# RESPONSE OF FLEXIBLE PIPE SUBJECTED TO INCREASING OVERBURDEN STRESS

By

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To my mother and father

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I thank Dr. David Bloomquist and Dr. Raphael Crowley for aiding my development as a researcher and engineer. I thank the Coastal Engineering Laboratory personnel, especially Ryan Mackey and Vik Adams, for their hard work and dedication to my project. Finally, I thank my wife, Carrie Pimentel, who has supported me endlessly throughout my undergraduate and graduate school education.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| FDOT | Florida Department of Transportation |
| FEM | Finite Element Modeling |
| HDPE | High Density Polyethylene |
| OSHA | Occupational Safety and Health Administration |
| PSI | Pounds per Square Inch |
| PVC | Polyvinyl Chloride |
| SGH | Simpson, Gumpertz, and Heger |

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

# RESPONSE OF FLEXIBLE PIPE SUBJECTED TO INCREASING OVERBURDEN STRESS

By

Victor Konn

May 2013

Chair: Robert J. Thieke
Major: Civil Engineering

For flexible pipes installed under roadways, the Florida Department of Transportation requires inspection when backfill reaches 3 feet above the pipe crown or after placement of the stabilized subgrade. This research aims to help identify pipes whose deflections are within the 5% specification tolerance at time of inspection but may ultimately exceed this tolerance at the time of project acceptance. The flexible pipes targeted in this project are HDPE, corrugated aluminum, corrugated steel, and HDPE with trench box installation. These pipes were tested using the Soil Box, a large geotechnical testing enclosure, located at the University of Florida.

# CHAPTER 1
# BACKGROUND

## 1.1 Purpose

For pipes installed under roadways, the Florida Department of Transportation (FDOT) requires inspection when backfill reaches 3 feet above the pipe crown or after placement of the stabilized subgrade (FDOT 2013). The purpose of this project was to assist the Florida Department of Transportation in the understanding of pipe-soil interaction by gathering deflection data of flexible pipes when subjected to overburden stress. These data will ultimately be used to identify pipes whose deflection are within the 5% specification tolerance at the time of inspection but may exceed this tolerance at the time of project acceptance.

## 1.2 Soil Box Design

The steel Soil Box (Figure 1-1) is 20 feet long, 10 feet wide, 8 feet tall, and is capable of testing full scale buried pipes. It is comprised of multiple partitions bolted together and reinforced with I-beams to prevent deflections of less than two millimeters when subjected to a geostatic earth pressure of 118 pounds per square inch (150 ft. of overburden). Observation portals located along the length of the Soil Box allow for monitoring of the pipe's diameter during loading.

## 1.3 Approach

### 1.3.1 Loading Mechanism

The loading mechanism consisted of ten three-quarter inch thick steel plates that lie on the surface of the soil. These plates were overlain by pressurized lift bags that applied simulated overburden pressures. A chain link fence was placed in between the

steel plates and soil surface to help uniformly distribute the stress to the soil. The loading mechanism can be seen in Figures 1-2 and 1-3.

A main regulator fed ten additional regulators that controlled the pressure to the lift bags (Figure 1-4). Six of these regulators controlled the large lift bags and the remaining four controlled the small lift bags.

### 1.3.2 Earth Pressure Cells

Earth pressure cells were strategically placed throughout the Soil Box to measure the stress distribution within the soil during testing. The cell locations varied slightly for each test due to different pipe diameters and the use of trench box installation (trench box installation will be discussed in Chapter 3). These locations are specified for each tested pipe in the chapters that follow. The collected soil pressure data was used in the finite element modeling (FEM) analysis.

### 1.3.3 Soil Displacement

Vertical displacement in the soil was measured using a settlement plate located near each pipe invert. The plate was connected to a string potentiometer that recorded the vertical movement of the soil mass. Soil displacement data was collected to aid in the FEM analysis.

### 1.3.4 Pipe Deflection

Pipe deflection was measured using a laser profiling system consisting of a displacement laser mounted to a fixed trolley. The laser was directed through the pipe such that it measures vertical deflection for each loading increment. The laser profiling system can be seen in Figure 1-5.

### 1.3.5 Simulation of Overburden

Six 42 inch square lift bags and eight 21 inch by 25 inch lift bags were utilized to apply the simulated overburden pressures. Simulated overburden was calculated using pressure data from the earth pressure cells located directly above the pipe crown and from nuclear density test results recorded at various locations within the Soil Box. The location and results of the nuclear density tests are specified for each pipe in the chapters that follow.

### 1.3.6 Boundary Friction

Boundary friction between the soil mass and side walls was minimized by placing two layers of lubricated polyethylene sheet in between the soil-wall interface.

### 1.3.7 Saturation

The soil backfill was saturated with water and drained prior to loading to simulate variable high groundwater conditions expected in Florida. To prevent water from seeping out of the Soil Box during saturation, the interior joints of the Soil Box were sealed using marine-grade sealant. A French drain is placed in the Soil Box to allow drainage after saturation.

### 1.3.8 Flexible Membrane System

The interface between the pipe ends and the Soil Box side walls was sealed using a flexible membrane system. This system was comprised of a rigid steel angle bolted to the Soil Box wall, two steel hose clamps, and a flexible rubber membrane. This prevented soil and water from escaping through the observation portals while allowing the pipe to deflect freely. This system can be seen in Figures 1-6 and 1-7.

### 1.3.9 Finite Element Modeling

Using data collected as part of this study, Dr. Timothy McGrath of Simpson, Gumpertz, and Heger (SGH) is programming a finite-element model (FEM) to simulate Soil Box conditions using ABAQUS. Results from this computational model will be presented in a future FDOT publication.

## 1.4 Basis of Development

The development of the Soil Box design and testing approach were based on tests previously performed in a laboratory setting (Brachman et al. 2000 and 2001).

## 1.5 Previous Tests

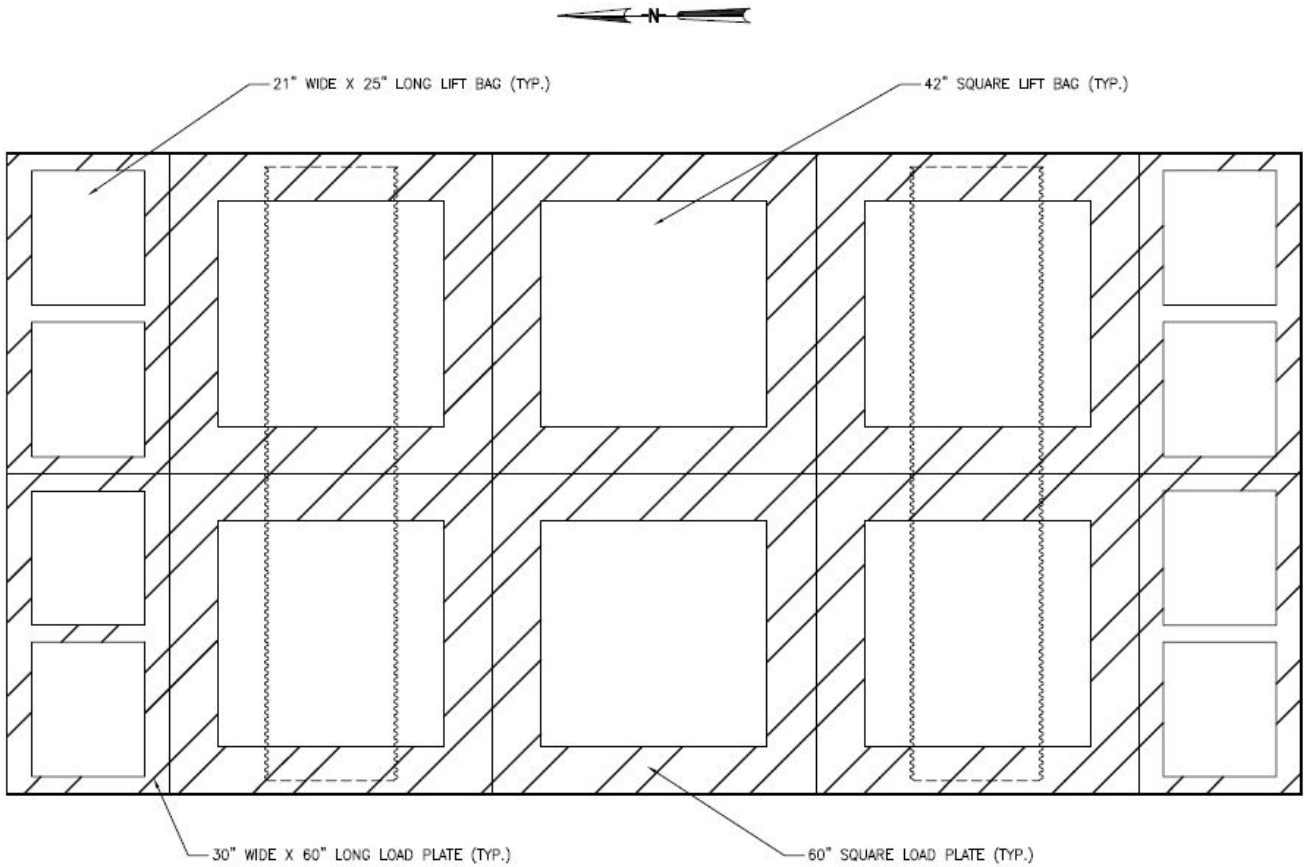
Brachman et al. (2001) performed testing of small-diameter buried pipes subject to biaxially compressive earth pressures in a laboratory facility. Issues such as simulation of overburden pressures, boundary stiffness of the testing chamber, and influence of side wall friction were discussed. He reported the overall effects on the pipe from the idealized laboratory model were small.

Faraone (2012) measured deflections of a 36 inch HDPE pipe with trench box installation using the Soil Box and an identical approach. He concluded the trench box installation technique had a major effect on the performance of the HDPE pipe. The trench box test appeared to show the largest deflections of the pipes tested, including the 36 inch HDPE without trench box. The 36 inch HDPE pipe with trench box installation examined in this thesis will be compared to the results reported by Faraone.

This thesis is a continuation of previous research performed on other flexible pipes for the same FDOT project. These pipes, all of which were 36 inches in diameter, included two HDPE pipes, two PVC pipes, two corrugated steel pipes, and one HDPE pipe with trench box installation.

Figure 1-1. The Soil Box located at the University of Florida. Photo credit: Z. Faraone.

Figure 1-2. Soil Box loading mechanism. Photo credit: V. Konn.




**SOIL BOX PLAN VIEW**
**WITH LOAD PLATES AND LIFT BAGS**
**(24 INCH DIAMETER PIPES)**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | | DRAWN BY: JP-KP |
| PROJECT #: | BDK75 977-21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |

Figure 1-3. Steel plates and lift bags for loading mechanism.

Figure 1-4. Regulators used to control lift bag pressure. Photo credit: Z. Faraone.

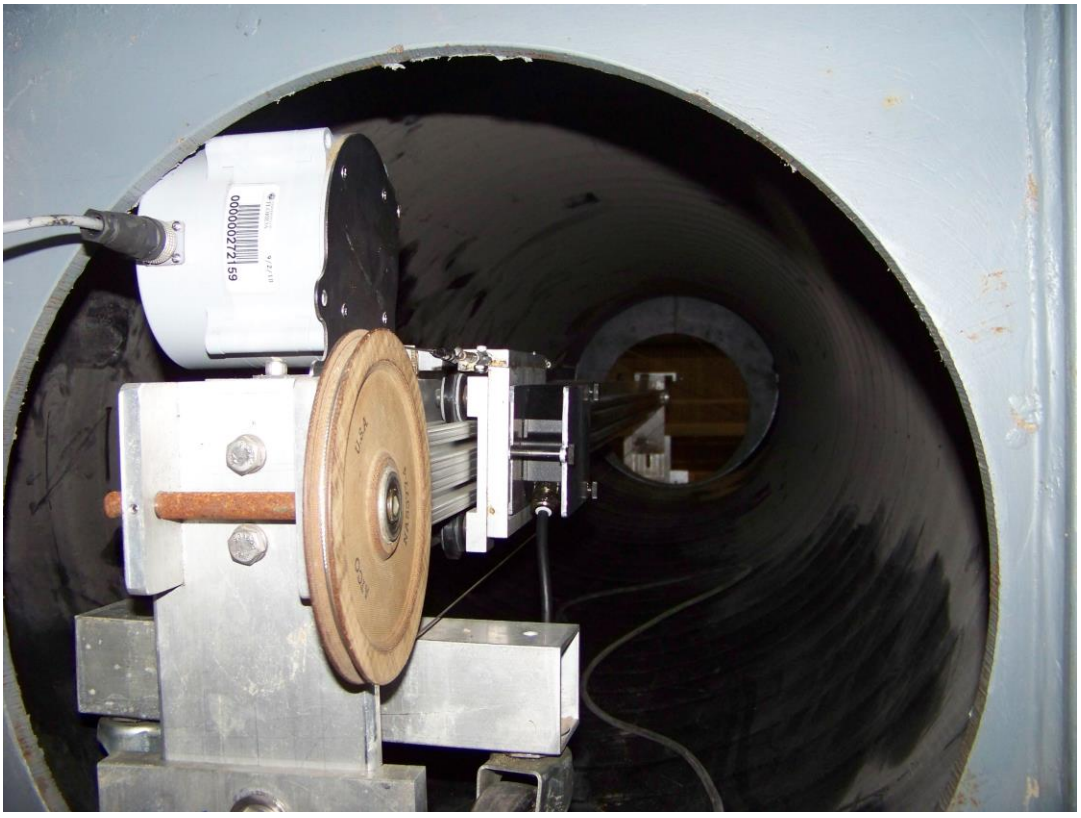


Figure 1-5. Laser profiling system.

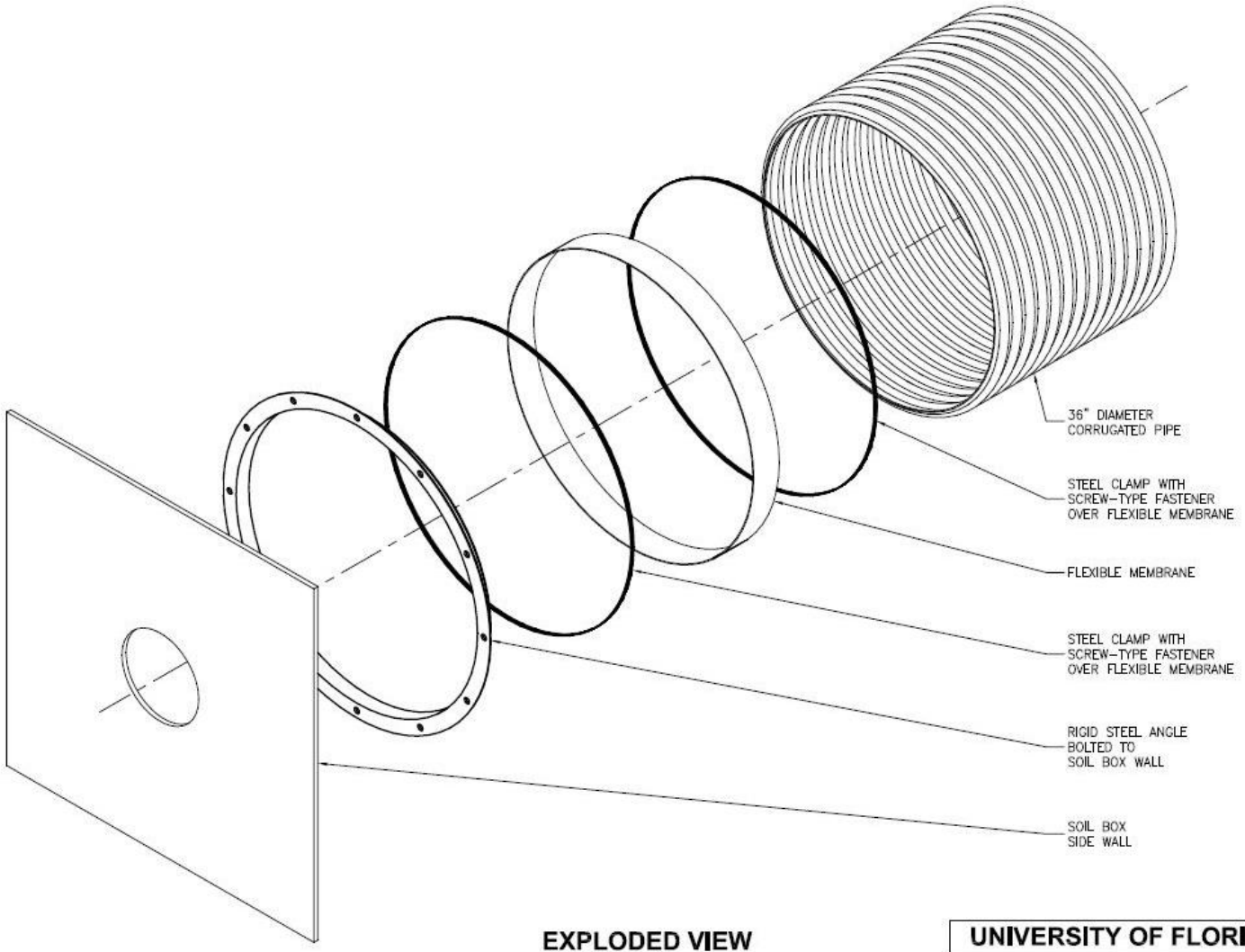
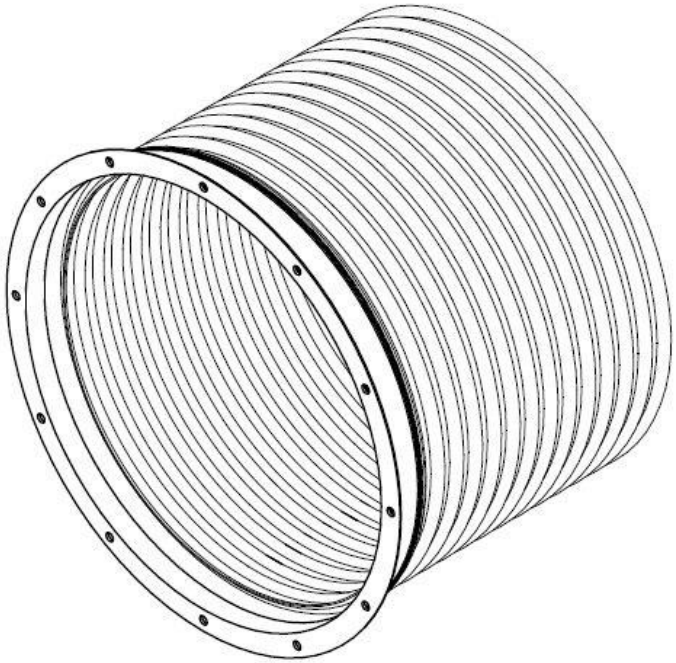
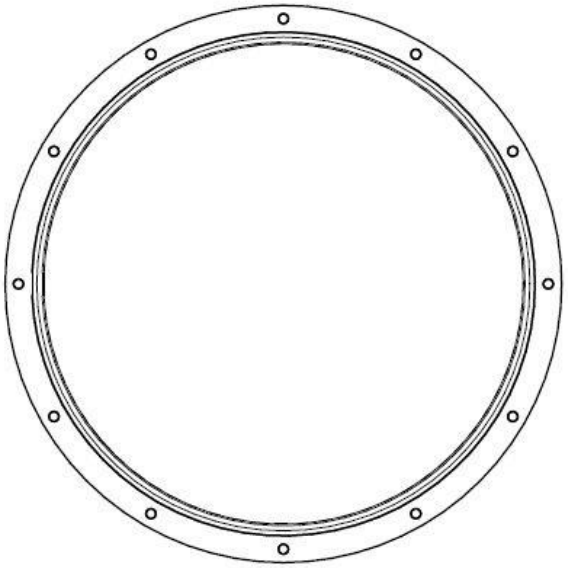



Figure 1-6. Exploded view of flexible membrane system.



ISOMETRIC VIEW



FRONT VIEW

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | 03–22–2010 |
| SCALE: | 1" = 1'–0" | PAGE: | C–15 OF C–16 |

Figure 1-7. Alternate view of flexible membrane system.

# CHAPTER 2
# PROCEDURE

## 2.1 Pipe Preparation

The pipes were cut slightly smaller than the ten foot Soil Box width, and their ends were modified to enable assembly to the flexible membrane system. The details of each pipe-end modification are discussed in the chapters that follow. The pipes were pre-deflected 4% of their nominal diameters by extending turnbuckles between two channels placed along the interior length of the pipe. As the turnbuckles were extended, measurements of the pipe diameter were taken until the diameter reached 4% deflection. An example pre-deflected pipe can be seen in Figure 2-1.

## 2.2 Soil Box Preparation

First, the interior joints of the Soil Box were sealed with marine-grade sealant. The rigid steel angles, as part of the flexible membrane system, were then fastened to the Soil Box (Figure 2-2). Next, a polyethylene sheet was placed on the side walls, lubricated with silicone grease, and followed by a second polyethylene sheet (Figure 2-3).

A 12 inch layer of soil was placed into the Soil Box via a front-end loader (Figure 2-4). The soil was leveled manually and compacted with a vibratory plate compactor. The soil during and after compaction are shown in Figures 2-5 and 2-6, respectively. Nuclear density tests were performed at multiple locations in the first layer for use in FEM analysis. The first set of earth pressure cells were then placed in their appropriate locations below the pipes.

The pipes were placed in the Soil Box via fork lift, rolled into their proper position, and the flexible membrane system is installed on each pipe end (Figures 2-7 and 2-8).

The Soil Box end partition was then fastened to the Soil Box and its joints were sealed as shown in Figure 2-9. Two lubricated polyethylene sheets were placed on the inside wall partition, and the remaining soil for the first 12 inch layer was placed and manually compacted.

A concrete bucket was filled with soil, hoisted above the box, emptied into the box, and manually evenly distributed with shovels. This was repeated in 18 inch lift-increments until the Soil Box is filled. The earth pressure cells were placed while soil was added and nuclear density tests were performed after each lift. Refer to the appendices for each test for the locations of the nuclear density tests and earth pressure cells. The Soil Box was then saturated and followed by a final nuclear density test. After saturation, the loading mechanism was installed (Figure 2-10).

After installing the loading mechanism, the three top Soil Box partitions were fastened to the Soil Box. Each section was hoisted onto the box via a lift truck and secured with nuts and bolts (Figure 2-11). The turnbuckles were removed and the laser profiling system was installed in each pipe (Figure 2-12).

## 2.3 Testing Procedure

The loading sequence was comprised of five pound per square inch increments. Each increment was held for one hour before deflection readings were recorded. The increments were increased until they reached 130 pounds per square inch because this was the maximum amount of pressure the lift bags could tolerate without failure. For every third loading increment (45 pounds per square inch, 90 pounds per square inch, and 130 pounds per square inch, respectively), the load was held for 24 hours and deflection readings were taken at one hour, four hour, eight hour, and 24 hours to test the creep characteristics of the pipes. Table 2-1 displays the loading sequence and

deflection reading times. As the load was increased, pipe deflection was monitored, and the lift bag regulators were adjusted to maintain uniform deflection along the pipes' length.

After the loading sequence was concluded, the unloading sequence began. This sequence consisted of reducing the pressure in the same increments in which it was increased. Each increment was held for an hour. Throughout the loading and unloading sequence, pressure cell readings and soil deflection readings were recorded.

Table 2-1. Loading sequence and deflection reading timing.

| Pressure Applied to Main Regulator (PSI) | Deflection Readings taken x hours after pressure is applied |
|---|---|
| 0 | 1 |
| 5 | 1 |
| 10 | 1 |
| 15 | 1 |
| 20 | 1 |
| 25 | 1 |
| 30 | 1 |
| 35 | 1 |
| 40 | 1 |
| 45 | 1, 4, 8, 24 |
| 50 | 1 |
| 55 | 1 |
| 60 | 1 |
| 65 | 1 |
| 70 | 1 |
| 75 | 1 |
| 80 | 1 |
| 85 | 1 |
| 90 | 1, 4, 8, 24 |
| 95 | 1 |
| 100 | 1 |
| 105 | 1 |
| 110 | 1 |
| 115 | 1 |
| 120 | 1 |
| 125 | 1 |
| 130 | 1, 4, 8, 24 |

Figure 2-1. Example pipe pre-deflected to 4%. Photo credit: V. Konn.

Figure 2-2. Side wall flange. Photo credit: Z. Faraone.

Figure 2-3. Installed lubricated polyethylene sheets. Photo credit: V. Konn.

Figure 2-4. Soil being placed with front end loader. Photo credit: V. Konn.

Figure 2-5. First lift during compaction. Photo credit: V. Konn.

Figure 2-6. First lift after compaction. Photo credit: V. Konn.

Figure 2-7. Properly positioned pipe before flexible membrane system installation. Photo credit: V. Konn.

Figure 2-8. Installed flexible membrane system. Photo credit: V. Konn.

Figure 2-9. Fastening of Soil Box end partition. Photo credit: V. Konn.

Figure 2-10. Loading mechanism. Photo credit: V. Konn.

Figure 2-11. Top partition hoisted onto Soil Box via lift truck. Photo credit: Z. Faraone.

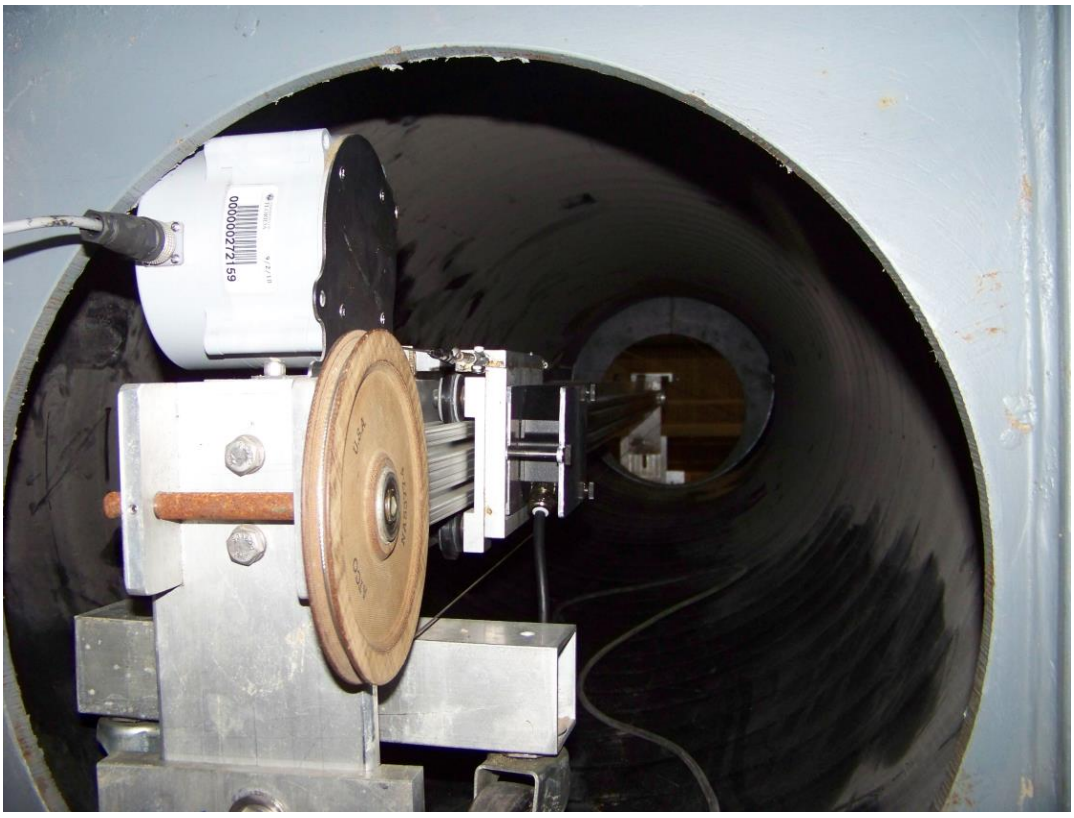


Figure 2-12. Installed laser profiling system. Photo credit: V. Konn.

# CHAPTER 3
# 36 INCH HDPE PIPE WITH TRENCH BOX AND 36 INCH ALUMINUM PIPE TEST

## 3.1 Trench Box Purpose

A trench box is a structure that protects workers within it and withstands the forces imposed on it by a cave-in during trench excavation (OSHA 1926.650). When laying pipe, a trench box is placed in the excavated trench while workers install a pipe section. The trench box is then pulled forward and this procedure is repeated until the pipe laying is complete.

Strength of flexible pipe is based upon passive soil pressures developed at the sides of the pipe when subjected to overburden stress. When pulling the trench box forward during pipe installation, the voids left by the trench box are supposed to be filled and compacted. This test aims to account for the impact of a contractor's use of a trench box for pipe installation on the most backfill sensitive pipe, HDPE.

## 3.2 Test Modifications

Several modifications were required for the trench box test. An aluminum ring was riveted on each end of the aluminum pipe and one corrugation was removed on each end of the HDPE pipe (Figures 3-1 and 3-2). This allowed the pipes to connect to the flexible membrane system.

To prevent damage, the pressure cell cables were rerouted underneath the trench box. These cables were buried before the installation of the trench box as shown in Figure 3-3.

The trench box was installed after the placement of the remaining soil for the first 12 inch layer. The trench box was hoisted over the box via a lift truck and placed around the HDPE pipe as shown in Figures 3-4 and 3-5.

The lift capacity of the lift truck was exceeded by the estimated force on the trench box due to the soil. Therefore, as the Soil Box was filled, the trench box cross bars were removed to allow individual removal of the trench box walls (Figures 3-6 and 3-7). The voids left by the trench box removal were then filled. The locations of the nuclear density tests and earth pressure cells are shown in Appendix A.

### 3.3 Saturation Failure

During saturation, soil began flowing out of the HDPE pipe observation portals. After examining the failure, it was apparent that the flexible membrane was breached. A void formed at the top of the Soil Box down through the observation portals exposing the HDPE as shown in Figures 3-8 and 3-9.

The performance of flexible pipes is directly related to lateral passive pressures developed by the soil-pipe system. These passive pressures were not developed due to the reduction in soil density from trench box removal, and as the HDPE pipe deflected, the stress on the flexible membrane increased ultimately causing its failure.

To remedy this issue, the membrane failure was sealed by placing an inflatable inner tube inside the HDPE pipe. The void was filled and saturation was completed. This failure is identical to flexible membrane failure of the previously tested HDPE pipe with trench box installation (Faraone 2012).

### 3.4 Lift Bag Failure

Two lift bag failures occurred during testing. The first failure occurred in a small lift bag located in the Northeast corner of the Soil Box (Figure 3-10). The lift bag was leaking air through a small tear first observed during the early stages of the loading sequence. When the loading sequence reached 90 pounds per square inch, the lift

bag appeared to be leaking significantly. To avoid overstressing the air compressor, the air supply to the lift bag was removed.

The second lift bag failure occurred during the 110 pounds per square inch load increment in a large lift bag located in the center east side of the Soil Box (Figure 3-10). This lift bag ruptured without warning. The rupture resulted in immediate pressure loss.

Although the failed lift bags were not located directly over the pipes, the failures caused a discontinuity of surcharge in the Soil Box, which ultimately reduced the simulated overburden pressure. These lift bags were utilized through several loading and unloading sequences and most likely failed due to fatigue.

## 3.5 Results

The HDPE pipe with trench box appeared to show the largest deflections of the pipes tested. A plot of deflection versus simulated overburden for three points (mid-span and 18 inches from each end) in the pipe can be seen in Figure 3-11. As shown, the mid-span point appears to indicate the highest deflection reading. This may indicate the flexible membrane system did not perform as expected. The flexible membrane was designed to prevent soil from exiting the Soil Box while allowing for free deformation of the pipe. This difference of deflection between the three points may be caused by a partially fixed boundary condition at the pipe and wall interface. There is a small amount of creep deflection in the HDPE pipe (Figure 3-12).

A plot of the two tested HDPE pipes with trench box can be seen in Figure 3-13. The simulated overburden for this test yielded lesser depths than Faraone's previously tested HDPE pipe with trench box. This result is most likely due to the lift bag failures during testing.

The aluminum pipe yielded deflections less than the HDPE pipe with trench box. This was expected because aluminum is a stiffer material than HDPE. The deflection of three points in the aluminum pipe versus simulated overburden is shown in Figure 3-14. There does not appear to be any significant creep of the aluminum pipe (Figure 3-15). Table 3-1 displays the simulated overburden depth results HDPE pipe with trench box and aluminum pipe.

Table 3-1. Simulated overburden for 36 inch HDPE with trench box and aluminum pipe test.

| Pressure Applied to Main Regulator (PSI) | Deflection Readings taken x hours after pressure was applied | Simulated Overburden Over HDPE Pipe (feet) | Simulated Overburden Over Aluminum Pipe (feet) |
|---|---|---|---|
| 0 | 1 | 2.2 | 4.9 |
| 5 | 1 | 2.5 | 5.5 |
| 10 | 1 | 3.3 | 7.0 |
| 15 | 1 | 3.9 | 8.3 |
| 20 | 1 | 4.6 | 9.7 |
| 25 | 1 | 4.9 | 10.7 |
| 30 | 1 | 5.6 | 12.1 |
| 35 | 1 | 6.2 | 13.3 |
| 40 | 1 | 6.8 | 14.5 |
| 45 | 1, 4, 8, 24 | 6.8 | 15.2 |
| 50 | 1 | 7.0 | 15.9 |
| 55 | 1 | 7.8 | 16.6 |
| 60 | 1 | 8.2 | 17.0 |
| 65 | 1 | 8.6 | 17.8 |
| 70 | 1 | 8.4 | 18.1 |
| 75 | 1 | 9.0 | 18.6 |
| 80 | 1 | 9.4 | 19.1 |
| 85 | 1 | 9.8 | 19.5 |
| 90 | 1, 4, 8, 24 | 9.3 | 19.5 |
| 95 | 1 | 9.2 | 20.6 |
| 100 | 1 | 9.6 | 21.4 |
| 105 | 1 | 9.9 | 22.0 |
| 110 | 1 | 10.2 | 22.0 |
| 115 | 1 | 9.6 | 21.3 |
| 120 | 1 | 9.8 | 21.7 |
| 125 | 1 | 10.1 | 22.2 |
| 130 | 1, 4, 8, 24 | 9.9 | 22.8 |

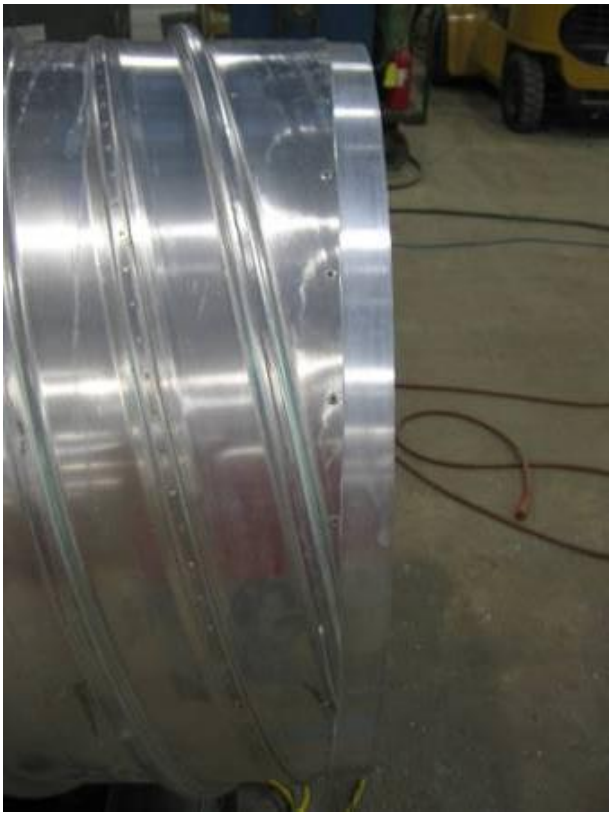


Figure 3-1. Aluminum pipe end modification. Photo credit: V. Konn.

Figure 3-2. HDPE pipe end modification. Photo credit: V. Konn.

Figure 3-3. Rerouted pressure cell cabling. Photo credit: V. Konn.

Figure 3-4. Hoisting trench box into Soil Box. Photo credit: V. Konn.

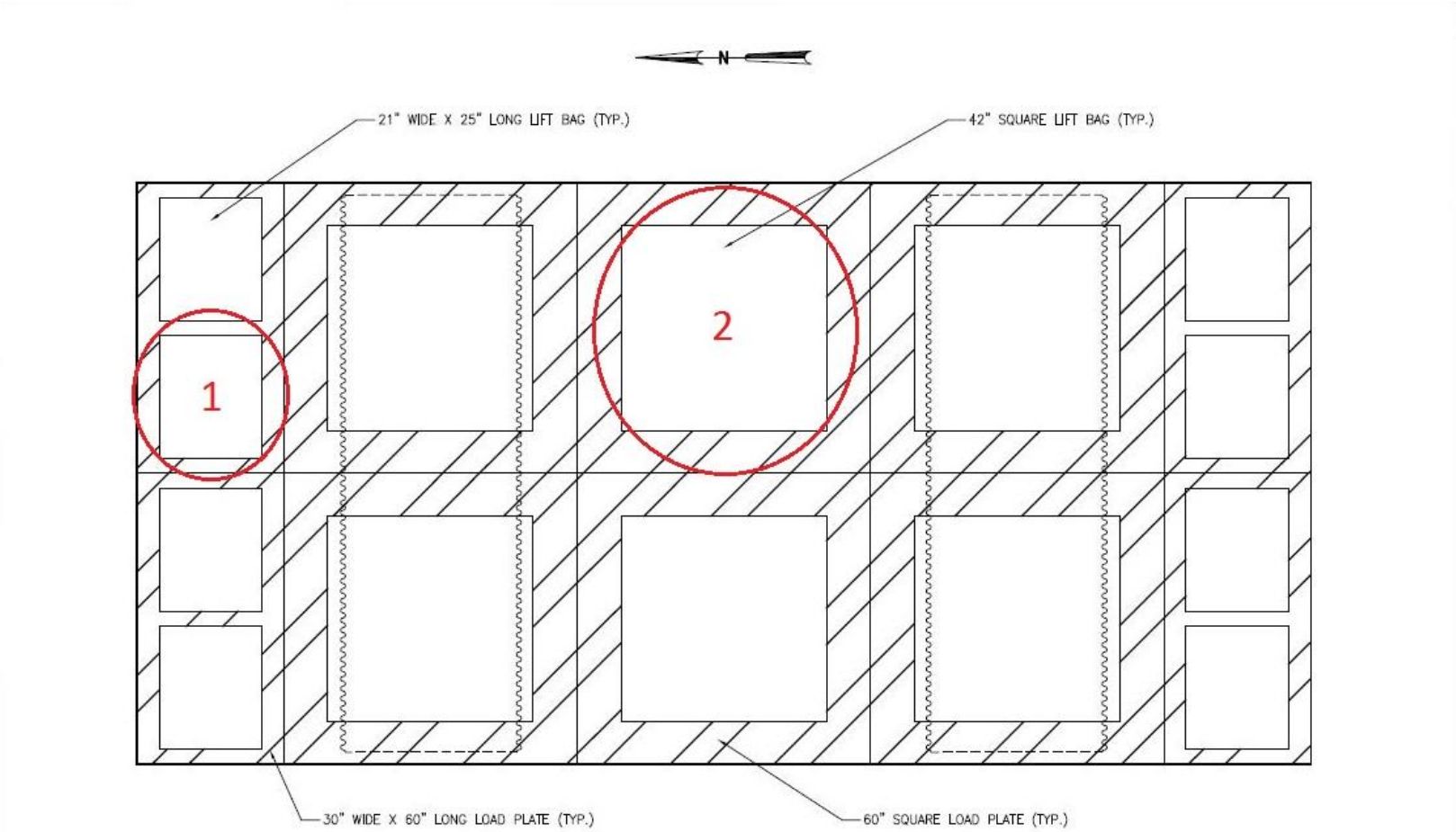
Figure 3-5. Installed trench box. Photo credit: V. Konn.

Figure 3-6. Removal of trench box walls. Photo credit: V. Konn.

Figure 3-7. Voids from removal of trench box walls. Photo credit: V. Konn.

Figure 3-8. Void formed from flexible membrane breach. Photo credit: V. Konn.

Figure 3-9. Top view of void (circle showing HDPE pipe). Photo credit: V. Konn.




**SOIL BOX PLAN VIEW**
**WITH LOAD PLATES AND LIFT BAGS**
**(36 INCH DIAMETER PIPES)**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP-KP |
| PROJECT #: | BDK75 977-21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |

Figure 3-10. Lift bag failure locations.

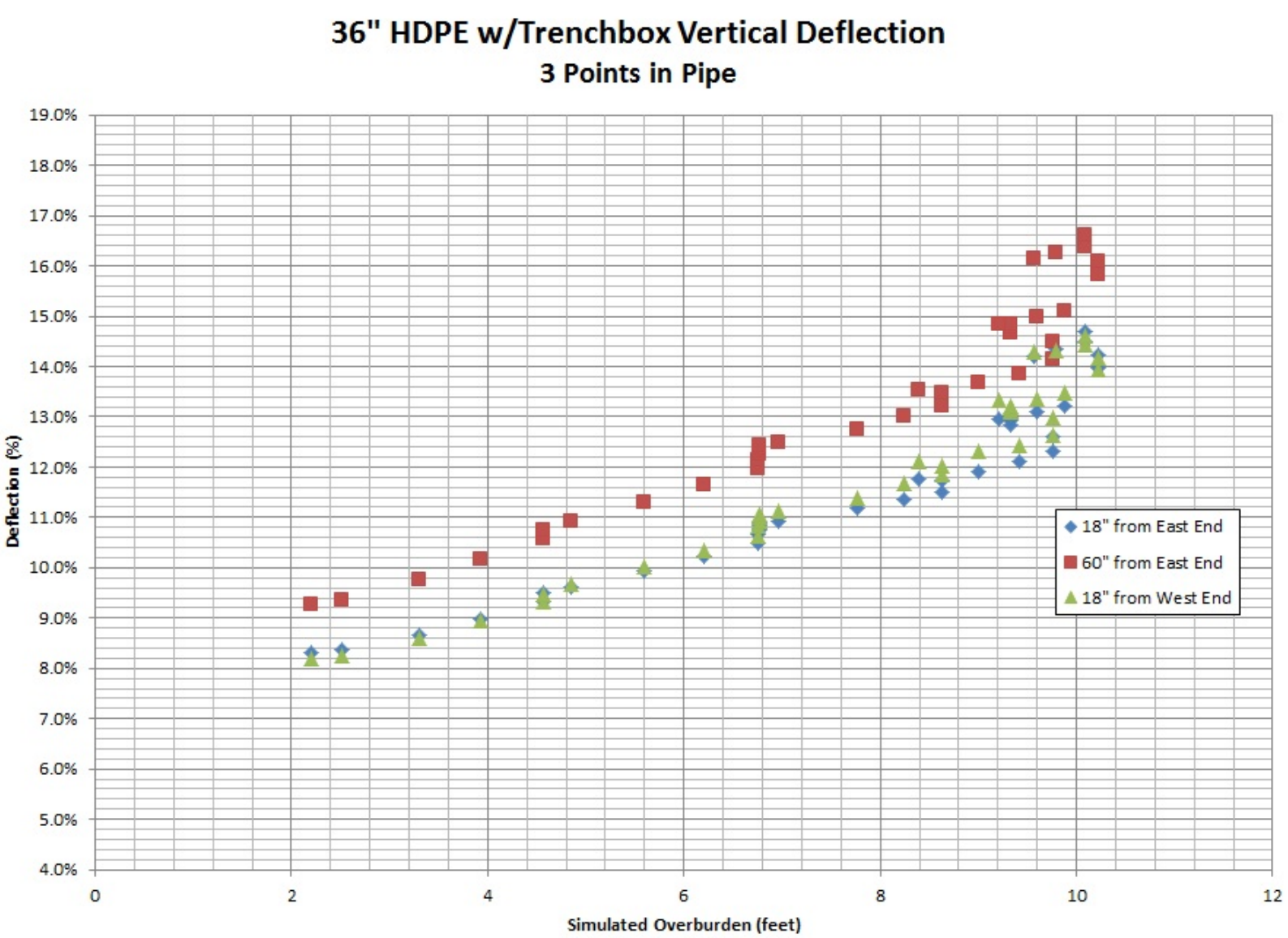



Figure 3-11. Three points in 36” HDPE pipe with trench box, deflection versus simulated overburden.

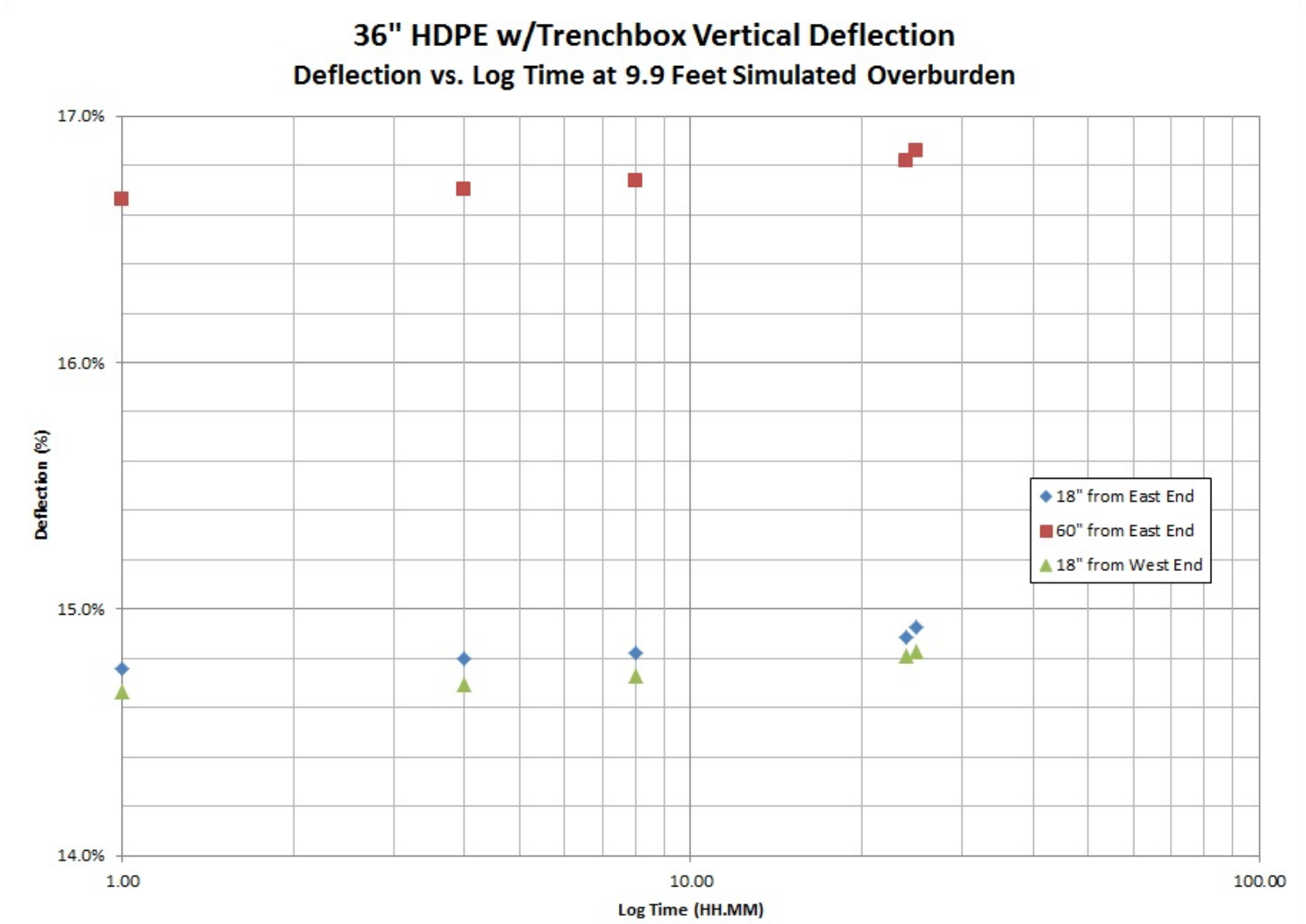



Figure 3-12. Deflection of 36” HDPE pipe under 9.9ft of simulated overburden over time.

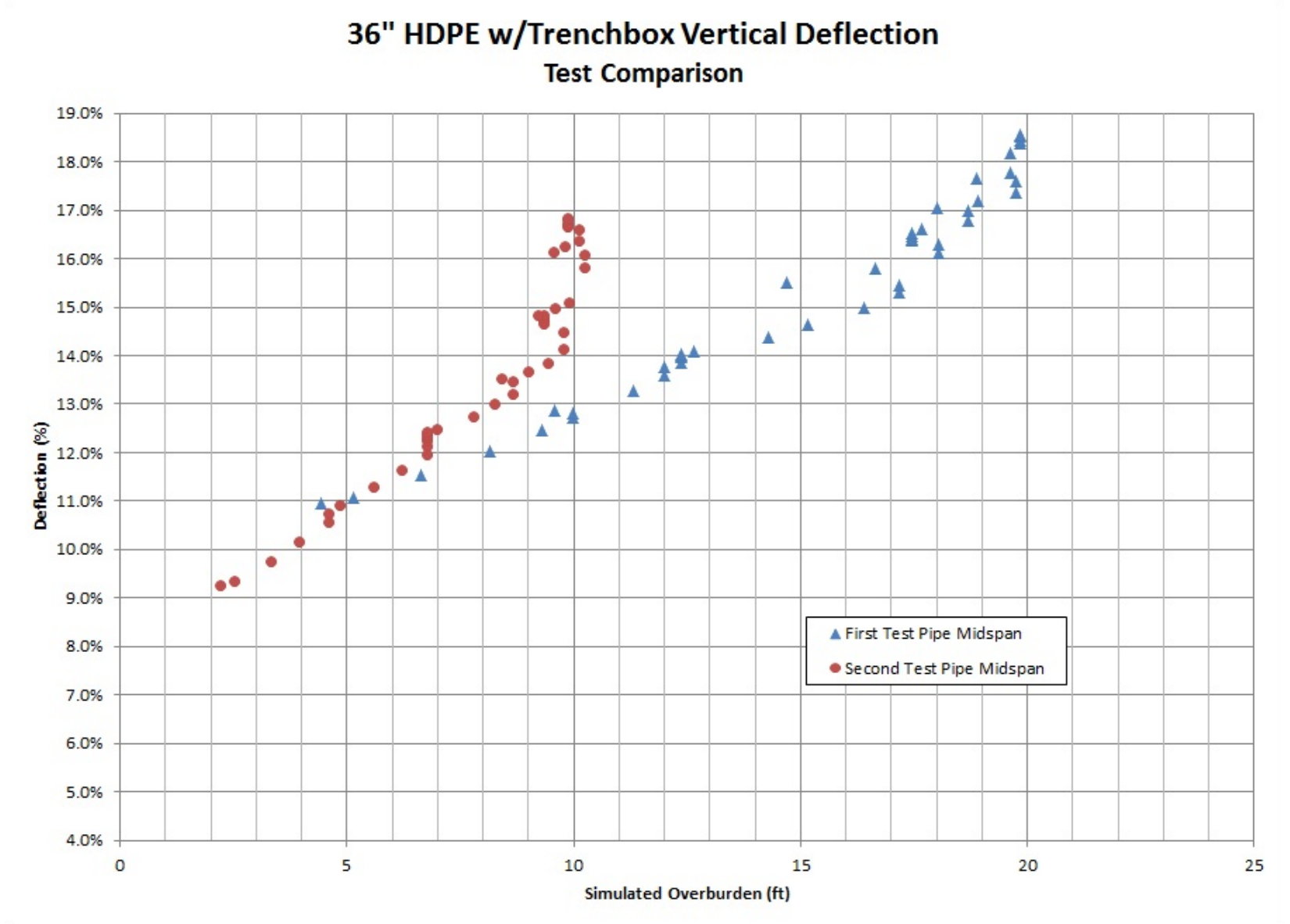



Figure 3-13. Deflection comparison of 36” HDPE pipe with trench box tests.

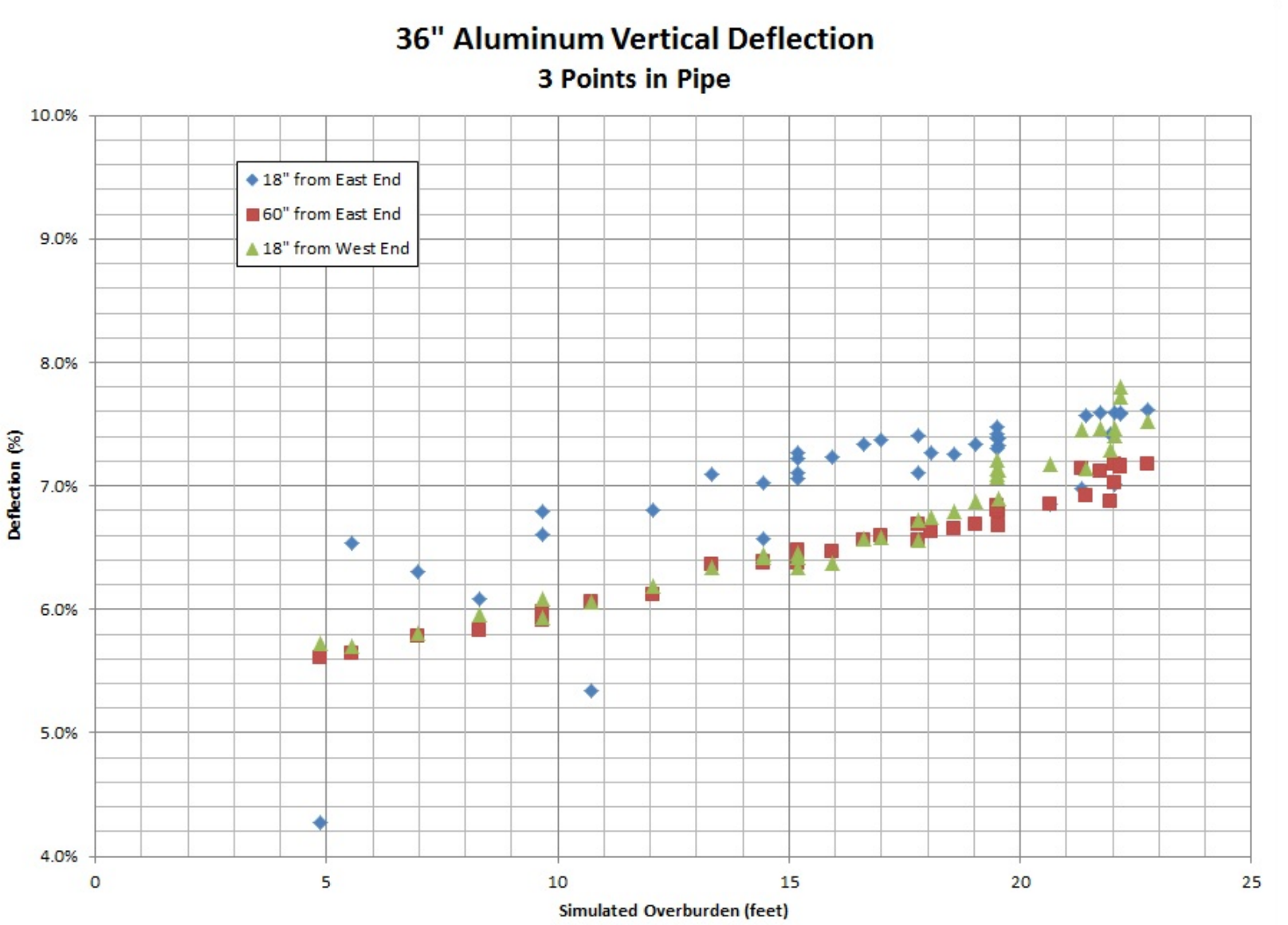



Figure 3-14. Three points in 36” aluminum pipe, deflection versus simulated overburden.

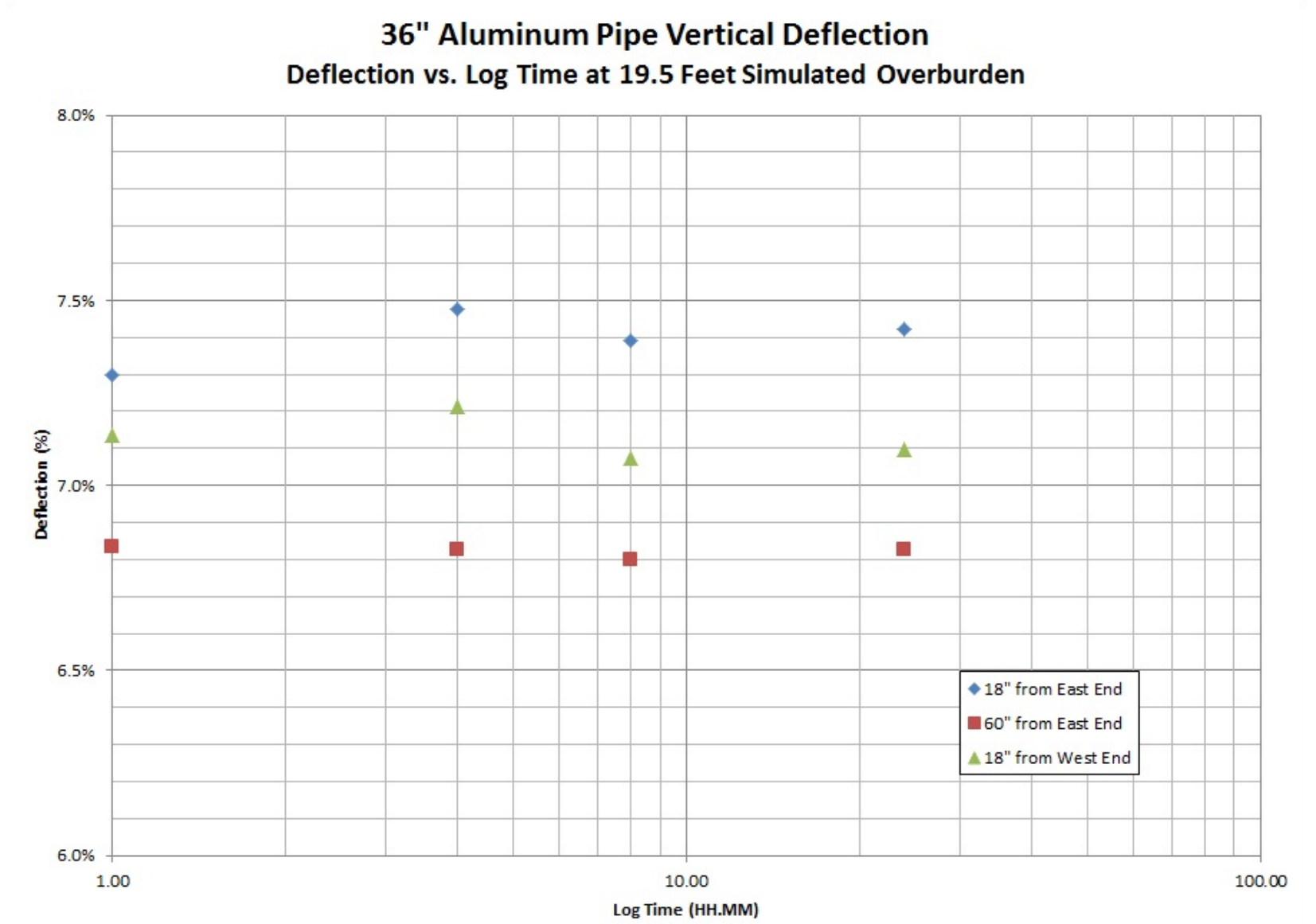



Figure 3-15. Deflection of 36” aluminum pipe under 19.5ft of simulated overburden over 24 hours.

# CHAPTER 4
# 24 INCH HDPE PIPE TEST

## 4.1 Test Modifications

Several modifications were required for the 24 inch diameter HDPE pipe test. The locations of the pressure cells were modified to account for the smaller pipe diameter; these locations are shown in Appendix B.

The flexible membrane system was modified to fit the 24 inch pipes. A replacement rigid steel angle was fabricated, painted, and bolted to the Soil Box wall. A single corrugation on each end of the HDPE pipes was removed to allow assembly to the flexible membrane system (Figures 4-1 and 4-2).

The laser previously used to measure displacements of the 36 inch pipes did not have adequate precision to measure displacements of the 24 inch pipes. A new ILD1700-250VT laser was purchased from Micro-Epsilon. Two aluminum plates were attached to the laser's exterior casing so that it could be properly mounted on the laser profiling system (Figures 4-3 and 4-4).

## 4.2 Lift Bag Failure

A lift bag failure occurred during the 110 pounds per square inch load increment in a small lift bag located in the Northeast corner of the Soil Box (Figure 4-5). Although the failed lift bag was not located directly over the pipes, it caused a discontinuity of surcharge in the Soil Box, which ultimately reduced the simulated overburden. This may explain the difference in simulated overburden of the two HDPE pipes shown in Table 4-1. The lift bag was utilized through several loading and unloading sequences and most likely failed due to fatigue.

## 4.3 Results

The North HDPE pipe appeared to produce approximately uniform deflection along its length (Figure 4-6). Results appear to show creep deflections in this pipe over a 24 hour time period (Figure 4-7). A deflection versus simulated overburden plot of three points in the South HDPE pipe displays a 2% deflection discrepancy between each end of the pipe (Figure 4-8). The creep characteristics for the South HDPE pipe over a 24 hour time period displays a similar upward trend (Figure 2-9).

The North pipe consistently deflected about 2% more than the South pipe during the loading sequence (Figure 4-10). This deflection appears to conflict with the overburden simulations calculated for both pipes (Table 4-1). The simulated overburdens for the South pipe versus the North pipe are higher, but the deflections recorded in the South pipe versus the North pipe are smaller. A possible reason for this discrepancy is the variation of the soil density in the Soil Box and variable contact areas between the lift bags and their corresponding load plates. During the loading sequence, the load plate settles with the soil causing a reduction in contact area between the lift bag and load plate. This reduction in contact area decreases the simulated overburden pressure applied to the soil.

Table 4-1. Simulated overburden for 24 inch HDPE pipe test.

| Pressure Applied to Main Regulator (PSI) | Deflection Readings taken x hours after pressure was applied | Simulated Overburden Over North HDPE Pipe (feet) | Simulated Overburden Over South HDPE Pipe (feet) |
|---|---|---|---|
| 0 | 1 | 3.8 | 4.2 |
| 5 | 1 | 4.4 | 4.7 |
| 10 | 1 | 5.6 | 6.3 |
| 15 | 1 | 5.7 | 6.8 |
| 20 | 1 | 6.4 | 7.5 |
| 25 | 1 | 8.9 | 10.3 |
| 30 | 1 | 9.5 | 11.0 |
| 35 | 1 | 11.0 | 12.9 |
| 40 | 1 | 12.4 | 14.6 |
| 45 | 1, 4, 8, 24 | 12.9 | 15.0 |
| 50 | 1 | 13.3 | 15.5 |
| 55 | 1 | 14.7 | 17.3 |
| 60 | 1 | 15.0 | 17.5 |
| 65 | 1 | 15.4 | 17.8 |
| 70 | 1 | 16.6 | 19.4 |
| 75 | 1 | 16.6 | 19.2 |
| 80 | 1 | 17.2 | 20.0 |
| 85 | 1 | 18.6 | 21.6 |
| 90 | 1, 4, 8, 24 | 19.1 | 22.0 |
| 95 | 1 | 19.0 | 21.8 |
| 100 | 1 | 19.8 | 22.8 |
| 105 | 1 | 20.8 | 23.9 |
| 110 | 1 | 21.8 | 25.1 |
| 115 | 1 | 21.6 | 23.7 |
| 120 | 1 | 22.3 | 24.6 |
| 125 | 1 | 23.0 | 25.3 |
| 130 | 1, 4, 8, 24 | 23.4 | 26.2 |

Figure 4-1. Shaved corrugation on HDPE pipe prior to flexible membrane installation. Photo credit: V. Konn.

Figure 4-2. Installed flexible membrane system. Photo credit: V. Konn.

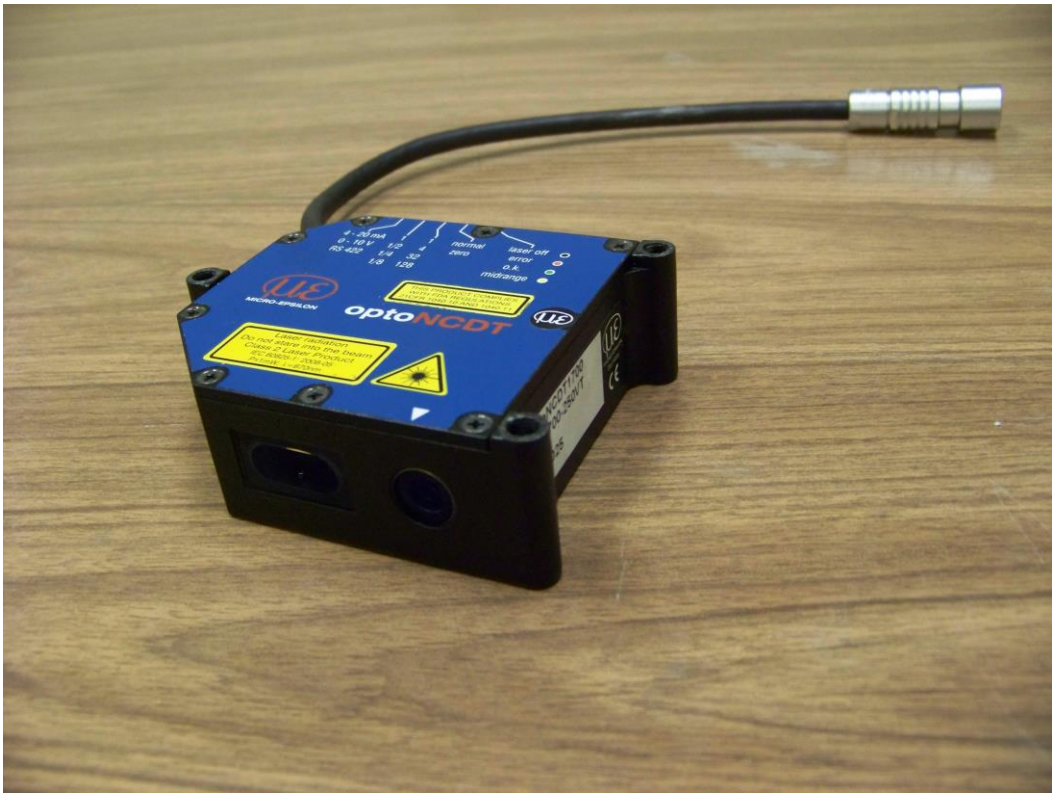


Figure 4-3. Purchased laser for 24 inch pipe testing. Photo credit: V. Konn.

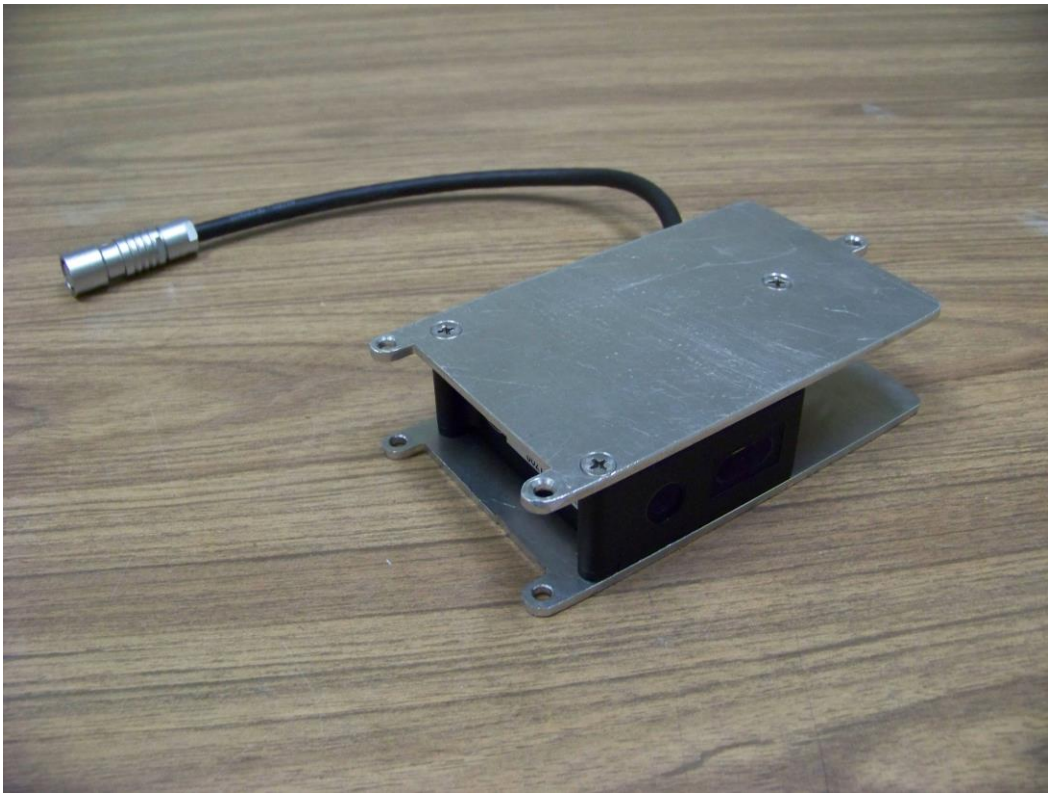
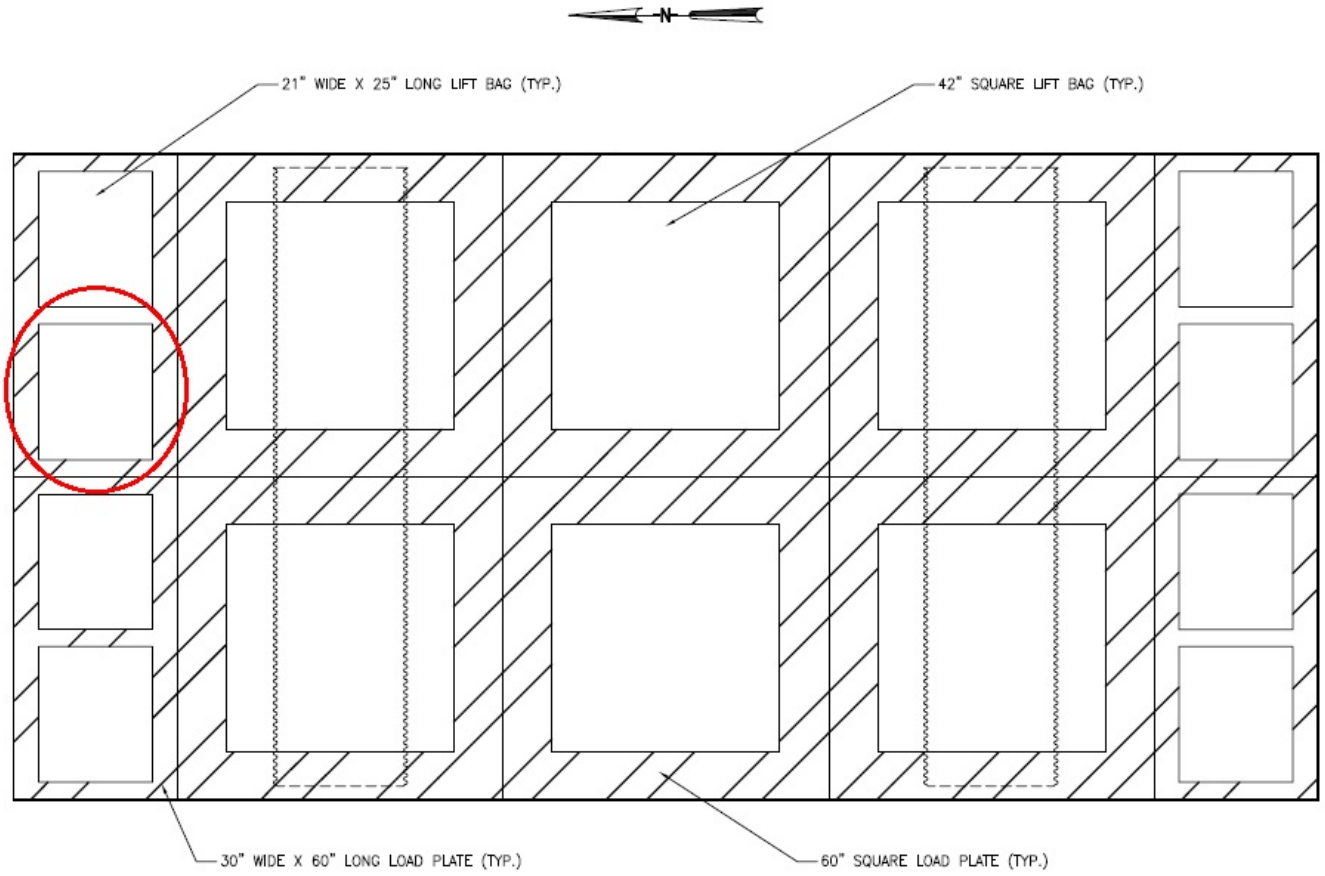


Figure 4-4. Modified laser. Photo credit: V. Konn.




**SOIL BOX PLAN VIEW**
**WITH LOAD PLATES AND LIFT BAGS**
**(24 INCH DIAMETER PIPES)**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |

Figure 4-5. Lift bag failure location.

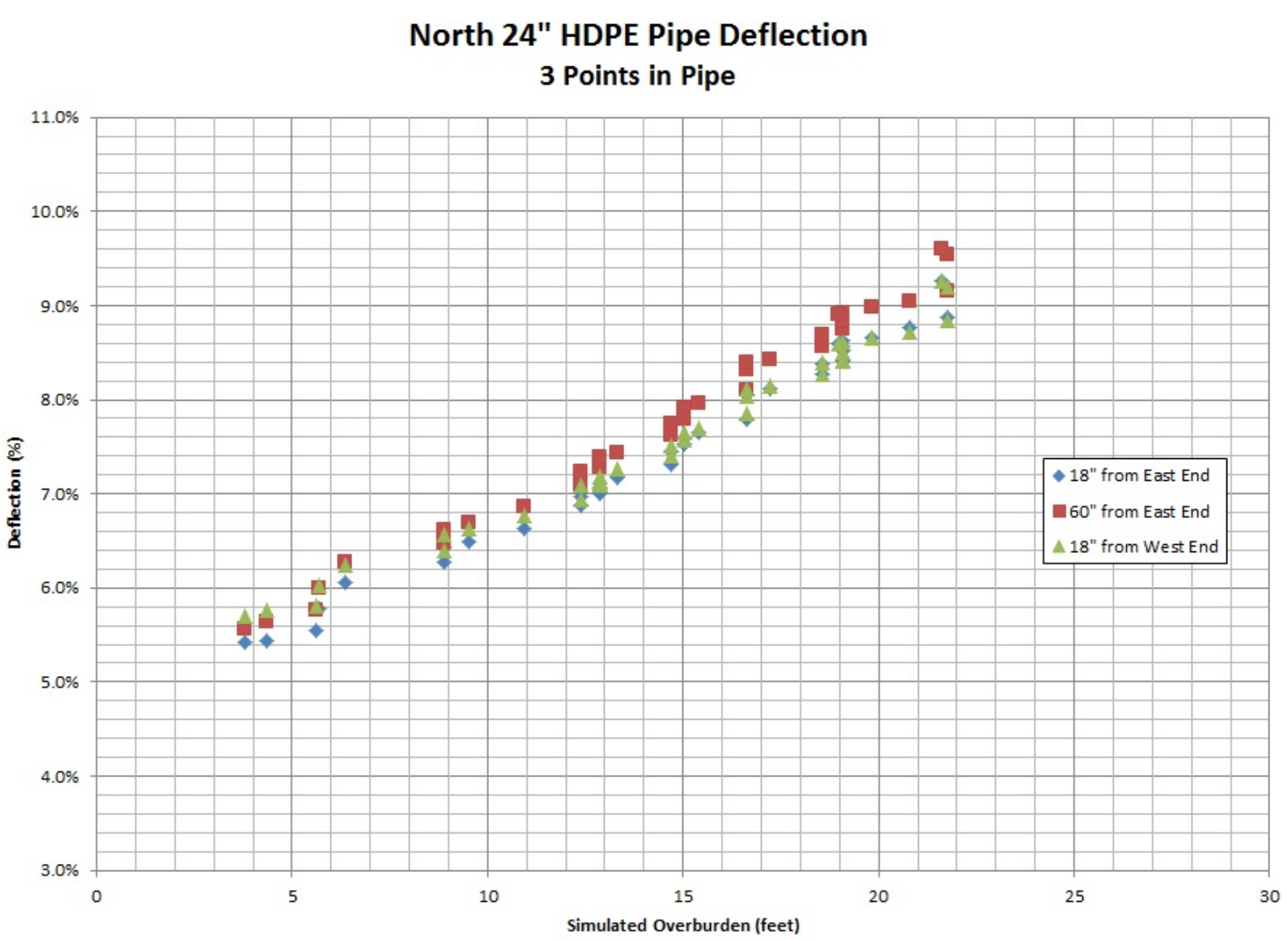



Figure 4-6. Three points in North 24” HDPE pipe, deflection versus simulated overburden.

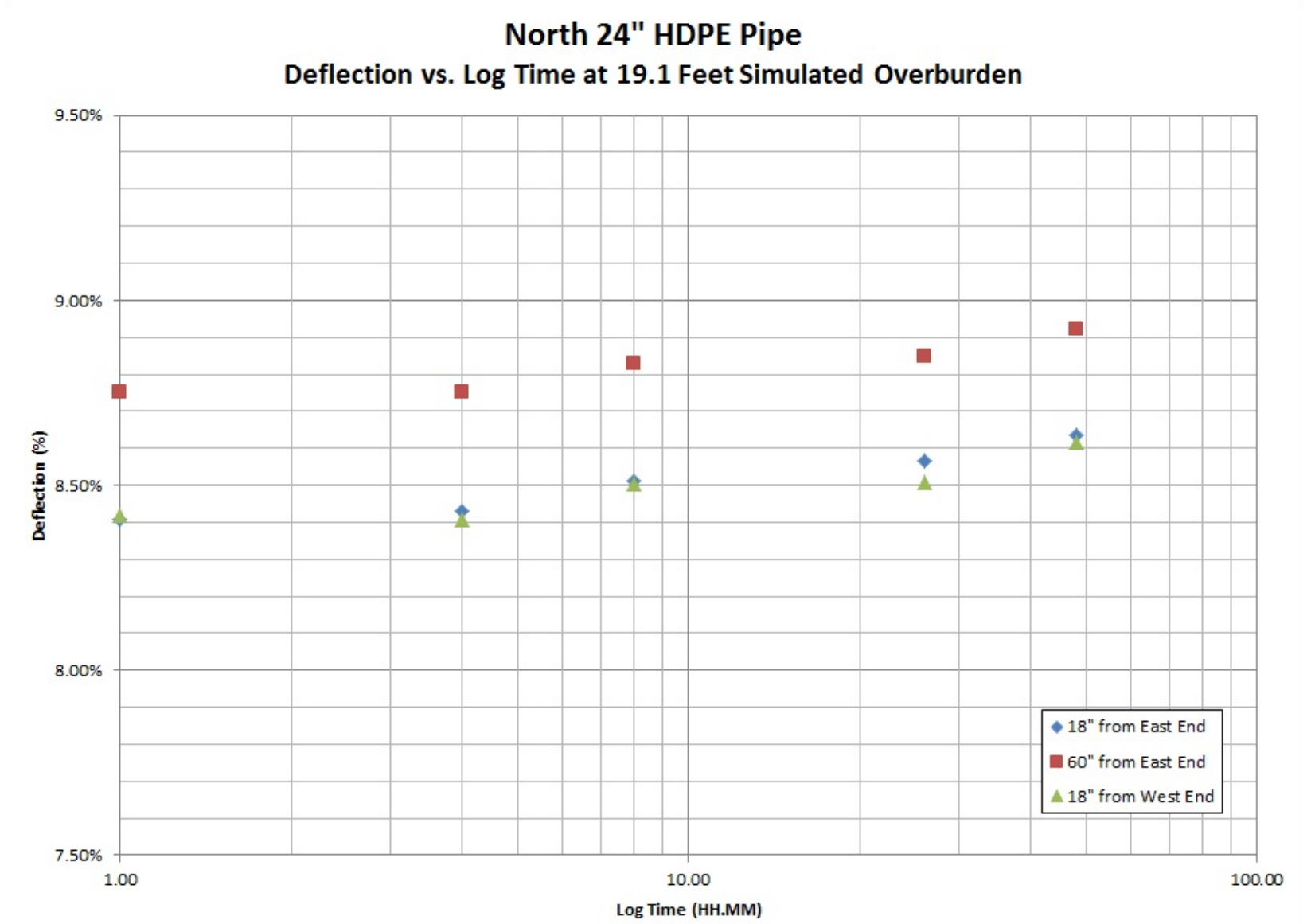



Figure 4-7. Deflection of North 24” HDPE pipe under 19.1ft of simulated overburden over 24 hours.

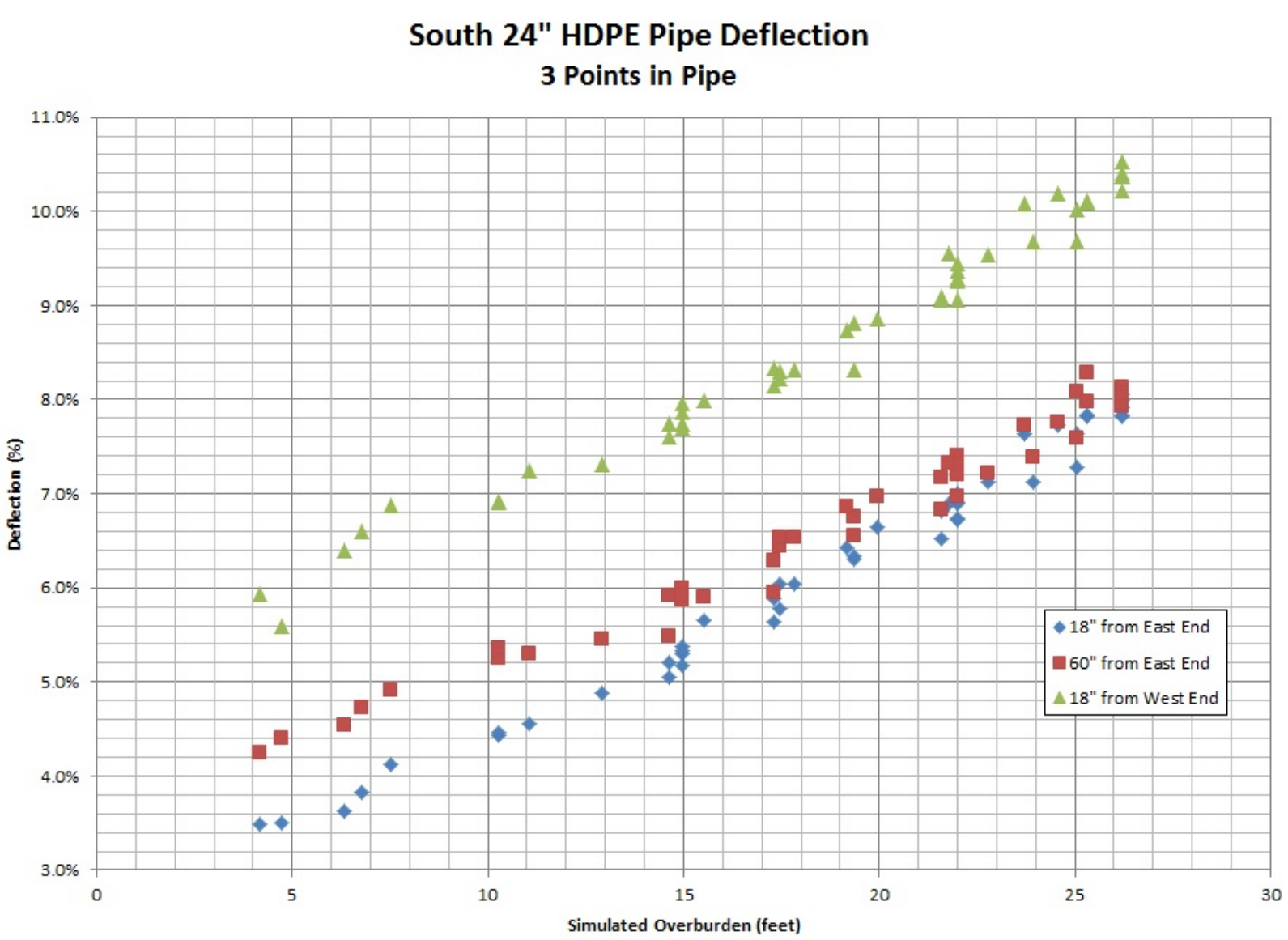



Figure 4-8. Three points in South 24” HDPE pipe, deflection versus simulated overburden.

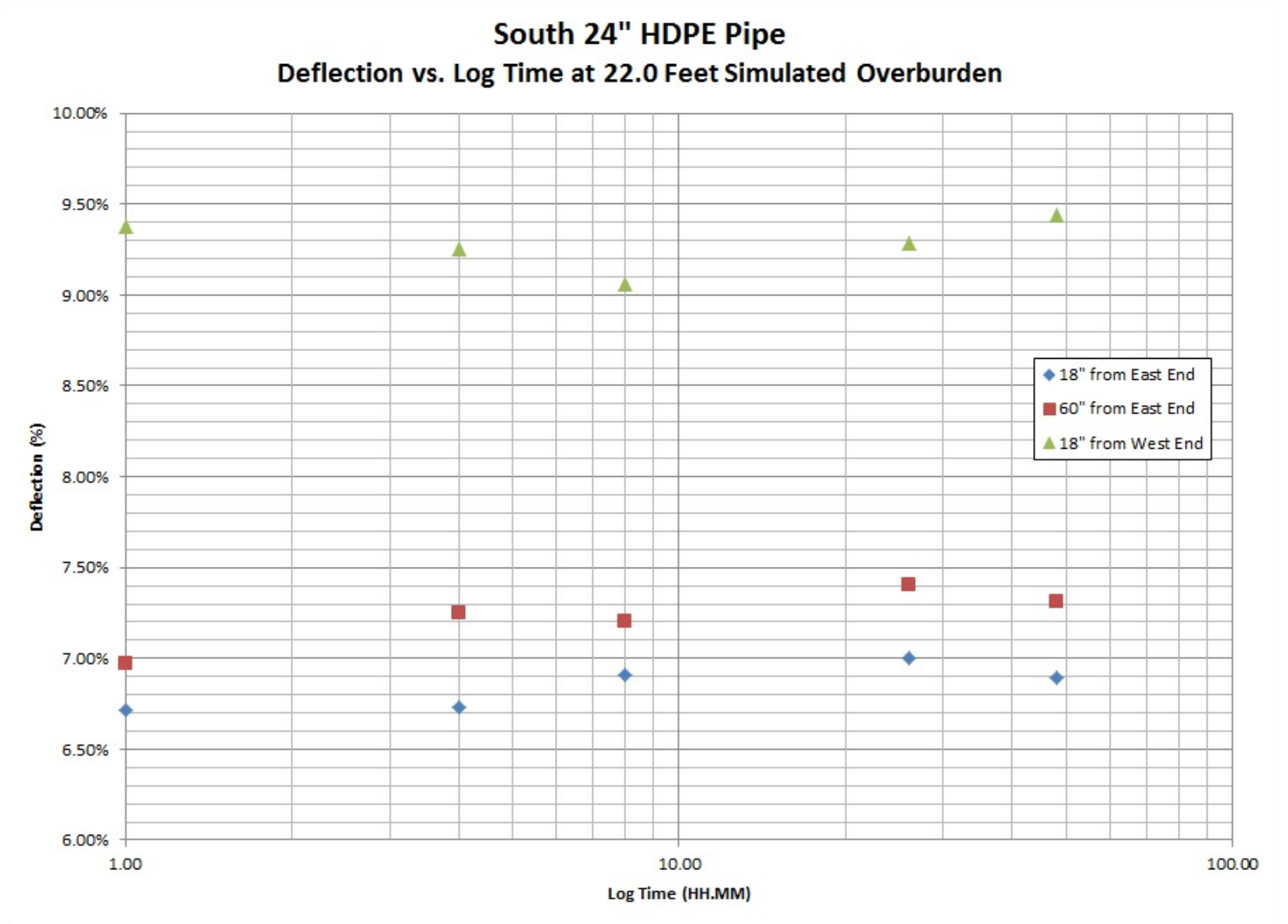



Figure 4-9. Deflection of South 24” HDPE pipe under 22.0ft of simulated overburden over 24 hours.

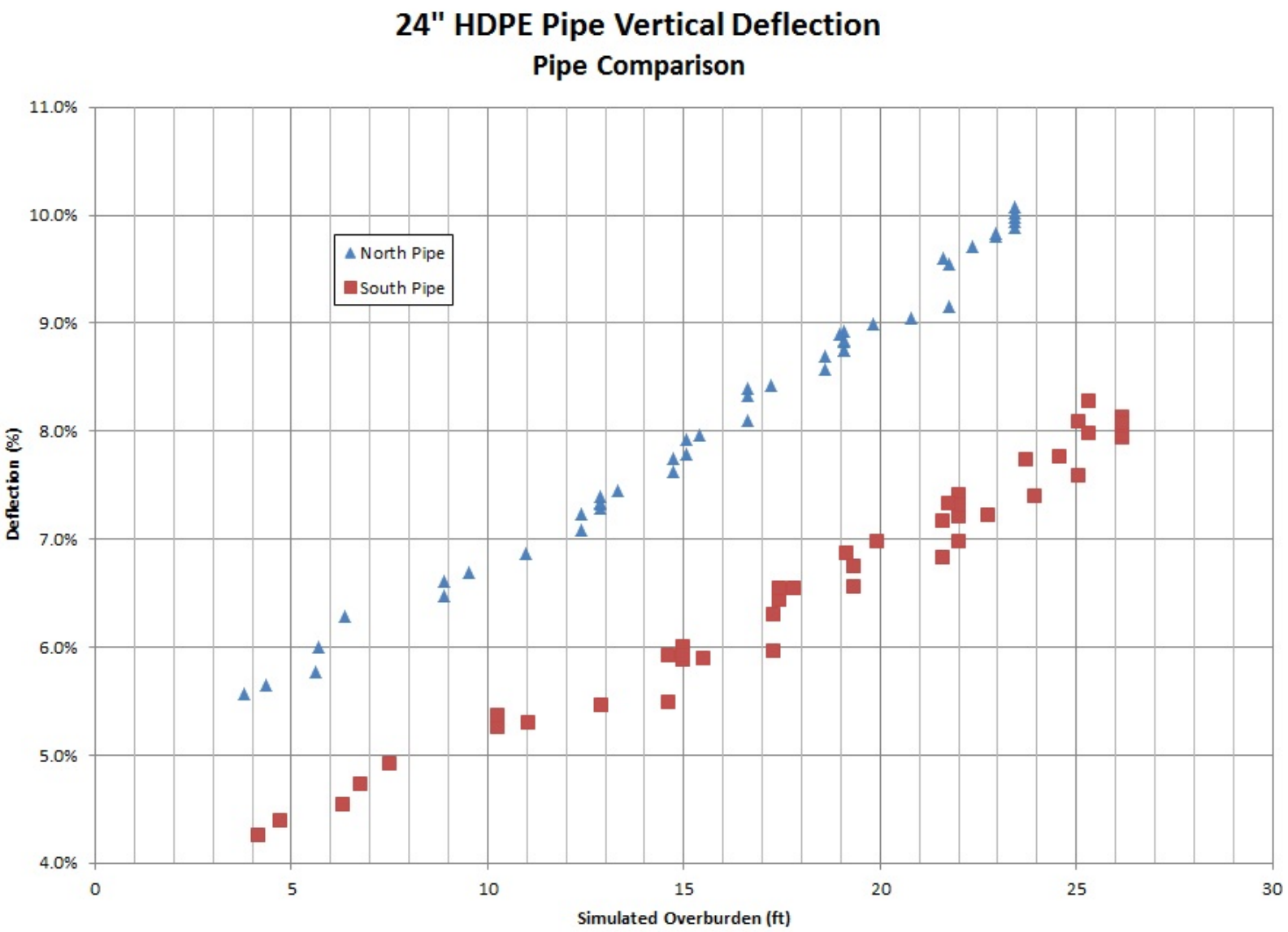



Figure 4-10. Deflection comparison of 24” HDPE pipes.

# CHAPTER 5
# 24 INCH STEEL PIPE TEST

## 5.1 Test Modifications

Similar modifications to the 24 inch diameter HDPE pipe test were required for the 24 inch diameter steel pipe test. The locations of the pressure cells were modified to account for the smaller pipe diameter; these locations are shown in Appendix C. A steel ring was spot welded onto each end of the steel pipes to allow assembly to the flexible membrane system.

## 5.2 Results

The North steel pipe appeared to produce approximately uniform deflection along its length (Figure 5-1). Results appear to show creep deflections in this pipe over a 24 hour time period (Figure 5-2). A deflection versus simulated overburden plot of three points in the South steel pipe displays a 1.5% deflection discrepancy between each end of the pipe (Figure 5-3). The creep characteristics for the South HDPE pipe over a 24 hour time period displays a similar upward trend (Figure 5-4).

A comparison of the North and South pipe deflections appears to be approximately equal during the loading sequence (Figure 5-5).

Table 5-1. Simulated overburden for 24 inch steel pipe test.

| Pressure Applied to Main Regulator (PSI) | Deflection Readings taken x hours after pressure was applied | Simulated Overburden Over North Steel Pipe (feet) | Simulated Overburden Over South Steel Pipe (feet) |
|---|---|---|---|
| 0 | 1 | 6.6 | 7.3 |
| 5 | 1 | 8.3 | 9.3 |
| 10 | 1 | 10.0 | 11.3 |
| 15 | 1 | 12.0 | 13.4 |
| 20 | 1 | 13.5 | 14.9 |
| 25 | 1 | 15.3 | 16.8 |
| 30 | 1 | 17.2 | 18.9 |
| 35 | 1 | 19.0 | 20.7 |
| 40 | 1 | 20.8 | 22.8 |
| 45 | 1, 4, 8, 24 | 22.7 | 25.0 |
| 50 | 1 | 24.4 | 26.5 |
| 55 | 1 | 25.9 | 28.2 |
| 60 | 1 | 27.8 | 30.3 |
| 65 | 1 | 29.7 | 32.4 |
| 70 | 1 | 30.5 | 33.1 |
| 75 | 1 | 32.2 | 35.0 |
| 80 | 1 | 33.3 | 36.1 |
| 85 | 1 | 35.0 | 38.0 |
| 90 | 1, 4, 8, 24 | 37.2 | 40.4 |
| 95 | 1 | 39.0 | 42.1 |
| 100 | 1 | 40.4 | 43.5 |
| 105 | 1 | 42.1 | 45.2 |
| 110 | 1 | 43.5 | 46.6 |
| 115 | 1 | 44.5 | 47.7 |
| 120 | 1 | 45.9 | 49.1 |
| 125 | 1 | 47.6 | 51.0 |
| 130 | 1, 4, 8, 24 | 48.5 | 51.6 |

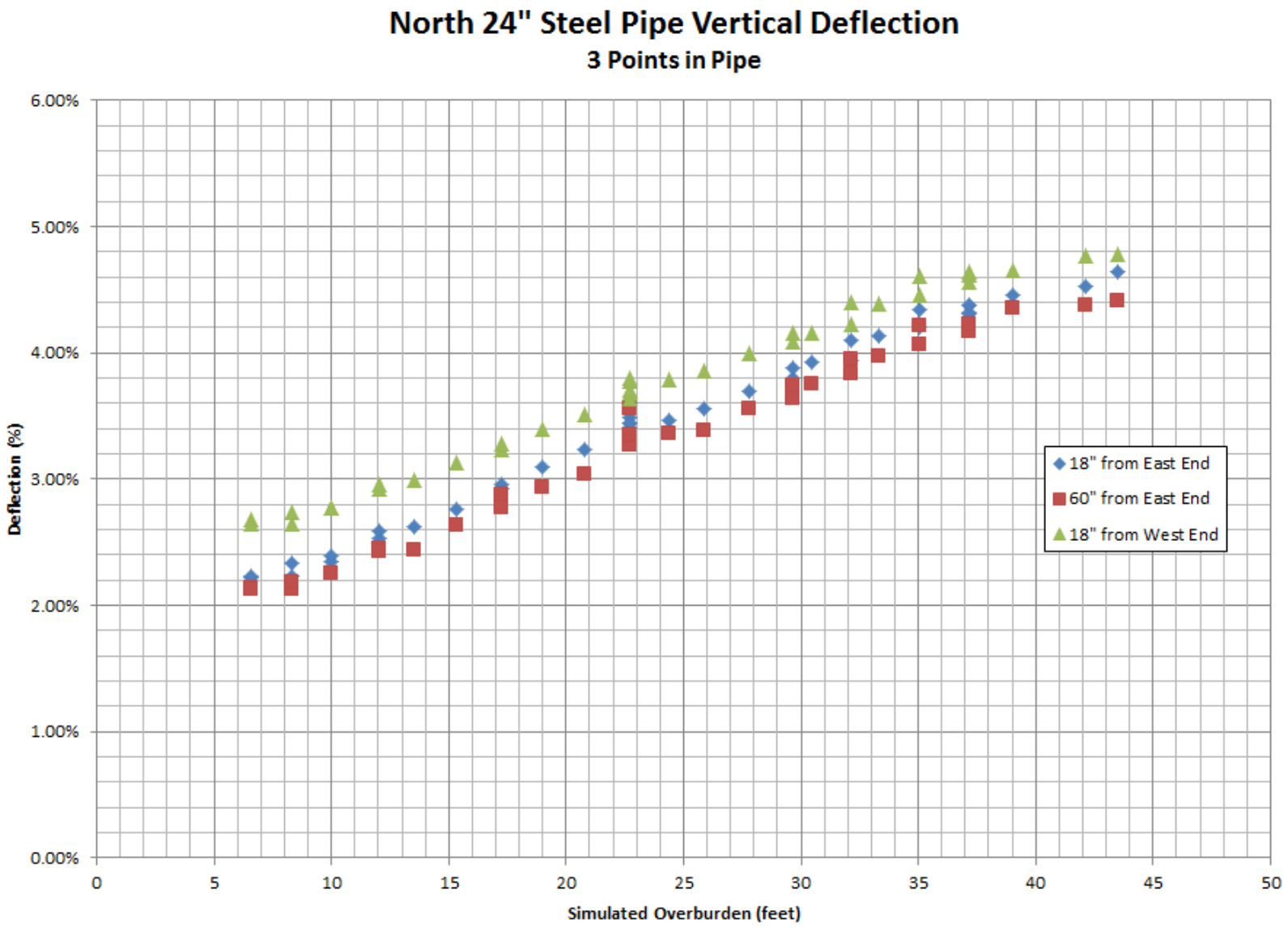



Figure 5-1. Three points in North 24” steel pipe, deflection versus simulated overburden.

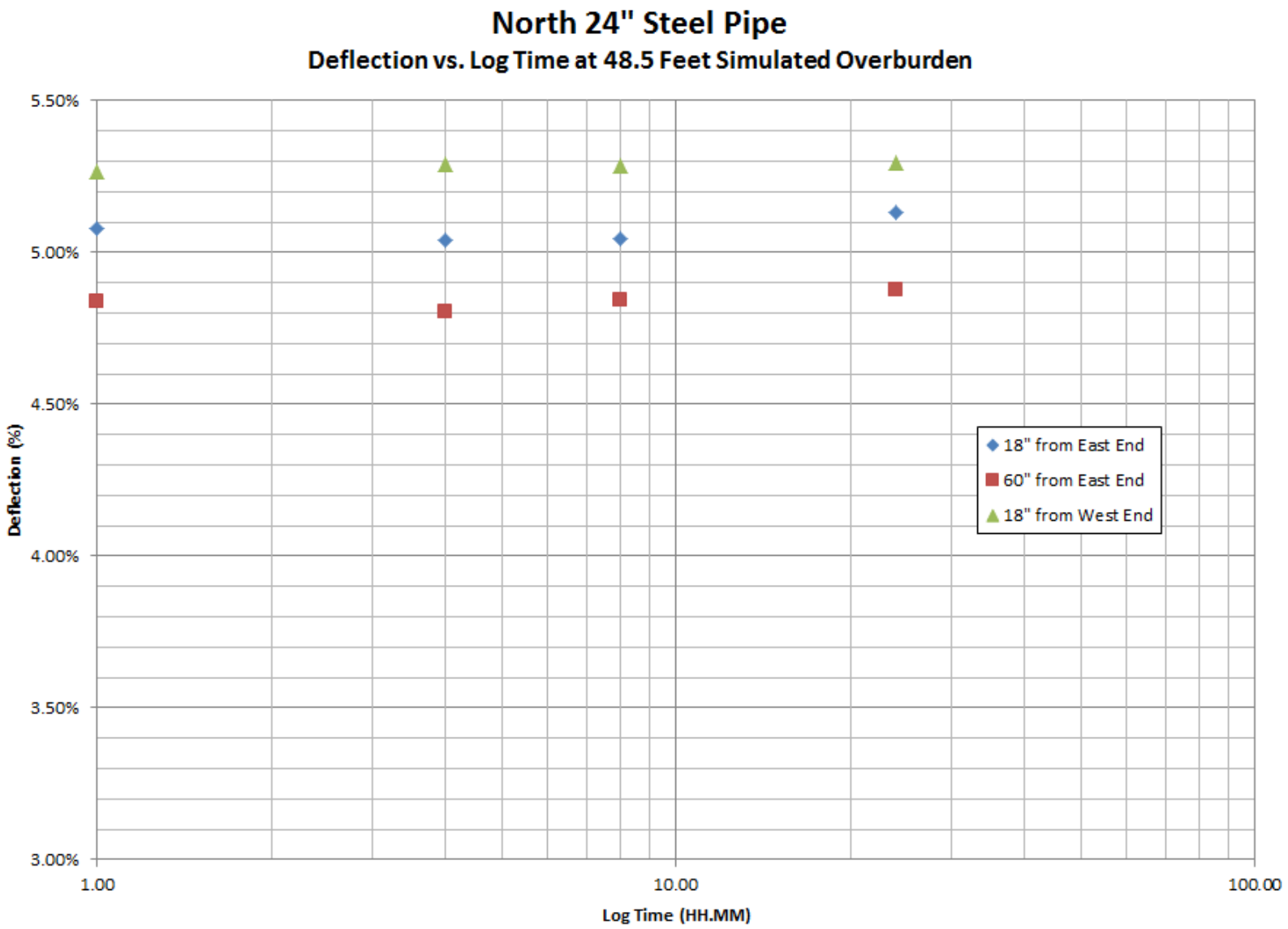



Figure 5-2. Deflection of North 24” steel pipe under 48.5ft of simulated overburden over 24 hours.

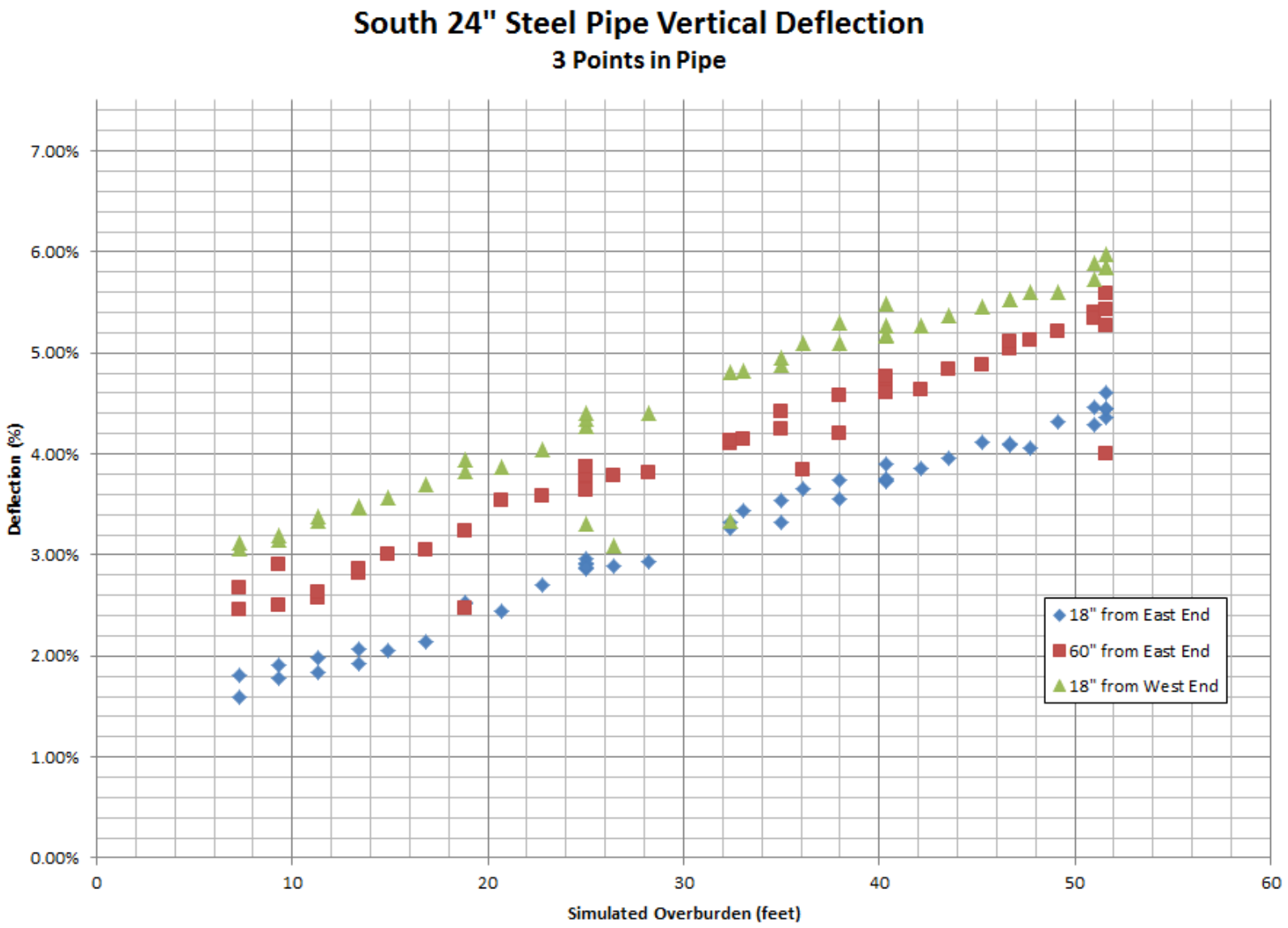



Figure 5-3. Three points in South 24” steel pipe, deflection versus simulated overburden.

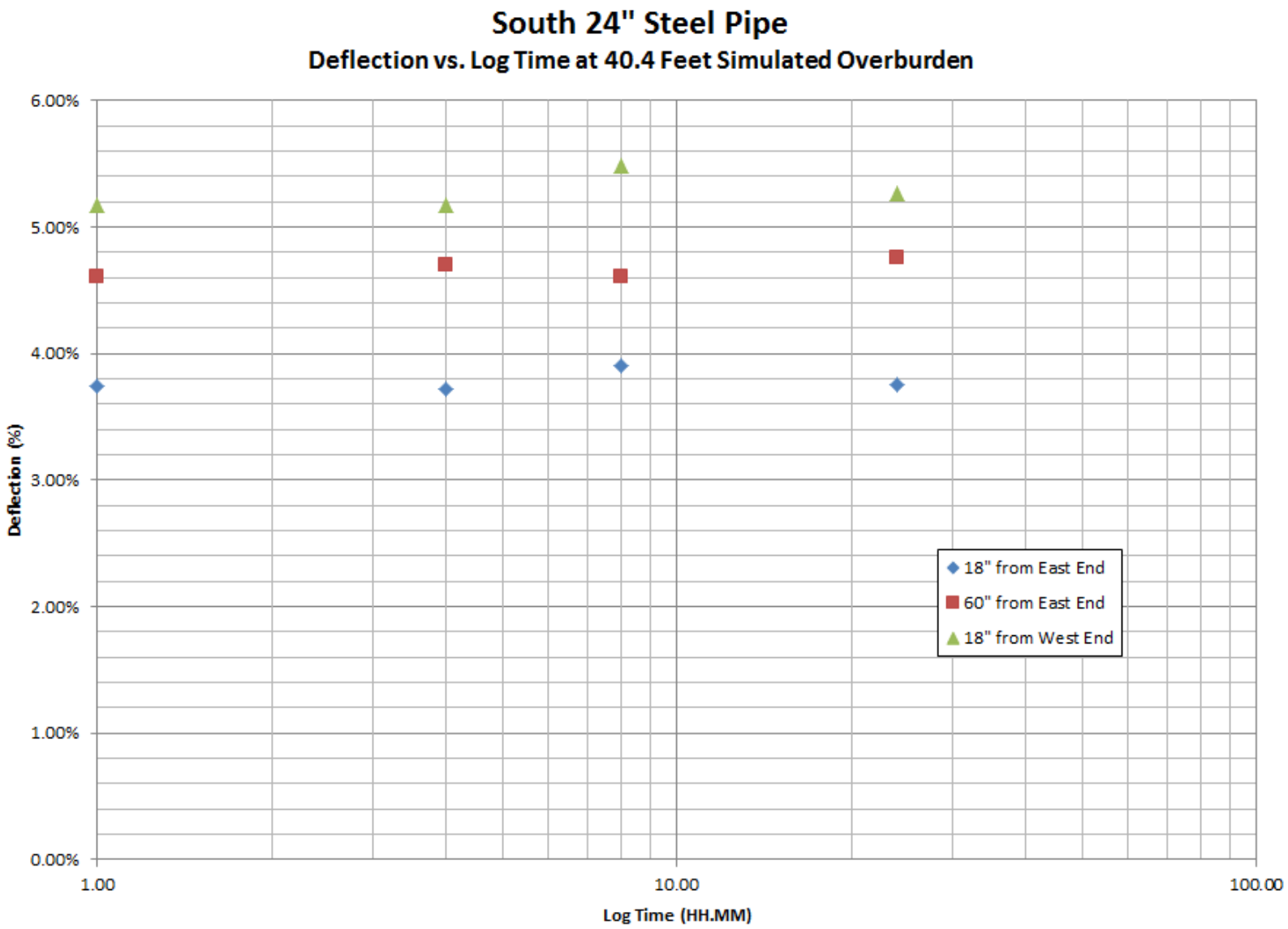



Figure 5-4. Deflection of North 24” steel pipe under 40.4ft of simulated overburden over 24 hours.

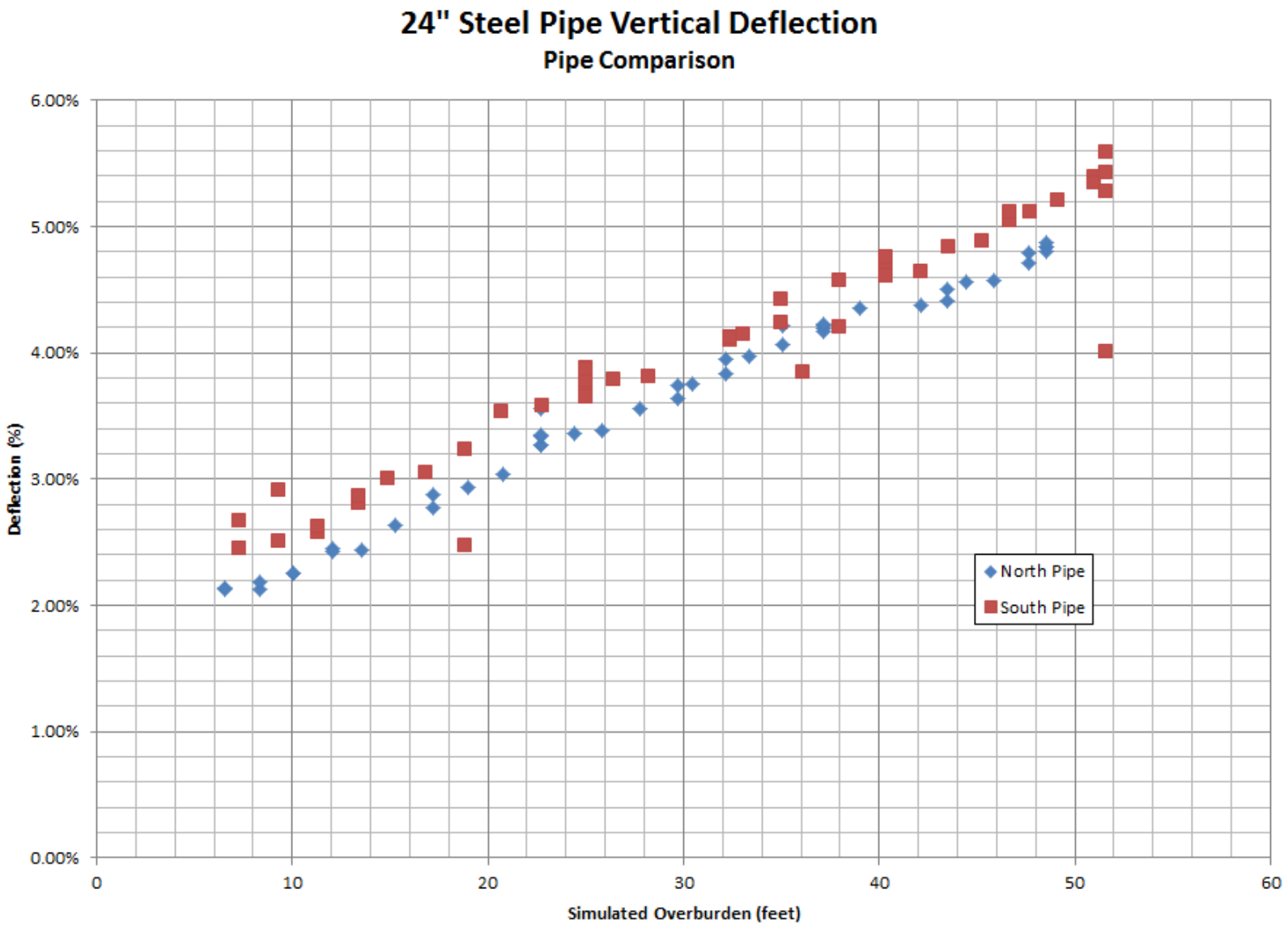



Figure 5-5. Deflection comparison of 24” steel pipes.

# CHAPTER 6
# CONCLUSION

The deflection data for the 36 inch HDPE pipe with trench box, 36 inch aluminum pipe, and 24 inch HDPE and steel pipes displayed trends expected for their specified material type. The greatest deflections occurred in the 36 inch HDPE pipe with trench box installation followed by the 24 inch HDPE pipes. The 36 inch aluminum pipe and 24 inch steel pipes deflected the least.

The differences in simulated overburden, as shown in Figure 6-1, can be attributed to the density variability of the soil backfill and the variable contact stresses in the loading mechanism. Contour plots of each test at various loading increments can be seen in Figures 6-2 through 6-14. These plots display the stress variation in the Soil Box at eight inches above the pipe crown. The location of the pressure cells used in the contour plots can be seen in Figures 6-15 and 6-16.

The more flexible pipes (HDPE) measured deflections much greater than the stiffer pipes (steel) and resulted in smaller overburden pressures. During the loading sequence, the steel load plates settle with the soil. This causes a smaller contact area between the lift bags and load plates therefore reducing the simulated overburden. The use of multiple lift bags to apply simulated overburden resulted in an unknown pressure distribution across the soil surface. This uncertainty was diminished by monitoring the pressure cells placed throughout the Soil Box and deflection measurements recorded during loading. An improvement to this loading mechanism would be to use single rubber membrane across the entire surface area of the Soil Box.

Overall, the results obtained through this research show good development of flexible pipe response subjected to overburden stress. Pending a comparison with the

FEM analysis, the results can better aid the FDOT identify pipes whose deflections are within the 5% specification tolerance at time of inspection but may ultimately exceed this tolerance at the time of project acceptance.

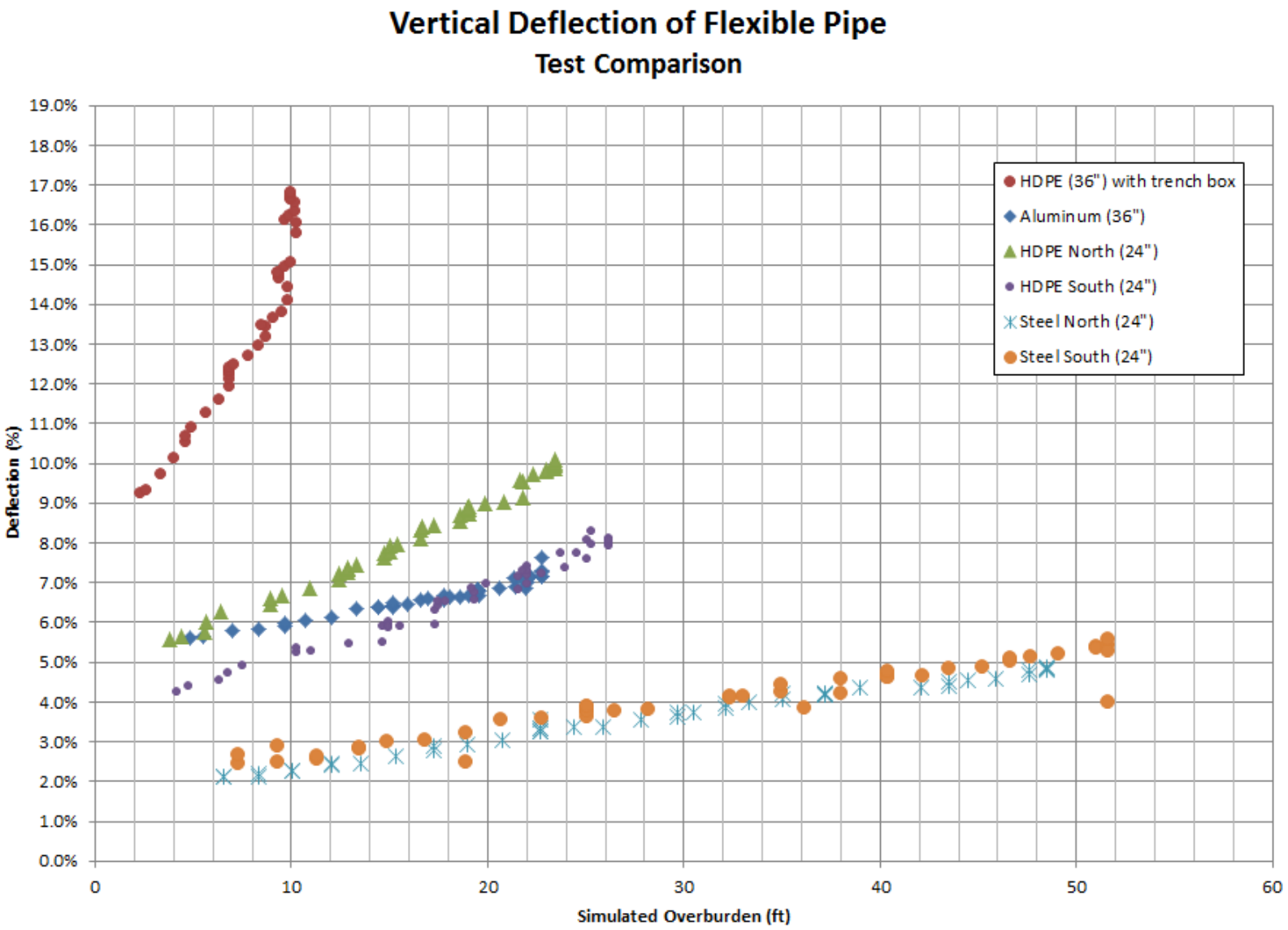
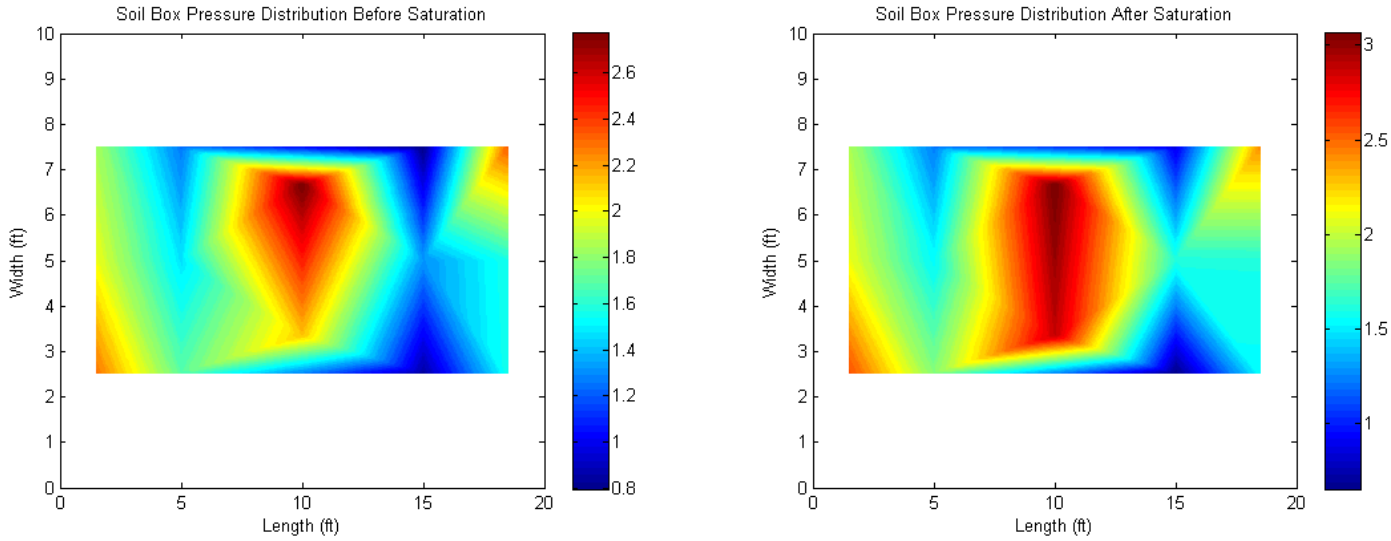
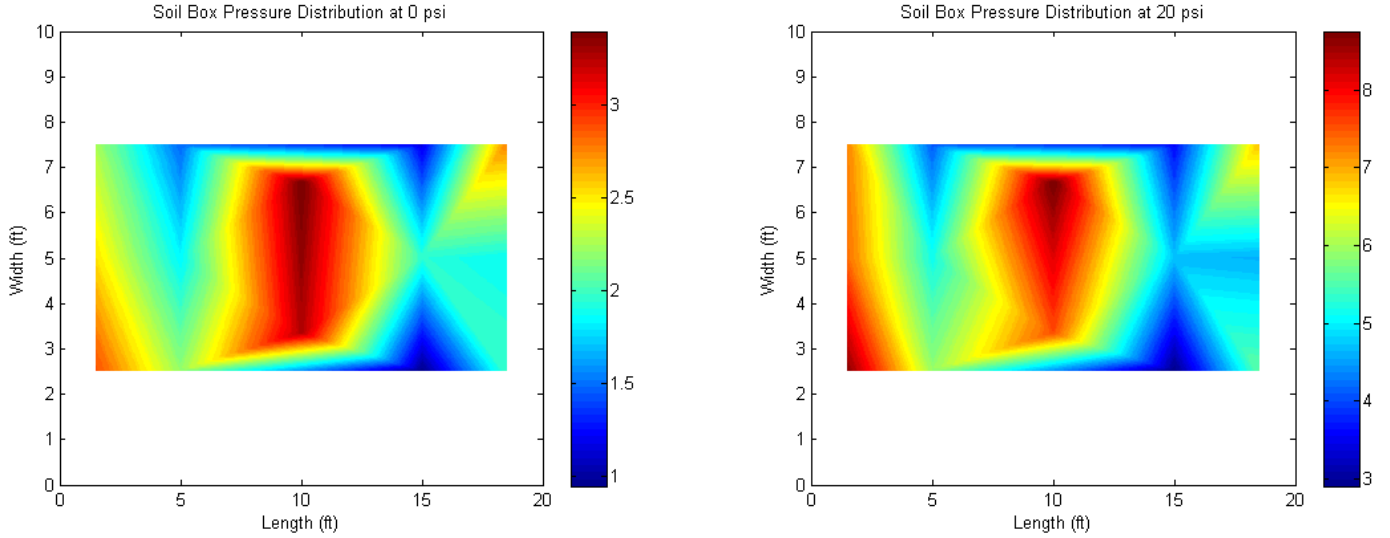



Figure 6-1. Deflection comparison of tested pipes.



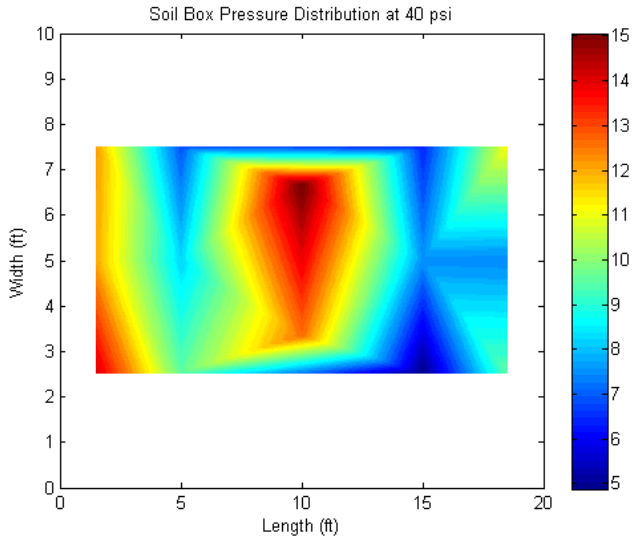

A B

Figure 6-2. Stress distribution before and after saturation for 36 inch HDPE with trench box and 36 inch aluminum pipes.

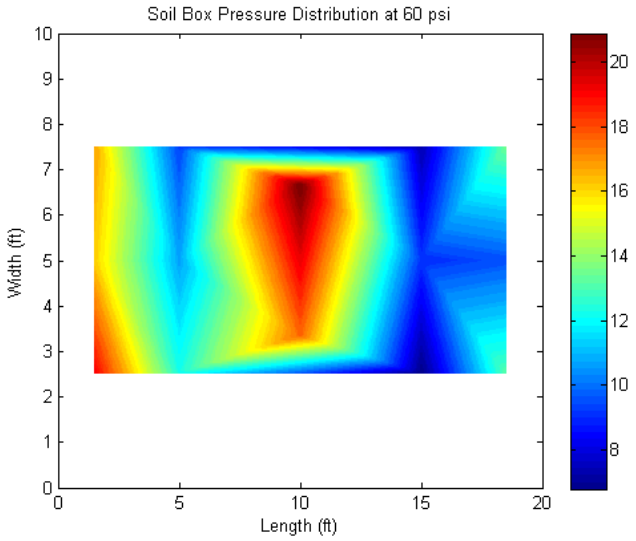



A B

Figure 6-3. Stress distribution at 0 psi and 20 psi for 36 inch HDPE with trench box and 36 inch aluminum pipes.

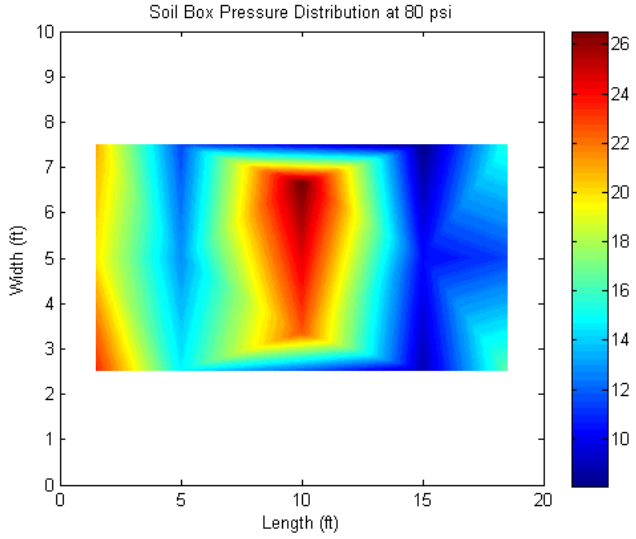



A

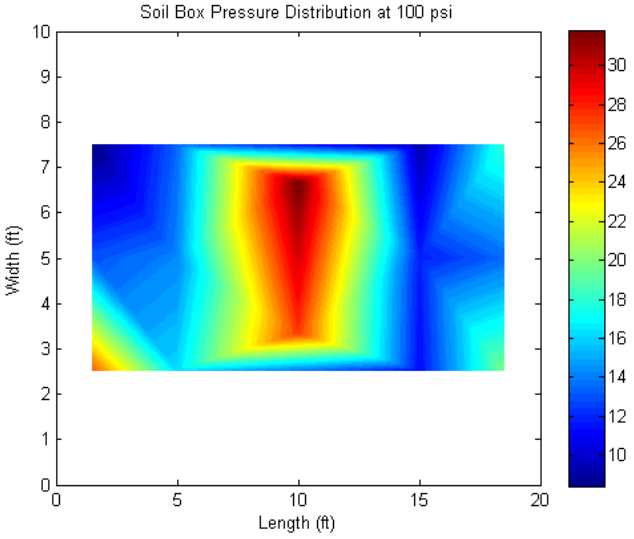



B

Figure 6-4. Stress distribution 40 psi and 60 psi for 36 inch HDPE with trench box and 36 inch aluminum pipes.

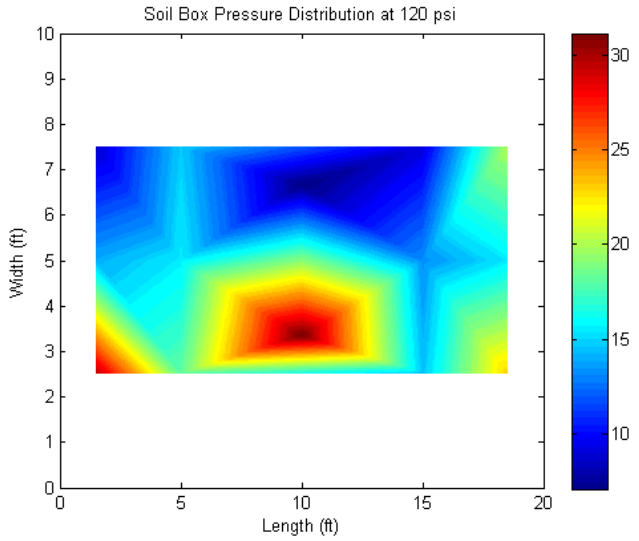



A

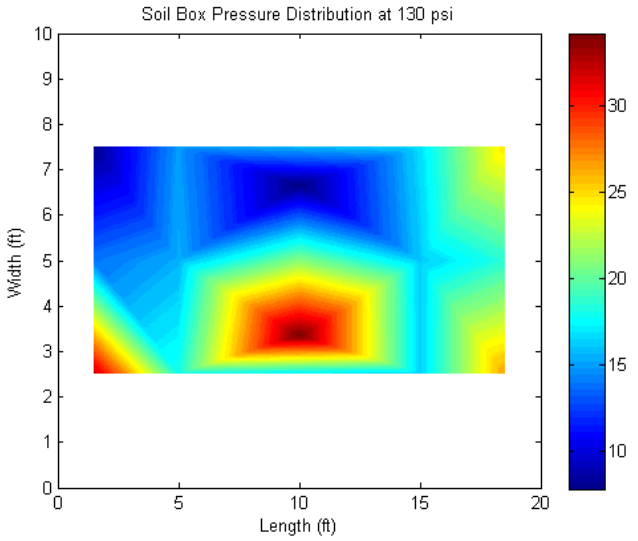



B

Figure 6-5. Stress distribution at 80 psi and 100 psi for 36 inch HDPE with trench box and 36 inch aluminum pipes.

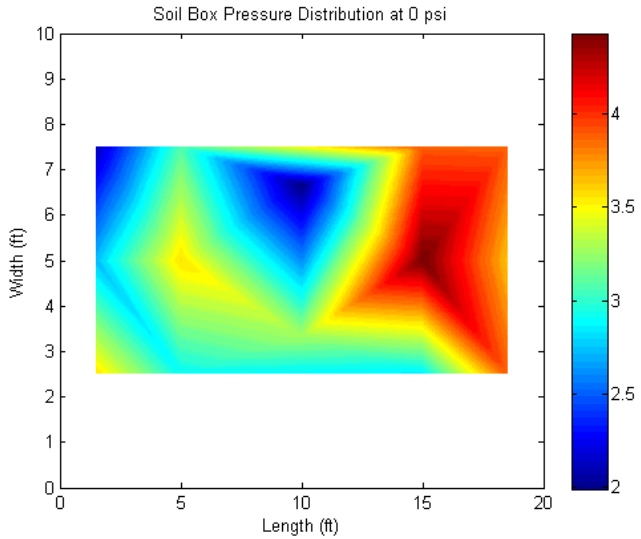



A




B

Figure 6-6. Stress distribution at 120 psi and 130 psi for 36 inch HDPE with trench box and 36 inch aluminum pipes.

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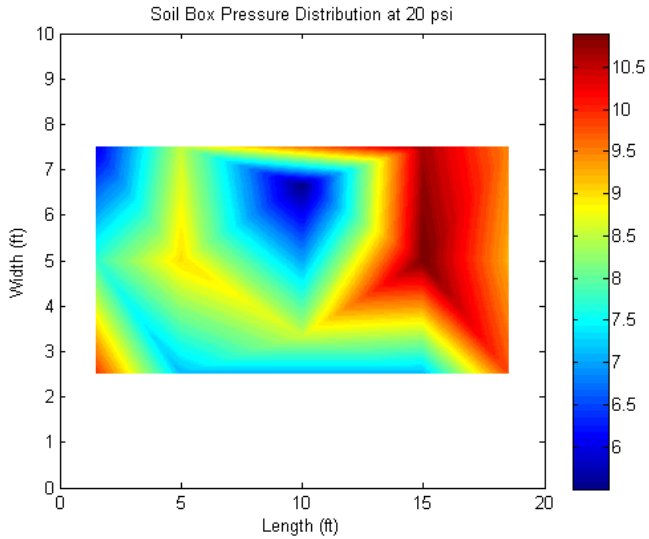
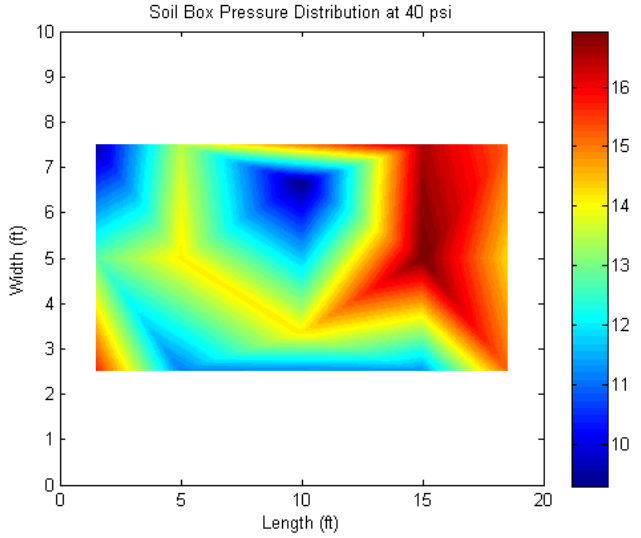
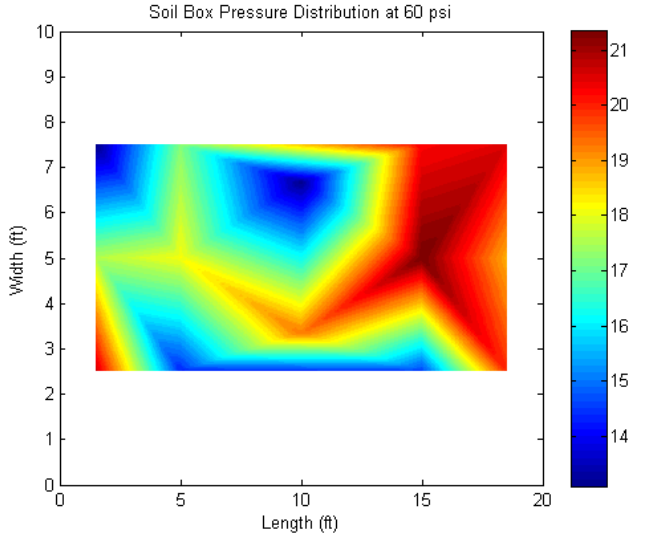



B

Figure 6-7. Stress distribution at 0 psi and 20 psi for dual 24 inch HDPE pipes.

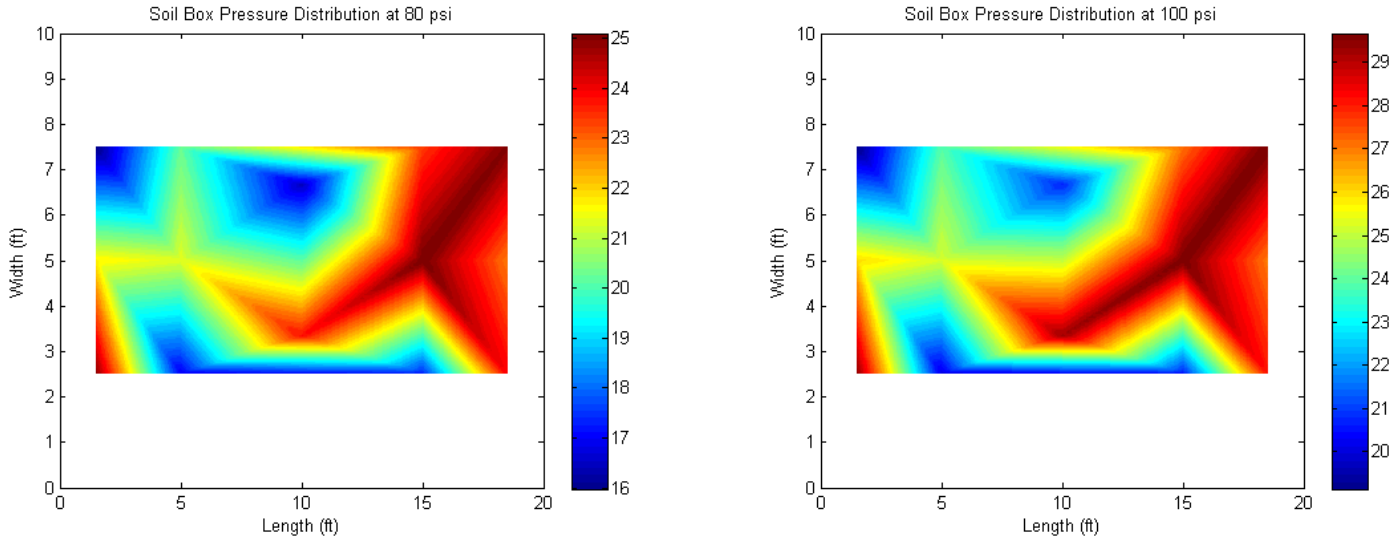



A



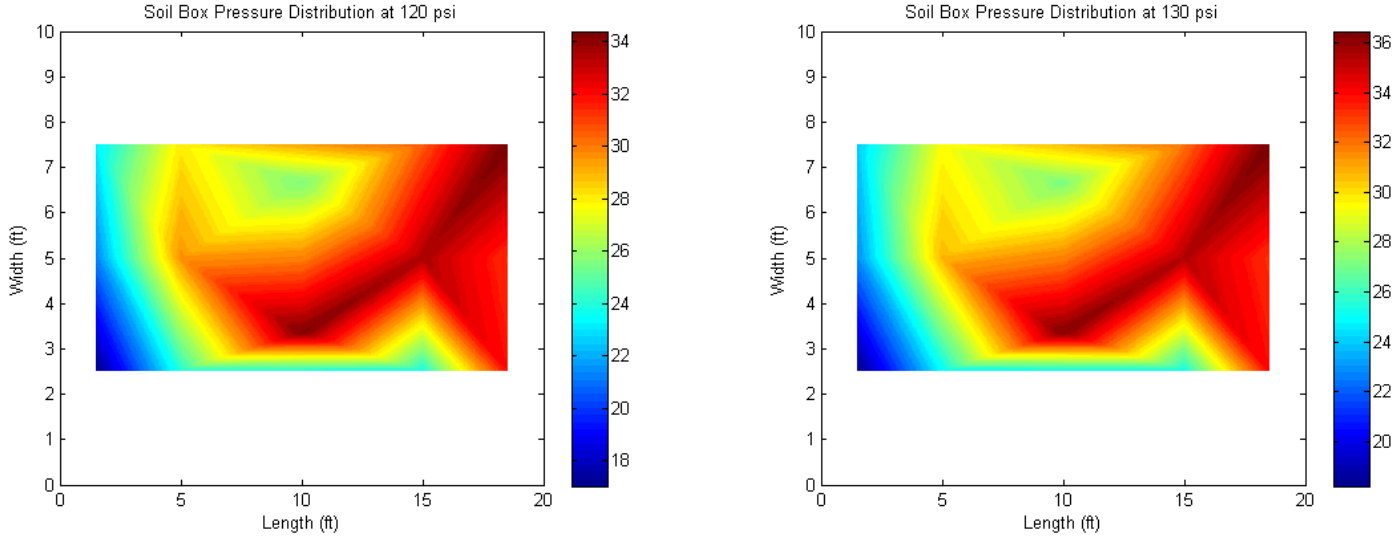

B

Figure 6-8. Stress distribution at 40 psi and 60 psi for dual 24 inch HDPE pipes.



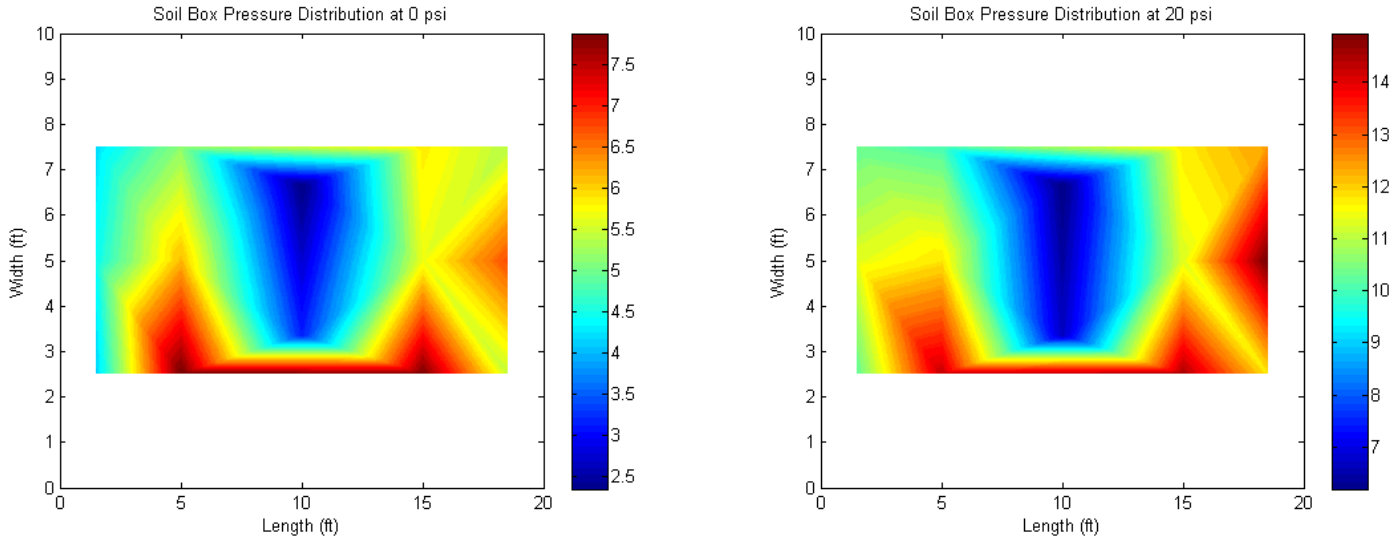

A B

Figure 6-9. Stress distribution at 80 psi and 100 psi for dual 24 inch HDPE pipes.



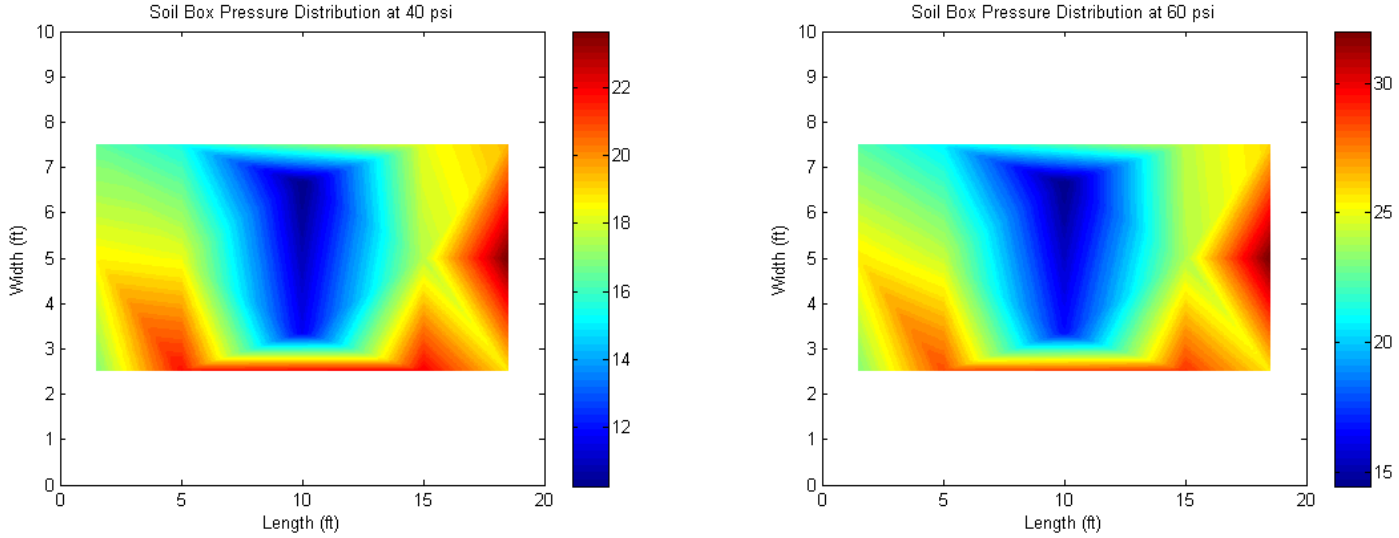

A B

Figure 6-10. Stress distribution at 120 psi and 130 psi for dual 24 inch HDPE pipes.



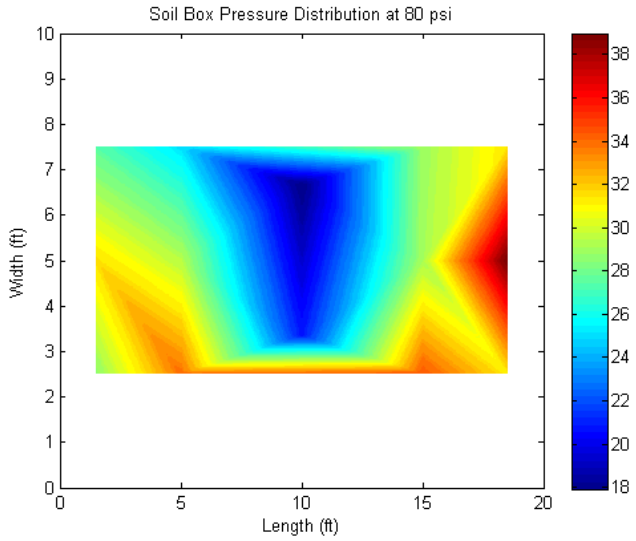

A B

Figure 6-11. Stress distribution at 0 psi and 20 psi for dual 24 inch steel pipes.

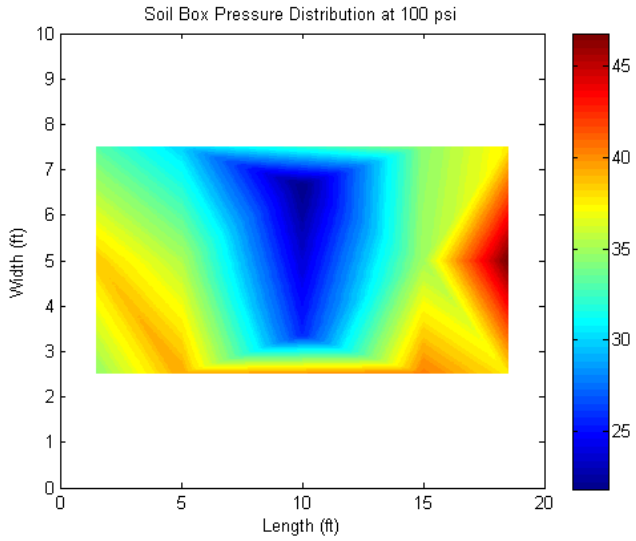



A B

Figure 6-12. Stress distribution at 40 psi and 60 psi for dual 24 inch steel pipes.

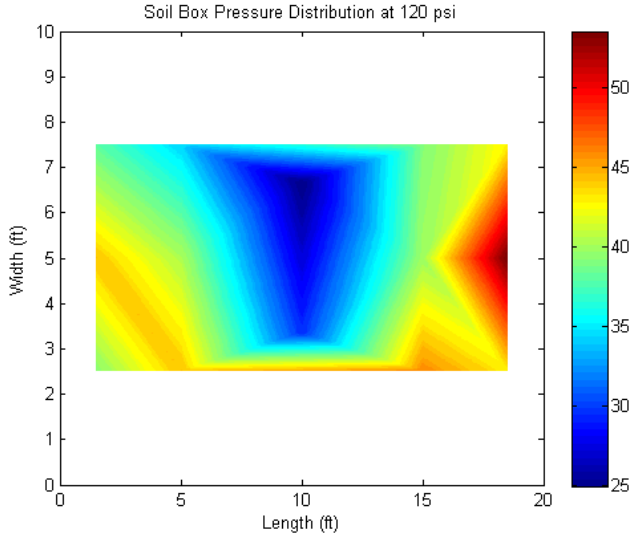



A

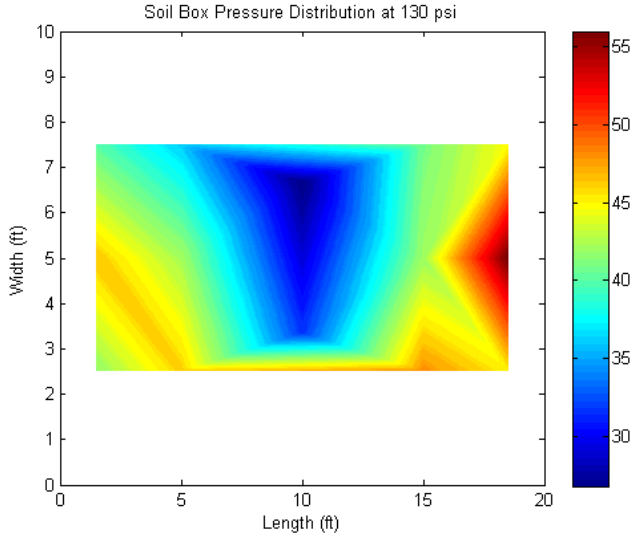



B

Figure 6-13. Stress distribution at 80 psi and 100 psi for dual 24 inch steel pipes.




A




B

Figure 6-14. Stress distribution at 120 psi and 130 psi for dual 24 inch steel pipes.

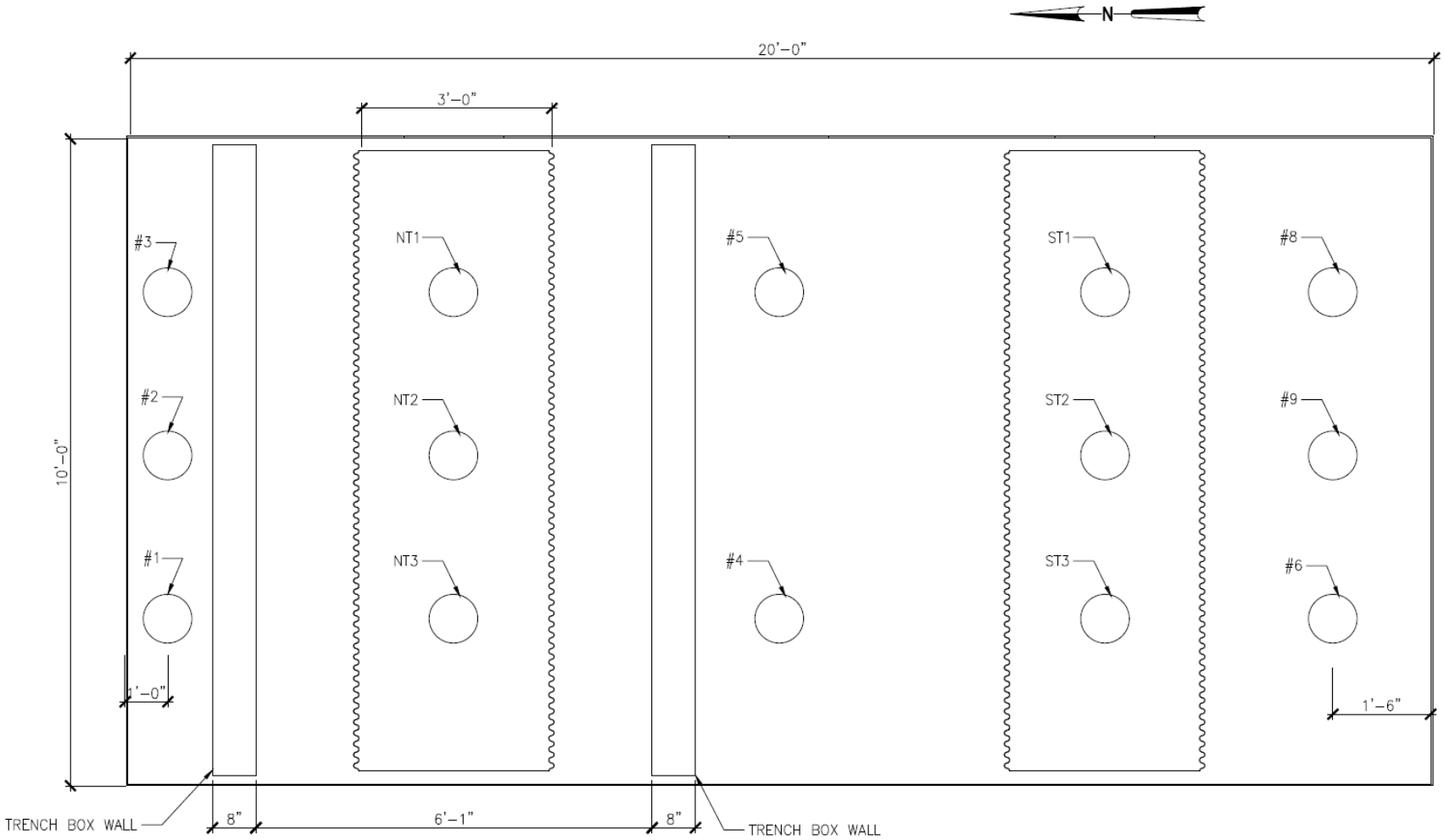



Figure 6-15. Contour plot pressure cell layout for 36 inch HDPE with trench box and 36 inch aluminum pipes.

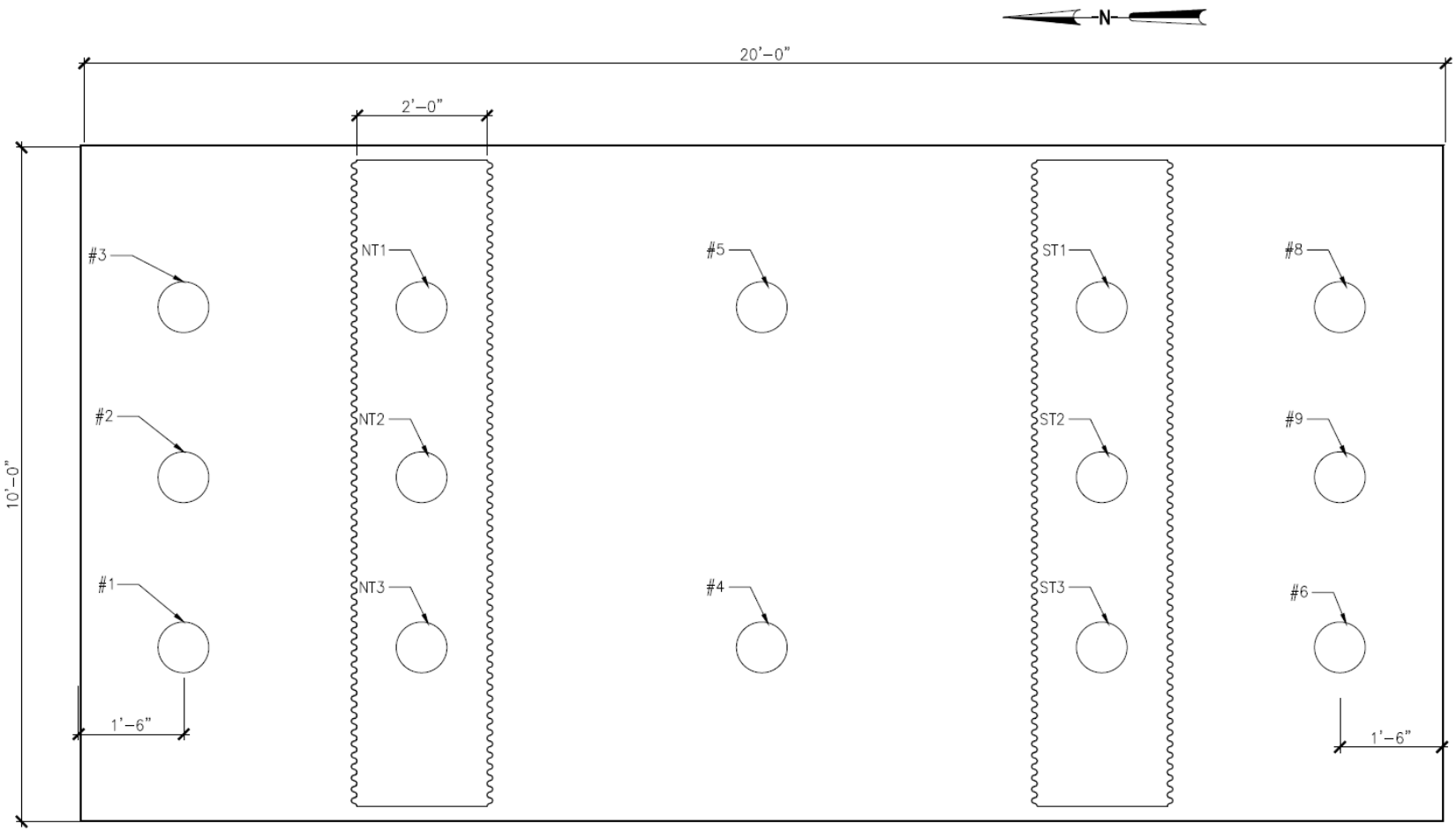
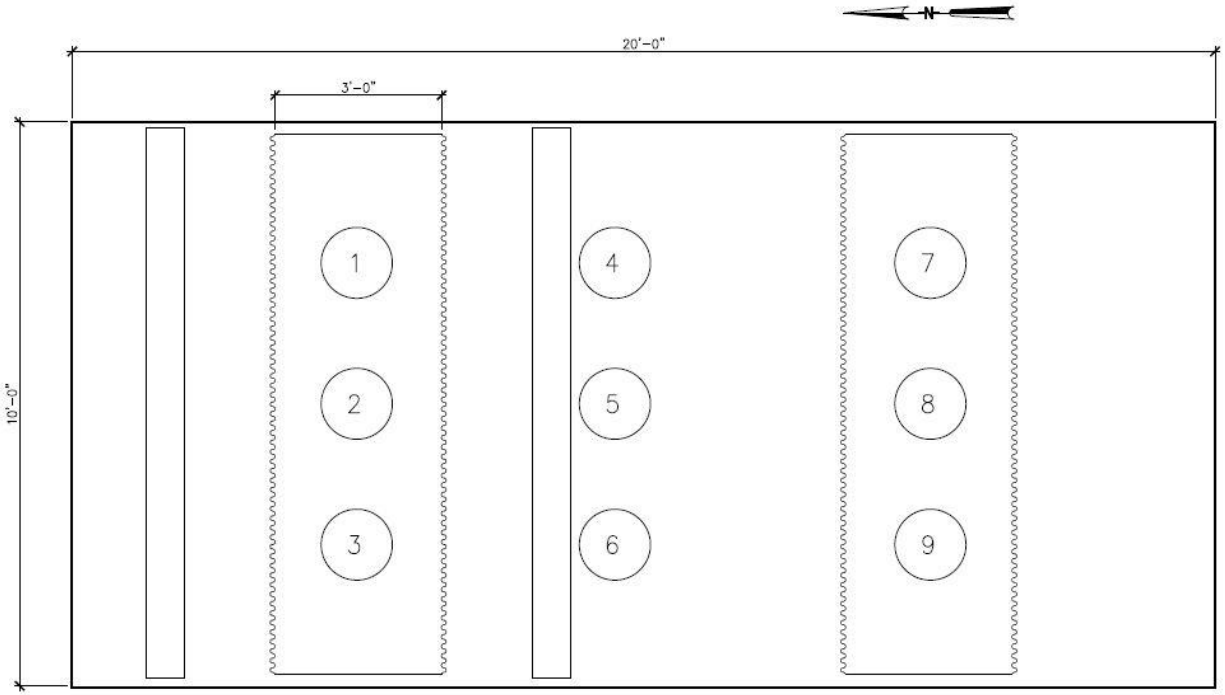



Figure 6-16. Contour plot pressure cell layout for dual 24 inch HDPE and steel pipes.

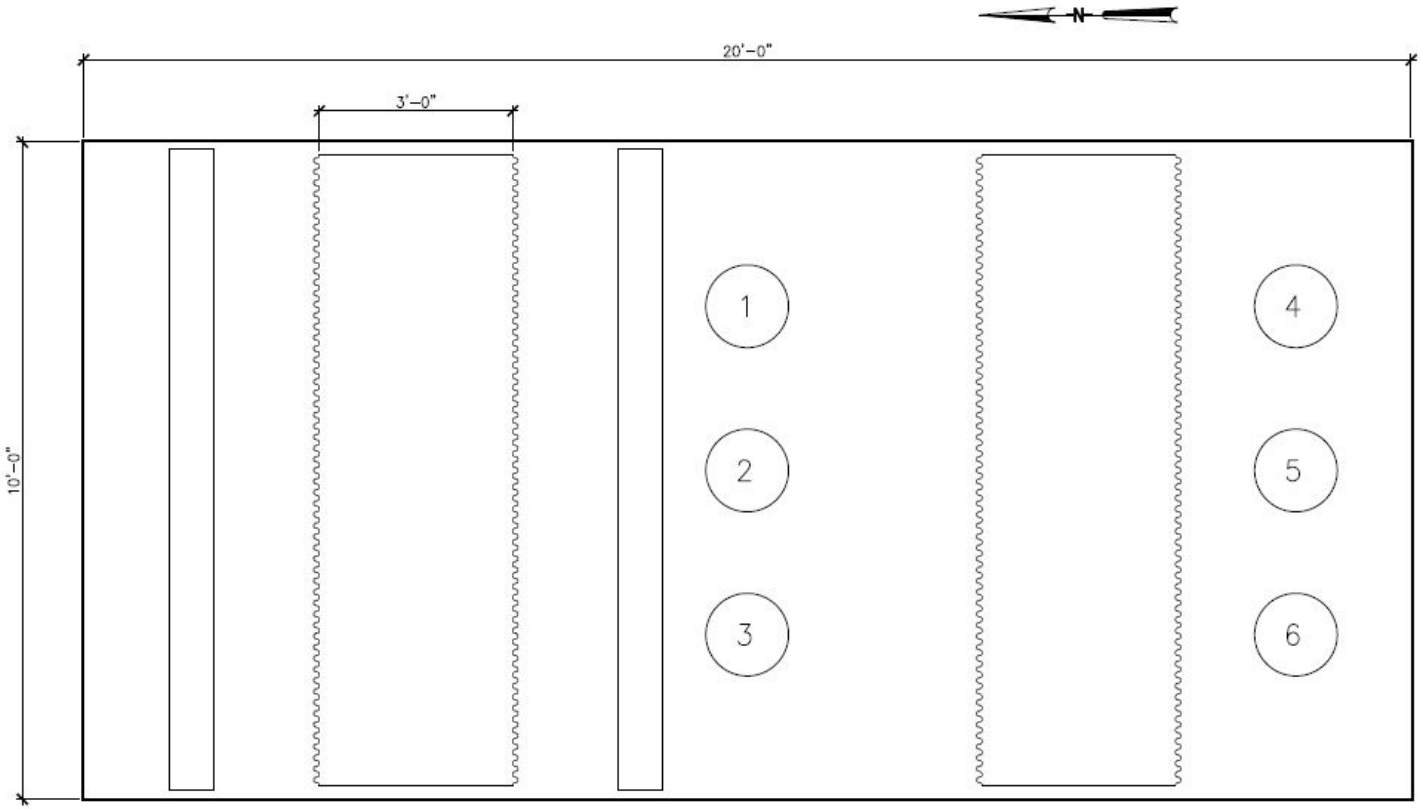
APPENDIX A
36” HDPE PIPE WITH TRENCH BOX AND 36” ALUMINUM PIPE TEST

**Nuclear Density Test Locations**




**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON 05-02-2012**
**12" FROM BOTTOM**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | | DRAWN BY: JP-KP |
| PROJECT #: | BDK75 977-21 | DATE: | 03-16-2012 |
| SCALE: | 1:30 | PAGE: | C-17 OF C-21 |




**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON**
**05-15-2012 & 05-18-2012**
**2.5' & 4' FROM BOTTOM**

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|---|---|---|---|
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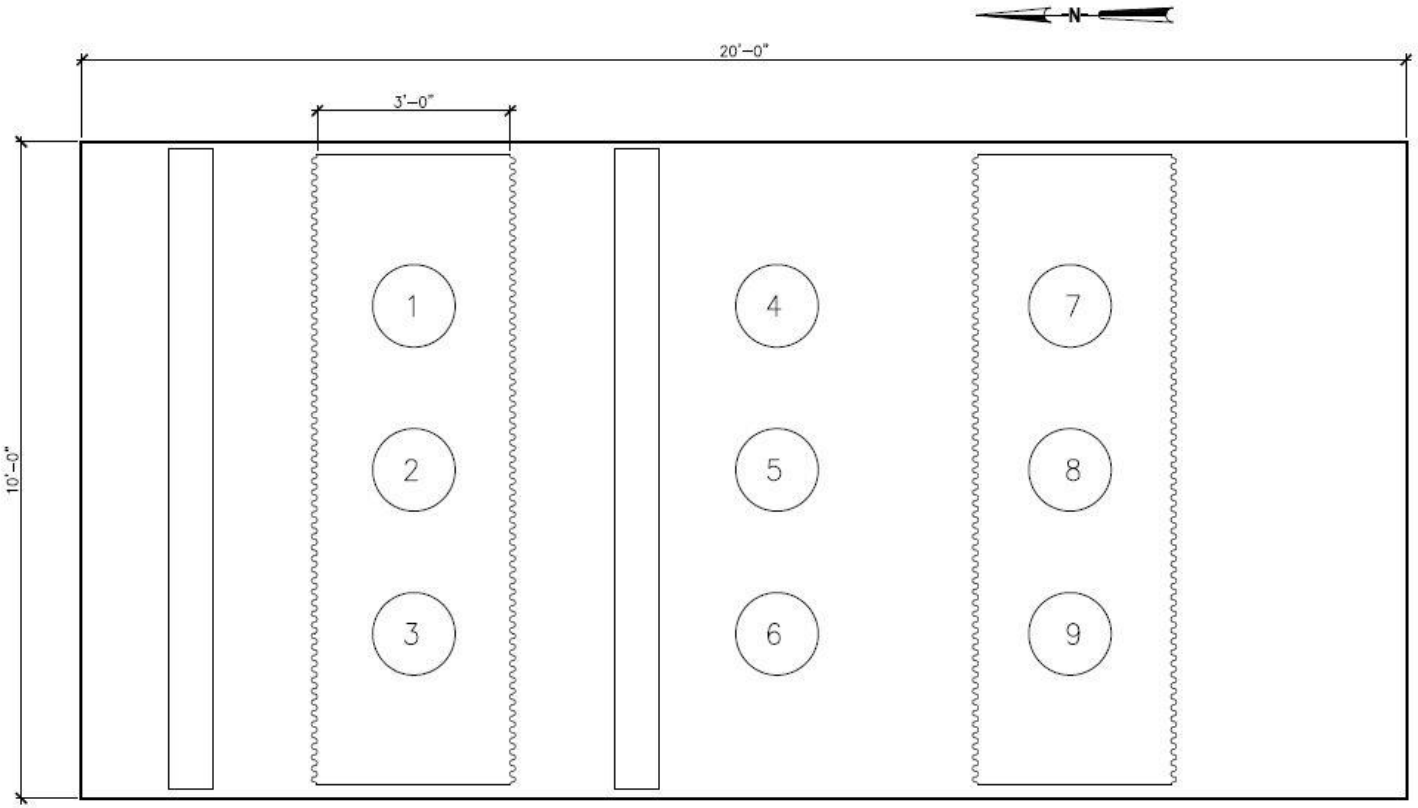
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | | DRAWN BY: JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | 03–16–2012 |
| SCALE: | 1:30 | PAGE: | C–18 OF C–21 |




**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON**
**05-22-2012 & 05-30-2012**
**5.5' & 7.5' FROM BOTTOM**

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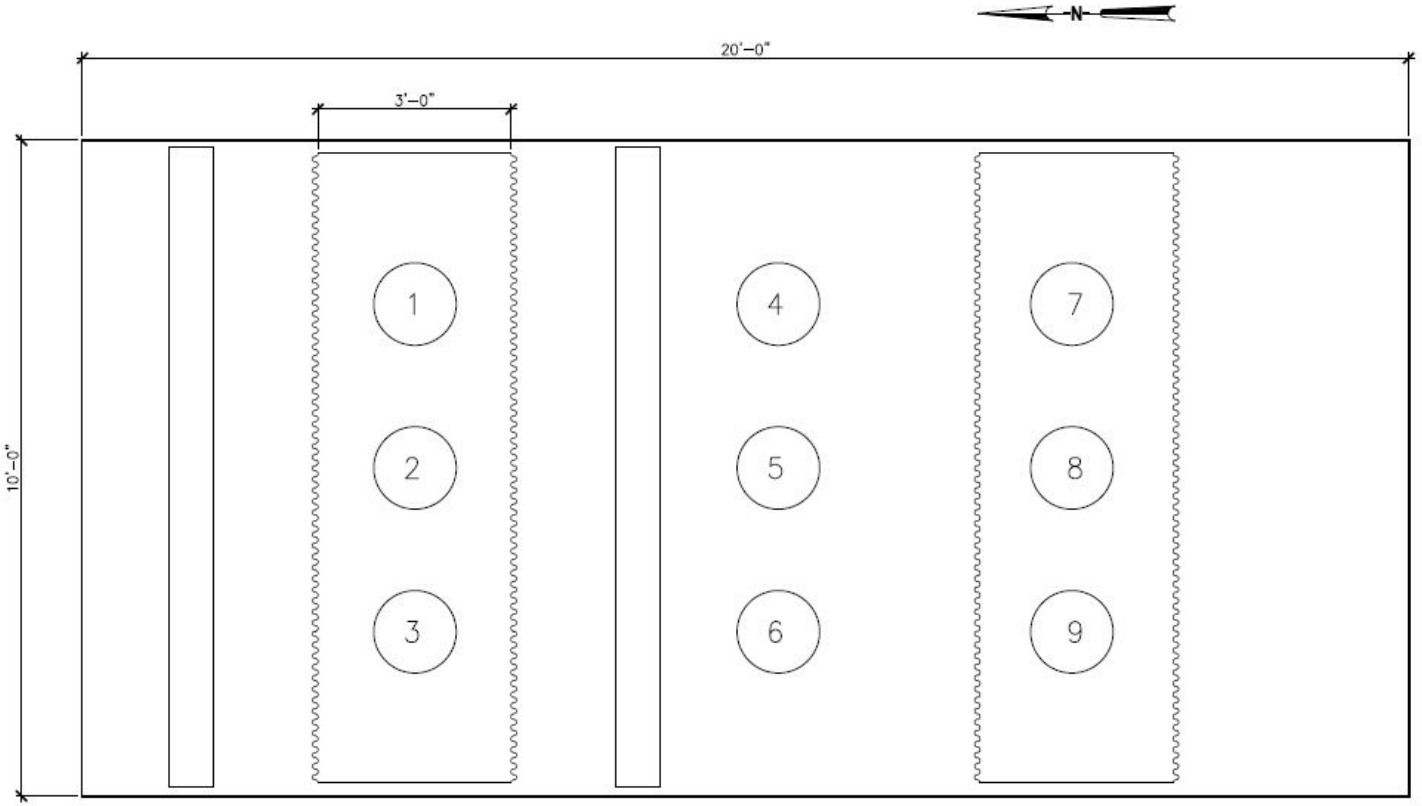
| DESIGNED BY: | D. BLOOMQUIST, P.E. | | DRAWN BY: JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | 03–16–2012 |
| SCALE: | 1:30 | PAGE: | C–18 OF C–21 |




**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON**
**06-07-2012 (POST-SATURATION)**
**7.5' FROM BOTTOM**

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| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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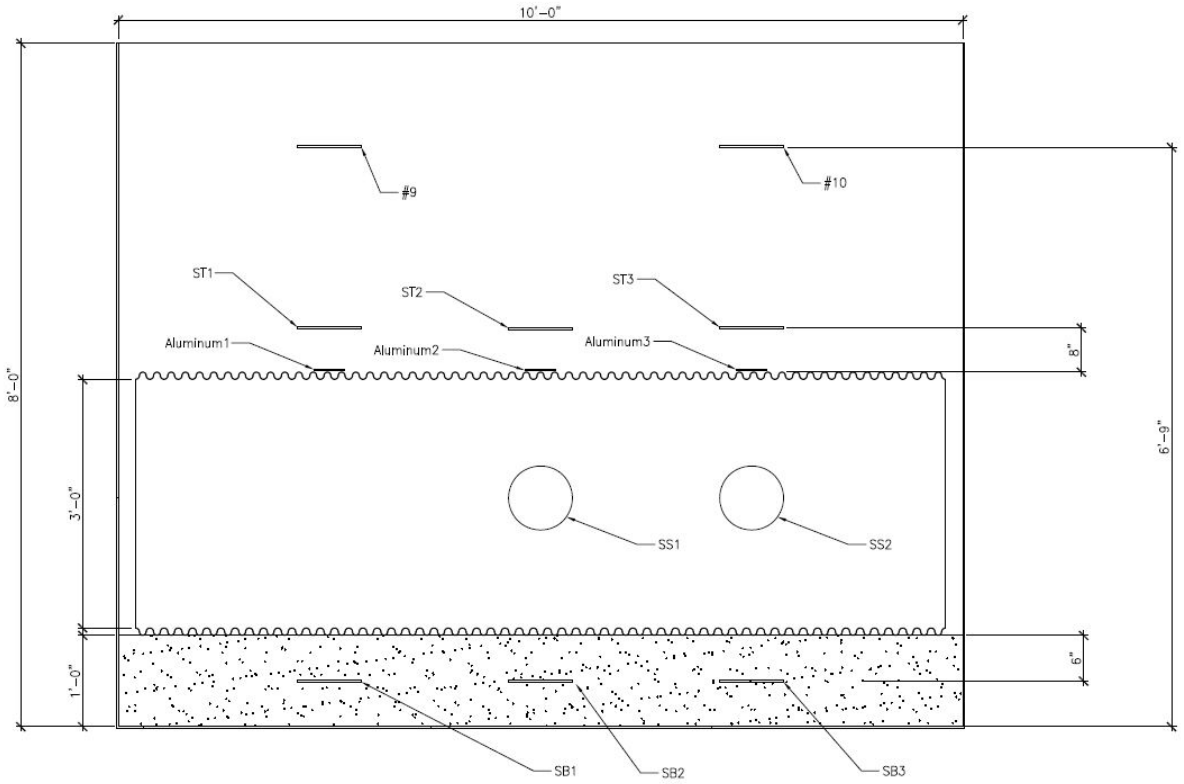
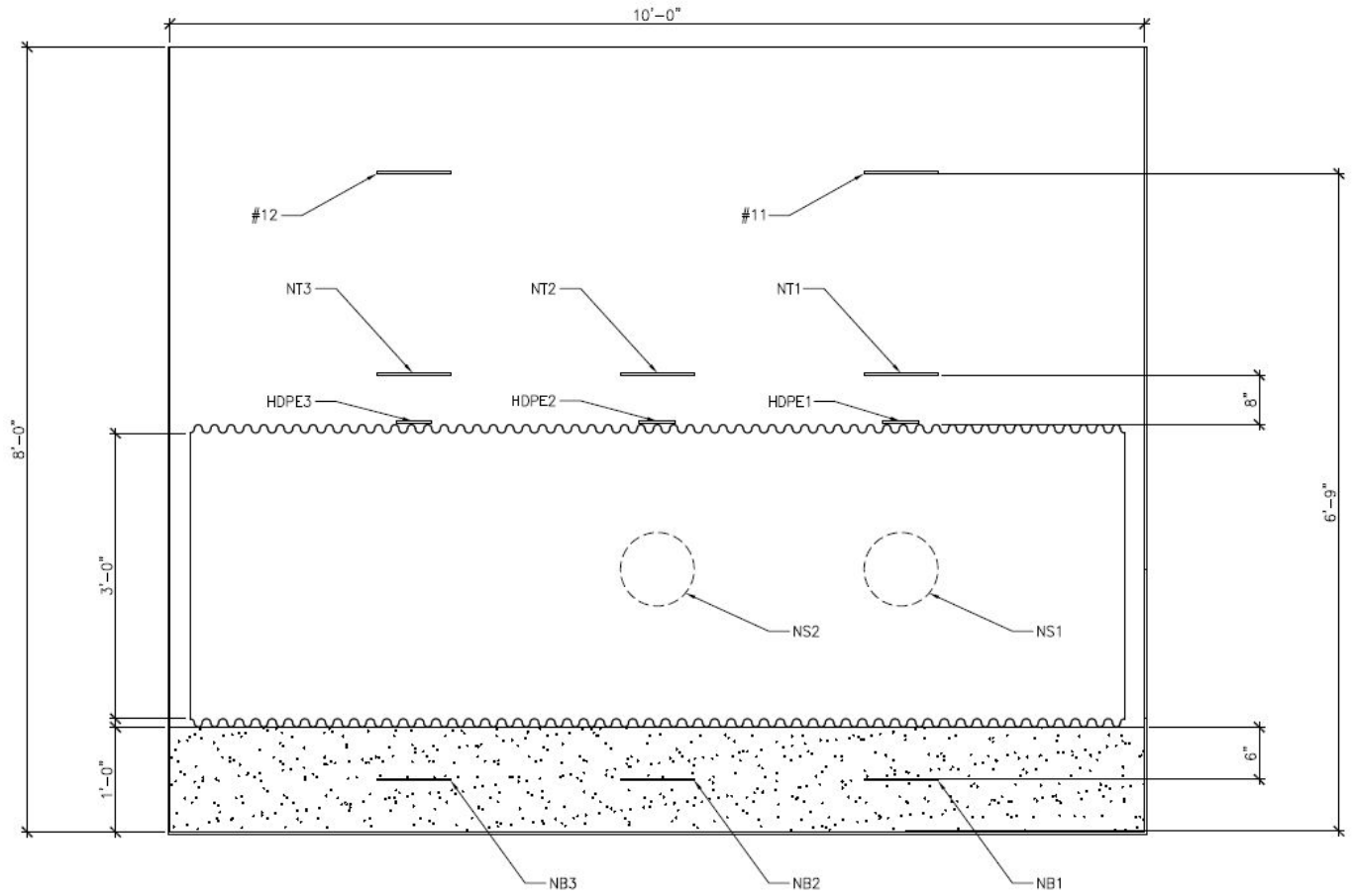
| DESIGNED BY: | D. BLOOMQUIST, P.E. | | DRAWN BY: JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | 03–16–2012 |
| SCALE: | 1:30 | PAGE: | C–18 OF C–21 |

## Earth Pressure Cell Locations




**SOIL BOX PROFILE VIEW**
**SECTION E-E**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | | DRAWN BY: JP-KP |
| PROJECT #: | BDK75 977-21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |




**SOIL BOX PROFILE VIEW**
**SECTION F-F**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
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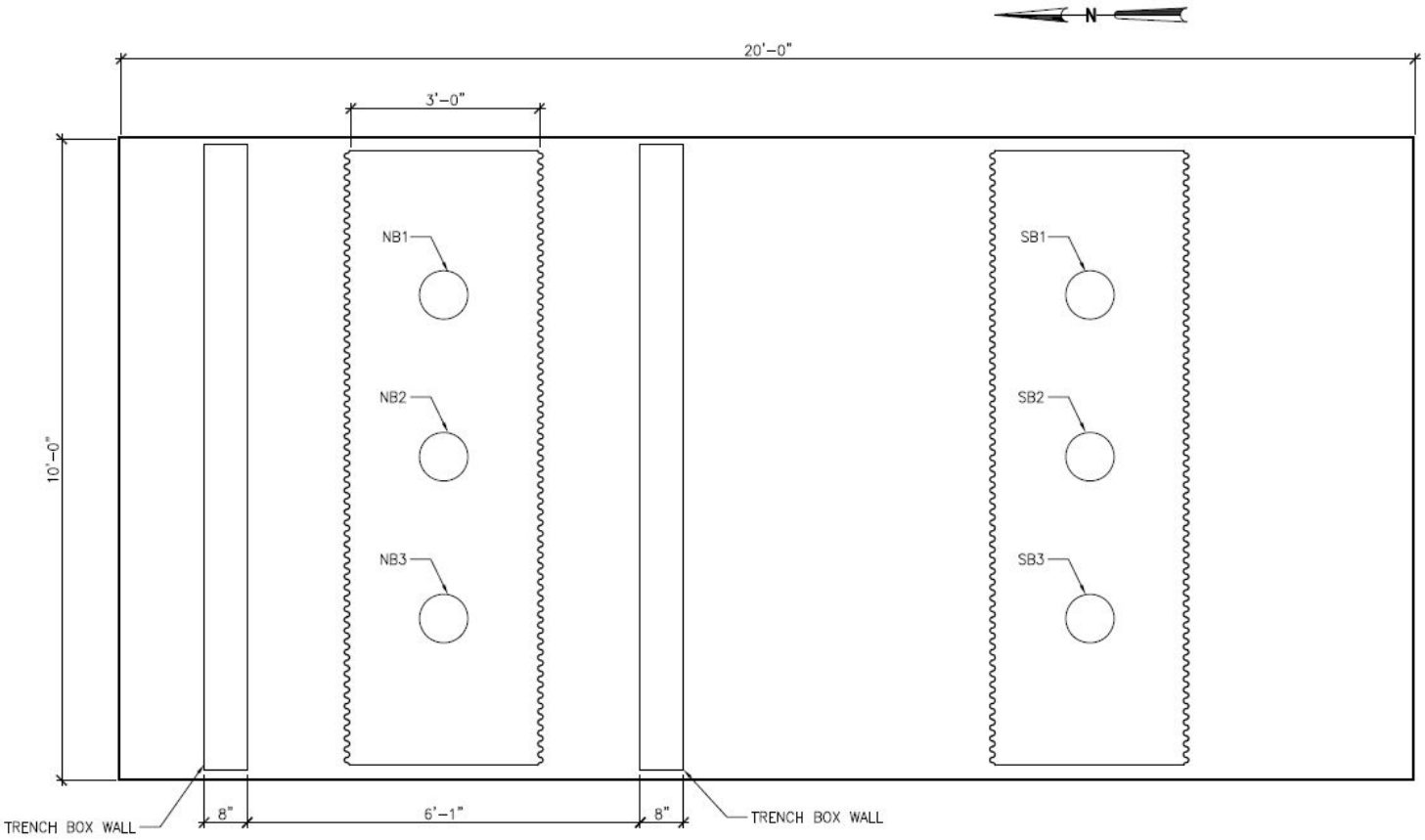


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 6" FROM BOTTOM**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
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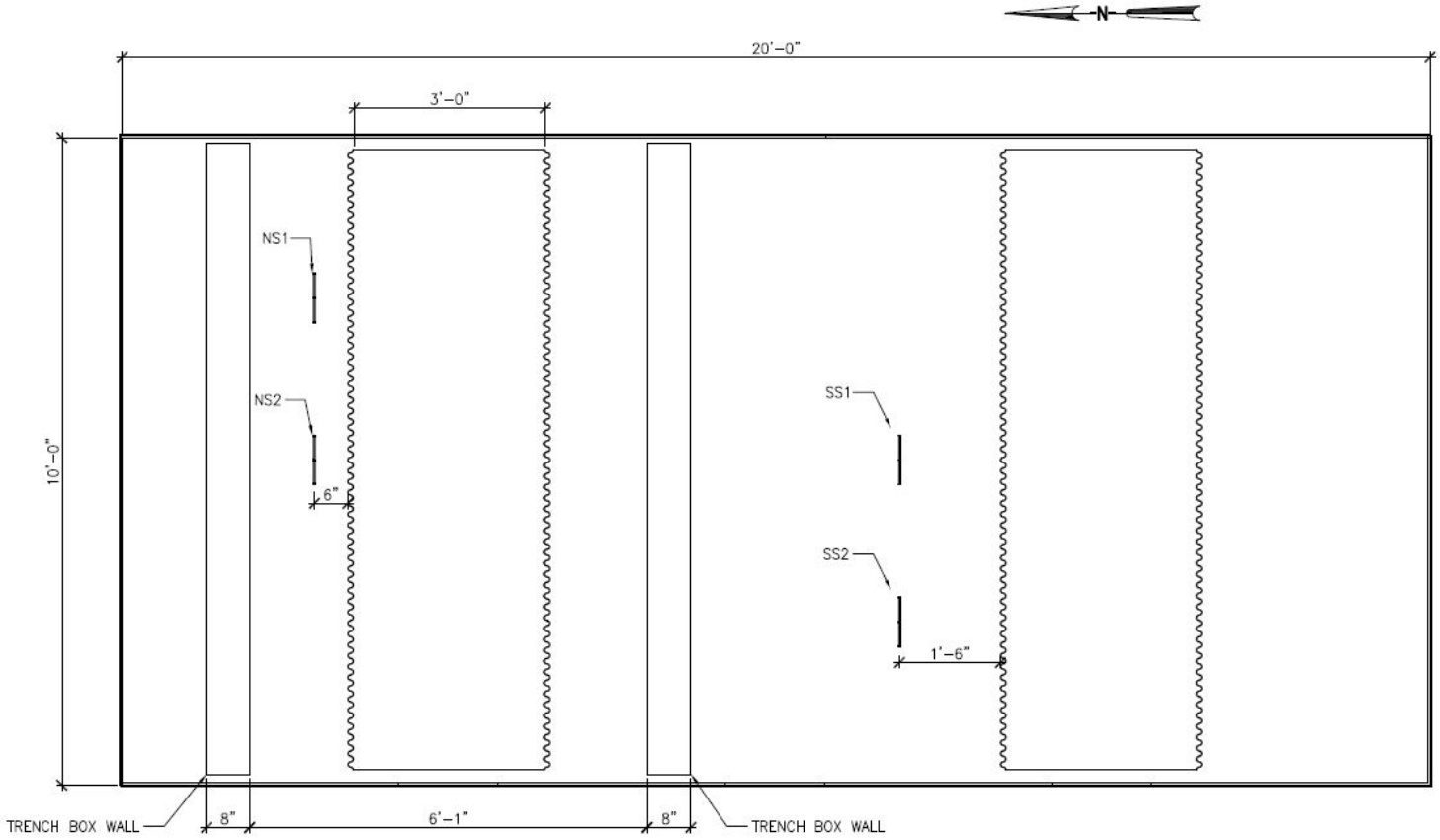


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 2' 6" FROM BOTTOM**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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| PROJECT #: | BDK75 977–21 | DATE: | DATE |
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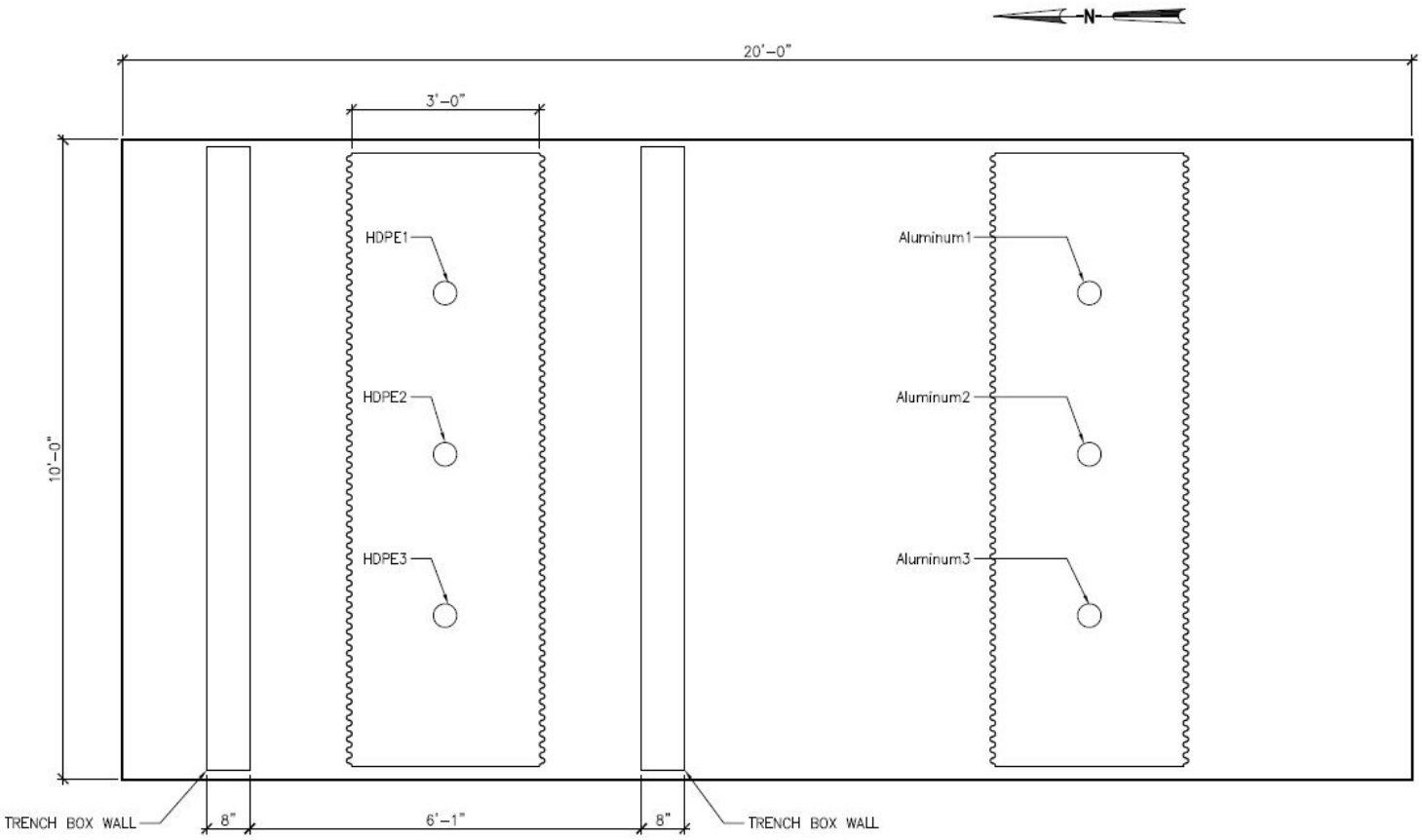


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE CELLS 4'-0" FROM BOTTOM (DIRECTLY ON TOP OF PIPE)**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP-KP |
| PROJECT #: | BDK75 977-21 | DATE: | DATE |
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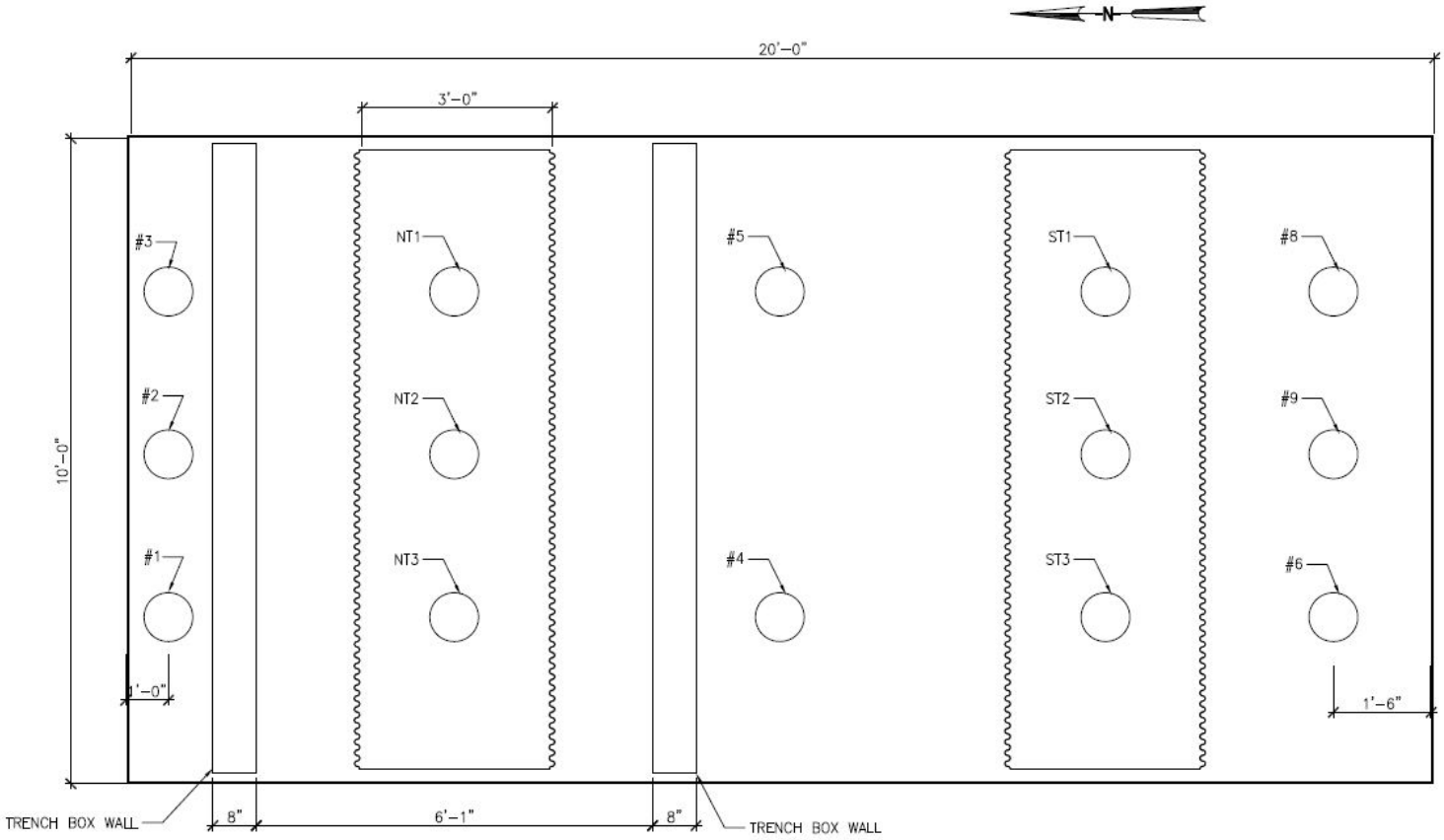


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 4' 8" FROM BOTTOM**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
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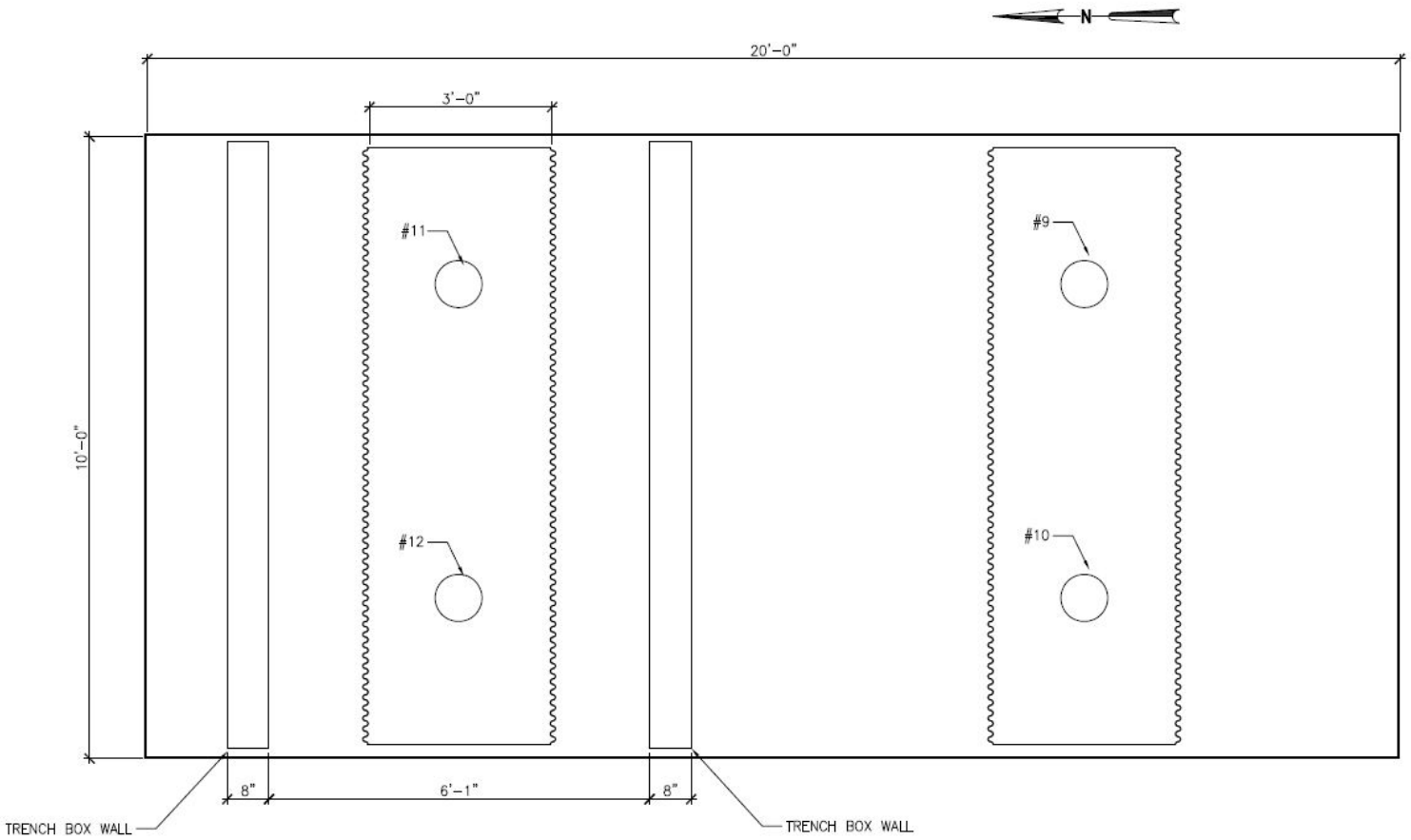


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 6' 9" FROM BOTTOM**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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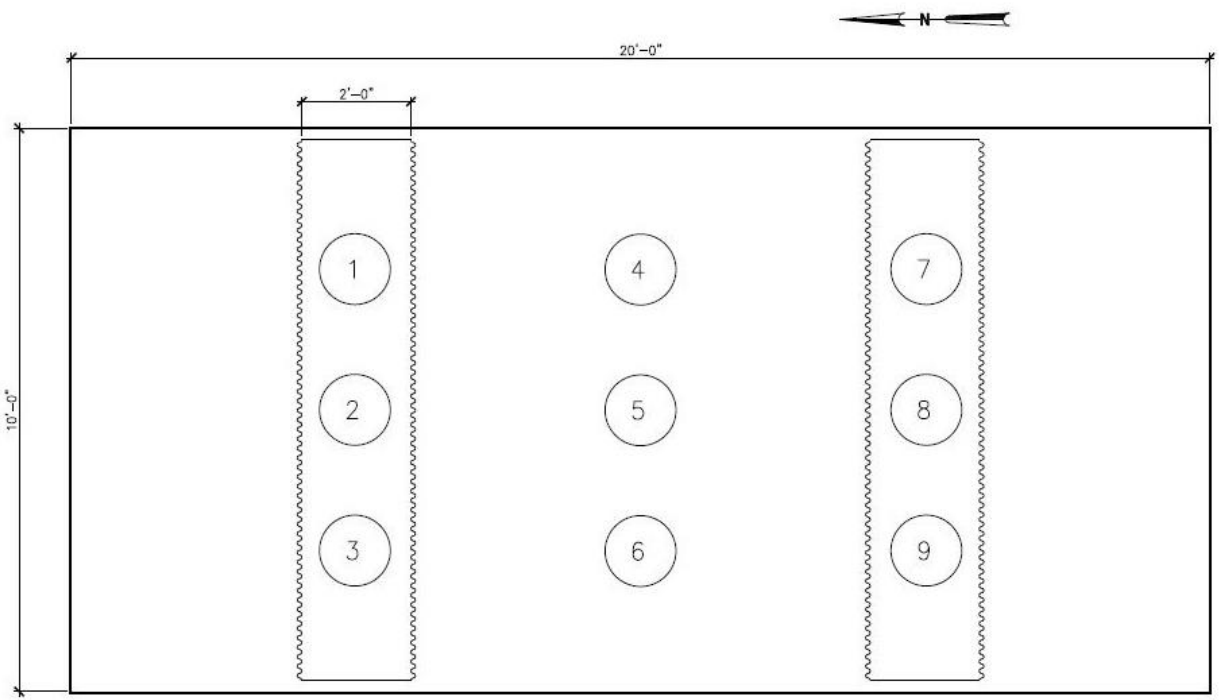
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP-KP |
| PROJECT #: | BDK75 977-21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |

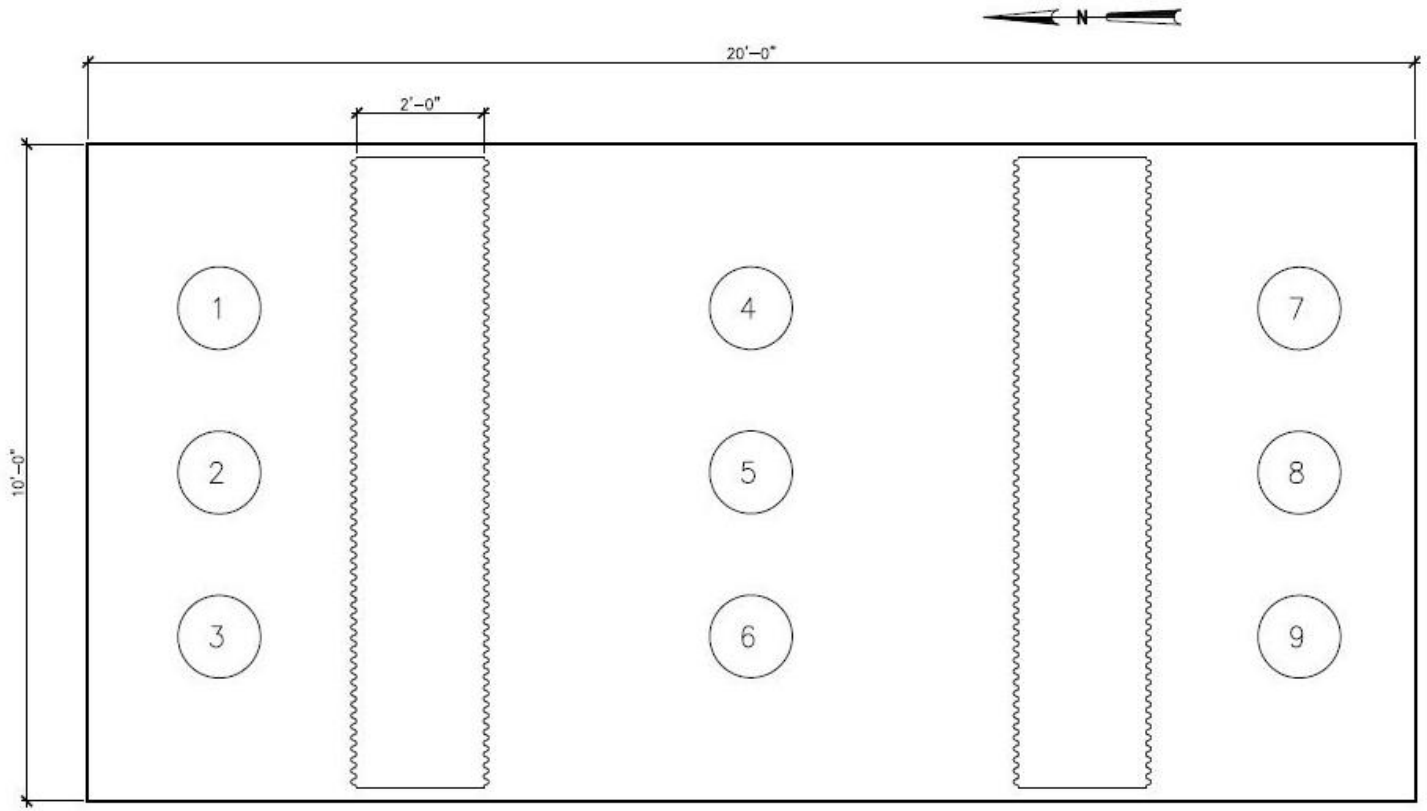
APPENDIX B
24” HDPE PIPE TEST

**Nuclear Density Test Locations**




**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON 08-06-2012**
**12" FROM BOTTOM**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |




**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON**
**08-13-2012 & 08-20-2012**
**2'-6" & 4'-0" FROM BOTTOM**

| UNIVERSITY OF FLORIDA | | | |
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| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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| DESIGNED BY: | D. BLOOMQUIST, P.E. | | DRAWN BY: JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
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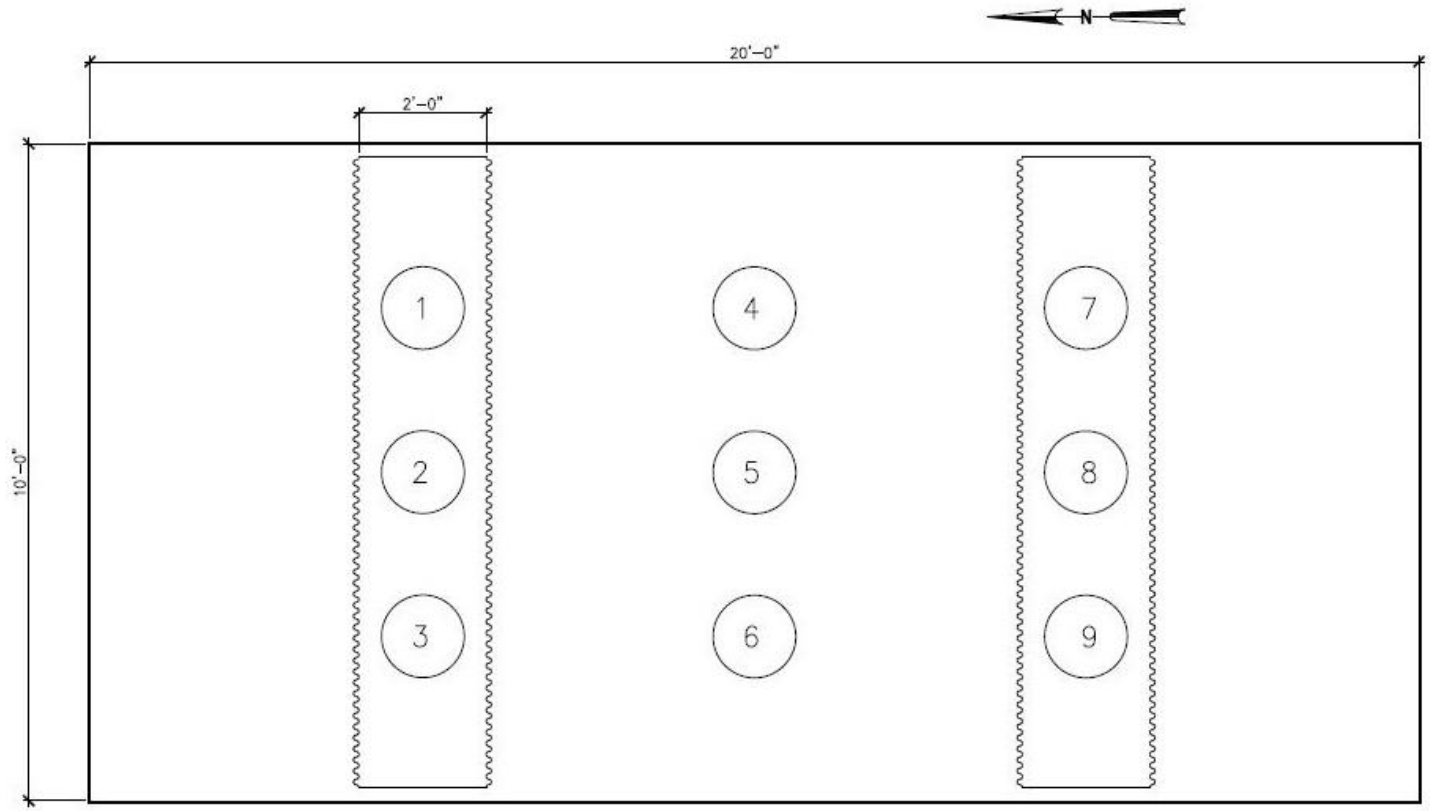


**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON**
**08-22-2012 & 08-24-2012**
**5'-6" & 7'-0" FROM BOTTOM**

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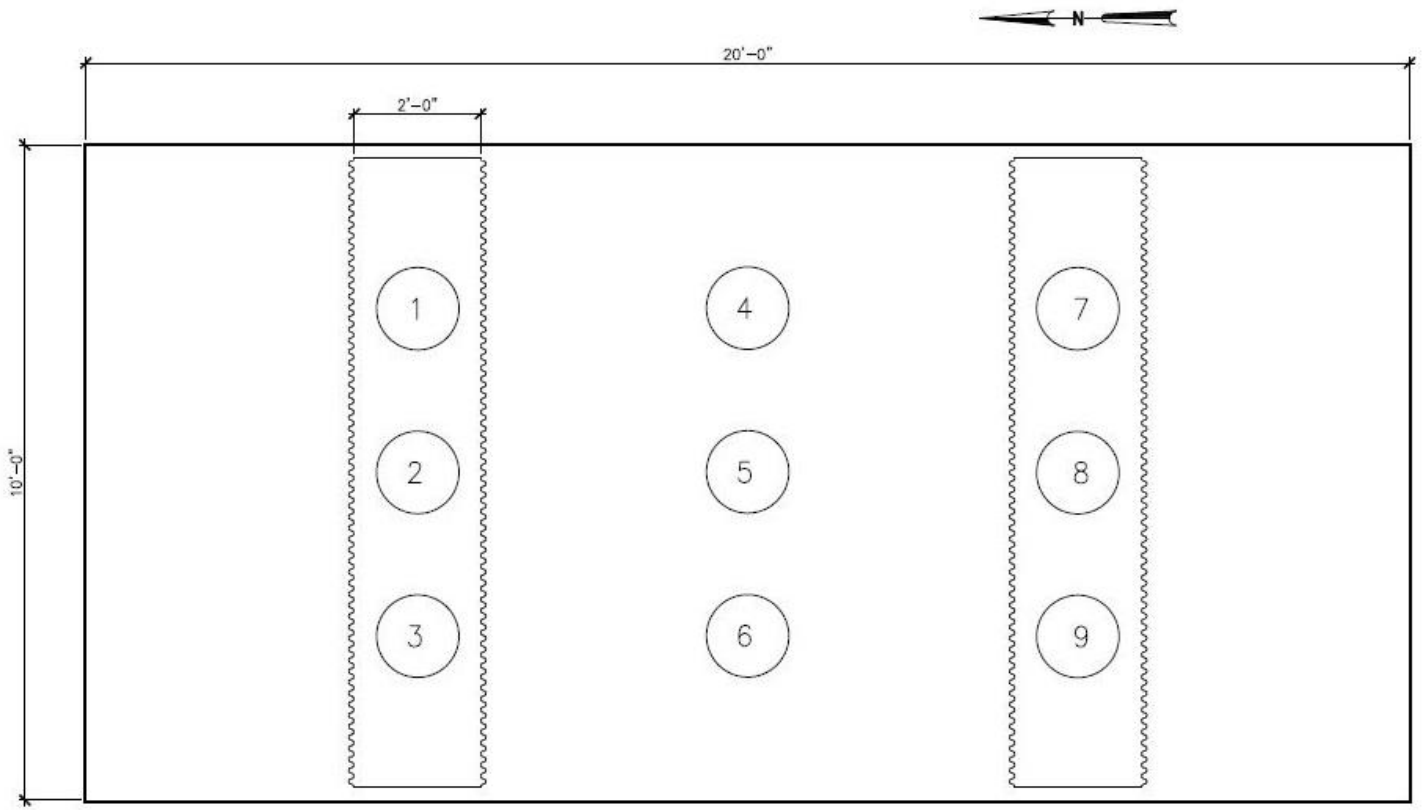
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |




**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON**
**08-30-2012 (POST-SATURATION)**
**7'-6" FROM BOTTOM**

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| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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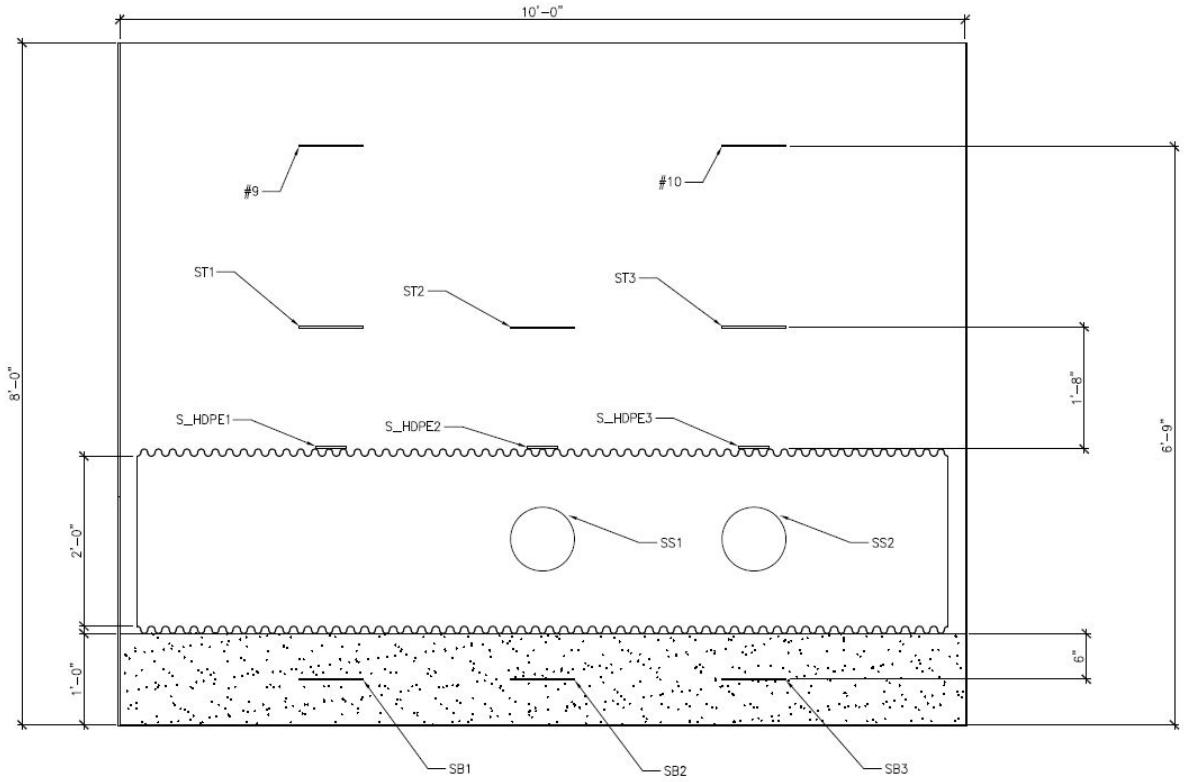
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |

## Earth Pressure Cell Locations




**SOIL BOX PROFILE VIEW**
**SECTION E-E**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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| DESIGNED BY: | D. BLOOMQUIST, P.E. | | DRAWN BY: JP-KP |
| PROJECT #: | BDK75 977-21 | DATE: | DATE |
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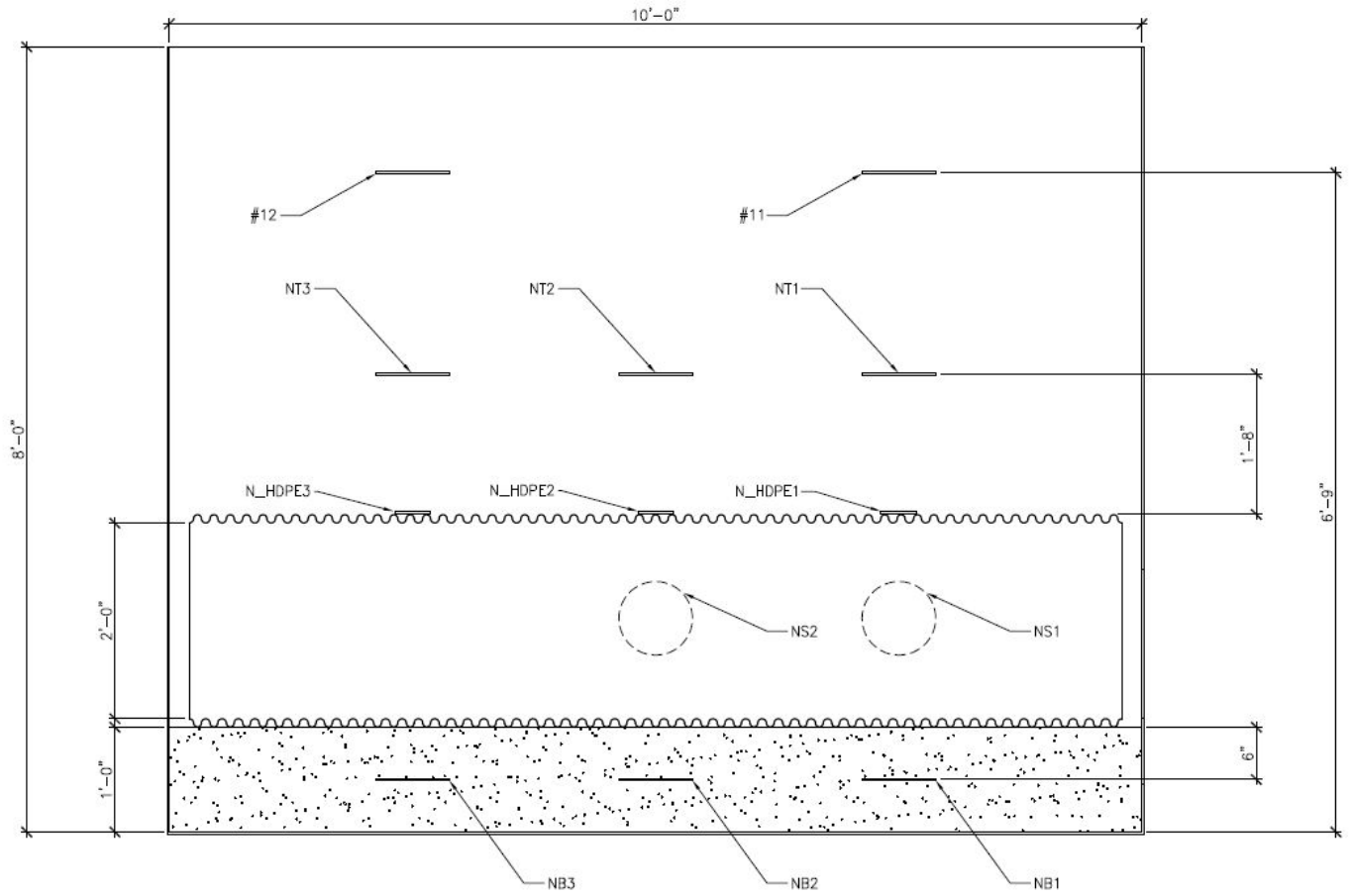


**SOIL BOX PROFILE VIEW**
**SECTION F-F**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
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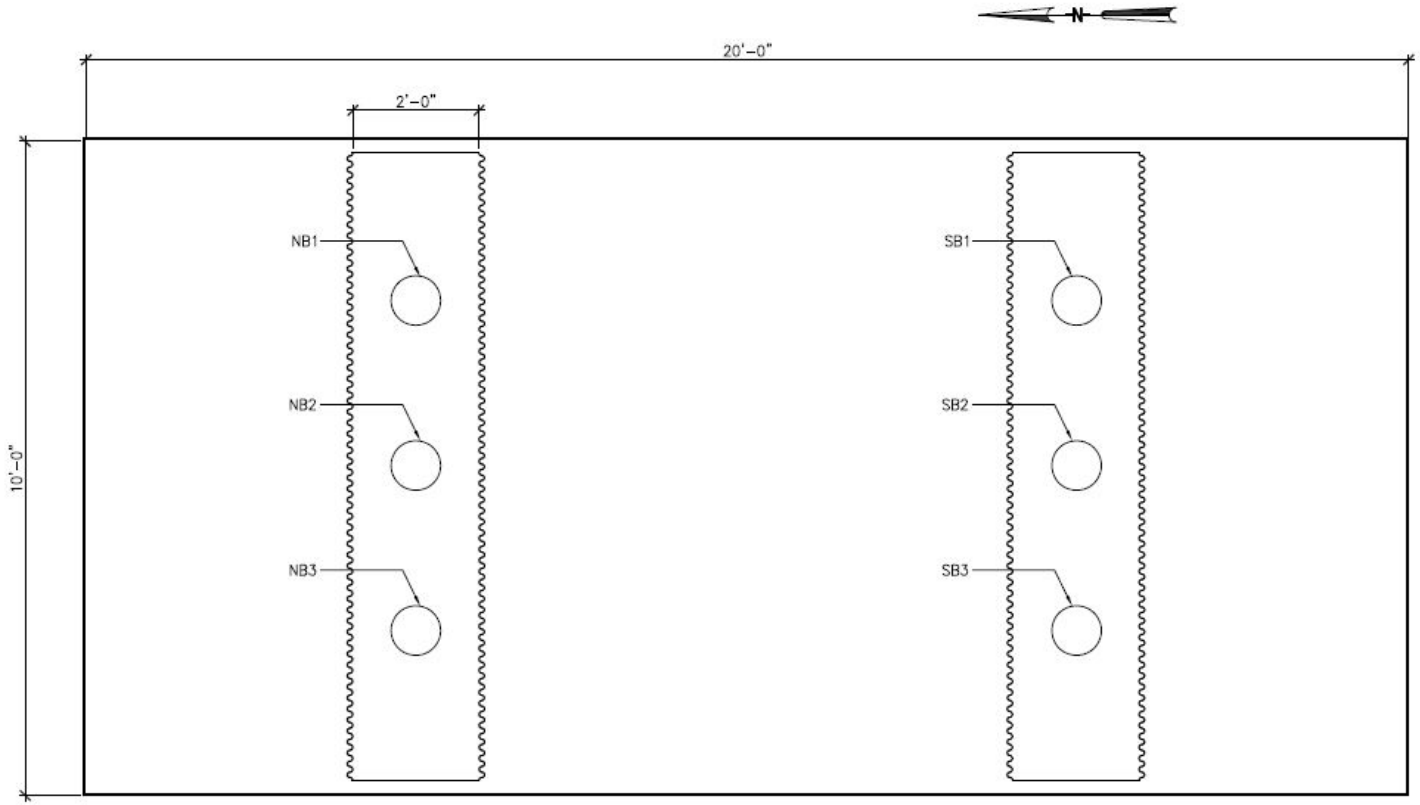


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 6" FROM BOTTOM**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP-KP |
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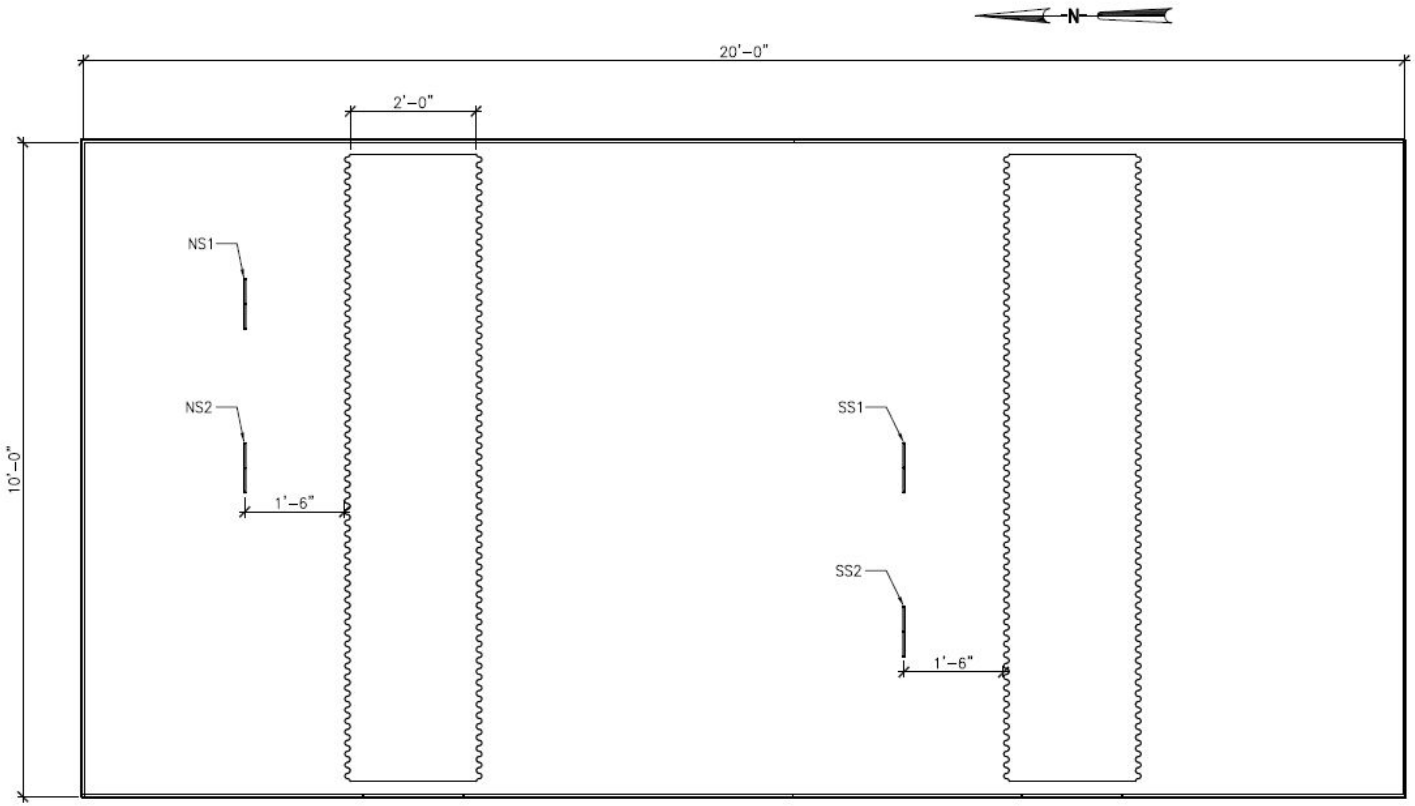


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 2' 6" FROM BOTTOM**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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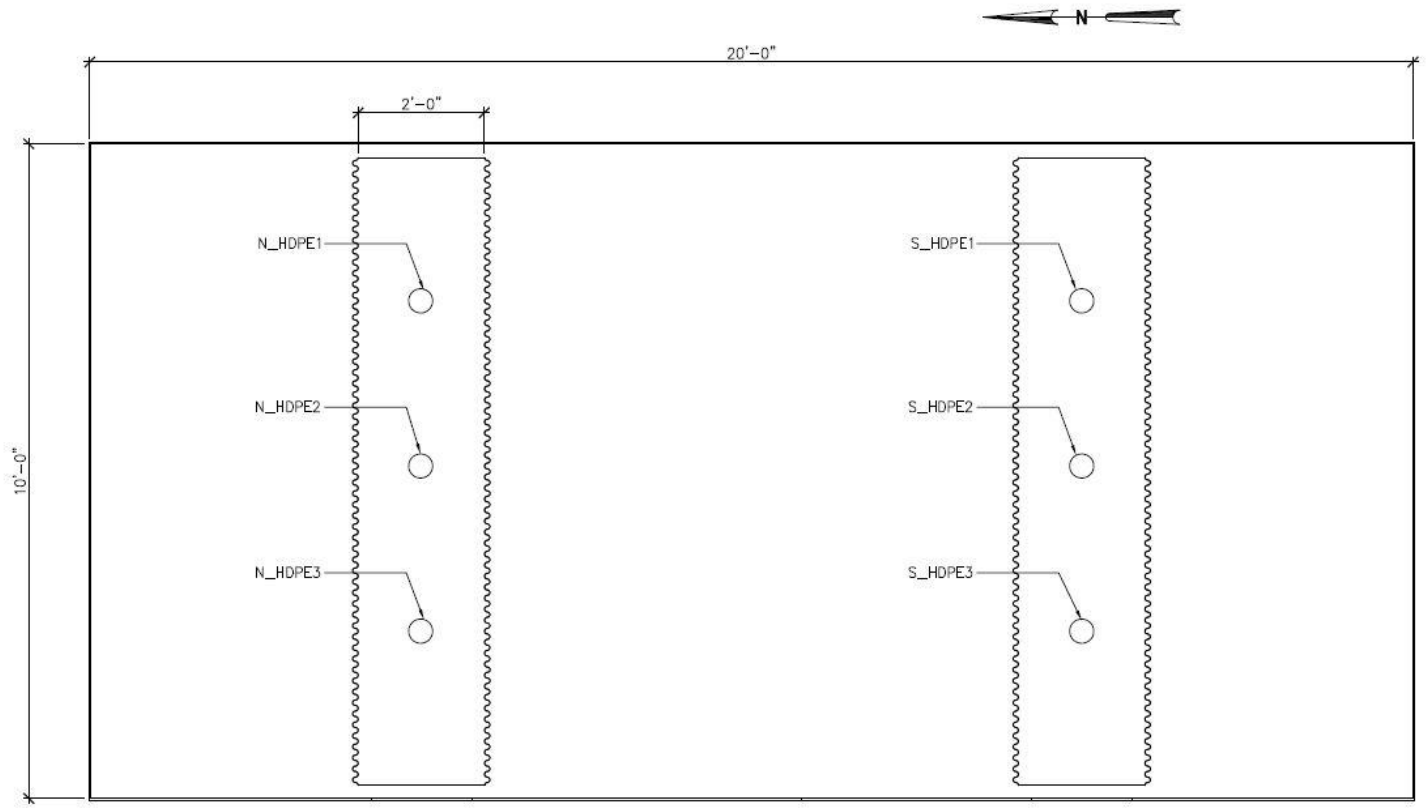
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |




**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE CELLS 3'-0" FROM BOTTOM (DIRECTLY ON TOP OF PIPE)**

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|---|---|---|---|
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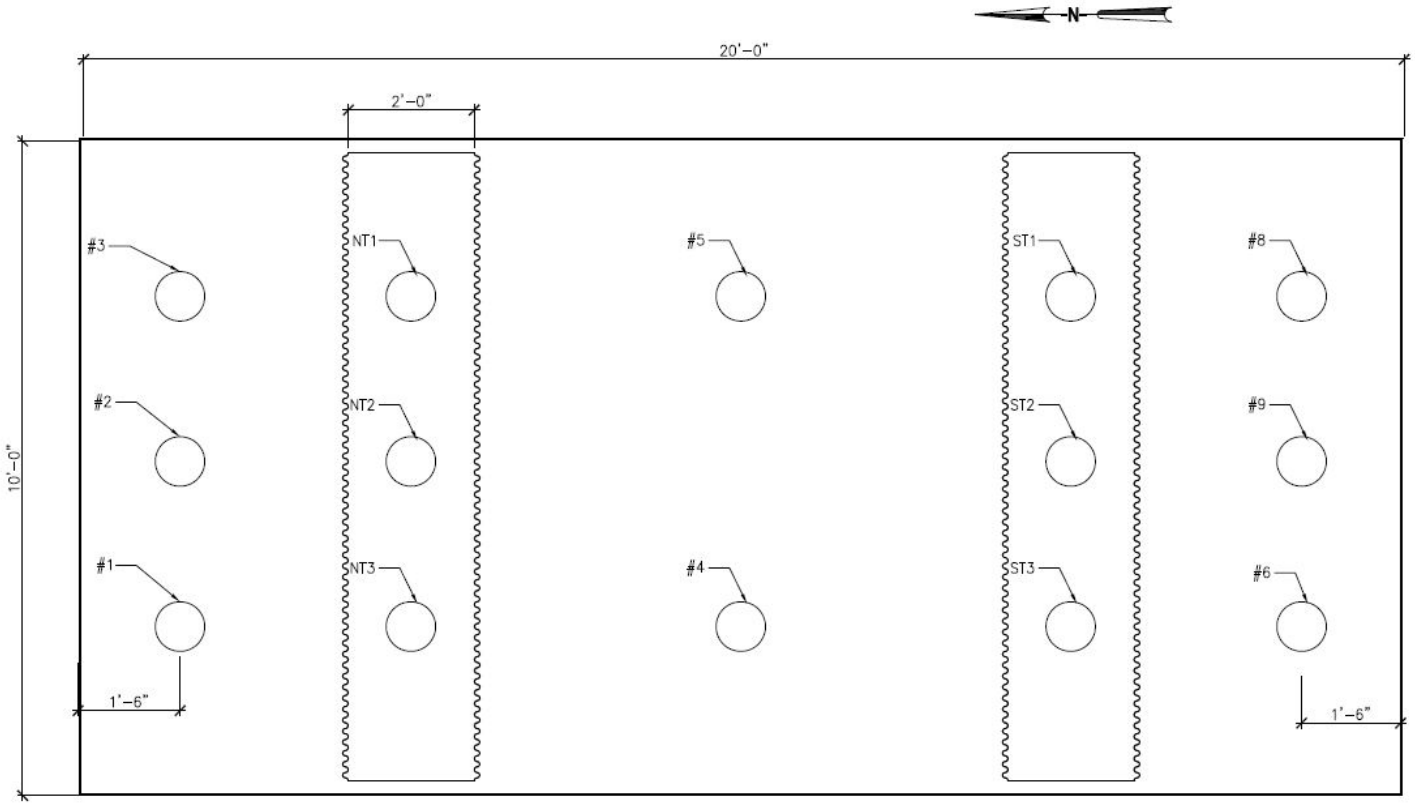
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP-KP |
| PROJECT #: | BDK75 977-21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |




**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 4' 8" FROM BOTTOM**

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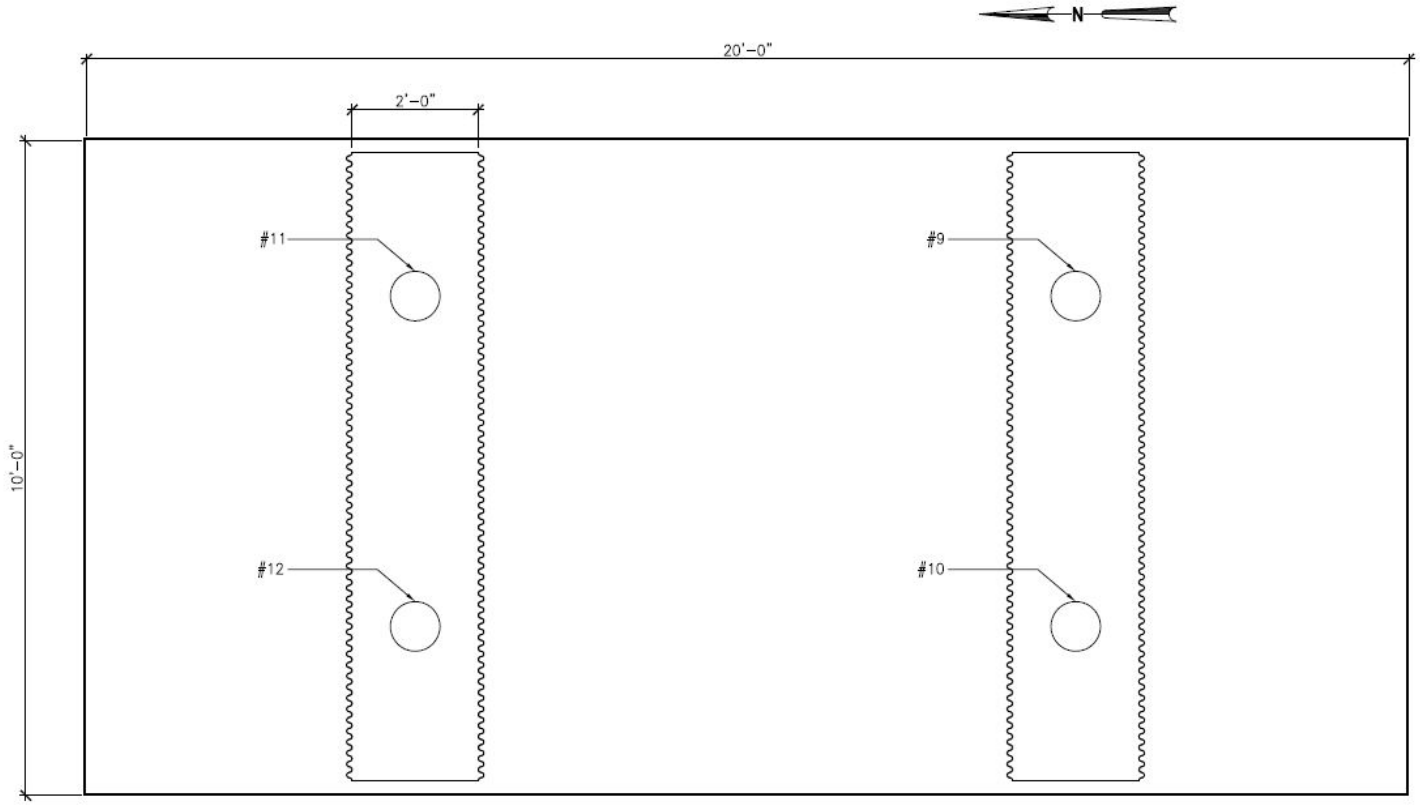


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 6' 9" FROM BOTTOM**

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|---|---|---|---|
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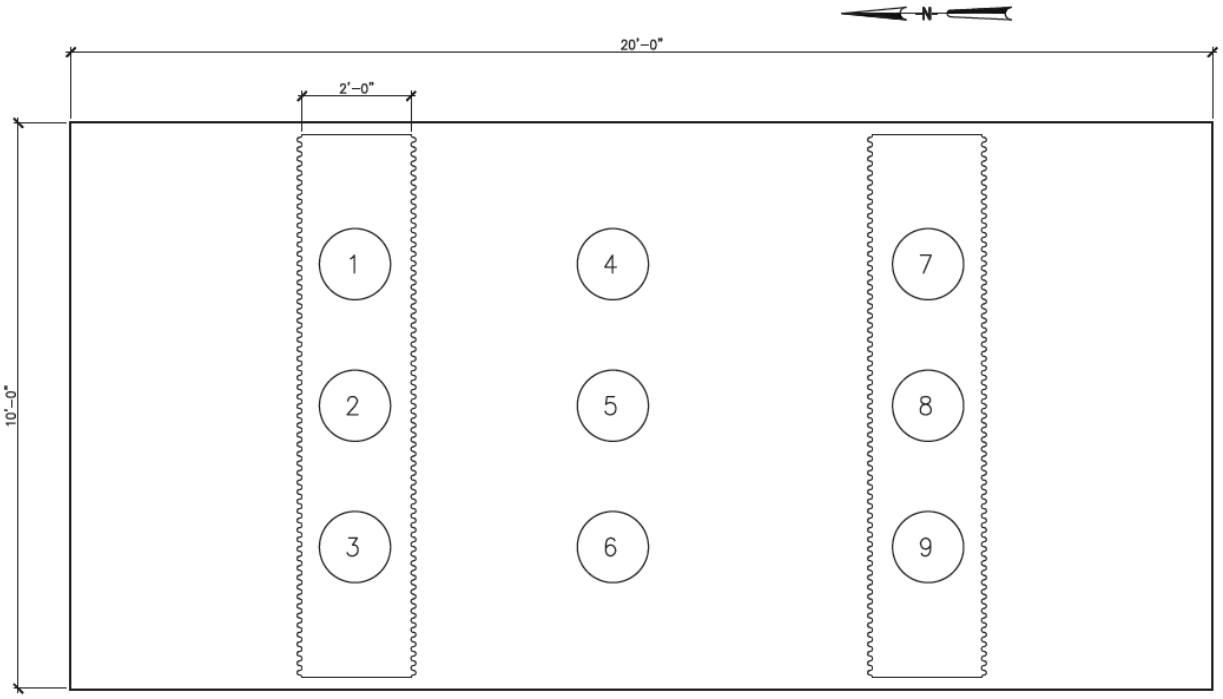
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP-KP |
| PROJECT #: | BDK75 977-21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |

APPENDIX C
24” STEEL PIPE TEST

**Nuclear Density Test Locations**




**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON 01-25-2013**
**12" FROM BOTTOM**

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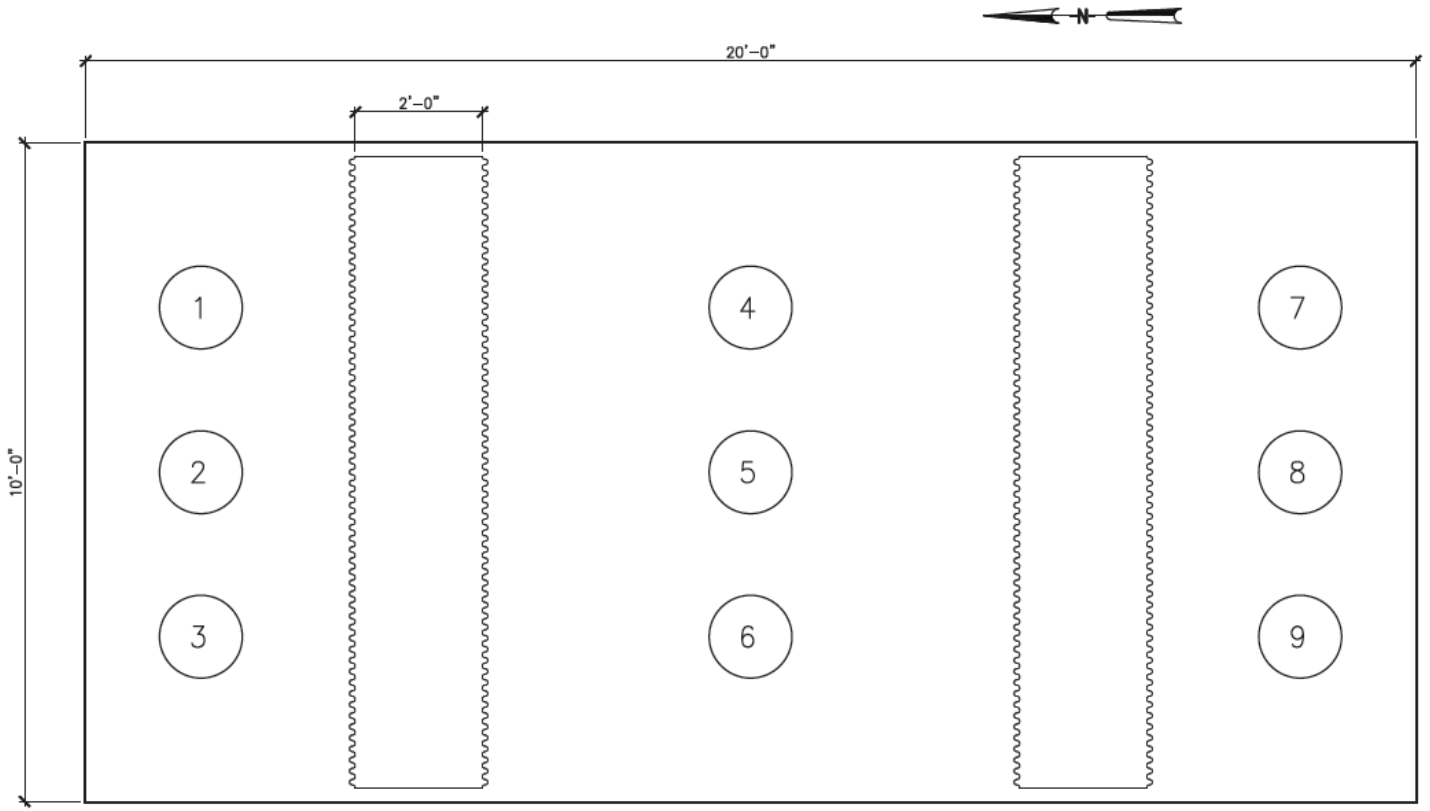
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | 03–16–2012 |
| SCALE: | 1:30 | PAGE: | C–17 OF C–21 |




**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON**
**2.5' FROM BOTTOM**

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| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP-KP |
| PROJECT #: | BDK75 977-21 | DATE: | 03-16-2012 |
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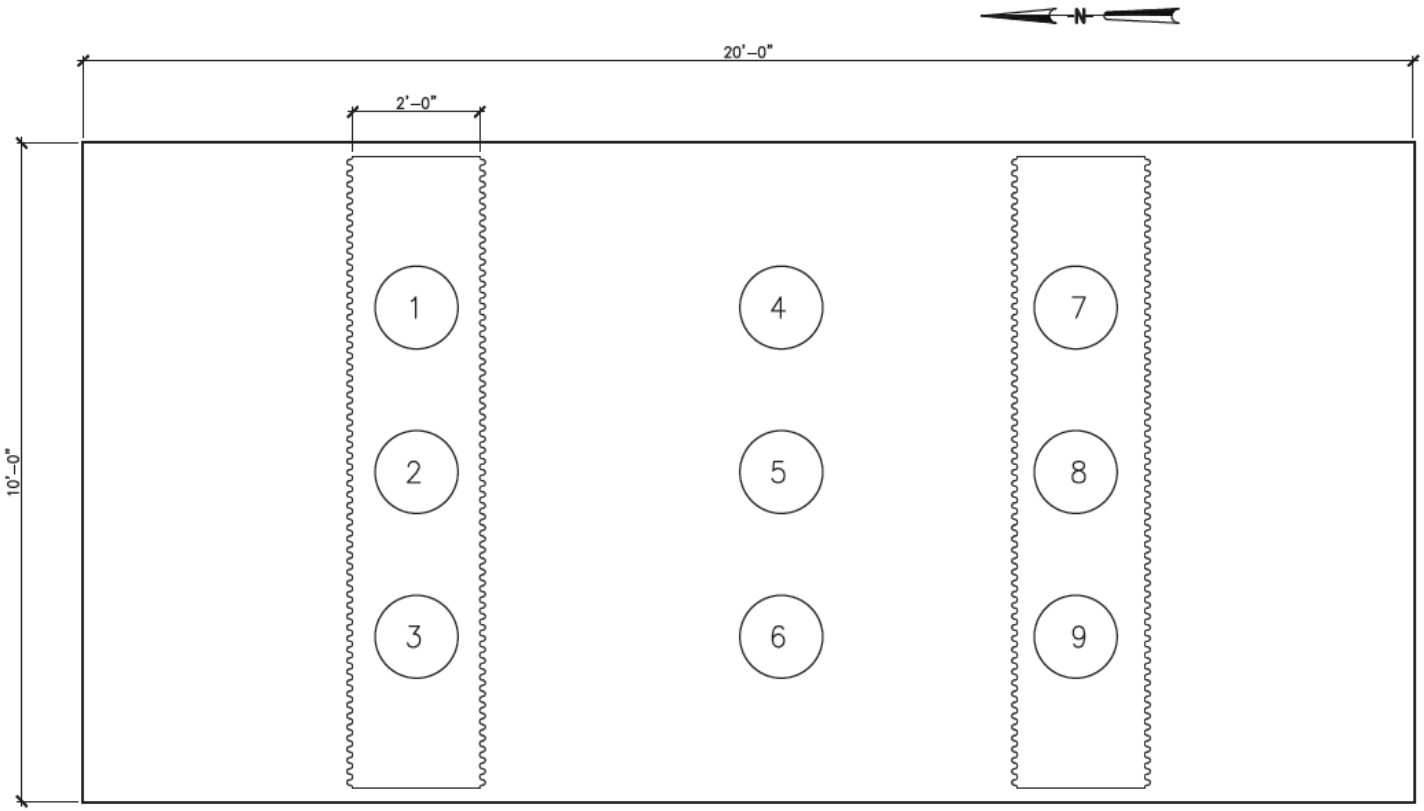


**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON**
**02-14-2013, 02-18-2013 & 02-22-2013**
**4', 5.5' & 7' FROM BOTTOM**

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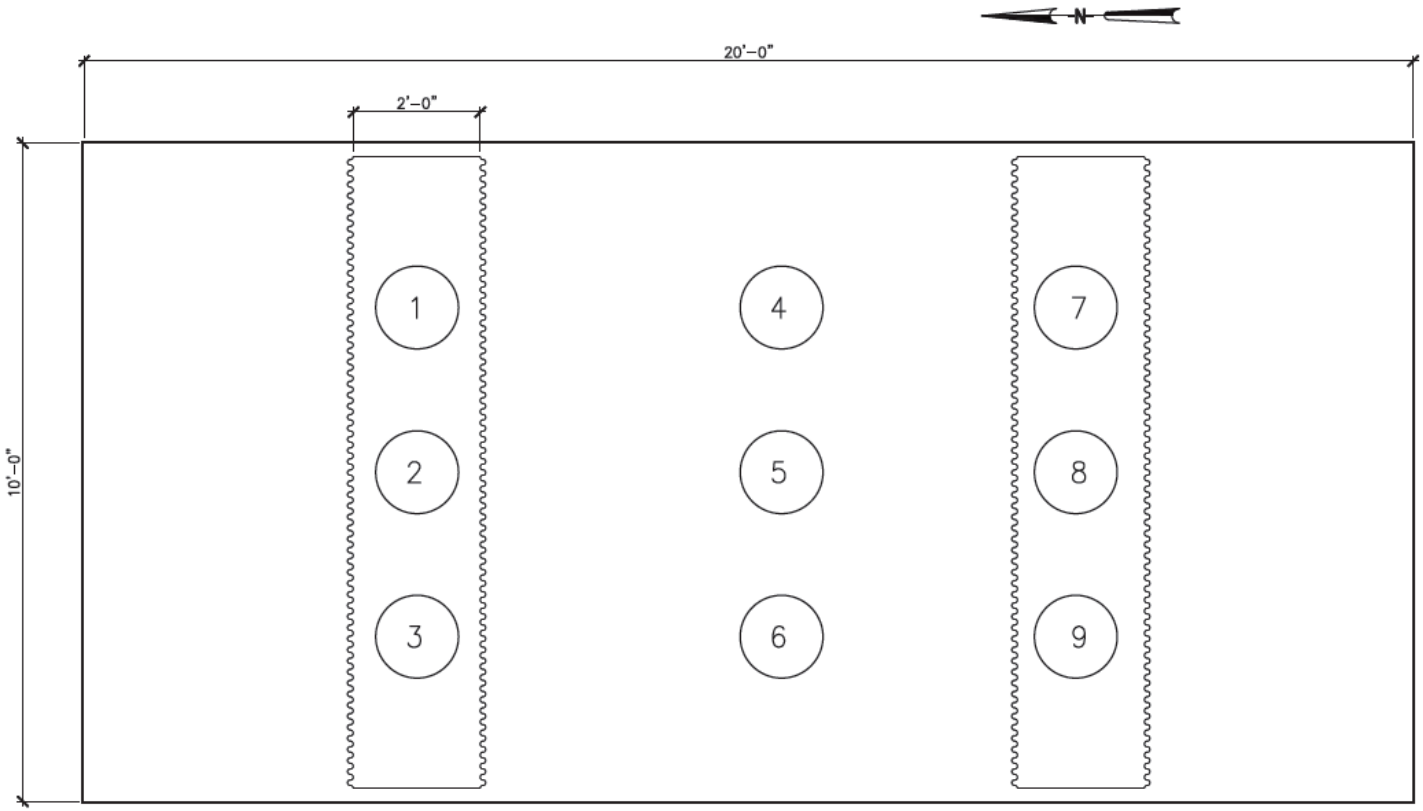
| PROJECT #: | BDK75 977–21 | DATE: | 03–16–2012 |
| SCALE: | 1:30 | PAGE: | C–18 OF C–21 |




**SOIL BOX PLAN VIEW**
**LOCATION OF NUCLEAR DENSITY**
**TESTS PERFORMED ON**
**02-25-2013 (POST-SATURATION)**
**7.5' FROM BOTTOM**

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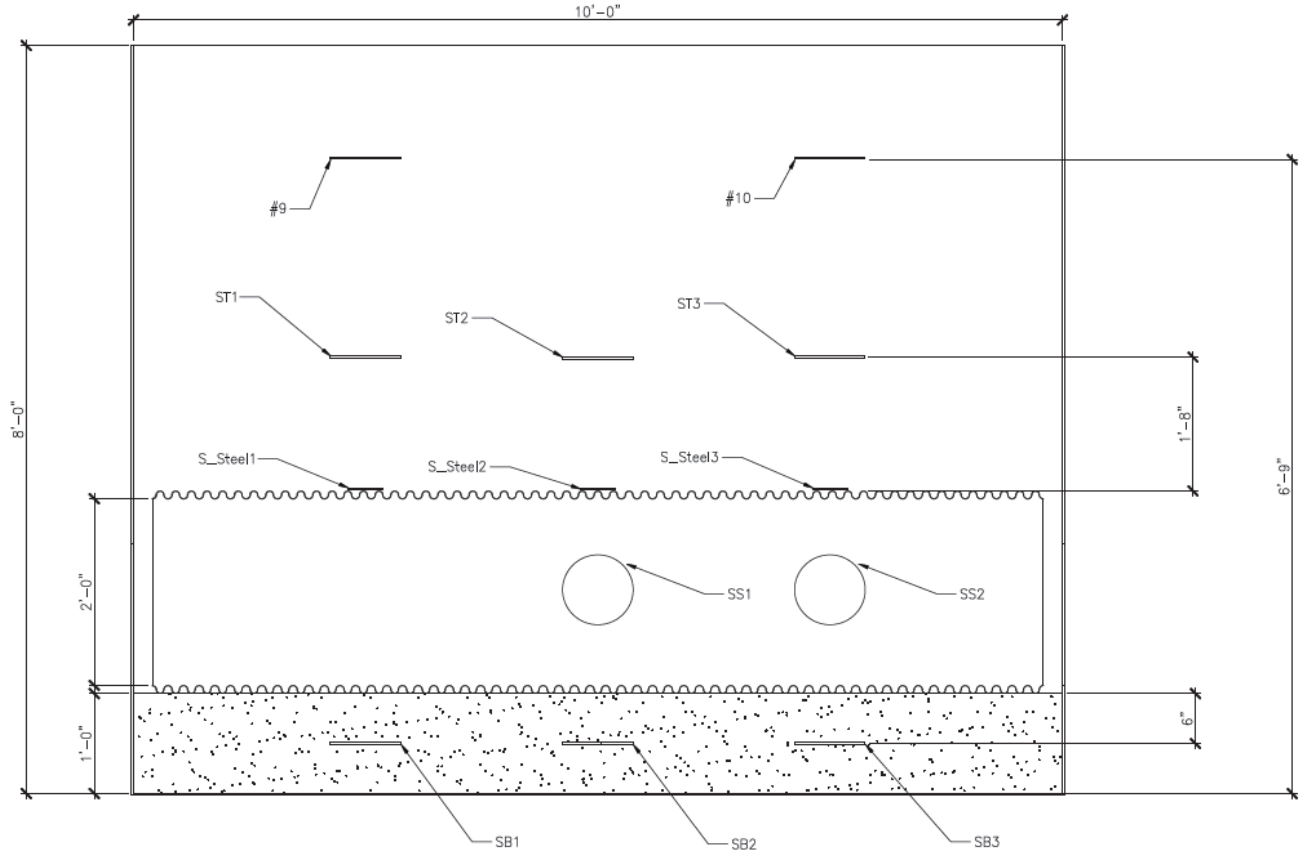
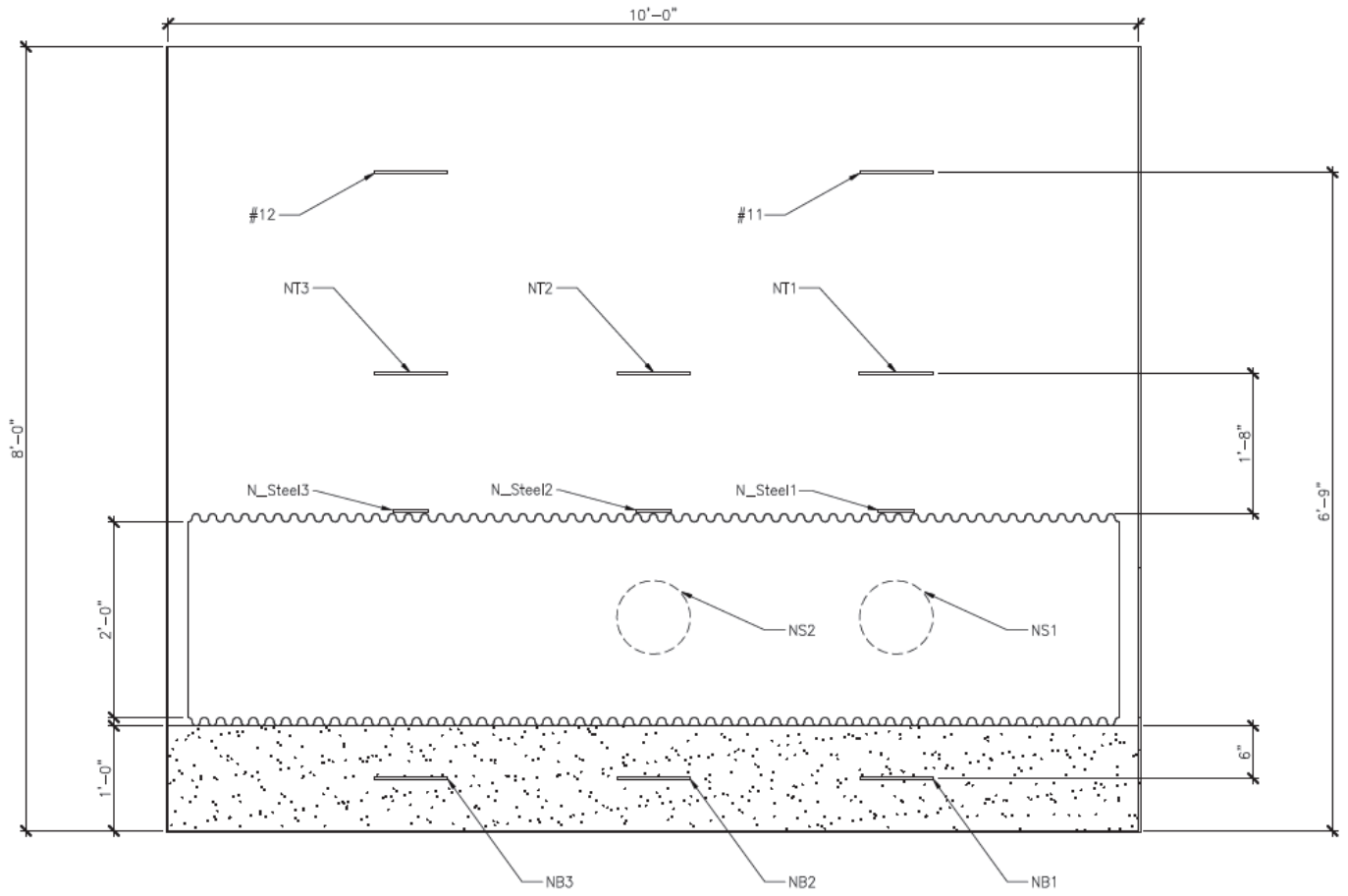
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | 03–16–2012 |
| SCALE: | 1:30 | PAGE: | C–18 OF C–21 |

## Earth Pressure Cell Locations




**SOIL BOX PROFILE VIEW**
**SECTION E-E**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP-KP |
| PROJECT #: | BDK75 977-21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |




**SOIL BOX PROFILE VIEW**
**SECTION F-F**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
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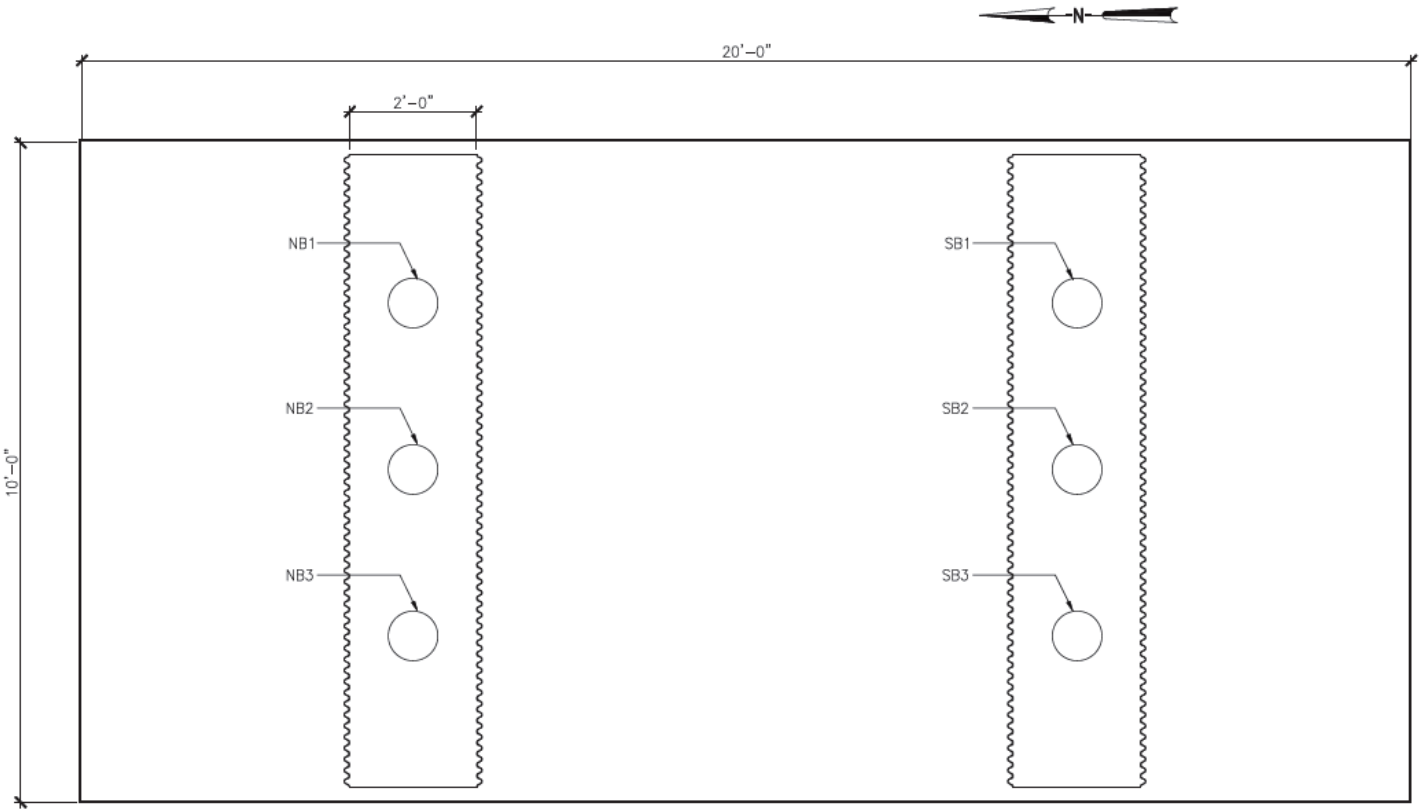


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 6" FROM BOTTOM**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | 02–01–2012 |
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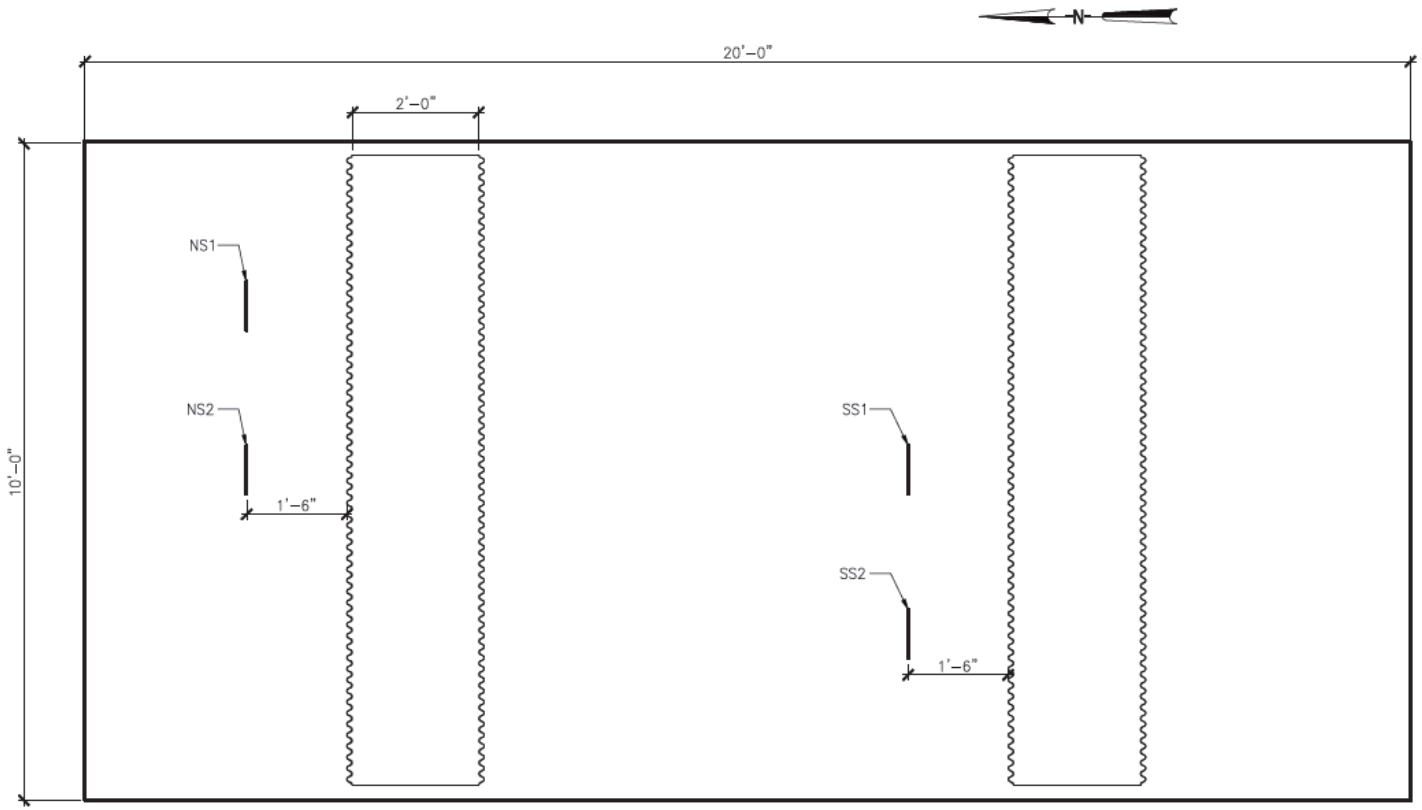


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 2' 0" FROM BOTTOM**

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|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
| FDOT SOIL BOX PROJECT | | | |
| DESIGNED BY: | D. BLOOMQUIST, P.E. | DRAWN BY: | JP–KP |
| PROJECT #: | BDK75 977–21 | DATE: | DATE |
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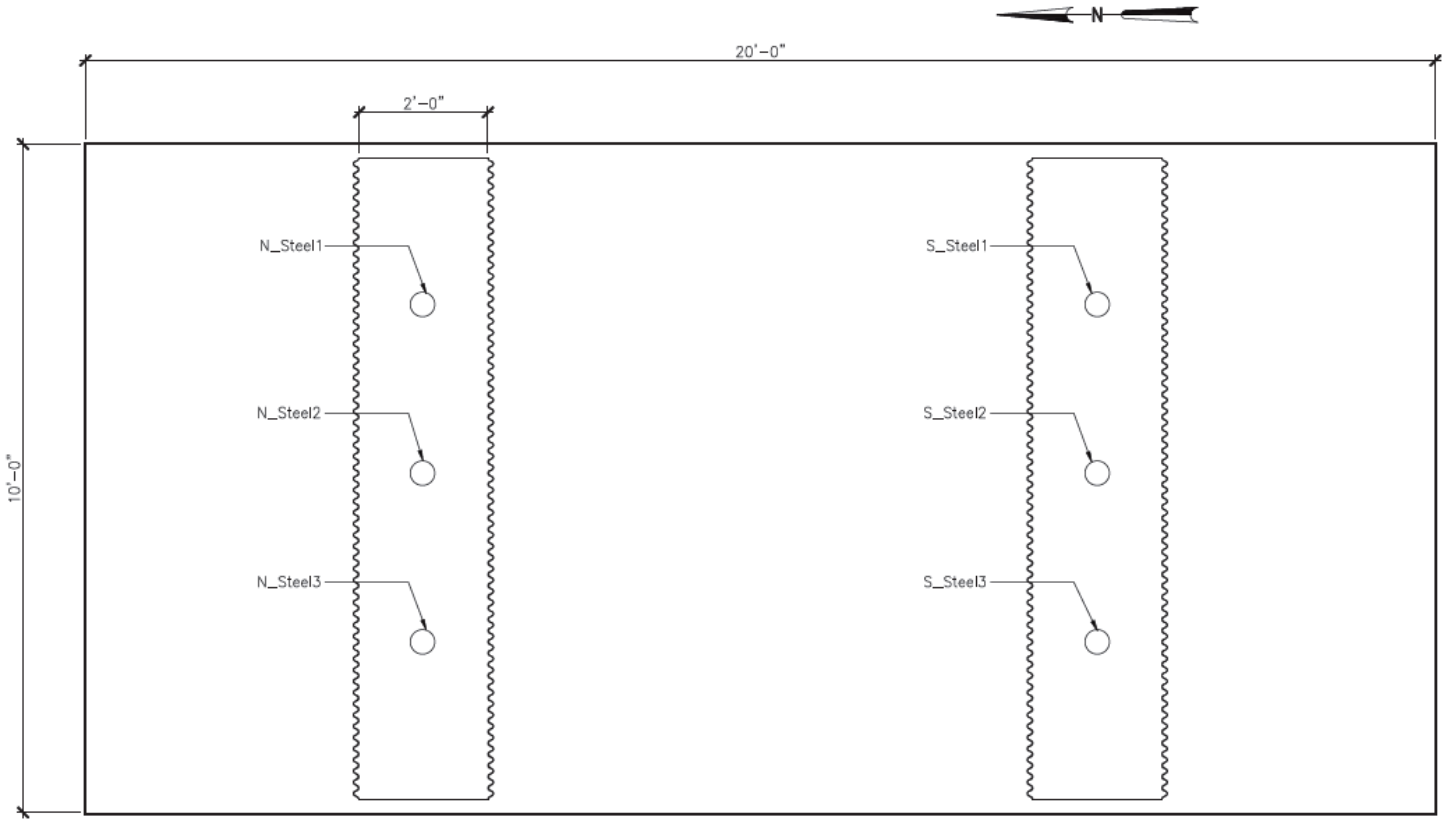


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE CELLS 3'-0" FROM BOTTOM (DIRECTLY ON TOP OF PIPE)**

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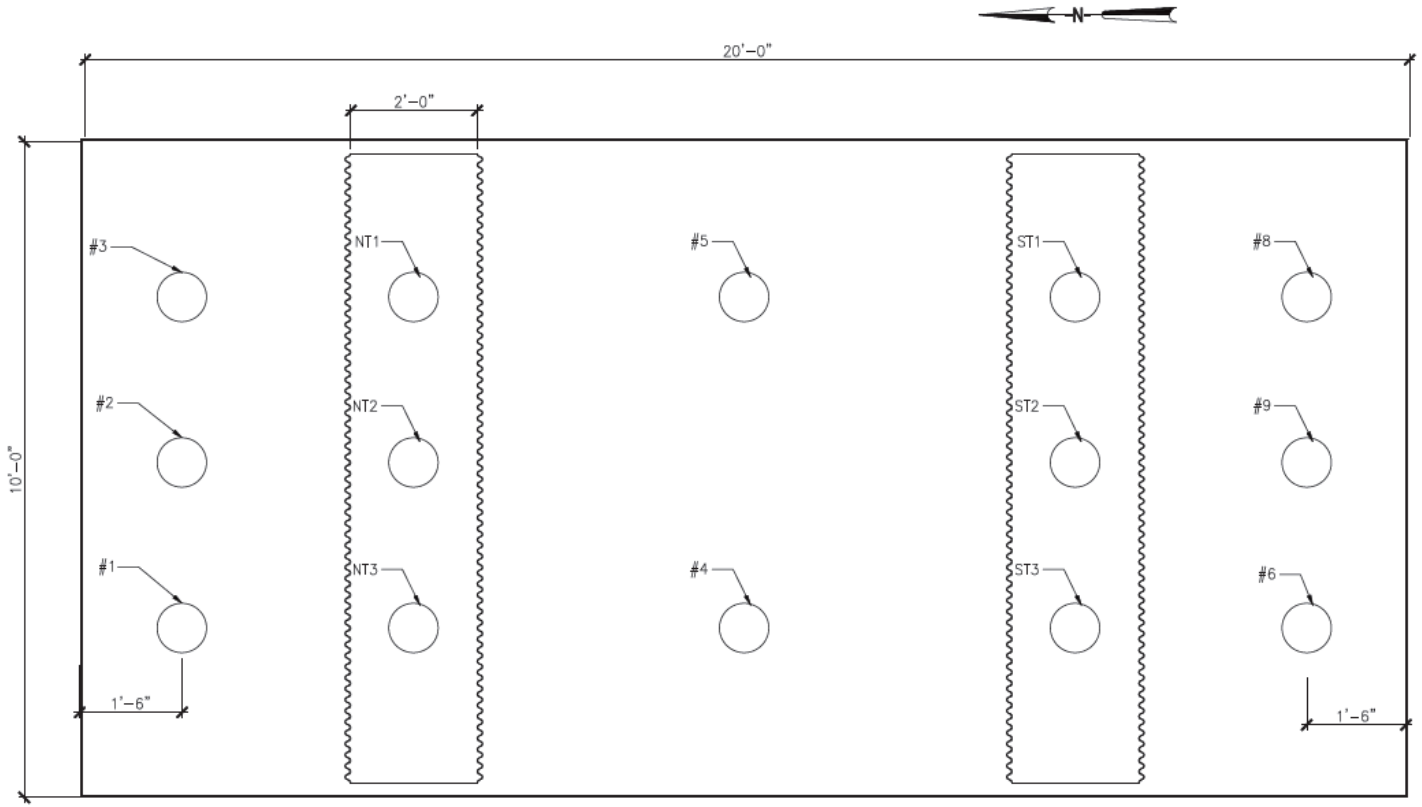
| PROJECT #: | BDK75 977-21 | DATE: | DATE |
| SCALE: | SCALE | PAGE: | PAGE |




**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 4' 0" FROM BOTTOM**

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|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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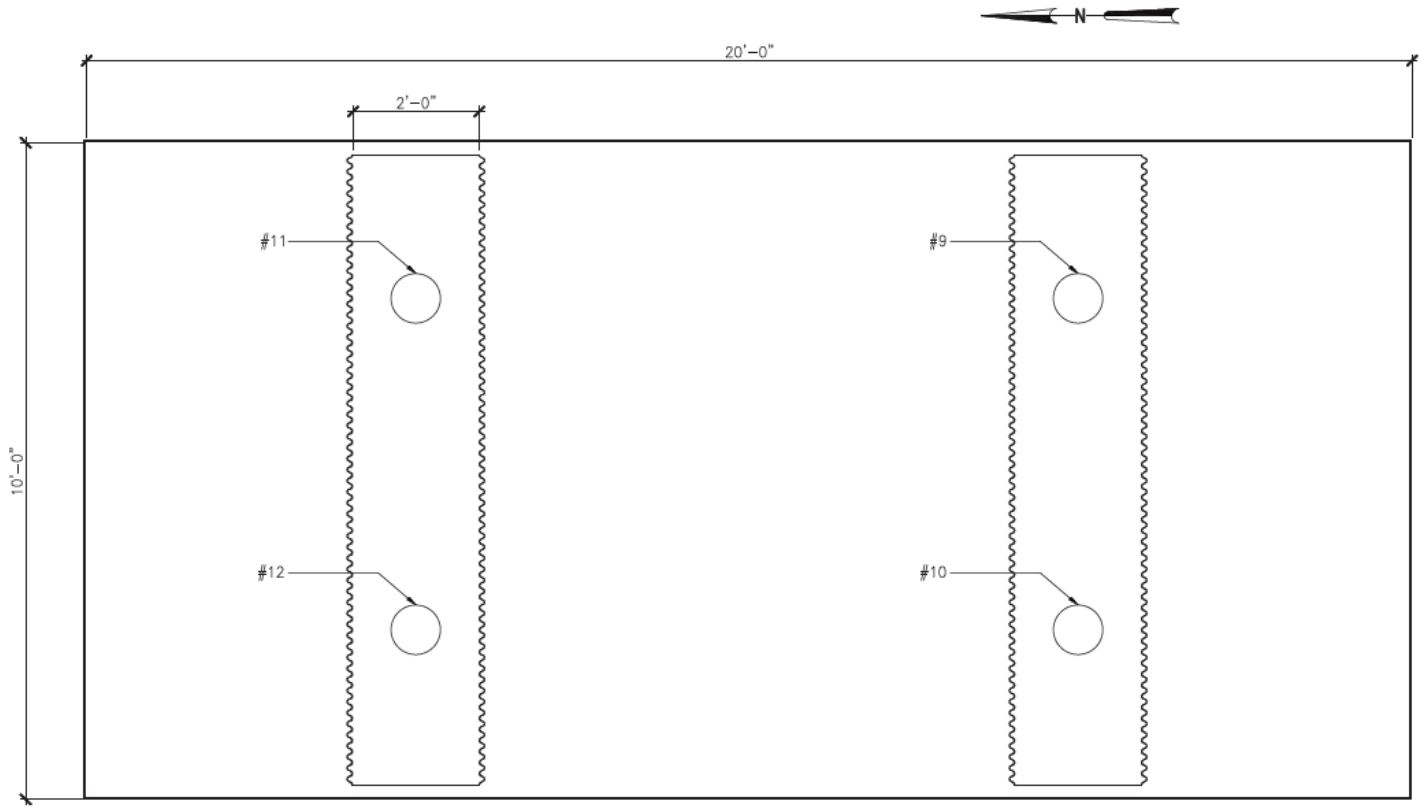


**SOIL BOX PLAN VIEW**
**LOCATION OF EARTH PRESSURE**
**CELLS 6' 9" FROM BOTTOM**

| UNIVERSITY OF FLORIDA | | | |
|---|---|---|---|
| DEPARTMENT OF CIVIL AND COASTAL ENGINEERING | | | |
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| SCALE: | SCALE | PAGE: | PAGE |

# LIST OF REFERENCES

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# BIOGRAPHICAL SKETCH

Victor Konn was born in 1988 in New York, New York. He was raised in Teaneck, New Jersey before moving to Wellington, Florida at the age of 15. While in school, Victor excelled in the math and sciences, and after graduating high school he decided to pursue a career in engineering. He worked part time while enrolled at Palm Beach Community College before transferring to the University of Florida to study civil engineering.

While earning his undergraduate degree, Victor developed a strong interest in geotechnical and structural engineering. In the summer of 2010, he worked as an undergraduate assistant researching epoxy creep and anchorage failure. In the 2010 fall semester, Victor became a teaching assistant for Dr. Bloomquist's soil mechanics course until graduating in December 2011.

After graduating at the top of his class with a Bachelor of Science in Civil Engineering, Victor received the opportunity to become a research assistant and pursue a Master of Engineering degree specializing in geotechnical engineering. Due to his strong interest in structural engineering, Victor split his graduate coursework between geotechnical and structural design.

Upon completing his Master of Engineering degree, Victor plans to begin a career utilizing his strong geotechnical and structural education designing bridge or building structures.