Chapter 4

Virginia Tech Calibration Chamber and Pluviation System

4.1 Introduction

The focus of this chapter is to outline the calibration chamber used for the testing. The chapter includes discussions of both the existing chamber and the additions to the chamber that allow for the post placement saturation of sand samples. A general discussion of the sample preparation and testing procedures has also been provided.

4.2 Calibration Chamber Specifications and Features

4.2.1 Introduction

A major portion of the investigative work associated with this study involved cone penetration testing in the Virginia Tech calibration chamber. The calibration chamber at Virginia Tech was built by Sweeney (1987) as part of a project involving the evaluation of the liquefaction potential of soil deposits using a miniature cone penetrometer. The chamber was modeled after the original CRB chamber designed by Holden (1991), and is very similar to other chambers around the world. Included in the following section is an overview of the primary components of the chamber. Also included in this section is a detailed discussion of the saturation system that was added to the chamber as part of this study and a summary of the sample preparation procedure. A complete checklist of the sample preparation procedure is presented as Appendix B.

4.2.2 Virginia Tech Calibration Chamber

The Virginia Tech calibration chamber is located at the Prices Fork Testing Facility. The chamber is housed in a sunken pit to allow for easy access to the to the top of the sample. A schematic of the Virginia Tech calibration chamber is presented as Figure 4.1, with the major components outlined in the following section.

The calibration chamber shell has an outside diameter of 1.6m, a wall thickness of 29mm, and is 1.7m in height. Flanges are located at both the top and bottom of the shell to allow the shell to be bolted to the lid and the chamber base plate. Forty 29mm (1.125 in) A325 high strength bolts are used to secure the shell to these upper and lower boundaries (Figure 4.2a). A groove and 12.7mm o-ring are located at the contact between the chamber base plate and the shell to provide a seal between the two units.

The vertical stress is applied to the soil sample through three Firestone #200 Airstroke Actuators (Figure 4.2b). These actuators are attached to the base plate of the chamber through a steel ring that contains an o-ring groove. A 25mm thick by 1.5m diameter sample base plate is placed on top of the airbags and secured with similar steel ring apparatuses (Figure 4.2b). This allows the air bags to be fastened to the top of the base plate and the bottom of the sample bottom plate, and results in an overall seal that keeps the air pressure applied to the airbags within the interior of the airbags. Guide posts and tubes are located on the underside of the sample base plate to ensure that there is no tilt in the displaced plate when they are engaged. An LVDT and an ultrasonic displacement transducer are located on the underside and center of the sample base plate to provide an indication of the amount of displacement of the plate during the application of the air pressure. Empirical relationships have been provided by the manufacturer that relate displacement and actuator air pressure combinations to induced force, provided a reactionary surface is present. Simple free body diagrams were used to determine this force for the vertical center of the sample location.

A 16-gauge perforated sheet metal forming jacket is placed inside the chamber between the shell wall and the sample base plate (Figure 4.3a). The jacket is 1.5m in diameter and extends down past the sample base plate to the base of the chamber. The forming jacket provides lateral support for the sample prior to the stress application and is held together by a hinge system (Figure 4.3b). This hinge system is opened once the sample is exposed to a confining stress by removing the 6.35mm fastening rod within the hinge. This causes the jacket to spring open against the interior wall of the chamber shell, resulting in the sample being supported solely by the confining stress.

A steel collar is positioned on the inside to the forming jacket and lined up with several of the bolt holes located on the flange of the chamber shell. Two 40-mil HDPE liners are placed on the inside the forming jacket and secured tightly over a lip on the collar (Figure 4.4a). Both rags and duct tape were used in the securing process. Fab-Seal Industrial Liners, Inc. of Shawnee OK donated and fabricated the liner to fit the dimensions of the inside of the forming jacket. Holes were cut at the base of the liner at the water inlet locations to allow water to enter the sample. Threaded 19mm male tube fittings were fit into these water inlet locations and securely fastened to a metal gasket with rubber on the bottom to ensure that water did not leak out of the sample (Figure 4.4a).

The sample is pluviated into the chamber using the pluviation apparatus described in Section 4.3. The sand is leveled and the final height of the sample is measured so that the density of the soil could be measured. The sample is then overlain by a 25mm thick by 1.5m diameter steel top plate (Figure 4.4b). The membranes are wrapped over the top plate and a 12.7mm diameter rubber o-ring is placed above the membranes in a groove located near the perimeter of the top plate (Figure 4.5). The purpose of the o-ring is to provide a seal so that the air pressure applied to the lateral boundary of the sample does not infiltrate into the sample. A 9.5mm thick virgin rubber mat is then placed across the entire top plate to serve as a secondary sealing device. The rubber mat was manufactured and donated by Goodyear Tire of Radford, Virginia for this project. A 1.78m diameter by 76mm thick lid is placed over the rubber mat and fastened to the underlying top plate through six 19mm hex nut bolts (Figure 4.6a). Seven 38.1mm holes are located in both the top plate and the lid that allow for multiple penetration ports into the underlying sample. A 12.7mm o-ring is placed in a groove located in the flange of the chamber shell to maintain the air pressure in the sealed chamber. This lid/top plate combination is then secured to the chamber shell through forty 29mm A325 high strength bolts.

A confining pressure is applied to the sample in the 70mm air annulus between the forming jacket and the inside of the chamber shell. The confining pressure is monitored at both the input location and within the void space through pressure gauges and transducers. A pressure differential was always noted between the two measurement locations, which is directly attributed to leakage out of the air annulus at the top lid/chamber shell interface. The connector pin is removed from the hinge in the forming jacket once the effective confining pressure in the annulus reaches a magnitude of 21 kPa (3 psi), causing the jacket to spring back against the interior of the chamber shell. The sample is laterally supported at this point by the confining stress, resulting in a flexible wall testing condition.

A loading frame that contains the hydraulic press used to advance the cone penetrometer is mounted on top of the chamber lid with four 19mm bolts at leg of the frame (Figure 4.6b). The hydraulic press is mounted to a trolley system that can be moved laterally across the lid to reach the three available testing locations (at a given location of the frame). The frame also has three different mounting locations on the lid so that all seven penetration ports could be accessed. The hydraulic press contains an 80mm diameter piston capable of travelling 1.63m and generating up to 71kN of force (Sweeney 1987). The piston force is generated by a 2 HP hydraulic pump manufactured by Parker Fluidpower. Pressure compensated control values are located on the hydraulic lines to maintain a constant penetration rate for different levels of resistance force. The rate of push was empirically set at 20 mm/sec for each of the penetration tests performed. A Celesco Model PT-111-75A displacement transducer was fixed to the frame and cone penetrometer to measure the magnitude of and rate of displacement during the penetration test.

A 2 HP air compressor with a 0.23m^3 reservoir supply was used to supply the compressed air for the vertical and confining pressures during each of the tests. A 2 HP auxiliary air compressor with a 0.11m^3 air capacity was lined in series with the 0.23m^3 unit to accommodate any volume requirements above that of the primary unit.

4.2.3 Newly Implemented Saturation System

A saturation system was added to the calibration chamber to allow for the saturation of samples after their placement into the chamber. Water is introduced into the chamber through an inlet port located in the cell wall 0.5m from the base. The inlet port was threaded on both sides of the wall and fitted with a 19mm elbow tube fitting on the inside of the wall and a 12.7mm reducing fitting on the outside (Figure 4.7a).

A 1m piece of 19mm HDPE tubing was attached to the inside elbow at one end and to a piece of 19mm copper tubing at the other end (Figure 4.7a). The piece of copper tubing was extended above the sample base plate, requiring that a portion of the forming jacket be cut. The purpose of the HDPE tubing was to allow for a point of flexure in the otherwise rigid system once the bottom plates are engaged during the application of the vertical stress. The copper tubing was extended down to a level below the bottom plate and then run from the bottom plate to the three 19mm water introduction ports (Figure

4.7b). The water introduction ports were threaded and fit with a 19mm T-connection at the closest port and elbow fittings at the other two locations. (Figure 4.8). The water introduction port was also threaded from the top of the bottom plate so fittings could be placed on both sides of the plate. The tubing system was attached to the underside of the bottom plate at 6 different locations using angle brackets. This ensured that the tubing system did not flex during the displacement of the bottom plate, which could lead to possible micro cracking and leakage at the sweat soldered connections.

The exterior of the chamber shell was also threaded at the inlet port location. A T-fitting was threaded into the reducing fitting and outfitted with a 12.7 mm tube fitting on one end and reduced to a 6.35mm tube fitting on the other. A flow valve was placed in between the two lines so that either water (12.7mm line) or CO_2 (6.35 mm line) could be brought into the chamber wall at the same location and introduced through the saturation tubing into the sample.

A backpressure saturation system was developed to allow for the testing of the sample at different total stress levels. An illustration of the system is presented as Figure 4.9. The backpressure is introduced to the sample through the application of air pressure to a water surface in a pressure vessel. This water pressure is transmitted to the base of the sample through the saturation system previously noted and is monitored through a pore pressure transducer located within the water line on the exterior of the chamber. The backpressure used in the testing was adjusted until the desired effective stress at the center of the sample was reached.

4.3 Pluviation System

The samples tested in the calibration chamber were fabricated using a large pluviator (Figure 4.10). The pluviator was designed by Eid (1987) based on a study involving the evaluation of scaling effects on cone penetration resistance measurements. The pluviator system is composed of the pluviator shell, a diffuser sieve and lifting cables, a perforated plate, and a perforated shutter plate. Samples are formed with the pluviator by dropping sand from a storage area onto the diffuser sieves so that the terminal velocity of the sand particles is reached. The diffuser sieves are lifted during the pluviation process to maintain a constant height of 61cm between the pluviated sand and the lower diffuser sieve. Different densities are obtained with the device by varying the diameter and surface area of the holes in the perforated plate.

The pluviator used in the testing is 1.75m in diameter and 2.3m tall (Figure 4.10). It is placed on the steel collar noted in Section 4.2.2 and aligned with the bolt holes in the chamber shell. The pluviation process involves placing soil in a large storage area in the pluviator and then raining the soil through the perforated plate and diffuser sieves once the shutter plate is opened. The size and number of holes located in the perforated plate control the density of the test specimen. Two perforated plates were used in the testing. The first plate consisted of a circular steel plate that was bolted to the inside of the pluviator shell. The plate has 421 holes that were 22mm in diameter on a 64mm by 64mm grid pattern (Eid 1987). This plate was found to produce an average relative density of 25% for the sand used in the testing, which was very similar to that noted by Sweeney (1987) for Monterey 0/30 sand. The second plate used in the testing was developed for the project. The plate consists of two semicircular sheets of 6.35 mm plywood that were overlain onto the plate used to form Dr = 25% samples. One hundred fifty six holes, each 20mm in diameter, were drilled into the wood on a 128cm by 128cm grid pattern. The plate generated an average relative density of 55% for the sand used in the testing.

The diffuser sieves are raised manually during the raining process to maintain a constant drop height between the bottom of the diffuser sieves and the top of the test specimen. The diffuser sieves were reduced in diameter 38.1mm as part of this study to account for the added thickness of the second membrane liner. This allowed the sieves to move more freely along the membrane surface and reduced the possibility of wedging the sieve and cutting the liner. More than 60 samples have been pluviated as part of this study. Maximum standard deviations of the relative densities were determined to be approximately 3.2% relative to the mean, revealing excellent repeatability of the sample density using the sample formation procedure.

4.4 General Test Procedure

Cone penetration tests were performed on pluviated samples that were exposed to three different levels of stress. Samples tested at the lowest stress level did not include the placement of the sample top plate and lid over the top of the sample. Consequently, the sample was not sealed and the sample relied on the rigid forming jacket for lateral support. Penetration tests performed at these stress levels defined a rigid wall boundary condition with a zero lateral strain, which is designated as BC3 by Lunne et al. (1997). The absence of the top plate and lid removed certain testing restrictions associated with one of the two cone penetrometers used in the testing. As such, penetration tests were performed with both penetrometers at both the center and off-center locations.

Penetration tests were also performed in the calibration chamber with stresses applied to the sample. The procedure associated with these tests involves the placement of the top plate, rubber gasket, and lid over the sample to separate the sample from the air induced confining pressure. Great care was taken to ensure that the rubber gasket and o-ring are carefully aligned with the top plate, for air leaks can develop across this interface and penetrate into the sample. The confining stress applied to the sample forces the soil away from the forming jacket, which was further ensured once the pin in the forming jacket was pulled and the jacket sprang back against the interior chamber wall. The sample at this point was solely supported by the air induced confining stress, suggesting that tests performed at the elevated stress levels represented a flexible wall condition with constant lateral stress boundaries (BC1). Since the diameter of the off-center holes in the top plate and lid were smaller than the diameter of the 15-cm^2 cone penetrometer, penetration tests were only performed in samples at the elevated stress levels at the center location. A further discussion of these testing restrictions is presented in Chapter 5.

Included in the following paragraph is a general discussion of the sample formation and test procedure. A complete checklist involving the specific procedures used in the sample formation and testing is included in Appendix B. The reader is referred to the pictures included in Figures 4.11 through Figure 4.13 to provide a better understanding of the information included herein.

The initial step in the pluviation process involves setting up the cable system and raising and lowering the diffuser sieves into the chamber to ensure that the diffuser does not get caught on the liner (Figure 4.11a). After checks are made to ensure that the shutter plate is closed, a small amount of moist sand is placed in the holes of the perforated plate to keep the dry sand from leaking out of the holes (Figure 4.11b). Metal hoppers are then filled with a bobcat, which are in turn weighed using a tension load cell and then placed into the storage area of the pluviator (Figure 4.12a). An air pressure is applied to the shutter plate through an air regulator after the storage area is filled with sand. Alignment of the shutter plate switch in the positive direction causes the air piston to pull the shutter plate so that the holes in the shutter plate are aligned with the holes in the perforated plate. As the soil is rained through the perforated plate, the diffuser sieves are raised manually to maintain a constant drop height between the bottom of the diffuser sieves and the top of the test specimen (Figure 4.12b). The rate of lift of the diffuser sieves that resulted in the most consistent density was empirically determined to be 25.4 mm/sec for the loose samples, which corresponded to the low setting on the lifting device of the overhead crane. The rate of lift for the medium dense samples was determined to be 12.0 mm/sec, which is roughly half that of the loose samples. The sand retained on the perforated plates is swept into the calibration chamber and the sample is leveled so the relative density could be calculated. (Figure 4.13a and 4.13b).

The sand sample generated through the pluviation process was 1.5m in diameter and 1.5m tall. The sample was pluviated into a 40-mil HDPE liner that was placed inside the rigid wall forming jacket. The sample was saturated with CO_2 for three hours and then inundated with water from the bottom to the top through the water saturation system. Approximately three to six pore volumes of water were circulated through the sample to minimize the air entrapped in the soil pores. Penetration tests performed at the low stress level involved mounting the push frame onto the chamber flange and then performing the penetration tests under ambient air conditions. Tests performed at the intermediate and high stress levels involved sealing the sample using the o-ring, rubber mat, top plate, and lid noted above. The horizontal and vertical stresses were then isotropically increased without allowing drainage out of the sample. B-values were checked at this time, which generally ranged from 0.9 to 0.97 for the samples tested. Given the possibility for compliance of the system, which would tend to reduce the measured value relative to the actual value, the range of B-values noted for the testing reveals a high degree of saturation of the soil. Similar B-values were reported by Bellotti et al. (1988).

As stated earlier, the stress conditions in the calibration chamber can be adjusted to simulate many field conditions. Samples were prepared and tested with and without backpressure applied to the interior of the sample to evaluate the effects of the backpressure on the measured penetration resistance and induced pore pressure values. Samples tested without a backpressure involved leaving the drainage valve open at the top of the sample so that the water pressure in the sample was always the unit weight of water times the depth into the chamber, which corresponded to 6.8 kPa in the center of the sample. Samples tested with a backpressure involved incrementally increasing the water pressure as the vertical and confining pressures were increased until the total and effective stresses reached the designative values. Precautions were taking during each of the loading steps to insure that the sample was not over consolidated. The drainage value was left open after the desired effective stress conditions were reached to allow drainage during the penetration test. A review of the pore pressure values measured during the penetration tests revealed that the induced pore pressure measured by the cone was not dependent on the magnitude of the backpressure applied to the sample.

The loading frame was then mounted on top of the chamber and the push rate of the hydraulic press was empirically set at 20 mm/sec (Figure 4.1). The deaired pore pressure elements were assembled onto the cone under a head of the glycerin/water mixture. The entire cone assembly was then attached to the vibrator, which was in turn attached to the hydraulic press. The displacement transducer and cone penetrometer were attached to their respective power supplies and test runs were performed with the data acquisition unit to ensure that the proper voltage signal was recorded. The data acquisition was started for ten seconds and then the cone penetrometer was displaced into the sample.

Penetration tests were performed at both the center and off center locations for each location of the push frame, provided that the cone diameter was less than the diameter of the port opening (40mm)(Figure 4.14a and Figure 4.14b). The load frame and lids were removed after the testing was completed and the sample was manually removed from inside the chamber. The sand was stockpiled outside of the facility and then systematically placed in a large drying oven in four metal storage containers. A typical drying time for the four containers of soil was usually on the order of 36 to 48 hours.

4.5 Summary and Conclusions

Included in the previous sections is a general overview of the calibration chamber used in the cone penetration testing program. Discussions of the pluviation apparatus and sample preparation and testing procedures are also presented. Based on these discussions, the following general conclusions can be made:

a) The Virginia Tech calibration chamber is similar in design to several chambers around the world. The sample contained in the chamber is 1.5m in diameter by 1.5m tall and is cylinder in shape. The total volume of soil incorporated into one sample is 2.65m^3.

b) The sample is prepared inside two HDPE membranes using a large pluviation device. The density of the sample is controlled by the size and number of the holes in a perforated plate located in the pluviation device. Two perforated plates that generated average relative densities of 25% and 55% were used in the testing.

c) The sample is sealed from the applied air pressure using a rubber mat and o-ring combination located at the top plate/ lid interface.

d) The confining pressure is applied independently of the vertical pressure so that the sample can be subjected to many stress conditions.

e) The vertical stress is applied to the sample from the bottom using three airstroke actuators. The pressure generated by the actuators is a function of the displacement and pressure of the unit.

f) A saturation system was added to the calibration chamber as part of the project, which allows for the saturation of the samples after pluviation. A backpressure can be applied to the sample using this saturation system, allowing for the testing of samples under many total and effective stress conditions. A high degree of saturation was observed in the samples prior to the testing.

g) The magnitude of the backpressure did not influence the induced pore pressure value recorded by the cone penetrometer during the penetration test.

h) The hydraulic press mounted on top of the lid is attached to a trolley system that can be moved laterally across the chamber to multiple penetration ports. A total of seven penetration tests can be performed in one sample, provided the cone diameter is less than the port opening.