Suction Compression Index based on CLOD Test Results

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Abstract

Determination of the suction compression index, $C_h$, is necessary for predicting expansive soil heave based on soil suction. The CLOD Test is a convenient laboratory procedure for determining $C_h$, however it is not widely used. Rather, engineers often rely upon empirical correlations to find $C_h$. A laboratory investigation was conducted to verify previously established empirical relationships. The investigation involved CLOD tests on relatively undisturbed drive samples of clay and claystone bedrock from the Denver, Colorado area. Test results generally matched previous studies. Samples utilized in this investigation spanned a large range of suction and moisture characteristics. A new empirical relationship for determining $C_h$ over a broader range of materials is presented.

In an effort to expedite the CLOD test, studies were performed to ascertain the effect of various procedural simplifications on the test results. Information obtained by these studies is used to suggest a modified procedure for professional practitioners. Filter paper suction, one-dimensional swell, Atterberg Limits, and gradation tests were also performed on numerous select samples. Swell prediction based on soil suction and the CLOD test results compared well with direct laboratory swell measurements. The average $C_h$ measured in the Denver area is shown to be a function of bedrock geology. A semi-empirical relationship is also presented between Atterberg limits, percent passing the No. 200 sieve and $C_h$.

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Introduction

The more traditional method of determining expansive soil heave in practice today in the Denver, Colorado area utilizes conventional, one-dimensional, swell-consolidation measurements. This method has an established heritage and is based on representing soil suction changes through “equivalent” changes in effective stress. Another method for estimating heave is based directly on soil suction. This method considers soil suction as the primary stress state variable and relates heave directly to suction changes. There are many methods of representing soil heave in terms of soil suction, some of which are described in Matyas and Radhakrishna (1968), McKeen and Nielsen (1978), Fredlund and Rahardjo (1993), and Hamberg and Nelson (1984). The subject of this particular study is a formalism presented by McKeen (1992) who incorporated a lateral restraint factor and combined the effects of changes in total suction and effective confining stress into one term and presented the equation

\[ \Delta H = C_h \Delta h \Delta t f s \]  

where \( \Delta H \) is the vertical movement of the layer being considered, \( \Delta h \) is total suction change, \( \Delta t \) is layer thickness, \( C_h \) is the suction compression index, \( f \) is the lateral restraint factor (between 0.5 and 0.8 for clays), and \( s \) is the load effect coefficient (typically 0.9). The latter equation has been used by engineers in the Denver, Colorado area (Thompson 1997, and Thompson and McKeen, 1995, and McOmber and Thompson, 2000).

Application of the McKeen method requires direct measurement of soil suction. This is typically accomplished by filter paper tests (McQueen and Miller, 1968 and ASTM D5298). The constitutive parameter used to relate total suction to volume change, called the suction compression index, \( C_h \), can be measured using the CLOD test (McKeen, 1985 and Hamberg, 1985) but is often found by an empirical relationship (McKeen, 1992)

\[ C_h = -0.02673 \left( \frac{\Delta h}{\Delta w} \right) - 0.38704 \]  

where \( \Delta w \) is the change in soil water content. This relationship is based on a line constructed at the 85th percentile for laboratory tests on Shelby tube and California drive samples.

The objectives of the present investigation are to augment the validity of the empirical suction compression index relationship, and expand its applicability to relatively undisturbed samples from the Denver, Colorado area. Laboratory procedures for measuring \( C_h \) are reviewed and a few methods for expediting the test are presented. Effects of plastic limit, gradation, and geology on \( C_h \) are discussed.

Investigation

A total of 89 relatively undisturbed soil and bedrock samples from 22 sites around the Denver, Colorado area were tested. Samples were obtained using a California type (6.4 cm or 2.5 in outside diameter) split barrel sampler. Sample depth generally ranged from 1.5 to 7.5 m (5 to 25 ft). Most samples were separated into two
pieces, and filter paper suction and CLOD tests were conducted. Some samples were separated into three pieces, and conventional swell tests were performed in addition to suction and CLOD tests. Atterberg limits and gradation information were obtained from nearby samples of representative soils and bedrock. Silt and clay content (percent passing the No. 200 sieve) ranged from 50 to 100 percent. Liquid limit and plasticity index ranged from 35 to 165 percent and 21 to 124 percent, respectively.

**Procedures**

All tests were performed by personnel employed by CTL/Thompson, Inc. Filter paper suction, one-dimensional swell, Atterberg limits and gradation tests were conducted according to standard procedures. Suction measurements were made by suspending the filter papers over the samples so as to measure total suction. Osmotic suction has been shown conclusively to be a valid stress state variable but its impact on soil behavior is subtle in comparison with soil response to matric suction (Miller and Nelson, 1993). It was assumed that osmotic suction changes were negligible during these tests and that total suction changes are equal to matric suction changes.

Standard test methods have not been developed for the CLOD test. McKeen (1985) originally formulated the CLOD test method based on the COLE (Coefficient of Linear Extensibility) procedure presented by the U.S. Department of Agriculture, Soil Conservation Service (1972). The method is also described in Nelson and Miller (1992) and in Hamberg (1985). Procedures for performing the CLOD test involve coating irregularly shaped soil specimens with liquid resin and monitoring weight and volume change over time while either air drying or wetting. Volume measurements are obtained by Archimedes principle which involves weighing the samples underwater, as shown in Fig. 1. The resin coating is essentially watertight, but is permeable to water vapor. Through these procedures a relationship between sample volume and water content is obtained. After the drying or wetting process, the specimens are oven dried and the suction compression index, $C_h$, is determined.

Fig. 1 Specimen Volume Change Measurement by Submersion
The precision of the CLOD test method was evaluated by testing 12 nearly identical remolded specimens from a homogeneous clay material. Deviations in CLOD test results for these samples are shown on the left side of Fig. 2. From these results, the limit of precision on the suction compression index of the CLOD test appears to be ±0.02. In heave calculations, this corresponds to about ±1.3% heave per 1 pF change in suction.

For this procedure to be practical, it is desirable to perform the tests as expeditiously as possible without sacrificing accuracy. Techniques of simplifying the CLOD test procedure were tried. One such technique was the elimination of the intermediate wetting/drying process, since the primary objective was only to determine the final value of $C_h$. To evaluate the effect of this procedural change, four soil and bedrock samples were tested by exposing half of each sample to a 10 day air drying process followed by 48 hr low temperature (75 deg C, 170 deg F) oven drying, while the other half of each sample was placed immediately in a high temperature oven for 48 hrs (105 deg C, 220 deg F). The results of these tests are shown on the right side of the bar graph in Fig. 2. In general, deviations in $C_h$ between the pairs of samples were small and within the anticipated test accuracy. All four specimens exposed to the higher temperature oven exhibited slightly more negative results, indicating larger overall volume change despite the much shorter drying period.

Fig. 2 Deviation of CLOD Test Measurements

The McKeen (1985) CLOD test procedure involves coating samples three times
separated by resin drying times of various durations. An attempt was made to evaluate the effect of Saran/resin thickness on measurements of $C_h$. Results are shown in the smaller graph at the top of Fig. 2. Samples were coated with variable numbers of resin layers indicate that there is no significant correlation between resin thickness and $C_h$. However, it was observed that cracking of the samples during drying occurred more abundantly for those specimens with thinner coatings of resin. This cracking has an apparently insignificant effect of the final $C_h$ value when only one submerged measurement after drying is required. A reduction in number of coatings appears to be permissible. It is recommended that McKeen’s method be followed when intermediate measurements are to be taken in order to establish the full drying/wetting function.

CLOD tests were also attempted on two samples without resin coating. It was postulated that if the volume measurement was conducted quickly there would be insufficient time for the clays to absorb additional water and the procedure could be further simplified. Unfortunately, the oven dried clays were so reactive to the water that their exteriors crumbled almost immediately upon immersion, thereby rendering the results useless.

Since suction and CLOD tests were performed on separate halves of the same California drive samples, it was found to be convenient to utilize specimens weighing between 70 and 90 g rather than the 120±20 g size recommended by McKeen (1985). As shown in the smaller graph at the lower right hand corner of Fig. 2, sample size had no discernable effect on the outcome of the tests. However, 140 g size samples were not tested. Common sense dictates that precision should improve with larger samples. As an aside, it was also shown that the weight of the identification tag had a negligible effect on test results, as shown in the smaller graph at the lower left corner of Fig. 2.

The time required for oven drying was also examined to determine if any reduction in drying time was permissible. Results of weight measurements in-air are plotted with respect to oven drying time for 16 samples of clay and claystone bedrock in Fig. 3. The weight measurements were normalized with respect to final oven dried values so that the specimens could be compared at the same scale. It can be seen from the figure that equilibrium oven-dried conditions appear to occur after 48 hours. This time duration matches the recommendation by McKeen (1985).

Considering time efficiency and the results of the test bias experiments, a slightly modified method of performing the CLOD test to determine $C_h$ is shown in Table 1. These procedures were followed for the majority of samples tested in this study.

Calculations

Initial water content is computed from CLOD test measurements as follows (Hamberg, 1985)

$$w_i = \frac{W_1 - W_t}{W_s} \times 100\%$$

(3)
Table 1. Expedited CLOD Test Method  
(modified from Hamberg, 1985)

1 Obtain specimens (clods) of undisturbed representative soil samples. The clods may be irregularly shaped. Take necessary precautions to maintain field moisture content of the specimens.

2 Separate the specimens into two halves. Perform a filter paper suction test on one half and reserve the other for immediate CLOD testing.

3 Measure the weight of each specimen (W1). Sample weight should be between approximately 70 and 140 g.

4 Tie a fine wire around each sample and attach a tag for handling and identification. Measure the weight of each tagged specimen (W2).

5 Coat the specimens with liquid resin similar to 1 part DOW Saran® F310 dissolved in 7 parts methyl ethyl keytone or acetone. The coating procedure should be done under a fume hood as follows: dip in resin, dry five minutes in air, then dip again and dry an additional fifty-five minutes in air. Weigh each coated specimen immediately after air drying (W3).

6 Set a container of water on an electronic balance and “tare out” its weight. The container should be large enough to facilitate specimen submersion without touching the sides. Momentarily submerge each specimen under water and record its buoyant force (W5).

7 Oven dry the specimens for 48 hrs at 105 deg C. Weigh the oven-dried specimens in air and submerged under water to determine W7 and W8, respectively.
where \( W_s \) is the weight of solids given by

\[
W_s = W_7 - 0.85(W_3 - W_2) - (W_2 - W_1) \tag{4}
\]

The weight measurements, \( W_1 \) through \( W_8 \), are defined in Table 1. The factor of 0.85 is applied to account for losses during oven drying due to volatility of the resin (McKeen, 1981 and Hamberg, 1985).

The suction compression index is obtained from (McKeen, 1992)

\[
C_h = \frac{V_i - V_f}{\Delta h(V_f)} \tag{5}
\]

where \( \Delta h \) is the change in soil suction (in pF units), \( V_i \) is initial specimen volume, and \( V_f \) is oven dried specimen volume. It is generally accepted that a suction value of about 5.5 pF corresponds to the shrinkage limit (McKeen and Nielsen, 1978). Thus, the change in soil suction, \( \Delta h \), during the CLOD test is the filter paper suction measurement from the other half of the specimen minus 5.5 pF. The initial and final specimen volumes are calculated from CLOD measurements as follows (Hamberg, 1985).

\[
V_i = \frac{W_3}{\gamma_w} - \frac{(W_3 - W_2)}{\gamma_r} \tag{6}
\]

\[
V_f = \frac{W_8}{\gamma_w} - \frac{0.85(W_3 - W_2)}{\gamma_r} \tag{7}
\]

The parameter \( \gamma_w \) is the unit weight of water (1 g/cm\(^3\)) and \( \gamma_r \) is the density of resin (1.3 g/cm\(^3\) for DOW Saran F310 at 1:7 solute:solvent).

In order to correlate with previous studies, computation of the ratio of suction change to water content change, \( \frac{\Delta h}{w} \), was necessary. Here, suction change is taken as the difference between the field suction value and the commonly accepted oven-dried intercept suction value of 6.25 pF. Water content change is simply the initial water content, \( w_i \), from Eq. (3), since the water content of oven dried soil is presumed to equal zero.

**Results**

Suction compression index results from CLOD tests are plotted against the ratio \( \frac{\Delta h}{w} \) in Fig. 4. The diagonal dashed line shown in the figure represents the empirical relationship previously derived by McKeen (1992), Eq. (2). It can be seen that data from undisturbed drive samples tested in this investigation generally match McKeen’s relationship, thereby supplementing its validity and versatility. Soil and bedrock specimens tested in this study had a greater range in plasticity compared to those tested by McKeen. The outlying points at more negative \( \frac{\Delta h}{w} \) values consisted of low-plasticity, sandy clay samples, whereas the outlying point at the least negative value of

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\( \frac{h}{w} \) consisted of very high plasticity claystone bedrock (Plastic Index of 124).

Although McKeen’s empirical relationship fits the data for the samples in mid-range, it is less dependable at the extremes. A qualitative assessment of the practical limits of \( C_h \) can be made by hypothetically assuming that soil suction changes by approximately -2.15 pF between field moisture and oven-dried conditions (i.e. 4.1 pF - 6.25 pF) for all types of soils. For example, the field moisture content of silty sands might be 10 percent, so \( \frac{h}{w} \) would be on the order of -21.5. Cleaner sands should have even lower moisture contents, and consequently, lower (more negative or absolute) values of \( \frac{h}{w} \). One would expect materials in this extreme to exhibit very small volume change due to suction, therefore \( C_h \) should approach zero for very negative values of \( \frac{h}{w} \). On the other hand, the field moisture content of highly plastic clays might be 30 percent, so \( \frac{h}{w} \) would be on the order of -7.2. These materials are expected to exhibit large changes in volume due to changes in soil suction, thus \( C_h \) should continue to become lower (more negative) as \( \frac{h}{w} \) approaches zero. Given the new data and the foregoing discussion on limits, a relationship shown by the solid curve in Fig. 4 is suggested. Derivation of this logarithmic statistical fit is described in the next section.

![Fig. 4 Suction to Water Content Ratio and Suction Compression Index Data](image)

Heave values predicted using McKeen’s method, Eq. (1), and measured suction compression index data are compared with measured one-dimensional swell in Fig. 5.
Some uncertainty exists as to the value of soil suction to be used in Eq. (1) that appropriately describes the final conditions in a conventional swell test. Since the sample is completely submerged during this test, there has been some speculation that the specimens approach their field capacity at a suction value of 2.5 pF. At this value, model predictions severely overestimate actual sample swell. By trial and error, the best possible statistical fit between swell based on suction and swell measured conventionally was obtained by setting the final suction value equal to 3.5 pF. It is believed that the difference between field capacity and the final suction value suggested by the best fit is the result of a high osmotic suction component for soils in Denver, Colorado. CTL/Thompson, Inc. is currently conducting a subsequent investigation into the osmotic component of soil and bedrock. Initial evidence indicates that the difference between total and matric suction is almost always on the order of 1.0 pF in the Denver area.

![Fig. 5. Comparison Between McKeen Model and Measured Swell](image)

Due to geologic uplifting and subsequent weathering of bedrock along the toe of the Rocky Mountains, a number of different geologic units appear from east to west across the Colorado Front Range. Geologic information was available for a number of the sites where samples were obtained. Suction compression indices were averaged for each major geologic unit. Results are shown in Fig. 6 along with a local bedrock stratigraphic column. It is observed that the suction compression index is strongly related to geology. In fact, the volume change responses of older, Cretaceous system formations are significantly greater than that of the younger, Tertiary system formations.
This conclusion is consistent with local philosophy.

Fig. 6 Suction Compression Indices for Various Colorado Bedrock Types

Analysis
Through iterations of empirical data analysis, the relationship shown in Fig. 7 was eventually found between $C_h$ and the $h/w$ ratio. In this figure, the logarithm of the absolute values of $1/C_h$ and $h/w$ are plotted with respect to one another. A statistical linear regression was performed on the data and the resulting slope and intercept were astonishingly close to integers.

The equation for the straight line in Fig. 7 is

$$\log\left(\frac{-1}{C_h}\right) = 2.0 \log\left(\frac{-\Delta h}{\Delta w}\right) - 1.0$$

(8)

which, by algebraic manipulation, simplifies to

$$C_h = -10 \left(\frac{\Delta h}{\Delta w}\right)^{-2}$$

(9)
This is the equation for the solid curve plotted in Fig. 4, as described previously. For purposes of discussion, Eq. (9) will be referred to as the PTN relationship.

The PTN relationship (Eq. (9)) is compared with the presently used McKeen linear empirical relationship (Eq. (2)), in Fig. 8. Expansive soil classifications of low, moderate and high heave potential based on McKeen (1992) are shown at the top of the graph. The differences between the suction compression indices determined by the two methods are plotted along the y-axis. Above the zero baseline (i.e. the line depicting where the two methods are equal), the shaded area indicates that the PTN relationship yields more negative values than does the McKeen relationship, indicating that it is more conservative. Conversely, the shaded area below the baseline indicates that the McKeen relationship is more conservative than the PTN relationship.

A significant observation is that, for moderate expansive soils, both methods are essentially the same, within the expected accuracy of the CLOD test. For low expansive soils, the McKeen relationship predicts positive values of $C_h$ indicating compression, whereas the PTN relationship tends toward zero. For these low expansive soils, the differences between McKeen and PTN are not particularly relevant except that the PTN relationship prevents misleading predictions of soil compression. At the other extreme, the PTN relationship again tends toward more negative values of $C_h$ than those of the McKeen relationship. Consequently, the PTN relationship tends toward higher estimates of soil heave.
Further analysis of laboratory CLOD test data qualitatively indicated that $C_h$ values are exponentially related to soil plasticity. There also appears to be some dependence on silt and clay content, as should be expected. It is desirable to better relate suction compression index to the Atterberg limits and gradation of a soil specimen. Statistical regressions were performed on the data, but a convenient representation was not found. Instead a semi-empirical approach was taken. The method is called semi-empirical because it is theoretically derived based on the empirical PTN relationship.

It is believed that the plastic limit of a soil generally corresponds to a soil suction value of between 3.0 and 3.5 pF (McKeen, 1992). As mentioned previously, the suction of oven-dried soil has been found experimentally to be 6.25 pF. The change in water content between the plastic limit and oven-dried conditions is simply the plastic limit. Therefore, the suction compression index according to the PTN relationship should be approximately equal to

$$C_h = -10 \left( \frac{3.25 - 6.25}{PL} \right)^2 = -\frac{10}{3} PL^2$$  \hspace{1cm} (10)$$

where PL is the plastic limit (%). However, this equation does not account for the sand fraction of the soil, which has a $C_h$ of nearly zero. The expression in Eq. (10) can be
adjusted to account for the coarse fraction by performing a simple correction similar to a “rock correction” in soil density testing. Subtracting the coarse volume, C, from the total volume in the definition of $C_h$ given by Eq. (5) yields

$$\frac{10}{3}PL^2 = \frac{\Delta V}{(V_i-C)\Delta h} = \frac{\Delta V}{V_i\Delta h-C\Delta h}$$

(11)

Taking the inverse of Eq. (11) results in

$$-\frac{3}{10PL^2} = \frac{V_i\Delta h}{\Delta V} - \frac{C\Delta h}{\Delta V}$$

(12)

The volume of coarse material in a soil is

$$C = \frac{W_c}{\gamma_w G_s}$$

(13)

where $G_s$ is soil mineral specific gravity, and $W_c$, the weight of coarse grained solids, is simply

$$W_c = V_i \gamma_d (1-F)$$

(14)

where $\gamma_d$ is the dry unit weight of soil and F is the weight percent passing the No. 200 sieve. Substituting Eq. (14) into Eq. (13) and then the result into Eq. (12) produces

$$-\frac{3}{10PL^2} = \frac{V_i\Delta h}{\Delta V} - \frac{\gamma_d (1-F) V_i \Delta h}{\gamma_w G_s \Delta V}$$

(15)

Recognizing that $\gamma_d/(\gamma_w G_s) = 1/(e+1)$ where e is void ratio, and that $V_i/ \gamma_d V$ is the inverse of $C_h$, the semi-empirical relationship between suction compression index, plastic limit and percent passing the No. 200 sieve is found by solving Eq. (15) for $C_h$

$$C_h = \frac{-10}{3}PL^2 \frac{(e+F)}{e+1}$$

(16)

The validity of Eq. (16), hereafter termed the PL-200 relationship, was evaluated by comparing $C_h$ values with those determined using the McKeen and PTN relationships, as shown in Fig. 9. Ratios of predicted to measured $C_h$ are shown in the larger graph. In the smaller graph, $C_h$ values were used to categorize samples according to the expansive soil classification provided by McKeen (1992). Soil sample classifications based on the measured swell from one-dimensional, oedometer type tests are also shown.

Inspection of Fig. 9 reveals that the McKeen relationship poorly matches measured $C_h$ for low swelling soils at the larger (least negative) values of $C_h$, but otherwise exhibits good correlation. The PL-200 relationship tends to underestimate $C_h$ in the midrange, but appears to be a worthwhile method especially considering that the
plastic limit and percent passing the No. 200 sieve information was obtained from representative samples and not from the actual samples tested. Predictions based on the PTN relationship most closely fall within the boundaries of accuracy anticipated for the laboratory CLOD test method. All three $C_h$ relationships are valid for classification of samples according to low, moderate or high swell potential.

Fig. 9 Summary Comparison Between Various $C_h$ Prediction Models

**Conclusions**

A laboratory investigation was conducted into the determination of the suction compression index, $C_h$ (McKeen, 1992), using the CLOD test method (McKeen, 1985, Nelson and Miller, 1992, Hamberg, 1985). A new empirical correlation (termed the PTN relationship) was developed to relate $C_h$ to the ratio of change in suction to change in water content. The PTN relationship agrees closely with an empirical correlation previously presented by McKeen, but is more realistic and accurate at very low or very high ratios of suction to water content change. A semi-empirical relationship was also developed that relates $C_h$ to the Plastic Limit. This method appears to correlate fairly well with the other methods for the soils tested. Heave prediction based on suction also correlated well with conventional one-dimensional swell measurements. A procedure for expediting the CLOD test is presented.

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**Nomenclature**

\( w \) \text{ unit weight of water (g/cm}^3) \\
\( r \) \text{ unit weight of resin (g/cm}^3) \\
\( h \) \text{ compressibility coefficient (Pa}^{-1}) \\
\( a \) \text{ unit weight of soil (g/cm}^3) \\
\) H \text{ soil heave (m)} \\
\) h \text{ change in soil suction (pF)} \\
\) t \text{ soil layer thickness (m)} \\
\) w \text{ change in specimen water content (}) \\
\) F \text{ total stress (Pa)} \\
D_s \text{ suction-volume change constitutive parameter} \\
D_t \text{ effective stress-volume change constitutive parameter} \\
f \text{ lateral restraint factor} \\
F \text{ weight fraction passing the No. 200 sieve (}} \\
PL \text{ plastic limit (}} \\
s \text{ load effect coefficient} \\
u \text{ pore air pressure (Pa)} \\
V_i \text{ initial volume of CLOD specimen (cm}^3) \\
V_f \text{ oven dried volume of specimen (cm}^3) \\
w_i \text{ initial specimen water content (}} \\
W_s \text{ weight of solids (g)} \\
W_1 \text{ initial weight of CLOD specimen (g)} \\
W_2 \text{ weight of tagged specimen (g)} \\
W_3 \text{ weight of resin coated, tagged specimen (g)} \\
W_5 \text{ initial specimen buoyant force (g)} \\
W_7 \text{ weight of oven dried specimen (g)} \\
W_8 \text{ oven dried specimen buoyant force (g)}

**References**


Department of Transportation, Federal Aviation Administration, Report No. DOT/FAA/PM-
85/15, Program Engineering and Maintenance Service, Washington, D.C. 20591
International Conference on Expansive Soils, pp. 1-6
Meeting Session on Unsaturated Soil, Dallas, TX, ASCE Geotechnical Special Publication
No. 39
Nelson, J.D. and Miller, D.J. (1992) Expansive Soils: Problems and Practice in Foundation and
Pavement Design, John Wiley and Sons, New York, NY
Special Publication No. 68, Proceedings of Sessions on Unsaturated Soils at Geo-Logan ‘97,
The Geo-Institute, ASCE, Logan, Utah.
ASCE Soil Suction Applications in Geotechnical Engineering Practice, Geotechnical Special
Publication, No. 48, pp. 1-12.
U.S. Department of Agriculture (1972) “SCS, Soil Survey Laboratory Methods and Procedures for
Collecting Soil Samples”, Soil Survey Investigations Report No. 1, Soil Conservation Service