TIME DEPENDENT LOAD RESPONSE OF FLEXIBLE PIPE SUBJECTED TO SUSTAINED LOADING

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

2011

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To everyone in my life who has helped me along the way, giving me purpose and the inspiration to accomplish whatever may be in my path.

ACKNOWLEDGMENTS

I thank my supervisory committee for their mentoring and assistance throughout my undergraduate and graduate careers at the University of Florida. I thank the members of the University of Florida Coastal Engineering Laboratory for their dedication to the project I worked on. I thank my parents and family in general, for their love and inspiration, which ultimately served as the motivation for me to pursue my master's degree.

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LIST OF ABBREVIATIONS

FDOT	Florida Department of Transportation
FEM Analysis	Finite Element Analysis
HDPE	High Density Polyethylene
PVC	Polyvinyl Chloride
SMO	State Materials Office
UF	University of Florida

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Engineering

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By

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May 2011

Chair: David Bloomquist
Major: Civil Engineering

It is crucial to the long term sustainability of roadway drainage systems that manufacturing guidelines are stringent, but reasonable, so as to allow for maximum life efficiency of the selected products. For this reason, the Florida Department of Transportation (FDOT) has contracted the University of Florida (UF) and members of Simpson, Gumpertz, & Heger, Incorporated (SGH) to perform a series of static load tests on a variety of flexible pipe materials used for storm water runoff along Florida highways.

The flexible pipe materials consist of High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), aluminum, and stainless steel. During a loading sequence, there are two pipes of the same material which are lowered into a soil box. The soil box is then backfilled with soil, sealed, and then pressurized, allowing a load to be uniformly distributed to the pipes.

The purpose of this testing is to record and collect pressure data from load cells placed at precise locations throughout the soil box. The pressure data, along with deflection data recorded and collected from a displacement laser which runs along a track for the length of each of the two pipes, will provide the input for an FEM analysis to

be performed. The FEM analysis is being performed by Timothy J. McGrath, Ph.D., P.E. of SGH.

The FEM analysis will allow for a variety of loading situations to be simulated. The results of these analyses will allow for the FDOT to codify a baseline manufacturing guideline for each of the four different pipe materials. To be specific, each pipe is manufactured with a certain amount of pre-deflection. The FDOT is looking to minimize this number so that pipes which are subjected to a variety of loading conditions on a job site will ultimately perform as they are supposed to for their life expectancy, rather than fail prematurely.

The scheduled completion date for this project is the third quarter of 2013; therefore, the information presented herein will cover from the project start in the last quarter of 2009, through the first quarter of 2011.

CHAPTER 1
DESIGN

Soil Box

The soil box being used for the testing procedures is made of steel and is assembled in a number of different pieces. There are three bottom sections, three top sections, and a total of eight side sections, one for each of the North and South faces and three for each of the East and West faces. When fully assembled, the soil box measures 20 feet long by 10 feet wide by 8 feet deep. The fully assembled soil box can be seen in Figure 1-1 at the end of this chapter. In regards to the specific design aspects which follow, there were many considerations to take into account, as specified in previous studies (Brachman et al. 2000).

Sealing of Open Gaps

One of the most important aspects of the testing procedure is to keep the system completely closed. At the project onset, this particular item proved to be quite difficult to solve. Each of the three side sections for the East and West faces has an open porthole. More detail of the soil box and the loading configuration can be seen in Figures 1-2 through 1-13 and Figures 1-18 through 1-20. The testing procedure calls for only two pipes of the same material to be tested at any one time. Therefore, the portholes on the center side sections are covered using the apparatus shown in Figure 1-21.

For the interface between the pipe ends and the soil box side walls, there was a lot of discussion about an appropriate sealing system. Among the considerations in the selection process were the following: the side walls of the soil box are not completely vertical; the solution must provide for adequate free movement on both ends of the pipe,

so that the pipe ends do not drag on the side of the soil box; and that all the pipes have either spiral or circular corrugations, making it difficult for any elastic type material to completely wrap around the outside pipe edge.

The first concept, which is detailed in Figures 1-14 and 1-15, involved using inflatable tubes around the pipe perimeter. The idea was to wrap a two inch wide PVC strip around the outside of the pipe end. Then, the tubes would be laid on the PVC strip, deflated. A secondary two inch wide PVC strip, with a larger diameter than the first, would then serve as an outer casing for the tubes so that the inflated size would be limited. This would be performed on both ends of the pipe, and then the assembly would be lowered into the tank, after which time the tubes would be inflated.

Ultimately, this option brought up concerns of cost feasibility because of the custom nature of most of the parts that would need to be used. Also, the pressure that the tubes would need to be inflated to in order to provide adequate seal would have been so much that the pipe would effectively be fixed at both ends. This would have interfered with the dynamics of the test, not allowing the pipe to move freely along its entire length.

Details for the second concept can be found in Figures 1-16 and 1-17. This concept makes use of a wall flange bolted onto the wall of the soil box. A rubber membrane is then wrapped around the protruding part of the flange. The other end of the membrane is then wrapped around the pipe end. Spirally corrugated pipes have the membrane wrapped around a metal strip that was machined to the inside pipe perimeter, extending slightly beyond the pipe end. For the pipes with circular corrugations, the rubber membrane wraps around a portion of the pipe where the

corrugation has been filed back about two inches. Pictures for the modified pipe ends for both types of corrugations are found in Figures 2-4 through 2-6.

As long as the rubber membrane is between the range of soft to medium soft, this option will allow the pipe to move freely along its entire length. Moreover, the rubber membrane will be fabricated to be slightly wider than needed. Therefore, when the load is applied from above and movement of the pipe begins, there will not automatically be any pulling of the membrane, since there is some “slack” built into it. This concept was also selected because of its cost effectiveness, with only the rubber membrane needing to be purchased from an outside vendor.

The third concept was only briefly discussed, but nonetheless was an option to consider. The idea was to create a square Styrofoam block with a hole cut through the center, the hole being the size of the diameter of the pipe. The Styrofoam would then be pressed on to the pipe end on both sides, and the assembly would then be lowered into the soil box. As with the first concept, this was eventually ruled out because the Styrofoam would have to be so stiff, that it too would make the pipe ends fixed to the soil box walls.

Differential Settlement

Another task of importance was the discussion and selection of an appropriate method for avoiding differential settlement of the load plates. This particular issue with the project has proved somewhat difficult to find a solution to. It was ultimately decided that the load plate configuration chosen would not allow for differential movements. The chosen layout can be seen in Figures 1-12 and 1-13.

Earth Pressure Cells

In regard to the selection of locations for earth pressure cells within the soil box, only 18 earth pressure cells are necessary for the soil box being tested with two pipes. The earth pressure cells that are being used can be seen in Figure 1-22. Figures 1-2 through 1-11 provide numerous views and details of the locations for the earth pressure cells. Figures 1-2 through 1-6 detail the locations for the tests with the 24 inch diameter pipes, while Figures 1-7 through 1-11 detail the locations for the tests with the 36 inch diameter pipes. This setup represents the best layout of earth pressure cells to be able to obtain the most variety of data. The location of all the earth pressure cells and their respective names can be found in Figures 1-18 through 1-20.

Pipe Deflection Measurement

Whereas it was initially thought that a laser system would be cost prohibitive, an industry contact offered to provide the university with a track-mounted laser which had a 360 degree spinning mirror, as well as a camera. The pieces of equipment needed, along with the software and other data logging equipment, was going to be provided free of charge. This initial idea was strongly considered based on the review of a study performed at the University of Texas at Arlington using the CUES, Inc. Laser Profiler (Abolmaali 2008). However, the industry contact informed the university of the unavailability of the equipment that had been promised. This was an unfortunate setback; another study performed at the University of Texas at Arlington provided added verification as to the accuracy of the CUES, Inc. system (Motahari et al. 2008). A different solution, however, was quickly discovered.

On another FDOT/UF project, a laser had been used for the purposes of displacement measurement. That project has since been brought to a close, and the

laser was unused over at the FDOT State Materials Office (SMO). Daniel Pitocchi, the Soils and Foundation Lab Manager over at the SMO, was kind enough to provide the laser. A detailed discussion of the mounting system will take place towards the end of this chapter.

The laser being used, shown in Figure 1-23, has a start of measuring range equal to 200 mm, or 7.9 inches, and an end of measuring range of 950 mm, or 37.4 inches. This means that the target can be no closer than 7.9 inches, and no farther away than 37.4 inches. The mounting system developed takes into account these maximum and minimum limits. The laser's resolution is 50 micrometers, or about 0.002 inches. This is more than accurate for the tests being performed.

Load Plates and Lift Bags

The load plate and lift bag configuration had to be designed to achieve the most uniform pressure distribution and to avoid eccentric loading. A number of loading conditions and methods of load transfer were analyzed for this particular aspect of the project (Smith et al. 2005). Initially, the uniform loading of the soil box was going to take place with the use of eight, five foot square load plates. Each load plate would have a 42 inch square lift bag on top of it. However, this setup did not provide for optimal testing conditions because the plates were located in such a manner that the joint between two plates was over the centerline of the pipe. This issue would cause extreme tilting of the plates once the loading began.

Instead, the decision was made to use six of the five foot square plates towards the inside of the box, and four smaller plates towards the outside. Four new lift bags with smaller dimensions had to be ordered to accommodate this new design. Details of this layout are found in Figures 1-12 and 1-13. With this setup, the load plates are either

directly over the fill, or directly over the centerline of the pipe. The tilting settlement is therefore eliminated.

The change in number and layout of load plates and lift bags was made prior to the ordering of the plates, so no additional plates were necessary. However, the layout design modification did come after the eight large lift bags were ordered and delivered. Four smaller lift bags had to be ordered. The loads plates and lift bags can be seen in Figures 1-24 and 1-25. The lift bags were delivered along with all the necessary connectivity equipment, including regulators, valves, and hoses. These are seen in Figures 1-26 through 1-28.

Pipe Pre-deflection

This aspect of the testing aims to further simulate field conditions during pipe installation. This pre-deflection of the pipes was made possible with the use of manual turnbuckles, shown in Figure 1-29. Four percent pre-deflection, or 1.44 inches, was achieved for the 36 inch diameter HDPE pipes.

Because this decision was made after one of the pipes had already been installed in the soil box, the pipe was removed, pre-deflected, and then reinstalled. In order to maintain the deflected shape, the turnbuckles remain in place until the tests are begun. The lift bags will exert enough pressure on the pipes so that the turnbuckles are released, allowing for their safe removal through the portholes.

Soil Saturation

One of the important parts of the testing procedure is to fully saturate the soil. The soil added to the soil box has a moisture content of around three percent. Using soil phase diagram relationships and an average of the actual dry unit weights obtained from the triaxial test results, it was calculated that approximately 3,200 gallons of water

would be needed to fully saturate the soil. This number was based on two assumptions: that the soil box was filled completely with soil and that the soil could be fully saturated. As can be seen in Figure 1-30, there are about six inches of freeboard near the top of the box. Also, it would be near impossible to fully saturate the soil, unless all the soil was maintained in an airtight configuration and flooded. That was not a likely consideration.

To be able to accurately record exactly how much water was being added to the soil box, a trial was performed outside of the UF Coastal Engineering Laboratory. The footprint of the soil box was measured out and outlined with orange chalk. A lawn sprinkler was then connected to the water supply, and the pressure regulated until the water fell within the chalk boundary. This pressure was then held constant while the sprinkler was held over a bucket of known volume. The time required to fill the bucket to three gallons was one minute and 55 seconds. The above steps can be seen in Figures 1-31 through 1-34.

It would take approximately 34 hours to fill the soil box with 3200 gallons, maintaining the low pressure necessary to stay within the footprint. The lawn sprinkler represents the best way to uniformly distribute the water over such a long period of time.

Displacement Laser

The laser mounting system allows for extremely precise deflection measurements. The process is accomplished by means of a beam that is fixed to the soil box walls at each end of the pipes. The laser is attached to a cart which moves along the length of the beam with the use of a hand-crank, attached on the West end of the soil box. Attached to the cart is a string which is spooled inside of a string potentiometer. As the

cart moves along the length of the pipe, both displacement measurements from the laser and horizontal distance along the pipe from the string potentiometer are output to a data acquisition program. The hardware can be seen in Figures 1-35 and 1-36.

It was ultimately decided that a string potentiometer would be best to measure the horizontal translation of the laser as the laser moves along the track system it is mounted on. The string potentiometer outputs to the same piece of equipment as the other instrumentation, simplifying the data acquisition process.

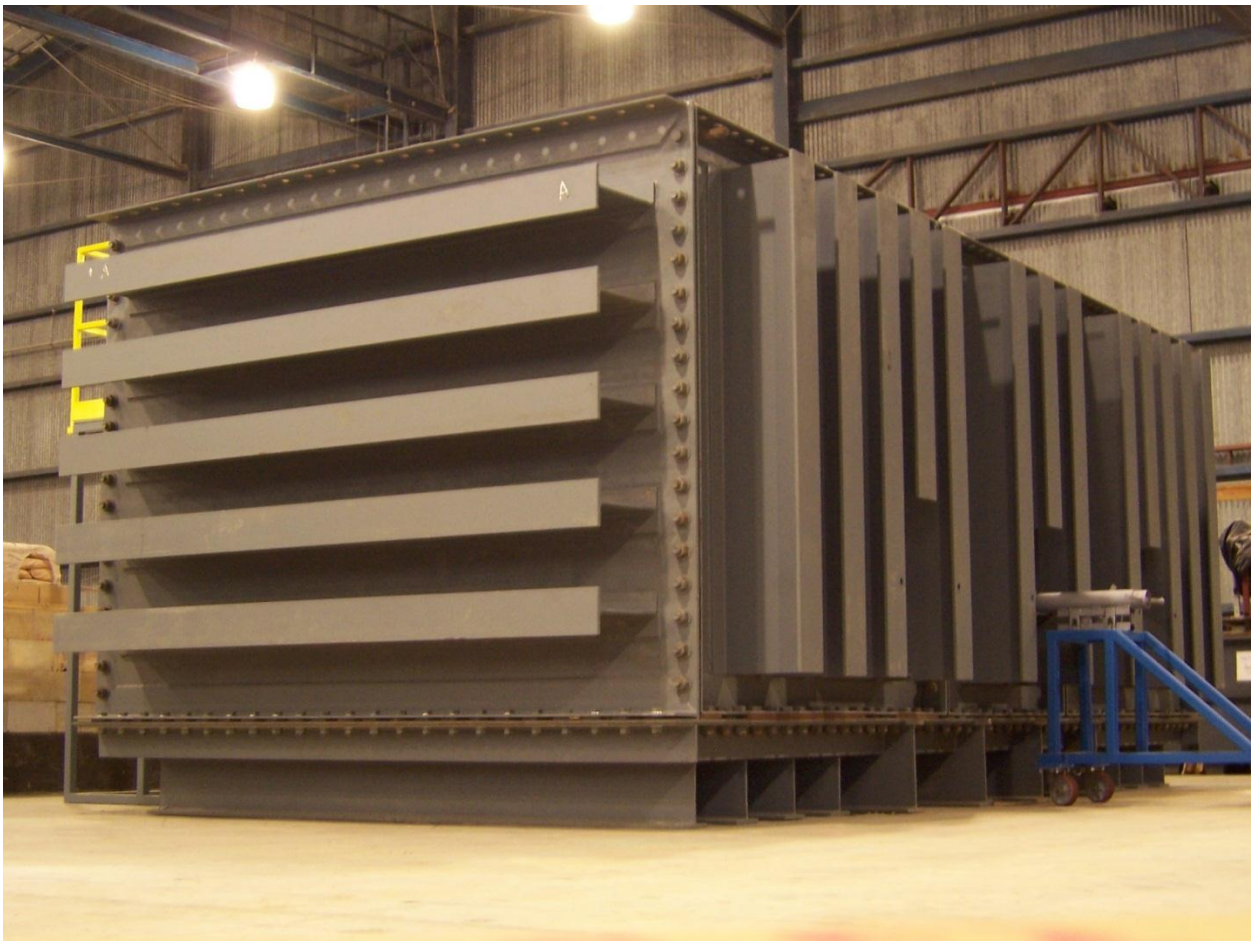

Figure 1-1. Fully assembled soil box shell. Photo credit: K. Pasken.

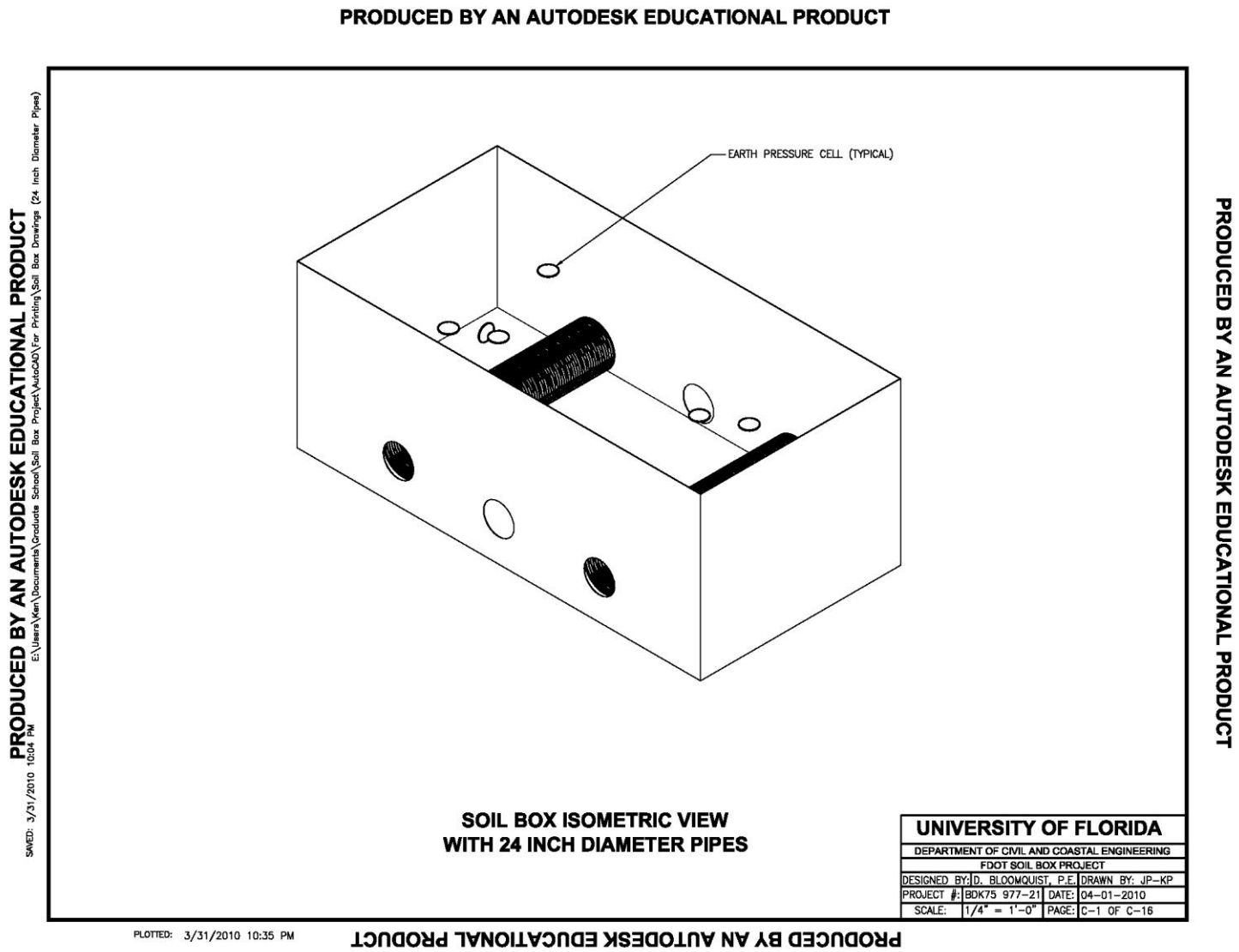

Figure 1-2. Soil box isometric view with 24 inch diameter pipes. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 19). University of Florida, Gainesville, Florida.]

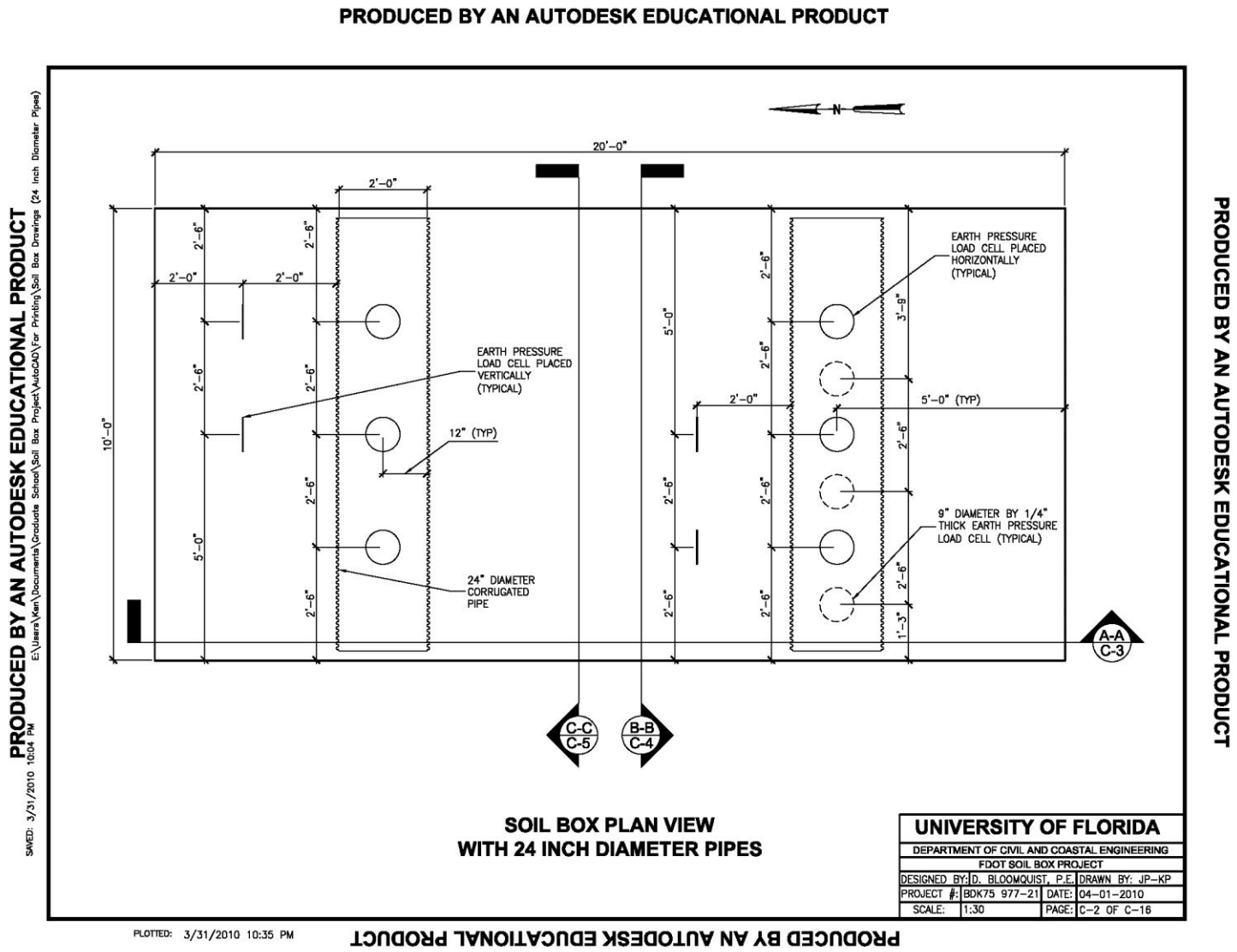

Figure 1-3. Soil box plan view with 24 inch diameter pipes. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 20). University of Florida, Gainesville, Florida.]

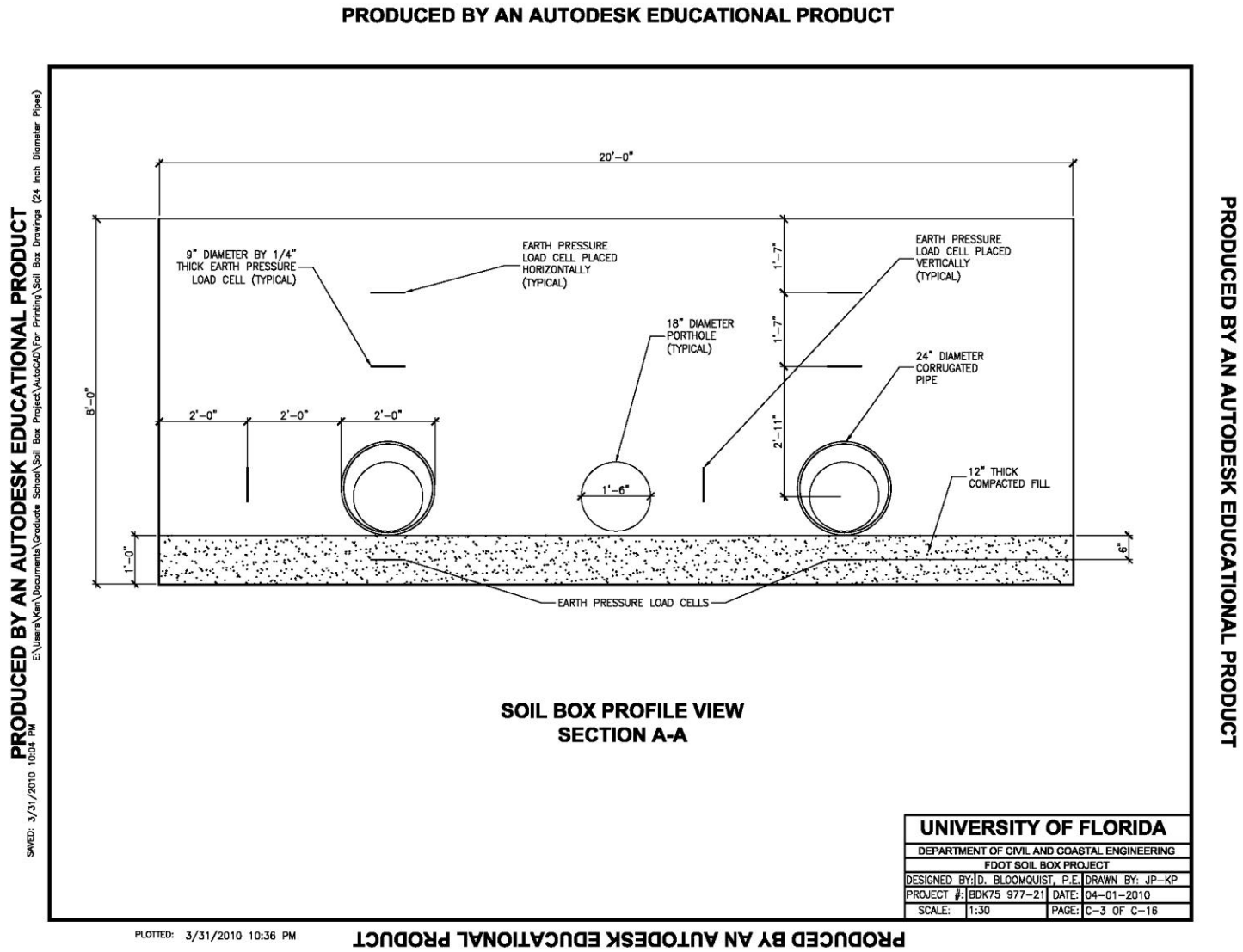

Figure 1-4. Soil box profile view, section A-A. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 21). University of Florida, Gainesville, Florida.]

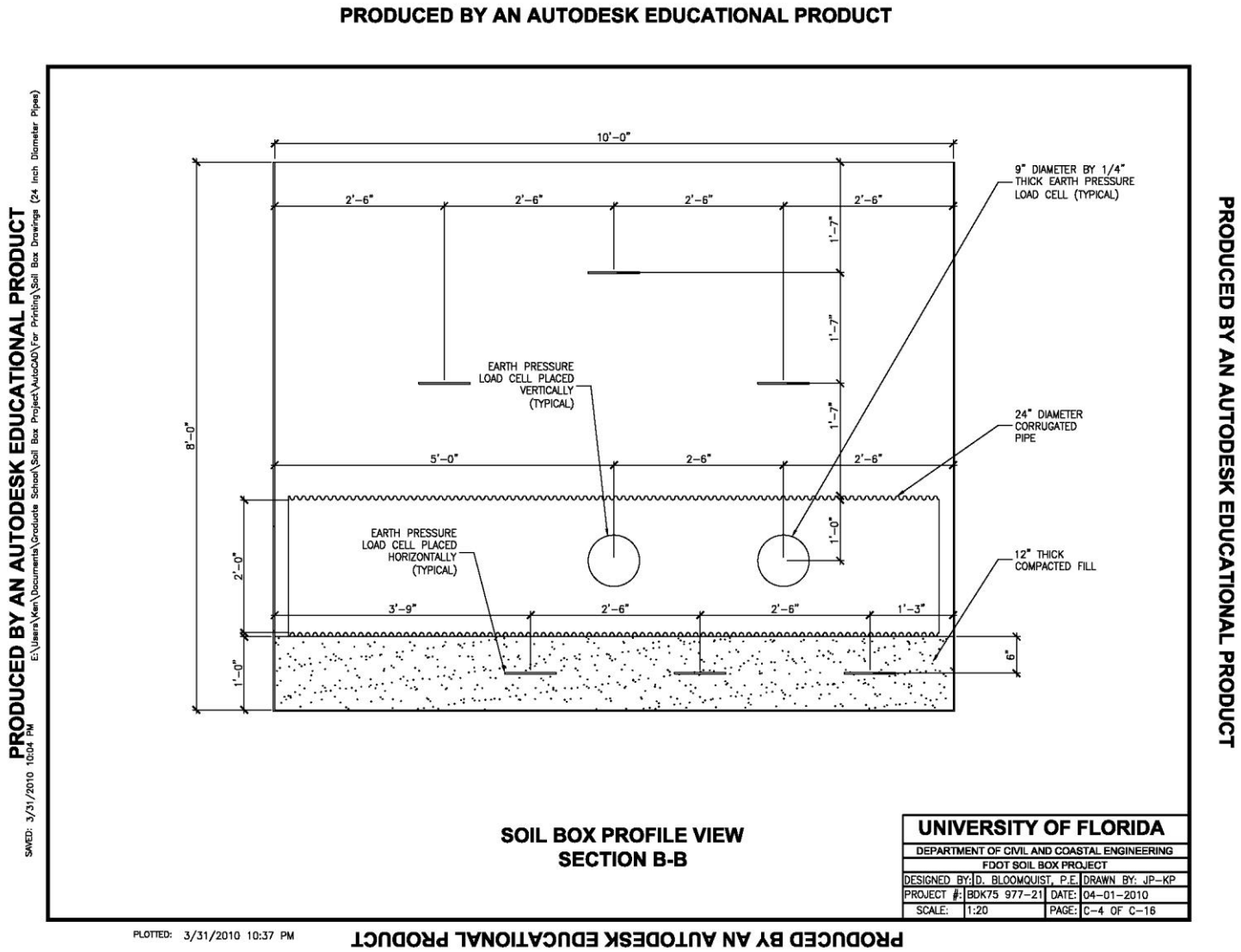

Figure 1-5. Soil box profile view, section B-B. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 22). University of Florida, Gainesville, Florida.]

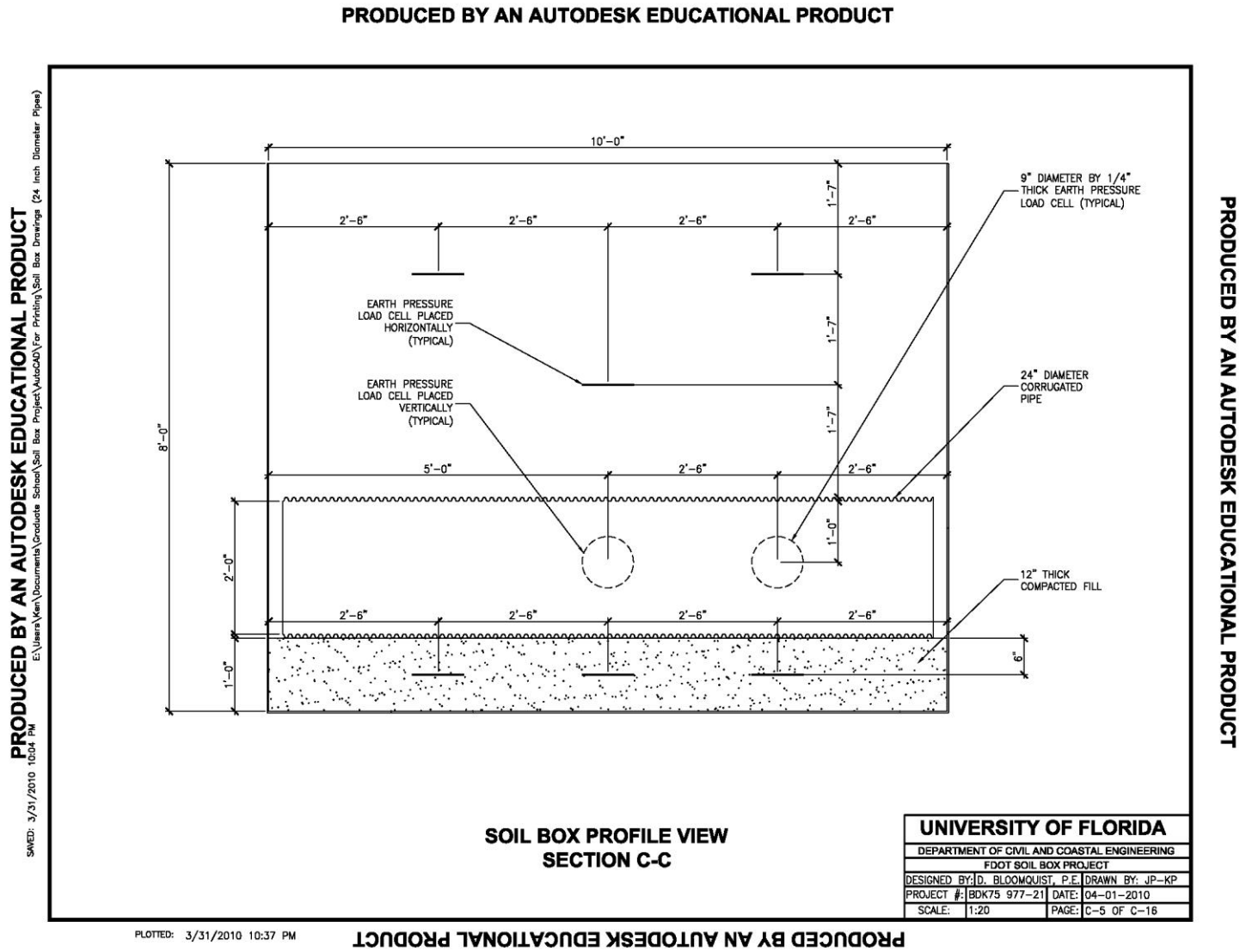

Figure 1-6. Soil box profile view, section C-C. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 23). University of Florida, Gainesville, Florida.]

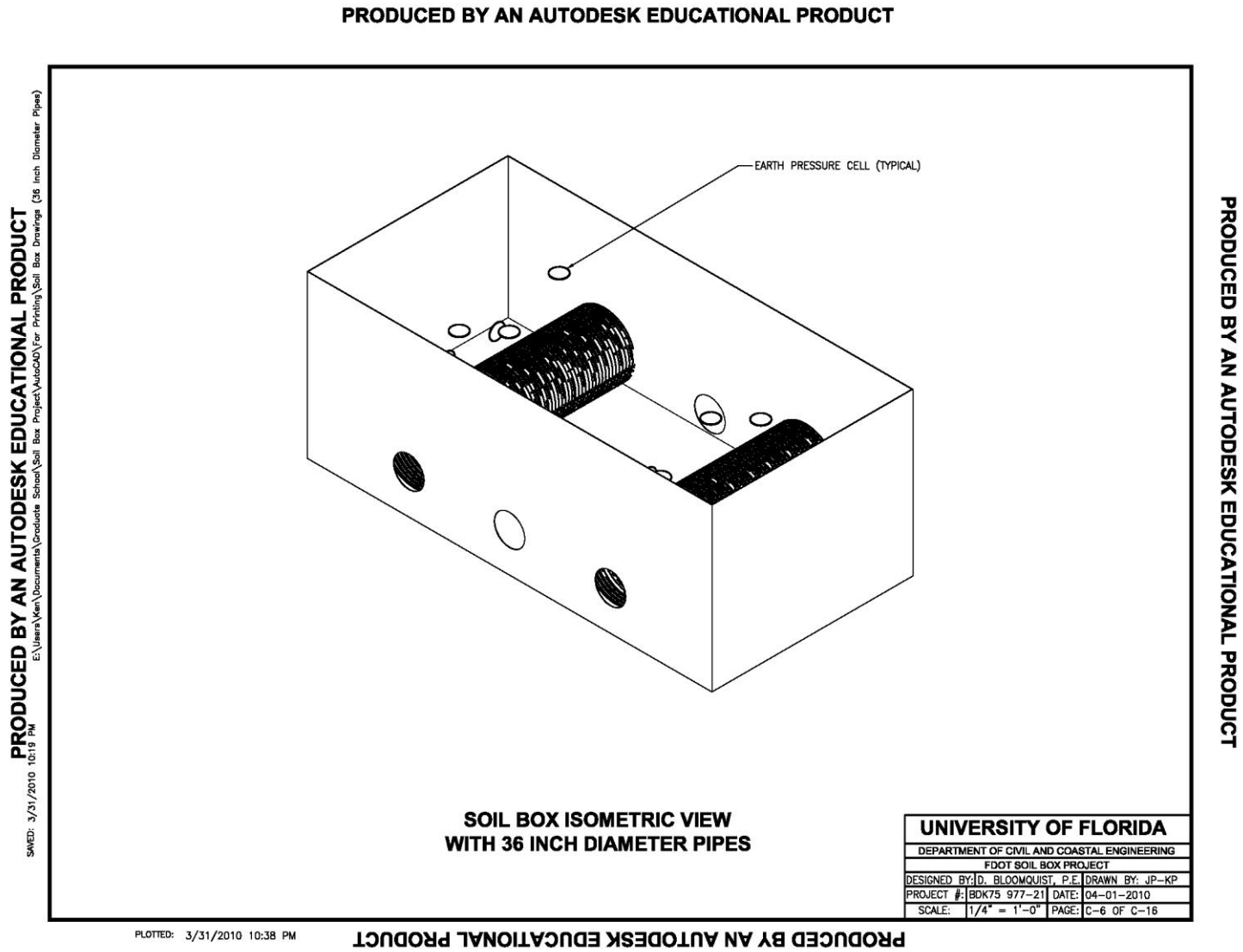

Figure 1-7. Soil box isometric view with 36 inch diameter pipes. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 24). University of Florida, Gainesville, Florida.]

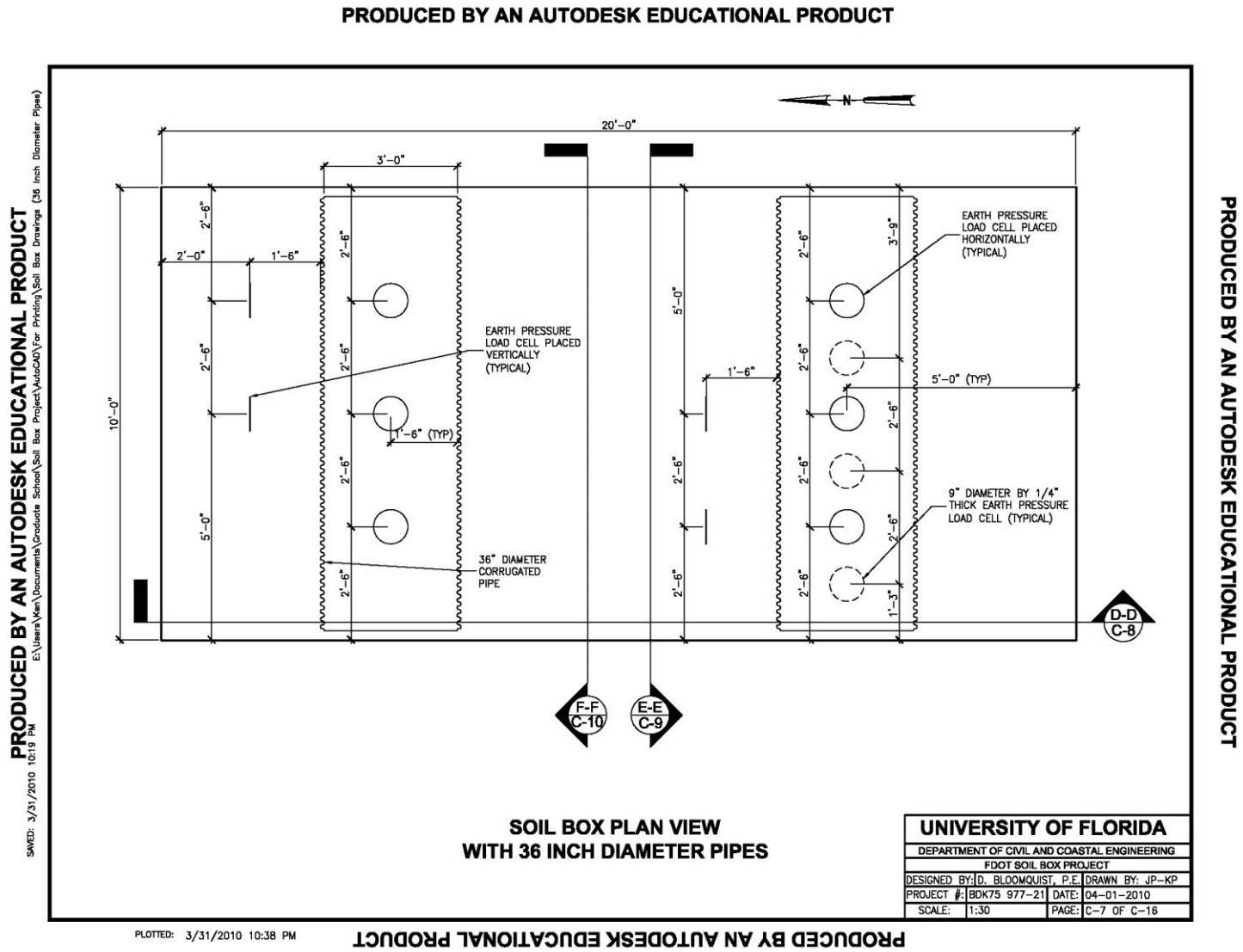

Figure 1-8. Soil box plan view with 36 inch diameter pipes. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 25). University of Florida, Gainesville, Florida.]

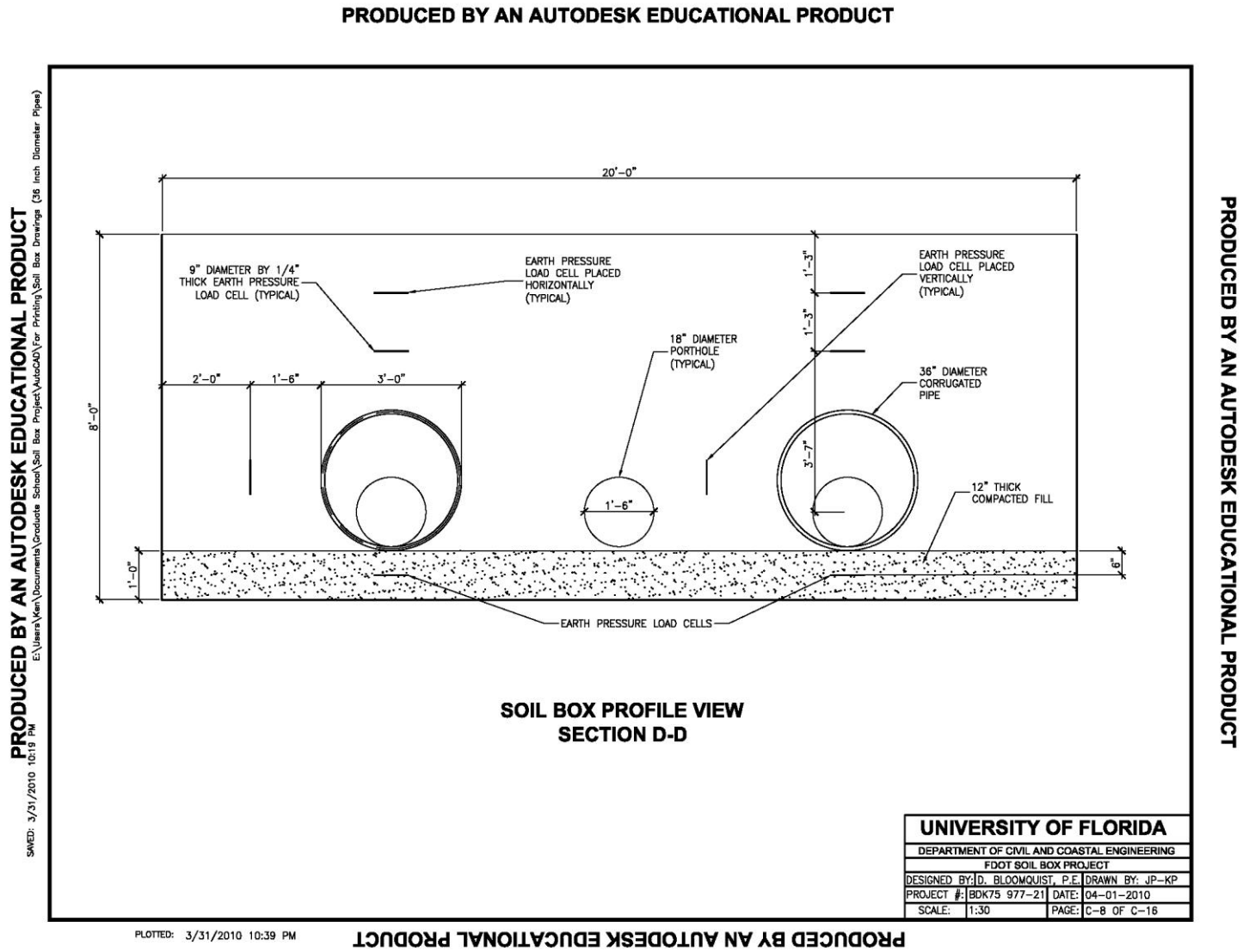

Figure 1-9. Soil box profile view, section D-D. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 26). University of Florida, Gainesville, Florida.]

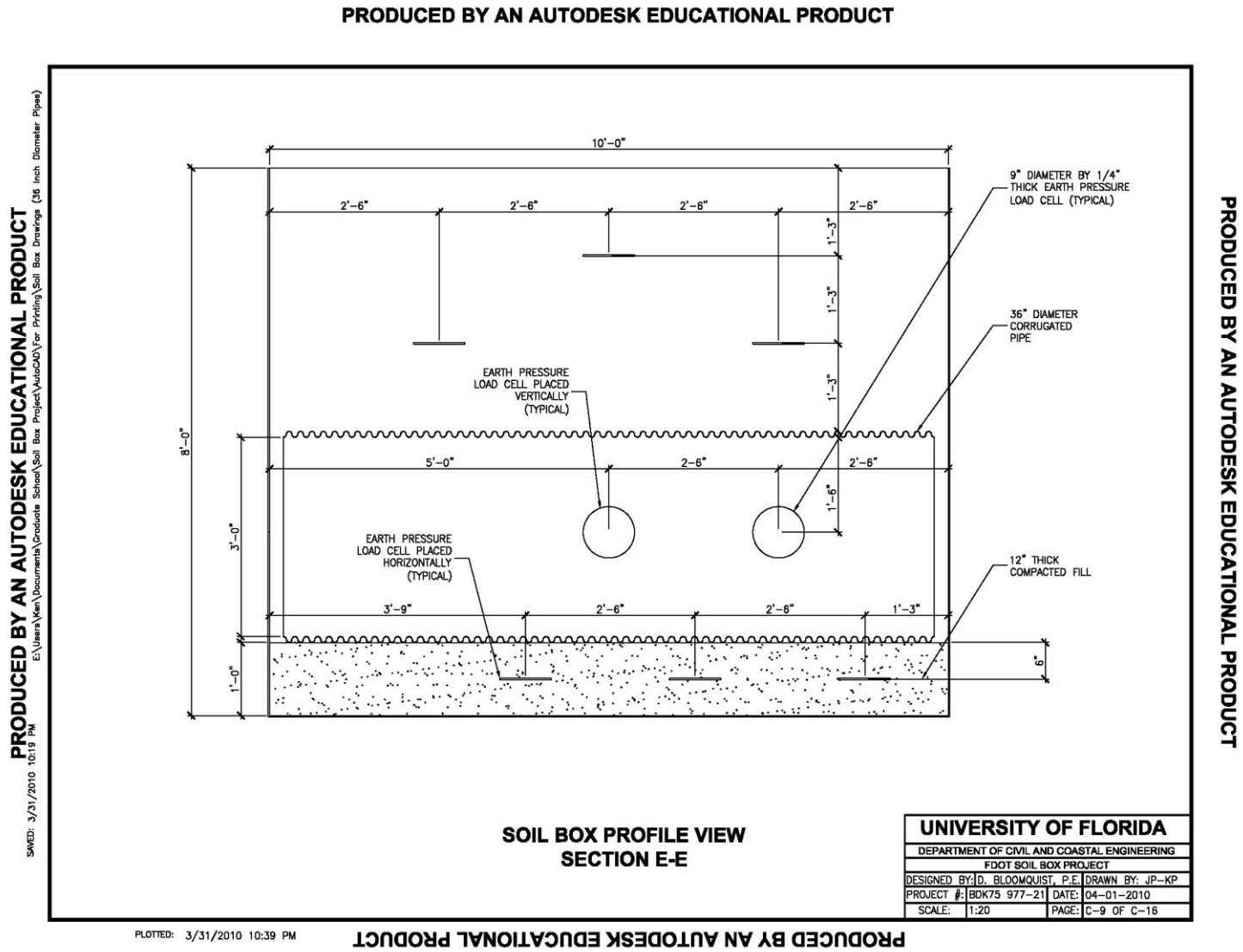

Figure 1-10. Soil box profile view, section E-E. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 27). University of Florida, Gainesville, Florida.]

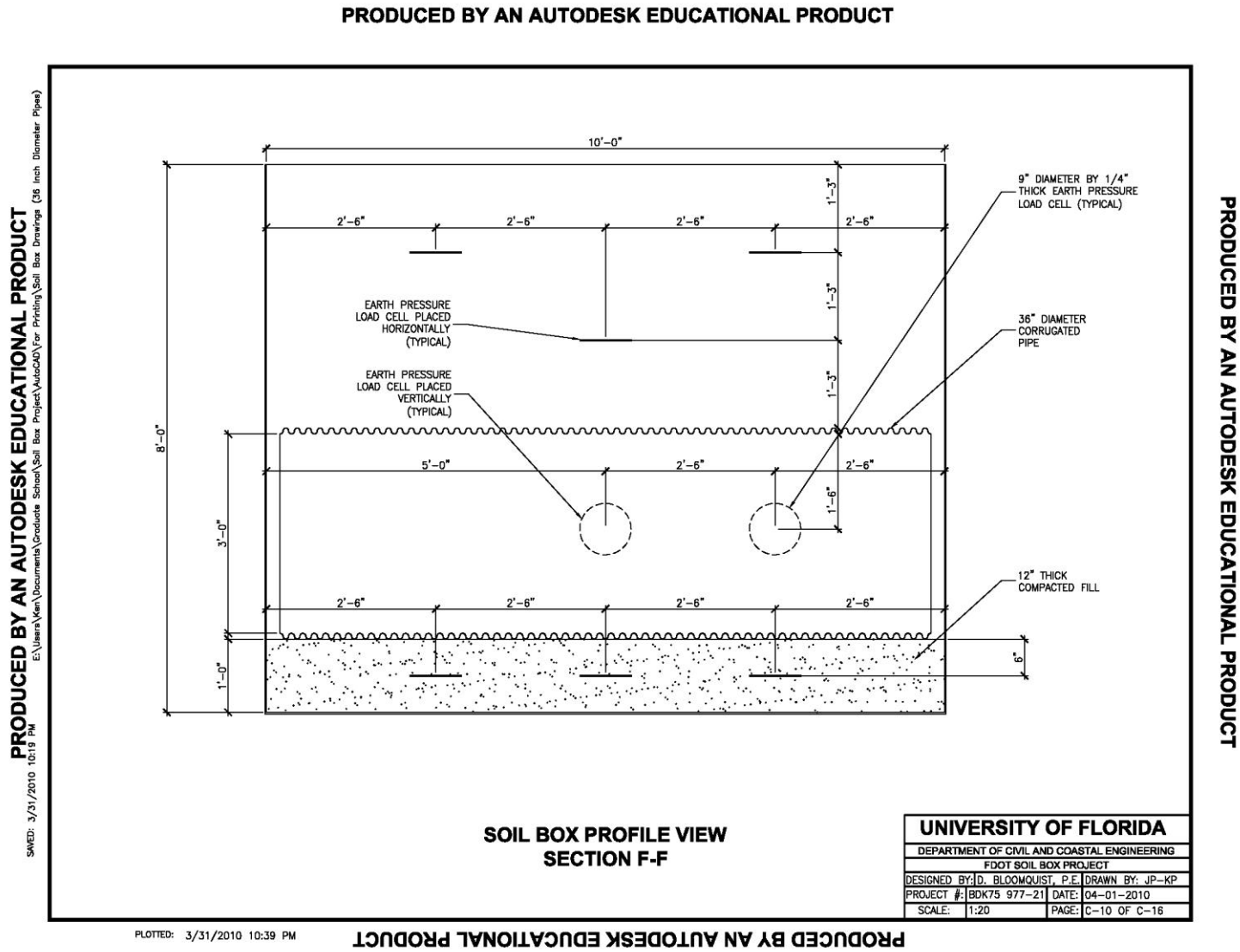

Figure 1-11. Soil box profile view, section F-F. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 28). University of Florida, Gainesville, Florida.]

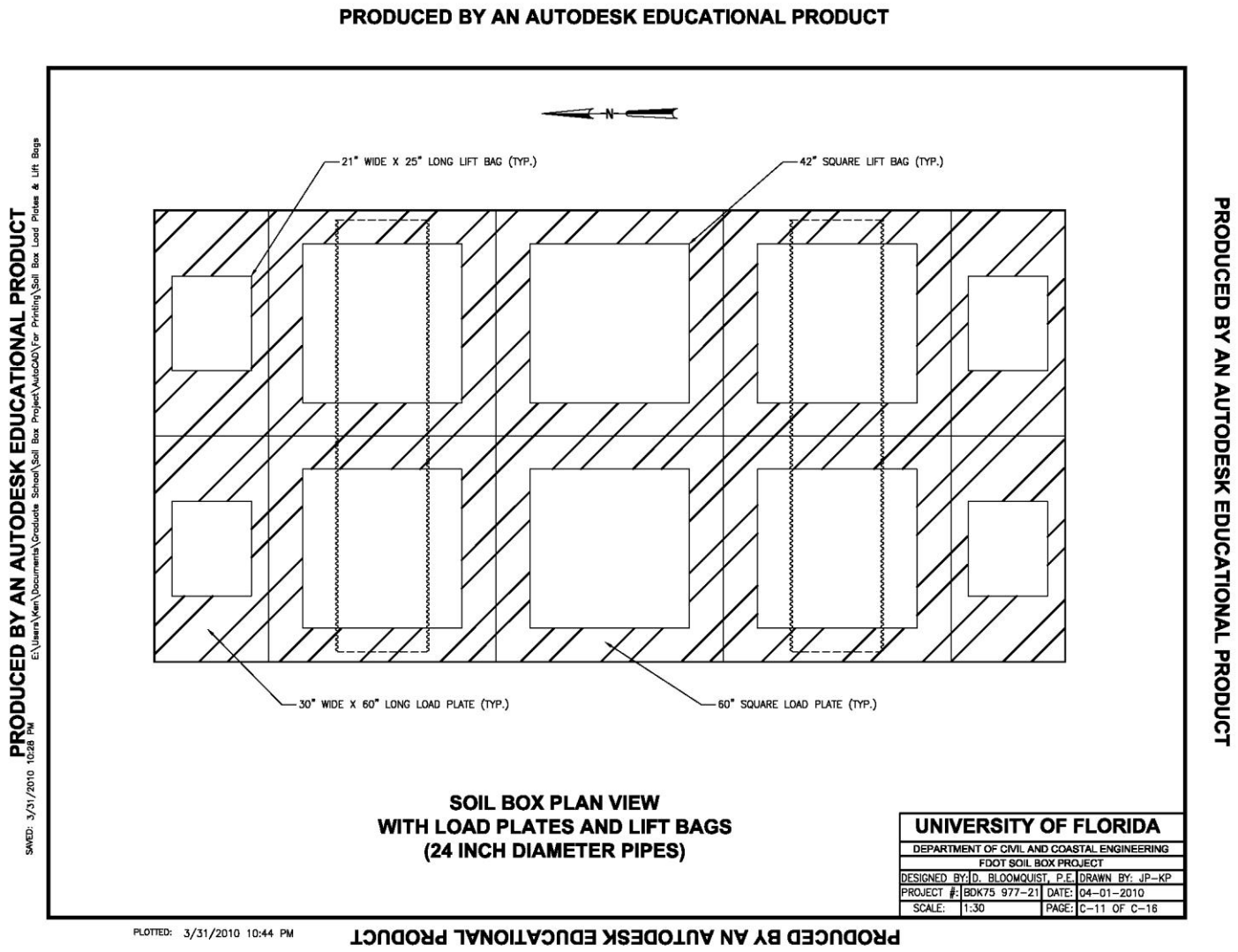

Figure 1-12. Soil box plan view with load plates and lift bags (24 inch diameter pipes). [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 29). University of Florida, Gainesville, Florida.]

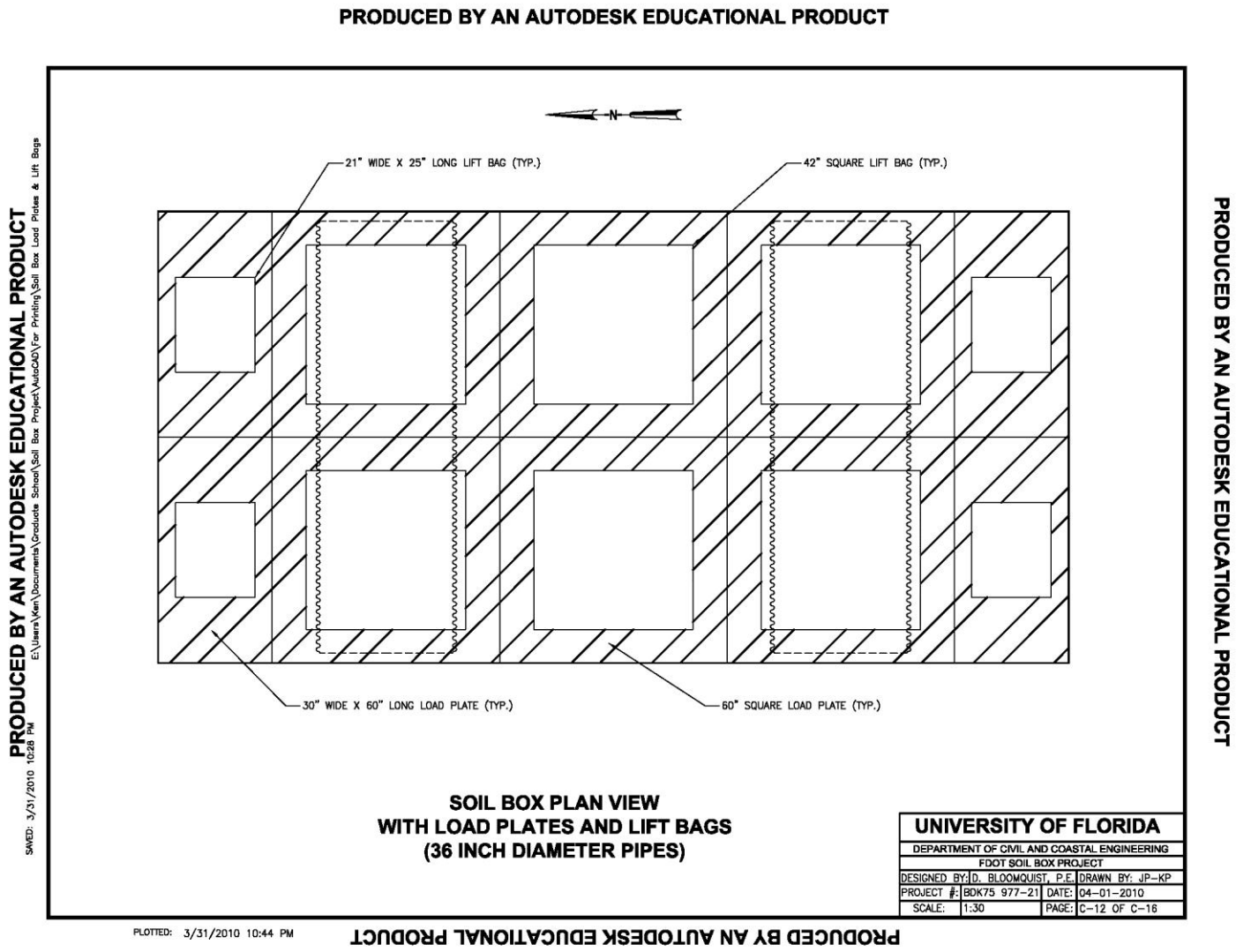

Figure 1-13. Soil box plan view with load plates and lift bags (36 inch diameter pipes). [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 30). University of Florida, Gainesville, Florida.]

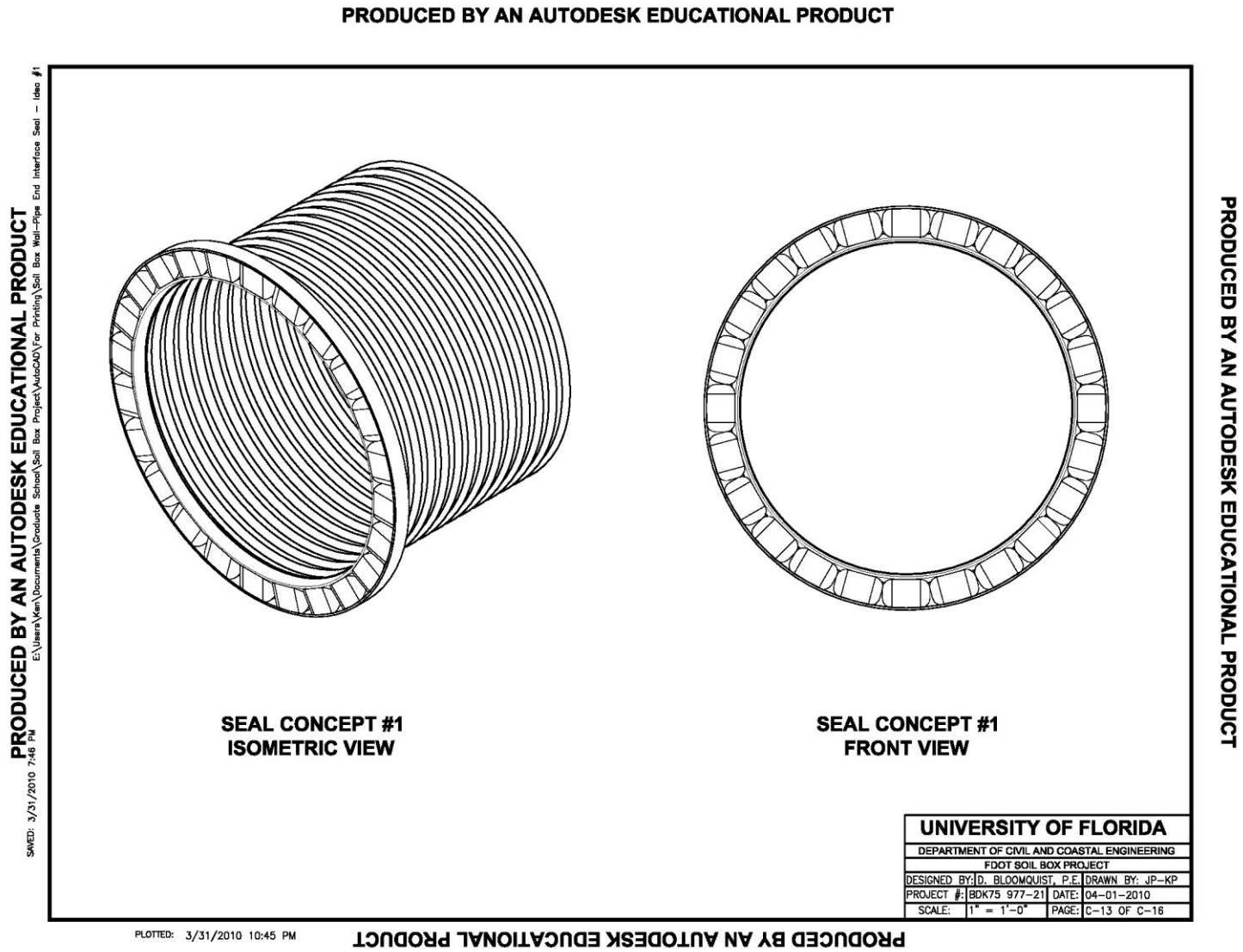

Figure 1-14. Seal concept #1, isometric view and front view. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 31). University of Florida, Gainesville, Florida.]

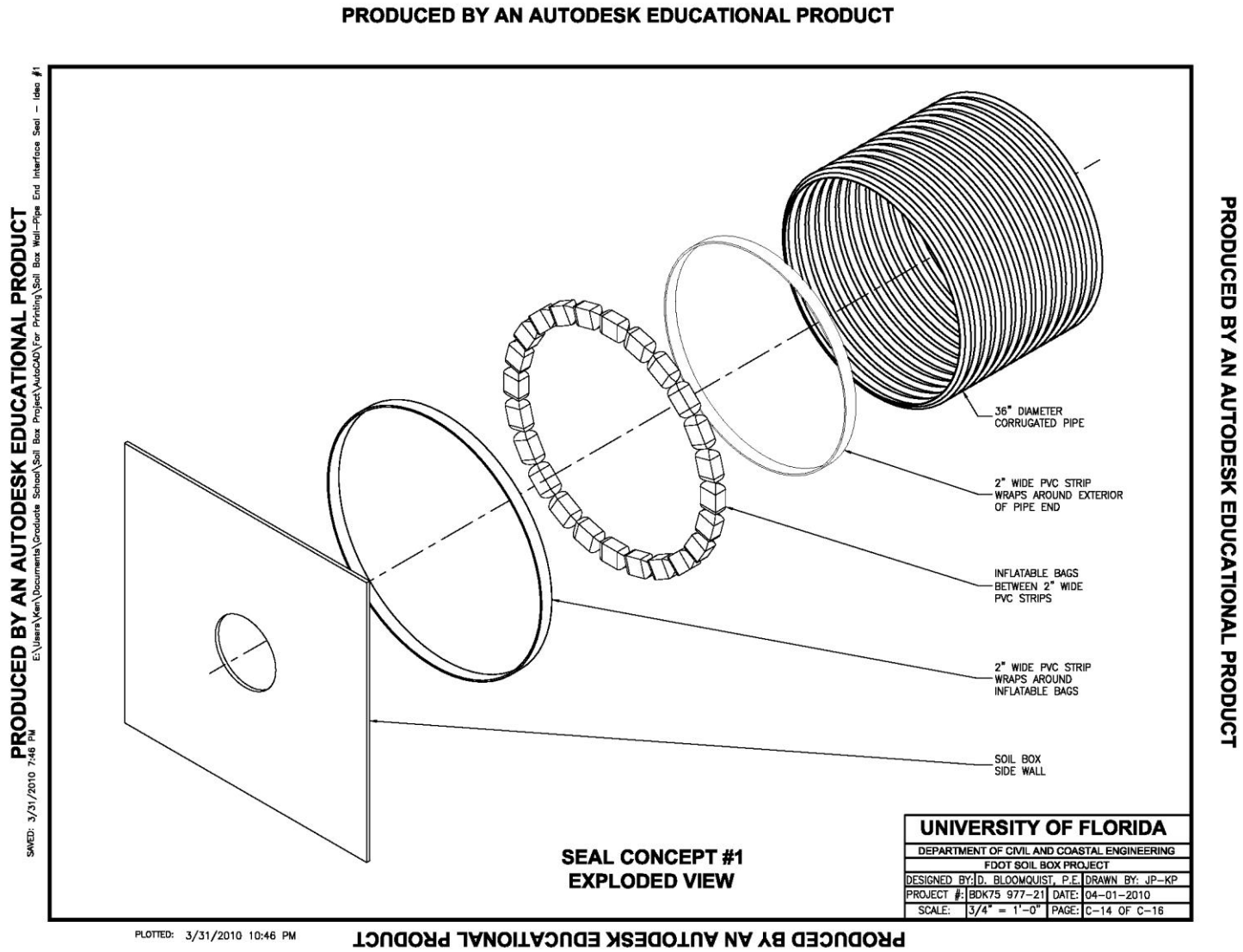

Figure 1-15. Seal concept #1, exploded view. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 32). University of Florida, Gainesville, Florida.]

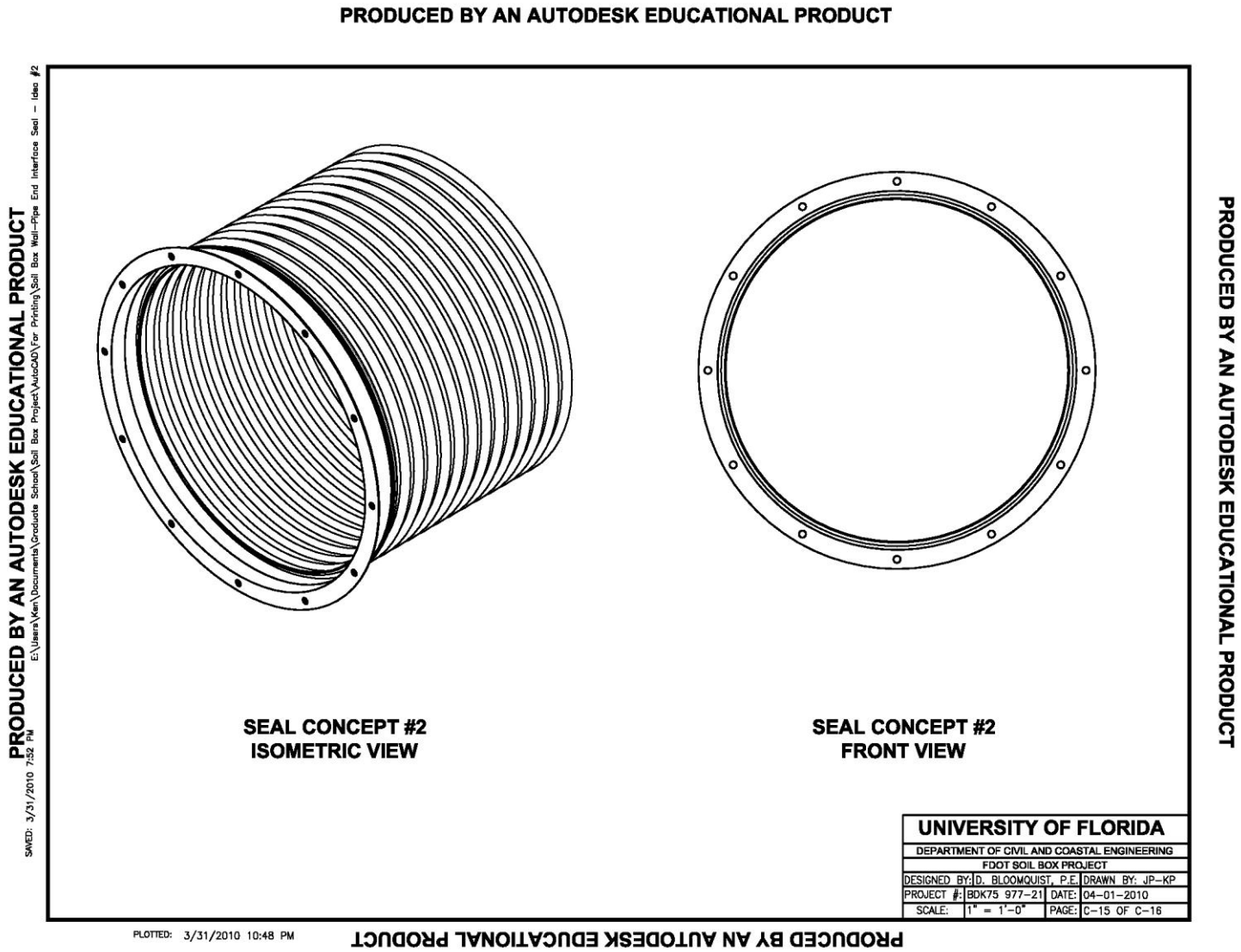

Figure 1-16. Seal concept #2, isometric view and front view. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 33). University of Florida, Gainesville, Florida.]

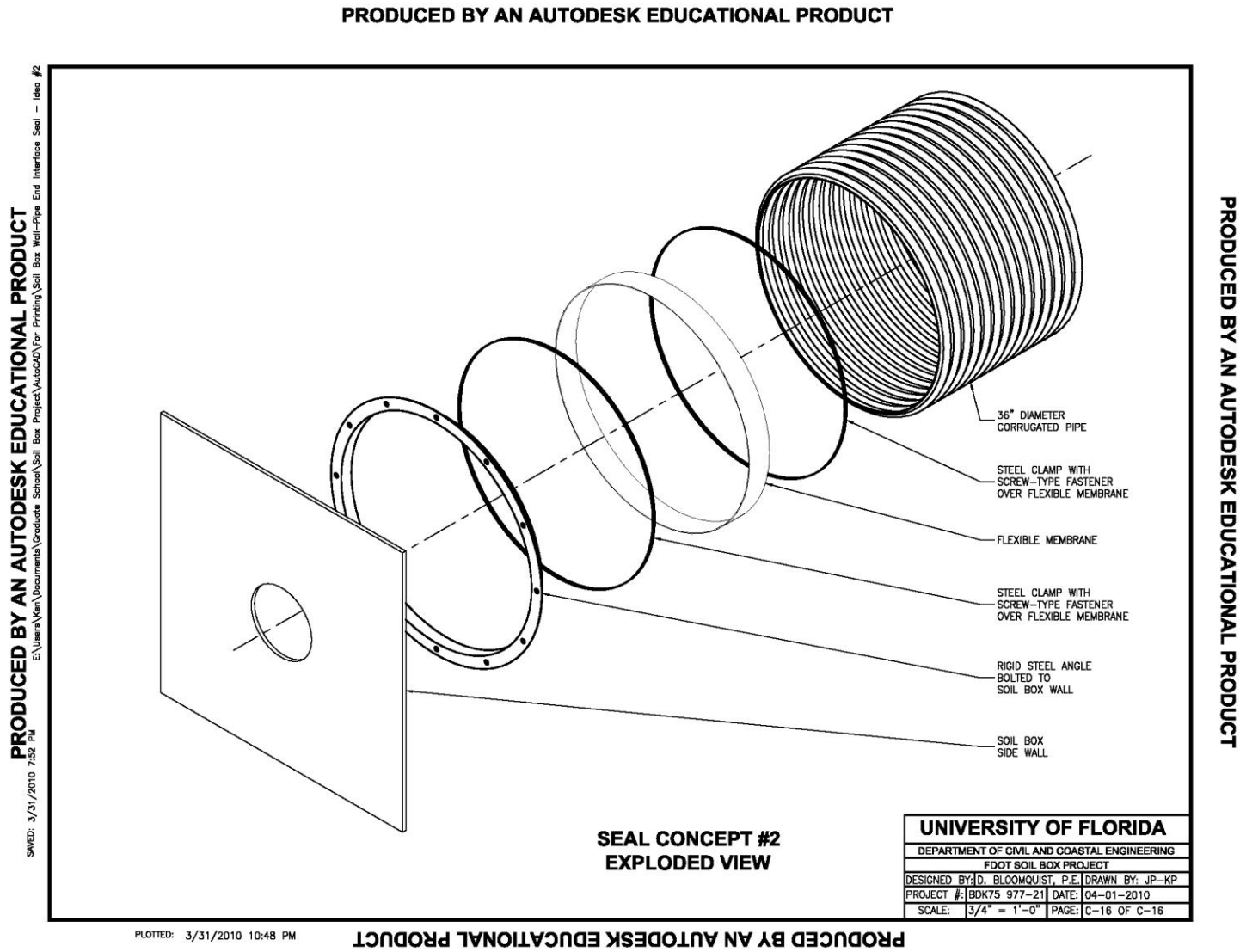

Figure 1-17. Seal concept #2, exploded view. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 2 (Page 34). University of Florida, Gainesville, Florida.]

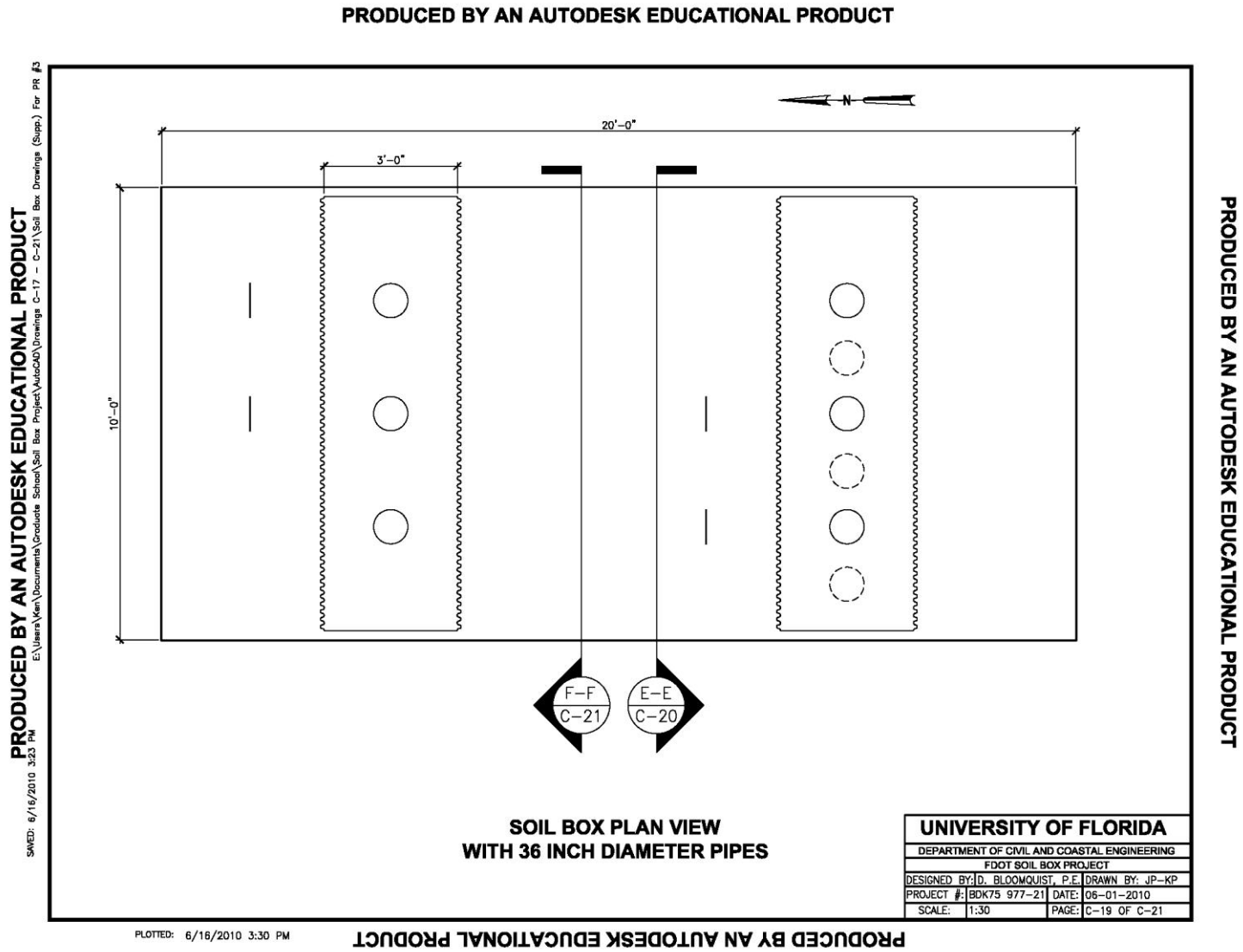

Figure 1-18. Soil box plan view with 36 inch diameter pipes. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 3 (Page 27). University of Florida, Gainesville, Florida.]

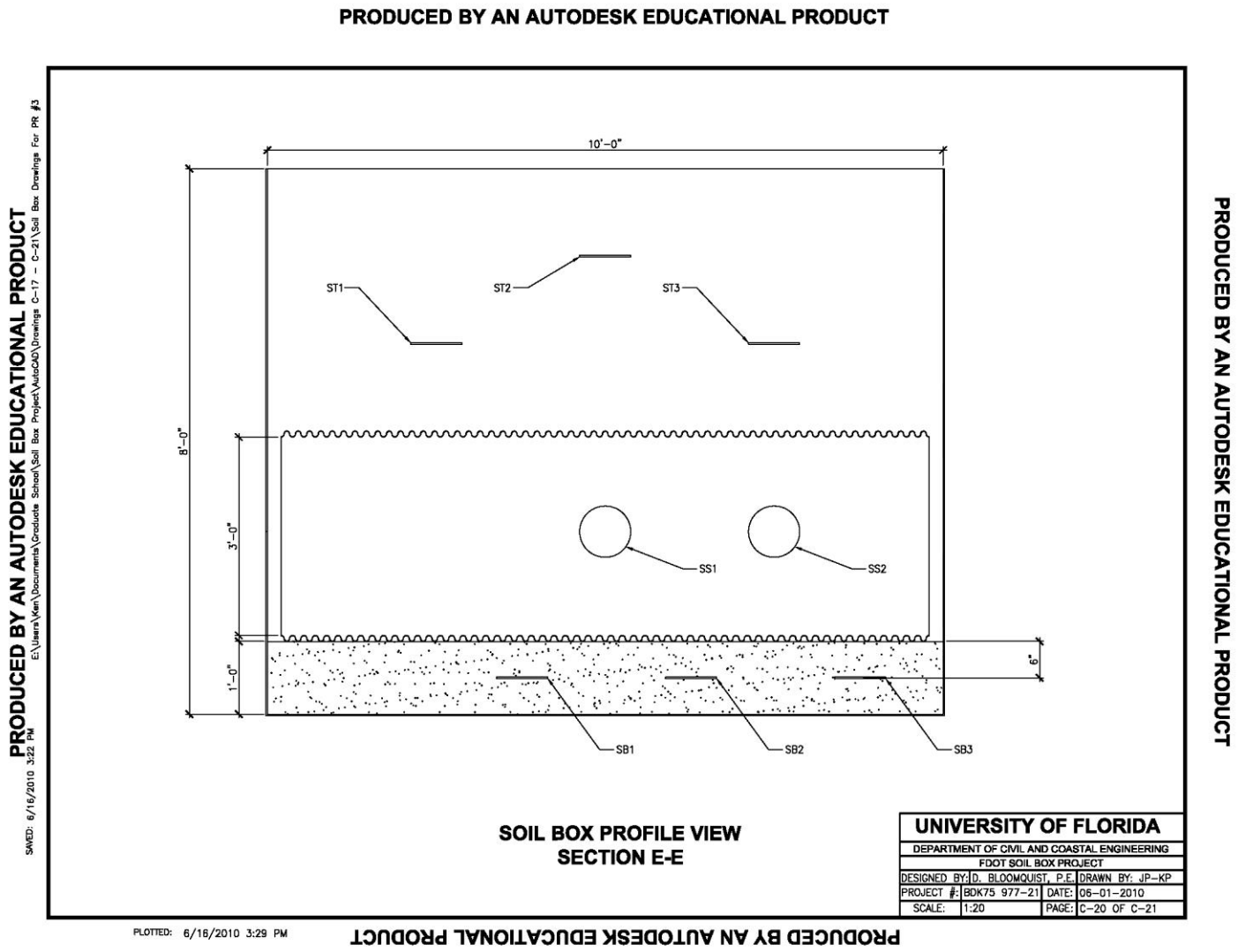

Figure 1-19. Soil box profile view with named earth pressure cells, section E-E. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 3 (Page 28). University of Florida, Gainesville, Florida.]

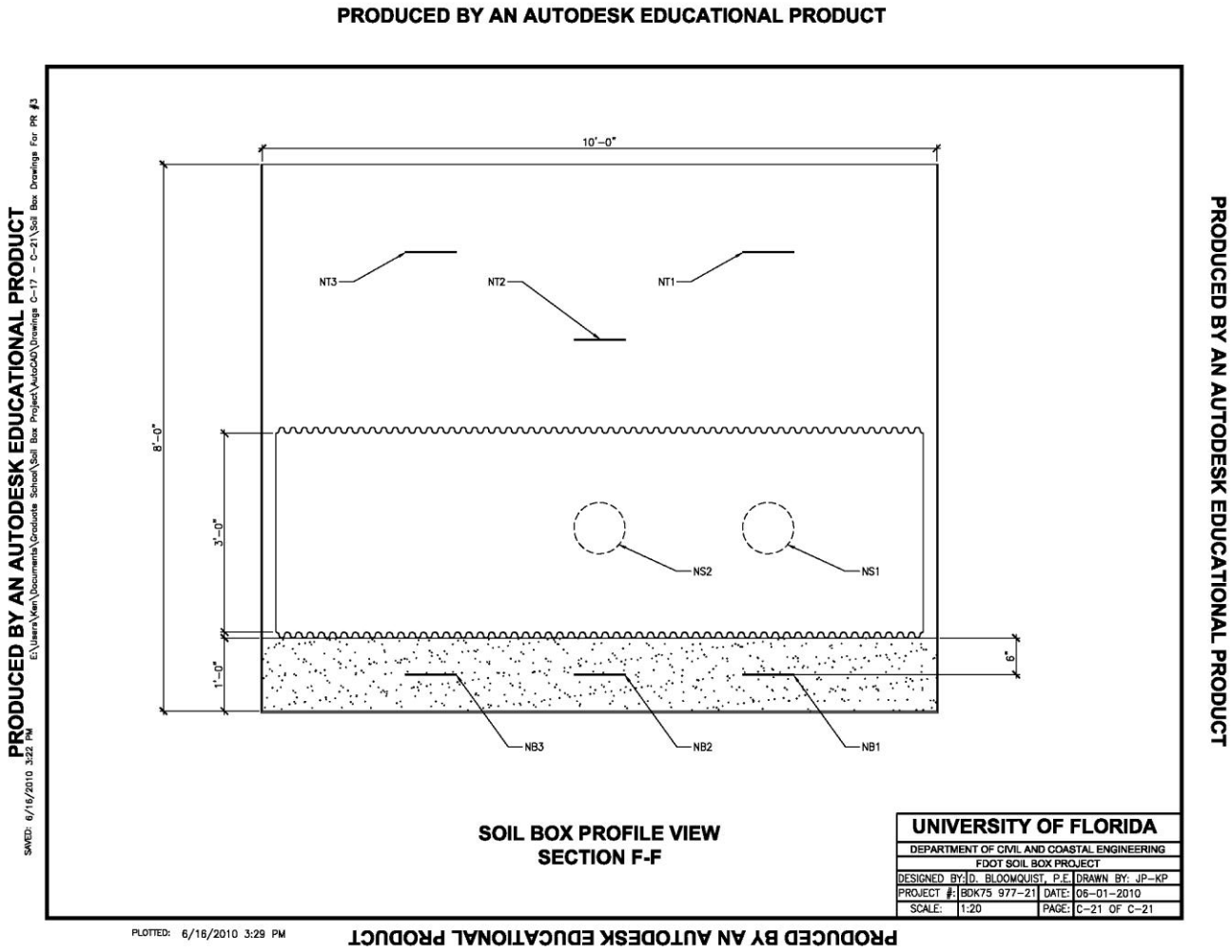

Figure 1-20. Soil box profile view with named earth pressure cells, section F-F. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 3 (Page 29). University of Florida, Gainesville, Florida.]

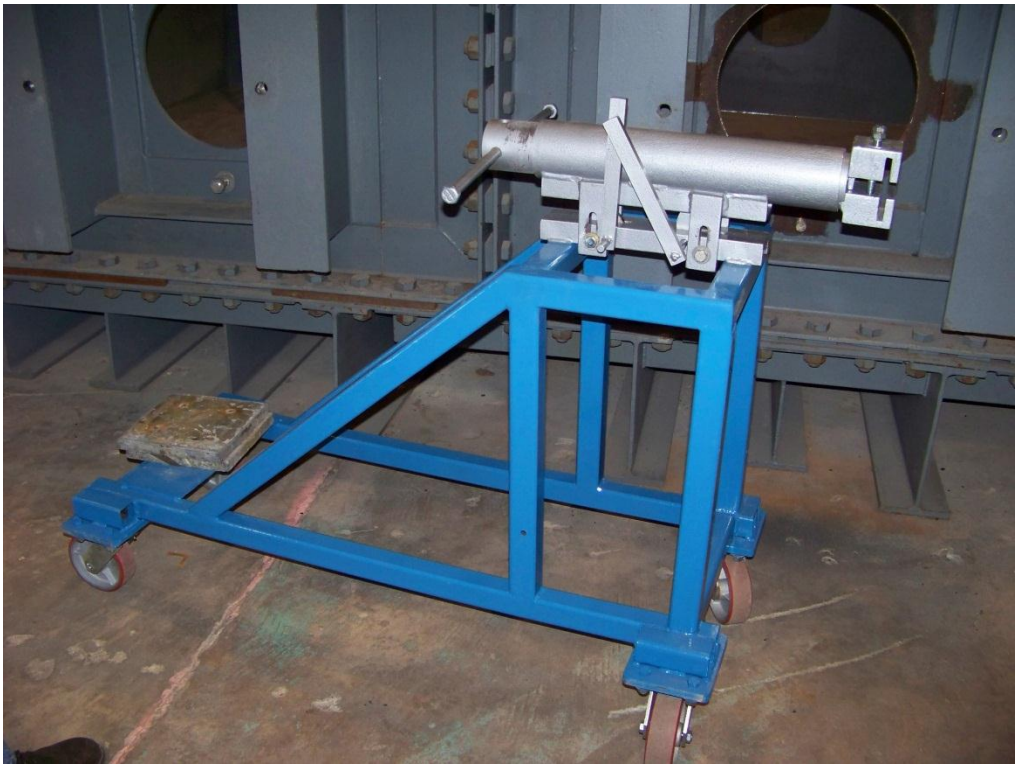

Figure 1-21. Porthole cover extractor/positioning device. Photo credit: K. Pasken.

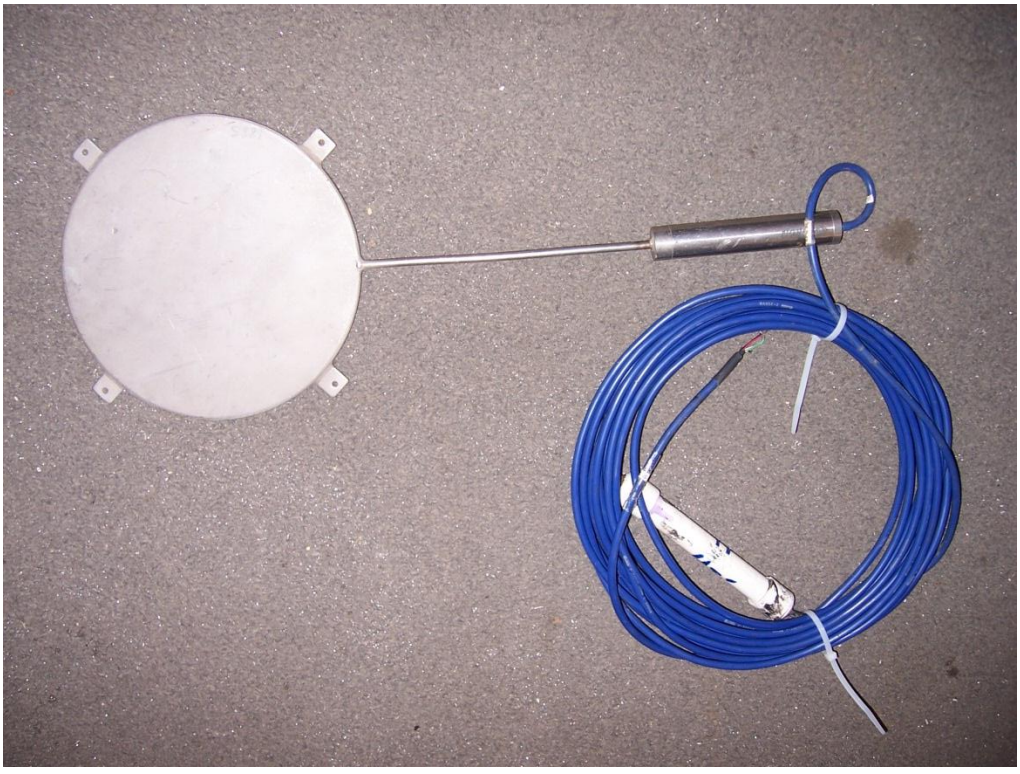

Figure 1-22. Earth pressure cell. Photo credit: K. Pasken.

Figure 1-23. Micro-Epsilon laser displacement sensor and cabling. Photo credit: K. Pasken.

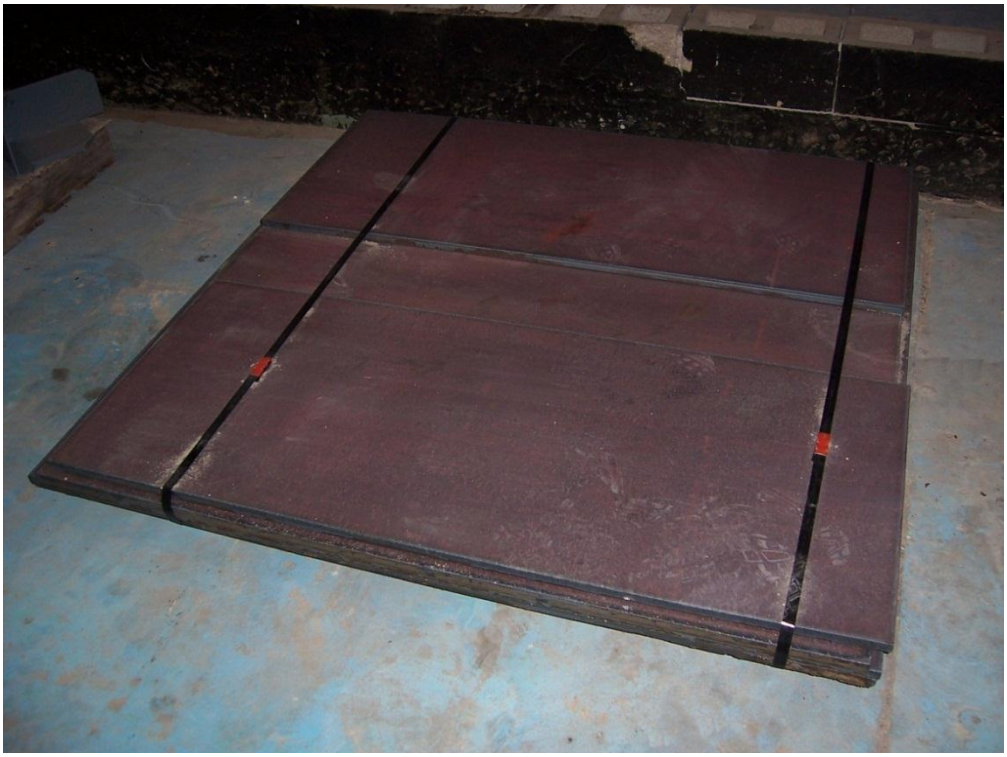

Figure 1-24. Load plates. Photo credit: K. Pasken.

Figure 1-25. Lift bags. Photo credit: K. Pasken.

Figure 1-26. Regulator. Photo credit: K. Pasken.

Figure 1-27. Air hoses. Photo credit: K. Pasken.

Figure 1-28. Valve stem. Photo credit: K. Pasken.

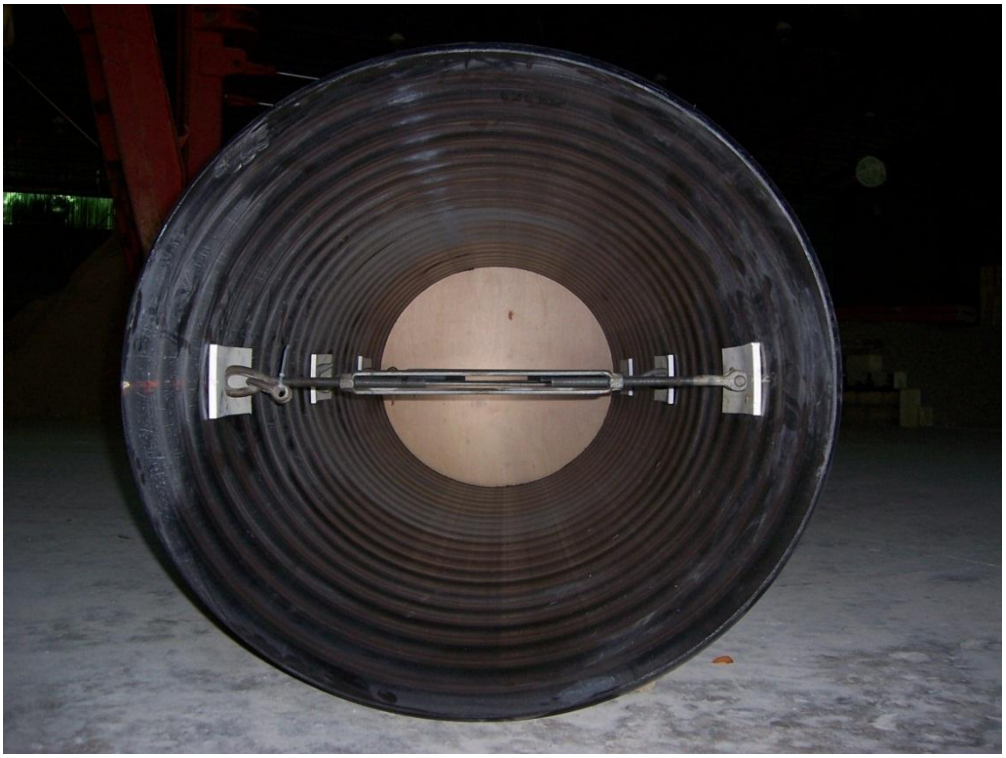

Figure 1-29. Pre-deflected HDPE pipe with turnbuckles. Photo credit: K. Pasken.

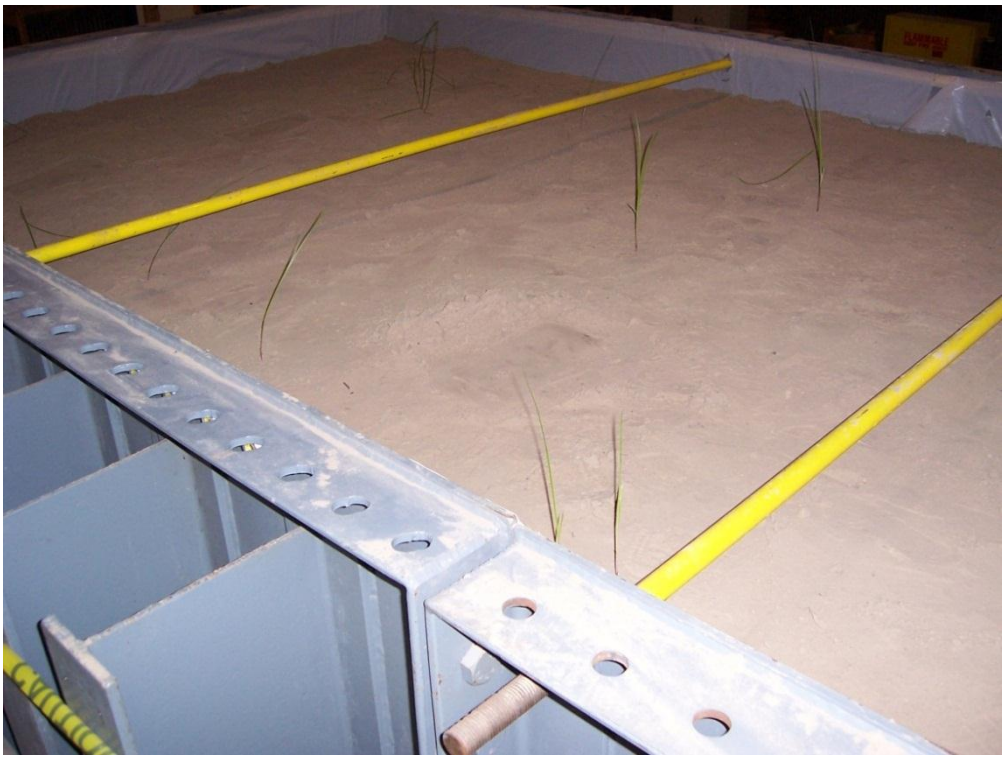

Figure 1-30. Soil profile following addition of final soil lift and completion of leveling. Photo credit: K. Pasken.

Figure 1-31. Footprint of soil box outlined with orange chalk. Photo credit: K. Pasken.

Figure 1-32. Water pressure being regulated for water to stay within the footprint. Photo credit: K. Pasken.

Figure 1-33. Filling of bucket at constant pressure. Photo credit: K. Pasken.

Figure 1-34. Stopwatch used to record the amount of time needed to fill the bucket. Photo credit: K. Pasken.

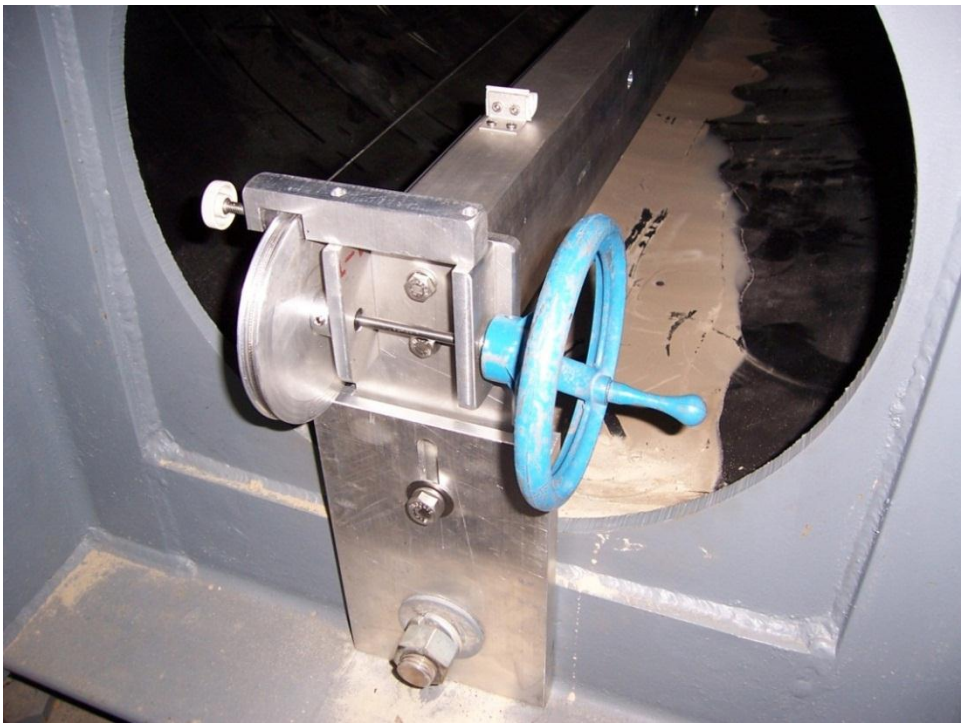

Figure 1-35. Hand-crank and reel on West end of soil box. Photo credit: K. Pasken.

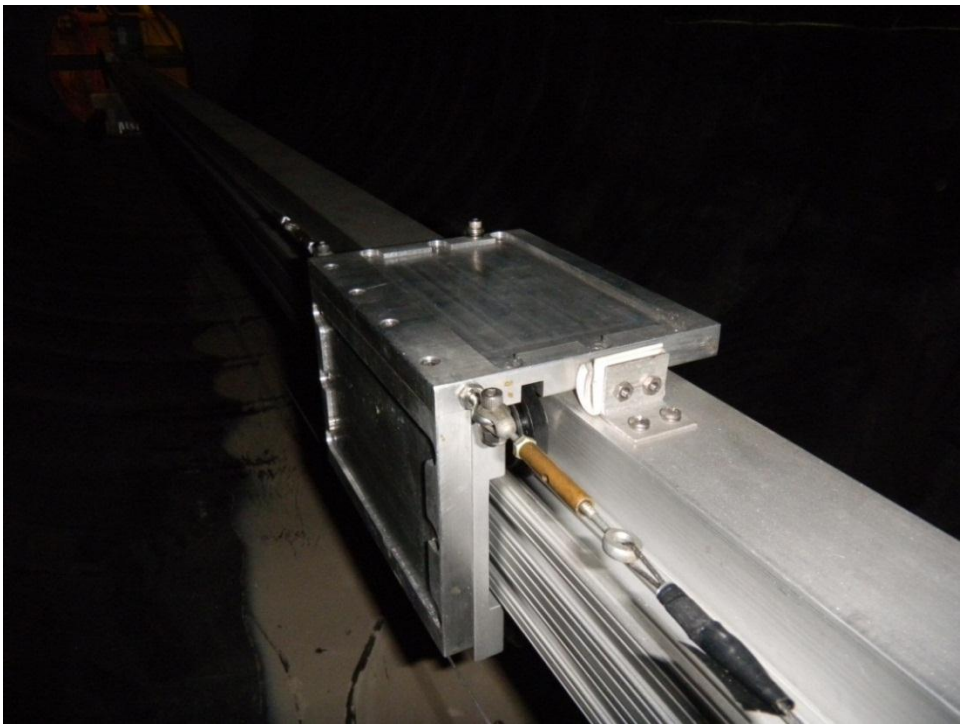

Figure 1-36. The cart on which the displacement laser mounts. Photo credit: K. Pasken.

CHAPTER 2
FABRICATION

Sealing System

Figure 2-1 demonstrates what the completed wall flange looks like when bolted onto the soil box side wall. Due to the large amount of instrumentation equipment being used for this project, careful attention was taken to ensure proper organization of all wiring. All instrumentation wiring will exit through the center porthole on the East side of the soil box. This porthole cover was machined, as shown in Figure 2-2, to allow for proper exit of all instrumentation wiring. Figure 2-3 shows what the instrumentation wiring will be guided through so there is no chance of wires being cut or improperly handled. These “knobs” are screwed into the threaded holes that were machined on the soil box porthole cover.

In order for the pipes to properly interface with the sealing system discussed in Chapter 1, the spirally corrugated pipes needed to have a strip of metal welded to the inside perimeter. This slight modification can be seen below in Figure 2-4 for the aluminum pipes. The same modification was performed on the stainless steel pipes. For the pipes with circular corrugations, no additional metal strip was added. Instead, the corrugation was filed back. See Figures 2-5 and 2-6 for the HDPE and PVC pipes.

Instrumentation Room

The instrumentation room was required for protection of all data acquisition hardware and the various pieces of instrumentation. There is a window on the East face of the room to allow for air ventilation. It also provides ease of communication between the person operating the laser and the person sitting at the computer at which the data

is collected. Exterior and interior views of the completed instrumentation room can be seen in Figures 2-7 and 2-8.

Instrumentation Wiring

One of the major concerns in the final phases before testing was electrical noise present in the instrumentation signals for the displacement laser and string potentiometers. Figure 2-9 represents the initial condition which had a great deal of clutter. Absent from that figure is the power source for the displacement laser. Figure 2-10 represents the current condition for the instrumentation wiring. The two circuit boards have been replaced, and all connections have been soldered and heat-shrunk. Performing this upgrade to the instrumentation wiring has proved to be very successful in eliminating most, if not all, of the electrical noise.

Figure 2-1. Completed wall flange for sealing system. Photo credit: K. Pasken.

Figure 2-2. Machined porthole cover. Photo credit: K. Pasken.

Figure 2-3. Instrumentation wiring guide. Photo credit: K. Pasken.

Figure 2-4. Metal strip welded onto spirally corrugated pipes. Photo credit: K. Pasken.

Figure 2-5. Filed back corrugation on HDPE pipe. Photo credit: K. Pasken.

Figure 2-6. Filed back corrugation on PVC pipe. Photo credit: K. Pasken.

Figure 2-7. Completed exterior of instrumentation room. Photo credit: K. Pasken.

Figure 2-8. Completed interior of instrumentation room. Photo credit: K. Pasken.

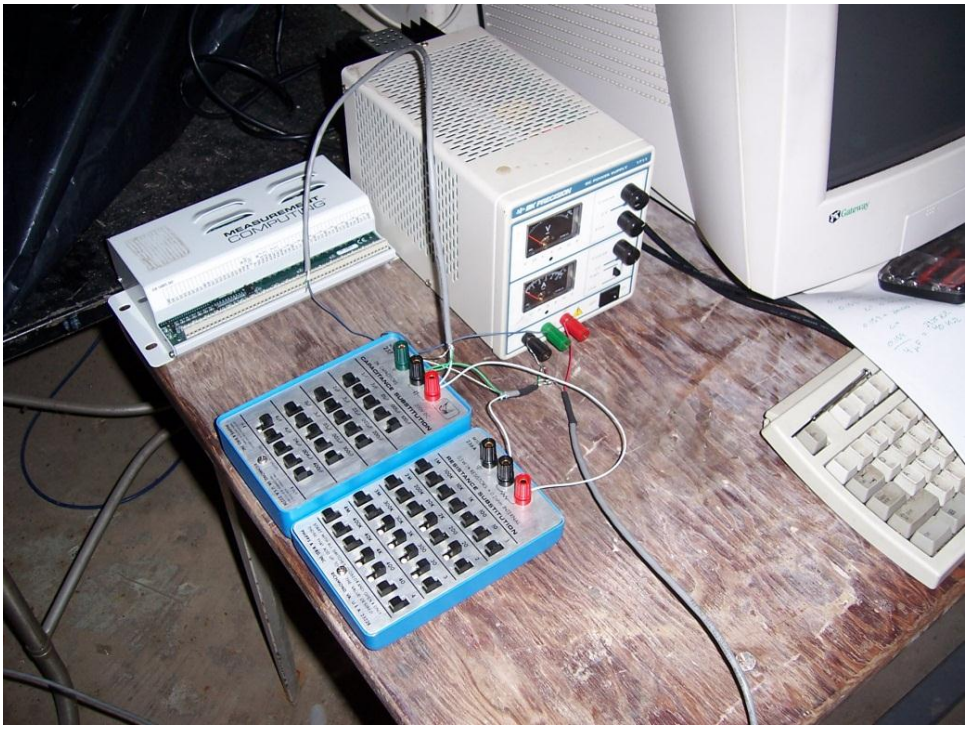

Figure 2-9. Instrumentation wiring prior to refining. Photo credit: K. Pasken.

Figure 2-10. Simplified instrumentation wiring, decreasing amount of electrical noise. Photo credit: K. Pasken.

CHAPTER 3
INSTALLATION

Industry Visit

The soil box was partially set up for the purposes of an industry visit which took place on Tuesday, March 16, 2010. This partial set up included the 12 inch thick layer of compacted soil at the bottom of the soil box, as well as the installation of an HDPE pipe in the North end of the box. As can be seen in Figures 3-1 through 3-3, the 12 inch thick layer was compacted uniformly and the rubber membrane sealing system was installed over the interface between the pipe end and the soil box wall.

Preparation for First Test

After the industry visit, the soil box continued to be prepared for the first test. This particular task was accomplished in a number of stages. The bottom 12 inch thick layer of compacted fill was already in place. The next step was to properly route all the instrumentation wiring through the center porthole. See Figures 3-4 and 3-5 for the completed instrumentation wiring.

The 36 inch diameter HDPE pipes were used for the first test. Figure 3-6 shows how the pipes are lowered into the soil box. Both pipes were pre-deflected to four percent along the ten foot length, or about 1.44 inches. After the pipes were lowered, the rubber membrane sealing system was installed over the four open joints. Views of the pipe/wall interface prior to and immediately after the installation of the sealing system can be seen in Figures 3-7 and 3-8, respectively.

Immediately following the installation of both pipes, soil began to be loaded into the box. This was done in three separate lifts, and was accomplished with the use of a front end loader dumping soil into a concrete bucket. The concrete bucket was then

hoisted over the soil box, and its contents emptied. This process can be seen in Figures 3-9 through 3-11.

The next step in the process, which took place in conjunction with filling, was to properly place the earth pressure cells. The cells needed to be located according to the specifications outlined in Chapter 1, as can be seen in Figures 3-12 through 3-14.

Finally, after the last lift of soil was added to the soil box, the soil was leveled uniformly. See Figure 3-15. Once again, careful attention was paid to ensure that the soil was not compacted any more than required. This was verified by nuclear density tests, which are discussed in Chapter 5. A final four to six inches of soil were added to close the eventual gap between the bottom of the soil box top and the lift bags that would be placed on top of the load plates. The final soil level can be seen in Figure 3-16.

The next step was to install the load plates on top of the soil. The load plates were lifted individually and set in their appropriate locations. As per the specifications, six five-foot by five-foot and four two-and-a-half-foot by five-foot load plates were installed. This step can be seen in Figure 3-17.

After the load plates were successfully installed, the lift bags needed to be set in place. They were hoisted into place in the same manner as the load plates. See Figure 3-18. The smaller lift bags seen towards the end of the long dimension of the soil box are so sized to account for the smaller load plates. This is to avoid eccentric loading of the soil.

The next step in the process was to connect all the necessary equipment for pressurizing the lift bags, as seen in Figures 3-19 through 3-22. The air hoses were

connected to the lift bags, routed through drilled holes in the soil box East wall and down the wall into a flange, connecting all the air hoses to one air supply.

Following the installation of the lift bags and air pressurizing equipment, the soil box top was ready to be installed. The top is comprised of three sections, the outer two being wider than the middle section. This particular task proved especially difficult due to the need to line up all the holes on the top with the vertical walls. The objects lying on top of the lift bags, seen in Figures 3-23 and 3-24, were used to temporarily hold the sections in place while the holes were lined up. These two figures also show the South section after placement.

Due to complications with correctly lining up all three sections, an end of the South section needed to be slightly trimmed. The alteration can be seen in Figure 3-25. Once this was performed, the top could be properly put in place and fastened with all the necessary hardware, seen in Figure 3-26. This was the last step in preparing the soil box itself for the first test.

Soil Saturation

Because full saturation could not be attained and because the soil box was not completely filled, water was added to the soil box for about half of the 34 hours, or about 18 hours. This was done over the course of three days. Figure 3-27 shows the sprinkler setup in the soil box towards the end of the watering process. In the middle of the photo, water can be seen beginning to form puddles.

French Drain

This particular task was needed for drainage purposes once the soil was saturated. The French drain is located along the South end of the soil box. A porous

membrane allows only water to penetrate into the drain. This prevents soil from clogging the drain. The drainage spout can be seen in Figure 3-28.

String Potentiometers

String potentiometers were ordered and subsequently installed on the laser mounting system. Each pipe being tested has the setup shown in Figure 3-29. This makes the data acquisition process much quicker when compared to having to move the entire rig from one pipe to the other.

Figure 3-1. 12 inch thick layer of soil at bottom of soil box. Photo credit: K. Pasken.

Figure 3-2. HDPE pipe installed in North end of soil box. Photo credit: K. Pasken.

Figure 3-3. Sealing system between pipe end and soil box wall. Photo credit: K. Pasken.

Figure 3-4. Completed routing of instrumentation wiring with sealant (view from inside). Photo credit: K. Pasken.

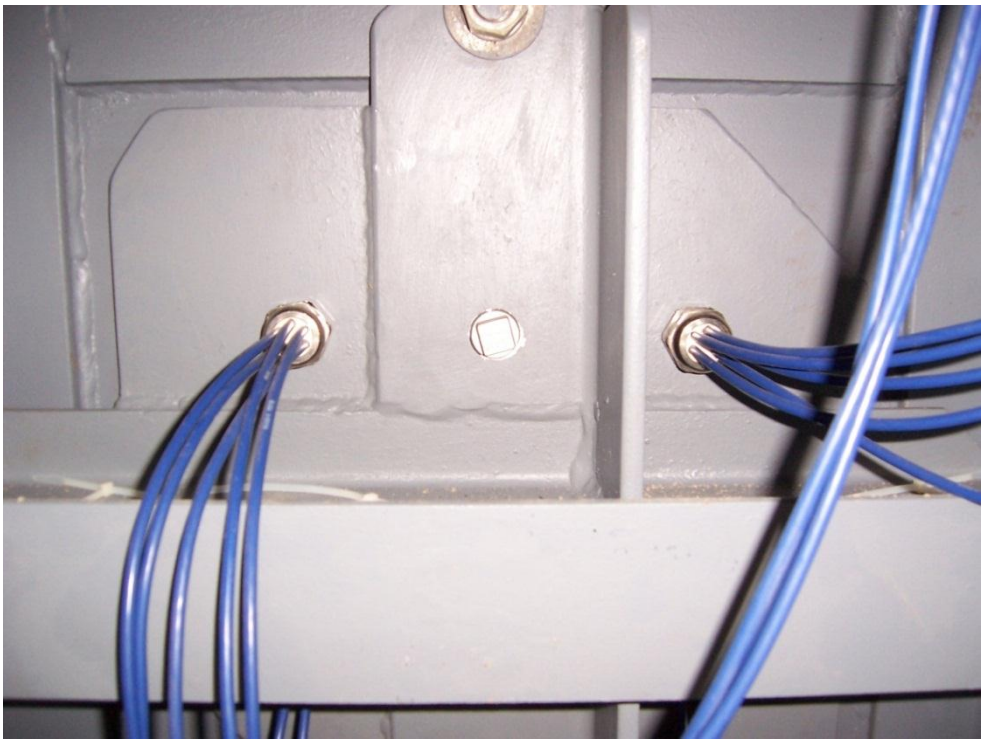

Figure 3-5. Completed routing of instrumentation wiring (view from outside). Photo credit: K. Pasken.

Figure 3-6. HDPE pipe being lowered into soil box. Photo credit: K. Pasken.

Figure 3-7. Pipe/wall interface prior to sealing. Photo credit: K. Pasken.

Figure 3-8. Installed rubber membrane sealing system. Photo credit: K. Pasken.

Figure 3-9. Dumping of soil into concrete bucket. Photo credit: K. Pasken.

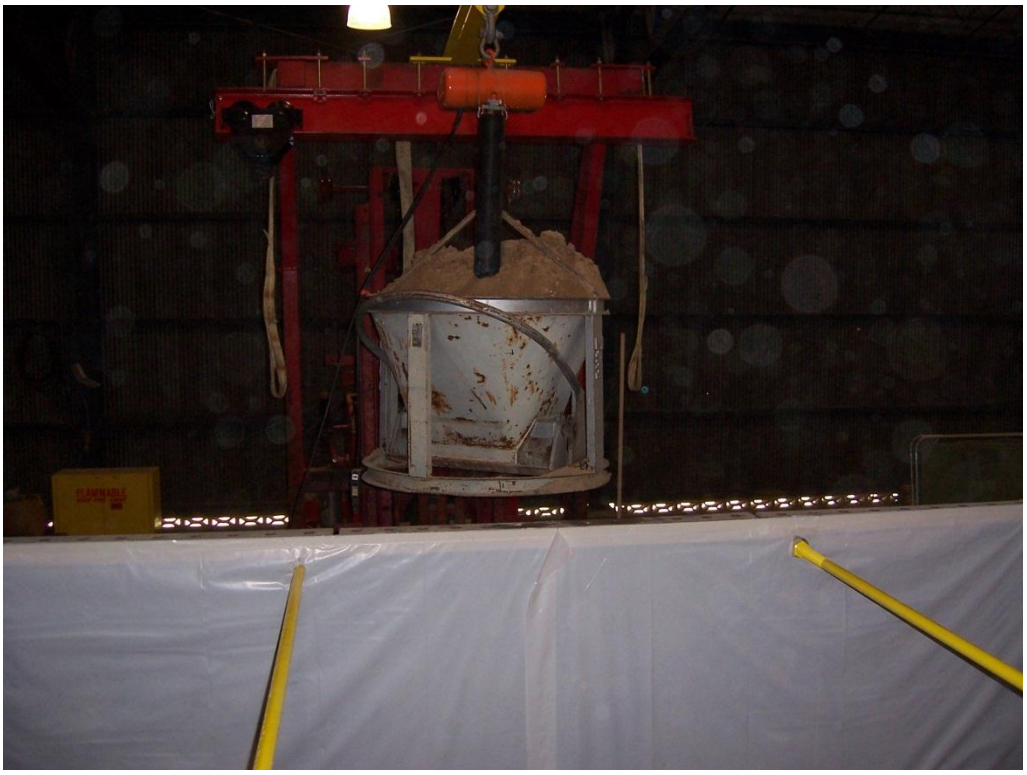

Figure 3-10. Full concrete bucket hoisted over soil box. Photo credit: K. Pasken.

Figure 3-11. Concrete bucket emptied over soil box. Photo credit: K. Pasken.

Figure 3-12. Placement of SS2 earth pressure cell. Photo credit: K. Pasken.

Figure 3-13. View of SS1 (left) and SS2 (right) earth pressure cells. Photo credit: K. Pasken.

Figure 3-14. Placement of NT3 earth pressure cell. Photo credit: K. Pasken.

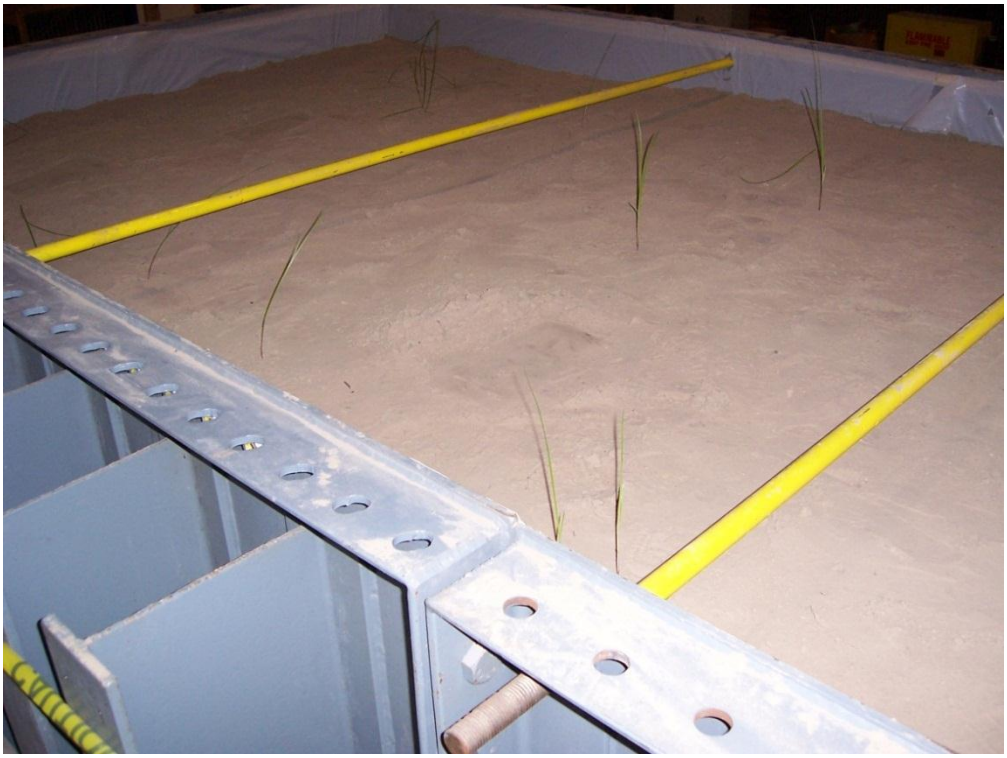

Figure 3-15. Soil profile following addition of final soil lift and completion of leveling. Photo credit: K. Pasken.

Figure 3-16. Final soil level in soil box. Photo credit: K. Pasken.

Figure 3-17. Load plates in the process of installation. Photo credit: K. Pasken.

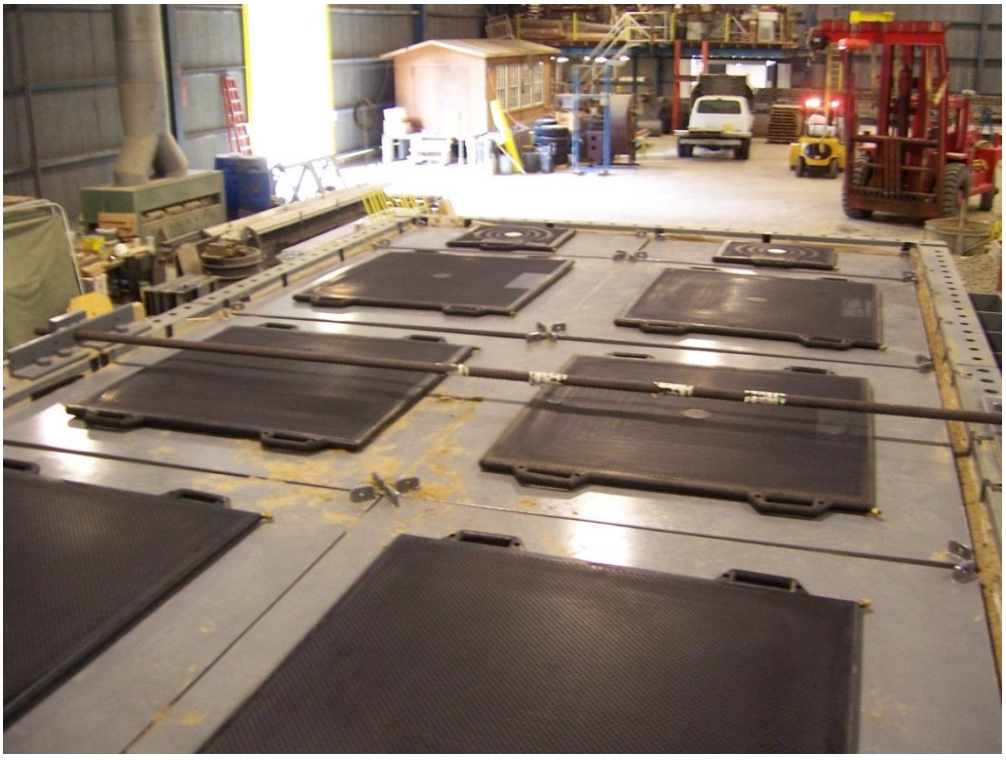

Figure 3-18. Lift bags after placement directly over center of the load plates. Photo credit: K. Pasken.

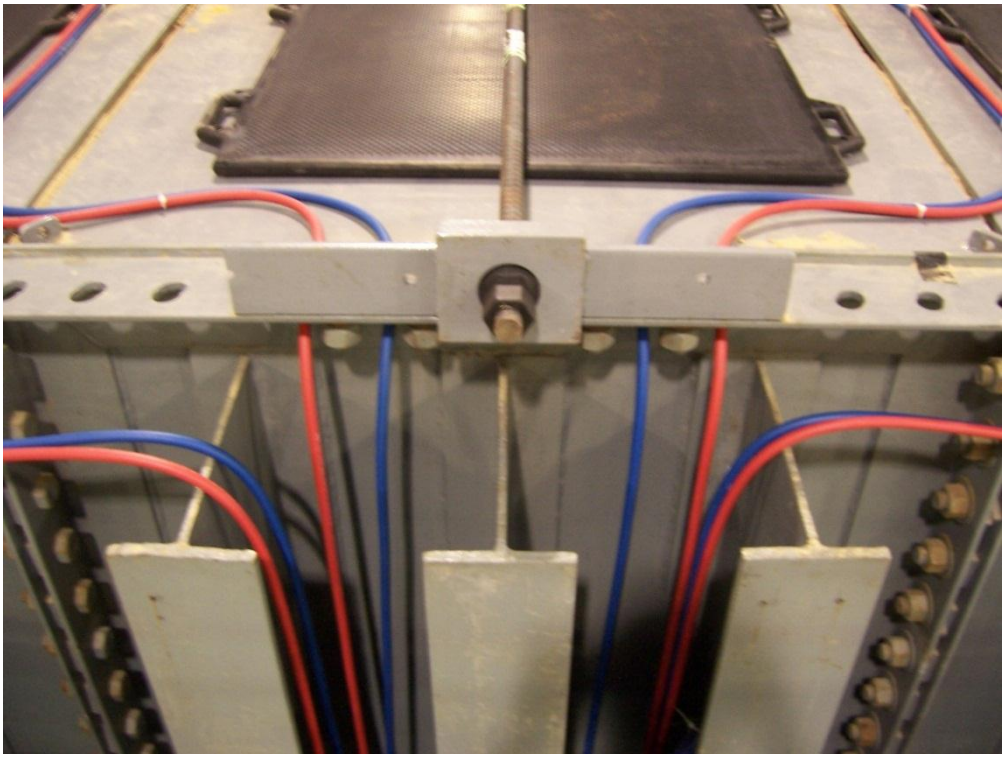

Figure 3-19. Air hoses routed through and down soil box East wall. Photo credit: K. Pasken.

Figure 3-20. Air hoses connected to lift bags. Photo credit: K. Pasken.

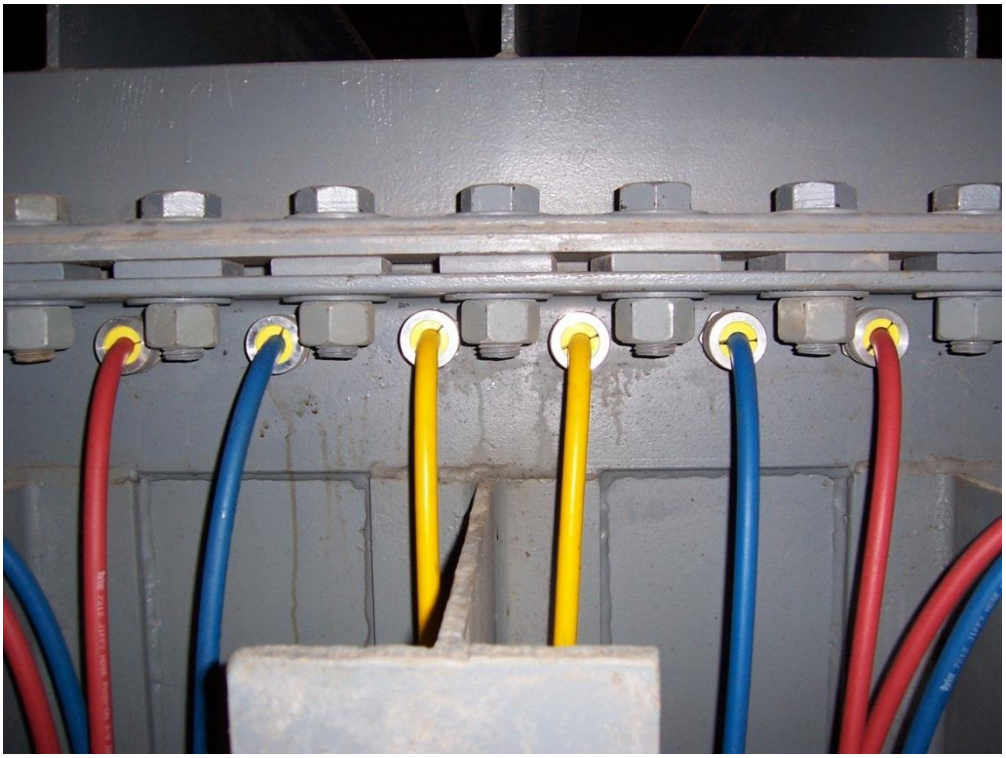

Figure 3-21. Close-up of air hoses being routed through soil box East wall. Photo credit: K. Pasken.

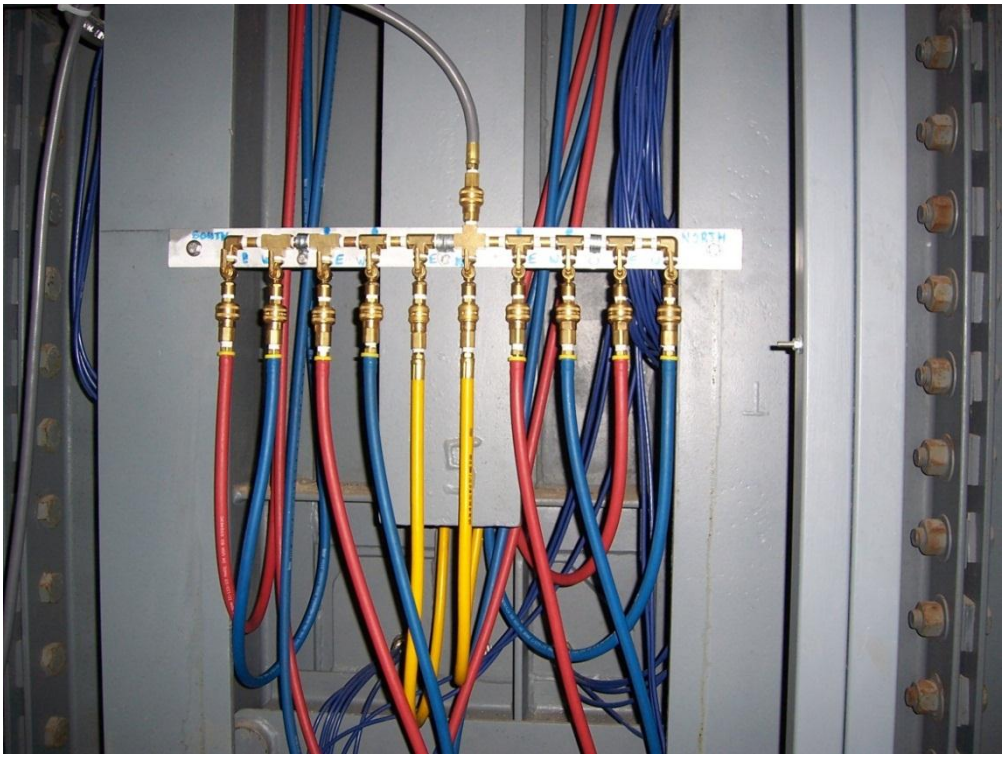

Figure 3-22. Air hoses connected to pressure source. Photo credit: K. Pasken.

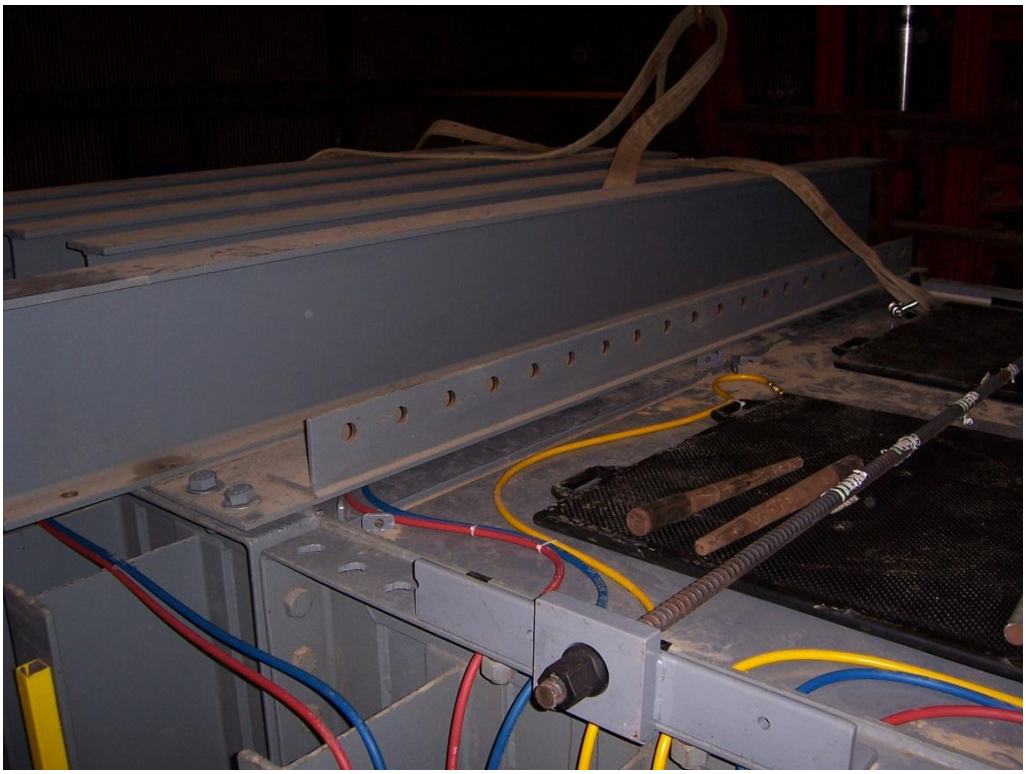

Figure 3-23. Partial installation of the soil box top. Photo credit: K. Pasken.

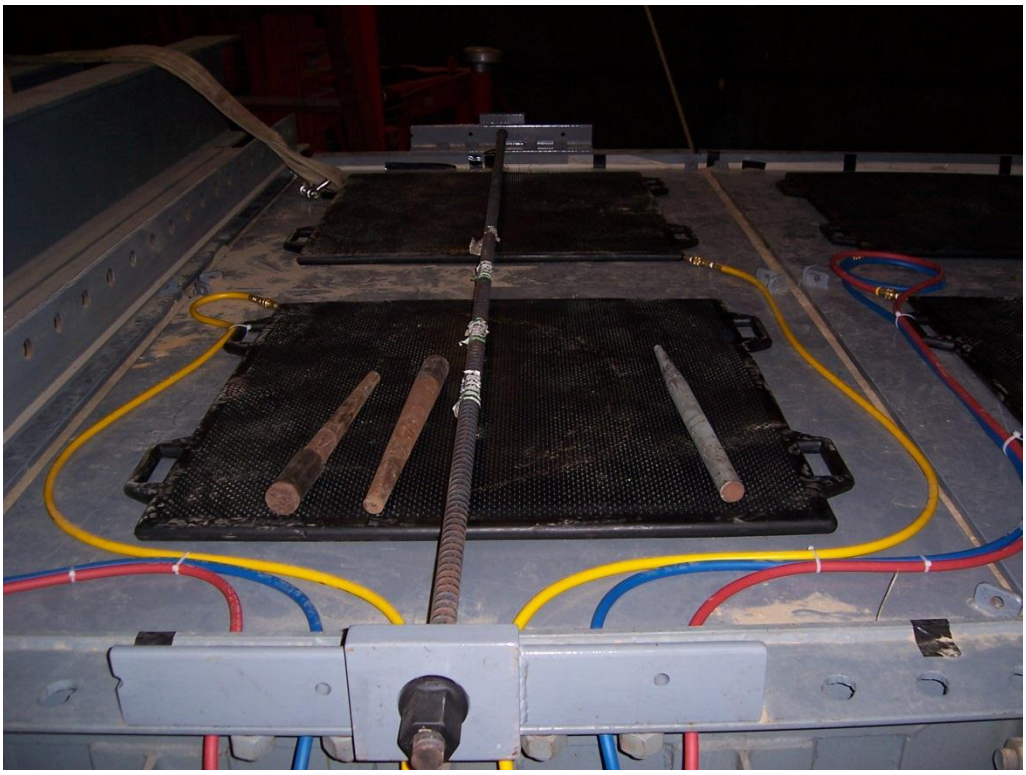

Figure 3-24. Partial installation of the soil box top. Photo credit: K. Pasken.

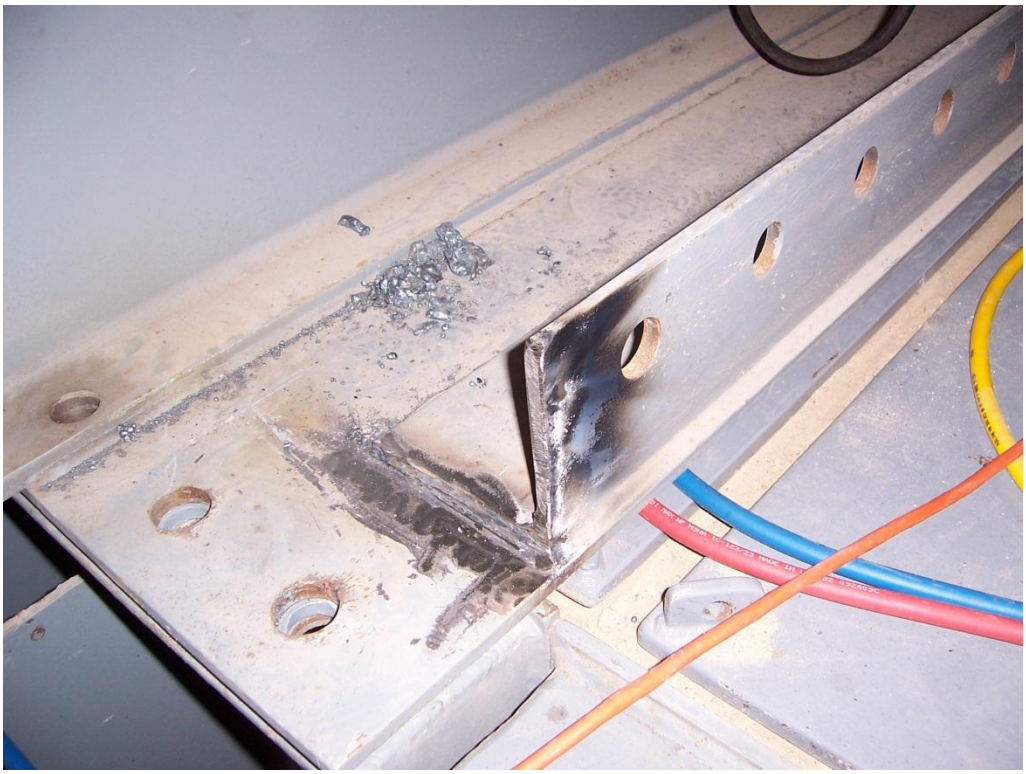

Figure 3-25. Trimmed end of South section of soil box top. Photo credit: K. Pasken.

Figure 3-26. Completed installation of soil box top. Photo credit: K. Pasken.

Figure 3-27. Sprinkler setup inside soil box with water beginning to form puddles. Photo credit: K. Pasken.

Figure 3-28. French drain release valve. Photo credit: K. Pasken.

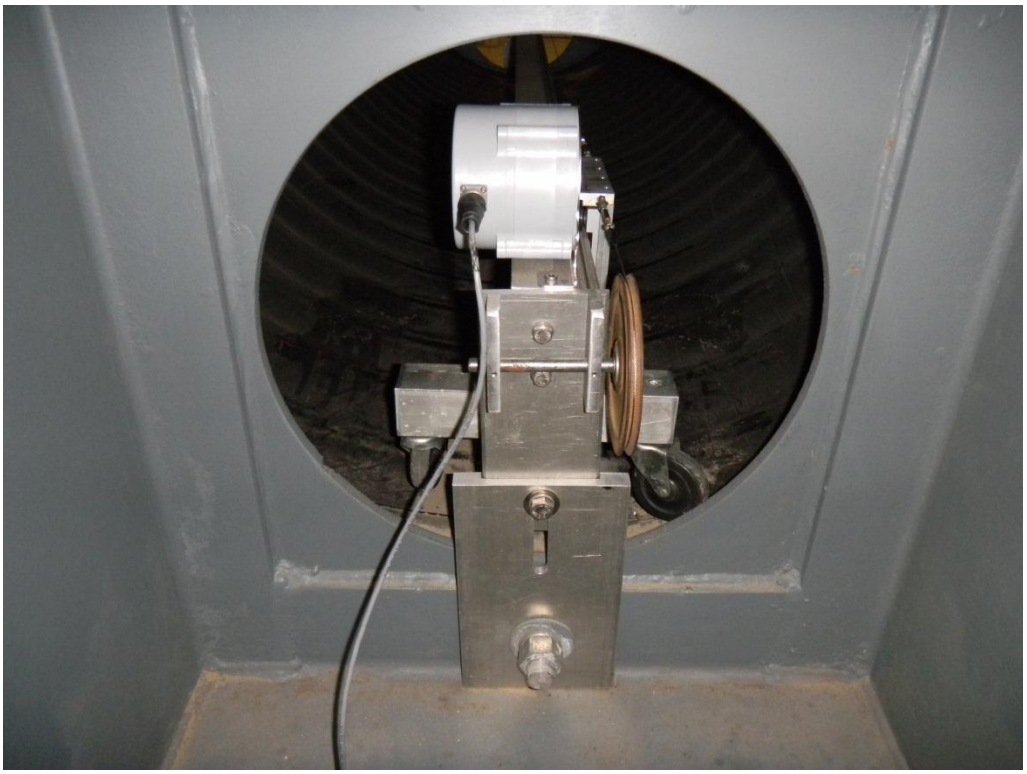

Figure 3-29. String potentiometer attached on the East end of the soil box. Photo credit: K. Pasken.

CHAPTER 4
IMPLEMENTATION

First Test

The first test began on Monday, August 23, 2010 with two pre-deflected 36 inch HDPE pipes inside the soil box. Zero readings were taken on all of the earth pressure cells and with the displacement laser on Thursday, August 19, 2010. On Monday the 23rd, the system began to be pressurized, starting off at 2 psi and increasing by 2 psi increments until 8.33 psi was reached. This specific pressure correlated to a surcharge load of 10 feet. The increments were then raised to 3.33 psi until a pressure of 16.67 psi was reached, simulating a surcharge depth of 20 feet. For the range of 20 feet to 50 feet of surcharge, or 16.67 psi to 41.67 psi, respectively, the pressure increment was increased to 5 psi.

Based on the earth pressure cell readings and displacement laser readings, some discussion began about what the actual pressures were that were being applied. In reality, when the lift bags are inflated, the footprint they have on the load plates is diminished because they expand in the vertical direction. It is because of this reduced contact area that the pressures being recorded throughout the soil were much less than what was being measured as the applied pressure from the air source.

Large quantities of measurements were taken to record pressures throughout the soil box and deflections of the pipes. Ultimately, a maximum pressure of 66.67 psi was applied to the lift bags. This was the maximum available air pressure capacity which could be provided by the air compressor at the UF Coastal Engineering Laboratory. The initial loading sequence was followed by an unloading sequence, and then a more rapid reloading sequence. The latter is discussed in greater detail below. Part of the reason

for the extensive amount of time required for the first test was the need to unload the box at nearly the same rate at which it was loaded. With future tests, there will need to be less time in between pressure increases to cut down on the overall required time for each test.

Modification of Earth Pressure Cells

After the soil box was unloaded, two additional earth pressure cells were installed directly beneath the center load plates and the soil box was re-pressurized. The purpose of this particular task was to be able to more accurately assess the pressures being applied to the soil box. The issue has to do with the contact area between the lift bags and the load plates. Because of this, the pressure being applied to the lift bags is an overstatement of the pressures being applied to the soil beneath the load plates.

Since there was the unique advantage of having the entire setup assembled with all instrumentation still in place, the decision was made to install two pressure cells, one beneath the center of each of the two center load plates. The center section of the soil box lid was simply removed, along with the lift bags and load plates in the center section. The two new cells were installed, with cables being routed out of the soil box and into the data logging equipment. The load plates, lift bags, and center section of the soil box lid were then reinstalled. Aspects of the procedure can be seen in Figures 4-1 and 4-2.

A rapid reloading sequence ensued to record what the pressures were directly beneath the load plates. The time in between raising the pressure was not as much of a concern because the only interest was the pressure directly beneath the load plates, not the pressure in the soil. Therefore, the stress-strain properties of the soil did not affect the readings of interest. The reloading sequence was accomplished in one day. Even

with this extra task, there was still speculation about whether or not the numbers obtained could be relied upon. It was ultimately decided that a soil box calibration test should be performed. This is discussed in more detail in Chapter 5.

Soil Box Disassembly

The soil box was disassembled after successful conclusion of the first test. This project task was accomplished in a number of steps, paying very close attention to the layout of the earth pressure cells within the soil. It was very important to remove the soil in a manner consistent with not heavily disturbing the earth pressure cells, so as to avoid damaging the cells. The South pipe was the first to be removed, with the soil directly above the pipe being excavated out along with the pressure cells in the vicinity. This aspect of disassembly can be seen in Figure 4-3. The South pipe was then hoisted out of the soil box, as seen in Figure 4-4. The next step was to remove the North pipe. The approach for this particular step involved removing the North face of the soil box, allowing the soil to be removed from the box simply by gravity. The remaining soil was then removed with a front-end loader. Once enough soil had been removed, the North pipe was carefully removed, again with the use of the front-end loader. The remaining soil and earth pressure cells were finally removed, concluding the disassembly of the soil box. See Figures 4-5 through 4-7.

New Air Compressor Installed

A new, higher capacity air compressor was installed at the UF Coastal Engineering Laboratory to be able to more adequately meet the needs of this project. When the issue arose that the pressures being applied to the load plates were less than what was being applied to the lift bags, there was some concern about the air compressor being used on the project. Assuming the pressures in the lift bags and

those being applied to the load plates were equal, the air compressor being used reached its maximum output capacity when “simulating” a maximum surcharge of 50 feet. Seeing as how this was not the case, an air compressor was needed which could produce much higher pressures. Figures 4-8 and 4-9 show the old air compressor and the new air compressor, respectively.

Figure 4-1. Soil box center section being temporarily removed. Photo credit: K. Pasken.

Figure 4-2. One of two “new” pressure cells being added in the center of the soil box. Photo credit: K. Pasken.

Figure 4-3. Soil excavated from above South pipe. Photo credit: K. Pasken.

Figure 4-4. South pipe being removed from soil box. Photo credit: K. Pasken.

Figure 4-5. North face of soil box being removed. Photo credit: K. Pasken.

Figure 4-6. Soil removed with front-end loader. Photo credit: K. Pasken.

Figure 4-7. North pipe after removal from soil box. Photo credit: K. Pasken.

Figure 4-8. Old air compressor. Photo credit: K. Pasken.

Figure 4-9. New air compressor. Photo credit: K. Pasken.

CHAPTER 5
DATA ANALYSIS AND REVIEW

Nuclear Density Tests

Nuclear density tests were performed by FDOT technicians from the SMO on the soil being added to the soil box. These tests were done on four separate occasions: March 22, April 28, April 29, and May 3, 2010. Each of these dates corresponds to a lift of soil that had been added to the soil box. The test done on March 22 assessed the compaction in the first lift of soil which was 1 foot thick. Subsequently, two lifts each with a thickness of two feet were added to the soil box. The tests performed on April 28 and April 29 checked the respective compaction levels. Finally, two and a half feet of soil was added. The compaction of this final lift was assessed on May 3.

The location of all the nuclear density tests that were performed can be found in Figures 5-1 and 5-2. From the nuclear density test data, the average moisture content of the soil in the soil box was calculated as three percent.

Triaxial Tests

Existing triaxial test results were provided by Mr. Daniel Pitocchi, the Soils and Foundation Lab Manager at the SMO. The existing data corresponded to the soil being tested at 100 percent standard proctor density. Each sample was tested at 7, 14, and 21 psi confining pressures.

To be able to view the test soil's response under conditions similar to those existing in the soil box, new triaxial tests were performed. Specifically, new testing parameters included lowering the confining pressure to a level that could be maintained reliably, and testing at lower standard densities. The new tests were run on soil samples at 80, 85, and 90 percent standard proctor densities.

Earth Pressure Cell Readings

Earth pressure cell readings were taken on a number of dates. The data is being provided to Mr. Bryan P. Strohman of SGH in Microsoft Excel format. This is for the purposes of the FEM Analysis to be performed based on the pressure readings.

Displacement Laser Readings

Displacement laser readings were likewise taken on a number of dates. As with the earth pressure cell data, the displacement laser data is being provided to Mr. Bryan P. Strohman of SGH. Previous studies performed with similar designs and loading conditions are being taken into account when doing the data analysis and review for this project (Brachman et al. 1996).

Figures 5-3 through 5-18 show the deflection measurement of each pipe quadrant plotted against the length dimension of the pipes for the pressures being applied. There are noticeable changes in the plots as the pressure is increased. However, the deflections from the zero readings are not actually that large. This fact is what first sparked doubts regarding the actual pressure being applied in the soil. The graphic in Figure 5-19 shows the quadrant orientations when looking from the East end of the pipe to the West end. Therefore, Quadrant 1 points North, Quadrant 2 points to the top of the pipe, Quadrant 3 points South, and Quadrant 4 points to the bottom of the pipe.

Cone Penetrometer Readings

Cone penetrometer spot readings were taken after the lid of the soil box was removed. This task was performed simply to see what the state of the soil was after successful completion of a loading and unloading sequence. The test is a measure of the in-situ soil’s properties. The dial reading on the testing apparatus outputs units of kilograms per square centimeter, which is approximately equal to one ton per square

foot (tsf). A number of readings were taken throughout the footprint of the soil box, averaging about 20 tsf. The cone penetrometer can be seen in Figure 5-20.

Calibration Test

Towards the conclusion of the first test, it became apparent that a calibration test might be needed to better assess the pressures in the soil box. Although this requires the need for extra time, it was ultimately decided that this was a vital part of the experiment to validate the results collected thus far and those to be collected in the next six tests. A layout of the earth pressure cells for the calibration test can be seen in Figures 5-21 and 5-22. Vertical strains will be obtained at the specified locations with the use of string potentiometers mounted to stationary locations on the outside of the soil box. Although this number of cells may seem excessive, this layout was chosen because the equipment and data logging capacity was available. This redundancy also serves as a backup plan in case any of the cells fail. No pipes are installed in the soil box for the calibration test.

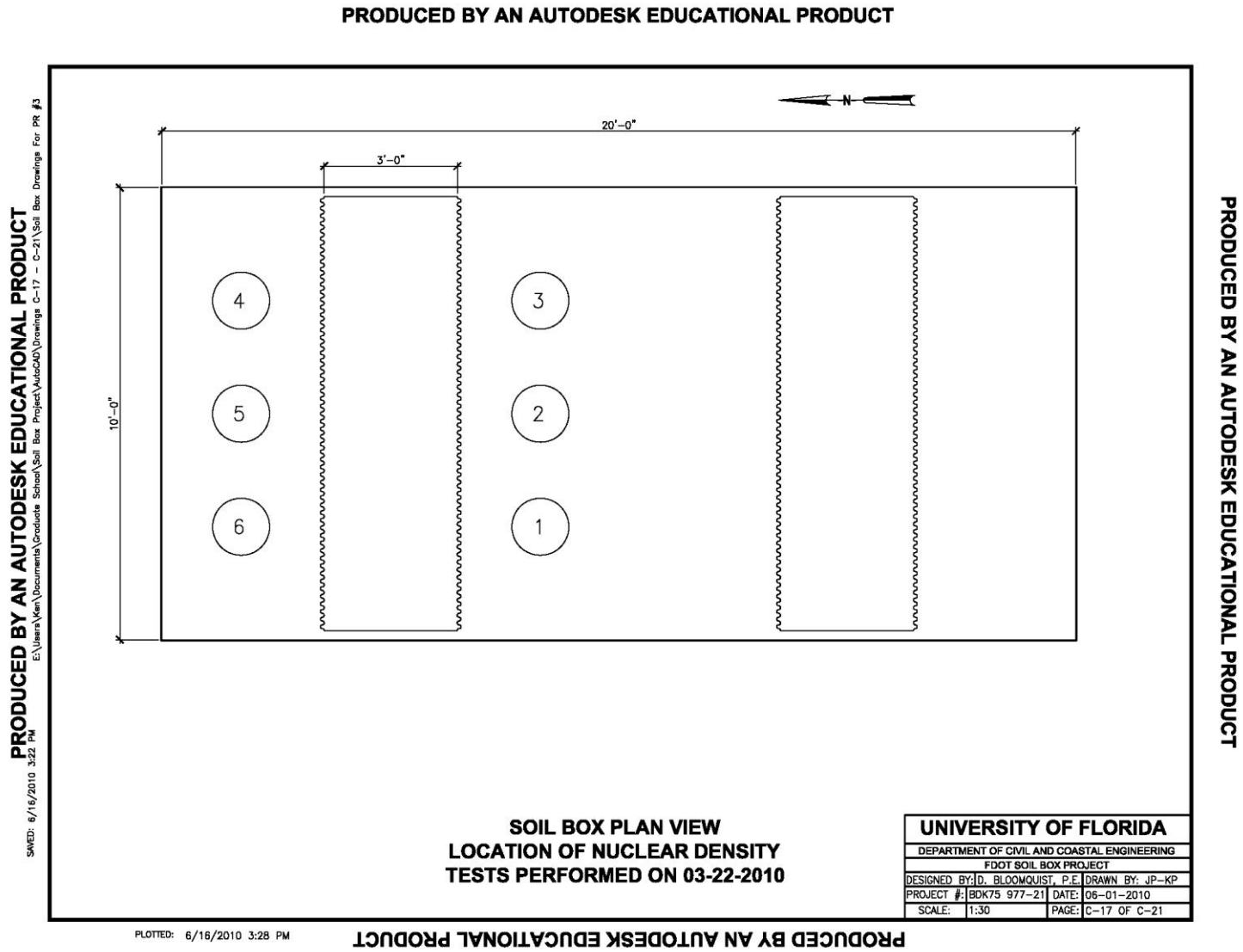

Figure 5-1. Location of nuclear density tests performed on 03-22-2010. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 3 (Page 25). University of Florida, Gainesville, Florida.]

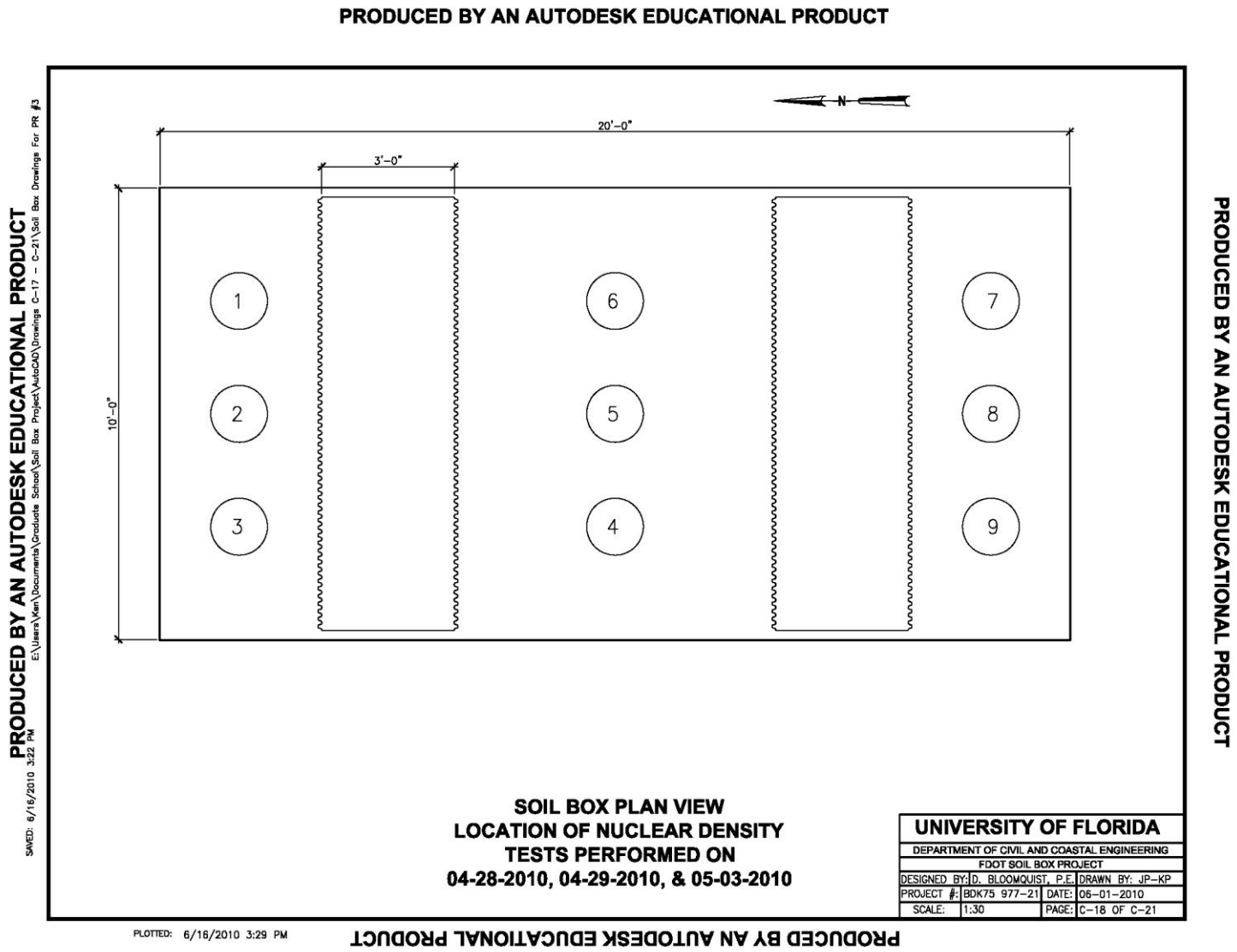

Figure 5-2. Location of additional nuclear density tests. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 3 (Page 26). University of Florida, Gainesville, Florida.]

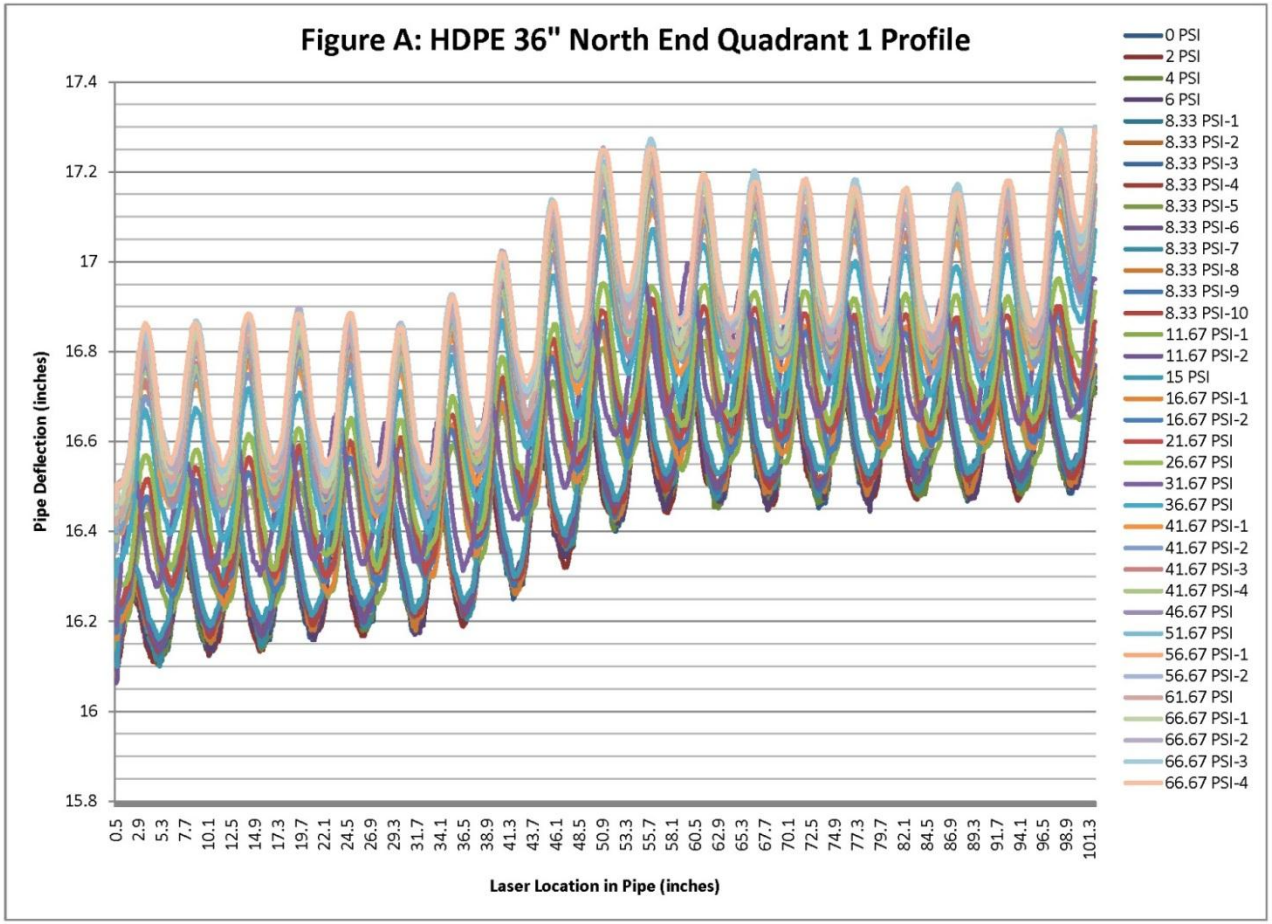

Figure 5-3. HDPE 36” North End Quadrant 1 Profile. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 20). University of Florida, Gainesville, Florida.]

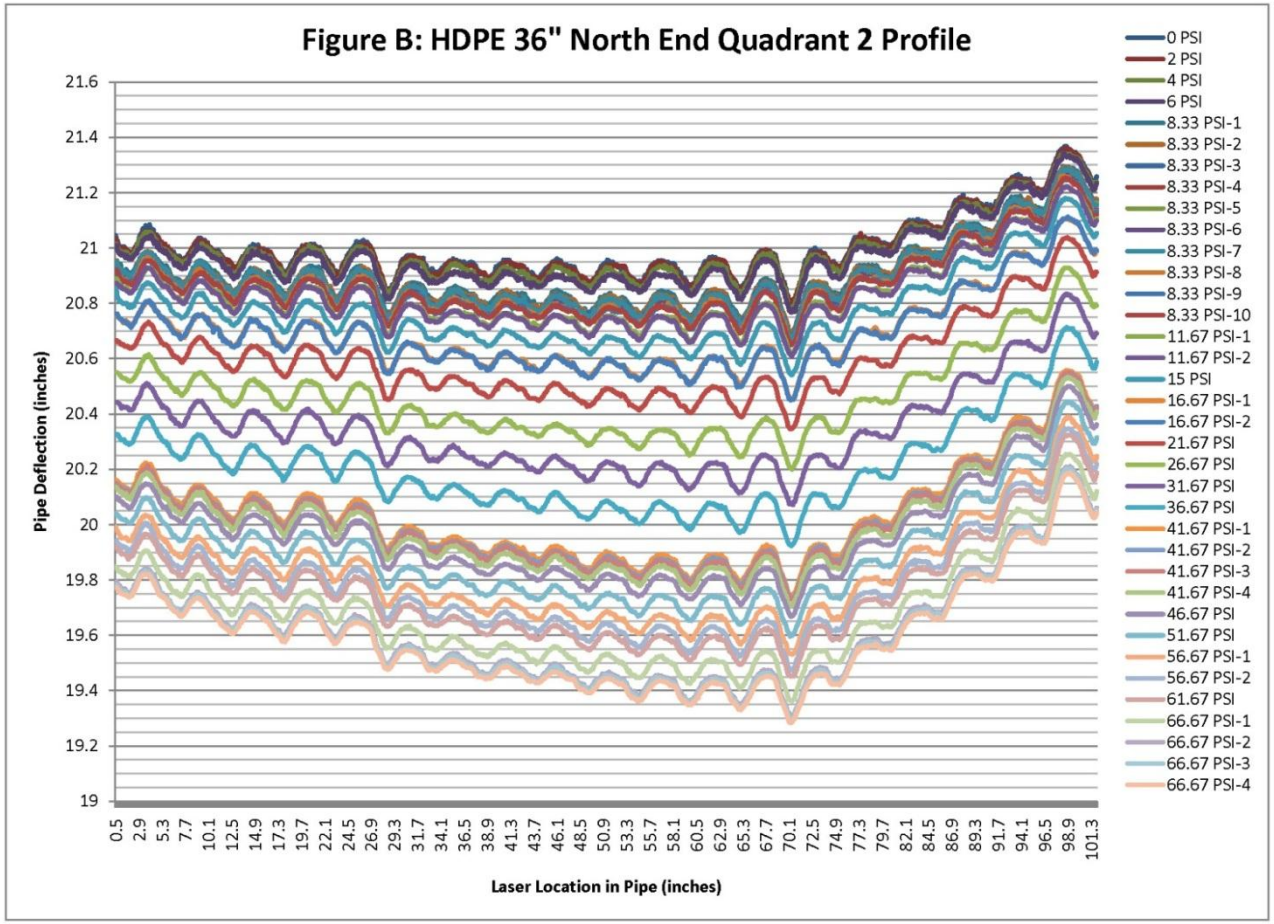

Figure 5-4. HDPE 36” North End Quadrant 2 Profile. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 21). University of Florida, Gainesville, Florida.]

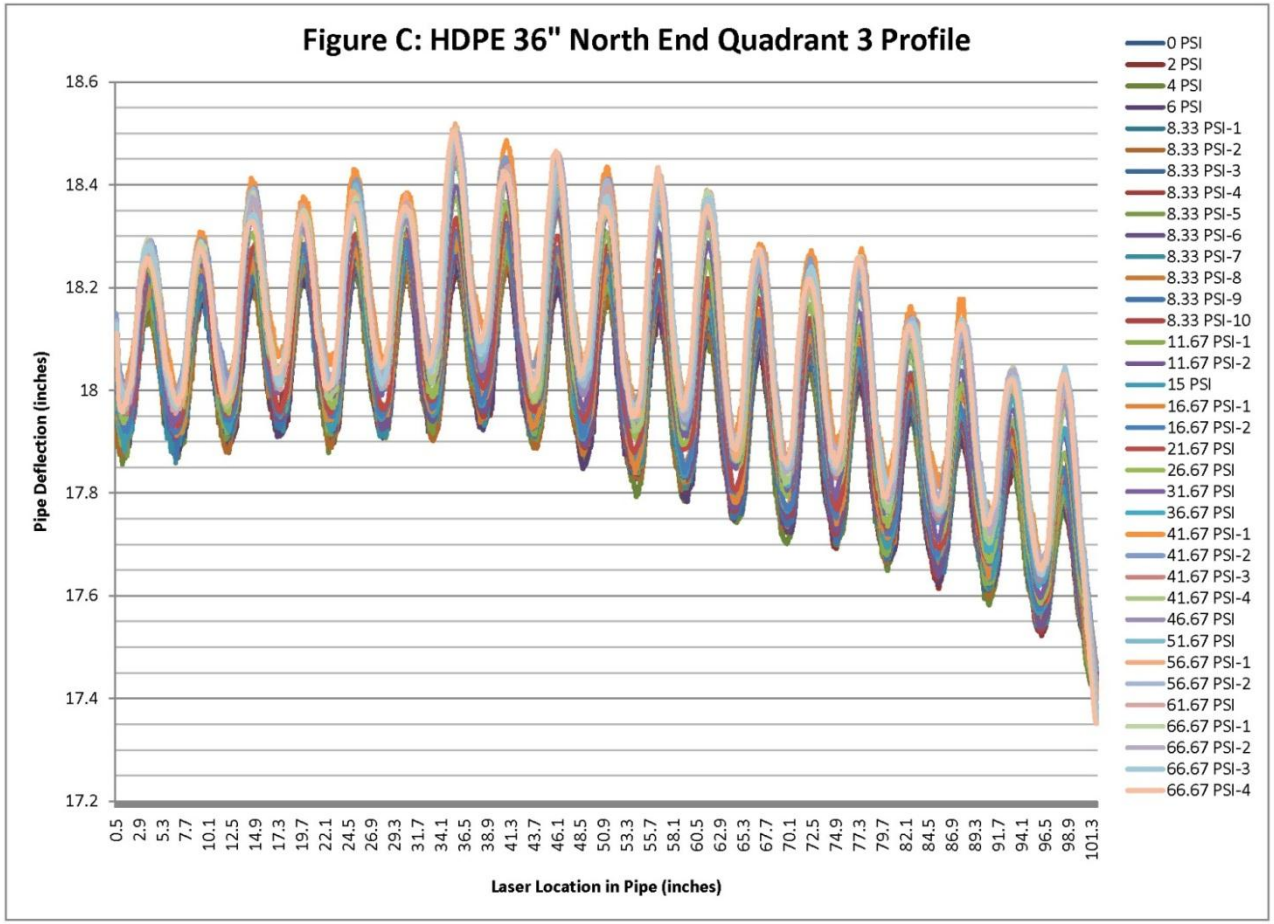

Figure 5-5. HDPE 36” North End Quadrant 3 Profile. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 22). University of Florida, Gainesville, Florida.]

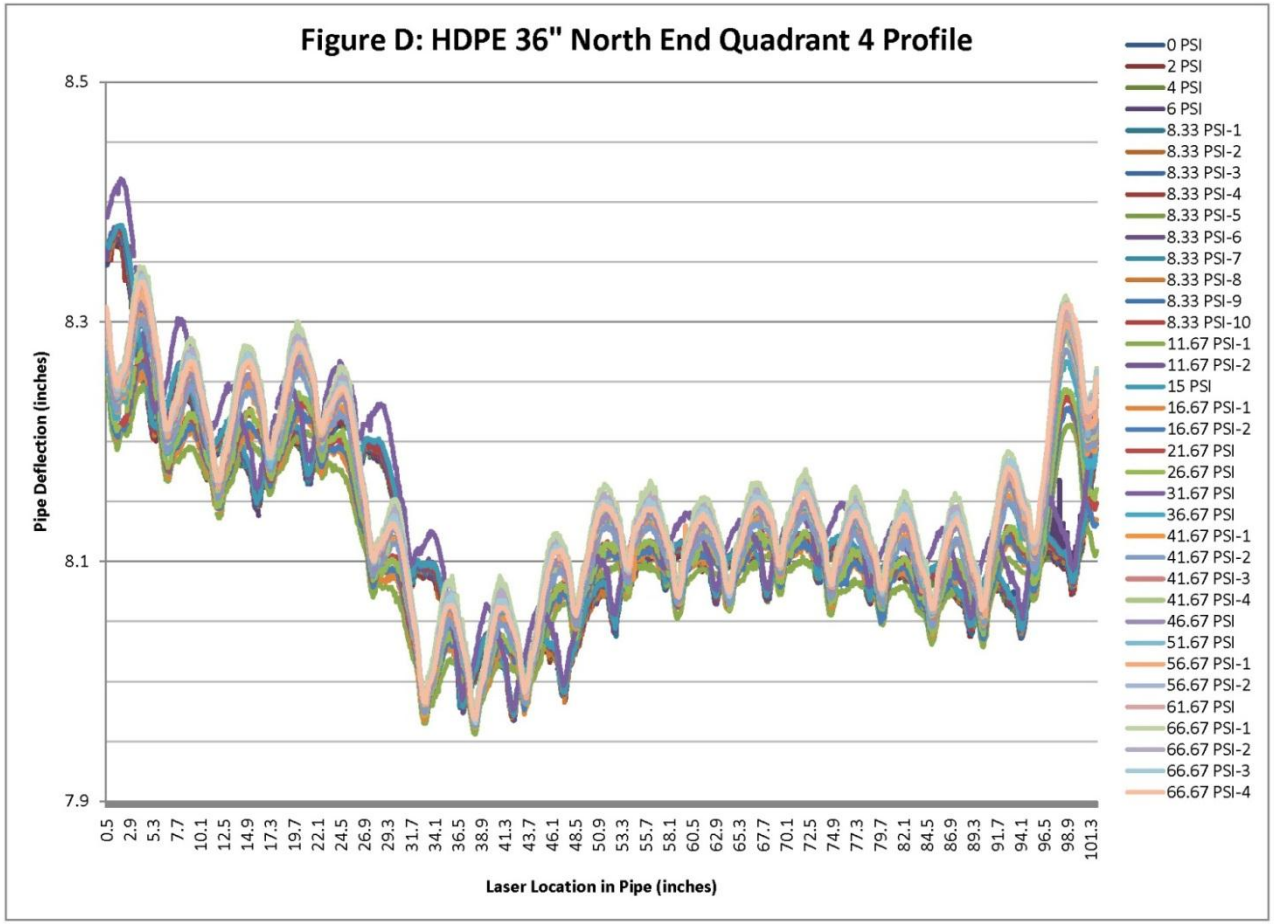

Figure 5-6. HDPE 36” North End Quadrant 4 Profile. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 23). University of Florida, Gainesville, Florida.]

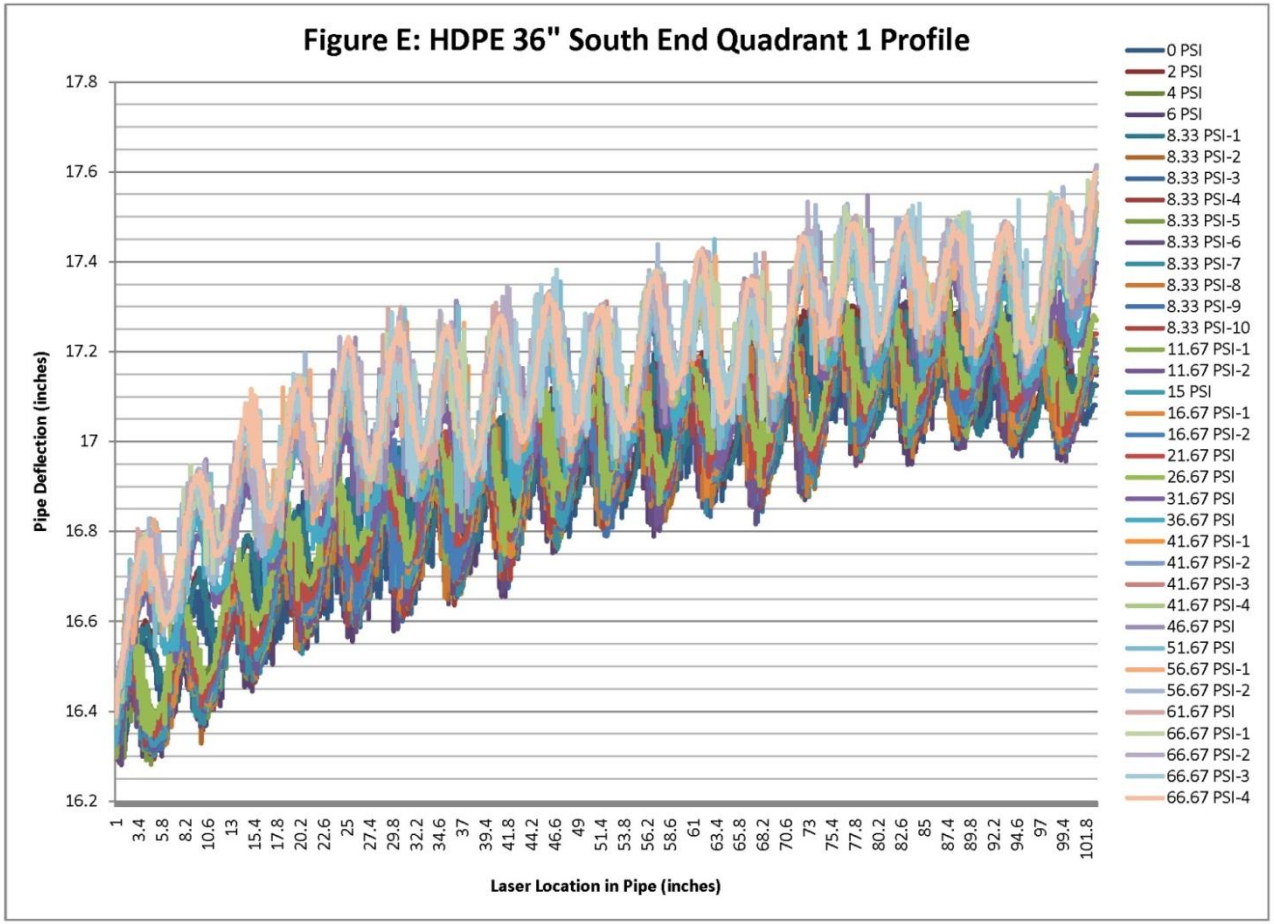

Figure 5-7. HDPE 36” South End Quadrant 1 Profile. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 24). University of Florida, Gainesville, Florida.]

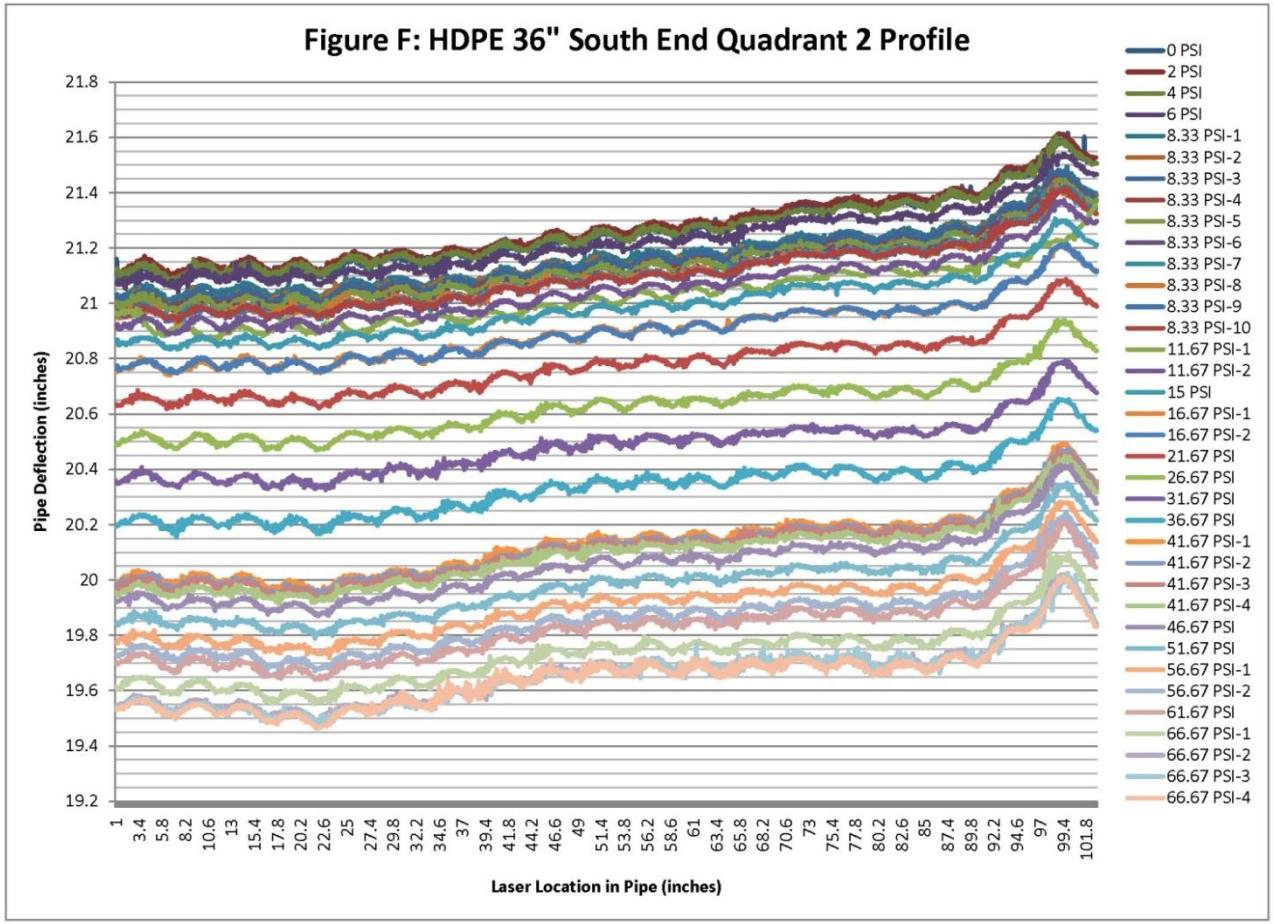

Figure 5-8. HDPE 36” South End Quadrant 2 Profile. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 25). University of Florida, Gainesville, Florida.]

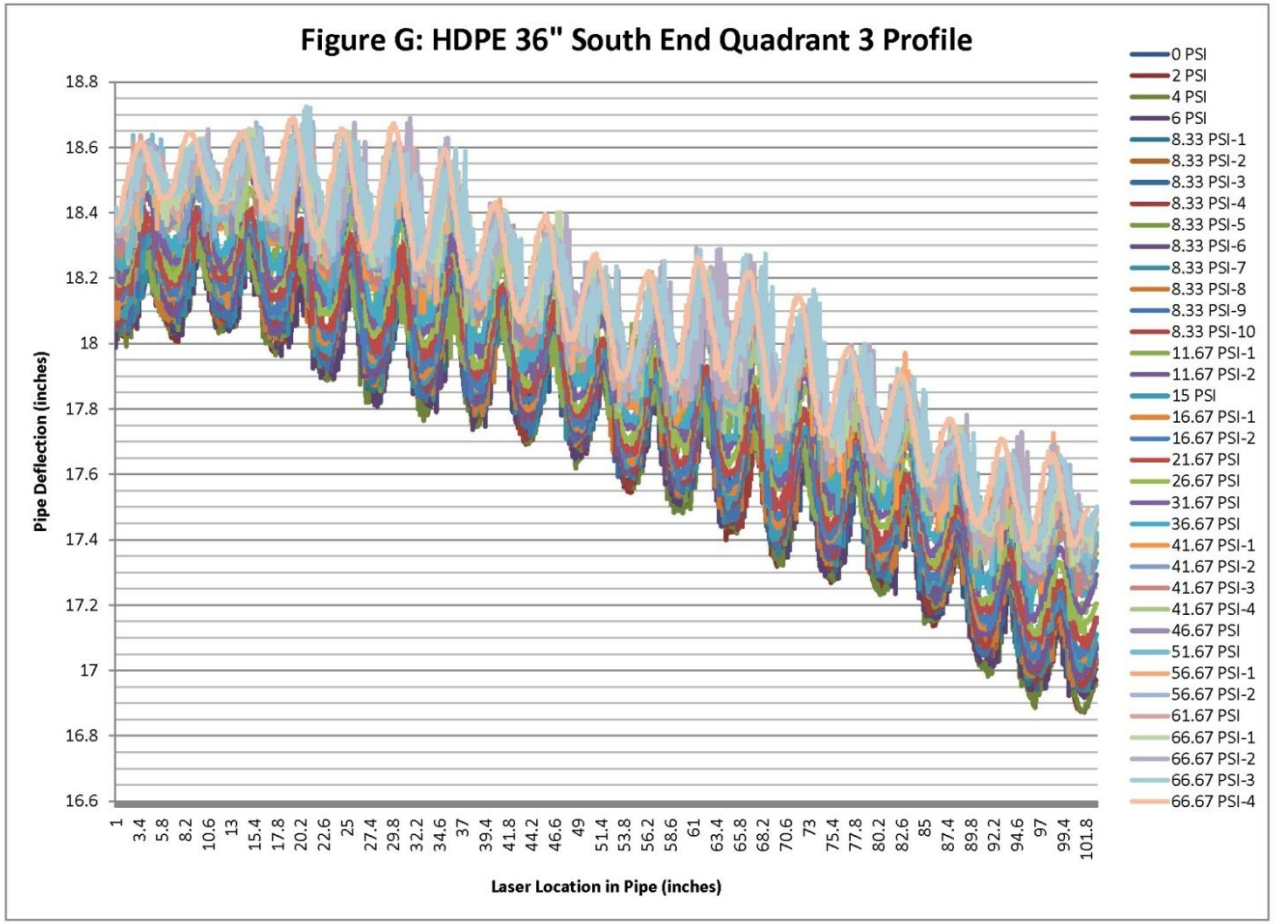

Figure 5-9. HDPE 36” South End Quadrant 3 Profile. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 26). University of Florida, Gainesville, Florida.]

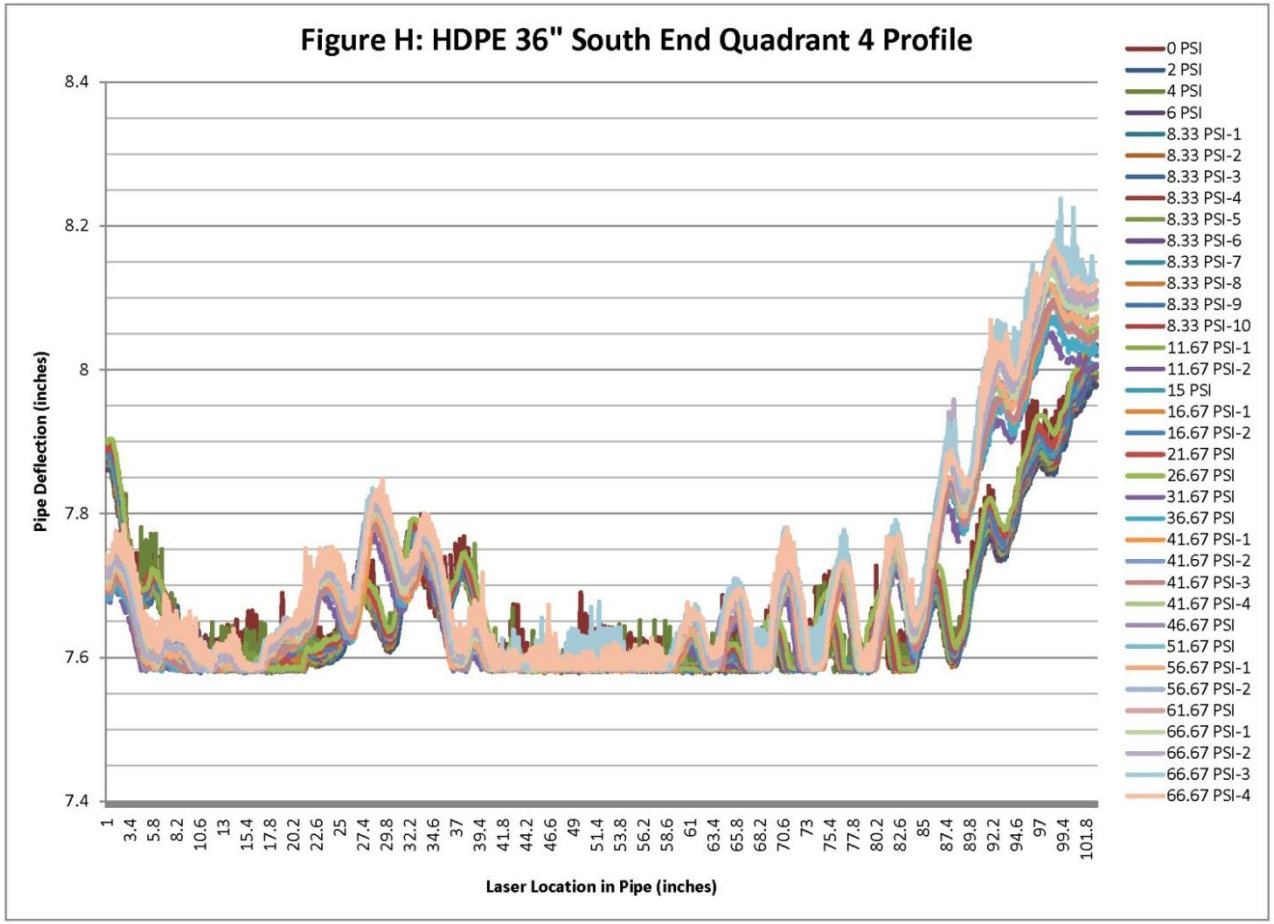

Figure 5-10. HDPE 36” South End Quadrant 4 Profile. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 27). University of Florida, Gainesville, Florida.]

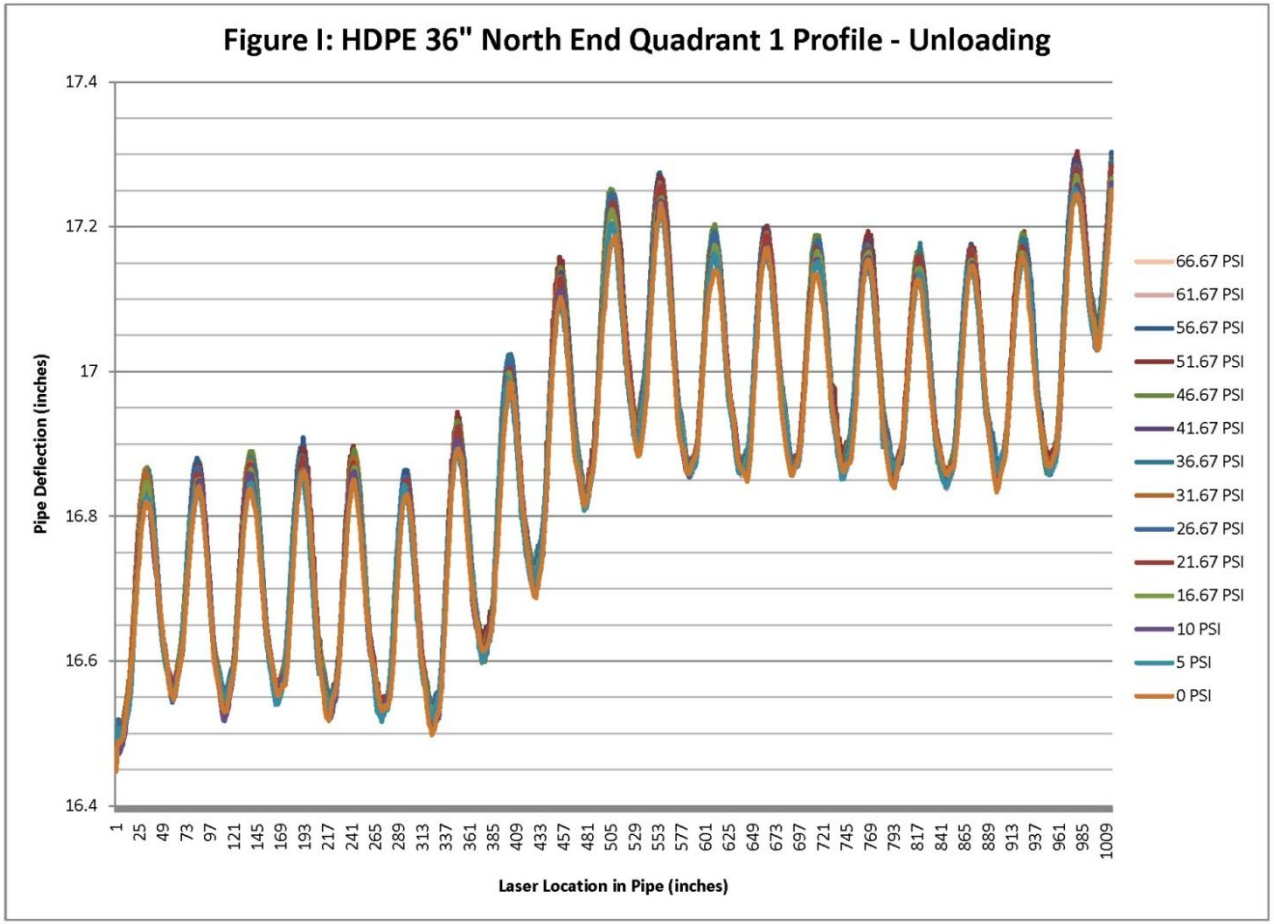

Figure 5-11. HDPE 36” North End Quadrant 1 Profile - Unloading. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 28). University of Florida, Gainesville, Florida.]

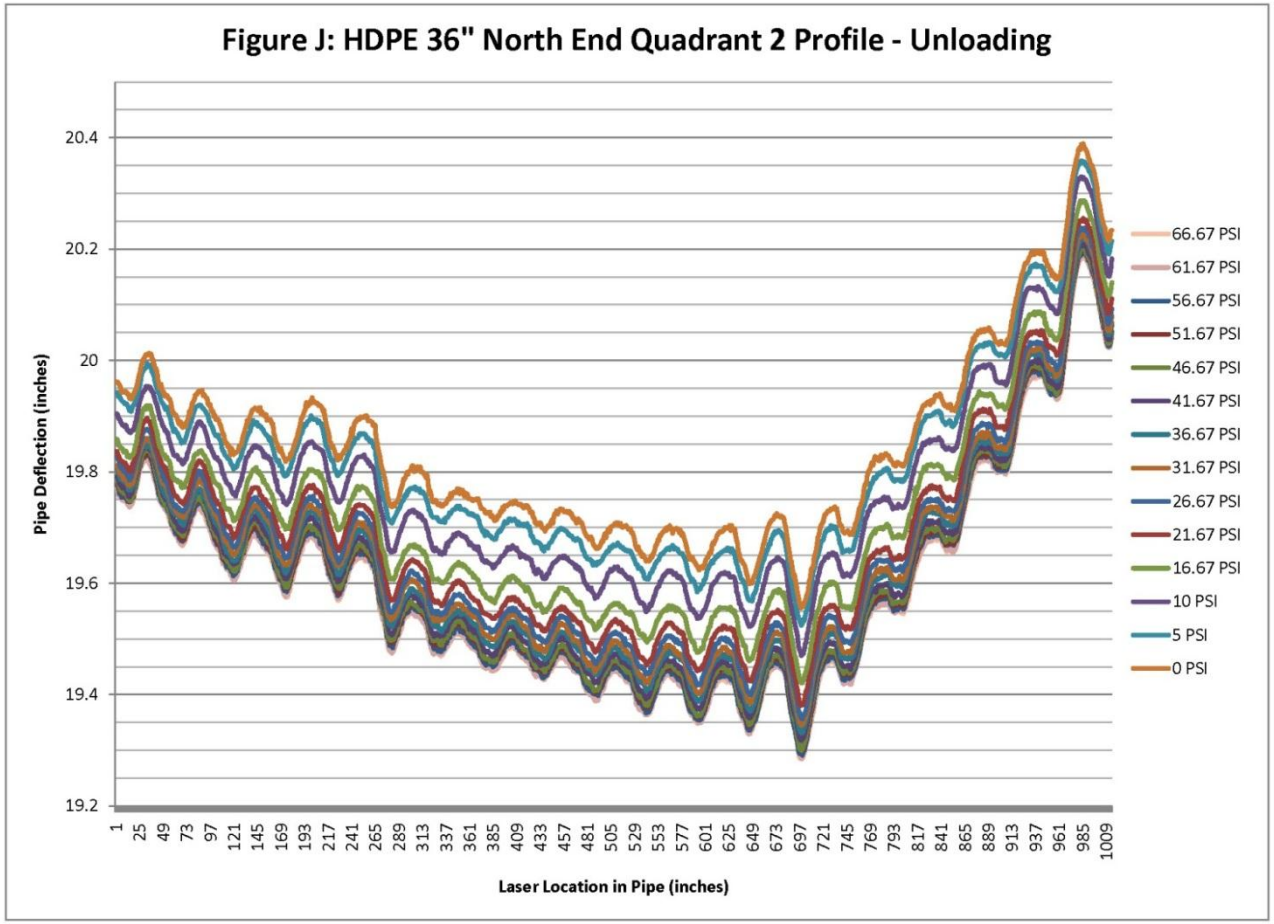

Figure 5-12. HDPE 36” North End Quadrant 2 Profile - Unloading. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 29). University of Florida, Gainesville, Florida.]

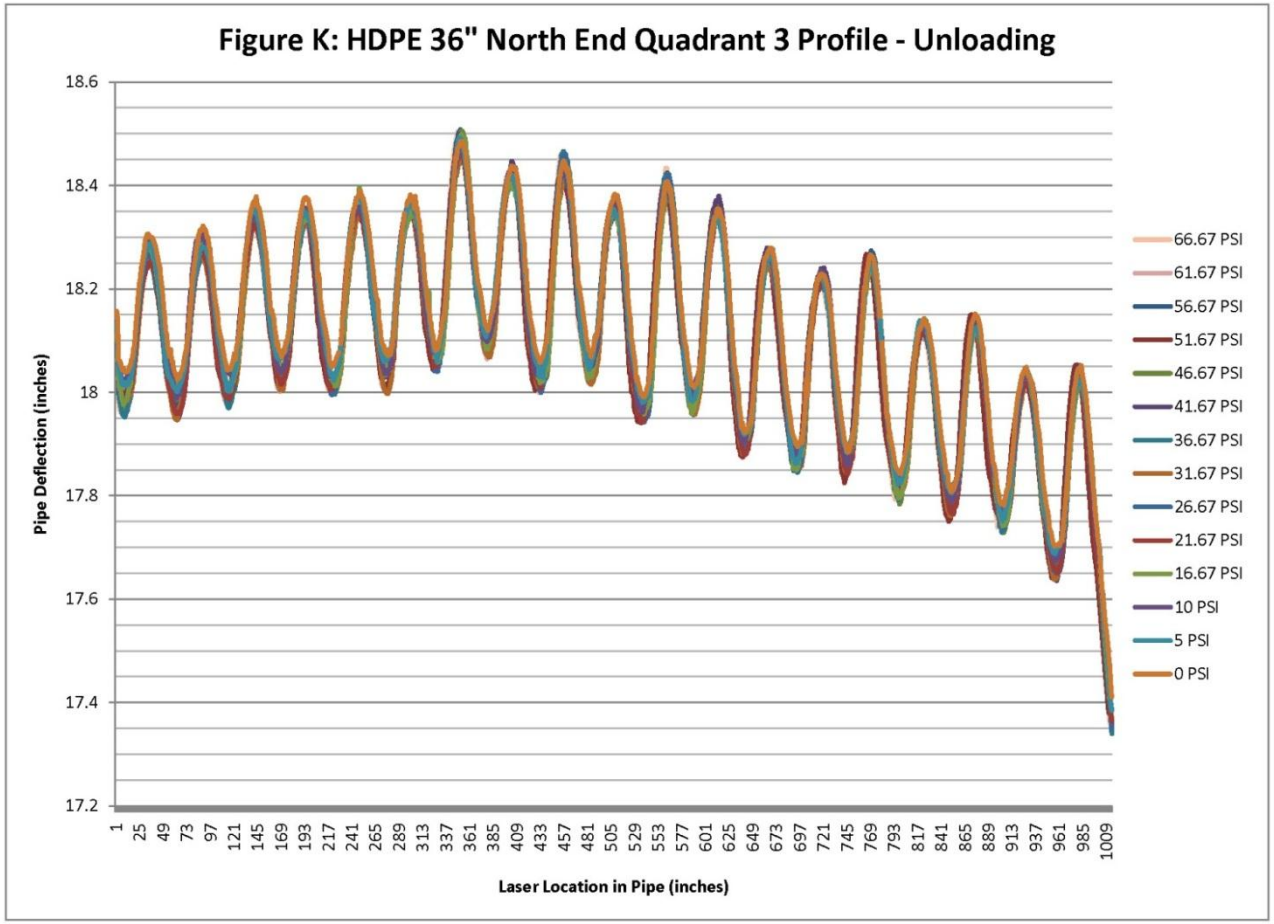

Figure 5-13. HDPE 36” North End Quadrant 3 Profile - Unloading. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 30). University of Florida, Gainesville, Florida.]

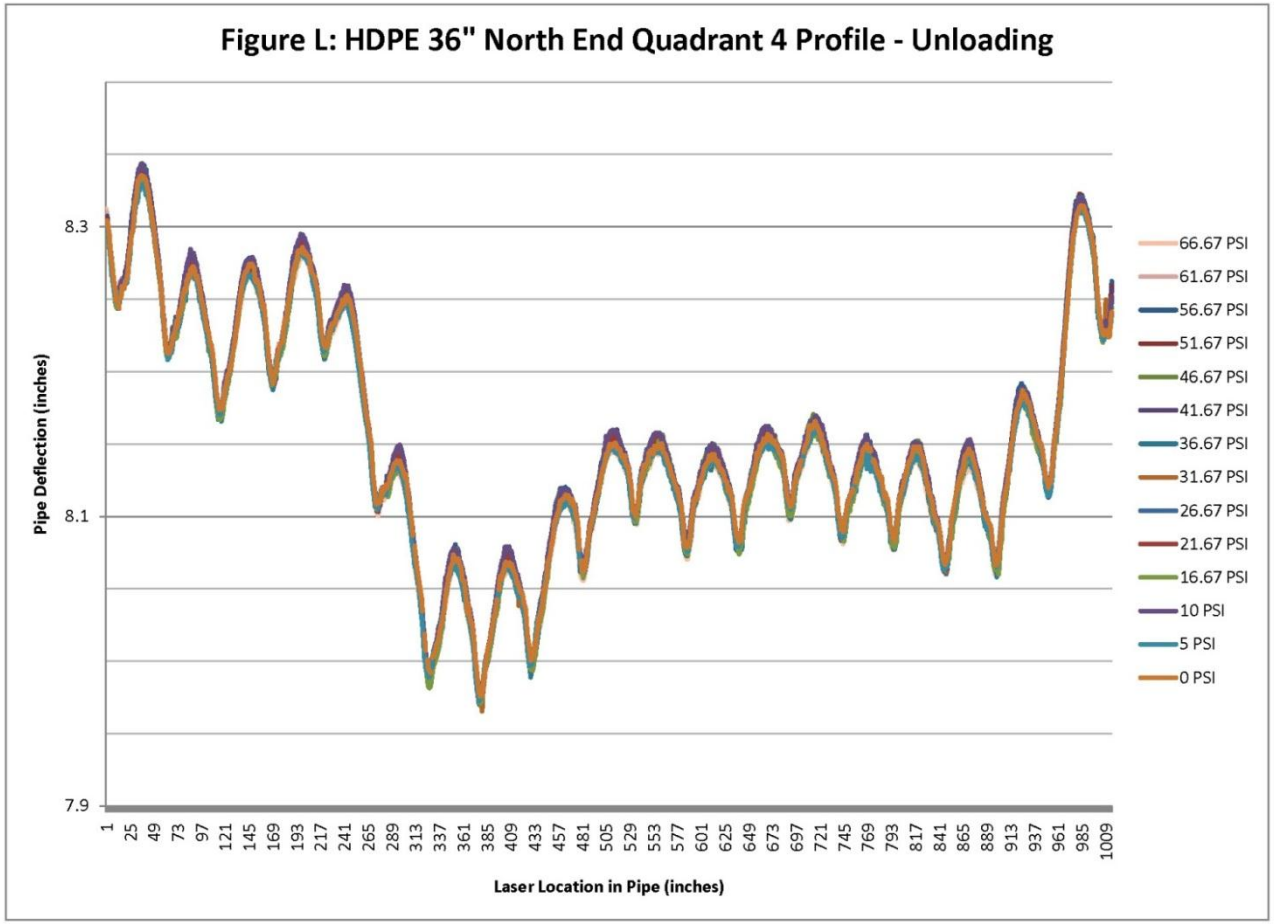

Figure 5-14. HDPE 36” North End Quadrant 4 Profile - Unloading. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 31). University of Florida, Gainesville, Florida.]

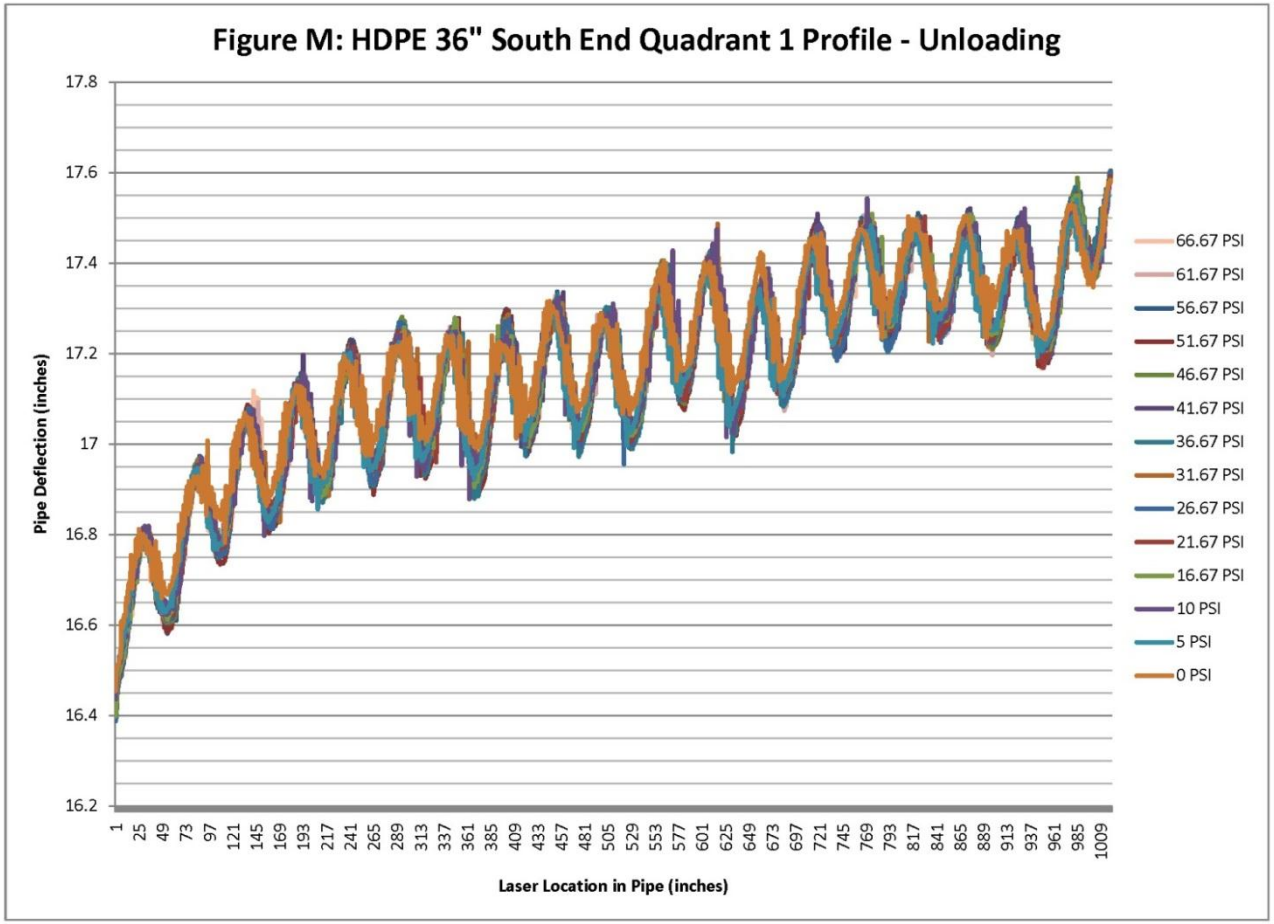

Figure 5-15. HDPE 36” South End Quadrant 1 Profile - Unloading. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 32). University of Florida, Gainesville, Florida.]

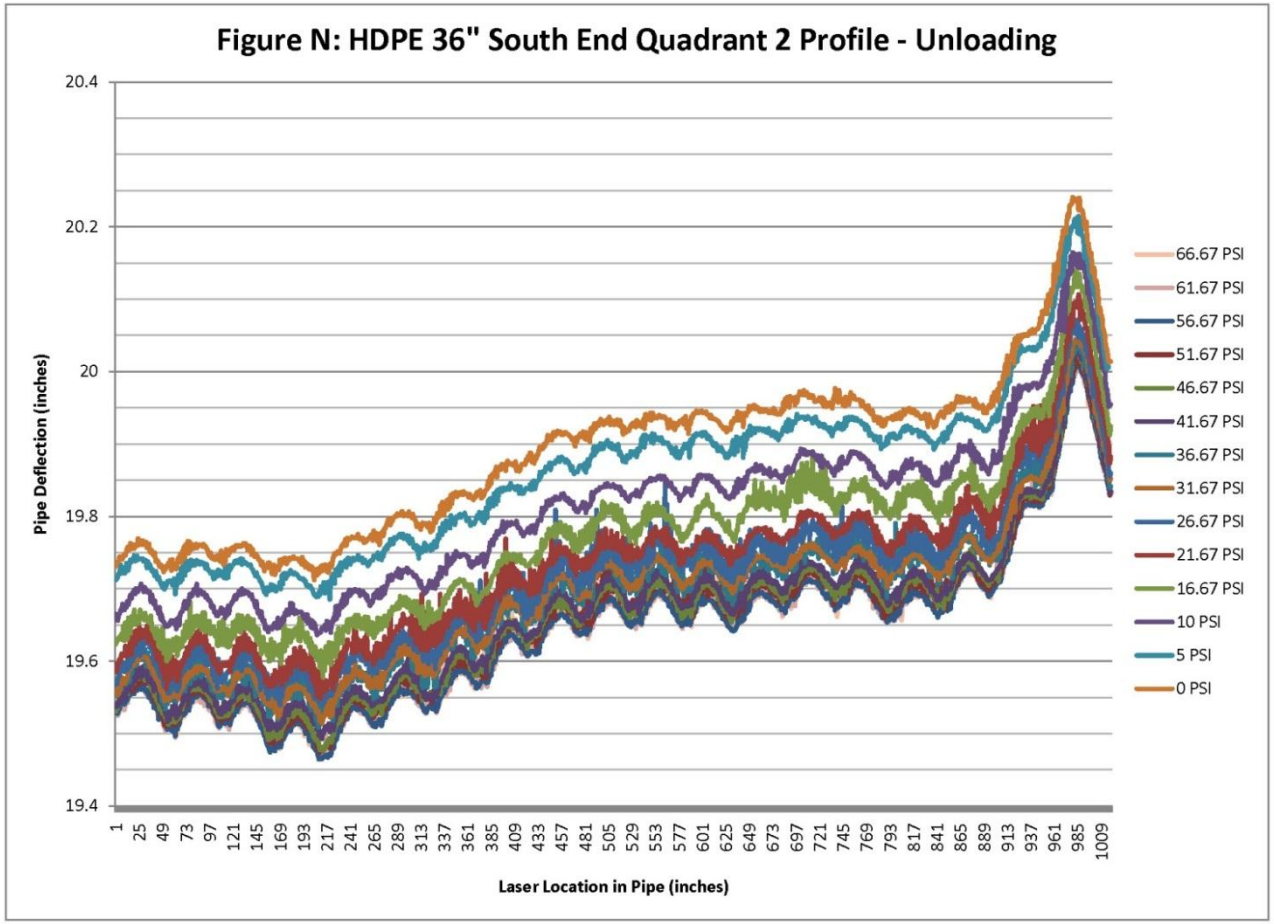

Figure 5-16. HDPE 36” South End Quadrant 2 Profile - Unloading. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 33). University of Florida, Gainesville, Florida.]

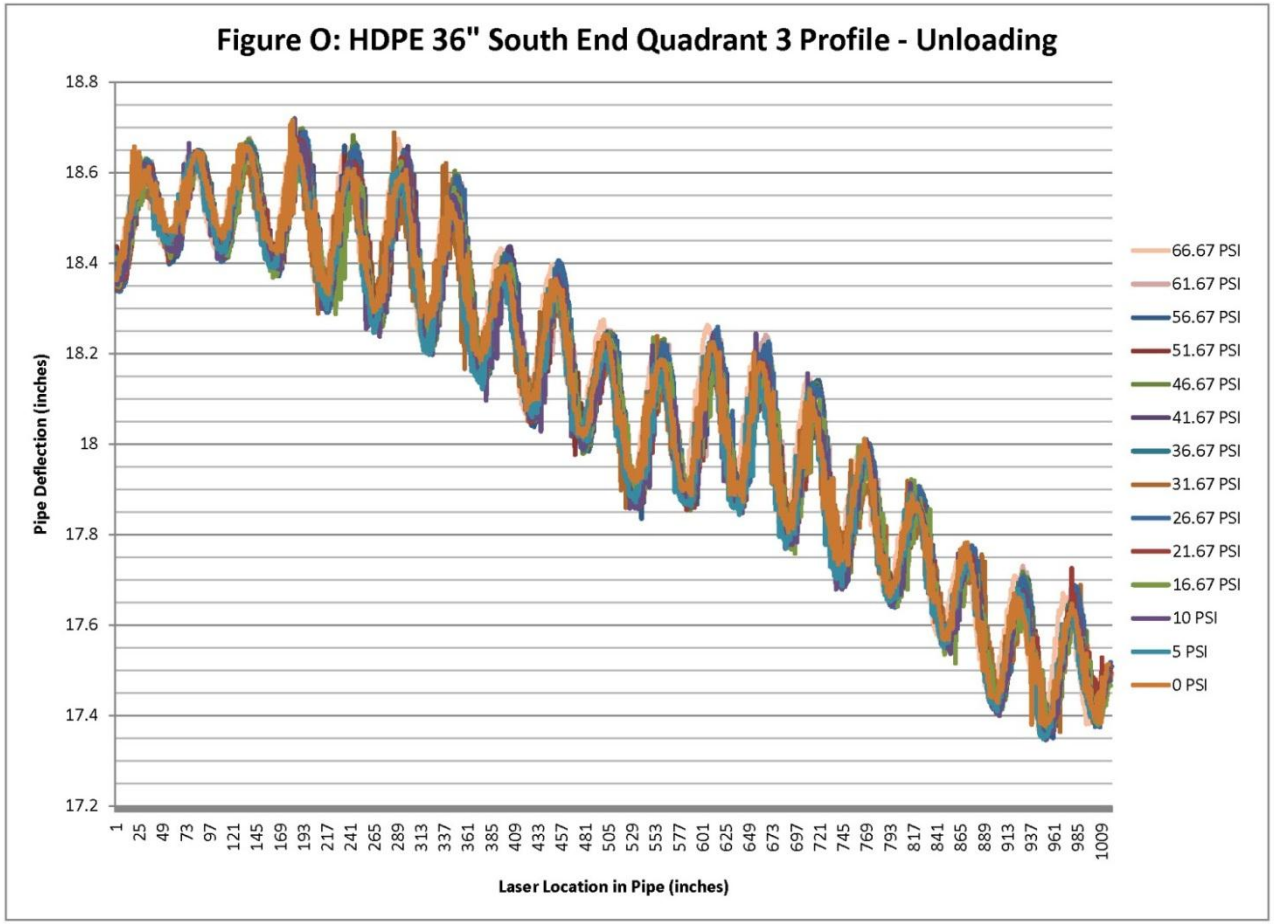

Figure 5-17. HDPE 36” South End Quadrant 3 Profile - Unloading. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 34). University of Florida, Gainesville, Florida.]

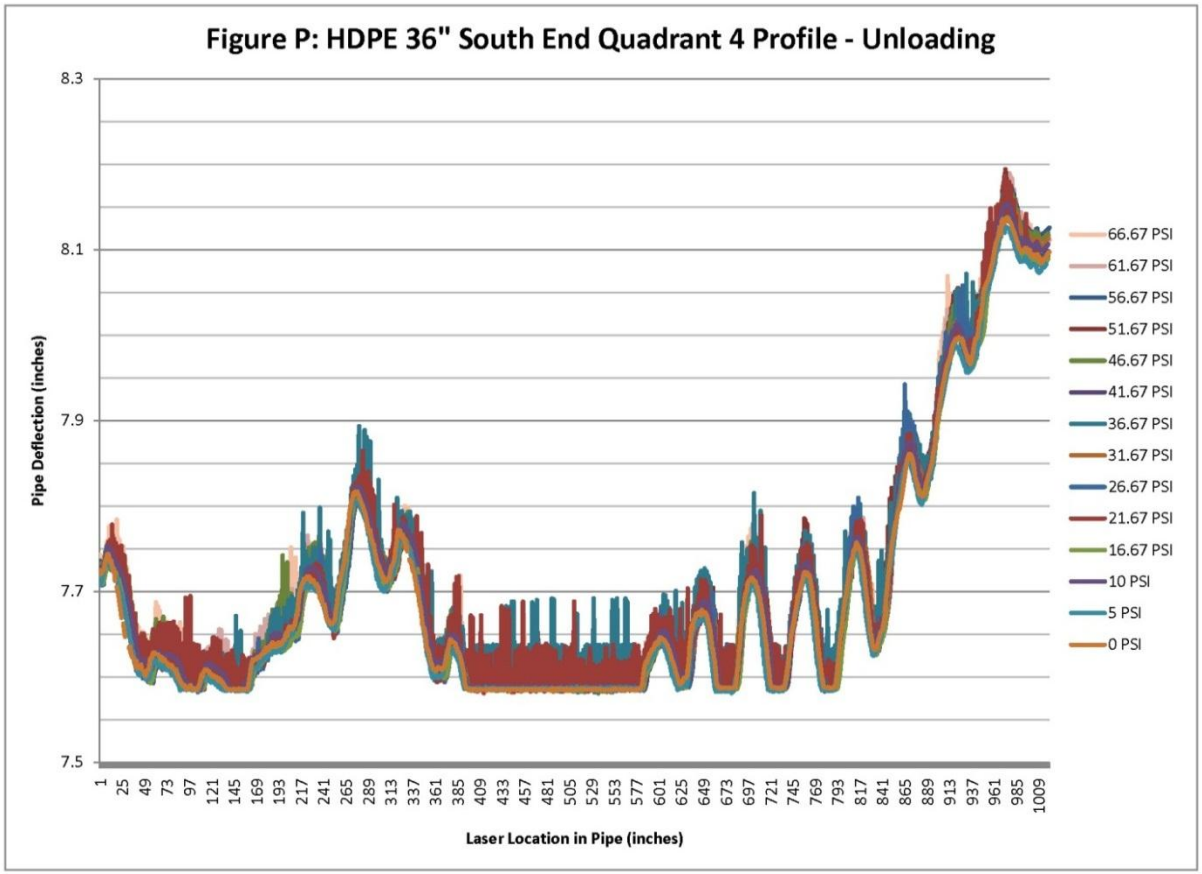

Figure 5-18. HDPE 36” South End Quadrant 4 Profile - Unloading. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 35). University of Florida, Gainesville, Florida.]

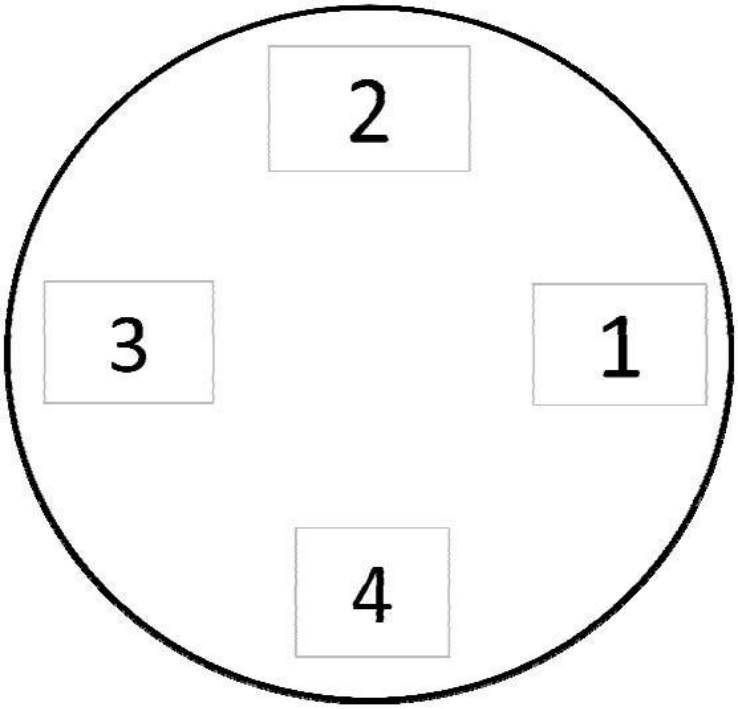

Figure 5-19. Quadrant orientations, viewing from East end to West end. [Reprinted with permission from Bloomquist, D. G. 2010. BDK75 977-21 Progress Report 4 (Page 18, Figure 19). University of Florida, Gainesville, Florida.]

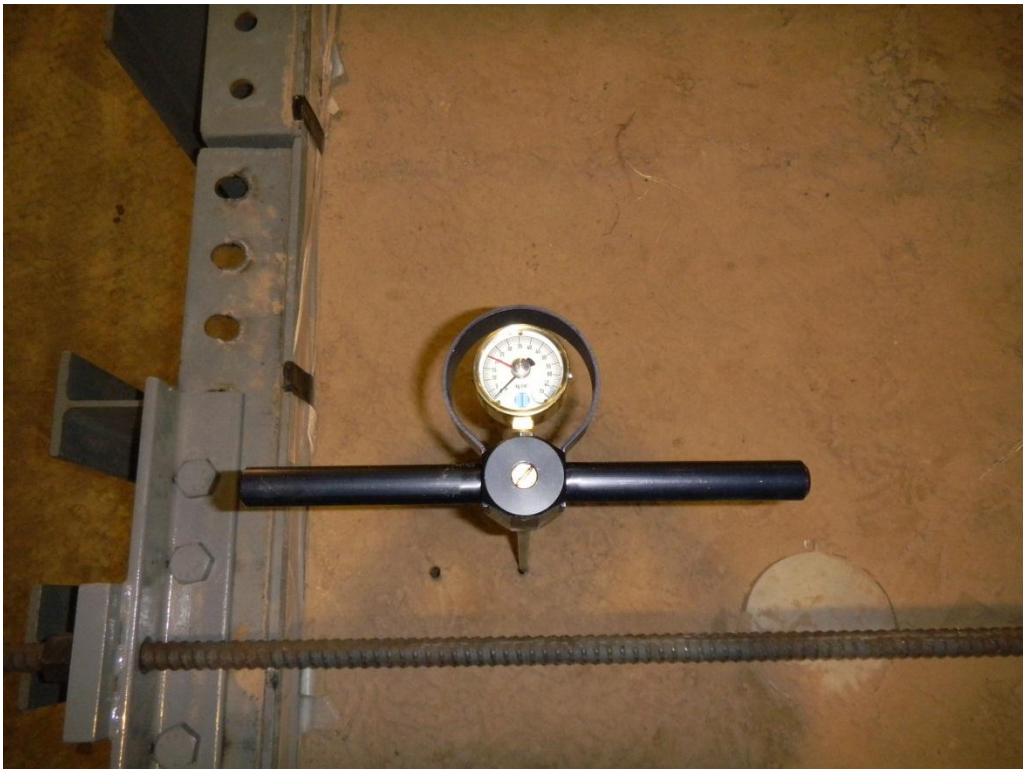

Figure 5-20. Cone penetrometer testing apparatus. Photo credit: K. Pasken.

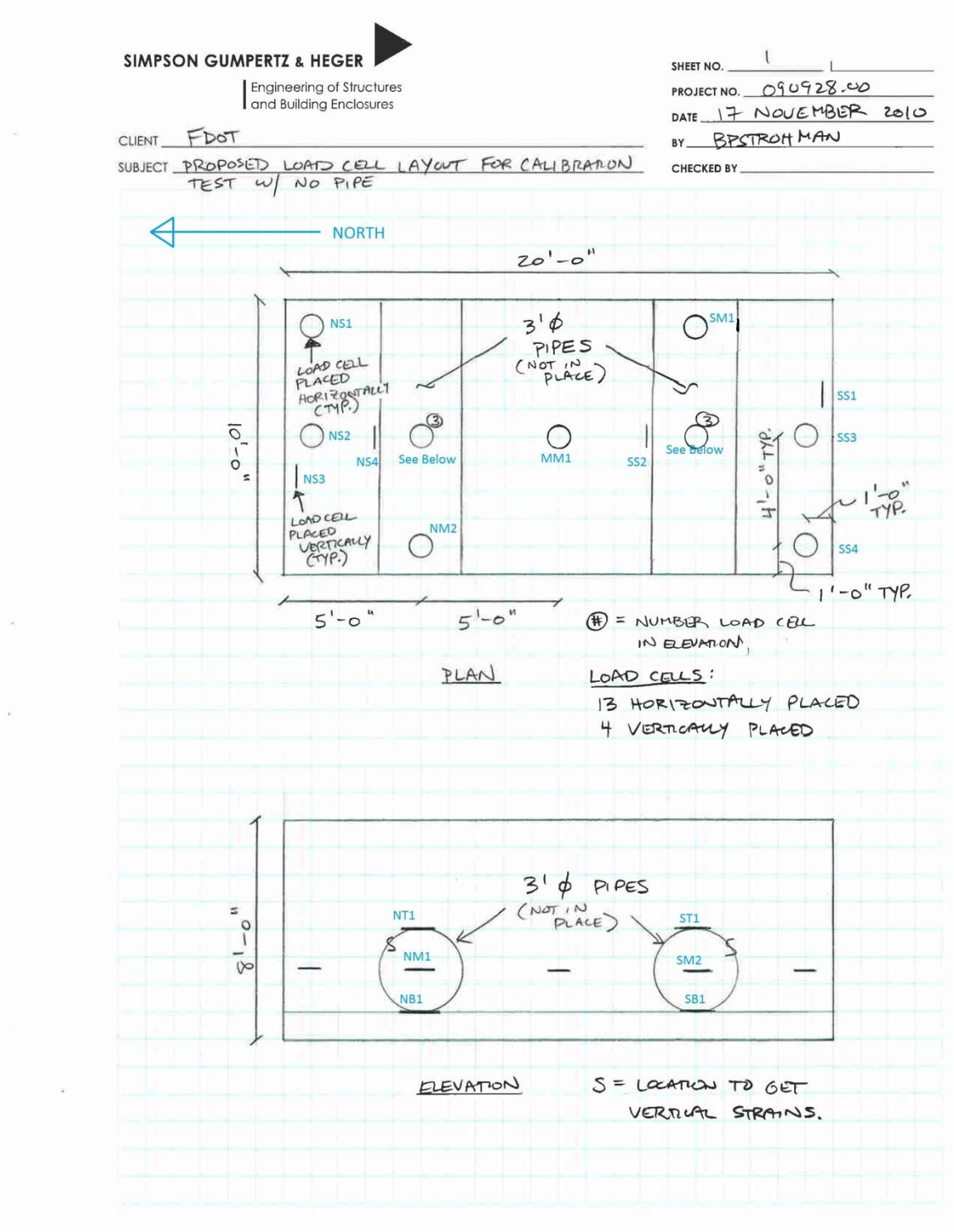

Figure 5-21. Earth pressure cell layout for calibration test, with naming convention. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 37). University of Florida, Gainesville, Florida.]

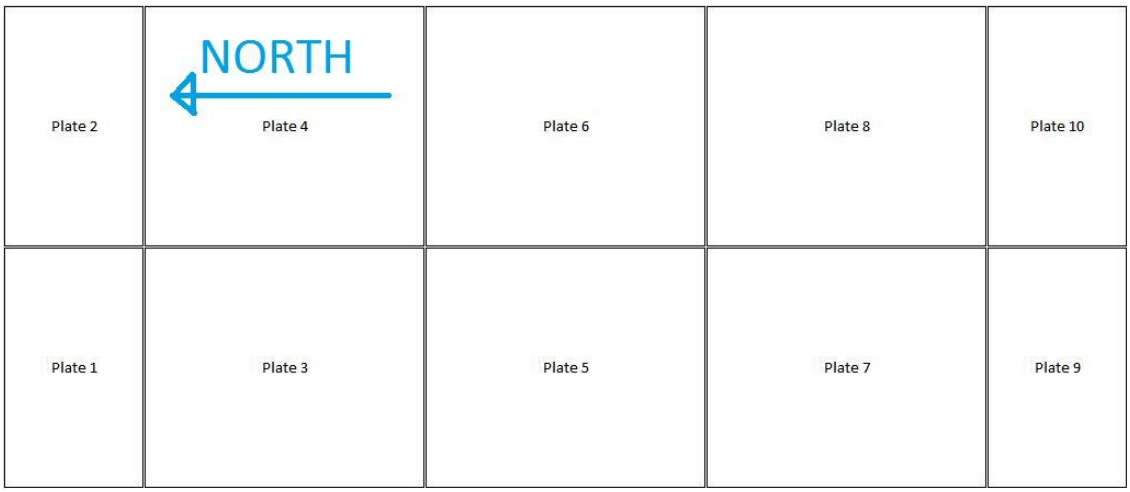

Figure 5-22. Name convention for earth pressure cells beneath plates. [Reprinted with permission from Bloomquist, D. G. 2011. BDK75 977-21 Progress Report 5 (Page 37). University of Florida, Gainesville, Florida.]

CHAPTER 6
CONCLUSION

At the time of this thesis being written, two modifications were being made to how the calibration test was going to be performed. The calibration test had been started, and the soil box was pressurized to 15 psi. A cursory review of the data from the earth pressure cells revealed that the pressures being recorded beneath the four smaller load plates were much less than those underneath the six bigger load plates.

A great deal of discussion prompted the following changes to be made: the ten earth pressure cells located beneath the center of the load plates would be embedded six inches beneath the soil surface. This would ensure that no errant readings would be output because of metal on metal forces between the earth pressure cells and the load plates. Secondly, the four smaller lift bags would be connected to a separate air supply, allowing for higher pressurization of the smaller bags. In this way, the pressure being applied to the four smaller bags will be increased to a level where the pressures felt beneath the ten load plates will all be about the same. Because of the larger contact area present with the larger lift bags, the larger lift bags will not have to have as much pressure applied into them to exert the same pressure as the smaller lift bags.

The data recorded and analyzed thus far shows very small pipe deflections in the HDPE pipe material. Although this can be attributed to the discrepancy between applied and actual pressures, it is unlikely that the deflections will become much greater. Since the HDPE pipe material is the softest of the four materials being tested, the assumption of the other pipe materials barely deflecting is being explored. If this is the case, there is the possibility of not having to test the aluminum and stainless steel pipe materials.

This research will prove to be very helpful in the making of guidelines for flexible pipe manufacturing. The goal is to be able to have a product which can withstand a variety of loading conditions, while at the same time operating effectively for the service life of the material. The FEM analysis to be performed will be instrumental in simulating many different loading conditions so that such guidelines may be accurately provided.

APPENDIX
LITERATURE REVIEW

An ongoing literature review is taking place throughout the duration of this project. The following pieces of literature, along with the references listed on the next page, have been reviewed as they pertain to the tasks being carried out.

Brachman, R. W. I., Moore, I. D., and Rowe, R. K. (2001). "The Performance of a Laboratory Facility for Evaluating the Structural Response of Small Diameter Buried Pipes." *Can. Geotech. J.*, 38, 260-75.

CleanFlow Systems (2010). "Analyzing the Accuracy of Profiler Equipment and Software."

CleanFlow Systems (2010). "Profiler Reporting For Flexible Pipes."

Moser, A. P. (2001). “Buried Pipe Design.” Second Edition. McGraw-Hill. New York, NY.

Palmer, M. (2005). "Results of Full-Scale Test on 16-inch HDPE Pipe."

Sargand, S. M., and Masada, T. (2002). "Soil Arching Over Deeply Buried Thermoplastic Pipe."

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Bloomquist, D. G. (2010). “BDK75 977-21 Progress Report 2.” University of Florida, Gainesville, FL.

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Bloomquist, D. G. (2010). “BDK75 977-21 Progress Report 4.” University of Florida, Gainesville, FL.

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Brachman, R. W. I., Moore, I. D., and Rowe, R. K. (1996). "Interpretation of Buried Pipe Test: Small-Diameter Pipe in Ohio University Facility." *Transportation Research Record 1541*, 64-75.

Brachman, R. W. I., Moore, I. D., and Rowe, R. K. (2000). "The Design of a Laboratory Facility for Evaluating the Structural Response of Small-Diameter Buried Pipes." *Can. Geotech. J.*, 37, 281-95.

Motahari, A., and Forteza, J. G. (2008). "Accuracy of Laser Profiling of Flexible Pipes Using CUES System." University of Texas, Arlington, TX.

Smith, M. E., Beck, A., Thiel, R., and Metzler, P. (2005). "Designing for Vertical Pipe Deflection Under High Loads."

BIOGRAPHICAL SKETCH

Kenneth Andrew Pasken was born in 1987 in Miami, Florida. The youngest of three children, he grew up in Miami, Florida, graduating from Christopher Columbus High School in 2005. He held a perfect attendance record throughout his four years in high school, in addition to being a member of a variety of honor societies. He decided to continue his educational career at the University of Florida, pursuing an undergraduate degree in civil engineering with a minor in business administration.

Throughout the summer months of his undergraduate college career, Kenneth worked as an intern with Pistorino & Alam Consulting Engineers, Inc. based out of Miami, FL. He performed a variety of duties, assisting members of inspection teams with whatever was necessary, including taking pictures, taking measurements, drawing up site sketches, reading building plans, researching building and fire safety codes, and performing other engineering related tasks.

Going to school during the fall and spring months, then working and taking classes for his minor in business administration during the summer months, proved to be challenging but well worth the time invested. Kenneth earned his Bachelor of Science degree in civil engineering with a minor in business administration in December of 2009. He had already decided during the fall of 2009 to pursue a master's degree in civil engineering at the University of Florida. He will earn his Master of Engineering degree in civil engineering in May of 2011.

Upon successful completion of his master's degree, Kenneth will be seeking employment in the field of civil engineering, with interests in the geotechnical, structural, and transportation disciplines.