Alternative Methods of Predicting Pre-compression Stress on Soils with Low Structural Stability

M.R. Mosaddeghi
Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan 84156, IRAN
mosaddeghi@yahoo.com

A.J. Koolen
Soil Technology Group, Wageningen University, Mansholtlaan 10, 6708 PA Wageningen, The Netherlands

A. Hemmat
Department of Farm Machinery, College of Agriculture, Isfahan University of Technology, Isfahan 84156, IRAN

M.A. Hajabbasi
Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan 84156, IRAN

P. Lerink
Netagco Potato Division b.v., Laan van Moerkerken 85, 3271 AJ Mijnsheerenland, The Netherlands

Abstract
Compaction is an important component of soil degradation. In this regard, the pre-compression stress ($\sigma_{pc}$) concept is more considered in mechanized agriculture nowadays. In general, whenever the external forces exceed the internal strength (pre-compression stress) of soil, soil structure and physical quality will be deteriorated. This concept was introduced at first for confined consolidation of non-structured, homogenized and saturated subsoils in civil engineering. This concept is also suitable for agricultural conditions where the topsoil and subsoil are considered and often structured, heterogeneous and unsaturated. The best method for predicting $\sigma_{pc}$ is by the plate sinkage test (PST) in the field, but it is expensive and time-consuming. This study was conducted to find an alternative laboratory method besides the confined compression test (CCT) for predicting $\sigma_{pc}$. The CCT may not be a good method especially at higher water contents and soils with low organic matter because of low sharpness of the critical region on the stress-strain curves. The study was performed on five soil types with a wide range of textures from central Iran using three loading types and three pF (i.e. Log [matric suction in cm]) values of 2.3, 2.7 and 2.9 with two replicates. Loading types consisted of CCT, semi-confined compression test (SCCT) and kneading compression test (KCT) at three maximum (or pre-compression) stresses of 200, 400 and 600 kPa. The idea was to determine how accurately each test (CCT, SCCT and KCT) could predict $\sigma_{pc}$ of the soil pre-compacted by another one. The applied combinations of CCT-SCCT, SCCT-CCT and KCT-CCT mean that the soil pre-compacted by the first loading type and evaluated by the second one. The results showed that the $\sigma_{pc}$ and the sharpness of $\sigma_{pc}$ region were significantly affected by loading types as well as soil conditions. The highest sharpness of $\sigma_{pc}$ region was observed in SCCT and the lowest in CCT. The sharpness of critical region was in the order of CCT-SCCT>SCCT-CCT>KCT-CCT. The sharpness of $\sigma_{pc}$ region reduced when soil water content was higher and soil texture was coarser. Regardless of the soil and loading conditions, the prediction by SSCT is consistently more accurate than CCT. The prediction of $\sigma_{pc}$ by SCCT was more precise in comparison with CCT especially at higher stresses and water contents. However, the prediction of $\sigma_{pc}$ by SCCT was very appropriate at pF values of 2.7 and 2.9 and low $\sigma_{pc}$ values when compared with the actual values of $\sigma_{pc}$. For the clayey soil at pF value of 2.3, no pre-compression region (zero $\sigma_{pc}$) could be determined by CCT at maximum axial stress.
of 600 kPa. This can be related to incompressibility of soil water at near-saturated status of the soil in this high stress. However, the sharpness of the critical region in SCCT was close enough to predict $\sigma_{pc}$ satisfactorily. There was no significant difference between the combinations of SCCT-CCT and KCT-CCT in predicting $\sigma_{pc}$. SCCT is a compromise method that is in the middle between CCT and PST. The PST has the advantage of using a limited and definite soil volume that can be modeled as a soil element. Marginal effects of disturbance caused by coring/sampling as well as pre-test sample preparation seem to have minor effects on the stress-strain curve determined by SCCT in comparison with CCT. Moreover, the soil volume needed for the test is not larger than that for CCT.

**Keywords:** Pre-compression stress, Confined compression, Semi-confined compression, Kneading compression, Sharpness of pre-compression region, Weak structure

### 1 Introduction

One of the most important factors in soil degradation is soil compaction. The study of constitutive stress-strain curves is very applicable to this. A worthwhile point on soil stress-strain curve is pre-compression stress ($\sigma_{pc}$). It is an important soil mechanical property that quantifies the soil in terms of compaction history. Pre-compression stress ($\sigma_{pc}$) divides the stress-strain curve into an elastic and a plastic region and may then represent the greatest effective stress that the soil has been subjected to in the past (Casagrande, 1936). The concept of $\sigma_{pc}$ gets much interest recently. It is postulated that by limiting the load to below $\sigma_{pc}$, the risk of additional soil compaction can be minimized and the deformation will be only elastic (Alexandrou and Earl, 1998).

The “sharpness” of the $\sigma_{pc}$ boundary is a matter of importance. It is important because it can affect the accuracy of $\sigma_{pc}$ estimation. It seems that this boundary is rather sharp for a structured dry soil, so that the $\sigma_{pc}$ has a meaningful value. But the boundary may not be sharp for sandy soils and/or soils with low organic matter and structural stability (Koolen and Kuipers, 1989). When soils are low in organic matter, coarse textured or weakly structured, bonds between solids are weak in comparison to the inter-granular forces that can be induced by an external compactive load. Under these conditions soil ’operations’ increase bulk density (BD). It might be also affected by the water content and loading types. The confined compression test (CCT) is in general closer to agricultural practices (Koolen, 1987). However, there is a challenge to compare other tests in addition to CCT for $\sigma_{pc}$ evaluation. These tests are kneading tests (like those of Söhne (1958) and Lerink (1990)), plate sinkage test (PST) and triaxial test. In kneading tests, the principal stress directions change, which may have very significant effects for some soil conditions. These direction changes also occur in some agricultural practices. PST and triaxial test allow soil to be laterally expanded but PST is easier than the triaxial test to perform and can be used in situ.

The objectives of this study, which was conducted on the soils with low structural stability, are: 1) to compare the sharpness of $\sigma_{pc}$ region of soils under confined, semi-confined and kneading compression tests for different soil types and conditions, 2) to assess suitability of a loading type in predicting $\sigma_{pc}$ of a soil pre-compacted by another test, and 3) to evaluate the consistency of the prediction methods for different soil and loading conditions.

### 2 Literature

The concept of pre-consolidation stress was first defined for consolidating saturated civil soils in confined conditions (Casagrande, 1936). Pre-consolidation stress is considered to be a threshold, above which further compression is considerable and permanent. The concept was entered into agricultural engineering and was named pre-compaction or pre-
compression stress ($\sigma_{pc}$) of the unsaturated agricultural soils (Koolen and Kuipers, 1983). The concept has been used in soil compaction and tillage research by using the same method of compaction i.e. confined compression test (CCT). CCT is often used as a simple means of characterizing the behavior of soil under rapidly increasing principal stress. In an undrained condition in this test, the compaction process will stop when most of the air has been pressed out and the soil has become saturated. In order to simulate the soil behavior under the wheels, the test must be quick so that sometimes it is named “quick confined or uni-axial compression test” (Koolen, 1987).

There is little information on the sharpness of $\sigma_{pc}$ region on the stress-strain curve. Eriksson et al. (1974) performed CCT on 21 Swedish subsoils but did not find it appropriate to describe their strength by the $\sigma_{pc}$. Salire et al. (1994) reported the values of $\sigma_{pc}$ for eight soils under different traffic systems, although in many cases there was no clear stress limit when the soil changed from reversible to irreversible deformation. Arvidsson et al. (2001) were not able to attain $\sigma_{pc}$ on a sandy soil because of very low sharpness of the critical region. It is also uncertain which procedure should be used in order to measure the $\sigma_{pc}$ value. A test with long loading times, as carried out in civil engineering, will probably give the most well defined results. However, it does not resemble the short load application that occurs under tires. Another problem is that no unique method exists for deriving $\sigma_{pc}$ from the stress-strain curve (Casagrande, 1936; Dias Junior and Pierce, 1995; Alexandrou and Earl (1995)).

Translation of laboratory results to principal stress situations in the field is complicated by the fact that stress duration, stress path and degree of soil confinement appear to have a substantial effect on the level of compaction obtained. Moreover, the directions of the principal stresses change in a soil-wheel system. The compaction behaviour of a specific soil is determined mainly by the maximum principal stress, the stress path, the stress duration and the degree of confinement it is subjected to (Koolen, 1994). It is necessary to include the simple methods that are more similar to these conditions. In agricultural practices, the soil is partly confined under the load and the plastic deformation of the soil occurs easily in wet conditions. It seems that in spite of the feasibility of well-known CCT in determining soil compressibility, it does not completely describe the soil behavior in field. There is a challenge to compare other tests besides CCT for evaluating $\sigma_{pc}$. Koolen (1994) stated that two processes named compression and shear happen in practice. The first causes a volume decrease or increase in density, through the expulsion of soil air and the second causes deformation through the rearrangement of soil particles or micro-aggregates. Changes in stress direction lead to compaction as well as shear. Söhne (1956) also showed that the effect of different loading conditions depend on soil texture as well as water content. The difference between the compaction obtained with his kneading compaction apparatus and CCT was more pronounced in loamy and sandy soils at moderate water contents. In wet soils, the soil distortion without volume change is more significant under kneading compaction (Dawidowski, et al., 1990; Lerink, 1990). There is insufficient information on agricultural soils pre-compacted by methods beside CCT. Alexandrou and Earl (1995) successfully used PST as a kind of semi-confined test to determine $\sigma_{pc}$ of a soil. Dawidowski et al. (2002) compared CCT and PST with respect to $\sigma_{pc}$ prediction. There are difficulties in combining $\sigma_p$ concept with kneading compaction methods. One reason may be irregular shape of soil compacted in kneading manner and non-homogeneous compacted soil media. Thus, it is worthwhile to compare the different loading types and find a suitable method for $\sigma_{pc}$ determination.

3 Materials and methods
3.1 Soils
Topsoil of five different soil series was collected from Isfahan province in central Iran to include a range of soil textures and organic matter. These soils are typical soil series in the
region. The mean annual precipitation and temperature at the region are about 160 mm and 16 °C, respectively. Classification and some general properties of the soils are shown in Table 1.

Table 1  Classification (USDA) and some general properties of the topsoil of the studied soils

<table>
<thead>
<tr>
<th>Soil No.</th>
<th>Soil classification</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Texture*</th>
<th>OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aquic Haplocalcids</td>
<td>127</td>
<td>348</td>
<td>525</td>
<td>C</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Typic Haplargids</td>
<td>158</td>
<td>502</td>
<td>348</td>
<td>SiCL</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Fluventic Haplocambids</td>
<td>240</td>
<td>472</td>
<td>348</td>
<td>CL</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>Typic Torrifluvents</td>
<td>532</td>
<td>301</td>
<td>167</td>
<td>SL</td>
<td>9.3</td>
</tr>
<tr>
<td>5</td>
<td>Not Available</td>
<td>432</td>
<td>396</td>
<td>172</td>
<td>L</td>
<td>8</td>
</tr>
</tbody>
</table>

* USDA textural classification, C= Clay, SiCL= silty clay loam, CL= Clay loam, SL= Sandy loam, L= Loam and OM= organic matter content

3.2 Experimental procedure for sample preparation

The experiment was conducted on the topsoil samples (generally 0-20 cm) in the laboratory. Sufficient soil was collected from the ploughed layer in suitable water content (between plastic limit and shrinkage limit) by composite sampling and great care was taken not to crash soil clods and aggregates during sampling. The samples were air-dried and passed through 10 mm sieve. Soil was poured and knocked slightly into cylinders with diameter and height of 9.86 and 5 cm, respectively in order to achieve a uniform initial dry packing state (BD of 1.2 Mg.m⁻³). Before soil filling, cloth pieces were tightened by rubber under the cylinders.

The prepared soil cylinders were saturated from bottom (to prevent air entrapment) for 2 days. Then, the soil cylinders were placed on sand-kaolin box (pF¹ 2.3-3) for adjusting the matric potential to pre-test pF values of 2.3, 2.7 and 2.9 (i.e. matric suctions of 20, 50 and 80 kPa, respectively). The equilibrium time of 5 days were found to be satisfactory. After that, the soil cores were weighed and loaded as defined in the next section. After compaction processes, the soil cylinder were oven-dried for 48 hr in 105 °C in order to calculate soil water content and if necessary BD. The experiment contained five types of soil, three pF values (2.3, 2.7 and 2.9), three maximum stress or $\sigma_{pc}$ values (200, 400 and 600 kPa) and three combination of loading types with two replicates. Therefore, total tested soil samples were 240 (5 × 3 × 3 × 3 × 2).

3.3 Loading characteristics

Compaction of the soil cores was accomplished using a Zwick Universal Testing Machine. The machine was fully controlled by PC through an interface with software of Xpert and has several options that can be adjusted for different tests. The master program of Hysteresis (he006.zpv) and sub-program of staircase loading were used in order to collect the data on loading as well as unloading and reloading paths. Pre-load, pre-load and loading speeds were set respectively to 5 kPa, 50 and 10 mm.min⁻¹ for all the tests. It is believed that this strain rate is one order of magnitude slower than strain rate in normal agricultural practices. Upper reversal force was pre-set with considering the maximum stress and loaded surface. Three maximum or pre-compression stress values of 200, 400 and 600 kPa and three combination of loading types with two replicates. Therefore, total tested soil samples were 240 (5 × 3 × 3 × 3 × 2).

Combinations of confined (CCT), semi-confined (SCCT) and kneading (KCT) compression tests were performed in Lerink’s kneading apparatus (Lerink, 1990). A schematic of the apparatus is presented in Fig. 1. It was designed in principle for kneading distortion on the

¹- pF = Log [h] where h is the matric suction of the soil with length dimension i.e. head (cm).
wet soil samples without any volume change. Of course, it is also possible to conduct the tests by Söhne (1958) and Proctor kneading tests, but the degree of deformation cannot be controlled precisely. Moreover, using Söhne (1958) and Proctor kneading tests on wet soils do not end to a regular shape of the soil to sample for further analysis. The idea was that how accurate each test (CCT, SCCT and KCT) could predict $\sigma_{pc}$ of the soil pre-compacted by another one. The applied combinations of CCT-SSCT, SCCT-CCT and KCT-CCT mean that the soil pre-compacted by the first loading type and evaluated by the second one. The second loading event was continued up to 1000 kPa. For CCT, the soil was compacted in the rigid cylinder under a plate fitting inside it until the pre-set $\sigma_{pc}$. The piston stroke of the kneading apparatus was used for SCCT (the loaded area had the diameter of 5 cm in the center of the soil core). Alternative strokes of piston and annulus were applied for KCT (Fig. 2). The strokes of piston and annulus were limited to 20 mm (Lerink, 1990), therefore, for some cases of high water content (e.g. pF of 2.3) and $\sigma_{pc}$ (e.g. 400 and 600 kPa), it was not possible to apply the exact stresses in one alternative stroke of piston and annulus. Thus, the samples were first brought to a lower stress (e.g. 200 kPa) and then to the desire value of the $\sigma_{pc}$. For the combinations of SCCT-CCT and KCT-CCT, a copecky cylinder (diameter 5 and height 5.1) was inserted in the center of the pre-compacted soil by the first method. The reason was due to the fact that the soil in the center (diameter of 5 cm) was mainly compacted (Lerink, 1990). Moreover, reloading by CCT on uneven surface of the soil pre-compacted by SCCT and KCT was not possible. During the tests, the force was measured as a function of sinkage.

Figure 1  Schematic diagram of the kneading compression apparatus (after Lerink, 1990).

Figure 2  Schematic diagram of the kneading compression test (KCT). For semi-confined compression test (SCCT), only piston-down movement was used (b) (after Dawidowski et al., 1990)
From the output of the Universal Testing Machine, stress-apparent strain curves were calculated by dividing the measured force by the loading area and the sinkage by the initial height of the sample. The actual values of $\sigma_{pc}$ were calculated by considering the registered upper reversal force and the loaded area. Since there were two values of $\sigma_{pc}$ for KCT, the mean value was computed by a weighing formula because the loaded surface of annulus is 3 times of piston:

$$\sigma_{pc(\text{mean})} = (\sigma_{pc(\text{piston})} + 3\sigma_{pc(\text{annulus})})/4$$  \hspace{1cm} (1)

Where $\sigma_{pc(\text{mean})}$, $\sigma_{pc(\text{piston})}$ and $\sigma_{pc(\text{annulus})}$ are the mean pre-compression stress and the values of pre-compression stress under piston and annulus, respectively.

### 3.4 Prediction of the pre-compression stress values

Casagrande’s (1936) method was used in a package written in MATLAB and followed by the procedure of Dawidowski and Koolen (1994). The package can reduce and filter the data to cope with ever-present small fluctuation in the experimental results and determine the data pair for which the smallest radius of curvature of axial strain vs. log axial strain ($\varepsilon_1\text{-log} \sigma_1$) has occurred. Then, it characterises bisector line between tangential line on curve in point of smallest radius and horizontal line. Finally, the threshold value ($\sigma_{pc}$) can be found by stress ordinate of intersection of the bisector and the extension of virgin compression line (VCL).

### 4 Results and discussion

#### 4.1 Effect of loading types and soil conditions on the sharpness of the pre-compression stress region

The sharpness of $\sigma_{pc}$ region is important in determining the $\sigma_{pc}$ value of a soil. If the sharpness of the critical region is low, determination of the point of maximum curvature (Casagrande, 1936) and consequently the tangential line in that point is difficult and the possibility of a non-accurate prediction is high. The results showed that the $\sigma_{pc}$ and the sharpness of $\sigma_{pc}$ region were significantly affected by loading types as well as soil conditions. The highest sharpness of $\sigma_{pc}$ region was observed in SCCT and the lowest in CCT (Fig. 3). The sharpness of critical region was in the order of CCT-SCCT>SCCT-CCT>KCT-CCT. Results of Dawidowski et al. (2001) also showed that VCL for PST is steeper than CCT but there is no difference between them in swelling index (elastic part). An index of sharpness could be the quotient of compression index (slope of VCL) to swelling index (slope of over-compacted region). When a soil pre-compacted by KCT, reloading by CCT caused in lower sharpness of the critical region when compared with a soil pre-compacted by SCCT following by CCT (Fig. 3). It might be due to more compact arrangement of the soil under KCT, which will not be compacted significantly during reloading.

In general, the sharpness of $\sigma_{pc}$ region reduced when soil water content was higher and soil texture was coarser (Fig. 4). The sharpness of critical region was lower for CCT at higher water contents and maximum axial stresses. Thus, no or very low values of $\sigma_{pc}$ could be defined by CCT especially in high water content and high maximum axial stress because of extremely gradual and little change of plastic strain during reloading. This is due to the fact that while compression is taking place in a confined cylinder, there is a large increase of stress as the reduction in height approaches a limit imposed by the maximum potential BD of the soil. Moreover, confinement of the soil in CCT and the incompressibility of water do not let more compaction during reloading. In such conditions, little change or error in measurement of the stress-strain curve may lead to a large difference in predicted $\sigma_{pc}$. 

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Fig. 3. The sharpness of pre-compression region as affected by combination of loading types for Soil 1 at pF value of 2.3. KCT-P and KCT-A refer to piston and annulus stroke in kneading compression test and CCT and SCCT stand for confined and semi-confined compression tests, respectively.

However, the sharpness of critical region was almost high in SCCT independent of the water content (Fig. 4) and maximum axial stress. It might be because of semi-confined condition, which let lateral movement and freedom of the soil particles to rearrange during loading. Furthermore, it will not cause a build up in the pore water pressure. As it is shown in Fig. 4, even for the coarser soil at pF 2.3, the sharpness of $\sigma_{pc}$ region is fairly high when compared with pF 2.9. Even with normal scale of the stress, we can determine $\sigma_{pc}$ for SCCT (refer to method of Alexandrou and Earl (1995)). The problem with Casagrande’s (1936) method is the fact that a logarithmic scale for stress is rather insensitive and a small error in measuring strain will lead to inaccurate predictions of $\sigma_{pc}$.

Fig. 4. Combination of loading types for Soil 4 at pF values of 2.3 and 2.9. CCT and SCCT stand for confined and semi-confined compression tests, respectively.
4.2 Assessment of different loading types to predict pre-compression stress

Capability of a loading type in predicting $\sigma_{pc}$ of a soil pre-compacted by another one was assessed. The results of predicted versus actual values of $\sigma_{pc}$ are shown in Figs. 5 and 6. Regardless of the soil and loading conditions, the prediction by SSCT is consistently accurate than CCT. However, the prediction of $\sigma_{pc}$ by SCCT was better at higher stresses and wetter soil conditions when compared with CCT.

Fig. 5. Predicted versus actual values of pre-compression stress for Soil 1 at two pF values. CCT, SCCT and KCT stand for confined, semi-confined and kneading compression tests, respectively. The combinations of the loading types mean that the soil had been pre-compressed by the first one and then predicted by the second method.

Fig. 6. Predicted versus actual values of pre-compression stress for Soil 4 at two pF values. CCT, SCCT and KCT stand for confined, semi-confined and kneading compression tests, respectively. The combinations of the loading types mean that the soil had been pre-compressed by the first one and then predicted by the second method.
With increasing water content and axial stress, the sharpness and prediction of $\sigma_{pc}$ by CCT was very poor. For Soil 1 at pH value of 2.3, no pre-compression region (zero $\sigma_{pc}$) could be determined on the stress-strain curves at maximum axial stress of 600 kPa (indicated by an arrow in Fig. 5). It can be related to incompressibility of soil water at near-saturated status of the soil in this high stress. Koolen (1982) also reported that prediction of $\sigma_{pc}$ by CCT for a heavy silty clay loam in wet condition and at high values of $\sigma_{pc}$ is not good. However, the sharpness of critical region in SCCT was fairly enough to predict $\sigma_{pc}$ satisfactorily. An exception is maximum axial stress of 600 kPa at pH value of 2.3 where the prediction by SCCT is moderately good. Since the upper limit of normal stresses resulting from agricultural machinery is about 400 kPa (Koolen and Kuipers, 1983), it would not be an important disadvantage of SSCT. There was no significant difference between the combinations of SCCT-CCT and KCT-SCCT in predicting $\sigma_{pc}$.

Under the tires and in the wet conditions (e.g. pH value of 2.3), the induced positive pressure in the free water can act in the role of an isotropic stress in each direction. It causes damage to soil structure as well as a large lateral soil displacement and upheaval of the surrounding soil. It is obvious that in CCT, development of positive pressure causes a little soil strain and in reality, such thing can not happen under tires. It can be said that a very lower positive pore water pressure developed under SCCT or tires because of freedom of soil water for transport to surrounding soil volume. Thus, SCCT could simulate the compaction process under tires better.

In most of the cases, the $\sigma_{pc}$ values were to some extent over-estimated by SCCT (Figs. 5 and 6). This might be interpreted by well-known friction-cohesion law of Mohr-Coulomb. Since soil-cylinder wall friction for initial stage of compaction under CCT is low, soil will be compacted easily in this part. On the other hand, in SCCT a specific amount of load must be inserted to break the bonds between the soil under piston and the surrounding soil to start and continue the compaction process. The piston load could be imagined as a shear stress on the cylindrical interface of piston-annulus. Since sandy soils (e.g. Soil 4) are frictional and cohesionless, this process may not be important so that the predicted $\sigma_{pc}$ values are not very higher than the actual values.

### 4.3 Consistency of the prediction methods for different soil conditions

It could be concluded from Figs. 5 and 6 that the semi-confined method (SCCT) was always a suitable method for prediction of $\sigma_{pc}$ on pre-compressed soil independent of the loading or soil conditions. For low stresses and clayey soils, SCCT over-estimated the values of $\sigma_{pc}$ a little. The prediction by CCT is fairly good at low stresses (e.g. 200 kPa) but very poor at higher stresses (400 and 600 kPa).

### 5 Conclusions and recommendations

Tractors or other equipment in the field applied a certain load. This load is difficult to replicate in laboratory because it comprises of shear and vertical load and results in lateral and vertical soil compaction. The best way of testing soil is in situ plate sinkage test (PST) in the field. PST needs labour and complicated loading instruments in the field. Furthermore, the measured properties (i.e. pre-compression stress, compression index and swelling index) by this test cannot easily be related to a specific depth increment of the soil.

The results showed that CCT might not be a good method especially for the wet range of water contents and soils with low organic matter because of low sharpness of critical region on stress-strain curves. The first attempt to find an alternative lab method beside CCT has led to the valuable conclusion that semi-confined compression (SCCT) is a compromise
method that is in the middle between CCT and PST. Despite of PST, it has the advantage of limited and definite affected soil volume that can be modeled as a soil element. Marginal effects of disturbance caused by coring/sampling as well as pre-test sample preparation seems to have minor effect on stress-strain curve determined by SCCT in comparison with CCT. The effects of sampling will be more in the soil volume, which is near the internal wall of the cylinder and the soil in center of the cylinder is more or less undisturbed. The soil volume needed for the test is not larger than one for CCT. In addition, determining compressibility and stress-strain curves of the soil is possible in the lab and can relatively simulate soil behavior under PST at least for initial stage of compaction process where the pre-compression stress is expected. The soil between the piston circumference and the inner circumference of the sample ring has volume 3 times more than the soil under the piston and permit the soil directly under the load to move laterally. One may argue that the surrounding soil is not enough for letting the loaded soil under piston move infinitely like PST. As a matter of fact, the cone formation in soil under PST is likely to happen under wet status of the soil (Alexandrou and Earl, 1997). Inspection of the cross section of loaded soil by SCCT showed that only for high value of stress (400-600 kPa) and in wet conditions (pF values of 2 and 2.3), the surrounding soil is fully compacted and has an upward displacement. It is more significant for heavier soil because of flexibility of fine smeared clay particles for movement and incompressibility of soil water. However, it is worthwhile to study the effect of different ratios of diameter of piston and annulus on the results of SCCT.

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