models for predicting the shear strength of unsaturated soils are more suitable for predicting the peak strength which develops with limited displacement without significant changes in their original soil structure. However, in the case of compacted unsaturated soils there may not be a well defined peak strength that develops with limited displacements. In many cases, failure may be induced only after large displacements or deformations and therefore can result in significant changes in the original pore structure of compacted soils.

Therefore, it may be more desirable to utilize the critical state strength of unsaturated soils. Roscoe et al (1958) defined the critical void ratio as the ultimate state of a sample for which any arbitrary further increment of shear distortion will not result in any change of void ratio. It is is only achieved after very large deformations. Equipment such as the direct shear or triaxial shear devices modified to test unsaturated soils that are suitable for measuring peak shear strength, may not be suitable for measuring the critical state strength. The modified ring shear test device (MRST) used in this research provides a more reliable measurement of the critical state shear strength of compacted soils (Infante Sedano et al. 2007).

The critical state framework originally proposed for interpreting the saturated soils behaviour has been extended for unsaturated soils taking account of the influence of stress state variables including soil suction (for example, Alonso et al. 1990). Ridley (1995) studies show that at any particular level of matric suction, a well defined and linear set of ultimate states exist. The slope and zero stress intercept of the ultimate relationship are, however, both non-linear functions of the soil suction. Earlier studies undertaken by Croney and Coleman (1954) showed that clay specimens would reach an ultimate suction state when sheared at constant moisture content conditions. This line is referred to in the literature as the continuously disturbed line (CDL) and was found to be independent of the initial fabric (soil structure) of the soil. Limited studies by Ridley (1995) indicated, that the critical state line (CSL) and the CDL were parallel to each other.

A methodology that could allow the determination of the critical state properties of a soil without the complex experimental procedures would be useful for engineering practice applications for reliable interpretation of the mechanical behavior of fine-grained, compacted unsaturated soils.

2 BACKGROUND

Various interpretation techniques or simplified models have been proposed to describe the shear strength of unsaturated soils (Fredlund et al. 1978, Alonso 1990, Toll 1990, Vanapalli et al. 1996, Murray 2002). These models use two stress state variables: net normal stress, (σ - u_a), and matric suction, (u_a - u_w), where σ is the total normal stress, u_a is the pore air pressure, and u_w is the pore water pressure. In most cases, the degree of saturation at a given matric suction is required to calculate the contribution of the matric suction to the shear strength of an unsaturated soil. In the case of coarse grained soils, the degree of saturation can generally be used directly as a factor to calculate the fraction of the matric suction contributing to the shear strength (Vanapalli and Fredlund 2000). However, more generally the fraction of the matric suction contributing to the shear strength is expressed as a non-linear function of the degree of saturation at a given matric suction as obtained from the SWCC. Such is the case of the equation presented by Vanapalli et al. (1996) and Fredlund et al. (1996) which express the shear strength of an unsaturated soil, τ, as:

$$\tau = c' + \tan(\phi')(\sigma - u_a) + S^{\kappa}\tan(\phi')(u_a - u_w) \qquad [1]$$

where c' is the effective cohesion, ϕ' the effective friction angle, S is the degree of saturation, and κ is a fitting parameter.

Many critical state models are available in the literature to interpret the mechanical behavior of unsaturated soils (Alonso 1990, Toll 1990, Murray 2002, Tarantino and Tombalato 2005). The framework proposed by Tarantino (2007) makes use of the microstructural water ratio e_{wm}, which separates the regions of inter-aggregate porosity and that of intra-aggregate porosity as observed by Romero (1999) and Romero and Vaunat (2000). Only the water in the inter-aggregate macropores contributes to the mechanical behaviour of the soil, while the aggregates act as large individual soil particles. Romero and Vaunat (2000) introduced a term called the degree of saturation of the macro voids, S_{rM}, which they defined as:

$$S_{rM} = \frac{e_w - e_{wm}}{e - e_{wm}} \qquad [2]$$

where e_w is the water ratio (the ratio of the volume of water over the volume of solids), and e is the void ratio.

Using equation [2], Tarantino and Tombolato (2005), and Tarantino (2007) defined a framework for the critical state of unsaturated soils.

$$q = M\left(p + s\frac{e_w - e_{wm}}{e - e_{wm}}\right) \qquad [3]$$

where q is the deviatoric stress, M the stress ratio, p the average principal stress, and s the suction.

Rewriting this equation in terms of shear stress and net normal stress, it can be expressed as:

$$\tau = \tan(\phi')\left((\sigma - u_a) + (u_a - u_w)\frac{e_w - e_{wm}}{e - e_{wm}}\right) \quad [4]$$

where τ is the shear strength on the plane of failure, and σ is the total normal stress on the plane of failure.

Theoretically, all the parameters in this formulation have a physical meaning and could be measured. In practice, however, it is difficult to determine e_{wm}, and as such it may be more practical to consider it as a fitting parameter (Tarantino 2007). The advantage of this technique is that this fitting parameter can be fitted to a single test result, instead of a group of tests at a common net normal stress. It is therefore possible to see how the parameter varies as a function of the matric suction, and if it is indeed a single value parameter for a given soil.

Considering only the shear strength contribution due to suction, the parameter e_{wm} can be isolated from equation [4] by using the relationship $e_w = w\,G_s$:

$$e_{wm} = \frac{w G_s \tan(\phi')(u_a - u_w) - e\tau_{suction}}{\tan(\phi')(u_a - u_w) - \tau_{suction}} \quad [5]$$

The macrostructure of the soil is dependent on various parameters such as the compaction energy and water content. Using the critical state SWCC, where the macrostructure has been destroyed by shearing, could provide a unique SWCC and simplify the experimental programs. Given the observed links between the CSL and CDL lines, the current paper examines how the relationship of the water content of a compacted soil with respect to its suction relates to the CSL. This relationship, expected to bear similarities to the CDL will be called the Approximate CDL, or CDL_a.

3 TESTING PROGRAM

The following section outlines the properties of the soil tested, the development of the initial compaction energies curves, and the testing programs for compressibility, suction measurements and the MRST. The test specimens for the compressibility and suction measurements were prepared using six different initial compaction water contents and two different initial compaction energies. The specimens for the MRSTs were prepared using two different initial compaction water contents and sheared under both constant load (CLS) and constant volume (CVS) conditions.

The purpose of the experimental program was to compare the suction-water content relationship of the compacted specimens to the conditions of the specimen sheared to critical-state conditions.

3.1 Soil Tested

The soil used in this research project was a glacial till obtained from Indian Head, Saskatchewan. The tested soil had a liquid limit, w_L, of 32.5%, a plasticity index, I_P, of 15.5%, a specific gravity, G_s, of 2.72, a void ratio, e, after compaction ranging between 0.51 and 0.73, and φ' is 26.3° at critical state. The till is classified as *CL*, which is clay of low plasticity as per the USCS Classification System.

3.2 Development of the Initial Compaction Energy Curves

Prior to preparation of the specimens for testing, a Standard Proctor's test was conducted on the Indian Head till to obtain the upper boundary of the compaction energy that could be imparted to the soil. The initial water contents of the compacted specimens ranged from 14% to 19%. The optimum water content and maximum dry density of the till were found to be 14.4% and 18.3 kN/m^3, respectively.

Based on the results of the Standard Proctor's test two different static compaction stresses were selected to be used to prepare the test specimens. The first series of results are designated as LE, which corresponds to the low compaction energy. The static compaction stress of LE is equal to 375 kPa which for the soil tested corresponded to a compaction energy of 70 kJ/m^3. The second series designated as HE, corresponded to the high compaction energy specimens prepared with a static compaction stress of 700 kPa equal to compaction energy of 140 kJ/m^3. These energy compaction curves would then dictate the initial water content and density values for the test specimens. A comparison between the three compaction curves (Standard Proctor, high and low compaction energies) is shown in Figure 1.

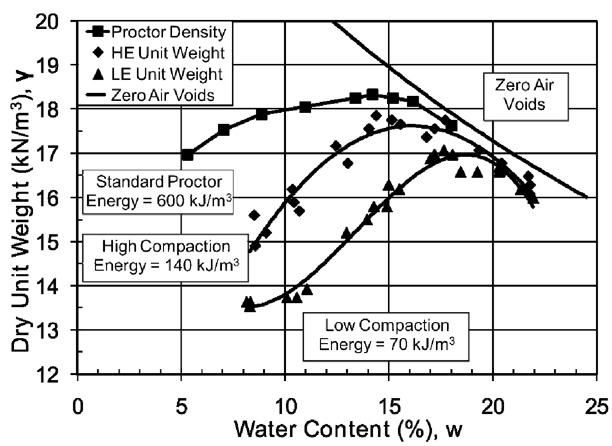

Figure 1: Comparison of high and low static compaction energy curves to the standard proctor curve for Indian Head glacial till (after Power et al. 2008).

During the development of the energy curves, the specimens were compacted within conventional 50 mm diameter oedometer rings to ensure consistency between the development and usage of the static loading. The initial compaction stresses were applied using a drill press. In order to determine the effort required to compact the specimens at the specific static stresses chosen, a load cell and a linear displacement transducer were used in conjunction with a computer which automatically recorded the process. This made it possible to continuously monitor the force applied during the compaction process so that the work done on the specimen could be computed.

3.3 Details of the Oedometer Testing

Oedometer test results were obtained for specimens prepared using both the low and high compaction energies for initial water contents in the range of 14% to 19%. All specimens were initially prepared in an unsaturated state. Half the specimens were then allowed to imbibe water following the ASTM Standard D4546-03 Method C (i.e. constant volume conditions) entitled, “Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils”. This technique was effective in saturating the soil specimen by gradually increasing the degree of saturation through inundation. Test specimens prepared in this fashion were designated as “inundated” test specimens. The remainder of the specimens were designated as “non-inundated” as they were tested in an unsaturated state.

Specially designed acrylic chambers were used to house specimens during testing. Conventional oedometer testing procedures were followed to determine the compressibility characteristics of both the inundated and non-inundated specimens in the stress range of 15 to 800 kPa (i.e., *e* vs. σ' relationship).

In order to ensure that outside environmental conditions (i.e. temperature or humidity level fluctuations) did not alter the test results obtained in this research, the laboratory environment was kept at a constant temperature of 22°C ±0.5°C and a humidity level of 40% ±10%. In addition, to maintain the initial compaction water content of the test specimens, a 100% humid air stream was pumped into the acrylic chambers for the entire duration of the testing period. The relative humidity conditions within the chambers were measured using RH meter which was monitored throughout the duration of the test. It is noted that the settlement in saturated soil specimens is associated with the drainage of water from the soil specimen; however, the change in settlement of compacted specimens in unsaturated conditions is associated with the expulsion of air (i.e. drainage of the air-phase). Full details of the oedometer testing program can be found in Power and Vanapalli (2008).

3.4 Details of the Modified Ring Shear Tests (MRST)

The MRST testing program included:

1) One specimen compacted at a water content of 15% and sheared under Constant Load and constant Suction (CLS) conditions ,
2) One specimen compacted at a water content of 15% and sheared under Constant Volume and constant Suction (CVS) conditions,
3) One specimen compacted at a water content of 19% and sheared under CLS conditions,
4) One specimen compacted at a water content of 19% and sheared under CVS conditions.

Each specimen was subjected to multi-stage shear tests, by successively increasing the matric suction to higher stages. In other words, after completion of each shearing stage, the matric suction was increased to the next level allowing the specimen to reach equilibrium while the amount of water expelled from the specimen was continuously monitored, during all stages of loading and shearing. All the different shear strength tests were consolidated under a net normal stress value of 150 kPa.

The Indian Head till specimens were prepared at compaction water contents of 15% and 19% using the LE condition compaction energy. The specimens were compacted in multiple layers within the MRST cell. More details of the testing procedures are available in Infante Sedano et al. (2007).

4 TEST RESULTS

The MRST results of the CLS series plotted as the variation of the shear strength with respect to matric suction reveals that the relationship is initially linear. The slope of this relationship is comparable to the φ' of 26.3° from MRSTs on saturated soil specimens. After reaching a breaking point, the curve diverges substantially from the 26.3° line and becomes almost horizontal (Figures 2 and 3). This breaking point occurs at a matric suction of 100 kPa, with a gravimetric water content of 15.5% for the specimen compacted at a water content of w_c=19% (Figure 2), and at a matric suction of 150 kPa, with a gravimetric water content of 15.7% for the specimen compacted at a water content of w_c=15% (Figure 3).

The break in the failure envelope can be attributed to the air-entry value (AEV) of the macro-structure of the specimen, within the active shearing zone. Below this matric suction value, the specimen is tension-saturated and all of the applied matric suction is transferred to the soil skeleton, thus resulting in an initially linear failure envelope. At higher matric suctions, within the limits of the suction range investigated, the specimen desaturates within the shear zone, and only a fraction of the matric suction increases are transferred to the specimen. This in turn translates into a much shallower and almost horizontal line for the case studied.

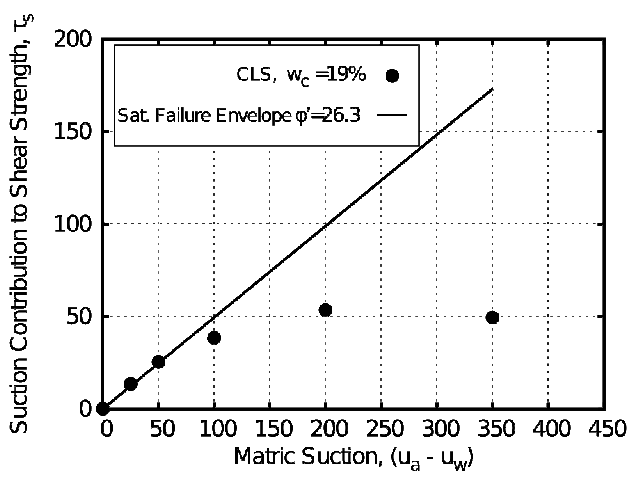

Figure 2: Critical state suction contribution to shear strength on Indian Head till against matric suction with a water content, w_c=19%.

Figure 4 shows the relationship between the gravimetric water content of the compacted soil specimens against the matric suction on a semi-log plot. The data points of these results form a single line for both the LE and HE specimens. A bilinear relationship is instead observed on the semi-log plot when the data of the MRSTs is plotted specimens tested under CLS conditions. At low matric suctions, the relationship of gravimetric water content to the matric suction forms a line that lies below the line generated from the compacted specimens. This initial MRST line also shows a shallower slope. After reaching a matric suction value in the vicinity of 200 kPa, the data from the MRSTs meet the points obtained from the compaction test, and with further increases in matric suction the relationship of the CLS tests follow the same trend as the compaction test results. This suggests that the results from the compaction curve test may be used to approximate the CDL.

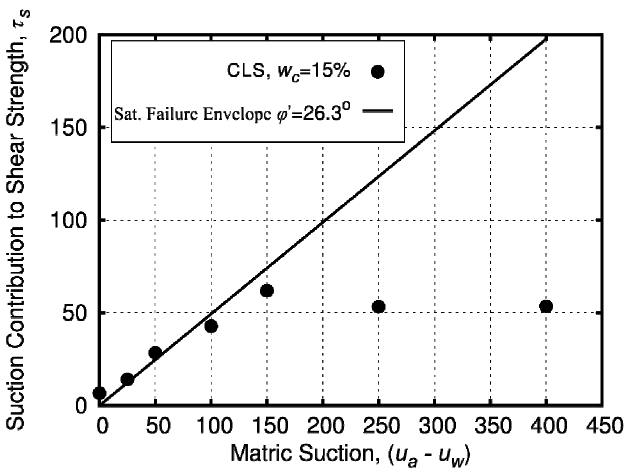

Figure 3: Critical state suction contribution to shear strength on Indian Head till against matric suction with a water content, w_c=15%.

The bilinear relationship does not appear to be specific to the tested Indian Head till in the present research program. A similar bilinear relationship can be observed in the final suction data on Kiunyu Gravel presented by Toll and Ali Rahman (2010), as shown in Figure 5.

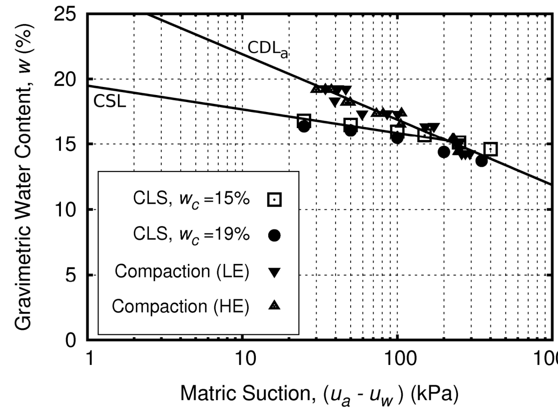

Figure 4: Comparison of the compaction water content to matric suction relationship and the critical-state water content to matric suction relationship from CLS tests on Indian Head till.

In the case of CVS tests, shear strength envelope as a function of matric suction cannot be readily generated as the net normal stress varies during the test in order to maintain a constant volume. However, the plot of gravimetric water content against the matric suction results in a linear relationship on the semi-log graph shown in Figure 6. The line generated from the CVS test results can be seen to lie below the CLS line, and intersect the compaction test CDL_a at a higher matric suction value.

As the CVS test results are barely touching the line generated from the compaction test data (Figure 6), it is unclear whether the relationship would become steeper at this point, and follow the CDL_a generated from the compaction tests, as was the case for the CLS test results (Figure 4).

The nature and location of the break point in the CSL generated from MRSTs can be further explored by considering the critical state framework proposed by Tarantino (2007). The parameter e_{wm} should be unique for a given unsaturated soil and can be isolated from a single test. By using equation [6], it is possible to plot the relationship of e_{wm} as a function of matric suction as shown in Figure 8.

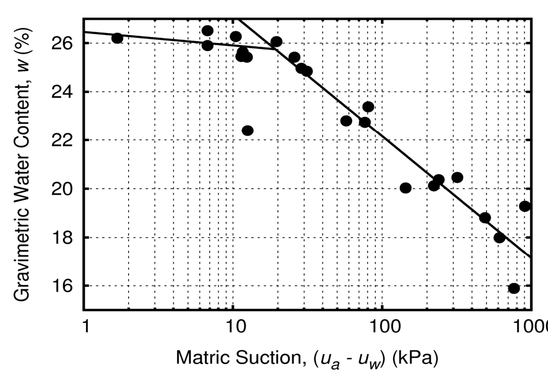

Figure 5: Final suction after shear for Kiunyu Gravel (after Toll and Ali Rahman, 2010).

From the back-calculated value for the e_{wm} parameter, it can be observed that it varies significantly for values of matric suction below a 200 kPa threshold value. At higher suctions, e_{wm} becomes stable at about 0.34, for both the CLS and CVS test results.

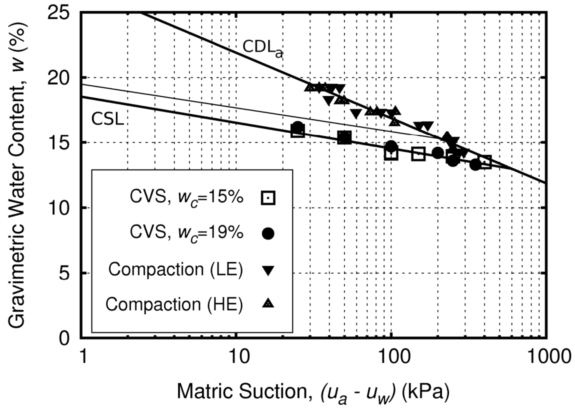

Figure 6: Comparison of the compaction water content to matric suction relationship and the critical-state water content to matric suction relationship from CVS tests on Indian Head till.

This threshold value of 200 kPa is higher than the apparent AEV observed in the CLS tests, yet closely corresponds with the apparent breaking point of the CSL generated from CLS tests as seen in Figure 4. This suggests that there might be a transition range of matric suctions after the AEV has been reached before the ultimate unsaturated behavior of the soil is fully developed.

It is not possible from the suction values of the compacted specimens to directly determine what the degree of saturation at critical state would be. Infante Sedano (2006) compared the apparent SWCC of MRST from both CSL and CVS test series. The apparent SWCC is obtained by normalizing the SWCC so that it reaches 100% saturation at a zero matric suction value. The results showed that the apparent SWCC of specimens sheared to large deformations under CLS or CVS conditions, dry or wet of optimum was unique for Indian Head till specimens sheared under a net normal stress of 150 kPa.

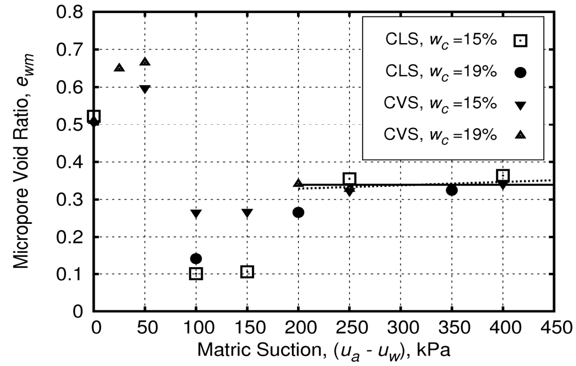

Figure 7: Microstructural void ratio as a function of matric suction for Indian Head till.

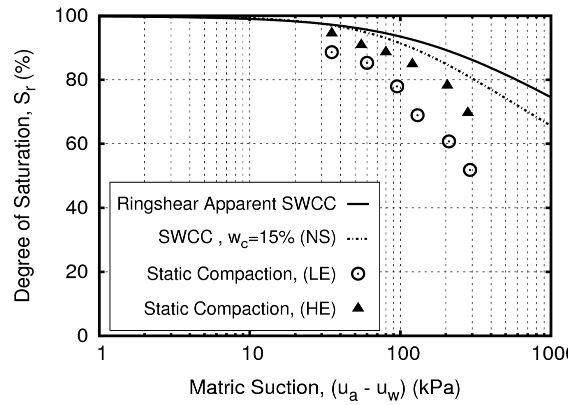

Figure 8: Relationship for the degree of saturation, as a function of the matric suction for specimens compacted at low energy (LE) and high energy (HE) compared to the SWCC of a specimen having been previously consolidated under a net stress (NS) of 150 kPa, and the Apparent SWCC from CLS and CVS tests

It can be observed from Figure 8 that the specimens compacted at high energy and low energy, result in different relationships between the degree of saturation and the matric suction. At higher energies, the curve is closer to the SWCC generated from Indian Head specimens subjected to a consolidation stress of 150 kPa. The SWCC of the consolidated specimens shows the closest agreement with the apparent SWCC of the sheared specimens.

Figure 9 shows that the compaction energy has no influence on the relationship between *e* and *S* of the compacted specimens. Changing the water content, however results in two parallel curves which are offset with each other. This suggests that the compaction water content affects the macrostructure of the soil, reflected by the different offsets, but not its microstructure, reflected by the identical slopes.

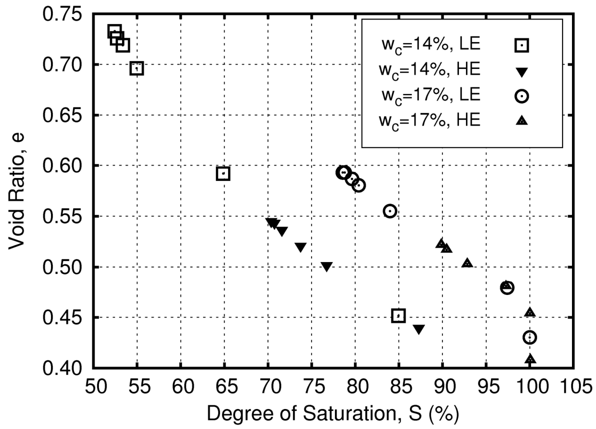

Figure 9: Void ratio vs degree of saturation for specimens compacted at low energy (LE) and high energy (HE), at compaction water contents of 14% and 17% (after Power 2005).

Figure 10 shows the relationship between the variations of void ratio as a function of the gravimetric water content for the compacted specimens. From these results, it is apparent that as the compaction water content increases, the void ratio for the compacted specimens decreases and tend towards similar values, for both the HE and LE specimens. This ultimate value, lies close to the zero air voids line, where the specimen would be saturated. At low compaction water contents, the LE specimens show the highest void ratio.

This behaviour illustrates the effect of compaction water content on the structure of the compacted soil, resulting in a more open, flocculated, structure, with large voids when lower energy is used than when a higher energy level is used. As the water content increases the compacted soil takes on as more dispersed structure, with smaller voids and the difference between the high energy and low energy curves disappears. By the time critical state is attained, the influence of structure is stabilized has unique characteristics for data points which lie below the HE compacted specimens in all instances of CLS or CVS ring shear tests.

By tracing the initial and final trends of the high energy curve, an intersection point can be found at a gravimetric water content value of 15.6%. This value happens to lie exactly within the range of water contents determined to be the boundary of the shear strength envelope where Indian Head till behaved as a tension saturated soil as seen in Figures 2 and 3.

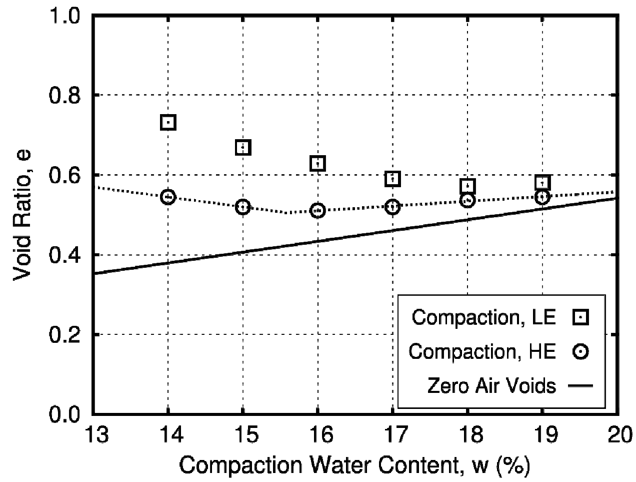

Figure 10: Void ratio vs gravimetric water content for compacted specimens of Indian Head till.

When the critical state condition from the MRSTs is overlaid on the compaction data, it can be seen that the MRST data follow a curve that varies much less at the low water contents, and is generally parallel to the final slope of the compaction curve. The smaller variability of the void ratio at low water contents can be attributed to the destruction of the original structure and attaining a new unique structure associated with the compaction of the unsaturated specimen during shearing to critical state.

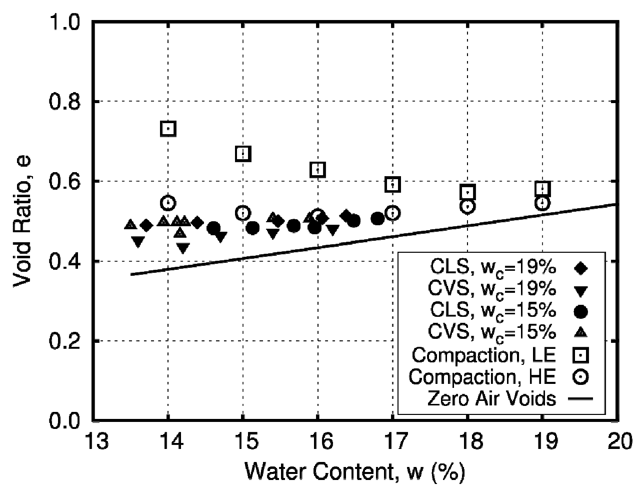

Figure 11: Void ratio vs gravimetric water content for compacted specimens and ring shear test results on Indian Head till.

The variation of the compression index, C_c, of Indian Head till as a function of the compaction water content is shown in Figure 12. When the water content of the specimens was left at the compaction value, it can be seen that the compression index of non-inundated specimens follows similar trends as the void ratio, with a much higher compressibility apparent for the LE specimens than for the HE specimens. Again, this is due to the flocculated structure of the specimens compacted at low energy, where the matric suction allows the macro-structure to be arranged in a much looser configuration. Because the pores are bigger, the soil is more compressible, and shows a greater change of volume for a given change in applied normal stress. When the specimens are inundated before the consolidation tests, however, much of that structure is lost due to the reduction of the matric suction. As a result, there is a much smaller difference between LE and HE specimens for the case of inundated specimens.

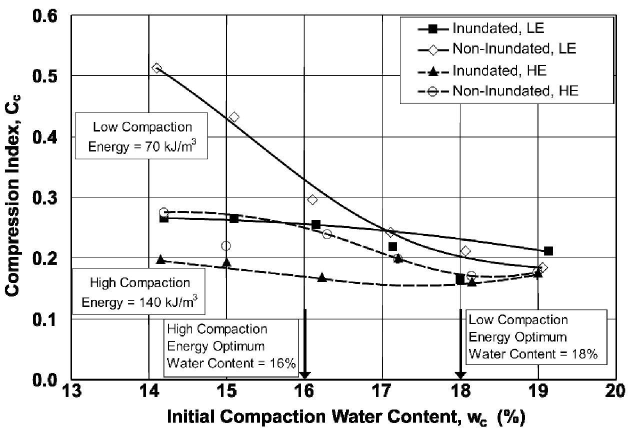

Figure 12: Compression index vs. initial soil water content for specimens prepared using both low and high compaction energies (after Power and Vanapalli 2008).

In all cases however, it can be seen that as the compaction water content increases (the matric suction decreases), the compression index of all types of all test series tend towards a constant value of C_c of about 0.2 for and a void ratio of about 0.5 at compaction water contents of 17% and higher. This is in good agreement with the high energy and low energy plots shown in Figure 10, where the compaction water content of 17% and even more so at 18% marks a point where specimens compacted at both high energy and low energy converge towards a common void ratio.

5 CONCLUSIONS

The CDL_a from compacted specimens is in good agreement with the CSL for those suction values that lie above the AEV of the specimen. Within this zone of agreement between the CDL_a and CSL there seems to be a single value of the microstructural water ratio, e_{wm}, that fits the critical state framework proposed by Tarantino (2007). At matric suctions below this value, no single e_{wm} can be used to fit the data, and the variations can be substantial.

From MRSTs conducted following CLS under a net normal stress of 150 kPa, there appears to be no influence of the compaction water content. The CLS from specimens prepared both dry and wet of the optimum met the CDL_a generated from the compaction data at the same point. However, CVS test results, which are subjected to different net normal stresses as the volume is maintained constant, do not lie along the same line. This behavior suggests that there exists a range of matric suctions at which the line generated from critical state shear tests will meet the line generated from the compaction tests. The variation in the meeting point would appear to be a function of the void ratio (and by extension the net normal stress) at critical state for a given matric suction.

The available test results suggest that simple compaction tests combined with matric suction measurements conducted using the filter paper method can allow the approximation of the CDL of a soil for a range of suctions where the microstructure water ratio is constant. The compaction data could also be used to identify the AEV of the sheared specimens: the matric suction values up to which the shear strength envelope remains linear. An experimental program is ongoing at the university of Ottawa to investigate these possibilities.

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