GCTS TESTING SYSTEMS

SWC-150

Fredlund Soil Water Characteristic Device

Operating Instructions

Version 1.1

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1.0 SAFETY PRACTICES

Review these guidelines to ensure that your current operating procedures do not result in hazardous situations. Although all hazards may not be able to be eliminated, the following guidelines can be used to identify hazards so that the proper training, operating procedures, and safety equipment can be implemented.

System operators should fully review the documentation supplied to gain an understanding of the system functions. Figures will be placed throughout the manual and should be reviewed.

To ensure smooth system operation during the first execution of the control software, the user should be very familiar with this section and the specific test module to be used.

After the documentation for the SWC-150 has been reviewed, make modifications to your current operating procedures which will minimize hazards. It may be beneficial to make an adjustment checklist that corresponds to your specific hardware.

1.1 Operating Safety Considerations

The following operating safety considerations are applicable to most testing systems. The user is required to read each item below and determine if it is applicable to the testing system for which the SWC-150 and load frame will be used. The user is also required to obtain and review all safety instructions on specific testing equipment used in the system.

EMERGENCY STOPS

Determine the location of system emergency stop buttons to allow for quick emergency stops. Refer to the individual product manuals for instructions on how to wire additional emergency stop circuits.

INTERLOCK DEVICES

Interlock devices, such as the Emergency Stops, should always be used and properly adjusted. Test all interlock devices immediately before each test. Because of the possibility of operator error, system

WARNING misadjustment, or component failure, interlock devices cannot be relied on to protect personnel, test specimens, or test equipment. Thus, standard precautions about staying clear of the ram should always be followed.

STAY CLEAR OF LOADING PISTON

WARNING

When system power is on, stay clear of each end of the actuator piston rod. The area on the base plate used for component installation should be worked around with caution. Never place any part of your body between the actuator piston rod and base plate when the hydraulic/pneumatic pressure is on. Due to test specimen failure, operator error, or other factors, the actuator could unexpectedly react and cause personal injury.

DANGERS DUE TO SUDDEN SYSTEM MOVEMENTS

WARNING

High forces and rapid motions are usually present in testing systems. Unexpected actuator responses can be very dangerous. Likely causes of dangerous actuator reactions are operator error and equipment failure due to damaged or abused equipment. An actuator piston rod that reacts suddenly can strike an operator installing a test specimen or damage the load cell or expensive components. For the above reasons, anyone who operates, maintains, or modifies a system should read all provided manuals to acquire a thorough knowledge of the system's operating characteristics

STAY CLEAR OF TESTING SYSTEM

WARNING

Never allow bystanders to touch specimens or equipment while the system is operating.

EFFECTS OF CONTROL ADJUSTMENTS

CAUTION

Do not make mechanical, or software adjustments to system components unless you know exactly how the adjustment will affect system operation. In many cases a slight adjustment can throw the system out of calibration and cause divergence between the command and feedback. Consult an experience user when in doubt about any adjustment procedure.

PID GAIN ADJUSTMENTS

CAUTION

If operating the system in force or stress control, adjust the active PID Gain control to a value known by experience to be stable for the particular system in use. Otherwise, the possibility of violent instability should be anticipated when the test specimen comes in contact with the system ram.

SYSTEM OPERATION BY TRANSDUCERS

CAUTION

If the system is under control of a transducer, be certain that the transducer is not bumped accidentally. This could cause the ram or other system components to move suddenly. For example, if the test is deformation-controlled and the Linear Variable Differential Transducer (LVDT) is bumped, sudden movement of the ram may occur.

LOSS OF CONTROL FEEDBACK SIGNAL

CAUTION

If the control feedback signal is interrupted during operation, the controller senses an error. The actuator will attempt to correct the error by stroking at maximum velocity until it reaches an internal or external mechanical limit. The external mechanical limit may be any type of obstruction that is in the path of a stroking actuator (such as tools, specimens, or hands). Be aware that the full force of the actuator will be applied to an external mechanical limit or obstruction. The only effective way to minimize the static force capability of a system is to reduce the system hydraulic/pneumatic pressure.

The error detectors in the controller minimize the potential for specimen or equipment damage caused by loss of feedback or larger than normal feedback errors. The error detectors and can fault due to operator error or component failure.

SWITCHING FROM HIGH TO LOW PRESSURE GAUGE

CAUTION

Do not switch the range selector valve from “High” to “Low” if the system has more than 200 kPa present, Failure to do so will result in damage to the low pressure gauge.

USING A NITROGEN OR AIR TANK FOR PRESSURE SUPPLY

CAUTION

If there is no house air available and a compressed gas tank of nitrogen or air is to be used, ensure that the maximum outlet pressure cannot exceed 2000 kPa.

NON-RELIEVING PRESSURE REGULATORS

CAUTION

Some test systems will be supplied with non-relieving pressure regulators when operating with a nitrogen or air pressure tank. The non-relieving regulators minimize bleed off to maintain a constant pressure. In order to reduce nitrogen or air pressure in the system at test end, you must slowly open the pressure relief needle valve located on the rear of the pressure control panel. When the front pressure gauges indicate that the pressure to the SWCC cell has been reduced to 0 kPa, you can then safely open the cell.

ELECTRICAL POWER FAILURES

WARNING

The failure or shutoff of electrical power to the testing system when pressure is being applied can cause considerable and unpredictable actuator reaction. Under these conditions, loss of electrical power on servo controlled systems will generally cause the actuator to stroke at maximum velocity in either direction or, if a specimen is attached, to apply full tensile or compressive force.

Many systems contain hydraulic/pneumatic accumulators that store enough energy to temporarily operate the actuator at full force capacity even when the hydraulic/pneumatic pressure is shut off. For this reason, the usual interlock devices will not prevent hazardous actuator stroking.

2.0 FEATURES OF FREDLUND SWCC DEVICE

- Application of vertical pressure
- Tracking overall volume changes
- Tracking water content changes
- Applied of suctions up to 1,500 kPa
- Both drying (desorption) and wetting (adsorption) curves can be measured
- Dual pressure gauges and regulators for precise pressure control
- Null-type initial suction measurements using axis-translation technique (optional, requires a pressure transducer)
- Stainless steel construction with hand-operated knobs for fast setup
- Pressure compensator on the loading ram
- Ability to flush and measure diffused air
- Hanging column option for applying low suctions in the 1 to 5 kPa range
- Heat application for preventing vapor condensation inside the cell

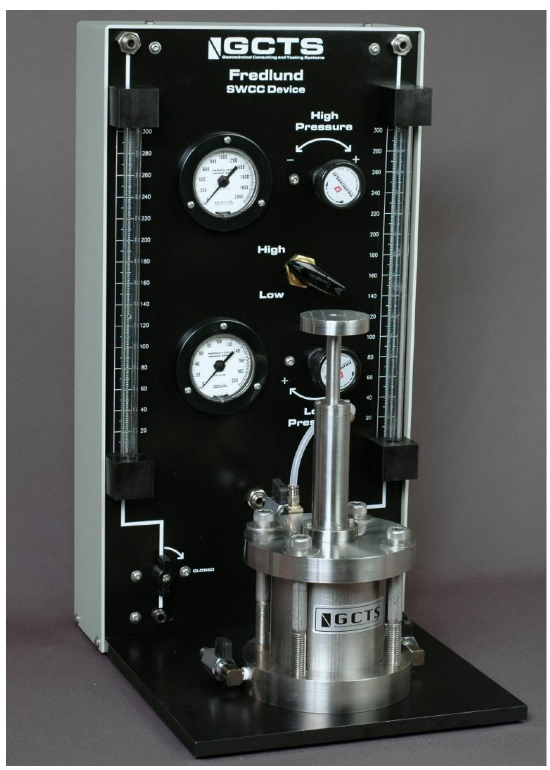

Figure 1. Fredlund SWCC Device.

3.0 APPARATUS

3.1 GENERAL

The **Fredlund SWCC Device** is a simple unsaturated soil testing apparatus that is capable of applying matric suctions while following various applied total stress paths. The device can be used to obtain the complete soil-water characteristic curve (SWCC) for a soil. The Fredlund SWCC Device can apply matric suctions ranging from near zero values up to 1500 kPa (i.e., 15 bars), and is capable of applying one-dimensional loading, K_o, to a soil specimen. The specimen diameter can be up to 71 mm. The device is a complete ‘turn-key’ system. The apparatus allows the use of a single soil specimen to obtain the entire SWCC with any number of equilibrium data points.

The cell is constructed of stainless steel and includes the necessary plumbing and valves for periodically flushing and measuring diffused air. Several different high air-entry ceramic disks (HAED) can be easily interchanged. An optional pneumatic loading frame is available for applying vertical pressures. Other options include a hanging column for applying low suctions (i.e., 1 to 5 kPa) and a small heater for the control of vapor condensation inside the cell.

The Fredlund SWCC device consists of two main components; namely, a **Pressure Cell Assembly** and a **Pressure Panel**. A **Loading Frame** is an optional component. The loading frame is fitted with a pneumatic cylinder for applying vertical loads to simulate overburden pressure or other total stresses. The pneumatic cylinder can also be used to compensate for friction in the loading piston. If the loading frame is excluded or the applied loads are small (i.e., less than 50 kg), dead weights can be used.

3.2 SCHEMATICS AND PHOTOGRAPHS

Figure 1 shows a photograph of the Fredlund SWCC device. A schematic diagram of the Fredlund SWCC Device is shown in Figure 2. This diagram shows the device with a specimen mounted inside the cell. An exploded view of the pressure cell is shown in Figure 3. The SWCC device can be used with or without a loading frame. Figures 4 shows a photograph of the system with a loading frame.

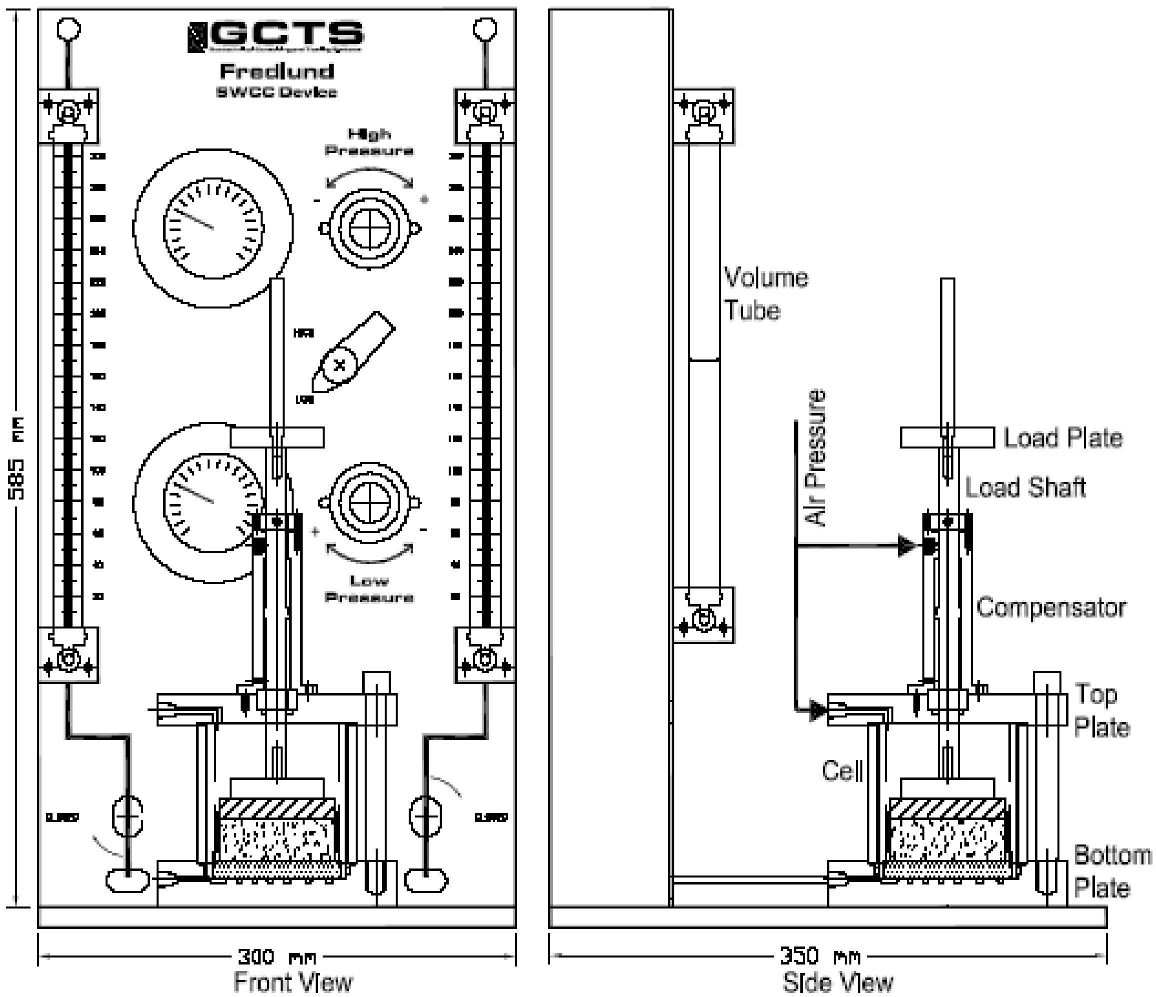

Figure 2. Schematic of Fredlund SWCC Device without the loading frame.

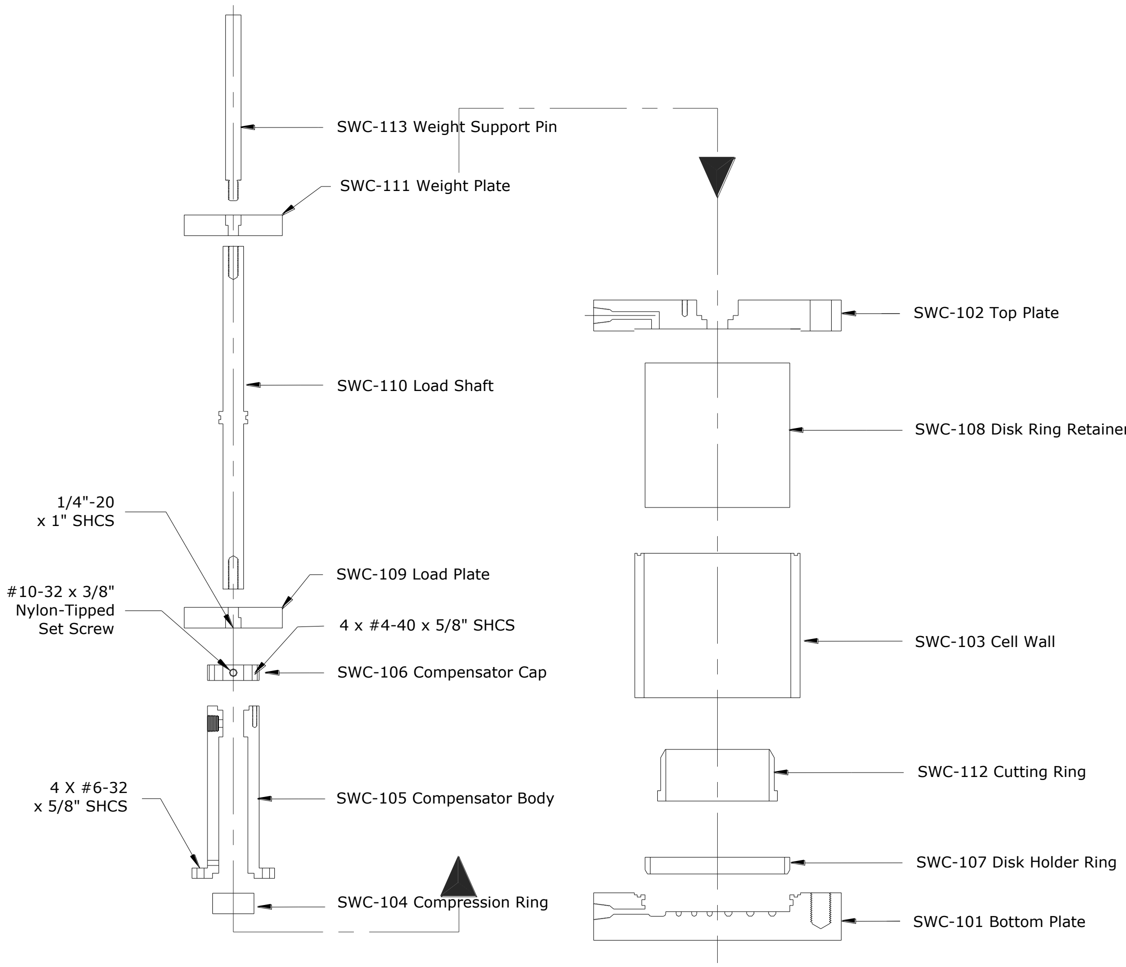

Figure 3. Schematic of the pressure cell assembly.

Figure 4. Fredlund SWCC Device with loading frame.

3.3 ACCESSORIES NEEDED

The accessories listed in Table 1 are required to assemble the system and carry out a test to measure soil-water characteristic tests, SWCC. Most of the items are commonly available in a soils laboratory. Special items such as ceramic disks and epoxy kits can be ordered through GCTS.

Table 1. Accessories for SWCC Testing

Accessory	Use / Remarks
Dead Weights	100 g, 500 g, 1 kg, 2 kg, 5 kg, 10 kg
Ceramic stones1	1, 3, 5, and 15-bar2 stones
Epoxy kit	for gluing ceramic stones
Masking tape	for covering ring and ceramic stone for gluing
Water supply	demineralized water
Electronic balance	accuracy of 0.01 g with at least 500 g capacity.
Metal rings3	brass or stainless steel specimen rings
Oven	for moisture content determination
Glass or plastic plates	for specimen preparation
Air compressor	air pressure source providing up to 1500 kPa
Compressed nitrogen	nitrogen bottle can be used as pressure source
Plastic containers	for specimen and ceramic stone saturation
Vernier caliper	for specimen height change measurements
Spring caliper	for taking height measurement
Hydraulic jack	for extrusion of tube samples
Porous stones	for specimen saturation process
Tools	allen-wrenches, screwdrivers, trimming tools, spoons etc.

Notes:

1. A 5-bar ceramic stone is provided with the system. Additional ceramic stones can be ordered from GCTS.
2. 1 bar = 1.0197 atmosphere ≈ 100 kPa = 14.5 psi.
3. One 63 mm (2.5”) diameter specimen ring is provided with the system. Additional rings can be ordered from GCTS.

4.0 PREPARATION OF CERAMIC STONES

A mounted (or glued), 5-bar ceramic stone is provided with the system. The ceramic stone should be saturated for about 8 hours before using. It is also advisable to keep the ceramic stone saturated between tests. Repeated rapid drying and wetting might damage the ceramic epoxy contact. Additional mounted or unmounted ceramic disks can be ordered from GCTS. Holder rings and epoxy kits should be requested when ordering unmounted ceramic stones. The following procedure can be used when gluing ceramic stones into the rings.

4.1 MOUNTING CERAMIC STONES

Figure 5. Mounting ceramic stones.

1. Cover the top and bottom sides of the ceramic stone with masking tape, leaving the perimeter open. Use a knife to remove excess masking tape. Figure 5 shows some of the steps associated with the gluing process.

2. Cover the sides of the ring with masking tape except on the inner surface where the ceramic stone is to be glued to the ring.

3. Place the ring and the ceramic stone on a sheet of paper on a flat working surface.

4. Mix sufficient epoxy and hardener on a sheet of paper per instructions on the epoxy kit, typically at a 1:1 ratio. Be careful not to entrap occluded air bubbles while mixing the epoxy. Allow the epoxy mix to harden for about 5 to 10 minutes before using.

5. Apply the epoxy around the perimeter of the ceramic stone with a spatula (or a similar tool) and place the ceramic stone carefully on the sheet of paper.

6. Apply epoxy around the inner surface of the ring and place the ring over the ceramic disks. The ring should be carefully positioned such that the clearance between the ring and the ceramic stone is even on all sides. Also, the beveled end of the ring should be towards the bottom.

7. Check the clearance between the ring and the ceramic disk for air bubbles. Any air bubbles should be removed using a needle. Add more epoxy if necessary. If the air bubbles cannot be completely removed, separate the ring and stone quickly and repeat the entire gluing process.

8. Remove all excess glue from the sides and top of the ceramic stone/ring using a thin piece of plastic or a paper without disturbing the ring and ceramic stone.

9. Leave the ring and the ceramic stone overnight for hardening.

10. Once the epoxy is hardened, carefully remove the masking tape.

11. Place the glued ceramic stone under demineralized water for about 24 hours for saturation.

12. Remove the ceramic stone from the water and remove any remaining masking tape, and store.

4.2 SATURATION OF CERAMIC STONES

The ceramic stones are hydrophilic and are therefore easy to saturate. If the ceramic stone is dry, place it under water overnight. Just before using in the apparatus, remove the saturated ceramic disk from the water, then dry the ring and lightly mop the top and bottom of the ceramic disk to remove excess water while achieving saturated surface dry (SSD) condition. Then weigh the ceramic disk and the ring.

5.0 SPECIMEN PREPARATION

5.1 UNDISTURBED TUBE SAMPLES

Tube samples obtained from a field sampling program should be carefully extruded into thin-walled stainless steel or brass rings prior to preparation for a test:

1. Partially extrude the tube sample using a hydraulic jack. Metal plates and spacers can assist in the sample extrusion process. Typically, the height of the SWCC specimen is 25 mm (1 inch), and therefore an extruded length of 30 mm (1.25 inches) should be adequate.

2. Place the specimen ring on top of the extruded soil and press the ring vertically down into the soil by means of a metal plate until the ring is full. The internal diameter of the tube should be the same or larger than the soil specimen ring. Smaller diameter soil specimen rings can be used. When the soil contains gravel-sized particles it is preferable to use soil specimen ring identical to the size (i.e., diameter) of the tube so the entire cylinder of soil can be transferred.

3. Separate the ring filled with soil from the tube, and trim the two ends.

4. If the drying SWCC is to be determined (which is generally the case), place the soil specimen on a porous stone covered with filter paper and place in a container. Fill the container with demineralized water until the water level is about 2 mm below the top of the specimen. This provides favorable conditions for saturation of the soil specimen from the bottom side. It is best to not completely submerge the soil specimen since this might block the release of entrapped air from the specimen. It is desirable to place a small weight on the top of the soil specimen during the saturation process. However, if the specimen is highly expansive, soil may expand above the ring and have to be trimmed from the ring prior to testing. It is also possible to use a spacer when preparing the soil specimen, thereby preparing a soil specimen that is slightly thinner than the steel ring.

5. If a wetting SWCC is to be measured, starting from in situ moisture conditions, then the specimen can be directly mounted into the apparatus for testing.

6. If the testing or saturation is not performed immediately, the specimen should be stored in such a way as to not allow moisture to escape until the specimen is tested.

5.2 DISTURBED SAMPLES

Disturbed samples collected in the field can be prepared for measuring the soil-water characteristic curve, SWCC, by reconstituting or compacting the soil into the rings. Only the portion of soil passing No. 4 sieve (4.75 mm) should be used in this procedure:

1. Determine the dry density (γ_d), specific gravity (G_s), and grain size distribution (GSD) of the soil.

2. Assume the Plus No. 4 material of the soil mass does not significantly affect the air entry value and residual conditions of the SWCC. This may not always be true; however, this is a reasonable assumption when dealing with granular soils or soils with some Plus No. 4 material.

3. Perform the volume-mass calculations listed in Table 2.

4. Weigh the Minus No. 4 material, *M*. Calculate the moist mass of the sample. Compact the soil in the ring in two 12.5 mm (1/2-inch) lifts, attempting to maintain homogeneous compaction. If the sample is quite dry, it may be necessary to add approximately 2 to 5% water to the soil sample to facilitate compaction.

5. Perform the last three steps of the procedure described in Section 4.1.

Table 2. Calculation of dry mass of soil required for the ring.

Calculation	Symbol	Formula	Remarks
Mass of Minus No. 4 material	M_1	$M_1 = \gamma_d \times P_4$	P_4 is Percent Passing No. 4 sieve
Mass of Plus No. 4 material	M_2	$M_2 = \gamma_d \times (1-P_4)$	
Volume of Plus No. 4 material	V_2	$V_2 = M_2 /(G_s \times \gamma_w)$,	γ_w is the unit weight of water
Volume of Minus No. 4 material	V_1	$V_1 = 1 - V_2$	
Dry density of Minus No. 4 material in the field	γ_{d1}	$\gamma_{d1} = M_1 / V_1$	
Dry mass of Minus No. 4 material required to fill the ring that gives a density of γ_{d1}	M	$M = \gamma_{d1} \times V_{ring}$	V_{ring} is the volume of ring

6.0 SATURATION OF SOIL SPECIMENS

The specimen must first be saturated if the drying SWCC is to be measured. The main steps in the saturation process were presented in Section 4.1.

1. Once the specimen is prepared by reconstitution or compaction, place the specimen on a porous stone covered with a filter paper, and place in a container. A wide glass or plastic container is suitable. Several specimens can be saturated at the one time in one container.

2. Fill the container with demineralized water until the water level is about 2 mm below the top of the soil specimen as shown in Figure 6. This allows the soil to be saturated from the bottom up. Do not completely submerge the soil specimen since this might entrap air in the soil.

3. It is desirable to place a small weight on the top of the soil specimen during the saturating process. However, if the soil is highly expansive, the expanded soil may need to be trimmed prior to testing.

4. The time for saturation will be only a couple of hours for granular materials while several days is required for highly plastic clay soils.

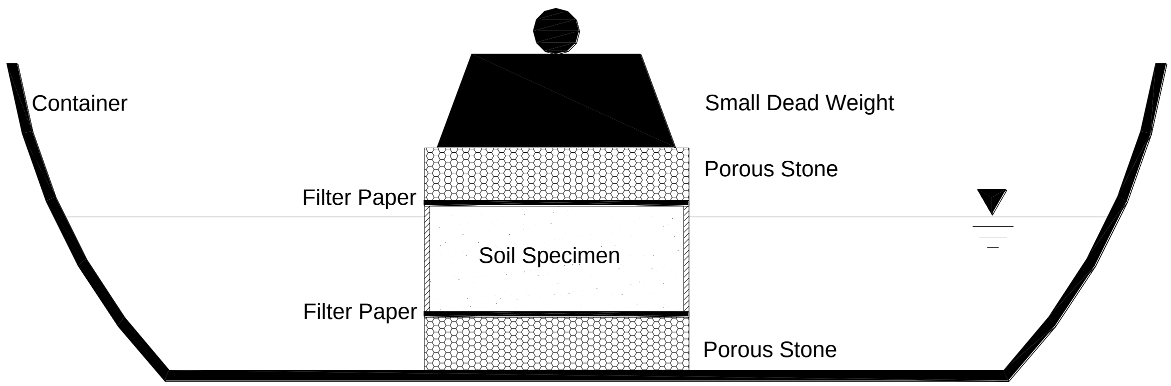

Figure 6. Saturation of the soil specimen.

7.0 SWCC TESTING PROCEDURE

Prior to commencing the SWCC test, it is useful to measure the initial dry density, water content, grain-size distribution, plasticity index, and specific gravity on a representative sample. The grain-size distribution and plasticity index tests will help identifying the type of soil and use the family of curves given in Figure 8 as a guide. The specific gravity is required to compute the degree of saturation of the sample. Once the soil specimen is ready for testing, follow the testing procedure given below:

1. Select a dry glass plate (approximately 4"x 4") and record the weight.

2. If the “wetting” SWCC is to be determined, place the soil specimen on the glass plate. Go to Step 6 (It is also possible that other test procedures could be selected such as the case where the entire soil sample is first dried and then trimmed to fit the confining ring).

3. If the “drying” SWCC is to be determined, the soil specimen should be saturated as described in Section 5. Remove the saturated specimen from the water and place it on the glass plate without the porous stone and the filter papers.

4. Allow the soil specimen to drain any excess water onto the glass plate. The excess water can be removed by mopping with a paper towel.

5. Dry any water from glass plate and the outside of the ring.

6. Weigh the soil specimen and glass plate.

7. Select the most suitable ceramic stone, remove it from the water and wipe out excess as described in Section 3.2. Weigh the ceramic stone. Use Table 3 as a guide for selecting the ceramic stone.

Table 3. Selection of ceramic stones

Type of Soil	Rating of Ceramic Stone
Sand	1-bar
Silty Sand, Clayey Sand	3-bar
Sandy Silt, Sandy Clay	5-bar
Clay	15-bar

8. Transfer the soil specimen onto the ceramic stone. Ensure that the soil specimen is properly centered on the ceramic stone and weigh the ceramic stone and the soil.

9. Prepare the SWCC cell assembly by cleaning the O-rings and surfaces. It is important that these surfaces be free of any grits of sand or any other impurities. Place the O-rings in the grooves of the bottom plate and the cell wall (This can also be done beforehand).

10. Connect the two tube ends coming from the water volume change tubes to the bottom plate by inserting the tube ends into the two quick-disconnect fittings located on the sides of the apparatus (See Figure 7). Note: When inserting the tube into a quick-disconnect fitting, press the tube all the way into the fitting. When disconnecting, press and hold the outer ring located on the fitting with your fingers and then pull the tube out. If the tube is pressurized, release the pressure before disconnecting.

11. Add some water into the bottom plate of the cell. Moisten the outside of the ceramic stone ring. Open the valves at the bottom of each water volume change tube and the bottom plate, and carefully press the ceramic stone and the soil specimen into the recess in the bottom plate. Water will rise in the water volume change tubes while undertaking this step.

12. Place the load plate centered on the specimen. The end of the load shaft can be connected to the load plate with a screw. However, it is not necessary to connect the load plate to the load shaft for SWCC testing.

13. Place the disk ring retainer and cell wall on the base ensuring the cell wall is placed properly within its O-ring so that there will be no air leakage (see Figure 3 for identification of components).

14. Assemble the top plate, compression ring, compensator body, compensator cap, and load shaft using the following procedure:
    a) Insert the O-ring in the center hole of the top plate.
    b) Screw the compression ring on to the top plate. There are two wrench flats on the top of the compression ring. Slightly tighten the compression ring with an adjustable wrench by grabbing at wrench flats so that the O-ring is compressed.
    c) Insert the load shaft into the compensator body ensuring the O-ring around the ridge in the middle of the shaft is properly in place and well lubricated with an O-ring lubricant.
    d) Insert the bottom end of the load shaft into the cell through the compression ring. Light force may be required, as the shaft must pass through the compressed O-ring.
    e) If the compression ring is not tight enough, the load shaft will freely slide down. In this case, the cell may not be air tight for application of air pressure. On the other hand, if the compression ring is too tight, it will create excessive friction. Both cases mentioned above should be avoided to have an air tight and low friction assembly. The right condition can be achieved by a couple of trial and error steps.
    f) Attach the compensator body on to the top plate with the four screws.

g) Now the top portion of the load shaft should be visible on the top of the compensator body. Slide the O-ring along the load shaft into the grove on the top of the compensator body.

h) Attach the compensator cap to the top of the compensator body using four screws.

15. Place the assembly on the cell wall observing proper placement of top plate over the O-ring.

16. Attach the weight plate and weight pin to the load shaft for placing dead weights. If loads are to be applied using a loading frame, weight pin is not required. Refer to Section 8 on the Loading Frame for details.

17. Secure the top plate to the bottom plate by tightening the four 4.5-inch long socket-head cap screws (SHCS) that seal the cell walls.

18. Connect the pressure source to the pressure panel through one of the quick disconnect fittings located on the back of the panel using ¼-inch plastic tubing. The second quick disconnect fitting and valve is for supplying air pressure to the loading frame. Keep this valve closed if the loading frame is not in use.

19. Fill the left volume tube with demineralized water through the opening located on the top left hand corner of the panel (Opening L on Figure 7). Water will flow into the right volume tube pushing some of the trapped air in the base. Stop filling when the tubes are about half full.

20. Use the flushing device (ball-pump) to expel any remaining trapped air in the base. Insert the tip of the ball pump into Opening **L** and squeeze the pump. Be careful not to push the water column into the base plate or spill water from the opening located on the top right water column (Opening **R** on Figure 7). Repeat the flushing process changing water columns until no air bubbles appear during flushing.

21. The water columns should level out in both tubes within a few minutes. Record the two initial volume tube readings along with the date and time. If necessary, more water can be added to bring the water level higher.

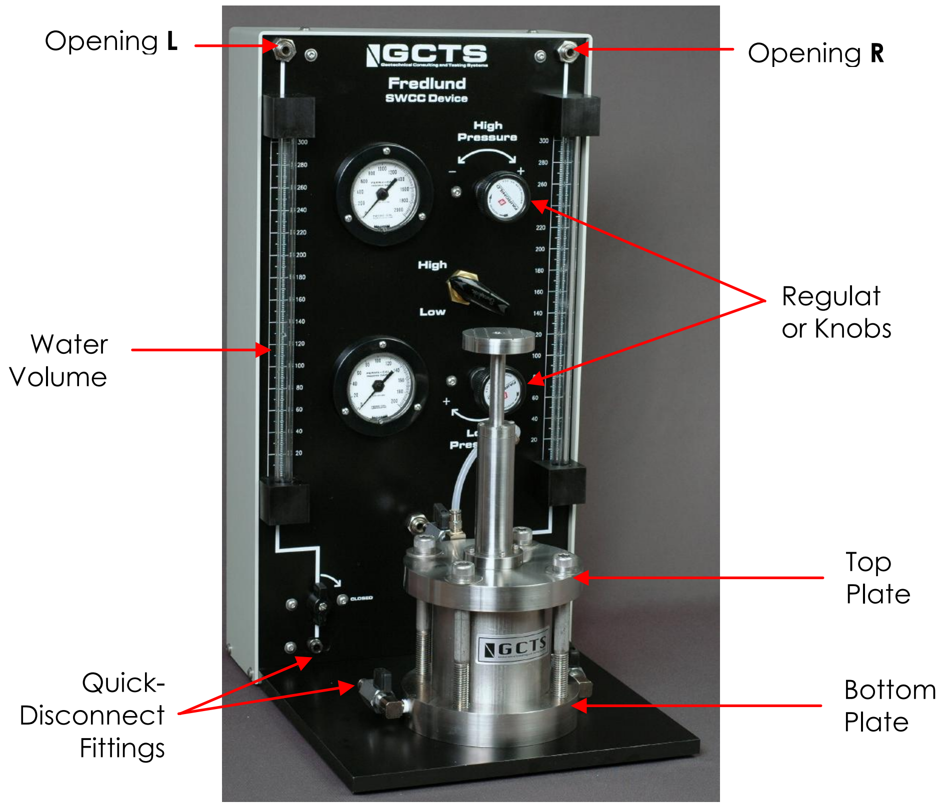

Figure 7. Bottom plate and water volume change tubes

22. Select target pressures to be applied to the soil specimen during the test. For example: for a granular soils, appropriate target pressures could be 5, 10, 20, 50, 100, and 500 kPa, while for a fine-grained soil the target pressures could be 10, 20, 100, 500, 1400 kPa. The selection of target pressures should be such that the selected pressures provide a wide distribution of suction values and degrees of saturation of the soil. It is best to have degrees of saturation that range between 0.10 and 0.90.

23. If the index properties of the soil are available, the following steps can be used to determine the target pressures for a soil.

24. If the soil is granular determine the D_{60} value from the grain-size distribution or, if the soil is fine-grained determine the weighted PI (wPI).

Notes:

1. D_{60} = Diameter of soil particles that represents 60% passing on the grain-size distribution curve.
2. wPI = (Percent Passing No. 200 Sieve expressed as a decimal) x (Plasticity Index).

25. Based on D_{60} or wPI, select the corresponding curve from the family of SWCCs shown in Figure 8, where D_{60} curves represents 1.0, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, and 0.1mm and wPI curves represent 0.1, 3, 5, 10, 15, 20, 30, 40, and 50, respectively.

Notes:

1. It may not always be possible to cover the entire range for fine-grained samples since the actual curves could extend well beyond the 1,500-kPa limit.
2. For fine-grained soils, the complete SWCC can be obtained by combining the test method presented here with another available test method such as filter paper method.
3. In place of the family of curves in Figure 8, a set of equations that was developed based on the findings of an extensive research work carried out at Arizona State University can be used to obtain an approximate SWCC of a soil. These equations are presented in the following reference.
4. Perera, Y.Y., Zapata, Z.E., Houston, W.N., & Houston, S.L. 2005. Prediction of the soil-water characteristic curve based on grain-size-distribution and index properties. *Proceedings of Geo-Frontiers 2005*. Austin, Texas, USA. January 24-26.

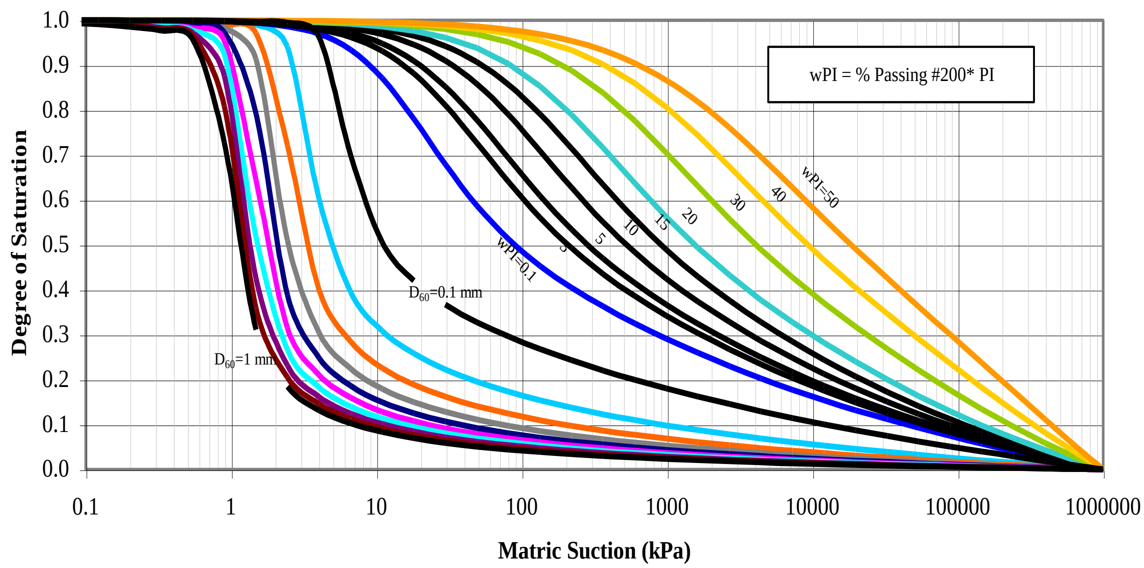

Figure 8. Family of SWCCs developed by Zapata in 1999.

26. Select target pressure values (i.e., matric suctions) corresponding to the entire range of degree of saturation values.

27. The system is now ready for the application of the first selected pressure. The pressure is applied by selecting either the low or high pressure gauge with the HIGH/LOW valve on the center of the panel. Depending on the pressure to be applied, switch the valve to LOW or HIGH. Use the corresponding regulator knob to apply the pressure in the cell.

28. Apply the first pressure increment to the cell. The pressure compensator on the top plate will automatically equalize the pressure exerted on the piston from within the chamber.

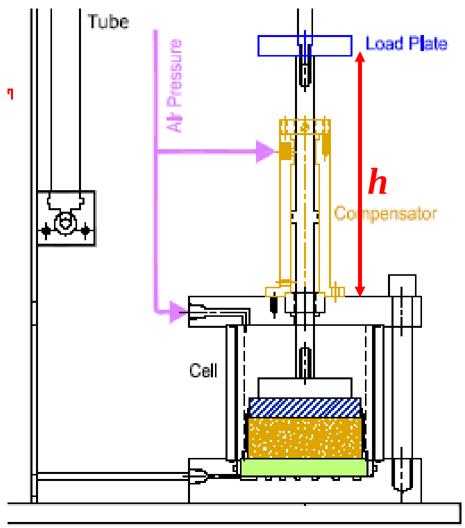

Figure 9. Height measurement

29. The next step is to compensate for the friction between the load shaft and the O-rings. Raise the load shaft and add weights on the weight plate until the shaft slowly moves down or move with a slight touch. At the end of this step, the load shaft should be seated on the load plate at the top of the specimen.

30. Put additional weights on the weight plate to simulate the desired total stress. The total stress might be the overburden pressure. In this case, the overburden pressure can be

calculated as the depth at which the sample was collected in the field multiplied by the field density.

Overburden pressure (p) = Field Density x Depth
Overburden load to be applied = (Overburden pressure) x Area of the load plate

31. Check the system for any air leaks. It is important that there be no air leaks during the test. Check particularly around the O-ring on the bottom of the cell wall and the O-ring at the top plate. A mixture of soapy water can be used to check for leaks. If there is any leaks re-assemble the unit.

32. Measure the distance between the top of the top plate of the cell and the bottom of the weight plate (height measurement, ***h***) using a pair of spring clippers and a Vernier caliper (see Figure 9).

33. Leave the system for equilibration, taking water volume change readings on a log time basis. The test may go for several days. Record readings before and after flushing for diffused air. Equilibration can be considered attained, and the system is ready to receive the next pressure increment when the volume readings do not change significantly (i.e., about one division) over a six-hour period with 1 and 3-bar ceramic stones or over a 24-hour period with 5 and 15-bar ceramic stones. The time required for the equilibration is a function of the soil type and the air-entry value of the ceramic stone. Note that highly plastic soils may require long equilibration time.

34. Before applying the next pressure increment, record the height measurement. It is also possible to record the height of the specimen each time that a water volume change reading is recorded. Increase the pressure by turning the regulator knob on the panel. Use LOW-pressure gauge/regulator for pressures between 1 and 200 kPa and switch to HIGH-pressure gauge/regulator for pressures between 200 and 1,500 kPa.

35. Repeat the same procedure for the remainder of the pressure increments.

36. At the end of the last pressure increment, take the readings (i.e., water volume change reading and height measurement), remove the weights, release the pressure, disassemble the apparatus, and take the soil specimen out.
    Warning: Never try to dismantle the cell without releasing the chamber pressure.

37. Record the weight of the moist specimen and place the specimen in an oven. Oven dry the soil for at least 24 hours at 110 ºC and record the dry weight.

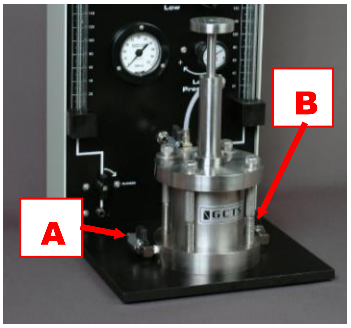

Figure 10. Removing ceramic stone

38. The following procedure (Refer to Figure 10) can be used to remove the ceramic stone from the bottom plate of the pressure chamber:
    - Disconnect one of the tubes on the bottom plate (Location A on Figure 10), connect the pressure source, and open the valve.
    - Closed the valve on the other side of the plate (Location B).
    - Slowly apply pressure to the bottom plate holding the ceramic stone down with the palm of the hand.
    - The ceramic stone should pop out of the base with a pressure of about 5 to 10 kPa. Be careful never to apply excessive pressure to the bottom of the ceramic stone since it can easily be cracked.

39. Bring the ceramic stone to a saturated but dry surface condition and record its weight. The difference between the initial weight and the final weight of the ceramic stone will

indicate if water has been absorbed or released from the ceramic stone during the test. If the difference is significant, the volume readings may need to be adjusted.

40. Once the dry weight of the soil is available, calculate the initial amount of water in the soil, the initial water content, initial dry density, and initial degree of saturation.

41. Using the initial data, calculate the water released, water content, specimen height, specimen volume, dry density, and degree of saturation for each pressure increment.

42. Use the oven-dried weight to calculate the water content of the soil specimen at the end of the test. Also, calculate the corresponding degree of saturation. Compare this degree of saturation with the degree of saturation corresponding to the last data point.

43. The above comparison provides a check on the test. If the two degrees of saturation agree closely the test results are accurate. Disagreement of the degrees of saturation at the end of the test could be related to an error during the test such as an air leak, incorrect data entry, lost of soil during the test, or shrinkage of the soil from the confining ring.

8.0 CALIBRATION OF WATER VOLUME CHANGE TUBES

The measurements obtained from the water volume change tubes represent a linear measurement in millimeters. These linear measurements should be converted to a gravimetric calibration factor, α, that can be determined as follows:

1. Fill one of the water volume change tubes with water with closed bottom valve. Record the water volume tube reading, X_1.

2. Drain about 100 mm of water from the volume tube into a container by opening the bottom valve. Again, record the water volume tube reading, X_2.

3. Weigh the collected water in grams, W.

4. Calculate the calibration factor, α, as follows: $\alpha = W/(X_1 - X_2)$

5. Use α to calculate the amount of water released or absorbed during the SWCC tests. For example, if the difference between the initial and final volume tube readings in a particular test is ΔX, the corresponding weight of water in grams is $(\Delta X) \times (\alpha)$

9.0 LOADING FRAME

The loading frame is capable of applying loads up to 10 kN. It is fitted with a pneumatic loader, a pressure gauge, and a pressure regulator. The procedure for using the loading frame is shown below.

1. Connect the pressure source to the loading frame by running a tube from the quick-disconnect (**A**) located on the back of the panel to the quick-disconnect located on the top of the loader (**B**). See Figure 11 for the locations of **A** and **B**.

2. Open the valve associated with quick-disconnect **A**, and increase the pressure using the regulator knob. The loading piston on the bottom of the loader will move down and touch the load plate. Caution: Turn the regulator slowly to avoid sudden impact of the piston on the load plate.

3. Read the pressure gauge and compute the corresponding loading using Table 4. The values in Table 4 are based on the area of internal diaphragm of the pneumatic loader. To obtain the vertical pressure applied on the soil specimen, divide the load, F by the area of the platen on the soil specimen.

4. To unload, decrease the pressure using the regulator knob. As pressure reaches zero, the loading piston should move upward. If the piston is still touching the load plate, assist it in moving upward.

Warning: Do not place your hand or fingers between the piston and load plate at any time.

Table 4. Pressure-Load Relationship for the Pneumatic Loader

Pressure, p		Load, F		
psi	kPa	lbf	kg	N
0	0	0	0	0
10	69	160	73	712
20	138	320	145	1423
30	207	480	218	2135
40	276	640	290	2847
50	345	800	363	3559
60	414	960	435	4270
70	483	1120	508	4982
80	552	1280	581	5694
90	621	1440	653	6405
100	689	1600	726	7117
110	758	1760	798	7829
120	827	1920	871	8541
130	896	2080	943	9252
140	965	2240	1016	9964
150	1034	2400	1089	10676

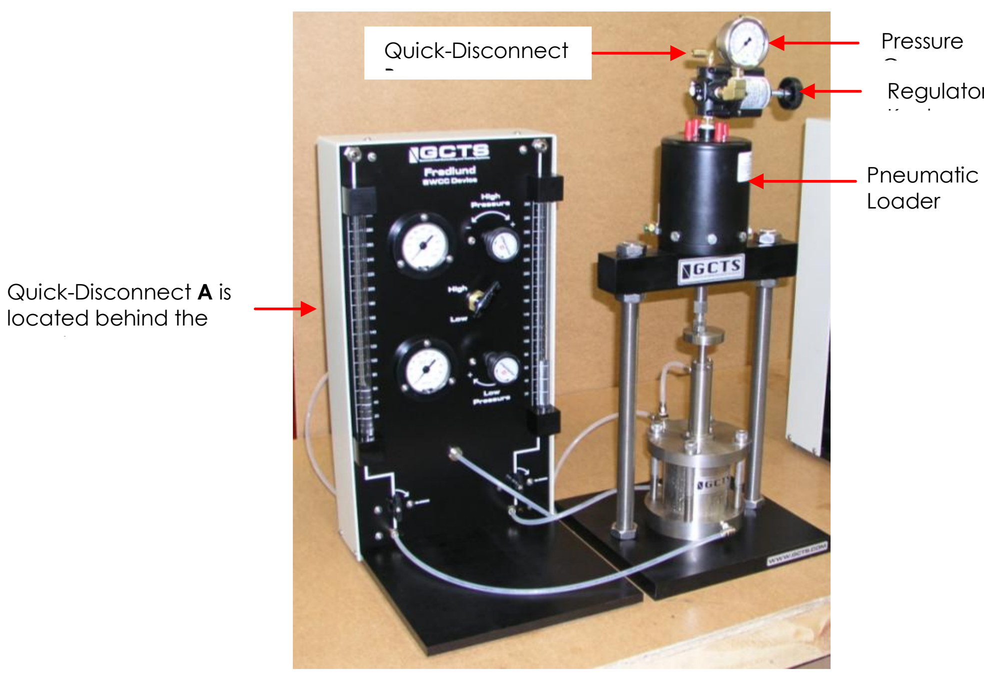

Figure 11. Using the loading frame

10.0 DATA REDUCTION

A sample data sheet for SWCC testing is shown in Figure 12. Main test data is recorded in the area designated Part (I) in Figure 12. The other areas, Parts (II) through (VI), contain the information needs to be recorded before and after the test. At the end of the test, based on the information on the data sheet, the degree of saturation corresponding to each suction value can be calculated as shown on the sheet in Figure 13.

(I) SWCC Test Data		
D_{60} = 12.09	Specimen ID >	SOIL-1
Passing #200=6.8%	CS ID >	5-Bar-A
PI = NP	Suction >	5;10;20;100;500 kPa
wPI = N/A	Station >	1
G_s = 2.71	Initials >	ABC

	Date	Time	kPa	Vol Reading L mm	Vol Reading R mm	Height mm
1	6/1/2005	10:05	5	91	92	62.70
2	6/3/2005	17:25	10	108	109	62.66
3	6/5/2005	22:45	20	179	180	62.56
4	6/10/2005	16:12	100	216	216	62.54
5	6/15/2005	10:40	500	261	261	62.51
6						
7						
8						
9						
10						
11						

(VI) End of the Test		
Wt. of Wet Specimen+Tare	g	228.9
Wt. of Dry Specimen+Tare	g	222.53
Wt. of Ring	g	44.69
Wt. of Tare	g	51.07
Wt. of Water	g	6.37
Wt. of Dry Soil	g	126.77
Final water content	%	5.02
Final Degree of Saturat		0.23

(II) Brass Ring:	ID >	Ring-4
Weight	g	44.69
Height	mm	25.4
Diameter	mm	61.25
Volume	ft^3	0.00264
(III) Ceramic St		
Wt. of SSD CS (initial)	g	198.71
Wt. of SSD CS (final)	g	198.69
(IV) Specimen:		
Wt of Saturated Specimn	g	152.07
Wt of Glass Plate (GP)	g	125.8
Wt. of Sat. Specmn + GP	g	323.22
Wt. of Sat. Specmn + CS	g	395.46
Wt. of Dry Specimen	g	126.77
(V) Overburder		
Density of Overburden	pcf	150
Height of Overburden	in	12
Overburden Pressure	psi	1.042
Diameter of Platen	mm	60.96
Overburden Load	lbs	4.712
Wt. to be applied	g	1859

Abbreviations	
CS	Ceramic Stone
NP	Non-Plastic
L	Left Water Volume Tube Reading
R	Right Water Volume Tube Reading
SSD	Saturated Surface Dry

Figure 12. Sample SWCC data sheet

Calculation of Degree of Saturation		
Initial amount of water absorbed	25.30	g
Initial Water content	19.96	%
Initial Dry Density	105.65	pcf
Initial Degree of Saturation	0.90	

Suction ψ kPa	Water Released g	Water Released from CS g	Water Content pcf	Specimen Height mm	Specimen Volume ft^3	Dry Density pcf	Degree of Saturation S
5	2.52	0	17.97	25.36	0.00264	105.71	0.81
10							
20							
100							
500							

Figure 13. Sample calculation sheet for Degree of Saturation, S.