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Utility cut repair techniques: investigation of improved utility cut repair techniques to reduce settlement in repaired areas, Phase II

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Utility cut repair techniques – Investigation of improved utility cut repair techniques to reduce settlement in repaired areas, Phase II

by

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ABSTRACT

Trench maintenance problems are caused by improper backfill placement and construction procedures. This thesis is part of a multi-phase research project that aims to improve long-term performance of utility cut restoration trenches. The goal of this research is to improve pavement patch life and reduce the maintenance of the repaired areas. The objectives were to use field-testing data, laboratory testing data, and long-term monitoring (elevation survey and FWD testing) to suggest and modify recommendations from Phase I and to identify the principles of trench subsurface settlement and load distribution in utility cut restoration areas by using instrumented trenches. The objectives were accomplished by monitoring local agency utility construction from Phase I, constructing and monitoring the recommended trenches from Phase I, and instrumenting trenches to monitor changes in temperature, pressure, moisture content, and settlement as a function of time to determine the influences of seasonal changes on the utility cut performance.

CHAPTER 1.0 - INTRODUCTION

1.1 - Background

Sustainable performance of replacement pavements over utility cut trenches on local and state roads is a concern of municipalities. Maintenance problems are caused by improper backfill placement and construction procedures. Removal of failed utility cut pavements creates additional and potential unnecessary solid waste for disposal (Gas Industries, 1994). The expense and inconvenience of repairing pavements because of poorly performing utility cut restorations can be reduced with proper backfill selection and construction practices. This thesis is part of a multi-phase research project that aims to improve long-term performance of utility cut restoration trenches. Monitoring of new utility trenches using recommended construction practices, and improved understanding of trench settlement and load transfer through the instrumentation of utility trenches are the major task of this project. The goal of this research is to improve pavement patch life and reduce the maintenance of the repaired areas.

To address these concerns, the Center for Transportation Research and Education (CTRE) at Iowa State University (ISU), along with the Iowa Department of Transportation (Iowa DOT), began a multi-year investigation into utility cut restoration failures. The Iowa Highway Research Board funded two phases of this investigation. "Investigation of Improved Utility Cut Repair Techniques to Reduce Settlement in Repaired Area," (Phase I) was an initial investigation into utility cut restoration failures to document the occurrence and frequency of failures and to determine the failure mechanisms. Phase II continued the Phase I investigations of failure mechanisms and the monitoring of utility cut restorations at various locations around Iowa. In addition, Phase II implemented the Phase I recommendations for construction and monitoring of several new utility cut trenches and investigated trench settlement using instrumentation in trenches.

Three activities took place during Phase I to evaluate the construction and performance of utility trench restorations: 1) a survey was conducted to document construction practices used in utility trench restorations in several cities in Iowa, 2) laboratory tests were performed on backfill to determine its engineering properties, and 3) trench restoration performance was monitored using Falling Weight Deflectometer (FWD) testing. Survey results indicated that many restored utility cut restorations fail in less than two years. Field and laboratory tests of backfill indicated inadequate compaction, moisture content, and density of the backfill are factors that contribute to utility cut trench restoration failures. FWD tests indicated weakened subgrade soil around the utility cut trench restorations. This weakened soil is known as the "zone of influence."

Based on the results of Phase I, a three-part research project, "Phase II Utility Cut Repair Techniques – Investigation of Improved Utility Cut Repair Techniques to Reduce Settlement in Repaired Areas, Phase II" (Phase II), was initiated to further investigate the influences of compaction, moisture content and density of the backfill, and the "zone of influence" on the performance of utility cut trench restorations. These research areas include: 1) continued monitoring of the utility cut restorations constructed during Phase I for two additional years, 2) the construction of new trenches using six recommended practices, and 3) instrumentation of three new trenches to understand the mechanisms of trench backfill settlement and load distribution.

The objectives of Phase II were to:

- Correlate the long-term performance of trench restorations with the in-situ properties of the backfill during construction and the engineering properties in laboratory testing.
- Continue the monitoring of the utility cut restorations constructed during Phase I.
- Compare the long-term performance of current practices to the suggested construction practices of Phase I for utility cut restorations.
- Research and identify the principles of trench subsurface settlement and load distribution in utility cut restoration areas using the three instrumented trenches.
- Update the recommendations made during Phase I and recommend best practices for utility cut restoration repair techniques for the Statewide Urban Design and Specification (SUDAS) Program.

This project (thesis) completed these elements of the Phase II research project:

- Continued monitoring of the constructed utility cut trenches from Phase I.
- Construction of five of the recommended trenches remaining from Phase I.
- Construction of three instrumented trenches on Kellogg Avenue in Ames, Iowa, to compare the performance of two of the Phase I-recommended construction practices to City of Ames standard utility trench restoration methods. The performance of the trenches will be evaluated based on measured settlement rates and overburden pressures.
- Evaluation of laboratory data for soil samples of backfill used in the trenches and soils excavated from the trench for the one trench restoration constructed during Phase I, the five trench restorations constructed during Phase II, and the three-instrumented trenches constructed on Kellogg Avenue in Phase II.

1.2 - Research Plan

To achieve the objectives of the project, four tasks were outlined. First, construction of the six trenches was completed using the recommended trench construction practices from Phase I. Second, three trenches were constructed to compare the performance trenches constructed using the recommended construction practices. Third, instrumentation was installed in three trenches to make these comparisons. Fourth, data collected from the first two steps were evaluated and summarized.

1.2.1 - Task 1: Continued Monitoring of Trenches Documented During Phase I

During Phase I, the construction practices of four utility cut restorations were documented across Iowa. While the trenches were being constructed, the top lift was tested using Nuclear Density tests and Dynamic Cone Penetration (DCP). After the restorations were completed, elevation surveys were performed; however, only three of the trenches were tested using FWD testing during Phase I. These three trenches were monitored during Phase II with elevation survey and FWD testing.

1.2.2 - Task 2: Construct the Five Remaining Trenches Proposed in Phase I and Monitor All Six Trenches using FWD

One of the six recommended trenches were constructed in Phase I; the remaining five utility cut restorations were constructed during Phase II. These utility cut trench restorations, along with the one constructed during Phase 1, were monitored using FWD testing for at least one year. Two FWD tests were performed on the recommended trench constructed during Phase I, and one FWD test was performed on each of the other five recommended trenches after their construction.

The engineering properties of the soil removed from the trenches and the backfill were measured in the field and in laboratory testing. The laboratory testing used sieve analysis, hydrometer, standard proctor tests and relative minimum and maximum density tests to find the engineering properties. During the construction of the proposed trenches field tests, Nuclear Density, DCP, and/or Clegg Hammer tests were used to evaluate the in-situ properties of the backfill material after it was placed. The results from the field and laboratory investigations were used to evaluate how the in-situ properties of the backfill material affect the long-term performance of the utility cut restoration.

1.2.3 - Task 3: Instrument and Monitor Three Additional Utility Trenches

To better understand the principles of settlement and load distribution in and around the utility cut restoration area, three trenches were instrumented. The trenches, located on Kellogg Avenue in Ames, Iowa, were constructed using:

- A shallow trench (less than 8 feet deep) using the City of Ames current construction practices. The current construction practices included lifts greater than or equal to two feet, granular backfill with minimum moisture and density control. (Trench 2)
- A shallow vertical walled trench with granular backfill, lift thickness less than 12 inches, moisture control, and relative density of 65 percent or more. (Trench 1)
- A shallow T-section trench with granular backfill, lift thickness less than 12 inches, moisture control, and relative density of 65 percent or more. (Trench 3)

The instrumentation monitored settlement with extensometers, overburden pressure with pressure cells, moisture content of the backfill material with moisture sensors, and temperature using temperature sensors. These trenches were monitored from fall 2007 to spring 2008 (7 months)

1.2.4 - Task 4: Data Evaluation

Data collected during Task 1 and 2 were analyzed. The field and laboratory testing data from Tasks 1 and 2 were compared with the settlement and FWD measurements. From this comparison, the goal was to determine if the recommend construction practices improved the performance of the utility cuts. The data output from the instrumentation in Task 2 was compared to determine the specific mechanisms that cause deterioration of the utility cut patches.

1.3 - Recommendations and Conclusion

Based on the continued monitoring of the trenches constructed during Phase I (Section 3.0), the six recommended trenches during Phase II (Section 4.0), and the three-instrumented trenches constructed during Phase II (Section 5.0) the following conclusions and recommendations can be made:

1.3.1 - Material Selection

- 3/8 inch minus backfill is not an acceptable backfill material, it exhibits collapse behavior when wetted, as seen when water infiltrated around the temporary patch into the trenches, and is frost susceptible, and undergoes heave during freezing conditions as shown in Trenches 1 and 3 where the backfill was placed with moisture control and proper compaction techniques.
- Soils containing silt-sized particles are most susceptible to frost heave.
- 1-inch clean limestone or other clean backfill with limited fines do not experience collapse and are least susceptible to frost-heave. The use of 1-inch clean limestone improved the performance of the trenches. It stiffened the response of the trench in FWD testing and the settlement within the trench is less than in trenches constructed with 3/8-inch minus limestone.

- Soils excavated from the trenches could be mixed with granular backfill if laboratory tests indicating the range of moisture content and densities that the material need to be placed at were conducted and appropriate quality control measures are used. Mixing a cohesive material and the granular backfill reduces the moisture content. The soils were placed at moisture contents that were below optimum moisture content.

1.3.2 - Construction Practices

- The use of a concrete patch with dowels performed the best over the long-term. This was documented with the Des Moines trench patch.
- Pavement should be removed from four feet around the perimeter of the trench and the area should be re-compacted if a T-section is not constructed. This is supported by the results in Trench A.
- The T-section did not abate the “zone of influence” on the trenches. Rather, the “zone of influence” moved outside of the T-section for all trenches, except Trench E where “the zone of influence” was evident on only one side of the T section.
- The T-section did not reduce the settlement in the trenches. The trenches without the T-section (Trenches A and D) performed better. During the construction of the T-section, a larger area of the street was disturbed and a large volume of backfill had to be evenly compacted. Because there was no quality management of the placement of the backfill to ensure that it was compacted to appropriate relative densities across the trenches, uneven settlements occurred.
- Another reason for the poor performance of the T-sections trenches could be the result of mixing the limestone backfills with other soils.
- The increased effort and resources used to construct the T-section trenches did not yield better trench performance.
- The T-section could be modified to use walls that are beveled outward to facilitate compaction of backfill. Beveled edges may reduce the amount of disturbance to the surrounding soil and eliminate the vertical excavation, however, it may make compacting the backfill at the edges difficult. This is expected to prevent the “zone of influence” from migrating outside of the T-section.

- Construction equipment should be kept away from the edges of the trench. FWD testing on the Cedar Rapids trench showed that damage caused by equipment during construction had a long-term impact on the performance of the trench.
- The FWD tests showed similar response of the trenches based on the season of the tests. According to the literature reviewed, this was the result of differences in the moisture content and stiffness of the soil during the spring and fall (Andersland and Landanyi 2004).
- The use of geogrid in the trenches did not improve the performance of the trenches compared to the trenches constructed without the geogrid for the trenches using 3/8-inch minus limestone. The geogrid appears to have stiffened the response of the trench based on FWD testing; however, it did not reduce settlement in the trenches.
- Cities should implement moisture control practices.

1.3.3 - *Quality Management*

- Quality control measures should be implemented in the field to ensure that compaction requirements are met. This includes achieving at least medium to dense relative density with moisture contents above the bulking moisture content for cohesionless soils and above 95% of Standard Proctor and +/- 2% of optimum moisture content for cohesive soils.
- An educational program should be established to educate city maintenance crews of the importance of proper construction practices. Based on the experience with the City of Ames, a program including demonstrations will help solidify the importance of moisture control during the construction of trenches.

1.4 - Future Research Needs

- Reconstruct the T-section trenches with 1-inch clean backfill. Several T-sections should be constructed to permit evaluating the performance of the trenches. (i.e. ensure that each lift is placed with moisture control at the appropriate relative density for the backfill being used).

- Construct trenches with a beveled cross section at the top to facilitate the compaction of the backfill at the perimeter of the trench.
- Continue FWD testing on the trenches.
- Continue to monitor the settlement of the trenches.
- Continue to monitor the instrumented trenches.

CHAPTER 2.0 - LITERATURE REVIEW

2.1 - Summary of Phase I Results

Pavement settlement at utility cuts is a common concern that requires municipal resources for additional maintenance. The Phase I Report concluded that utility cut restoration failures increased maintenance costs. Brinkley (1990) determined that non-shrink backfill in utility cuts prevented pavement failures in Prescott, Arizona. The increased cost of the of the non-shrinking slurry was offset by the cost savings of the improved efficiency of the backfilling process and the minimization of further maintenance of the utility cut.

During Phase I, a survey of several Iowa cities, supplemented with site visits, identified factors that contributed to the settlement of utility cut restorations in pavement sections throughout Iowa. The construction practices, backfills, compaction effort, and moisture content used in utility cut restoration were then documented, evaluated, and analyzed (Schaefer et al. 2005).

The results from the Phase I survey showed:

- The likely months for water main breaks were December and January. Frost loading increased the vertical loads on the water mains up to twice the original load, (Moser 1990).
- The majority of responding cities indicated that utility cut restorations showed signs of failure within two years.
- The specifications for compaction were based on the Standard Proctor test for all soil types.
- In the field, quality management of the backfilling operation was minimal.

The Phase I field investigation documented problems associated with utility cut trench restoration performance, construction, and backfilling. Problems identified during the field and laboratory investigations of Phase I were:

- The use of large construction equipment.

- Large equipment was unable to maneuver within the trench and compact the backfill causing uneven compaction and differential settlement especially along the edge of the trench.
- Large compaction equipment too near the edge of the utility cut damaged the pavement around the perimeter of the trench (see Figure 1).

- The placement of backfill in lift thicknesses greater than 12 inches (in some cities lift thicknesses exceeded 3 feet), see Figure 2.
- The placement of granular backfill within the bulking moisture content range. This increased the collapse potential of the backfill when subjected to changes in moisture content (see Table 1). These numbers were revised during Phase II based on Houston et al. (1996) (see Section 2.2.2).
- Inadequate compaction effort and minimal moisture content control in the field caused low relative densities and loosely compacted backfill (see Figure 3).
- During excavation of the utility cut, the surrounding soil are weakened because of the loss of lateral support. The affected region around the trench is known as the "zone of influence." During Phase I, it was determined that the FWD tests can detect the weakened zones of soil (see Figure 4).

Figure 1 -- Cracking pavement surrounding the utility cut area, because of construction equipment getting too close to the edge of open cut (Schaefer et al.. 2005)

Figure 2 -- Large lift thickness used in utility cut trench backfilling (Schaefer et al.. 2005)

Table 1 -- Measured moisture contents of granular backfill materials during installation compared to bulking moisture content (Schaefer et al.. 2005)

Backfill Material	Classification	γ_{Max} * (lb/ft^3)	Phase I W% (Bulking)	Phase II W% (Bulking)	*W*% (Field)
Ames	SM	140	5.0-9.0	4.0 to 8.0	4.3 to 5.4
Cedar Rapids	SC	130	5.5-10.0	7.0 to 10.0	5 to 7
Davenport	GC	140	3.5-7.5	4.0 to 8.0	6.3 to 7.8
Des Moines	SW-SM	138	4.5-12	7.0 to 11.0	5.4 to 11.7

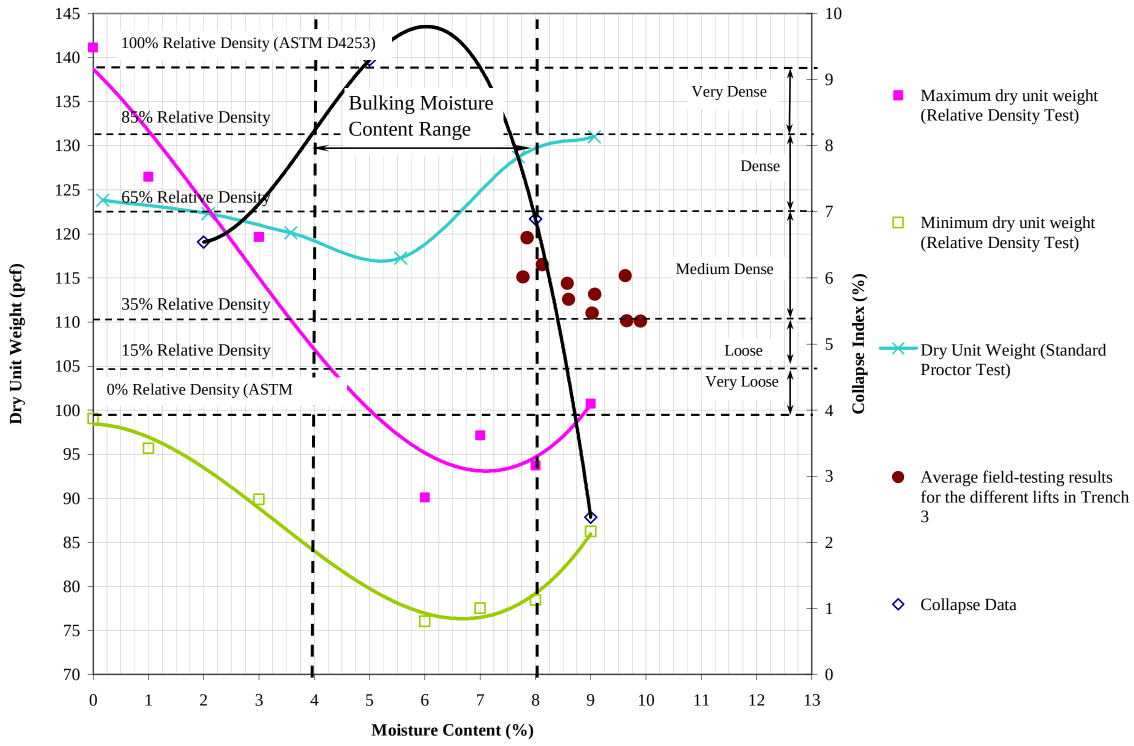


Figure 3 -- Measured densities compared with maximum and minimum densities, showing loose backfill material after compaction

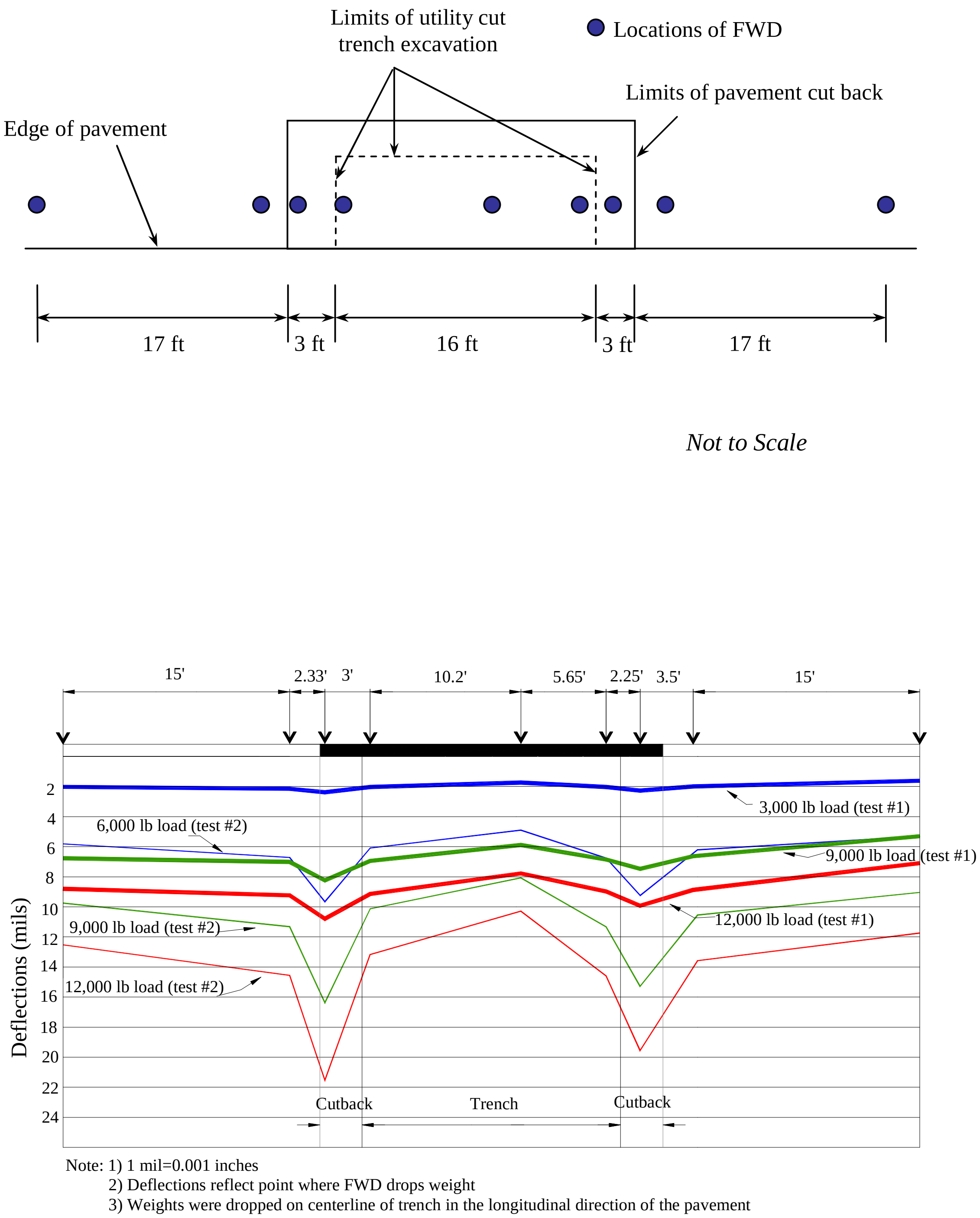


Figure 4 -- Locations and results of FWD tests performed at a utility cut location in Ames, Iowa showing deflection within the zone of influence (Schaefer et al.. 2005)

2.2 - Long Term Performance of Trench Restoration Literature Review

The Phase I report documented that utility cut restorations influence the performance of pavement systems and reviewed literature before 2005.

2.2.1 - Types of Failures

The Phase I report established that in Iowa there are several causes for utility cut restoration failure. The types of failures documented were: a) settlement of the utility cut restoration, b) a “bump” forming over the restoration, and c) weakening of the surrounding soils.

The first failure type was the settlement of the restoration. Two factors caused settlement. The first factor was poor compaction of the trench backfill. Poor compaction effort was the result of a combination of lift thickness and the equipment utilized. Second, wet and frozen conditions also increased the settlement caused by poor compaction effort.

The second failure type was a “bump” failure of a utility cut restoration. The bump was caused by frost action resulting in pavement heaving. Frost heave can occur in unsaturated soils. Taber (1929) noted that frost heave could occur in any soil where moisture was present. This created the illusion that the pavement ha heaved (Schaefer et al.. 2005).

The final type of restoration failure was the weakening of the surrounding native soils. The weakening of the native soil caused cracking in the surrounding pavement. When a trench was excavated, the stress state of the surrounding soil changed. This caused a zone of weakened soil around the trench. In the Phase I report, this was referred to as the “zone of influence” (see Figure 5). The Phase I also determined that “zone of influence” can be detected with FWD testing.

The magnification of these failures in utility cuts depended on the geometry of the trench. Trenches parallel to the curb were more susceptible to settlement along the edges than in the center of the trench (Schaefer et al.. 2005). Settlement in trench cuts that were perpendicular to the curb occurred in the wheel paths along the center of the trench. Most of the settlement occurred within the first two years of construction (Schaefer et al.. 2005).

Humphrey and Parker (1998) used finite element analysis to evaulate the failure mechanism of utility cuts up to depths of 5 feet. To model a utility cut to a depth of 5 feet and capture stress and displacements in the surrounding soil, the total model was extended 3 feet below the bottom of the cut and 4.9 feet beyond the edge of the cut. The total model dimensions, including the utiliy cut, was 7.5 feet in width and 8 feet in height: The model consisted of:

- 4 inches of asphalt concrete (AC)
- 8 inch granular base
- 8 feet granular fill/subgrade

The model was extended out from the trench. A step analysis was used to simulate the process of excavating a trench to a depth of 5 feet. The base and the fill/subgrade of the trench was modeled with well-graded gravel to sandy gravel.

The following results were documented from the model:

- After the utility cut was made, the unsupported face of the excavation displaced into the trench. The region of soil beyond the face of the cut that was affected by the displacements at the face extended up to 3.5 feet beyond the face of the cut.
- The displacements because of the "stretching" in the models were a function of the soil cohesion, angle of internal friction, density, and cut depth. Figure 6 shows the nodal displacement of the finite element model.
- The asphalt was in tension after the utility cut was made and restricted the movement of subbase. Tension cracking was likely between the utility cut and the active failure plane. However, the asphalt concrete pavement stabilized the soil and prevents cracking.
- The region of soil with the highest stress caused by the displacements at the face was the granular pavement subbase, which was located between the asphalt pavement and native soils that were being excavated.

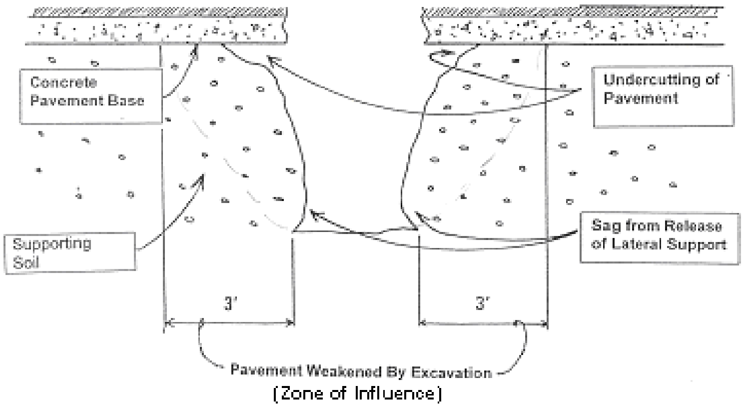


Figure 5 - Overstressing of the pavement and natural materials adjacent to the trench (modified from Schaefer et al.. 2005).

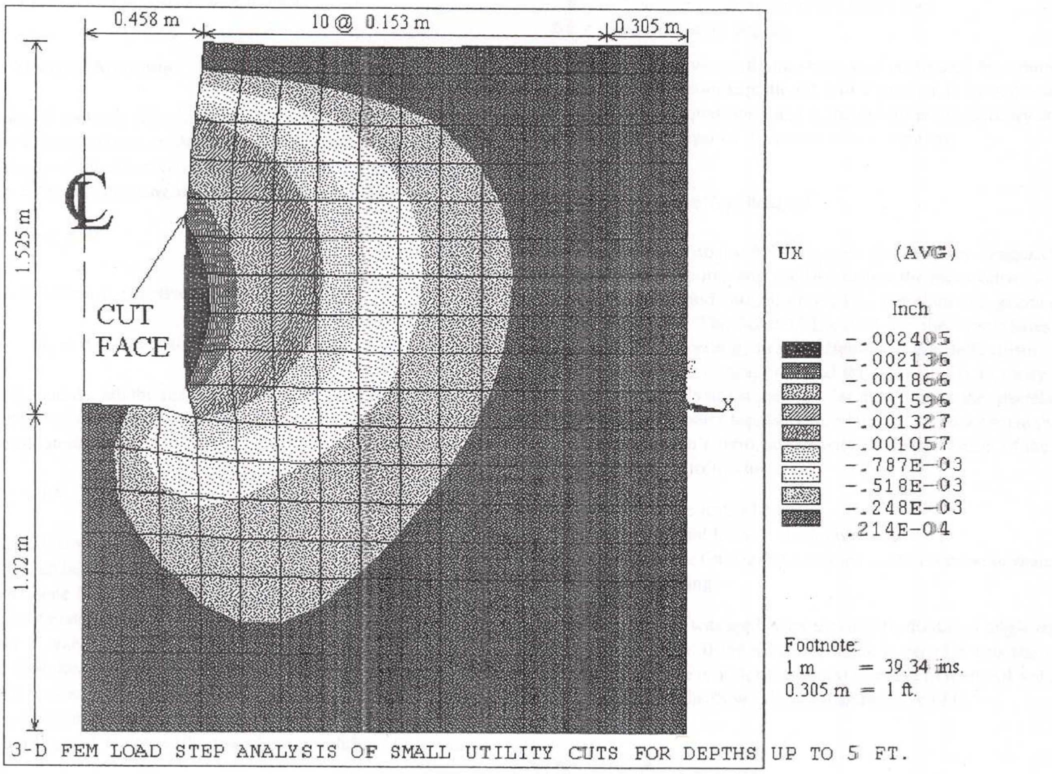


Figure 6 -- Finite element analysis from Humphrey and Parker (1998)

2.2.2 - Properties of Backfill Material

Classification of Backfill

Backfill was classified using the American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS) "Standard Classification of Soils for Engineering Purposes (Unified Soil Classification Systems" 2000). The AASHTO classification system ("Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes" 2000), used by the Iowa DOT for cohesionless materials, is presented in Table 2. Table 3 shows the AASHTO classification for cohesive materials. The USCS classification system is shown in Table 4.

To compare measured field parameters, published maximum dry unit weights, CBR values, and optimum moisture content for various compacted materials from the Navy Facility Commands (NAVFAC, 1986), Rollings and Rollings (1996) and Sowers (1979), are presented in Table 5. In Table 6, the relative density standards developed by Budhu (2000) are presented.

Table 2 -- AASHTO M145-91 for cohesionless materials (modified from AASHTO M145-91, 2000)

General Classification	Granular Materials (35% or Less Passing sieve #200)						
Group Classification	A-1		A-3	A-2			
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7
Sieve analysis, percent passing							
No. 10 (2.00 mm)	50 max	--	--	--	--	--	--
No. 40 (0.425 mm)	30 max	50 max	51 min	--	--	--	--
No. 200 (75 µm))	15 max	25 max	10 max	35 max	35 max	35 max	35 max
Characteristics of fraction passing 0.425 mm (no. 40)							
Liquid limit	--		--	40 max	41 min	40 max	41 min
Plasticity index	6 max		NP	10 max	10 max	11 min	11 min
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine Sand	Silty or clayey gravel and sand			
General rating as subgrade material	Excellent to Good						

Table 3 -- AASHTO classification for cohesive materials (modified from AASHTO M145-91, 1991 (2000))

General Classification	Silt-Clay Materials (More Than 35 Percent Passing the No. 200 Sieve)				
Group Classification	A-4	A-5	A-6	A-7	
				A-7-5	A-7-6
Sieve analysis, percent passing					
No. 10 (2.00 mm)	--	--	--	--	--
No. 40 (0.425 mm)	--	--	--	--	--
No. 200 (75 µm))	36 min	36 min	36 min	35 max	35 max
Characteristics of fraction passing 0.425 mm (no. 40)					
Liquid limit	40 max	41 min	40 min	41 max	41 min
Plasticity index	10 max	10 max	11 min	Equal to or less than LL-30	Equal to or greater than LL-30
Usual types of significant constituent materials	Silty Soils		Clayey Soils		
General rating as subgrade material	Fair to Poor				

Table 4 -- USCS (modified from ASTM D 2487 2000).

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests				Soil Classification	
				Group Symbol	**Group Name**
Coarse – Grained Soils More than 50% retained on the No. 200 Sieve	Gravels More than 50% of Coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines	$C_u \geq 4$ and $1 \leq C_c \leq 3$	GW	Well-graded gravel
			$C_u < 4$ and/or $1 > C_c > 3$	GP	Poorly graded gravel
		Gravels with Fines More than 12% fines	Fines Classified as ML or MH	GM	Silty gravel
			Fines classified as CL or CH	GC	Clayey gravel
	Sands 50% or more of course fraction passes No. 4 sieve	Clean Sands Less than 5% fines	$C_u \geq 6$ and $1 \leq C_c \leq 3$	SW	Well – graded sand
			$C_u < 6$ and/or $1 > C_c > 3$	SP	Poorly graded sand
		Sands with Fines More than 12% fines	Fines classify as ML or MH	SM	Silty sand
			Fines classify as CL or CH	SC	Clayey sand
Fine –Grained Soils 50% or more passes the No. 200 Sieve	Silt and Clays Liquid limit less than 50	Inorganic	PI > 7 and plots on or above the "A" line	Cl	Lean clay
			PI < 4 or plots below "A" line	ML	Silt
		Organic	Liquid limit – oven dry < 0.75	OL	Organic clay
			Liquid limit – not dried		Organic silt
	Silt and Clays Liquid limit 50 or more	Inorganic	PI plots on or above the "A" line	CH	Fat clay
			PI plots below "A" line	MH	Elastic silt
		Organic	Liquid limit – oven dried	< 0.75	Organic clay
			Liquid limit – not oven dried		Organic silt
Highly organic soils		Primarily organic matter, dark in color and organic odor		PT	Peat

Table 5 -- Properties of compacted materials

Group Symbol	Typical properties of compacted backfill materials (Modified) (NAVFAC 1986)			Maximum dry unit weight for Standard Proctor test (Sowers 1979) (pcf)	Range of CBR values (%) (Rollings and Rollings Jr. 1996)
	Range of maximum dry unit weight (pcf) for the Standard Proctor test	Range of optimum moisture (%) for the Standard Proctor test	Range of CBR values (%)		
GW: Well graded gravels	125-135	11-8	40-80	125 - 135	60 to 80
GP: Poorly graded gravels	115-125	14-11	30-60	115 - 125	35 to 60
GM: Silty gravels	120-135	12-8	20-60	120 - 135	40 to 80
GC: Clayey gravels	115-130	14-9	20-40	115 - 130	20 to 40
SW: Well graded sands	110-130	16-9	20-40	107 - 130	20 to 50
SP: Poorly graded sands	100-120	21-12	10-40	100 - 120	10 to 25
SM: Silty sands	110-125	16-11	10-40	110 - 125	20 to 40
SM-SC: Sand-silt clay	110-125	15-11	5-30		---
SC: Clayey sands	105-125	19-11	5-20	105 - 125	10 to 20
ML: Silts	95-120	24-12	15 or less	95 - 120	5 to 15
ML-CL: Inorganic silt and clay	100-120	22-12	---	---	---
CL: Lean clay	95-120	24-12	15 or less	95 - 120	5 to 15
OL: Organic silts and silt-clays,	80-100	33-21	5 or less	80 - 100	4 to 8
MH: Elastic silts	70-95	40-24	10 or less	75 - 100	4 to 8:
CH: Fat clay	75-105	36-19	15 or less	80 - 105	3 to 5
OH: Organic clays and silty clays	65-100	45-21	5 or less	70 – 100	3 to 5

Table 6 -- Relative density and compaction (Budhu 2000)

Compaction	Relative Density
Very Loose	0 to 15
Loose	15 to 35
Medium Dense	35 to 65
Dense	65 to 85
Very Dense	85 to 100

Moisture Content

The dry unit weight obtained during compaction was a function of the materials moisture content. When granular materials are moistened, water surrounds the particles. As water surrounds each particle, a meniscus forms between the particles (see Figure 7). The meniscus caused high capillary tension forces between the particles. The tension force between the particles prevented the particles from rearranging into denser alignments. These forces between particles are difficult to overcome (Schaefer et al.. 2005).

When additional water was introduced, the voids begin to fill up, the meniscus between the particles decreases, and the tension forces are released. This caused the granular material to move around each other again and configuration into denser arrangements. The increase in water content also made the soil susceptible to collapse behavior. Thus, after compaction effort, the soil has lower dry unit weight than if compacted at higher moisture contents. Collapse behavior of a soil can be determined in the field or laboratory.

Houston et al.. (1996) explored the differences between field and laboratory collapse testing. The field test was a plate load test and the laboratory test was a response-to-wettness test. The advantages of the field tests are: 1) there was minimal sample disturbance and 2) the degree of wetting to cause collapse was similar to actual conditions. The disadvantages of the field tests included non-uniform stress state of the soil contributing to settlement and also difficulty in determining the stress-strain relationship.

The advantage of the laboratory tests were that a uniform stress strain curve can be found. The disadvantages of the laboratory tests are that sample disturbance and that the saturation required to cause collapse in the laboratory was higher than in the field. The bases for judging which test is apporperate depends on the application, field conditions and avalibility.

In Phase I, the soils were tested in the laboratory. This means that the bulking moisture contents were higher than what was in the field. Based on Houston et al.. findings the bulking moisture contents were revised from Phase I. The adjusted criteria for the bulking moisture content was based on moisture content for the maximum collapse potential +/- 2%.

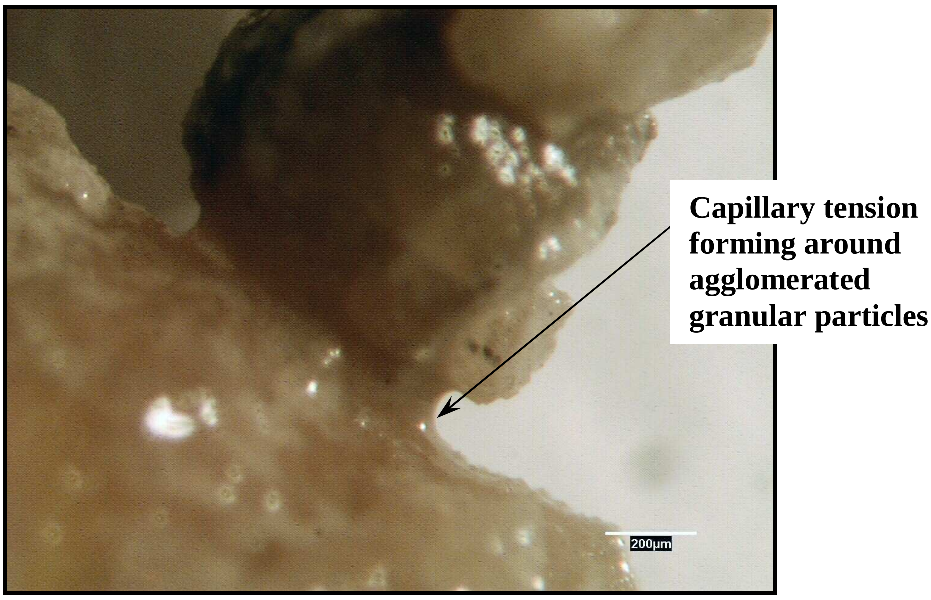


Figure 7 -- Meniscus between two granular particles (Schaefer et al. 2005)

2.2.3 - Iowa Backfill Standards

Acceptable Gradations

The Iowa DOT specifications allowed for a wide variety of backfill materials. SUDAS specifications also included several different types of trench backfill materials that were based on ASTM D 2321-00. SUDAS Class I material is a cohesionless material with fines limited to 5% and was classified as non-plastic. SUDAS Class I material was primarily used for pipe bedding but was also recommended for trench backfill in areas under pavement.

The Iowa DOT Specifications, Section 4120, contained several backfill gradations. Table 7 presents the Iowa DOT and the SUDAS specifications gradations.

Table 7 – Backfill material gradation standards (modified from Schaefer et al.., 2005)

Sieve Size	Acceptable Iowa DOT Gradations								SUDAS Class I Bedding & Backfill	
	No. 10		No. 11		No. 16		No. 32			
	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit
1.5"					100		100% passing the 3" sieve.		100	100
1.0"			100						100	95
3/4"	100		100	95						
0.500"			90	70	50	0			60	25
4	80	50	55	35	10	0	100	20	10	0
8	60	25	40	11						
200			16	6			0	10		

Backfill Placement

Schaefer et al.. documented lift thicknesses that often exceed 24 inches in Iowa. The SUDAS specifications stated that lift thicknesses should be a maximum of 6 inches in the primary and secondary backfill areas. Other lifts should be placed in loose lifts with a thickness less than 12 inches.

2.2.4 - Compaction Equipment

To properly select compaction equipment for a given backfill, three considerations should be made: type of material, lift thickness, and application (Hilf, 1991). Because of the confined area of a trench, the choice of equipment is limited. Table 8 shows two different equipment types and the requirements to meet 95 to 100 percent Standard Proctor Maximum Density.

As lift thickness increased beyond the recommended thickness for the equipment type, the effectiveness of the equipment decreased. With lightweight equipment, such as the equipment used in trenches, the effective compaction depth was shallow. Vibrations do not compact material deeper than 4 to 10 inches into the lift (Table 8). Conversely, for heavyweight equipment, the effective depth of compaction was deeper; however, material near the surface remained relatively unaffected by the vibrations being applied to the surface.

Another consideration when selecting compaction equipment was the effect of equipment on moisture content and dry unit weight. According to Winterkorn and Pamukcu, (1991), as the size of the backfill tamper equipment increased, the dry unit weight of the compacted soil decreased and the moisture content increased. In addition, they found base plate compactors in the field yielded higher optimum moisture content than found in laboratory testing.

Equipment Type	Applicability	Requirements for Compaction of 95 to 100 Percent Standard Proctor Maximum Density			Possible Variations in Equipment
		Compacted lift Thickness, inches	Passes or coverage	Dimensions and Weight of Equipment	
Vibrating Base plate Compactors	For coarse-grained soils with less that 12 percent passing No. 200 sieve. Best suited or materials with 4 to 8 percent passing the No. 200 placed thoroughly wet	8 to 10 inches	3 passes	Single pads or plates should weigh no more than 200 lbs. May be used in tandem where working space is available. For clean course-grained soils, vibration frequencies should be no less than 1600 cycles per minute	Vibrating pads or plates are available, hand – propelled or self – propelled, single or gangs, with width coverage from1 ½ to 15 feet. Various types of vibrating-drums equipment should be consider for lager areas
Power Tamper or Rammer	For difficult areas, trench backfill. Suitable for all inorganic soils	4 to 6 inches for silt or clay, 6 inches for coarse grained soils	2 passes	30 pounds minimum weight. Considerable ranged is tolerable, depending on materials and conditions	Weights up to 250 pounds; foot diameters 4 to 10 inches

Table 8 – Lightweight Compaction Equipment (modified from Hilf, 1991)

2.2.5 - Field Quality Management

During the Phase I project, it was concluded that backfill placement quality management on a project was critical to the performance of the utility cut restoration. To monitor the placement of backfill, three different tests were used: Nuclear Density, DCP, and Clegg Hammer.

Nuclear Density Test

The Nuclear Density test, ASTMD6938-08 Standard Test Method for In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (2008) provided the moisture content and dry unit weight for in-situ soils. The gauge works by emitting two types of radiation. The neutron radiation measures the moisture content of the material and the gamma ray radiation measured the dry unit weight of the material. The probe can be inserted up to 12 inches into the material being tested. When operating in a confined area (i.e. a trench), the nuclear density gauge must be calibrated.

Because of the radioactive material in the gauge, users are required to become certified to operate the equipment. Phase I found that some state and local governments are limiting the used of the nuclear density gauge because of the concerns about radioactive material.

DCP Test

The DCP test is an in-situ test. This test provides a profile of California Bearing Ratio (CBR) values for each test location. The test was performed by driving a cone-tipped rod into the ground with a 17.6-pound hammer. A vertical profile of millimeters per blow for the material was developed, and then the Dynamic Cone Penetration Index (DCPI) was calculated using Equation 1 (Sawangsuriya and Edil, 2004):

$$DCPI_{wtavg} = \frac{1}{H}\sum_{i}^{N}\left[(DCPI)_i \times (z)_i\right]$$

Equation 1

Where: *H = total penetration depth*

z = lift thickness

$DCPI_{wage}$ = penetration index for z

The DCPI was then correlated to the CBR. Several CBR correlations are available, however, to maintain consistency between the Phase I report and Phase II report, the same correlation was used (Equation 2):

$$CBR = \frac{292}{DCPI^{1.12}}$$

Equation 2

The ASTM standard for the DCP test is ASTM D 6951, Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications.

The Schaefer et al.. report stated the following advantages for the DCP test:

- Minimal training was needed for operation.
- Equipment was inexpensive.

The reported disadvantages of the DCP test are:

- Field results required detailed calculations to obtain CBR values.
- There can be inconsistencies for well-graded materials and granular materials.
- Test results are inconsistent if there were less than 10 millimeters were penetrated for a given blow count.

Clegg Hammer Test

The third test used to evaluate the placement of the backfill material was the Clegg Hammer test. The ASTM standard for the Clegg Hammer was ASTM Standard D5874, Standard Test Method for Determination of the Impact Value (IV) of a Soil. The Clegg Hammer test dropped a 9.9 pound hammer 18.0 inches. The hammer was dropped four times. The deceleration of the hammer was measured for each drop. The fourth drop was the IV reading. The IV reading was correlated to a CBR value by Equation 3 developed by Clegg (1986):

$$CBR = (0.24(IV)+1)^2$$ **Equation 3**

This equation is for general use. For other materials (including granular) laboratory and field-testing data need to be correlate for each individual material. According to Dr Baden Clegg:

> "However, since CBR is particularly subject to high variability, even within one organisation (sic), one soil type, etc., correlations from individual sources may vary from the general equation. To avoid a change of standards it is appropriate therefore that each organisation (sic) should consider establishing its own relationship for specific materials and conditions…"

For this project, the generalized equation was used for all soil types because no correlation was developed between field and laboratory results. Therefore, there may be inconsistencies with CBR values found from the Clegg Hammer test.

2.2.6 - Post-construction Monitoring

FWD testing can be used to monitor the long-term performance of pavements. The FWD test applies various point loads to the pavement and measures the deflections of the pavement under the load, 12 inches in front of the load, and behind the load at 8, 12, 18, 24, 36, and 48 inches. The deflections measured in the pavement are related to the strength/stiffness of the pavement. During Phase II, the FWD test was preformed at a series of locations across each trench. The locations that were chosen can be generalized as follows: outside the zone of influence, about 1 to 2 feet away from the edge of the edge of the trench, 1 to 2 feet inside the edge of the trench, and at the center. This testing plan was modified for each trench depending on the trenches geometry. By plotting the deflections under the load at each test point various distance weakened zones in the pavement structure.

Al-Suhaibano, et al.. (1992), used FWD testing to study utility cut restoration failures and the impact on the overall pavement performance. Seventy-five utility cut restorations were randomly selected across Riyadh, Saudi Arabia on roads wider than 25 feet. The utility cuts were monitored with FWD testing at four points on the trenches (center, inner edge of the cut, outer edge of the cut and on original uncut pavement). This is similar to FWD tesitng plan used in this project, where test points were located 1 to 2 feet inside the trench and 1 to 2 feet outside the trench to capature the "zone of influence."

This study concluded:

- Utility cuts increased the deterioration of the pavement compared to undisturbed pavements.
- The geometry of the trench affected the performance of the trench. As the width of the trench increased, the deflection of the center of the trench decreased in FWD testing.

This study recommended:

- Increasing the thickness of the pavement over the utility cut. This paper did not provided a recommended thickness.
- Removing the pavement adjacent to the trench and extending the patch over the existing subbase. This paper recommended researching the distance beyond the cut the pavement should be removed.
- Increasing quality management for the materials used and the construction practices.
- Increasing the width of the utility cut to allow for better compaction of the backfill material. Determining the appropriate width of a utility cut "warranted further study" concluded Al-Suhaibano, et al.. (1992).

Part of Phase II will help further refine Al-Suhaibano et al.. recommendations concerning the removal and replacement of pavement arround the trench and evaluate the performance of two different utility cut methods. This will be done using FWD testing.

FWD testing was performed on the trenches during the spring/ early summer and fall. Testing at these times of the year will help monitor the overall long-term performacne of the trenches, but also the seasonal affects on the stiffeness of the backfill and soils surrounding the trench. Andersland and Landanyi (2004) explained that the stiffeness of a pavement is related to the seasons and is cyclical in nature (see Figure 8). Using this and several seasons of monitoring, the deterioration of the ulitilty cut and the surrounding pavements can be quantified.

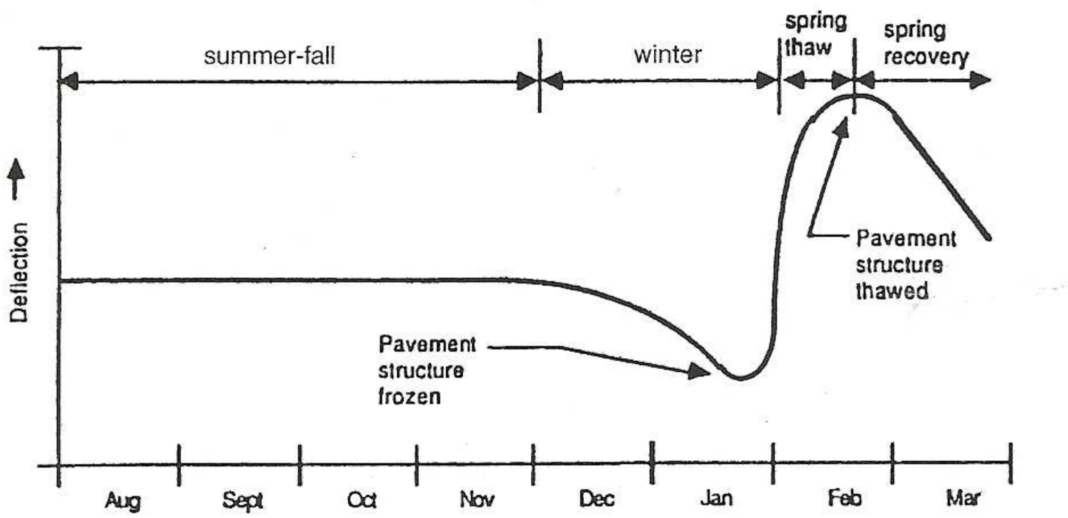


Figure 8 - Seasonal pavement surface deflections illustrating the large decrease in strength (stiffness) during spring thaw (Andersland and Landanyi 2004)

The FWD equipment used in this project was owned and operated by the Iowa DOT (see Figure 9). The deflection of the pavement was measured at the load application point, and at 10 additional points. The loads applied to the pavement were 6,000 pounds, 9,000 pounds, 12,000 pounds, and 15,000 pounds. These loads were chosen based on the experience of the Iowa DOT.

Figure 9 -- Iowa DOT FWD equipment

2.3 - Seasonal Effects

One of the major impacts of trench preformance is seasonal effects. One seasonal effect is frost. Frost can cause two problems according to Anderson et al. (1984). First, frost changes the stiffness of the soil structure during freeze and thaw cycles as shown in Figure 10. As frost forms, the pavement structure stiffens. When frost thaws, the increase in the water content in the soil causes the pavement structure to weaken. Second, displacements are caused by the formation of ice lens and the pressure on related structures which are normal to the growth of the lens (see Figure 10).

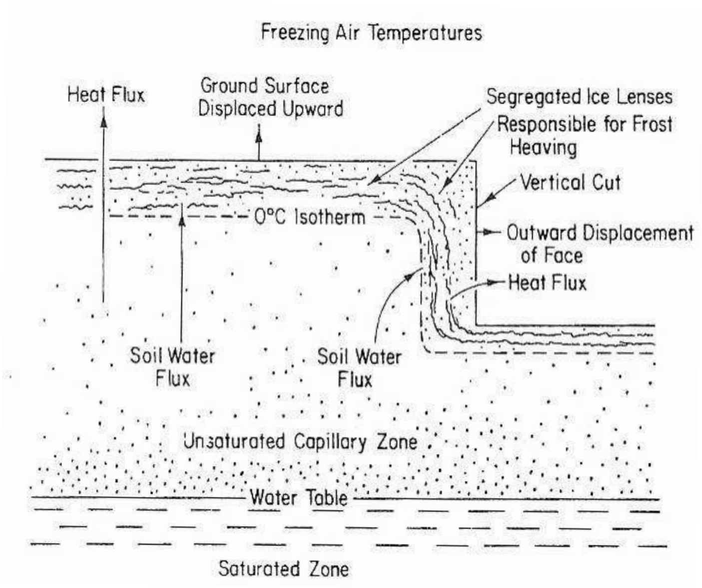


Figure 10 - Schematic illustration of frost heave (Anderson et al. 1984)

Frost formation is affected by the type soil and its thermal/ hydrostatic conductivities, the temperature gradient, and available moisture. Heat flux between the soil and adjacent medium (air or soil) flows perpendicular to the interface between the mediums as illustrated above in Figure 10. Frost formation affects pressures within a soil body and movements (both vertical and horizontal).

As frost forms in a soil, a frozen fringe develops (see Figure 11). This fringe develops at freezing temperatures and extends downward. The frozen fringe forms below where active lens are forming. As freezing temperatures penetrate deeper in a soil the frozen fringe and zone of active lens formation also migrate downward. The active ice lens layer in the soil is also a boundary where the permeability of the soil decreases (Andersland and Landanyi 2004) because the pores are filling with ice. This boundary prevents water from traveling upwards beyond the active lens zone. Because of this, no additional ice lens will form above the active ice lens zone. The downward movement of the frozen fringe affects the size of the ice lens. When the front advances rapidly through a soil, the lens will be thin; however, when the frozen fringe remains at a stationary point because of the heat flow balance, larger lens will form.

As ice lenses form, they exert an outwards pressure on the pore (Andersland and Landanyi 2004). When the pressures are greater than the overburden pressures the soil will heave. The heave (expansion of soil) occurs at the frost line, which is assumed to be at freezing. Frozen soils above the frost line do not expand because there is no influx of moisture (Andersland and Landanyi 2004)

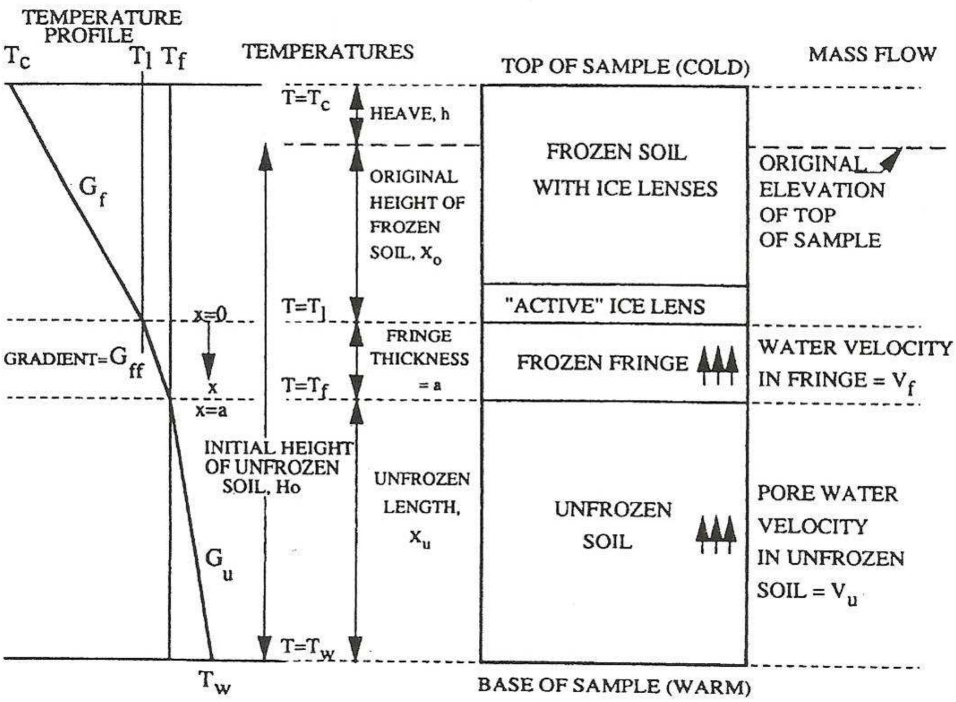


Figure 11 - Frost heave in an idealized one-dimensional soil column (Andersland and Landanyi 2004)

According to Taber (1929), soils do not need to be saturated to experience frost formation. Conversely, when a soil is at freezing temperatures, not all of the water is frozen. This is shown in Figure 12. The amount of frozen water in a soil varies by the type of soil.

When frost forms in soils, the heave causes pressures on adjacent structures. Figure 13 shows the linear relation between temperature and frost heave pressures. Heaving pressure only occurs at the frozen fringe and when the ice lens at the frozen fringe displaces a sufficient number of soil particles that exceed the overburden pressures.

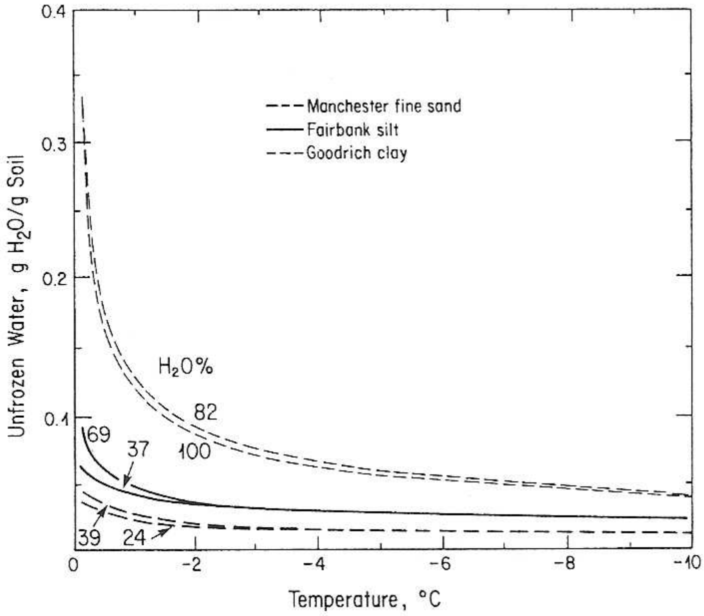


Figure 12 - Phase Comparison of representative soils (Anderson et al. 1984)

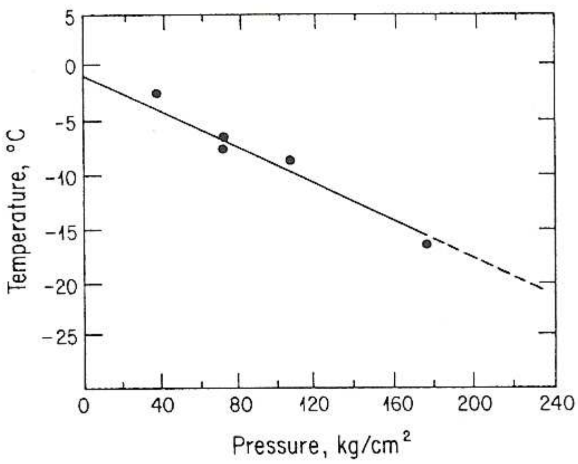


Figure 13 - Relationship between temperature and maximum observed heaving pressure in montonillonite clay (Anderson et al. 1984)

2.3.1 - Frost Susceptibility Classifications for Soils

Several methods have been developed to determine the frost sustainability of a soil. All of the classifications are based on the size and quantity of fine sized particles in any soil. According to Anderson et al. (1984), the frost susceptibility of a soil is a function of particle and void size. Gravels have large voids and large particles. This allows water to flow freely through the soil. When water does freeze in gravel, the void size is large enough so that as the frozen fringe passes through, the lens cannot grow large enough to displace the particles. Clays, at the other end of the gradation chart, have very small particles and small voids. Less forces is required to displace smaller soil particles than larger particles, such as gravels. This make soils with high percentages of fines more sustainable to frost. However, the low permeability and higher thermal conductivity, according to Anderson et al. (1984), results in the frozen front moving quickly through a soil before water is able to migrate to the frozen front. Anderson et al. (1984) states that silt size particles are more susceptible to frost formations and vertical movements than gravels or clays.

The Army Corp of Engineers has a classification system based on percentage of particle weight finer than 0.02 mm. Table 9 presents the classification system with the design group classification and Figure 14 presents the classification system graphically with the design group classification. The design group classification is used for design of structures in frozen soils. For this report, all frost heave classification will be based on the U.S. Army Corps of Engineering's system.

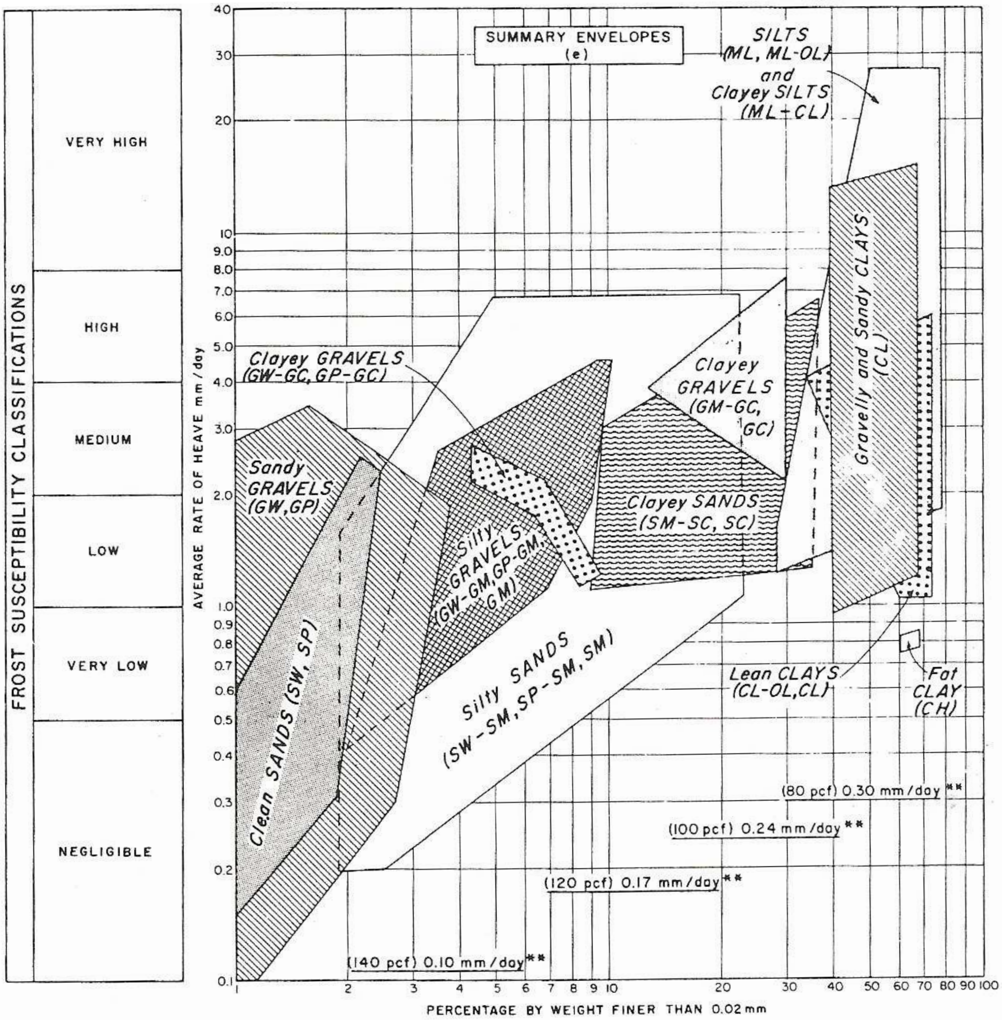
The Alaska frost susceptibility is based on percent of particles by weight finer than 0.074 mm and the depth below pavement (see Figure 15). Alaska classifications account for the affect of overburden pressure. As overburden pressures increase, the ability of frost heave decreases (Andersland and Landanyi 2004).

The New Brunswick frost susceptibility criteria is based on limiting the total fines smaller than 0.074 mm to less than 7% and, then using Figure 16, determining what percent of the fines are clay, sand or silt.

Table 9 - U.S. Army Corps of Engineers Frost Design Classification System (Anderson et al.. 1984)

Frost susceptibility[a]	Frost group	Kind of soil	Amount finer than 0.02 mm (wt %)	Typical soil type under USCS[b]
Negligible to low	NFS[c]	a. Gravels	0–1.5	GW, GP
		b. Sands	0–3	SW, SP
Possibly	PFS[d]	a. Gravels	1.5–3	GW, GP
		b. Sands	3–10	SW, SP
Low to medium	S1	Gravels	3–6	GW, GP, GW-GM, GP-GM
Very low to high	S2	Sands	3–6	SW, SP, SW-SM, SP-SM
Very low to high	F1	Gravels	6–10	GM, GW-GM, GP-GM
Medium to high	F2	a. Gravels	10–20	GM, GM-GC, GW-GM, GP-GM
Very low to very high		b. Sands	6–15	SM, SW-SM, SP-SM
Medium to high	F3	a. Gravels	>20	GM, GC
Low to high		b. Sands except very fine silty sands	>15	SM, SC
Very low to very high		c. Clays, $I_p > 12$	—	CL, CH
Low to very high	F4	a. All silts	—	ML, MH
Very low to high		b. Very fine silty sands	>15	SM
Low to very high		c. Clays, $I_p > 12$	—	CL, CL-ML
Very low to very high		d. Varved clays and other fine-grained banded sediments	—	CL and ML; CL, ML, and SM; CL, CH, and ML; CL, CH, ML, and SM

[a] Based on laboratory frost-heave tests.
[b] G, gravel; S, sand; M, silt; C, clay; W, well graded; H, high plasticity; L, low plasticity.
[c] Non-frost susceptible
[d] Requires laboratory frost-heave test to determine frost susceptibility.
Source: Johnson et al. 1986.



Gravelly Soils	F1	F1	F2	F3
SANDS (Except very fine silty SANDS)		F2	F3	
Very fine silty SANDS			F4	
All SILTS			← F4	
CLAYS (PI > 12)			← F3	
CLAYS (PI < 12), varved CLAYS and other fine-grained banded sediments			← F4	

NOTES: Standard tests performed by Cold Regions Research and Engineering Laboratory; specimens 6 in. dia. by 6 in. high, frozen at penetration rate of approximately 0.25 in. per day, with free water at 38°F continuously available at base of specimen. Specimens compacted to 95% or better of applicable standard, except undisturbed clays. Saturations before freezing generally 85% or greater.

* Undisturbed specimen

** Indicated heave rate due to expansion in volume, if all original water in 100% saturated specimen were frozen, with rate of frost penetration 0.25 inch per day.

Figure 14 - Degree of frost susceptibility of soils to the U.S. Army Corps of Engineers (Anderson et al.. 1984)

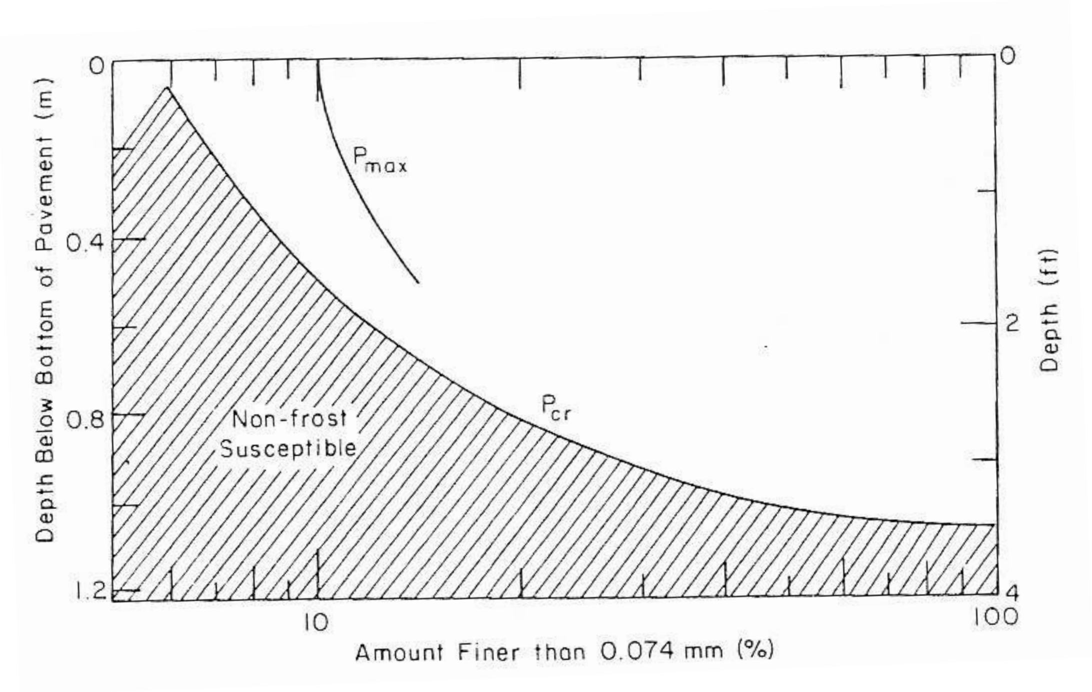


Figure 15 - State of Alaska frost susceptibility criteria (Anderson et al.. 1984)

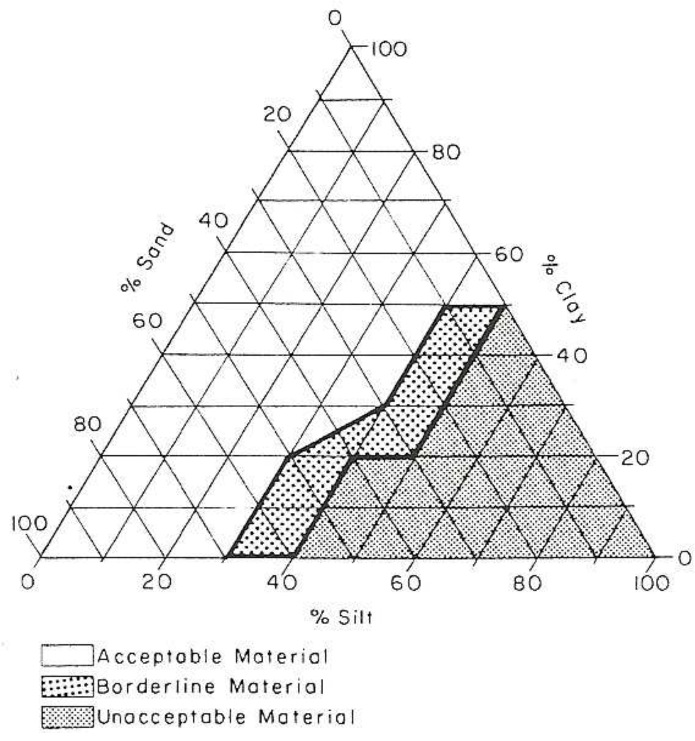


Figure 16 - New Brunswick frost susceptibility criteria (Anderson et al.. 1984)

2.4 - Summary

The literature review can be summarized as follows:

- Utility cut restorations cause pavements to deteriorate.
- Utility cut restorations increase the maintenance costs for municipalities.
- Utility cut failures are caused by large lift thickness, poor compaction, and placing granular backfills within the bulking moisture content.
- Outside the utility cut, the “zone of influence” occurs because of the loss of lateral support of the soils. This increased the deterioration of the surrounding pavements.
- Soils do not have to be saturated to under go frost heave.
- As ice lenses form, outward pressures are applied to the surrounding particles. When the outward pressures exceed overburden heave will occur.
- Soils with silt-sized particles are most susceptible to frost heave.

CHAPTER 3.0 - CONTINUED MONITORING OF PHASE I LOCAL AGENCY UTILITY CUT RESTORATIONS

Part of the Phase II project was to continue monitoring the performance of utility cuts that were observed in Phase I. The trenches selected for continued monitoring from Phase I had field tests on the backfill performed during the construction of the trench. Information and data from before May 2007 in this chapter was reported in the Final Phase I report by Schaefer et al.. 2005.

3.1 - Location and Summary of Local Agency Utility Cut Restorations

During Phase I, construction practices for utility cut restorations used in several cities in Iowa were documented at sites in Ames, Cedar Rapids, Council Bluffs, Davenport, Des Moines, Dubuque, and Waterloo, Iowa (see Figure 17).

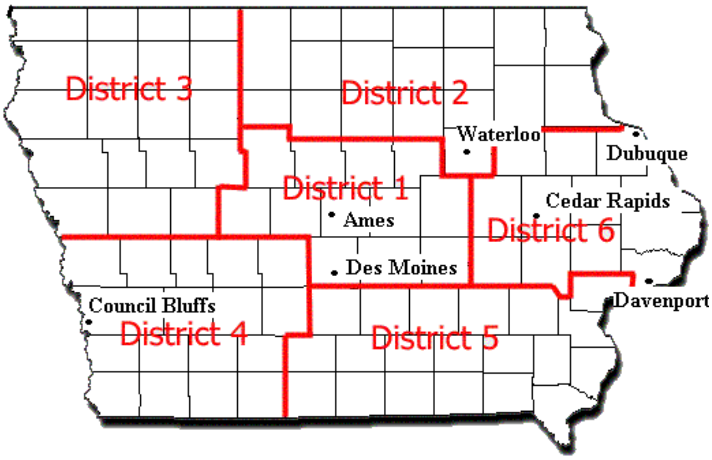


Figure 17 -- District map of Iowa showing the locations of cities where utility cut restoration practices were documented (from Schaefer et al.. 2005)

A wide variety of construction practices and backfill materials were used in utility cut trench restorations in Iowa. The selection of backfill mainly depended on its availability in the area. Backfill placed with lifts greater than 3 feet resulted in low dry unit weights, increased settlement, and distressed of pavement in the utility cut areas. To understand the effects of various backfills and lift thickness four sites were selected for field-testing and monitoring. Figure 18 shows the location of the trench sites:

- Ames, Iowa, 20th Street and Hayes Avenue
- Cedar Rapids, Iowa, Miami Drive and Sherman Avenue
- Davenport, Iowa, Iowa Street and East 4th Street
- Des Moines, Iowa, East Grand Avenue and East 28th Street

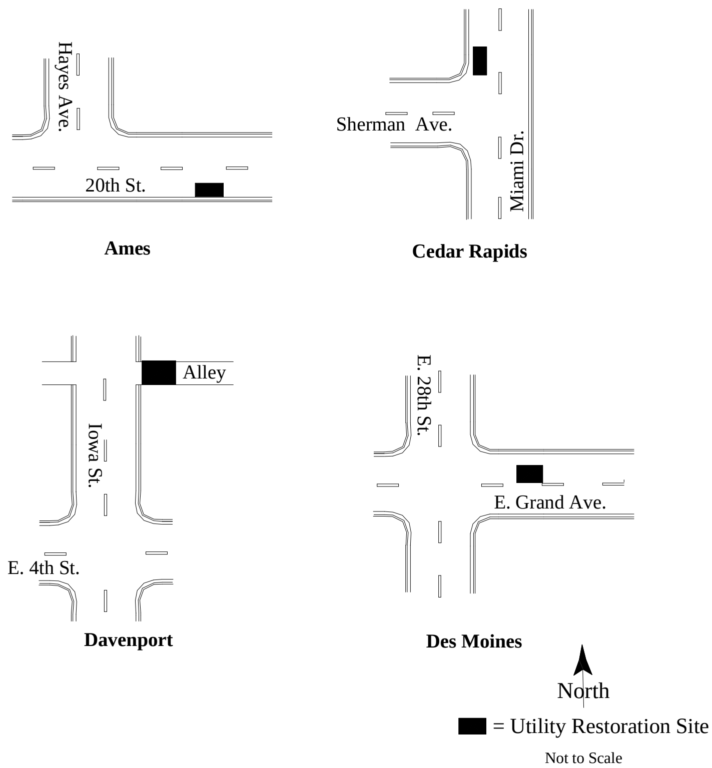


Figure 18 – Local agency utility cut restoration field-testing site locations (from Schaefer et al.. 2005)

Utility cut restoration sites in Dubuque, Waterloo, and Council Bluffs were visited, and the construction practices (materials, and lift thickness, and methods) were observed and documented by the Iowa State Research Team, however field tests were not performed on these sites because of time constraints.

A description of construction procedures, field testing, and laboratory testing results for the four sites selected for field-testing were summarized in the Phase I report. This thesis provides a brief summary of the construction, field-testing, and laboratory testing results for the sites in Ames, Cedar Rapids, and Des Moines. On these three sites, surveying and FWD testing was continued during Phase II. The Davenport site was not monitored because the utility cut spanned the length of the alley. Because of its length, it was not possible to conduct FWD testing. The portion of the trench where field-testing was performed is shown in Figure 18.

3.1.1 - Ames, 20th Street and Hayes Avenue

On October 18, 2004, a water main break required construction of a utility trench and its restoration at 20th Street and Hayes Avenue in Ames. The site was located in a high traffic area. Traffic loads consisted of traffic from the local high school and from the CyRide bus system. The City of Ames performed the excavation, construction, and restoration of the trench. The construction procedure can be summarized as follows:

- Asphalt pavement was removed from the trench area. The trench was approximately 16 feet long, 6 feet wide, and 10 feet deep.
- Saturated soil from the sides of the trench fell into the trench during the excavation.
- 1-inch limestone was placed as bedding material under the pipe and then was loosely placed as backfill around the pipe until the crown of the pipe was covered by two feet of this material.
- A vibratory plate compactor attached to a backhoe was used for compacting the bedding and backfill.
- After the 1-inch limestone was compacted, 3/8 inch minus limestone material (a by-product produced by Martin Marietta Quarry in Ames, Iowa) was placed in loose 2-foot lifts.
- After placement of the backfill in the trench to the level of the pavement, the trench remained open to traffic for about two weeks to further compact the backfill material.
- After 2 weeks, 2½ feet of additional pavement surrounding the trench was removed, the upper portion of the trench backfill material was removed, and the pavement patch material was placed over the trench and surrounding area.

Results from Field and Laboratory Testing

The laboratory testing in Phase I classified the 3/8 inch minus backfill as SP-SM – silty sands, poorly graded sand-silty mix. The Phase I report laboratory testing found the maximum dry unit weight was 140.0 pcf from the relative density test and the bulking moisture content ranged 6% to 8% based on relative density testing. During the Phase II investigation, the bulking moisture content range was revised to be 4% to 8% based on the collapse potential testing performed in Phase I. The complete field-testing results for this trench can be found on Table 14 in Schaefer et al.. 2005 (Phase I).

During the Phase I field work, there was only one Nuclear Density test performed. Schaefer et al.. 2005 stated this was the result of time constraints (see Field Investigation section of Schaefer et al.. 2005, page 61). The one Nuclear Density test performed on the top lift of backfill yielded a dry unit weight of 115.6 pcf at a moisture content of 6.3%. The backfill was compacted to a relative density of 47%, which according to Table 2-6 is medium dense. Figure 19 shows the results form the laboratory tests and the average field-testing results.

Schaefer et al.. 2005 stated that CBR values from the Clegg Hammer ranged from 5.8% to 7.6% with an average CBR value of 6.7%. The reported CBR values from the DCP test ranged from 3.7 % to 17.4% with an average CBR value of 11.3%. The CBR values from the DCP and Clegg Hammer tests were below the typical CBR values of 20% to 40% indicated by NAVFAC in Table 5. Complete CBR data is in Table 15 of Schaefer et al.. 2005 (Phase I). Schaefer et al.. 2005 concluded that the CBR values indicated that that the strength of the backfill was constant with depth.

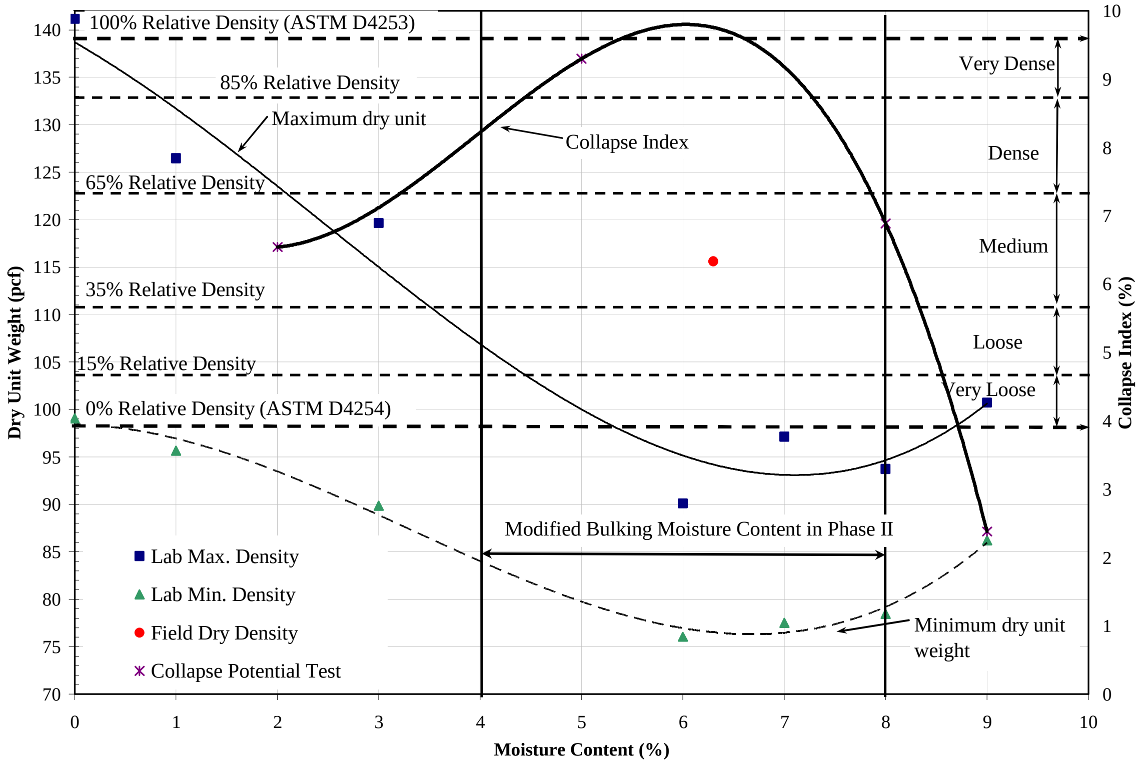


Figure 19-- Relative density and average field-testing results for the trench backfill material for the Ames site (modified from Schaefer et al.. 2005)

Continued Monitoring

The trench was surveyed three times (December 17, 2004, May 10, 2005, and May 11, 2007). Figure 20 shows the centerline profiles for the trench on these dates. The maximum settlement along the centerline of the trench was 0.96 inches at survey point 17. The maximum settlement, which was along the edge of the trench, was 1.20 inches at survey points 24 and 26. The maximum settlement along the centerline of the trench occurred where the patch was initially placed at a higher elevation than the surrounding patch. A line was drawn between the two survey points located outside the perimeter of the trench. This line shows the elevation of the patch if it was initially installed level with the road. The west side of the patch was placed below the level patch line. The patch experienced the majority of the total settlement between the December 17, 2004 and the May 10, 2005 survey, approximately within 6 months after construction of the utility trench. Settlement of the surrounding pavement also occurred.

Settlements as a function of time are shown on Figure 21. This shows that the settlements in the measure at survey points within the trench (15, 16, 17, 19, 20, and 21) have continued to settle with time. This rate of settle, which is the slope of the line between two survey points) in the first six months after construction was great (0.09 to 0.13 inches per month) than the rate of settlement (-0.005 (uplift) to 0.05 inches per month) for 6 to 18 months after construction. Survey points 18 and 19 experienced uplift from 6 to 18 months.

For the survey points outside of the trench (29, 30, 34 and 35, the settlement in the first 6 months after construction was similar to settlements measured within the trench. The settlement rate for the first six months ranged from 0.10 to 0.16 inches per month. Six to 18 months after construction, the survey points outside of the trench uplifted. The rate of uplift was 0.03 to 0.06 inches per month. Because of this uplift, the area outside the trench was at similar elevations from when the trench was first constructed. The uplift at the survey points outside of the trench resulted in a larger differential movements between the areas outside the trench and inside the trench.

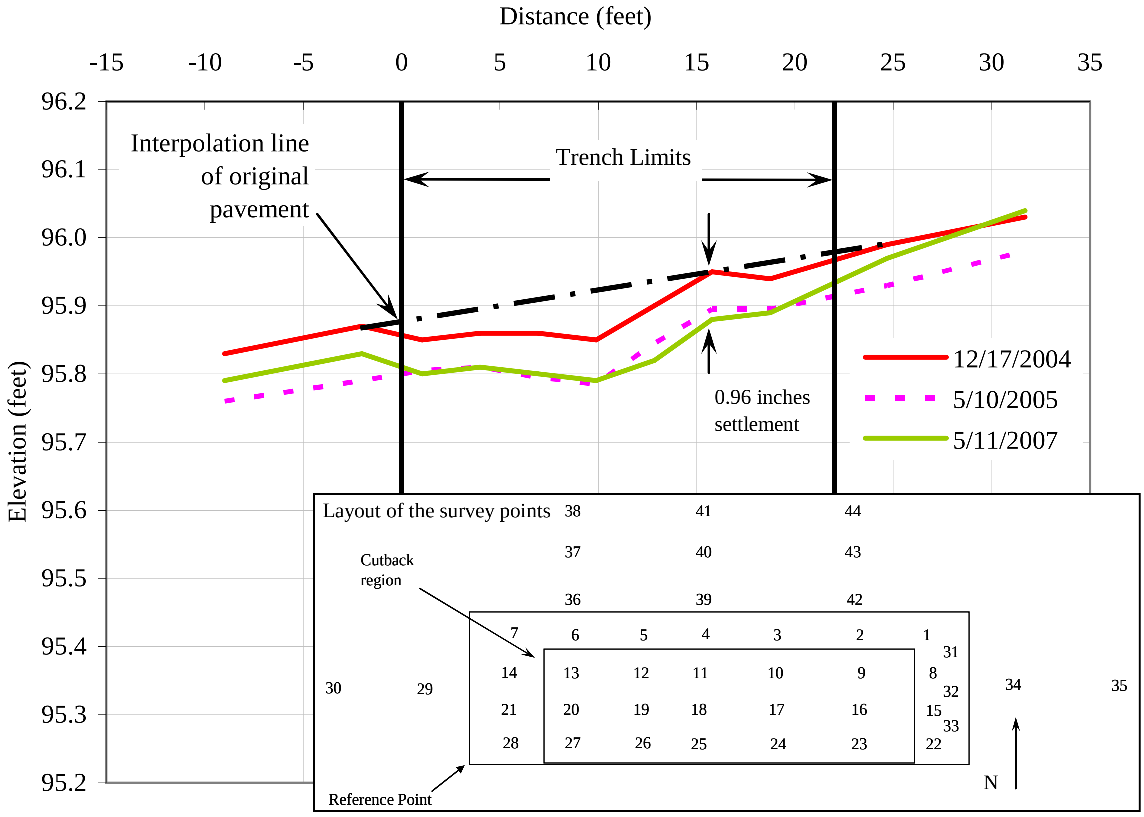


Figure 20 -- Profile of the Ames trench along the centerline of the trench

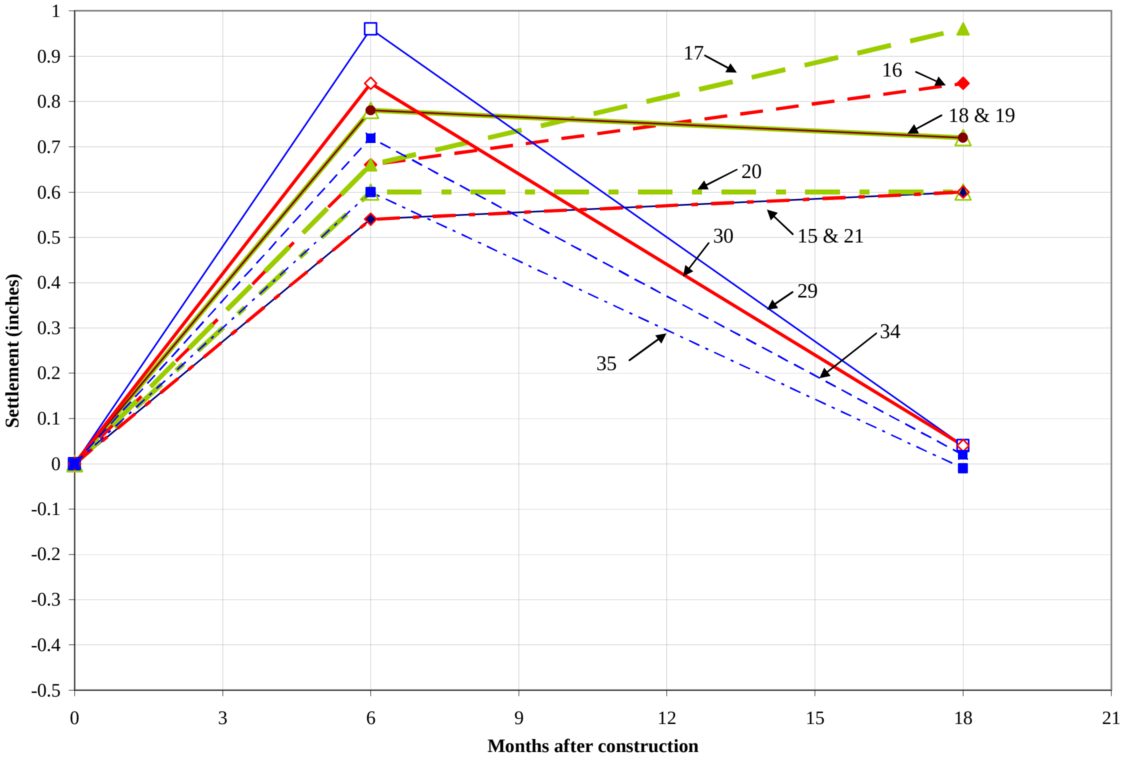


Figure 21 -- Settlement as a function of time for survey points along the centerline of the Trench

FWD testing was performed on November 22, 2004, April 11, 2005, June 11, 2007, and November 5, 2007. The FWD testing results for tests performed in 2004 and 2005 are in Appendix B in Schaefer et al.. 2005. Figure 22 shows the results from the FWD testing on June 11, 2007 and Figure 23 shows the results from FWD testing on November 5, 2007 for four different loadings.

Results of FWD tests from the spring/early summer (i.e. 4/11/05 and 6/11/08) were similar in shape for the 12 kip load ad shown in Figure 24. The FWD test results show no significant difference between the results on 4/11/05 and 6/11/07. The results from FWD tests in November 2004 and 2007 were also similar in response. This was mostly the result of the moisture present under the patches. In the spring, the subgrade had a higher moisture content. The increased moisture content caused the deflections to increase because the subgrade was softer. Then in the fall after the warm summer weather, the moisture under the patch decreased, and the subgrade stiffened.

Figure 25 shows the deflections from the 12 kip tests from four different deflection loadings.

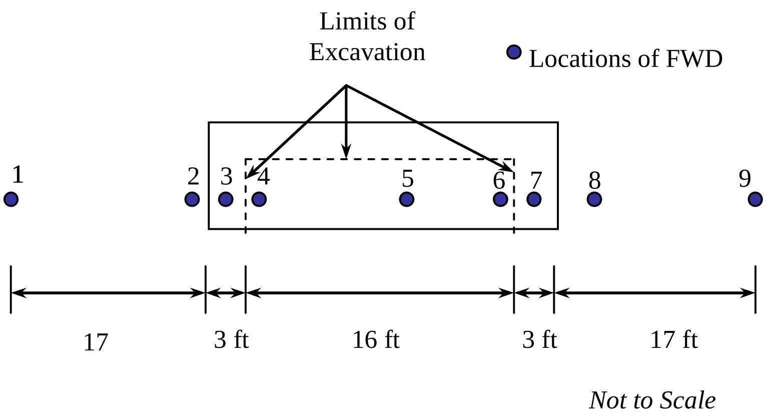


Figure 22 -- FWD testing locations (from Schaefer et al.. 2005)

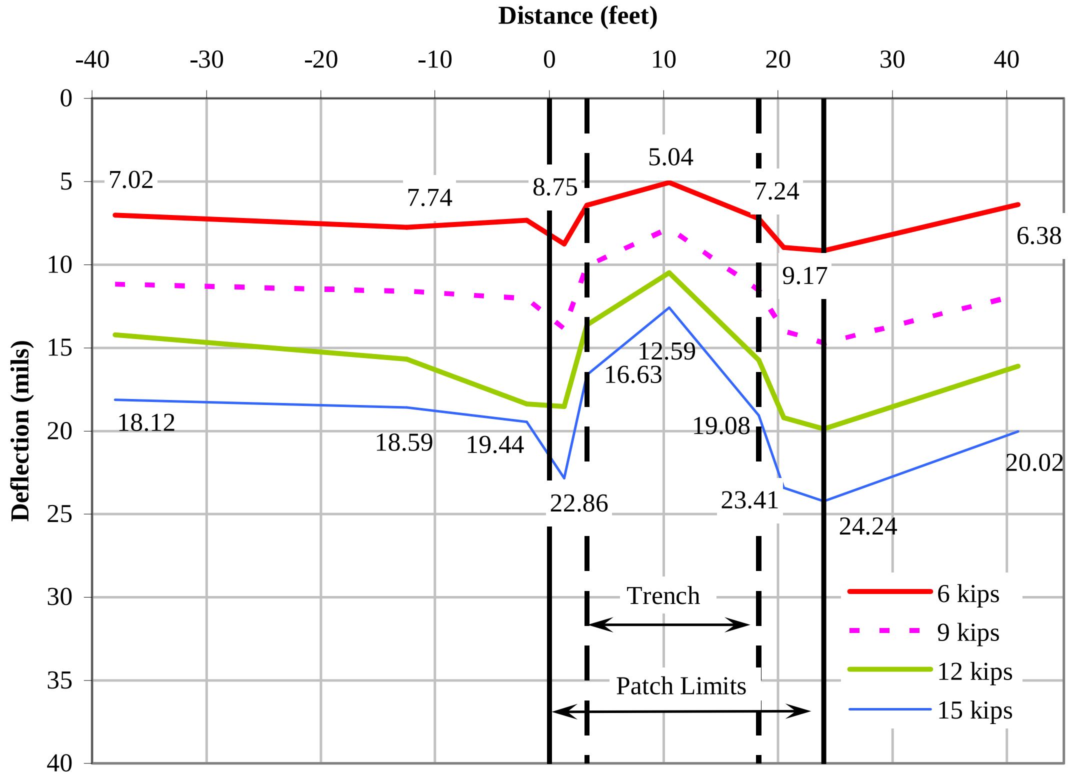


Figure 23 -- FWD testing results for the trench in Ames conducted on June 11, 2007

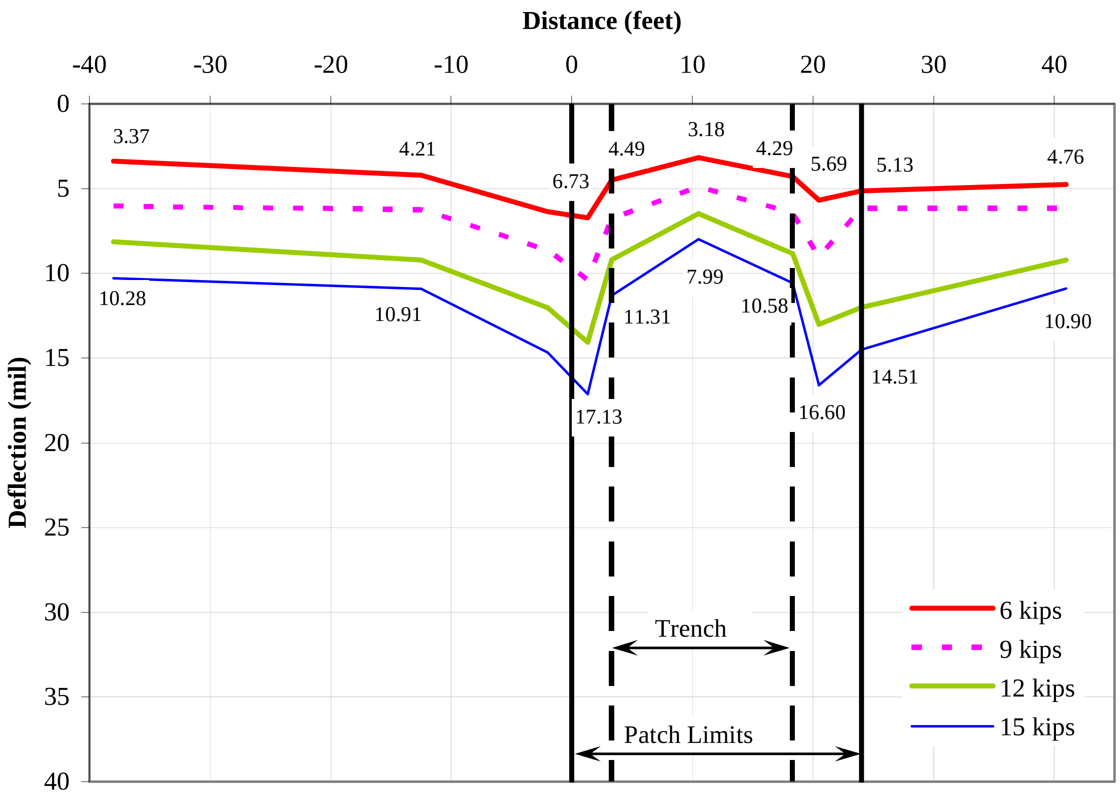


Figure 24 -- FWD testing results for the trench in Ames conducted on November 5, 2007

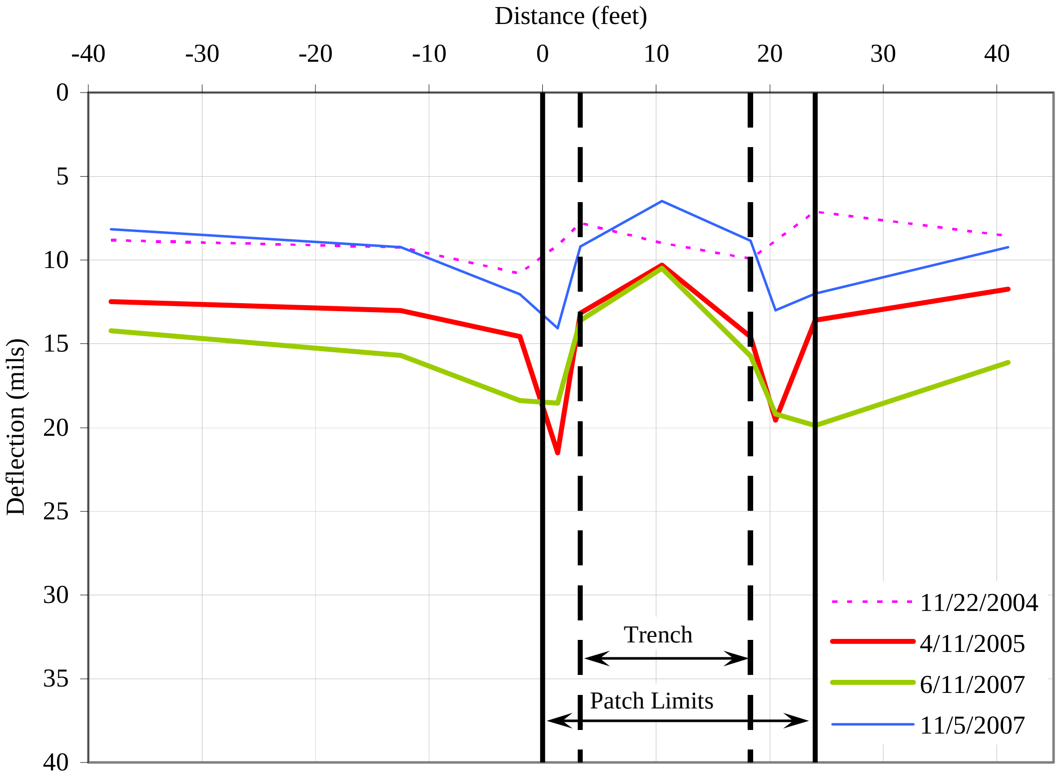


Figure 25 -- Comparison of deflections from the 12 kip load for the trench in Ames conducted on four test dates

3.1.2 - Cedar Rapids: Miami Drive and Sherman Avenue

On July 14, 2004, the excavation, construction, and restoration of a utility trench took place in Cedar Rapids at the corner of Miami Drive and Sherman Avenue to replace a leaking water main valve. The utility restoration site carried bus traffic from the bus depot. The completed trench was 8 feet wide, 12 feet long and 10 feet deep. The work was completed by the City of Cedar Rapids Water and Street Department. Important construction elements were:

- The existing pavement was a composite of 6 inches of concrete with 2 inches of asphalt overlay. The pavement was removed to the perimeter of the utility trench.
- The pipe bedding material consisted of 1-inch clean stone. Thickness of the bedding material was not documented in Phase I.

- Above the bedding material, the remaining lifts were constructed using recycled crushed concrete. The particle size was ¾ inch or less.
- The remaining lifts were 3 to 4 feet thick. A backhoe-mounted vibratory plate compactor was used to compact the backfill.
- The pavement area was patched, but it was not enlarged beyond the trench perimeter.
- The pavement outside of the patch area was cracked during construction because a loaded truck came close to the edge of the open trench.

Results from Field and Laboratory Testing

Phase I laboratory testing classified the ¾ inch minus crushed concrete backfill as a SC – clayey sand, poorly graded sand-clay mix. Laboratory testing determined the backfill had a maximum dry unit weight of 130.0 pcf from the relative density test. The bulking moisture content range was estimated to be from 7% to 10% in Schaefer et al.. 2005, However, since the completion of the Phase I work, the bulking moisture content has been revised to 4% to 8%. The backfill in the field was compacted to an average dry unit weight of 122.9 pcf and an average moisture content of 5.7%. Figure 26 shows the results from the laboratory tests and the average field-testing results. For the nine test points, Schaefer et al.. 2005 stated that the backfill was compacted to a dense to very dense state (72% to 95% relative density). The complete field-testing results for this trench can be found on Table 14 in Schaefer et al.. 2005 (Phase I final report).

Schaefer et al.. 2005 reported that the CBR values obtained from the Clegg Hammer test ranged from 8.2% to 12.9% with an average CBR value of 12.9%. The CBR values from the DCP tests ranged from 4.9% to 25.0% with an average CBR value of 13.3%. Schaefer et al.. 2005 stated that these values were "just above to below the typical CBR values of 10% to 20%." Complete CBR data is in Table 15 of Schaefer et al.. 2005 (Phase I final report).

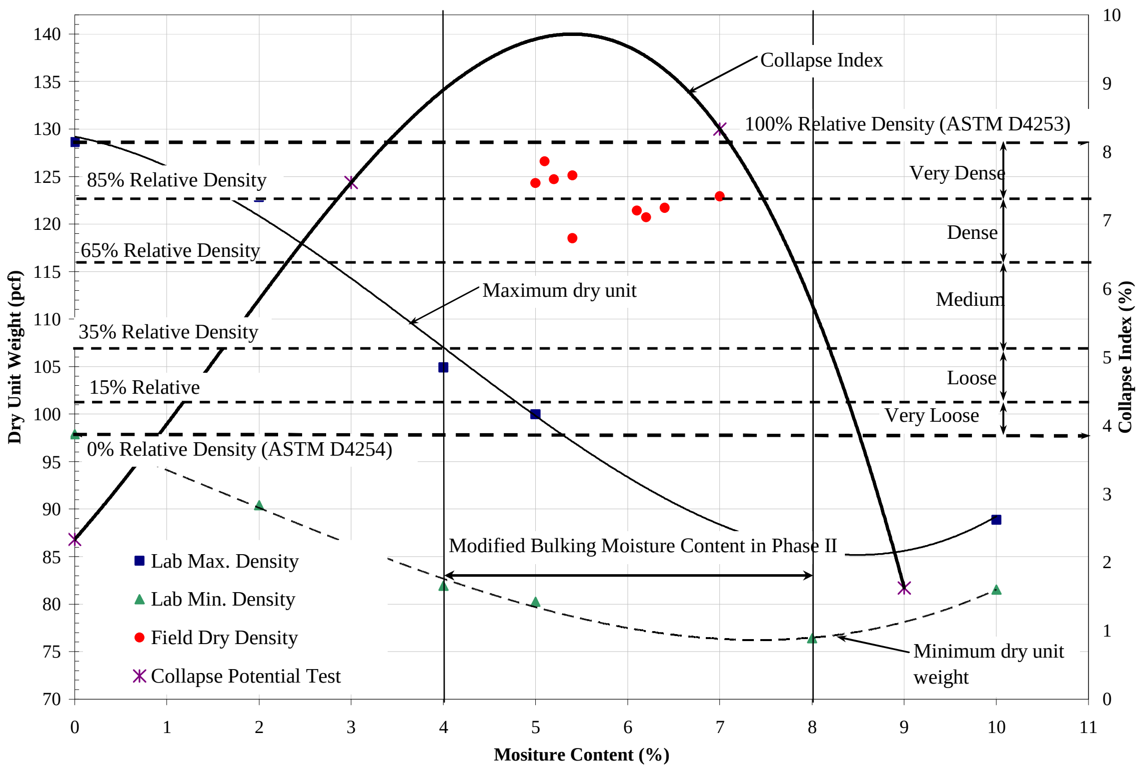


Figure 26 -- Relative density and average field-testing results for the trench backfill material for the Cedar Rapids site (modified from Schaefer et al.. 2005)

Continued Monitoring

The trench was surveyed four times (July 21, 2004, October 29, 2004, April 20, 2005, and May 22, 2007). Figure 27 shows the centerline profiles for the trench on the various test dates. The maximum settlement along the centerline of the trench was 0.48 inches at survey points 4, 6, 10 and survey point 14 outside the trench. This was also the maximum total settlement for the trench. When the patch was initially placed, the north edge of the patch was a low spot. The largest measured settlement occurred in the low spot of the patch. Settlement of the surrounding pavement was observed up to a distance of 3 feet from the trench.

Settlement as a function of time is shown on Figure 28 for survey points in along the center of the trench. The chart shows that the survey points within the trench (4, 6, 8, 10, and 12) have continued to settle based on the positive slope of the line between the survey points, except for survey point 12. The rate of settlement, which is the slope of the line, ranged from 0 to 0.04 inches per month for the first three months after construction. The rate of settlement increased for all the survey points within the trench during the time period from 3 to 6 months after construction. The rate of settlements ranged from 0.02 to 0.1 inches per month. The rates of settlement for 9 to 19 months after constructed ranged from -0.004 to 0.02 inches per month. Survey point 12 uplifted during this time interval. The survey points outside of the trench (1, 2, 14, and 15) settled to differing degrees. Survey point 15 has shown no movement since monitoring of the utility cut began compared to survey point 14 (closer to the trench), which has had the same settlements as survey point 10, which is within the trench. Survey points 1 and 2 have shown the opposite behavior. Survey point 1 furthest from the trench has continued to settle while survey point 2 has uplifted. The rate of settlement for the survey points outside the trench for the first 3 months ranged from 0 to 0.04 inches per month. From three to 9 months after construction the rate of settlement ranged form 0 to 0.10 inches per month. From nine to 19 months after construction the rate of settlement for the test points outside the trench ranged from -0.03 to 0.001 inches per month. The upper limit of this settlement rates was controlled by survey point 14.

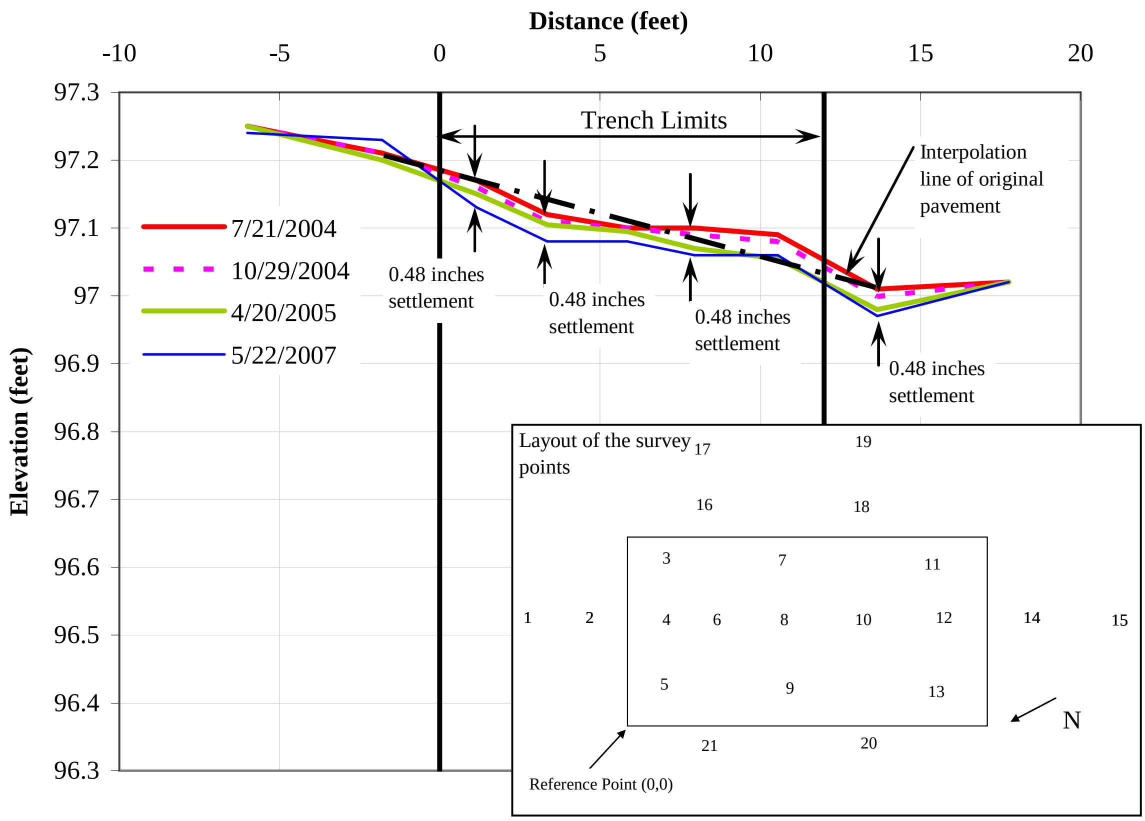


Figure 27 -- Profile of the Cedar Rapids trench along the centerline of the trench

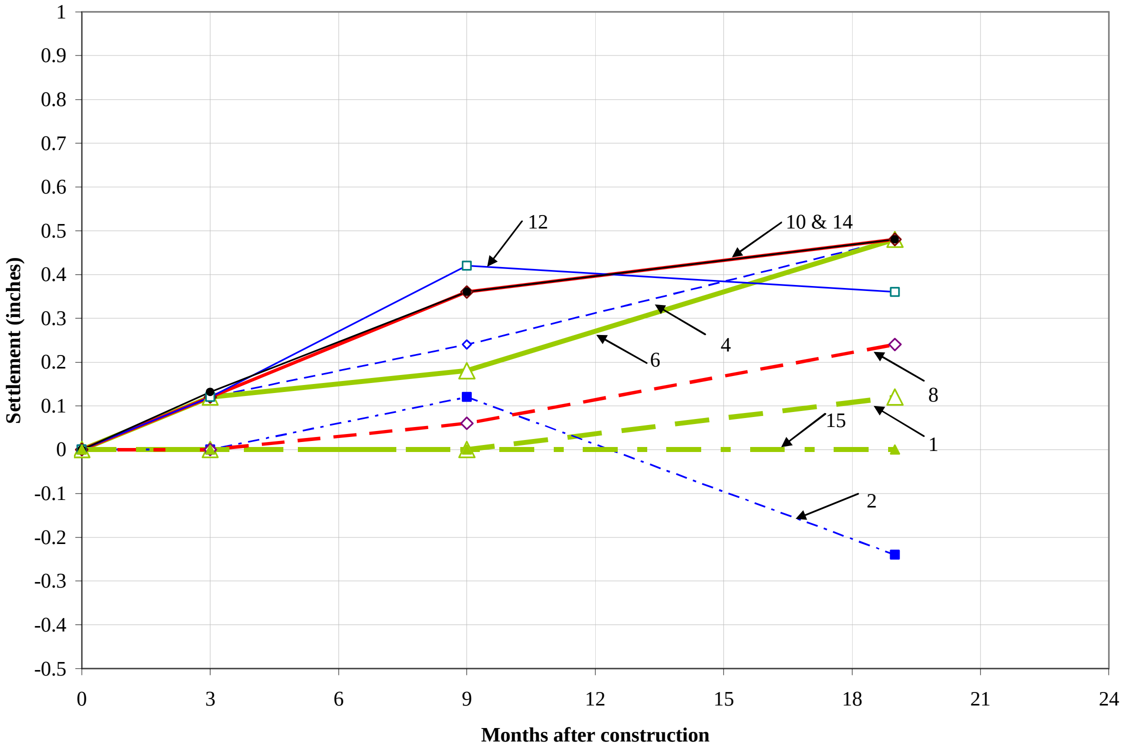


Figure 28 -- Settlement verses time for Cedar Rapids

On October 25, 2004, April 20, 2005, June 12, 2007, and November 5, 2007, the Iowa DOT performed FWD testing on the Cedar Rapids trench. The FWD testing results for tests performed in 2004 and 2005 are presented in Appendix B of Schaefer et al.. 2005 (Phase I final report). Figures 29 and 30 show the results from the FWD testing from June 12, 2007 and November 5, 2007, respectively. Four loadings (6, 9, 12, and 15 kips) were used each time. Figure 31 shows the deflections for the 12 kip FWD loadings from four different dates.

The FWD testing from the spring / early summer were similar in shape for the 12 kip load. This can be seen in Figure 32. The results from FWD tests in November 2004 and 2007 were also similar in response. This was the result of the moisture present under the patches and was supported by the literature review (see Figure 8). In the spring, the subgrade increased in moisture content. The increased moisture content caused the deflections to increase because the subgrade was softer. Then in the fall after the warm summer weather, the moisture under the patch decreased, and the subgrade stiffened. This trend was more evident in this trench than in the other trenches.

The FWD testing in 2007 shows a weakened zone at the edge of the trench. This weaken zone was present in earlier testing and was the result of the construction equipment being near the cut of the trench, according to Schaefer et al.. 2005.

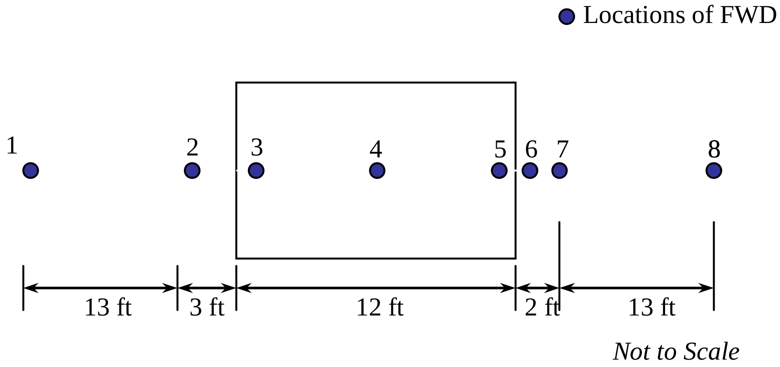


Figure 29 - Locations of FWD testing points for Cedar Rapids trench

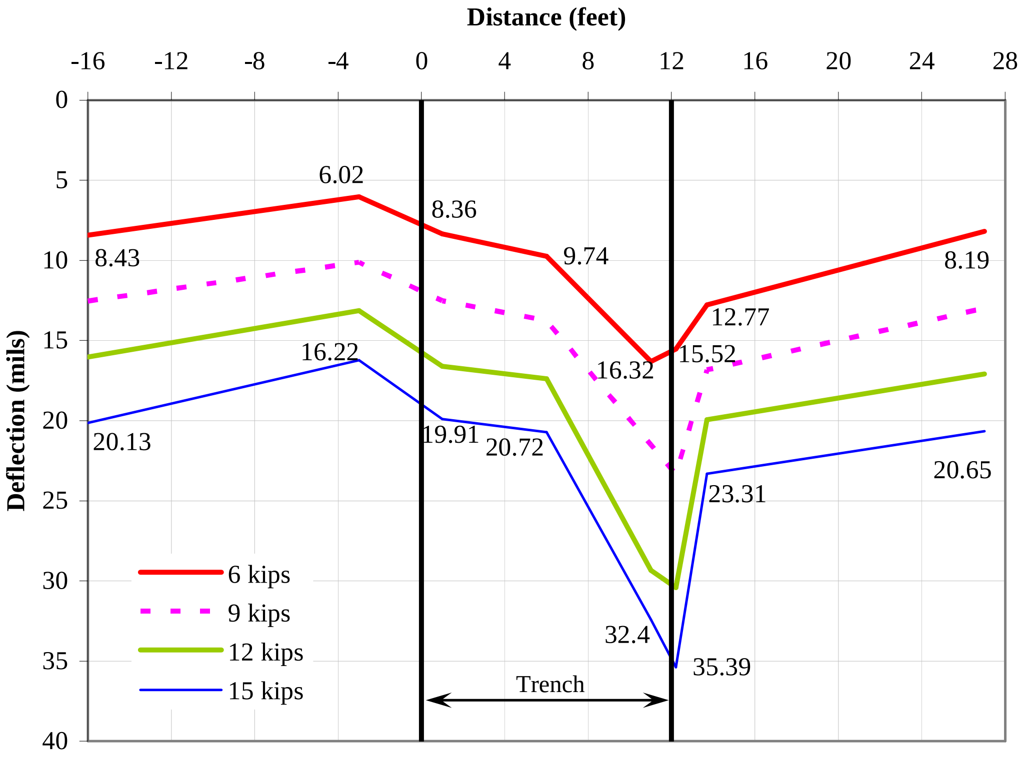


Figure 30 -- FWD testing results for the trench in Cedar Rapids conducted on June 12, 2007

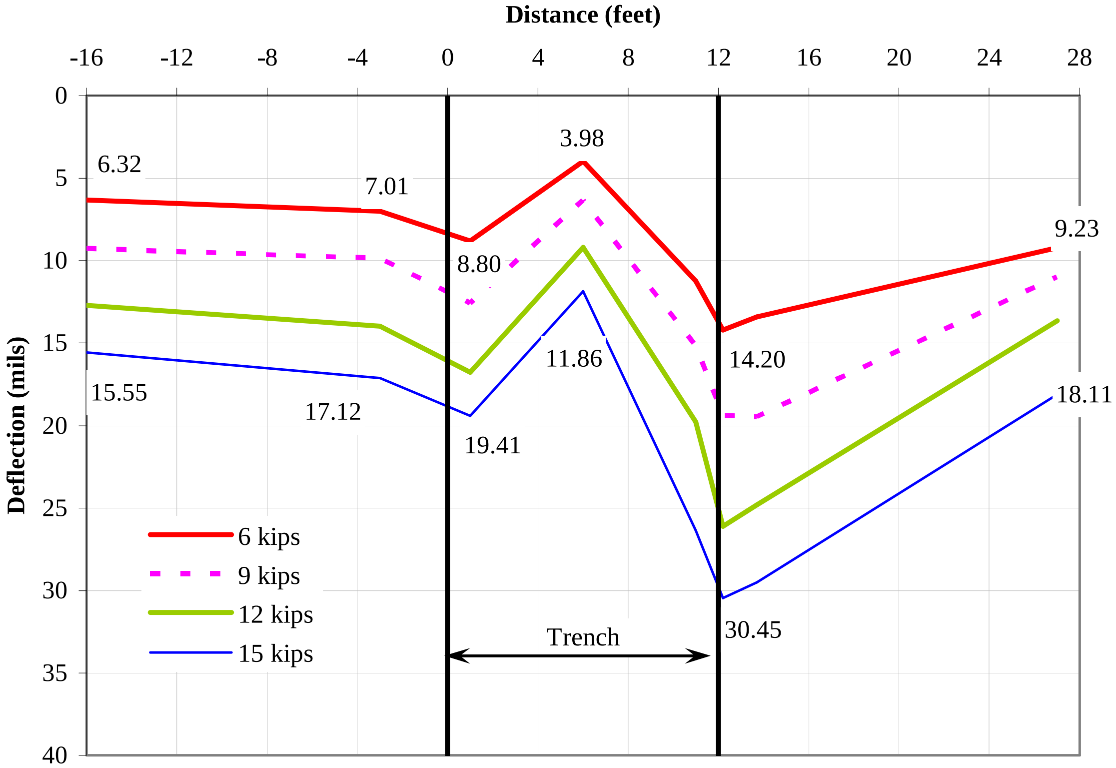


Figure 31 -- FWD testing results for the trench in Cedar Rapids conducted on November 5, 2007

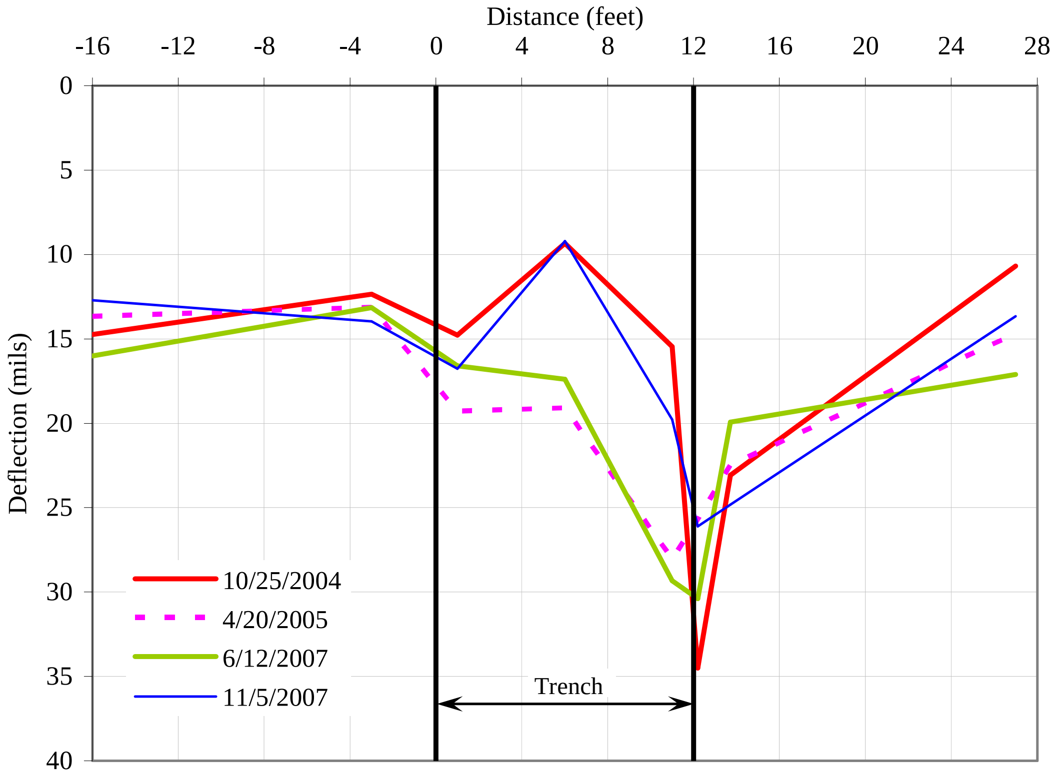


Figure 32 -- Comparison of deflections from the 12 kip load for the trench in Cedar Rapids conducted on four test dates

3.1.3 - Des Moines, East 28th Street and Grand Avenue

On June 30, 2004, a sewer main break was repaired in the City of Des Moines at East 28th Street and Grand Avenue. A private contractor completed the work. The Iowa State Research Team did not observe the repair of the utility. The Iowa State Research Team was present to test the final lift of soil and the placement of the patch. Important construction features on the utility cut were:

- The backfill material was sand-sized particles manufactured from limestone.
- The existing pavement was 8 inch thick concrete. The concrete was removed from around the trench. The size of the patch was not documented in the Phase I report.
- The patch was concrete. To tie the patch into the existing concrete road surface, dowel bars were used as a mechanical connection in the longitudinal and transverse directions.

After the concrete was allowed to cure, a joint was cut in the patch to match the surrounding joint spacing.

Results from Field and Laboratory Testing

Schaefer et al. 2005 reported that the backfill of manufactured sand was classified in Phase I as SW-SM – well graded sand with silt. Laboratory testing found the backfill to have a maximum dry unit weight of 135.0 pcf from the relative density test. The bulking moisture content range was reported to be from 7.5% to 11% by Schaefer et al.. 2005; however, since the completion of this Phase I, The bulking moisture content has been revised to 5% to 8%. The Nuclear Density tests yielded an average moisture content was 7.6%, and the average dry unit weight was 105.9 pcf for the sixteen test points. The backfill was placed at an average 29.3% relative density, which corresponded to a medium dense state. The moisture content of the backfill was at the bulking moisture content found in the laboratory testing. The complete field-testing results for this trench can be found on Table 14 in Schaefer et al.. 2005 (Phase I final report). Figure 33 shows the results from the laboratory tests and the average field-testing results.

Schaefer et al.. 2005 reported the following CBR results from the Clegg Hammer nad DCP test. The CBR values from the Clegg Hammer ranged from 4.6% to 15.1% with an average CBR value of 8.6%. The CBR values from the DCP test ranged from 2.7% to 34.9% with an average CBR value 12.5%. Schaefer et al.. 2005 were below the typical range of 20% to 50%. Complete CBR data is in Table 15 of Schaefer et al.. 2005 (Phase I final report).

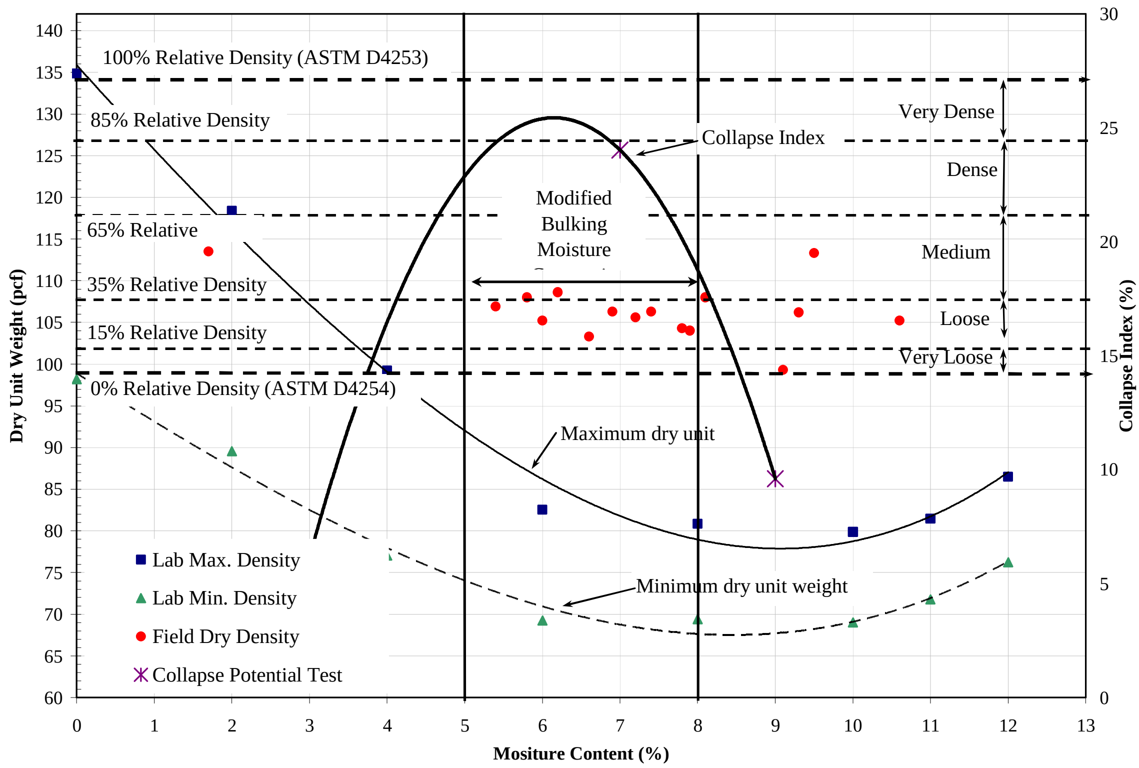


Figure 33 -- Relative density and average field-testing results for the trench backfill material for the Des Moines site (modified from Schaefer et al.. 2005)

Continued Monitoring

The trench was surveyed four times (July 17, 2004, October 29, 2004, April 16, 2005, and May 14, 2007). Figure 34 shows the centerline profiles for the trench on the four test dates. The maximum settlement along the centerline of the trench was 0.12 inches at survey points 2, 4, and 10. The maximum settlement of the trench, which was at the edge of the trench, was 0.36 inches at survey test point 11. Figure 34 also shows that when the patch was constructed it was higher than the surrounding road. When the patch was initially installed, the edge of the patch was higher than the center of the patch. As the trench settled over the last two years, the lowest point in the patch did not settle, however, the surrounding pavement in the patch settled to the same elevation.

Settlements verses time were plotted on Figure 35 This Figure shows that settlements as a function of time were less than in the other trenches. Maximum rate of settlement was

0.03 inches per month occurring 3 to 6 months after construction for survey points 2, 4, 10, 15 and 16. The maximum rate of uplift movement was 0.01 inches per month.

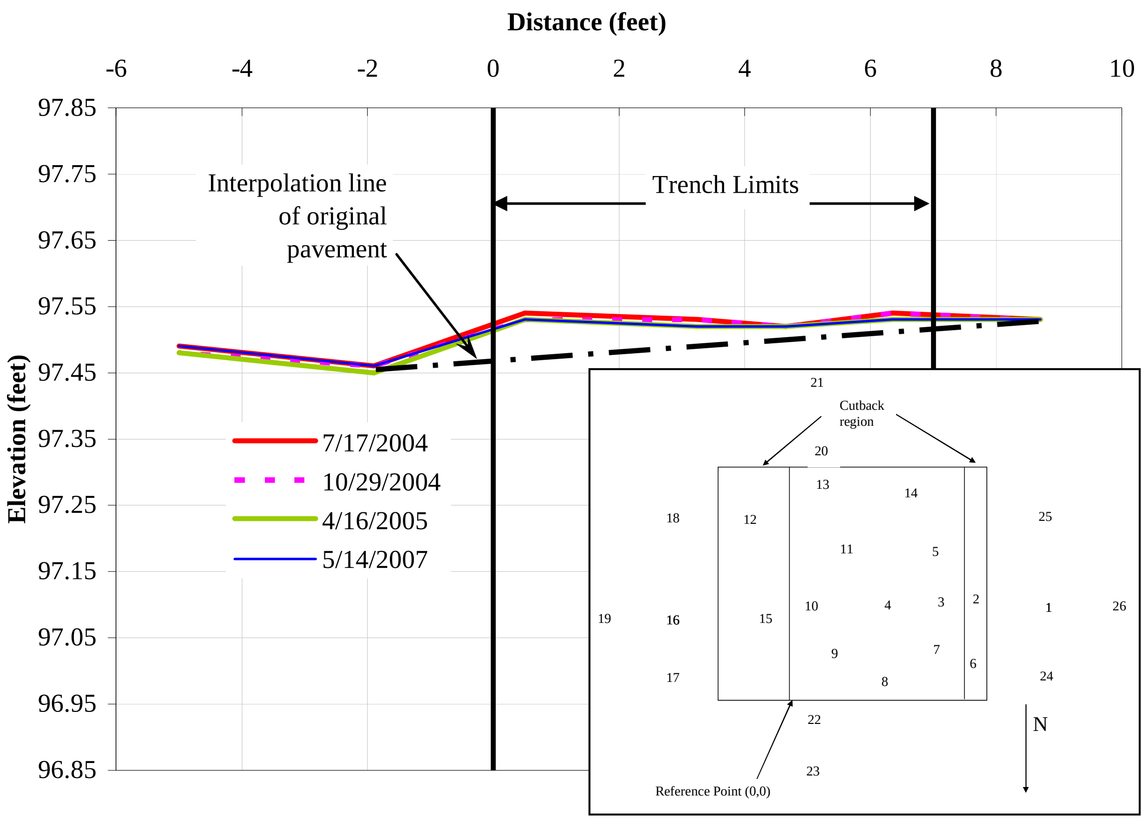


Figure 34 – Profile of the Des Moines trench along the centerline of the trench

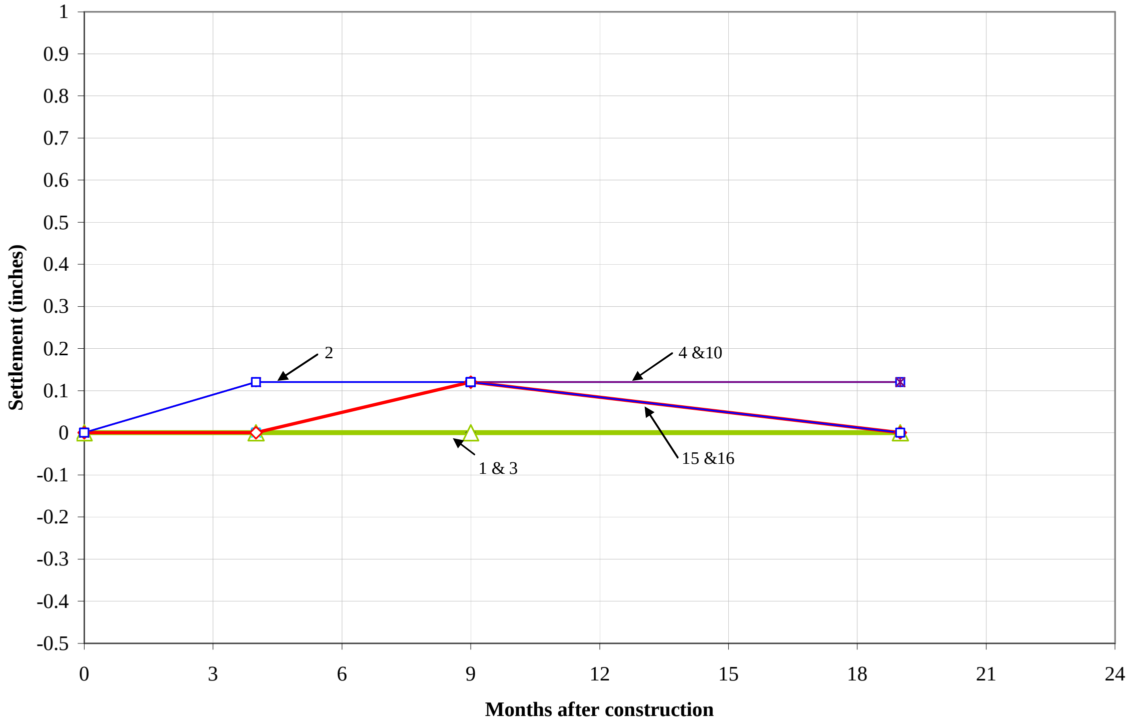


Figure 35 - Settlement verses time for Des Moines trench

FWD testing was performed on October 25, 2004, April 13, 2005, June 13, 2007, and November 5, 2007. The FWD testing results for tests performed in 2004 and 2005 are presented in Appendix B of Schaefer et al.. 2005 (Phase I final report). Figures 36 and 37 show the results from the FWD testing from June 13, 2007 and November 5, 2007, respectively. Four loadings (6, 9, 12, and 15 kips) were used each time. Figure 38 shows the deflections for the 12 kip FWD loadings from four different dates.

The FWD testing on this trench does not show the same seasonal affects as the other three trenches, which had higher deflections in the spring and early summer FWD tests and smaller deflections in the fall FWD tests. This was confirmed with plotting the test results from the 6 kip load Figure 39 and the 12 kip load in Figure 38. The response of the trench did not vary with seasonal effects. This was seen when comparing the June 2007 test to the November 2007 test. On one side of the trench the June 2007 FWD test was stiffer than November 2007, while on the over side of the trench the tests reversed in stiffness relative to each other. The inconsistencies in this trench's response was the possible the result of the patch being doweled.

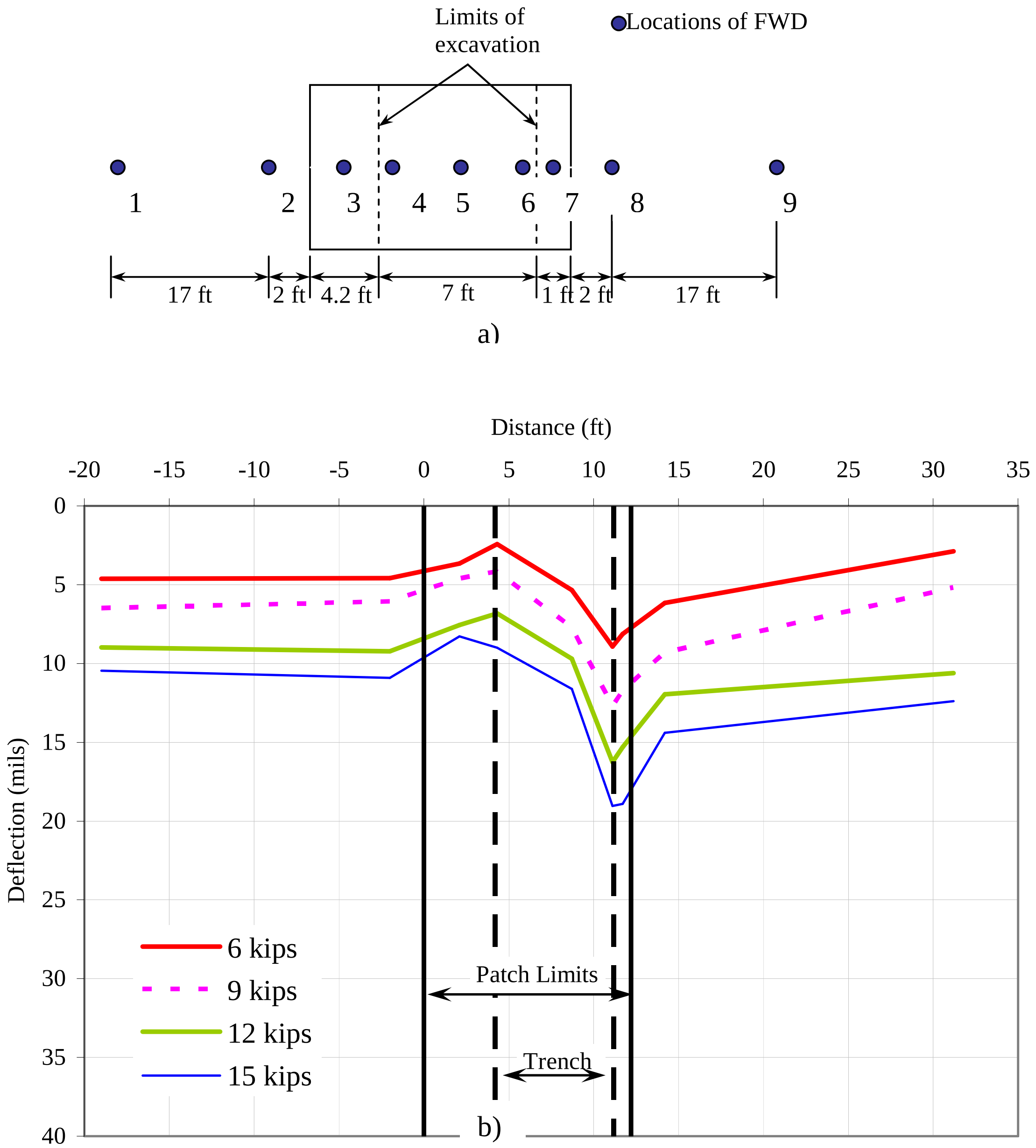


Figure 36 –a) Field-testing locations (from Schaefer et al.. 2006) and b) FWD testing for the trench in Des Moines conducted on June 13, 2007

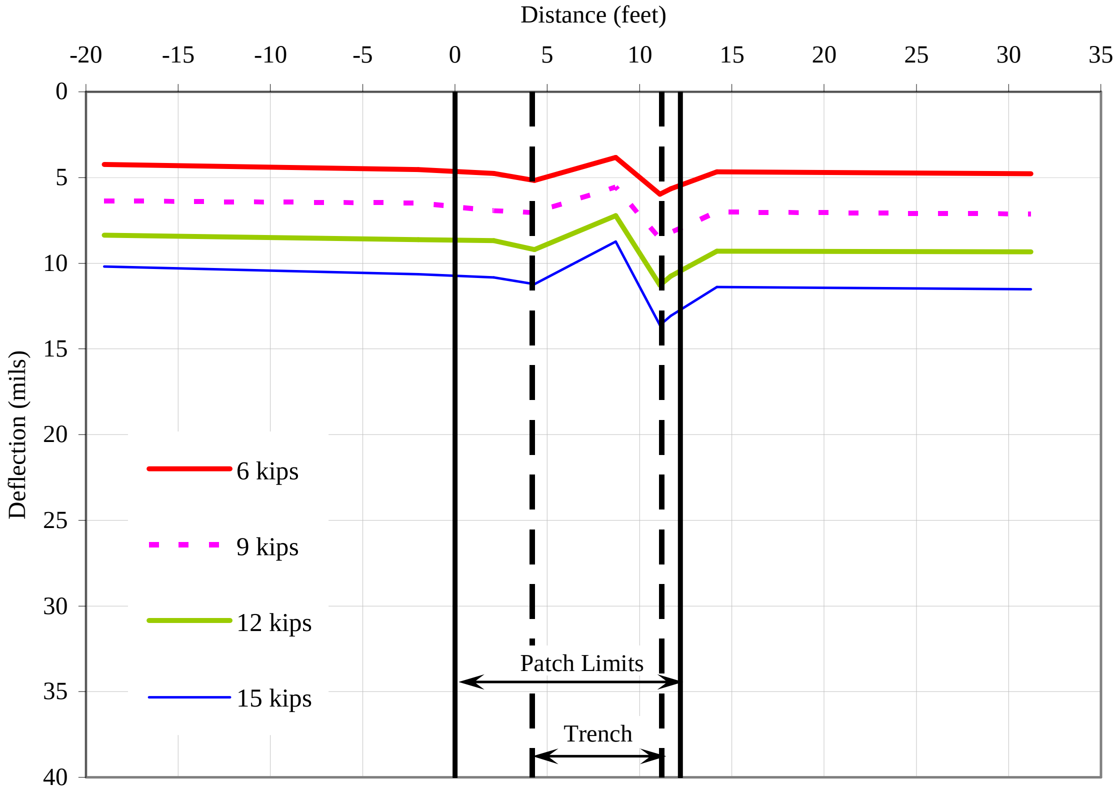


Figure 37 -- FWD testing for the trench in Des Moines conducted on November 5, 2007

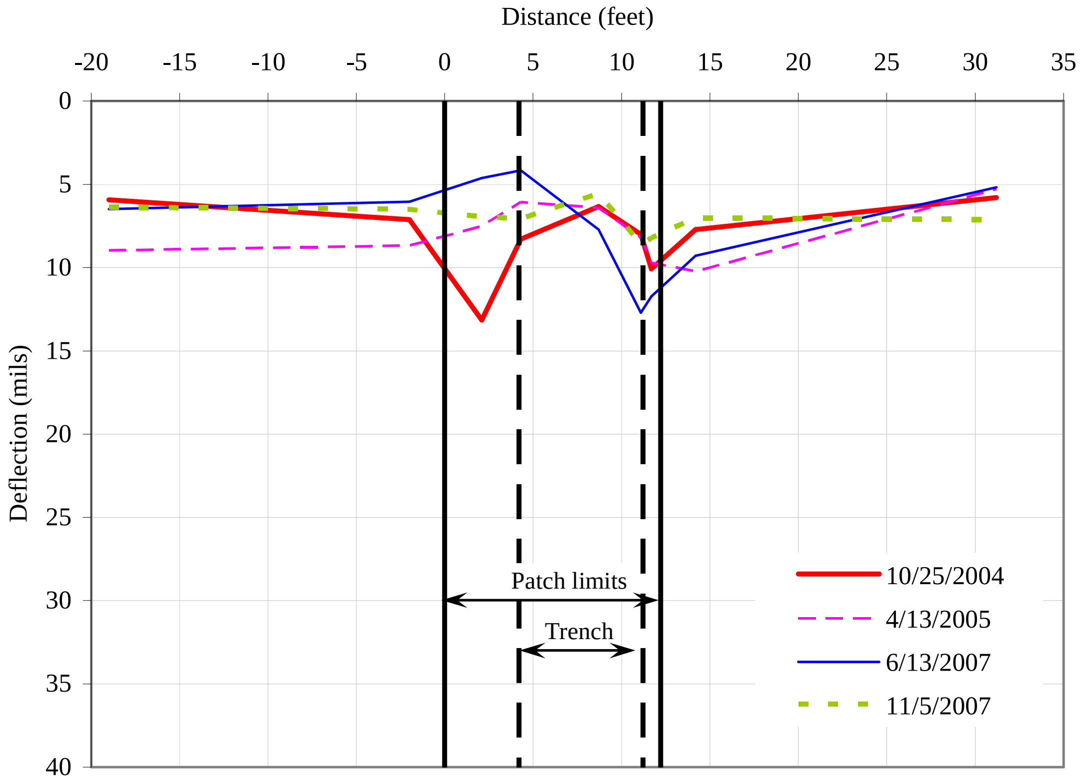


Figure 38 -- Comparison of deflections from the 6 kip load for the trench in Des Moines conducted on four test dates

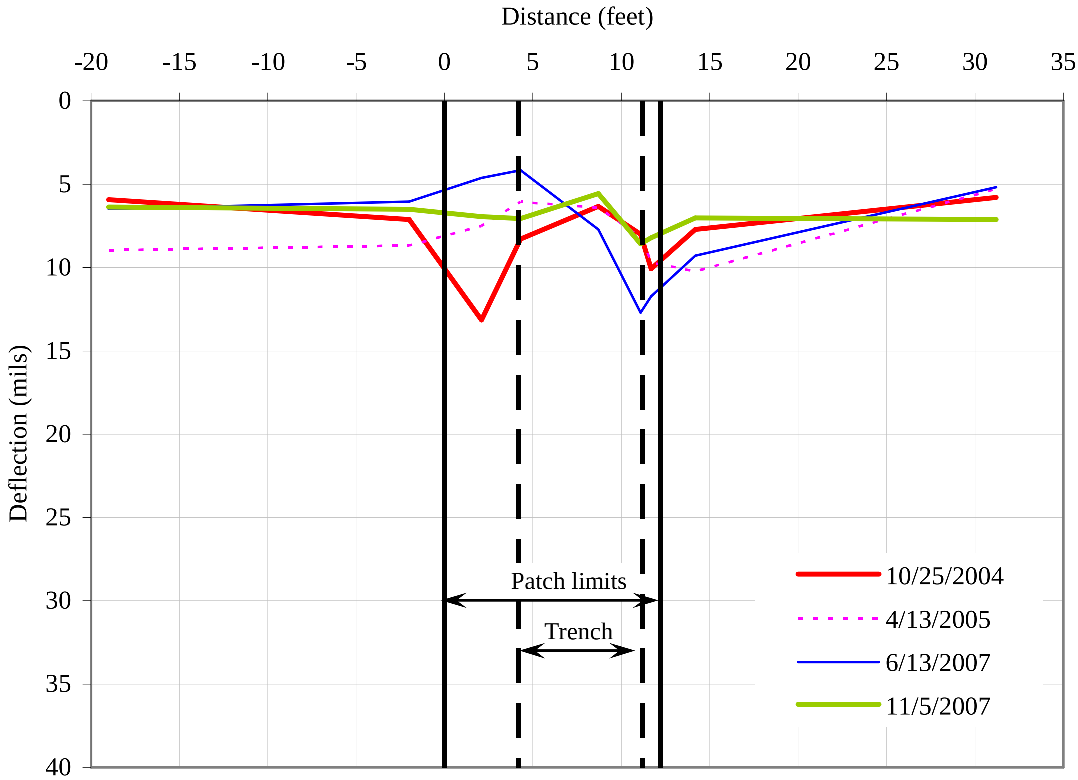


Figure 39 -- Comparison of deflections from the 12 kip load for the trench in Des Moines conducted on four test dates

3.2 - Comparison of Trenches

Table 10 compares the settlement of the three trenches with the field-testing results. This shows that in all the trenches the backfill was placed with in its bulking moisture content. This will result in all the trenches being suitable to collapse behavior. When comparing the Ames and Cedar Rapid trenches, which were constructed with an asphalt patch, the patch in Ames has settled more over time than the patch in Cedar Rapids. The backfill in the trench in Ames was placed at a lower relative density than the backfill in the Cedar Rapids trench. This accounts for the difference in the settlement between the two trenches. The Des Moines patch has had the smallest settlements; however, this trench was constructed by using dowels between the existing concrete and the concrete patch. The dowels allow for the patch to bridge over where the backfill has settled, leaving a void beneath the concrete. The settlement of the Des Moines patch is not necessarily the settlement of the backfill in the trench because of this bridging.

To compare the performance of the three trenches monitored in Phase I, the 12 kip FWD tests results from June 2007 (see Figure 40) were plotted and the November 2007 (see Figure 41). These figures show that the Des Moines trench had the lowest deflections from FWD testing in June. In November 2007, the Des Moines and Ames trenches provided similar responses. The deflection patterns across the trenches were similar on both sides of the trenches showing that the lose of moisture over the summer resulted in the response of trench becoming more uniform. This is important because when an area of the subbase is softer than the surrounding area, it places additional stress on the surrounding pavement. This effect on load distribution is also seen with beams supporting continuous elastic foundations and pile design. The Cedar Rapids trench did not show improved performance on both sides of the trench like Des Moines and Ames trenches. According to Schaefer et al.. 2005, the side of the highest deflections had equipment located on it during construction. The damage caused by the equipment to the subbase during construction was not minimized over time.

Table 10 - Comparison of field-testing results and settlements in the Trenches

Trench	Average relative density (%)	Revised bulking moisture content (%)	Average moisture content	Average CBR values from Clegg Hammer/DCP	Average settlement after one winter (inches)	Average settlement after two winters (inches)
Ames	18	4 to 8	6.3	6.7/8.5	0.70	0.56
Cedar Rapids	85	4 to 8	5.2	12.9/13.3	0.22	0.30
Des Moines	28	5 to 9	7.6	8.6/12.5	0.08	0.05

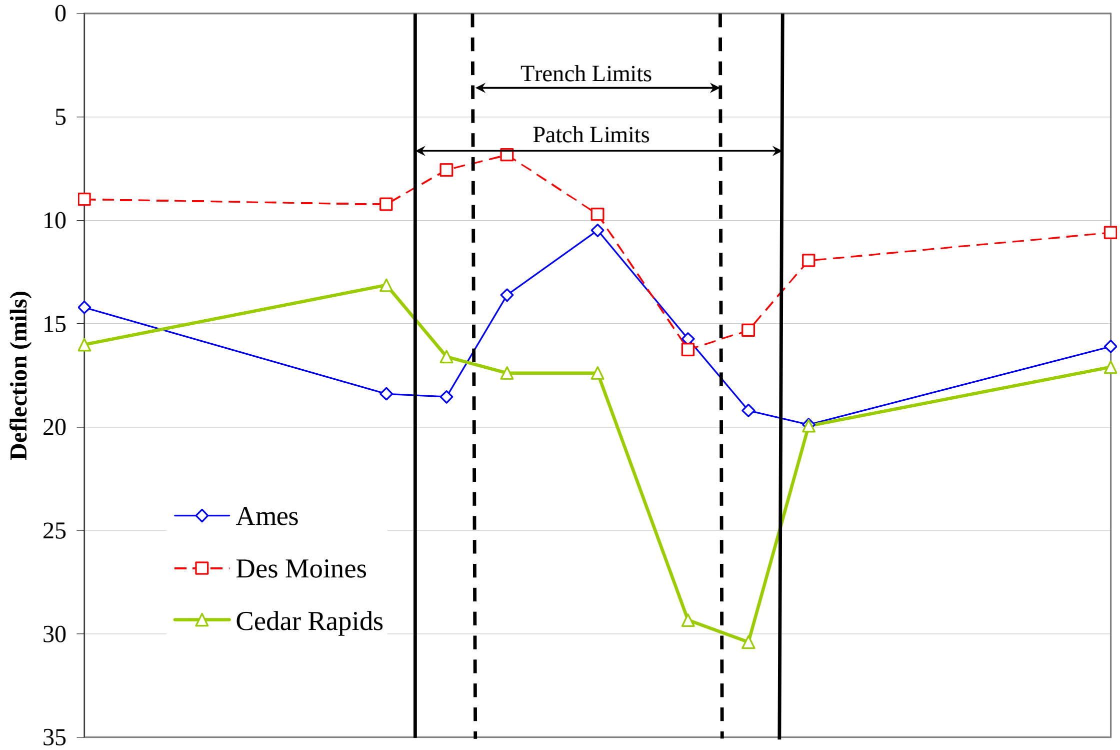


Figure 40 -- Comparison of the 12 kip FWD test results for June 2007

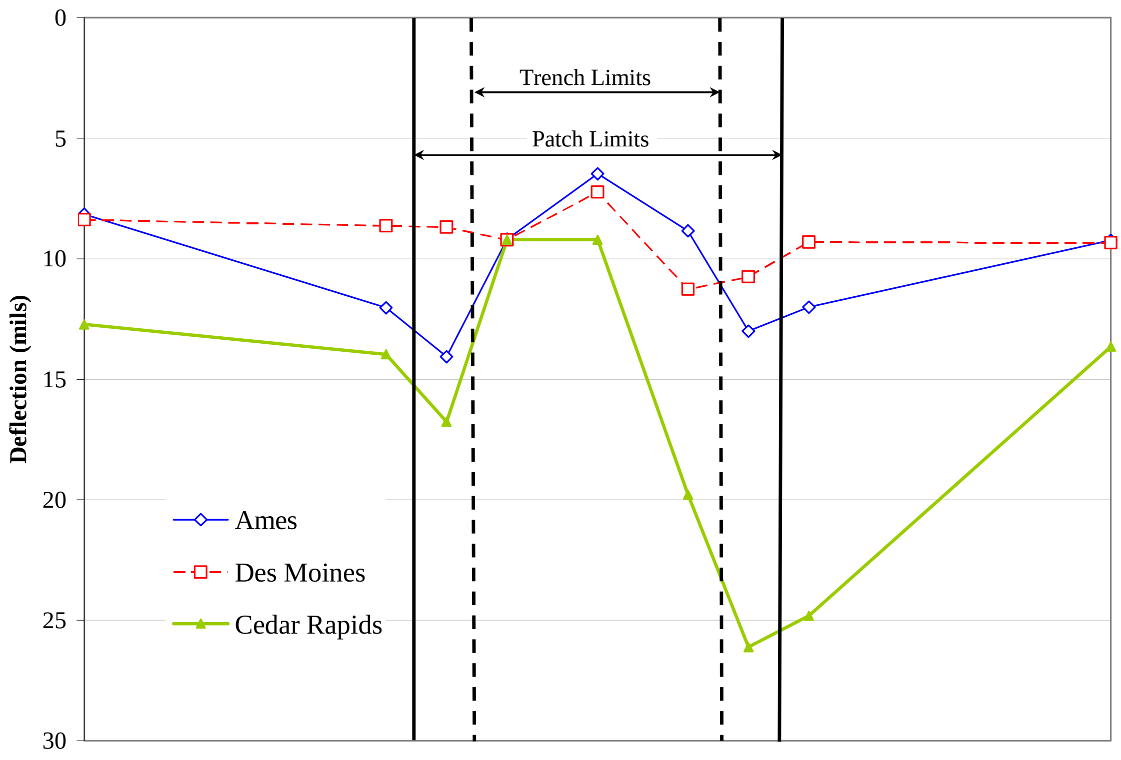


Figure 41 - Comparison of the 12 kip FWD test in November 2007

3.3 - Summary of Monitoring

The following was concluded from the continued monitoring of the utility cut restorations documented in Phase I:

- The patches that were originally installed were not even with the existing pavement.
- The trenches have continued to settle with maximum settlements ranging from 0.03 inches per month for the Trench in Des Moines to 0.13 inches per month for the trench in Ames. The maximum rate of settlement were measured in the over the winter months (expect point 2 in the Des Moines Trench)
- The Des Moines trench patch performed based on it had the lowest total settlements and uplifts for the patch and the surrounding pavement and it did not experience the same seasonal softening effects measured with FWD testing like the Trenches in Ames and Cedar Rapids . This was the result of the concrete being doweled into the surrounding pavement.

- The FWD tests showed similar response of the trenches based on the season of the tests. According to the literature reviewed, this was the result of differences in the moisture content in the soil during the spring and fall.
- The FWD testing on the Cedar Rapids trench showed that damage caused by equipment during construction had a long-term impact on the performance of the trench.

CHAPTER 4.0 - RECOMMENDED TRENCH CONSTRUCTION PRACTICES

4.1 - Recommended Practices from Phase I

Based on field observations, measurements, and laboratory testing during Phase I the following practices were recommended:

- When specifying granular soils as backfill, relative density criteria should be used. A minimum relative density of 65% was recommended.
- When using granular backfill for utility cut restorations, the moisture content should be greater than the bulking moisture content. This reduces the collapse potential of the soil that can occur with changes in moisture content.
- Quality management practices for backfill placement should be implemented in the field; however, specific tests were not specified.

In most states, the use of the Nuclear Density gauge to monitor the dry unit weight and moisture content in the field is becoming increasingly difficult because of regulatory concerns. The DCP test provides an alternative method for monitoring the quality of compacted backfills; however, each specific backfill requires different DCP correlations.

During Phase I, an area around the utility cut known as the "zone of influence" was found to be a factor in the degradation of a utility cut restoration. The "zone of influence" was a result of the loss of lateral support in the trench walls during excavation. As a result of Phase I, a 2 to 3 feet cut beyond the boundaries of the utility trench was proposed to mitigate the effects of the "zone of influence". Backfill placed in the pavement cut area and the excavation area would be compacted.

During Phase II, the six recommended trenches were constructed and monitored for about 10 months.

4.2 - Recommended Phase I Trench Designs

At the conclusion of the Phase I project, three trench restoration designs and two types of backfill were proposed to minimize settlement and the effects of the "zone of influence." The three trench restoration designs, shown in Figure 42, for each type of imported backfill were:

- A trench with vertical walls extending from the bottom of the trench to the overlying pavement and up to 3 feet of pavement removal around the perimeter of the utility trench. After the pavement removal, the exposed subgrade soil would be compacted in place (see Figure 42, Trenches A and D).
- A T-section vertical walls extending to the base of the trench and then the upper 2 feet of the trench being horizontally outward 2 to 3 feet beyond the perimeter of the normal trench walls and pavement removal to the limits of the T-section. The excavated soil from the T-section would then be placed across the trench in 1 foot lifts and compacted. When there is insufficient soil removed from the trench to complete the trench restoration, available granular soil may be used (see Figure 42, Trenches B and E).
- A T-section trench constructed the same as above, with a structural geogrid placed on the bottom of the excavated T-section area and across the trench (see Figure 42 Trenches C and F).

The 2 proposed backfills were 3/8-inch minus granular backfill (Trenches A, B, and C) and SUDAS Class I gradation granular backfill (Trenches D, E, and F). Figure 42 shows these trenches and the two types of backfill.

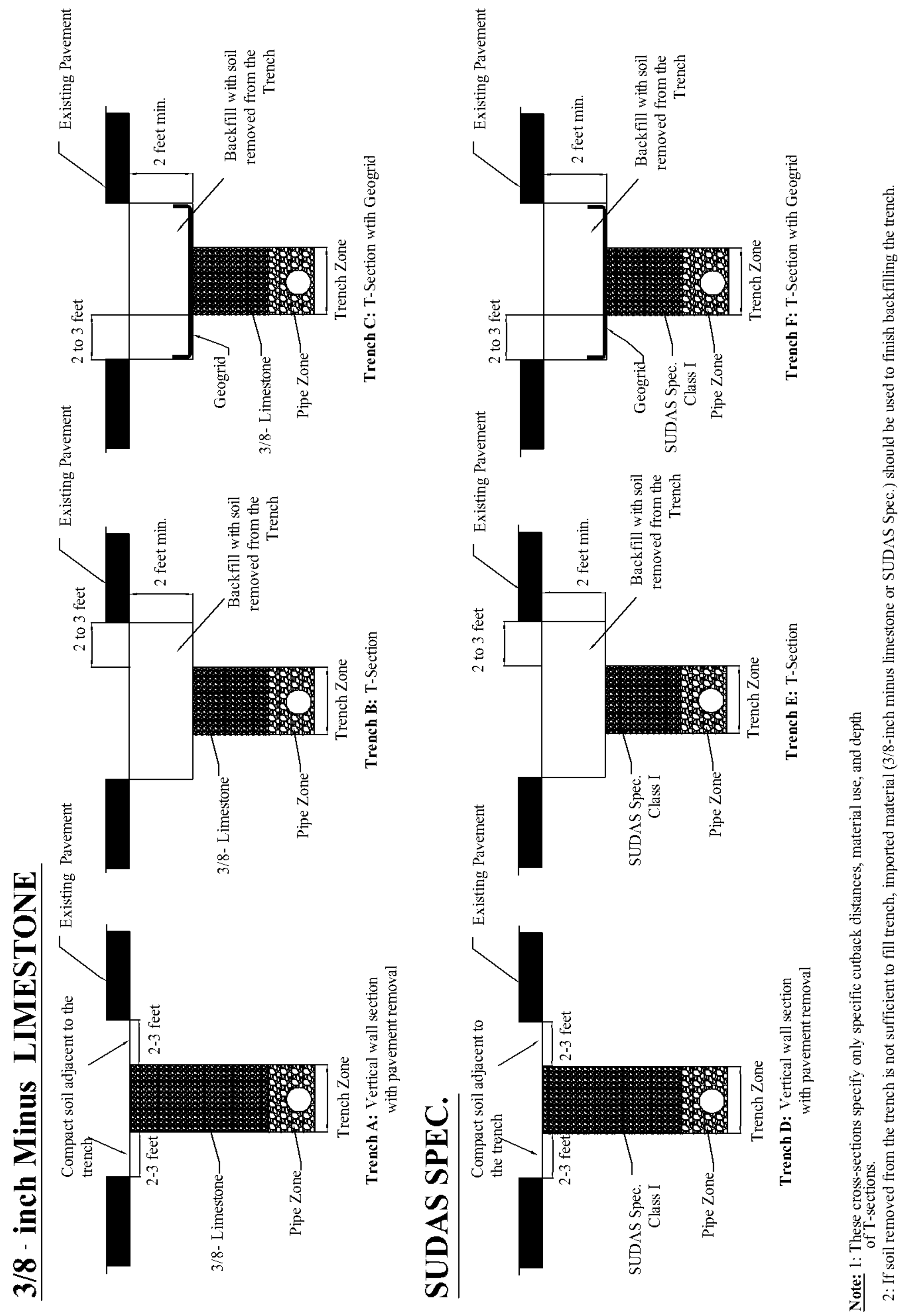


Figure 42 -- Phase I Recommended Utility Cut Trench Restorations (modified from Schaefer et al., 2005)

4.3 - Construction of the Recommended Trench Designs

Trench C shown in Figure 42 was constructed in Phase I, and the other five trenches (A, B, D, E, and F) were constructed in Phase II. Table 11 summarizes the location of each trench and the key design feature. Figure 43 shows the locations of the six trenches in the City of Ames.

Table 11 -- Summary of Recommended Trench Construction

Trench	Location*	Backfill	Design features
Trench A	1413 McKinley Drive	3/8-inch minus limestone	Vertical trench walls
Trench B	9th Street and Carroll Avenue	3/8-inch minus limestone	T-section
Trench C	Fillmore Avenue and McKinley Drive	3/8-inch minus limestone	T-section with geogrid
Trench D	2201 Ferndale Avenue	SUDAS Class I 1-inch clean limestone	Vertical trench walls
Trench E	7th Street and Carroll Avenue	SUDAS Class I 1-inch clean limestone	T-section
Trench F	6th Street and Carroll Avenue	SUDAS Class I 1-inch clean limestone	T-section with geogrid

*All trenches located in Ames, Iowa

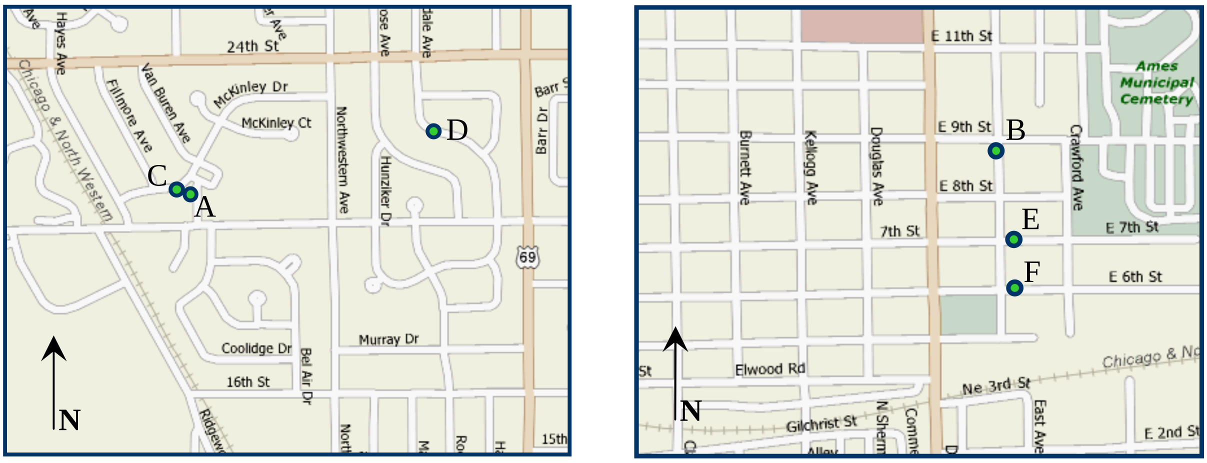


Figure 43 -- Locations of the recommended trenches in Ames, Iowa

To measure the field properties of the backfill at the sites, Nuclear Density, DCP, and Clegg Hammer tests were performed. The results from the field tests are summarized in Section 4.5. From these sites, bulk samples of the backfill and excavated soils removed from the excavation were collected for laboratory tests. The results of the laboratory testing are summarized in Section 4.4.

4.3.1 - Recommended Trench A

Trench A was constructed on August 7, 2007 on the south side of the street at 1413 McKinley Drive. The utility trench cut was made to replace a water main valve. The excavation, construction, and restoration of the trench were completed by the City of Ames.

The excavated trench was 26.5 feet long, 9.5 feet wide, and 6.5 feet deep. The base of the trench cut consisted of clay. The water from the water main break had saturated the clay. During the excavation of the trench, sand from a previous utility trench cut restoration was encountered on the south and west sides of the trench. Also, during the excavation of the trench the backhoe was located near the southwest edge of the trench (see Figure 44). The sand fell from the trench sides into the excavation. The trench was backfilled with one lift of 1½-inch limestone mixed with the saturated clay to from a base and five lifts of 3/8-inch minus limestone. A vibratory plate compactor attached to a backhoe was used to compact each lift. The backhoe was located on the northeast side of the trench, while on the east side of the trench the truck unloaded at the edge of the trench (see Figure 45). After backfilling, the trench was left open for three days to allow traffic to compact the backfill further.

On August 10, 2007, the City of Ames removed additional pavement from around the trench, 2 feet to the east, 2 to 3 feet to the north, and 1 foot south of the trench. A small vibratory compactor was used to compact the surrounding soil after the pavement was removed. Four inches of asphalt was then used to patch the trench. The completed patch was 30 feet long and 12 feet wide in plan view. Figure 46 presents a cross-section of Trench A.

Figure 44 -- Backhoe operating on southeast edge of Trench A

Figure 45 -- Truck backing into Trench A from east side of Trench A with backhoe with attached vibratory plate compactor operating on northwest side of Trench A

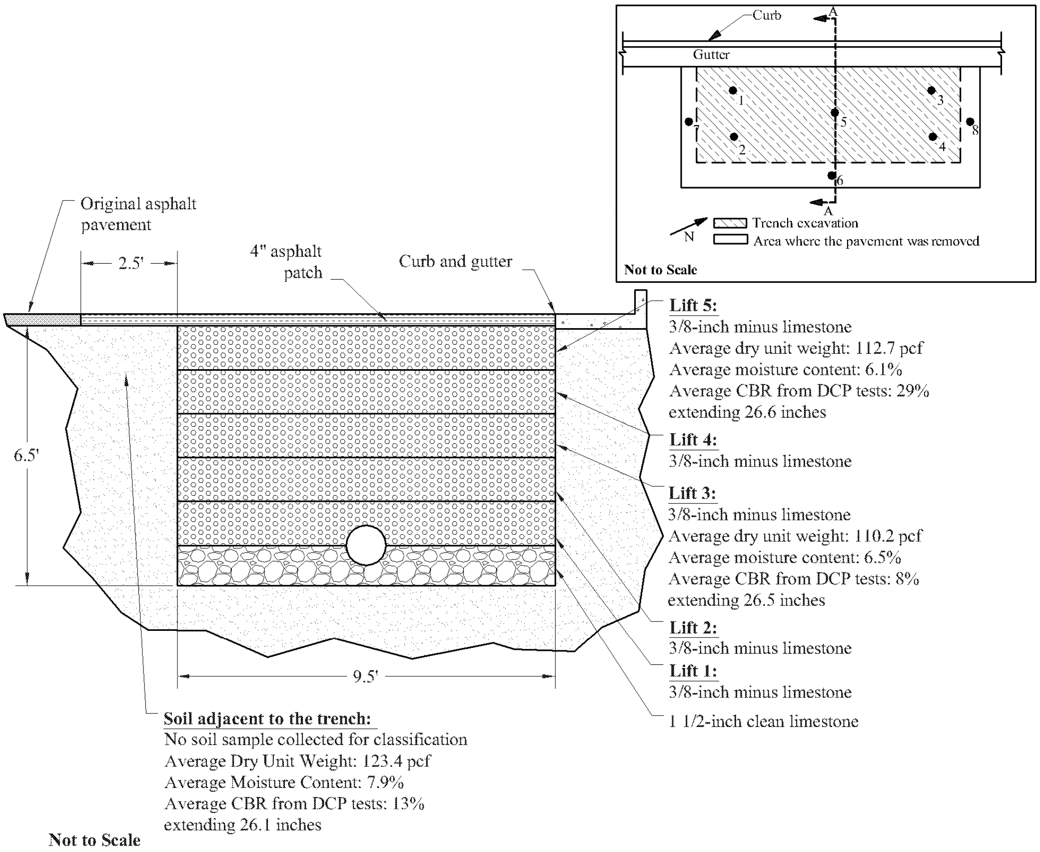


Figure 46 – North-south cross-section A-A for Trench A, a) Plan view; and b) Cross-section (Note: testing locations 6, 7 and 8 were located in the soil adjacent to the trench where the pavement was removed)

4.3.2 - Recommended Trench B

Trench B was constructed on July 12, 2007 on Carroll Avenue just south of 9th Street. The utility cut was constructed to replace a water main valve. The excavation, construction, and restoration of the trench were completed by the City of Ames.

The excavated trench was 10 feet long, 9 feet wide, and 9 feet deep. The trench was backfilled using 1½-inch limestone for bedding and 5 lifts of 3/8-inch minus limestone above the pipe. A vibratory plate compactor attached to a backhoe was used to compact each lift. After backfilling the trench, it was left open to traffic for five days.

Pavement around the trench was cut and removed on July 17, 2007. The total area of pavement removal was 15 feet wide by 33 feet long. The large area of pavement was removed because the original pavement was cracked during construction. On July 18, 2007, 2 to 3 feet of in-place soil around the trench was excavated.

During compaction, the backhoe drove into the cut area because it could not access the entire cut area (see Figure 47). The truck also backed into the open cut to reach the excavated area as shown in Figure 48.

Figure 47 -- Backhoe operating where pavement was removed on the northeast side of the trench

Figure 48 - Truck operating where pavement was removed on the northeast edge of Trench B

Supplemental backfill used in the T-section consisted of two different soils. The first soil was a mixture of organics, bottom ashes (cinders) from the coal burning power plant in Ames, Iowa, and 3/8-inch minus limestone (Backfill No. 1). The second backfill was cinders from the City of Ames Power Plant mixed with the 3/8-inch minus limestone backfill (Backfill No. 2). Backfill No.1 was placed below Backfill No. 2. Soil removed during excavation was not used because the City of Ames did not store the soil.

The trench was left open overnight. During the night, the City of Ames area received about 1½-inches of rain. The next day water was standing in the trench (see Figure 49). The trench was left open to allow it to air dry for seven days. By July 25, 2007, the surface of the trench had mostly dried. The City then placed a thin lift of 3/8-inch minus limestone on the south side of the cut area where standing water remained. The 3/8-inch minus limestone was compacted using a small, hand vibratory compactor as shown in Figure 50. The trench was then patched with about 6-inches of asphalt.

Field tests were performed on lifts 3 and 5 on July 17, 2007 (see Figure 51). When the T-section was constructed on July 18, 2007, lift 5 was removed to allow the placement of the replaced fifth (top) lift. On July 18, 2007 and on July 25, 2007 (see Figures 52 and 53) field tests were performed on the final lift constructed in the T-section at four points within the trench and four points in the area were the pavement was removed. The results from this testing can be found in Section 4.5.2.

Figure 49 -- Standing water in the trench after it rained

Figure 50 -- Small vibratory compactor used to compact the backfill

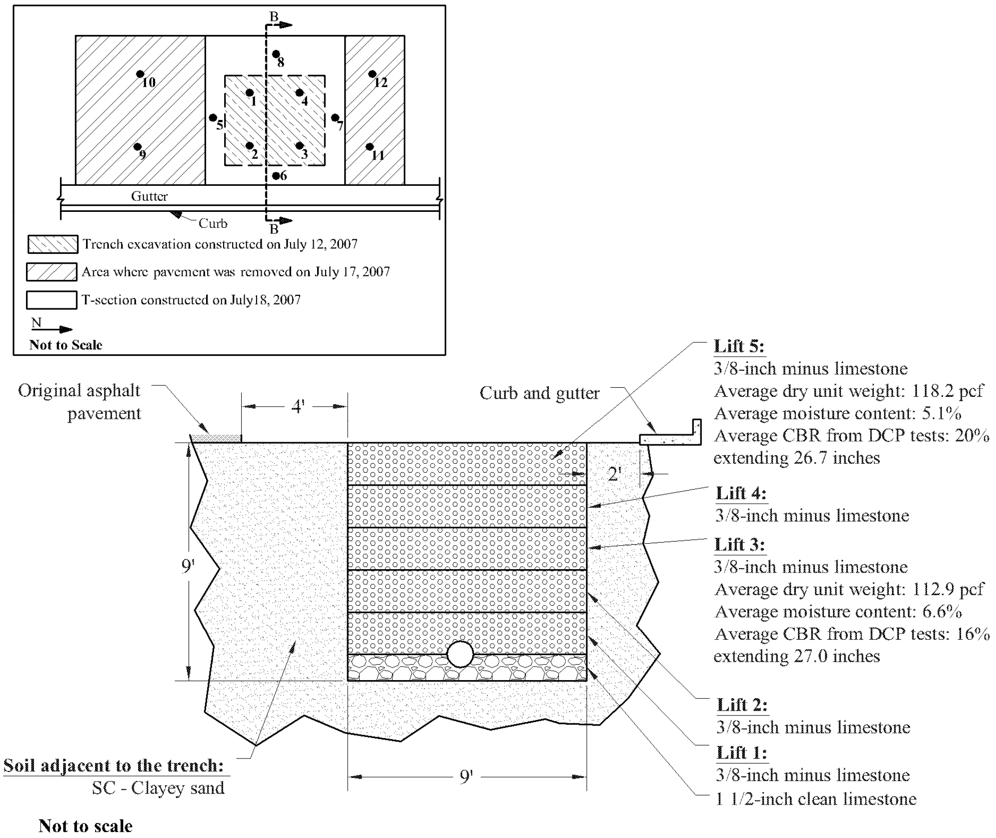


Figure 51 – East-west cross-section B-B for Trench B before the construction of the T-section on July 17, 2007, a) Plan view; b) Cross-section

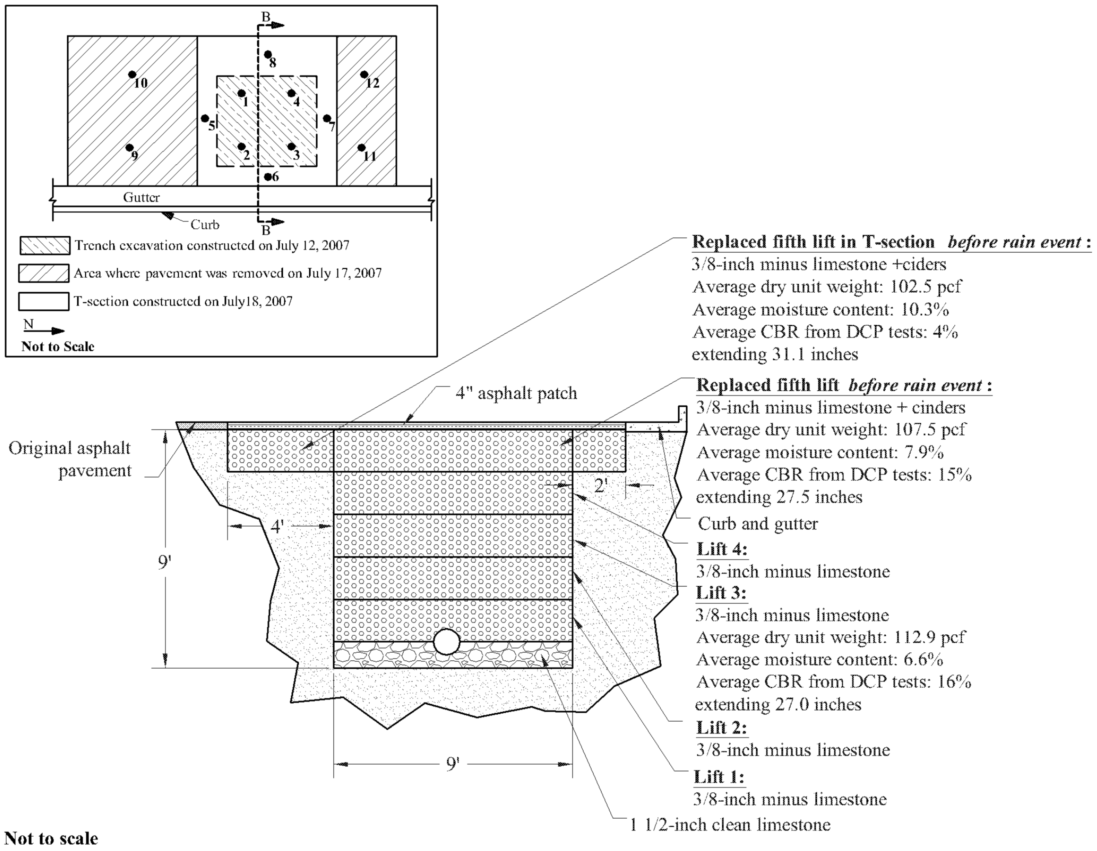


Figure 52 – East-west cross-section B-B for completed Trench B on July 18, 2007, a) Plan view, b) Cross-section

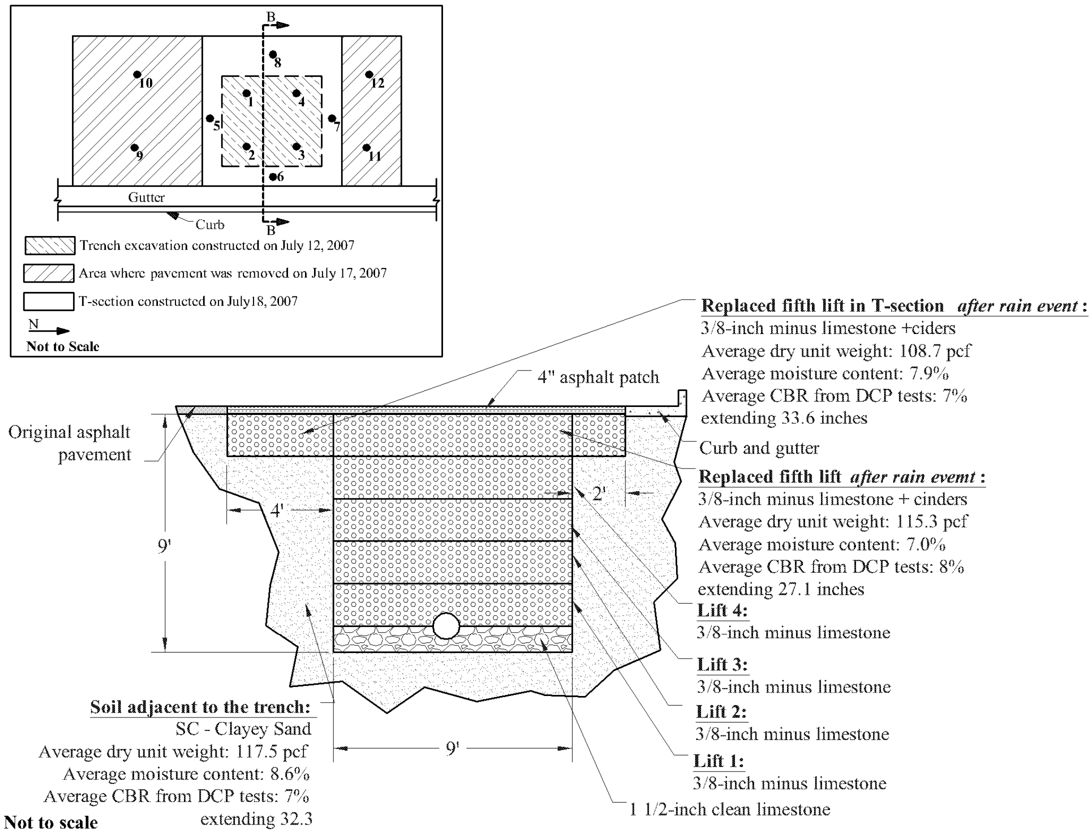


Figure 53 - East-west cross-section B-B for completed Trench B on July 25, 2007 after being left open for 6 days, a) Plan view, b) Cross-section

4.3.3 - Recommended Trench C

Trench C was constructed on May 16, 2005 at McKinley Drive and Fillmore Avenue. The excavation, construction, and restoration of the trench were completed by the City of Ames.

The completed trench (including the T-Section) was 24.7 feet al.ong the curb and 13.6 feet wide perpendicular to the curb. The T-section was 3 feet wide and 2 feet deep. The Iowa State Research team did not document the depth of the excavation or the placement of the backfill. The backfill for the lower lifts was 3/8-inch minus limestone backfill. A bulk sample was collected. The Iowa State Research team did not perform any field-testing below the geogrid. As a results, no comparisons between the field-testing results and laboratory testing results can be made for the lower portion of the trench.

After the T-section was excavated to a depth of about 2 feet for about 2 to 3 feet around the trench, BX 1100 geogrid was placed at the bottom of the T-section (i.e. about 2 feet below the ground surface). The Iowa State Research Team monitored the placement of the geogrid (see Figure 54) and the last two lifts to complete the trench.

The final two lifts of the trench were constructed used a mixtures of 3/8 inch minus backfill and soil excavation from the trench. No bulk samples of this material were collected. Because of this, the field-testing results for the top two feet of the trench cannot be compared with: a) laboratory testing results and b) generalize NAVFAC results because the there was not soil classification. Two one foot lifts were used to complete the trench. Field-testing consisted of Nuclear Density, DCP, and Clegg Hammer tests. The Clegg Hammer tests are not reported because of a malfunction with the device. The results from the field-testing are in section 4.5. Figure 55 illustrates the cross-section of Trench C.

Figure 54 -- Geogrid being placed in Trench C

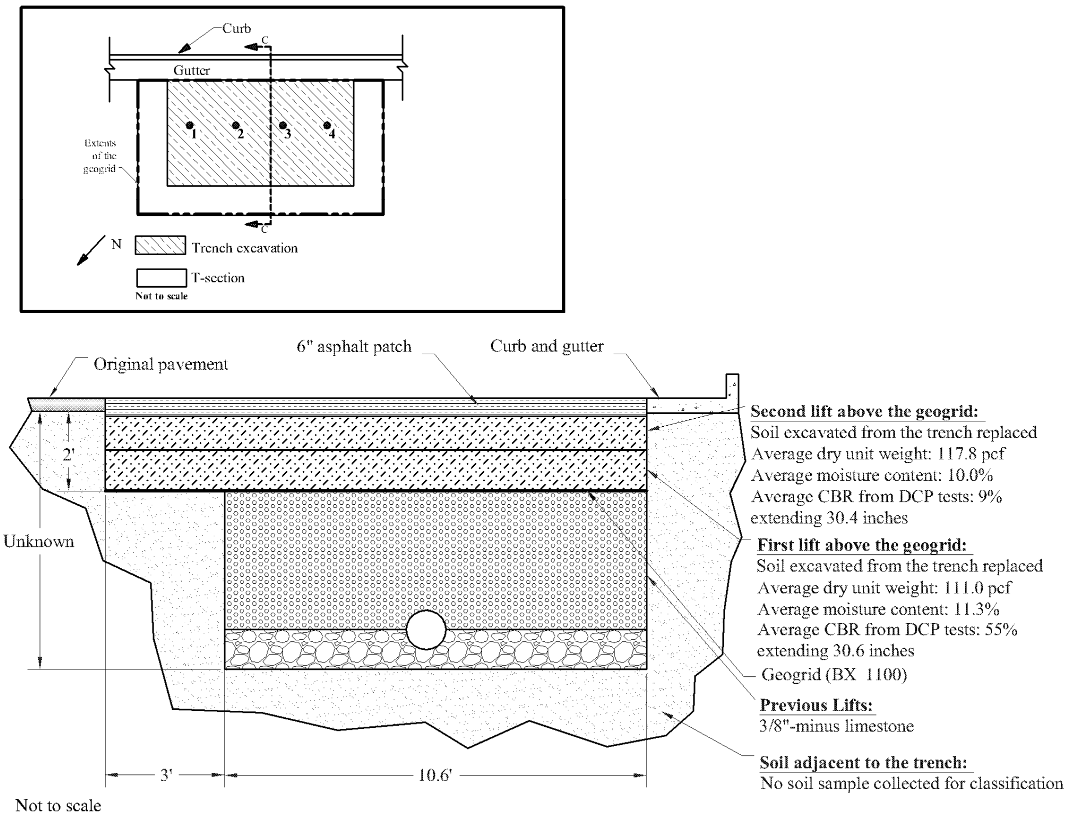


Figure 55 -- Cross-section of Trench C showing a) Plan view; b) Cross-section

4.3.4 - Recommended Trench D

Recommended Trench D was constructed on July 23, 2007 at 2201 Ferndale Avenue. The utility cut was constructed to replace a sanitary sewer. The excavation, construction of the trench, and restoration was completed by the City of Ames.

The trench was 7 feet wide, 11 feet long, and 8.5 feet deep. The sewer was repaired with PVC truss pipe, pipe bands, and cement. 1½-inch clean limestone was placed as bedding for the pipe and around the pipe. The trench was backfilled using 6 - 1 foot lifts of 1-inch limestone (SUDAS Specifications Class I). A vibratory plate attached to a backhoe was used to compact the soil. During the construction of the trench construction equipmented was located near the east and west edges of the trench (see Figures 56 and 57). After the final lift, the backhoe was driven over the trench to further compact the backfill. The trench was left open for about two days.

On July 25, 2007, the City of Ames removed additional pavement from the perimeter to the trench for a distance of about 1 foot around the trench. A small vibratory compactor was used to compact the surrounding soil where the pavement was removed. Four inches of asphalt was used to patch the trench. Figure 58 displays a cross-section of Trench D with the field-testing results.

Figure 56 - Backhoe operating on the east side of the trench and a dump truck operating on the north side of the trench

Figure 57 - Front-end loader operating on the southwest side of the trench

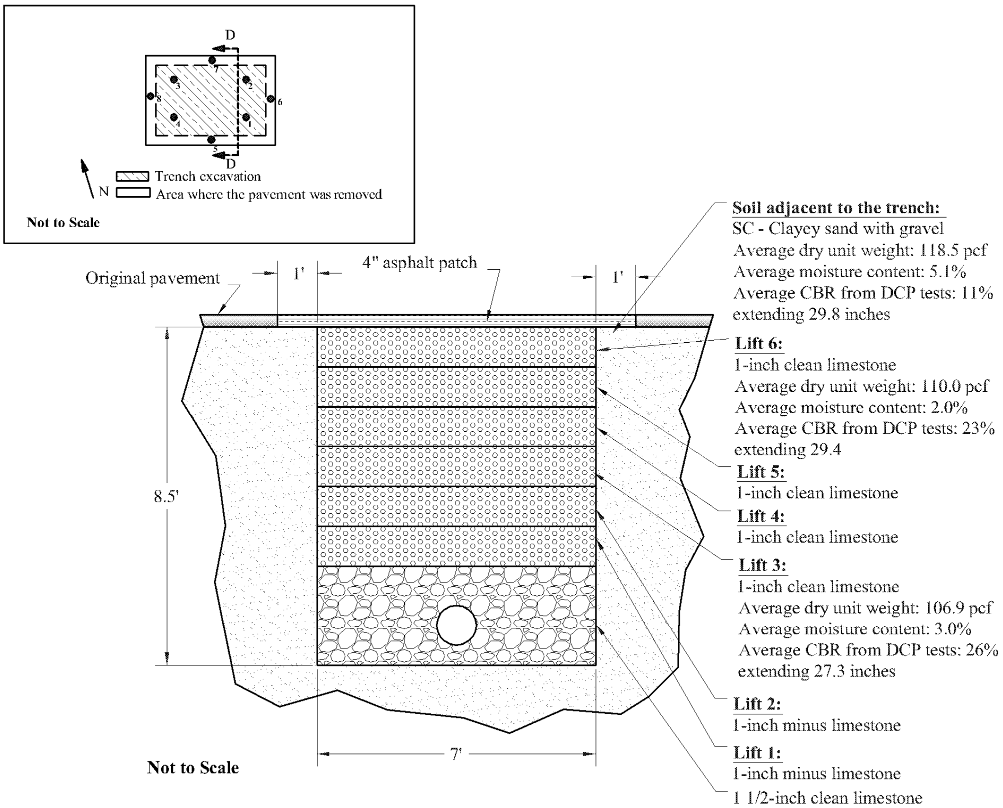


Figure 58 -- Cross-section D-D for Trench D, a) Plan view b) Cross-section

4.3.5 - Recommended Trench E

Trench E was constructed on July 11, and 12, 2007 on 7th Street east of Carroll Street. The utility cut was constructed to replace a water main valve. The excavation, construction, and restoration of the trench were completed by the City of Ames.

The excavation took place on July 11, 2007. The completed trench was 10 feet long, 7.5 feet wide and 6.5 feet deep, excluding the T-section. The valve was replaced on July 12, 2007. The first lift consisted of 1½-inch clean limestone to a thickness of about 1½ foot above the pipe. The remaining five lifts were SUDAS Class I limestone placed about 1 foot thick. A vibratory plate attached to a backhoe was used for compaction. The trench was filled until it was level with the top of the existing pavement. In addition to the vibratory plate compaction, the backhoe was driven over the trench multiple times. The trench was left open to traffic for about five days to further compact soil.

On July 17, 2007, the pavement around the trench was removed. On July 18, 2007 the T-section was excavated to a depth of about two feet. The T-section was backfilled with a mixture of 1-inch clean limestone and soil from the City of Ames soil supply piles. During the placement of the backfill, two different ratios of 1-inch clean limestone and soil from the City of Ames supply piles were used. Two bulk soil samples were collected of this backfill -- Additional Backfill No. 1 and Additional Backfill No. 2. The origin of the soil in the supply piles was not known. During construction, the equipment was close to the edge of the trench (see Figures 59 and 60). The T-section was backfilled until it was at the elevation of the bottom of the existing pavement. A thin lift of 3/8-inch minus limestone was loosely placed as a base for the pavement patch. The asphalt patch was six inches thick.

Figure 61 shows a cross section of Trench E on July 17, 2007 and Figure 62 shows the cross-section of Trench E on July 18, 2007.

Figure 59 --Soil removed from the trench being placed back into the trench by a truck located on the south side of the trench, and a backhoe operating on the east edge of the pavement for Trench E

Figure 60 -- Support of the backhoe at the edge of the pavement on the east side of Trench E

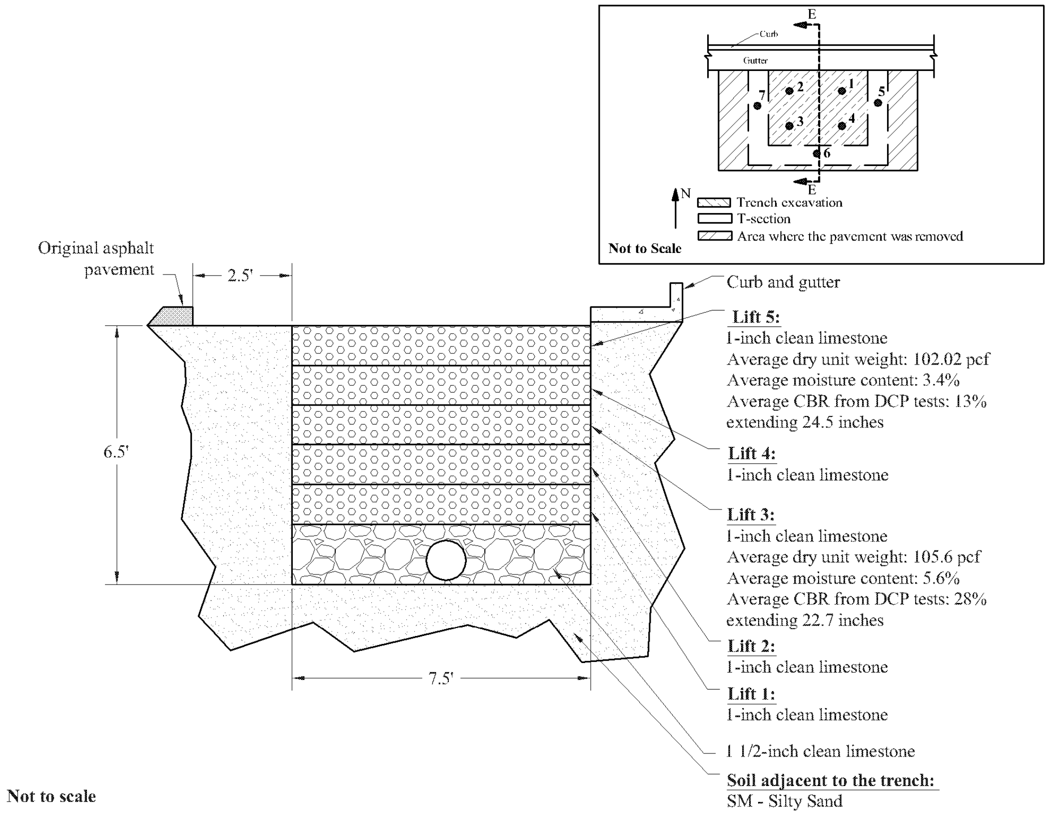


Figure 61 -- Cross-section of Trench E on July 17, 2008, a) Plan view, and b) Cross-section

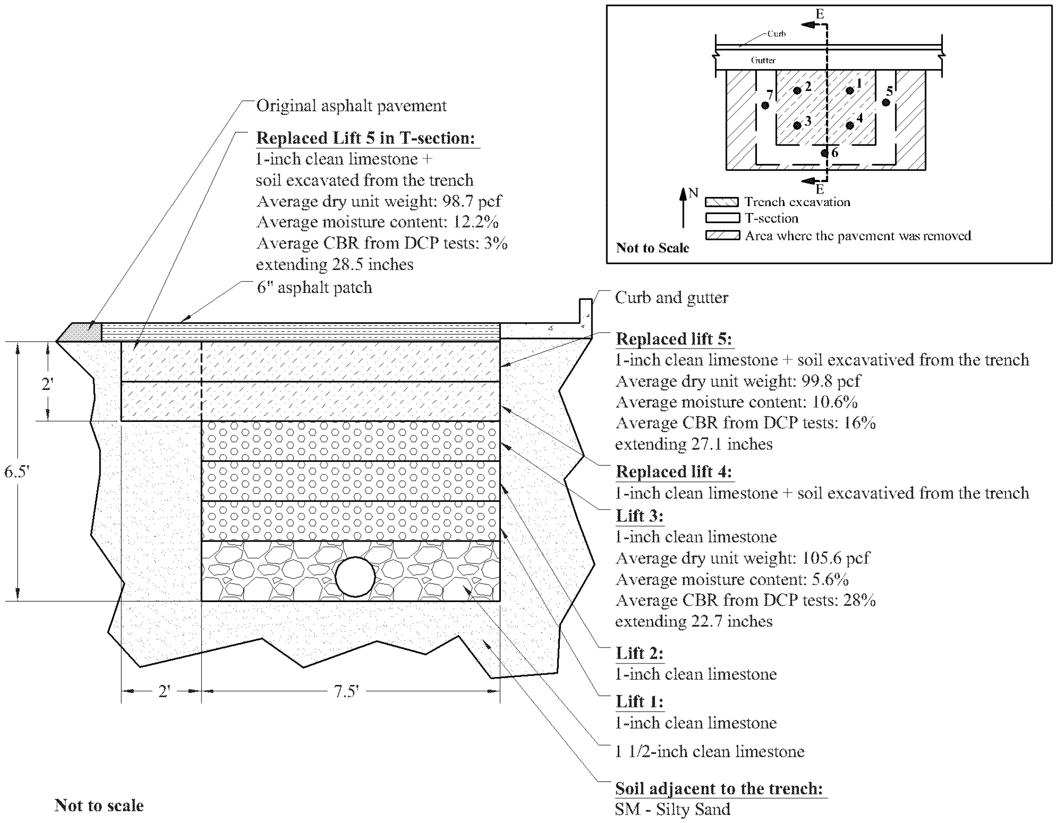


Figure 62 -- Cross-section of Trench E on July 18, 2007, a) Plan view and b) Cross-section

4.3.6 - Recommended Trench F

Trench F was constructed on July 11 and 12, 2007 on 6th Street just east of Carroll Street. The utility cut was conducted to replace a water main valve. The excavation, construction of the trench, and restoration was completed by the City of Ames.

The excavation of the trench took place on July 11, 2007. The completed excavation was 9 feet long, 7 feet wide and 5.5 feet deep, excluding the T-section. On July 12, 2007, the water value was replaced (valve and pipe were replaced and connected using pipe sleeves). Excess water from the water main spilled into the trench and was pumped out as seen in Figure 63.

For the first lift, the soil consisted of about 1½ feet of 1½-inch limestone. To complete the trench, three additional lifts of inch clean limestone were constructed for a total of four lifts (one lift of 1½-inch limestone, and three lifts of 1-inch clean limestone). The second and third lifts were about 1 foot thick and the fourth lift was 2 feet thick, which was removed to construct the T-section. During the construction of the trench construction equipment operated on the east and west edges of the trench (see Figures 64 and 65. All compaction was completed with a vibratory plate compactor attached to a backhoe. The backhoe drove over the trench to further compact the backfill. The backfill was leveled with the road surface. The trench was left unpaved for five days.

On July 17, 2007, the City of Ames returned to the site and removed pavement surrounding the trench to construct the T-section. On the July 18, 2007 the T-section was excavated 2 feet deep; the fourth lift was removed. Geogrid was placed in the excavated area (see Figure 66). The trench was then backfilled with soil excavated from the trench on July 11, 2007 and placed in a 2-foot lift. A vibratory plate compactor on a backhoe was used for compaction. Six inches of asphalt was installed for the permanent patch on the trench. Figure 67 illustrates the cross-section of Trench F on July 12, 2007 and Figure 68 shows the cross section of Trench F on July 18, 2007.

Figure 63 -- Water from the water main break being pumped out the trench

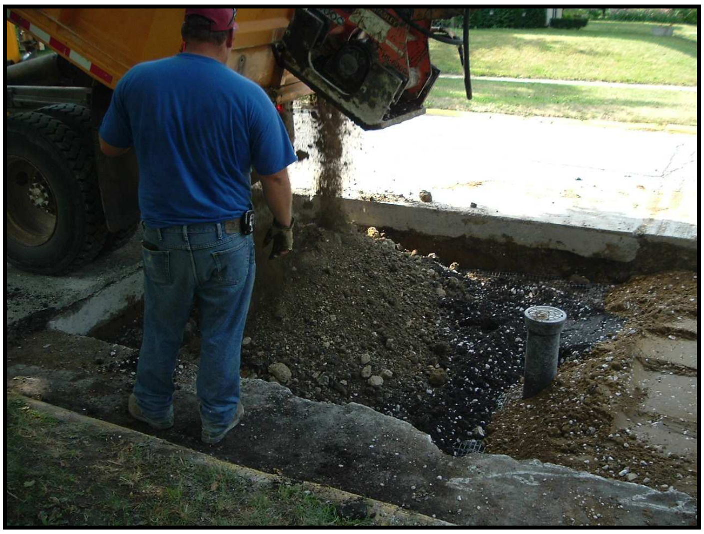


Figure 64 – Truck being backed up to east edge of Trench F

Figure 65 – Truck being backed up to west edge of Trench F

Figure 66 -- Geogrid being placed after the fourth lift and T-section were excavated with backhoe on east side of the trench

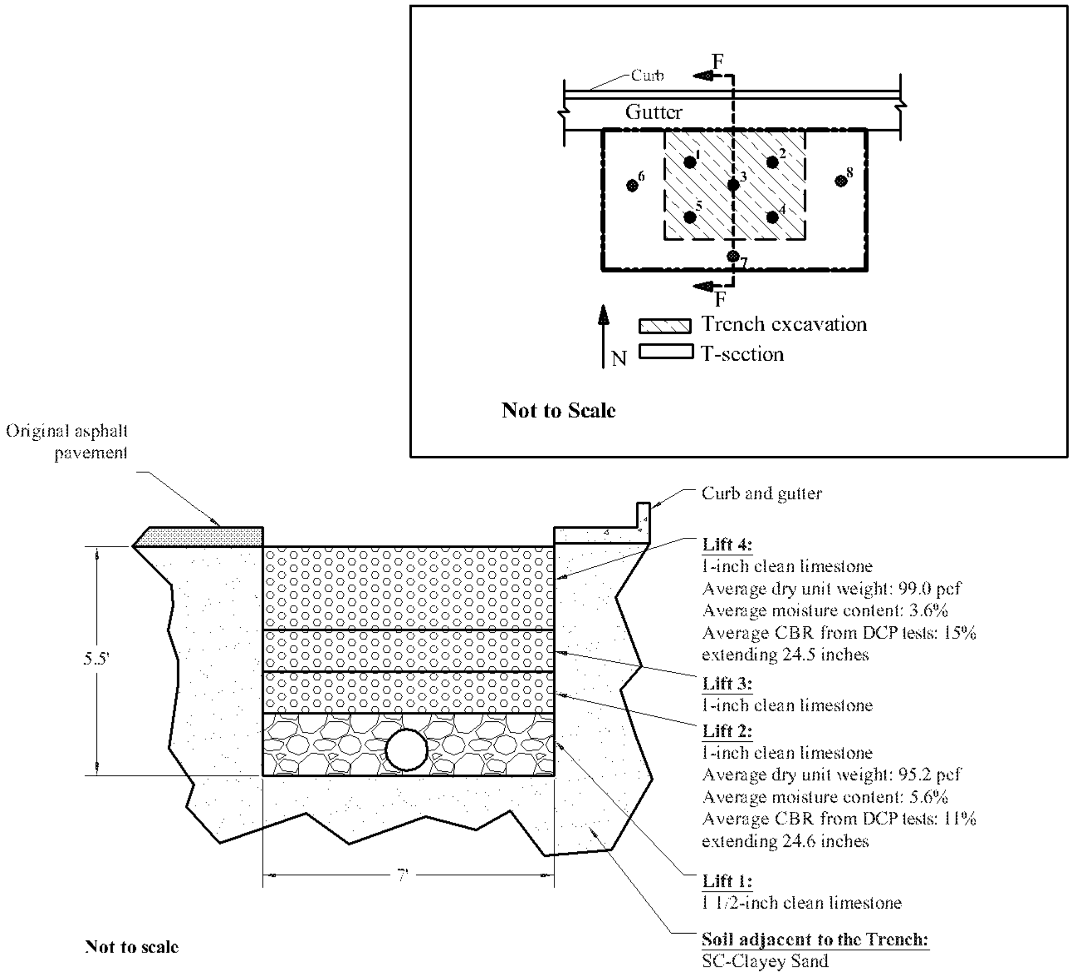


Figure 67 -- Cross-section of Trench F on July 12, 2007, a) Plan view; and b) Cross-section

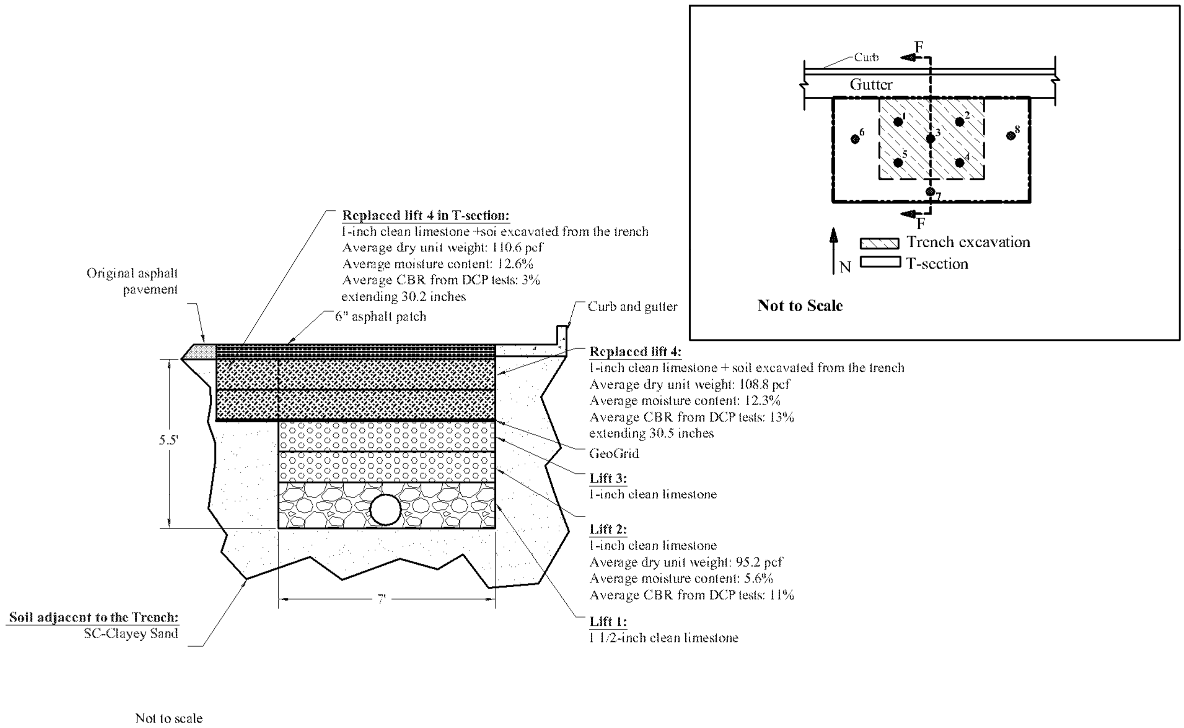


Figure 68 -- Cross-section of Trench F on July 18, 2007, a) Plan view and b) Cross-section

4.4 - Laboratory Test Results and Discussion

Laboratory tests performed according to the corresponding ASTM standards were conducted on the excavated soil and backfill used in the six recommended trenches. These tests included particle size distribution with sieve and hydrometer analyses, Atterberg Limits, water content, Standard Proctor, and minimum and maximum relative density. These laboratory tests were performed to determine soil properties and classify the soils used in the field as well as to compliment the field data (see Table 12). Laboratory data is summarized in Appendix A.

Table 12 -- Standards tests used in laboratory

Test	ASTM
Particle size distribution	STM D422-63 (2007) "Standard Test Method for Particle-Size Analysis of Soils."
Atterberg Limits	ASTM D4318-95a (1995) "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils."
Standard Proctor	ASTM 698-91, 1991 "Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort."
Maximum dry unit weight	ASTM D4253 2000 (2003), "Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table"
Minimum dry unit weight	ASTM D4254-2000 (2003), "Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density"

All soils were classified using the United Soil Classification System (USCS) and AASHTO. The AASHTO classification is used by the Iowa DOT for determining the appropriate use of soils on a construction project.

4.4.1 - Soil Gradation

Samples from both the soil excavated during the construction of the utility trench cut and the backfill were sieved. The 3/8-inch minus limestone backfill gradations are presented in Table 13. The gradations for the 1-inch clean limestone backfills are presented in Table 14. The gradations of the secondary backfills that were used in the T-sections of Trenches B, C, E, and F are presented in Table 15. The gradations of the soils excavated from the trench are presented in Table 16.

The gradation curves were constructed from the gradation tables and the hydrometer results. The gradation curves for the limestone backfills are shown in Figure 66. The gradations for backfills used in the top two feet are shown in Figure 67. The gradation curves for the soils excavated from the trenches are presented in Figure 68. The backfill soils used in Trench B consisted on cinders from the Ames Power plant. The shape of the cinders is oblong. Because of the elongation there was a bump in the gradation graphs between the sieve and hydrometer readings. The gradation curves for samples from Trench B have been smoothed out.

The 3/8-inch minus limestone used in trenches A, B, and C meets the Iowa DOT specifications standards for granular backfill (see Table 8). The 3/8 inch minus limestone was used on Trenches A, B, and C. Because the 3/8-inch minus backfills were from the same soil supply piles in the City of Ames, the results from their particle gradations were averaged, except for the 3/8-inch minus gradation from Trench C that was constructed in 2005. The gradation of the 3/8-inch minus soil from 2005 is also presented in Table13.

In Trench A, the 3/8 inch minus line stone was the only backfill used. In Trenches B and C, the 3/8 inch minus limestone was to backfill the trenches to about two feet below the surface. The remaining two feet of the trenches were filled with a mixture of 3/8 inch minus limestone and various cohesive materials. The soil mixture used in the top two feet of Trench B was a secondary backfill. In Trench C, no bulk samples of the mixed soils were collected. Therefore, there is not laboratory data for the top two feet of Trench C.

The 1-inch clean limestone meets the SUDAS specification standards. The 1-inch clean limestone was used in Trenches D, E, and F. In Trench D, 1-inch limestone was the only backfill used in the trench. In Trenches E and F, 1-inch clean limestone was used to backfill the trench to about two feet of the surface. The remaining two feet of Trenches E and F were filled with a mixture of 1-inch clean limestone and cohesive soils.

Table 13 -- Gradation of 3/8-inch minus limestone backfills used in the utility cut restoration

Sieve size/ Opening size (mm)	Trenches A and B 3/8-inch minus limestone from summer of 2007 (% Passing)	Trench C 3/8-inch minus limestone from the summer of 2005 (% Passing)
1½ in (38.1)	100	100
1 in (25.4)	100	100
3/4 in (19.05)	100	99
3/8 in (9.525)	----	---
No.4 (4.75)	99.4	97.9
No. 10 (2)	86.6	69.9
No. 20 (0.84)	59.9	35.0
No. 40 (0.425)	43.6	22.6
No. 60 (0.25)	27.5	13.3
No. 80 (0.18)	16.2	7.5
No.100 (0.15)	8.5	3.3
No. 200 (0.074)	3.5	0.8

Table 14 -- Gradation of the 1-inch clean limestone backfills used in the utility cut restoration

Sieve size/ Opening size (mm)	Trench D Ferndale 1-inch clean limestone (% Passing)	Trenches E and F 6th & 7th and Carroll 1-inch clean limestone (% Passing)
1½ in (38.1)	100	100
1 in (25.4)	98	100
3/4 in (19.05)	79	85.2
3/8 in (9.525)	---	---
No.4 (4.75)	23.6	31.7
No. 10 (2)	10.5	11.0
No. 20 (0.84)	8.3	6.5
No. 40 (0.425)	3.3	4.8
No. 60 (0.25)	1.2	3.6
No. 80 (0.18)	0.85	2.6
No.100 (0.15)	0.7	1.2
No. 200 (0.074)	0.6	0.6

Table 15 -- Gradation of the supplemental backfills used in the utility cut restoration

Sieve size/ Opening size (mm)	Trench B Backfill No. 1 (% Passing)	Trench B Backfill No. 2 (% Passing)	Trench E Additional Backfill No. 1 (% Passing)	Trench E Additional Backfill No. 2 (% Passing)	Trench F Final Backfill (% passing)
1½ in (38.1)	100	100	100	100	96.5
1 in (25.4)	100	100	100	100	92.9
3/4 in (19.05)	96.9	100	96.4	93.0	92.2
3/8 in (9.525)	94.2	100	88.0	85.0	90.3
No.4 (4.75)	87.4	80.7	73.1	79.2	86.7
No. 10 (2)	73.5	53.5	57.4	76.5	80.1
No. 20 (0.84)	50.2	53.5	41.1	51.8	49.6
No. 40 (0.425)	26.4	43.9	29.3	26.0	33.0
No. 60 (0.25)	14.0	37.2	26.5	21.1	29.2
No. 80 (0.18)	---	---	24.4	18.6	25.7
No.100 (0.15)	7.0	27.2	23.3	17.7	24.2
No. 200 (0.074)	3.0	22.5	20.2	16.0	20.3

Table 16 -- Gradation of soil excavated from the utility cuts

Sieve size/ Opening size (mm)	Trench A (% Passing)	Trench B (% Passing)	Trench D (% Passing)	Trench E (% Passing)	Trench F (% Passing)
1½ in (38.1)	100	100.00	100	100	100
1 in (25.4)	100	93.7	100	100	100
3/4 in (19.05)	100	86.7	99.1	100	100
3/8 in (9.525)	100	80.1	89.4	99.0	100
No.4 (4.75)	100	65.4	83.5	98.3	99.8
No. 10 (2)	100	38.0	79.8	95.2	99.4
No. 20 (0.84)	91.7	11.4	74*	82.6	97.9
No. 40 (0.425)	62.9	11.4	69*	64.3	93.7
No. 60 (0.25)	21.5	7.7	70.7	42.6	84.3
No. 80 (0.18)	8.0	6.1	62.1	25.6	70.8
No.100 (0.15)	3.7	5.4	58.6	19.5	60.0
No. 200 (0.074)	2.9	4.4	49.1	18.1	52.9

*These points were interpolated from the gradation graph

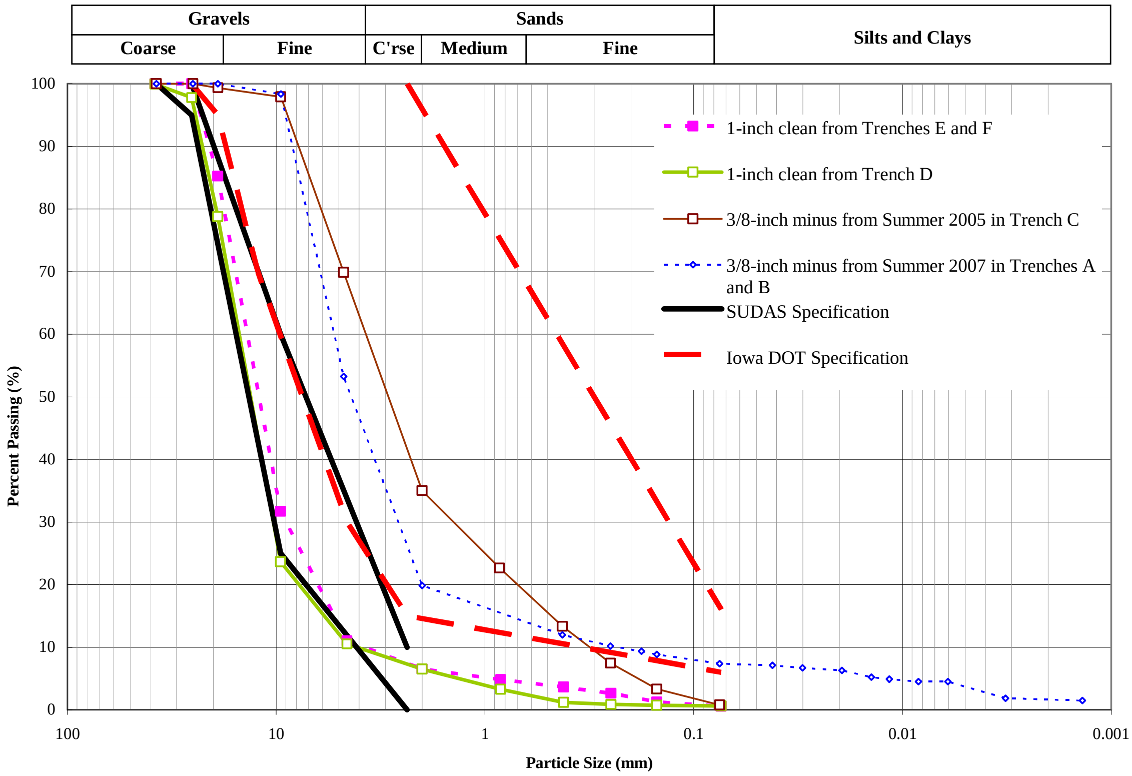


Figure 69 -- Gradation of backfill materials with the SUDAS specification and Iowa DOT specification

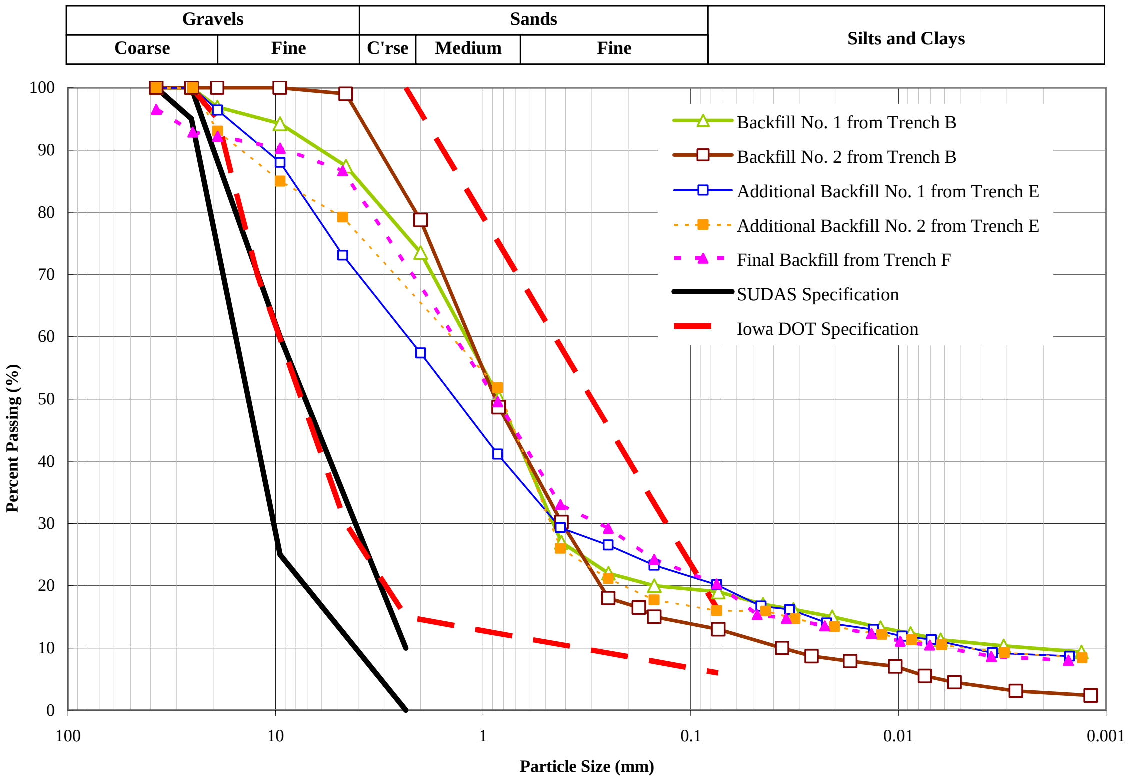


Figure 70 -- Gradation of supplemental backfill materials with the SUDAS specification and the Iowa DOT specification

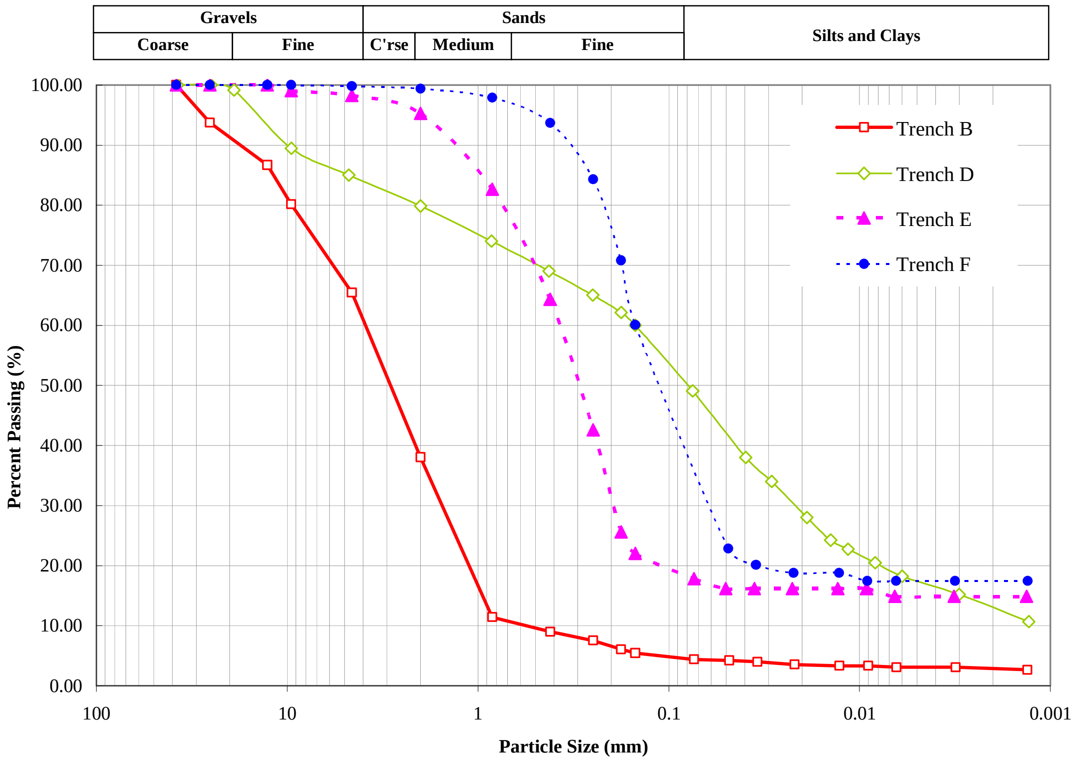


Figure 71 -- Gradation of soils excavated from different Trenches

4.4.2 - Classification of Backfills

Table 17 summarizes the backfill classifications for the limestone backfills, and Table 18 summarizes the supplemental backfills, which were mixtures of limestone backfill and other soils.

The 3/8-inch minus backfill was SP-SM - poorly graded sand with silt. The AASHTO classification was A-1-b - stone fragments, gravel, and sand. AASHTO rated subgrade suitability of this soil as good to excellent in Tables 2 and 3 .

The 3/8-inch minus backfill used in Trench C for the lifts below the geogrid, constructed in the summer of 2005, had a USCS classified of SM - sand with silt in the phase I report. The AASHTO classification was A-1-a - stone fragments, gravel and sand. AASTHO rated this soil as good to excellent for subgrade suitability in Table 2-3.

The 1-inch clean backfill used in Trenches D, C, and E had a USCS classification of GP – poorly graded gravel. The AASHTO classification of this soil was A-1-a – stone fragments, gravel and sand. AASHTO rated this backfill as good to excellent for subgrade suitability.

Table 17 -- Classification of the limestone backfills

Sample	Soil Classification						AASHTO subgrade rating
	C_U/C_C	% Passing No.4 / No. 200	USCS		AASHTO		
Trenches A and B Ames summer 2007 3/8-inch minus limestone	22.69/6.17	53.21 / 8.83	SP-SM	Poorly graded sand with silt and gravel	A-1-a	Stone fragments, gravel, and sand	Good to Excellent
Trench C Ames summer 2005 3/8-inch minus limestone	75.0/ 1.3	97.9 / 0.8	SM	sand/silt	A-1-a	Stone fragments, gravel, and sand	Good to Excellent
Trench D 1-inch clean limestone from 9th and Carroll	224.5/ 42.7	23.6 / 0.6	GP	Poorly graded gravel	A-1-a	Stone fragments, gravel, and sand	Good to Excellent
Trenched E and F 1-inch clean limestone from 6th/7th Carroll	487.5/ 18.0	31.7 / 0.6	GP	Poorly graded gravel	A-1-a	Stone fragments, gravel, and sand	Good to Excellent

4.4.3 - Classification of Secondary Backfills

Secondary backfills were used in Trench B, C, E, and F after the T-sections were constructed. Bulk samples were collected from Trenches B, E, and F; however, in Phase I, bulk samples were not collected from Trench C.

In Trench B, backfill consisting of cinders from the Ames Power Plant and 3/8-inch minus limestone was used. Some of the backfill contained organics along with the cinders and the 3/8-inch minus material (Backfill No. 1). The remaining backfill was 3/8-inch minus limestone with cinders (Backfill No. 2). For comparing laboratory testing results with field results the non-organic laboratory testing results were averaged together.

In Trench E, backfill samples consisted of 1-inch clean limestone and soil from the City of Ames supplies, which the origin of the soil was not known. Two different ratios of 1-inch clean and soil were used: Additional Backfill No. 1 and Additional Backfill No. 2. For comparing laboratory testing results to field-testing results, the non-organic laboratory testing results were averaged together.

In Trench F, the secondary backfill - Final Backfill was placed in the upper two feet of the trench was 1-inch clean limestone mixed with soil originally excavated from the trench.

The secondary soils used in these trenches were classified as SC- clayey sand with USCS. The AASHTO classification was A-2-6 – Silty and clayey gravel and sand. AASTHO rate this material as good to excellent according to Tables 2 and 3.

Table 18 – Supplemental backfills used in the top two feet of Trenches B, E, and F.

Sample	Soil classification							AASHTO subgrade rating
	C_U/C_C	Liquid Limit/ Plastic Index	% Passing No.4 / No. 200	USCS		AASHTO		
Trench B Backfill No. 1	220/ 42.6	39/ 21	79.0 / 16.0	SC	Clayey sand	A-2-6	Silty and clayey gravel and sand	Good to Excellent
Trench B Backfill No. 2	39.28/ 7.6	48/ 28	86.67/ 20.29	SC	Clayey sand	A-2-7	Silty and clayey gravel and sand	Good to Excellent
Trench E Additional Backfill No. 1	487.5/ 18.0	36/ 17	73.1 / 20.2	SC	Clayey sand	A-2-6	Silty and clayey gravel and sand	Good to Excellent
Trench E Additional Backfill No. 2	224.5/ 42.7	40/ 23	79.2 / 16.0	SC	Clayey sand	A-2-6	Silty and clayey gravel and sand	Good to Excellent
Trench F Final Backfill	187.5/ 13.3	26/ 11	86.7 / 20.3	SC	Clayey sand	A-2-6	Silty and clayey gravel and sand	Good to Excellent

4.4.4 - Classification of Soils Excavated from the Trenches

Table 19 summarizes the soil classification test results for the soils removed during the trench excavation.

Soil from around Trench A was not sampled. However, during the excavation of the trench, sand from the previous utility cut restorations was encountered. This sand was classified as SW- well graded sand. Soil removed from Trench B was classified as SW - clayey well-graded sand with USCS. The AASHTO classification was A-1-b - Stone fragments, gravel, and sand. AASHTO in Tables 2 and 3 rated this soil a good to excellent subgrade material. Soil removed from Trench C was not tested as part of the Phase II report. The Phase I report did not record data for the soil removed from the trench. Soil removed from Trench D was soil classified as SC – clayey sand with gravel for USCS. The AASHTO classification was A-6 clayey soil. The AASHTO classification in Table 2 and 3 rated Trench D soil as poor to fair for subgrade soil. Soil removed from Trench E was classified as SC – clayey sand. The AASHTO classification was A-2-4 - silty and clayey gravel and sand. AASHTO rated this soil as good to excellent for subgrade suitability. Soil removed from Trench F was classified as CL - sandy lean clay. AASHTO in Tables 2 and 3 classifications was A-6-clayey soil. AASHTO rated this soil as poor to fair for subgrade suitability in Tables 2 and 3.

Table 19 Soil classifications and laboratory results for soil excavated from the trench cuts

Sample	Soil classification							AASHTO subgrade rating
	C_U/C_C	Liquid Limit/ Plastic Index	% Passing No.4 / No. 200	USCS		AASHTO		
Trench A Sand from Previous Cut	12.34/ 1.05	---	100 / 2.9	SW	Well graded sand	A-3	Fine sand	Good to Excellent
Trench B	11.68/ 1.95	39/19	65.4 / 4.4	SW-SC	Well graded sand with gravel	A-1-B	Stone fragments, gravel and sand	Poor to Fair
Trench D	3.88/ 161	---	98.5 / 49.1	SC	Clayey sand with gravel	A-6	Clayey soil	Poor to Fair
Trench E	366/ 104.6	26/10	98.5 / 49.1	SM	Silty Sand	A-2-4	Silty and clayey gravel and sand	Good to Excellent
Trench F	---	40/23	99.8 / 42.9	CL	Sandy lean clay	A-6	Clayey soil	Poor to Fair

4.4.5 - Standard Proctor Test Results

The Standard Proctor test was performed on the following soil samples: soils excavated from Trenches B, C, D, and E, supplement backfills for Trenches B, C, E, and F, and on the 3/8-inch minus limestone from the City of Ames in summer 2007. Table 20 shows the results from the Standard Proctor tests for the various soils excavated from the trenches and the suggested values given by NAVFAC (1988) in Table 5. This table shows that for all backfills, the maximum dry unit weights and optimum moisture contents fall within the range typical values except for, 3/8-inch minus backfill. In the laboratory the standard proctor tests were performed several moisture contents.

To compare the field-testing data to the laboratory data for 3/8 inch minus limestone, the Standard Proctor test results from 2007 were plotted on the Relative Density test results from 2005.

Table 20 -- Standard Proctor test results

Sample	Classification	Maximum dry unit weight and optimum moisture content from the Standard Proctor Test		Range of dry unit weights and optimum moisture contents from NAVFAC	
		γ_{Max} (pcf)	Optimum Moisture Content (%)	γ_{Max} (pcf)	Optimum Moisture Content (%)
Ames summer 2007 3/8-inch minus limestone	SP-SM	131.0	9.0*	110 to 125	11 to 16
Ames summer 2005 3/8-inch minus limestone	SM	127.3	11.1*	110 to 125	11 to 16
1-inch clean limestone	GP	N/A	N/A	115 to 125	11 to 14
Trench B Backfill No. 1	SC	111.0	14.8	105 to 125	11 to 19
Trench B Backfill No. 2	SC	122.8	11.4	105 to 125	11 to 19
Trench E Additional backfill No. 1	SC	105.4	19.1	105 to 125	11 to 19
Trench E Additional backfill No. 2	SC	108.4	17.5	105 to 125	11 to 19
Trench F Final backfill	SC	119.1	13.2	105 to 125	11 to 19
Trench B	SW	128.8	9.1	110 to 130	9 to 16
Trench D	SC	120.2	12.1	105 to 125	11 to 19
Trench E	SC	123.7	10.9	105 to 125	11 to 19
Trench F	CL	122.7	11.9	95 to 120	12 to 24

*The maximum moisture content tested was reported because at higher moisture contents the water pooled in the bottom of the container and was not held between the particles

4.4.6 - Relative Density Test Results

Relative density tests were performed on the following samples: 3/8-inch minus limestone, 1-inch minus limestone and Trench A Sand from Previous Cut, which was the backfill material the City of Ames used in the 1990's. Table 21 shows the relative density test results.

The 1-inch clean limestone results from the relative density tests were not considered accurate for three reasons. First, there were limited fines in the samples. Therefore, when more water was added to the sample, it did not affect the particle interaction. Second, the aggregate was too large for the mold that was available in the laboratory. Finally, the particles were angular and interlocked when the test was performed, preventing further compact. However, when the particles were removed from the mold it was possible to rearrange the particles in the mold to a denser configuration. During the Phase I, SUDAS 1-inch clean material was tested. The results from Phase I were used to evaluate the performance of the trenches.

The relative density testing data from Phase II is not reported because of: a)problems were also experienced with the 3/8-inch minus limestone relative density test for samples of 3/8 inch minus limestone from 2007. In addition b) no collapse tests were performed on these samples. The data for 3/8 inch minus limestone can be found in the Appendix. The relative density testing results from Phase I was used to make comparisons.

Table 21 Relative density testing results for granular backfills

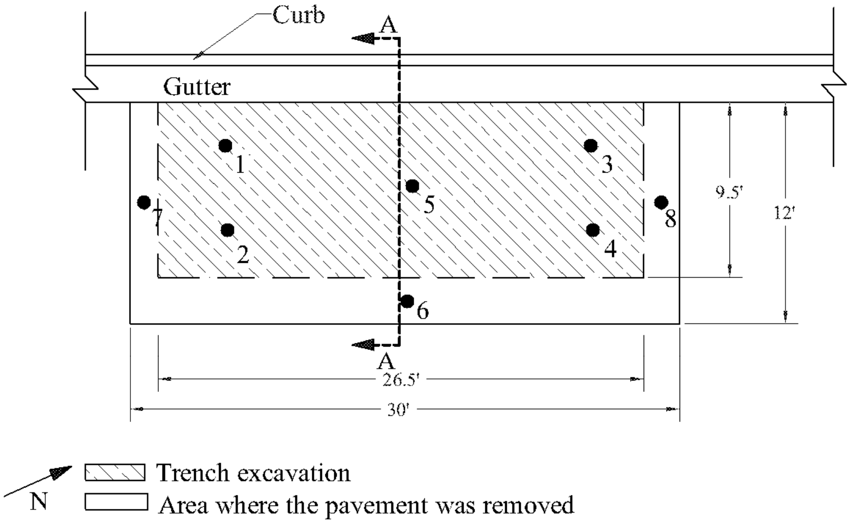
Sample	Maximum/ Minimum dry unit weight and bulking moisture content from Relative Density Testing		Range of maximum dry unit weights and optimum Moisture contents from NAVFAC	
	$\gamma_{Max}/\gamma_{Min}$ (pcf)	Bulking moisture content (%)	γ_{Max} (pcf)	optimum moisture content (%)
Trench A Sand from Previous Cut	104.7 / 100.0	2 to 6	110 to 130	9 to 16
Trench C Ames 3/8-inch minus limestone from summer 2005	140 / 99.0	4.0 to 8.0	110 to 125	11 to 16
Trenches D, E, and F 1-inch clean limestone from	132.3/ 85.2	---	115 to 125	11 to 14

4.5 - Field Test Results and Discussion for the Recommended Trenches

The field tests performed on the trenches were Nuclear Density, DCP, and Clegg Hammer tests. Clegg Hammer test reported but not presented on Figures or in comparisons because the Clegg Hammer was not operating properly during all of the field-testing. Complete field test results are summarized in Appendix B. FWD testing results are Appendix C and Survey results are in Appendix D.

4.5.1 - Recommended Trench A

The DCP and Nuclear Density tests were performed during construction at five different test points for the third and fifth (top) lifts on August 8, 2007. On August 10, 2007 (when the trench was patched) DCP, Clegg Hammer, and Nuclear Density tests were also performed on the same five points within the trench and at three additional points where the pavement was removed (see Figure 72 for test point locations). For the test points within the trench, additional tests were performed August 8, 2007 and August 10, 2007, to document changes in the backfill properties because the trench was left open for 2 days.



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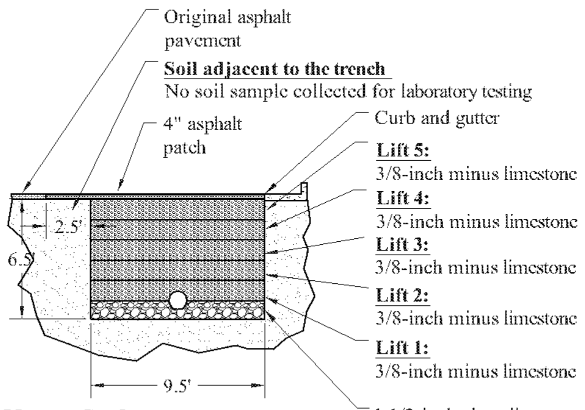

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Figure 72 -- Location of test points in Trench A and cross-section of the trench

Nuclear Density Test Results

Table 22summarizes the dry unit weights measured using the Nuclear Density test and Table 23 summarizes the moisture content results from the Nuclear Density test. The probe depth was six inches.

The third and fifth lift was constructed with 3/8-inch minus limestone. The limestone backfill was classified as SP-SM – poorly graded sand and silt. The typical dry unit weights from NAVFAC were 110 pcf to 125 pcf with optimum moisture contents ranging from 11% to 16%.

On August 8, 2007, the third lift had an average dry unit weight from the Nuclear Density test for the five points within the trench was 110.2 pcf and the moisture content was 6.5%. All the dry unit weights were within the typical range of values provided by NAVFAC. However, the moisture content was below the typical optimum moisture content for compaction provided by NAVFAC. Based on laboratory tests, the backfill was placed at a relative density of 34%. This corresponded to loose compaction according to Table 6. However, moisture content at placement of the material was within the bulking moisture content range, increasing the collapse potential of the backfill.

On August 8, 2007, the fifth (top) lift had an average dry unit weight for the five points within the trench of 120.7 pcf and a moisture content of 6.0%. The dry unit weights were above the typical range of values provided by NAVFAC. The moisture content was below the typical optimum moisture content for compaction provided by NAVFAC. The fifth (top) lift was placed at 60% relative density, which corresponds to a medium dense compaction state according to Table 6. The moisture content of the backfill at the placement was within the bulking moisture content range of the backfill (i.e. 4.0% to 8.0%).

On August 10, 2007 before the patch was placed, the fifth (top) lift had an average dry unit weight for the five points within the trench of 122.3 pcf and a moisture content of 6.1%. Leaving the trench open for two days resulted in an increase of 1.4% in the dry unit weight. The dry unit weights were above the typical range of values provided by NAVFAC. The moisture content was below the typical optimum moisture content for compaction provided by NAVFAC. Compaction of the soils below the optimum moisture content for compaction will make the trench more susceptible to collapse behavior. Based on the laboratory results, the backfill was placed at a relative density of 65%. This corresponded to a dense compaction. The moisture content of backfill after leaving the trench open for two days was within the bulking moisture content range, increasing its collapse potential.

The soil adjacent to the trench on August 10, 2007, had an average dry unit weight, from the Nuclear Density test for the three points (6, 7, and 8), of 123.4 pcf and the moisture content of 7.9%.

Table 22 -- Dry unit weight results from the Nuclear Density tests on Trench A

Location	Number of test points	Average dry unit weight (pcf)	Min/Max dry unit weight from field-testing (pcf)	Relative density (%)	Standard deviation	Coefficient of variance (%)
Third lift	5	110.2	107.8 / 111.2	34	1.4	1.3
Fifth lift test points within the trench tested on August 8, 2007	5	120.7	117.1 / 124.5	60	3.3	2.7
Fifth lift test points within the trench tested on August 10, 2007	5	122.3	120.1 / 125.7	65	1.8	1.5
Test points in the soil adjacent to the trench on August 10, 2007	3	123.4	122.3 / 125.4	N/A	1.7	1.4

Table 23 -- Moisture content results from the Nuclear Density tests for Trench A

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Bulking moisture content (%)	Standard deviation	Coefficient of variance (%)
Third lift	5	6.5	5.9 / 8.3	4.0 to 8.0	1.0	15.4
Fifth lift test points within the trench tested on August 8, 2007	5	6.0	5.6 6.2	4.0 to 8.0	0.3	5.0
Fifth lift test points within the trench tested on August 10, 2007	5	6.1	5.0 / 9.7	N/A	2.0	32.8
Test points in the soil adjacent to the trench on August 10, 2007	3	5.0	5.0 / 9.7	N/A	2.5	32.1

Figure 73 shows the results from the relative density testing performed in Phase I with the average field placement results superimposed. The Figure shows the collapse potential index for the 3/8-inch minus limestone. The figure clearly shows that the backfill was placed at a relative density ranging from 27% to 69% with moisture contents ranging from 5.0% to 8.3%, which was within the bulking moisture content range. This shows that the backfill was placed at average moisture content with the highest collapse potential. This increased the trench’s susceptibility to settlement. The circles around each lift shows which lift the various test points occurred on and that the moisture content and dry unit weights were similar within each lift. There is one outlier point; this point corresponded to test point 1 on lift 3.

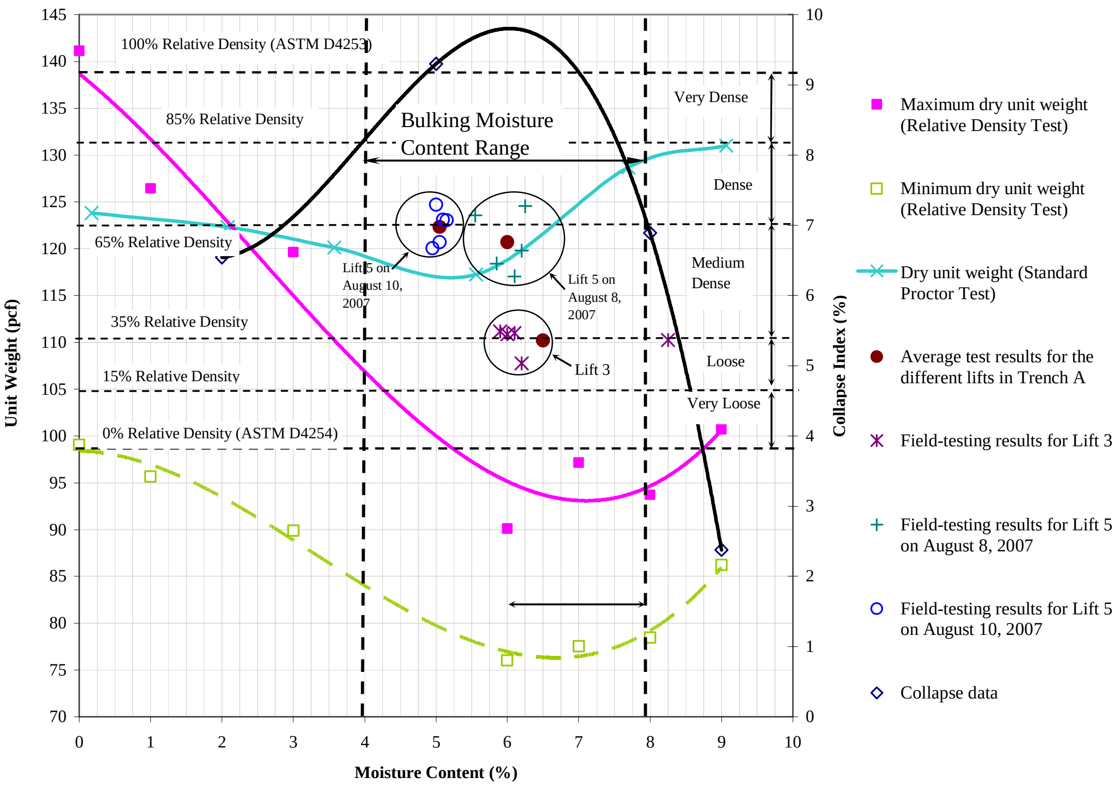


Figure 73 -- Relative density testing results for 3/8-inch minus limestone with field-testing results for 3/8-inch minus backfill within Trench A

DCP Test Results

The third and fifth lift was constructed with 3/8-inch minus limestone. The limestone backfill was classified as SP-SM – poorly graded sand with silt. The typical CBR values were 10% to 40% for poorly graded sand from NAVFAC (1986) in Table 5.

Table 24 summarizes the average Dynamic Cone Penetration Index (DCPI) readings from the DCP tests for Trench A and Table 25 summarizes the average California Bearing Ratio (CBR) results from the DCP tests for Trench A. The DCPI was calculated for each depth of the profile, and then the CBR was estimated along the profile for each trench. The average CBR values were weighted values by distance (used in Phase I) from CBR profiles and were not calculated from the average DCPI. The same procedure was used for all DCP performed on all trenches.

Table 25 shows the CBR values for the trench ranged from 8% for the third lift to 29% for the fifth (top) lift for the test points within the trench on August 10, 2007. Leaving the trench open for 2 days, caused the CBR values from the DCP tests to increased from 17% to 29% for the test points within the trench indicating an increase of 71%.

Table 24 -- DCPI results from the DCP tests for Trench A

Location	Number of test points	Depth of test (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	5	26.5	61.1	58.6	96.1
Fifth lift test points within the trench tested on August 8, 2007	5	27.5	15.2	7.0	46.1
Fifth lift test points within the trench tested on August 10, 2007	5	26.6	8.7	3.0	33.8
Test points in the soil adjacent to the trench on August 10, 2007	3	26.1	47.7	26.3	55.1

Table 25 -- Average CBR results from the DCP tests for Trench A

Location	Number of test points	Depth of test (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	5	26.5	8%	79.0	975.3
Fifth lift test points within the trench tested on August 8, 2007	5	27.5	17%	7.3	42.7
Fifth lift test points within the trench tested on August 10, 2007	5	26.6	29%	20.7	70.9
Test points in the soil adjacent to the trench on August 10, 2007	3	26.1	13%	20.4	156.9

For the third lift on August 8, 2007 the DCP test points within the trench had an average CBR value of 8%. Figure 74 shows the CBR values as a function of depth for lift 3. This Figure shows a wide variation of the CBR values among the test points. The CBR values range from 3% to 6.5% at the surface to 0.3% to 11.5% at the termination of the tests. The average CBR values range from 1% (point 5) to 14% (point 2). The tests ranged in depth from 22 inches to 28 inches.

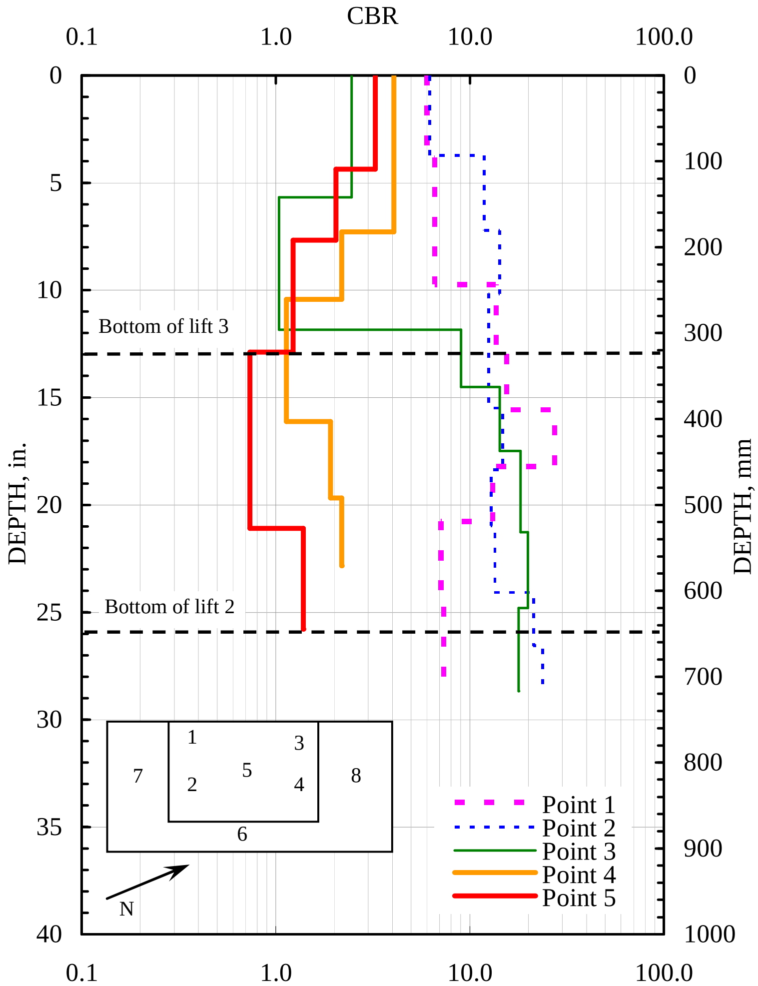


Figure 74 – CBR profiles from the DCP tests for Lift 3 in Trench A (boundary locations are estimated based on the total depth of the trench and the number of lifts)

The fifth (top) lift was tested on August 8, 2007 and August 10, 200. The test points in the soil adjacent to the trench were test on August 10, 2007. On August 8, 2007 the average CBR value within the trench was 17%. The CBR tests were conducted for a range of in depths from 21 inches to 28 inches. At the surface of the lift the CBR values ranged from 5% to 12%. These CBR values were below the typical CBR values from NAVFAC in Table 5. At the termination of the test the CBR values ranged from 20% to 47%. Figure 75 shows that the CBR profiles for each test point.

On August 10, 2008, the average calculated CBR value within the trench was 29% for the fifth lift. These tests ranged in depth from 25 inches to 27 inches (approximately the upper two feet of the trench). These values will affect the performance of the pavement the most. The Figure shows that at the surface the CBR values ranged from 16% to 24%. At the termination of the test, the CBR values ranged from 26% to 51%. The CBR values at the surface and the termination of the tests were within the typical range of values from NAVFAC in Table 5. Figure 76 shows the CBR profiles for all the test points.

When comparing the CBR profiles on August 8, 2007 to August 10, 2007, the CBR values at the surface had increased from an average of 7% to an average of 21%. The average values for the depth of the tests increased from 17% to 29%. The CBR values at the termination of the tests also increased but not to the degree as at the surface. At of the test points the CBR values increased with depth. The CBR profiles at each test point follow the same general profile through the depth of the profiles. This shows that the compaction effect was evenly applied. This shows that the compaction was effective through the thickness of the lift and caused the material to increase in density. In addition, the profile shows that compaction was evenly applied to each test area during compaction.

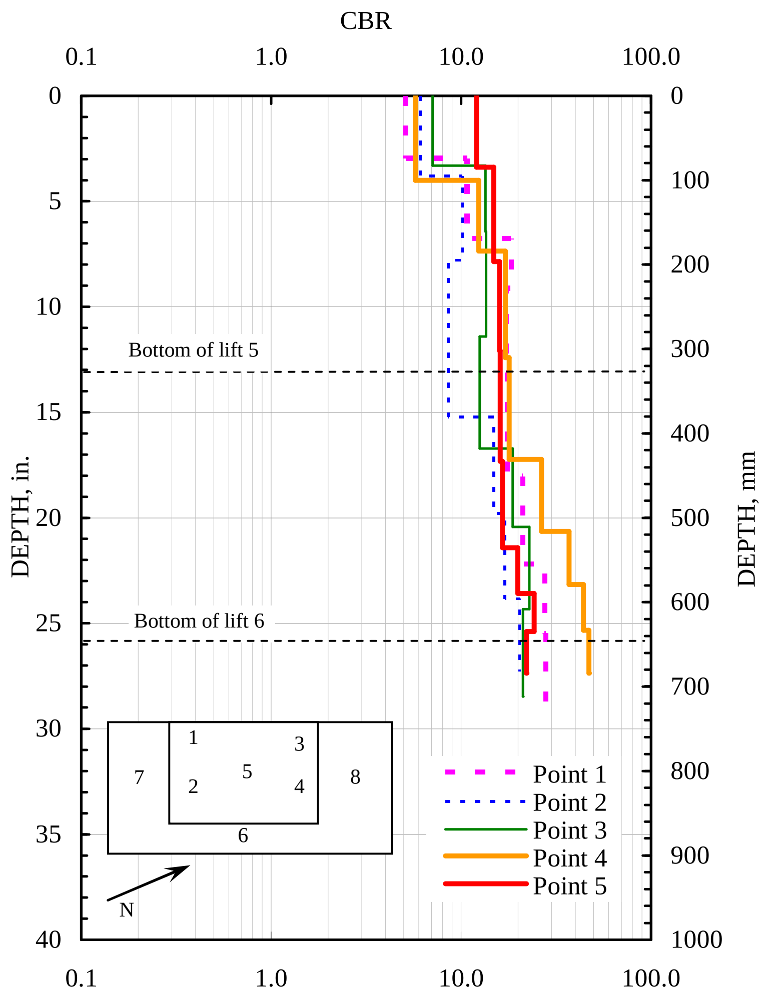


Figure 75 -- CBR profiles from the DCP tests for Lift 5 on August 8, 2007 for Trench A

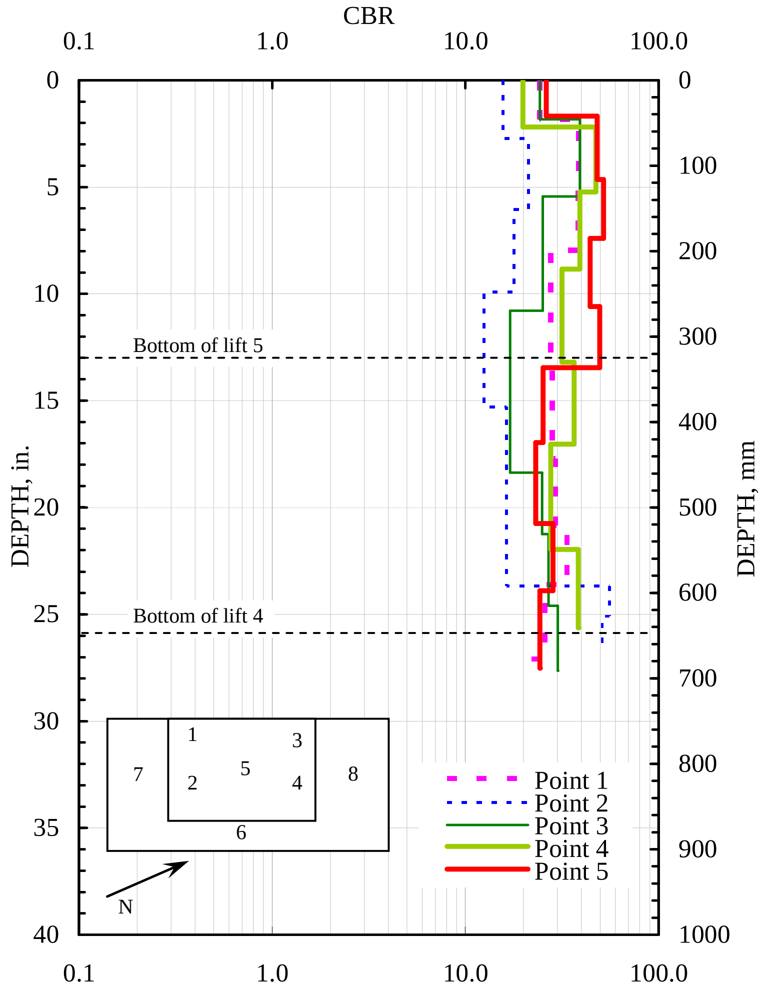


Figure 76 -- CBR profiles from the DCP tests for test points within Trench A for Lift 5 on August 10, 2007

On August 10, 2007, the DCP was conducted at the three points in soil adjacent to the trench. No bulk soil sample was collected of the soil adjacent to the trench for classification. The average calculated CBR value within the trench was 13%. The depth of the CBR profiles ranged from 25 inches to 26 inches. The average CBR value for the top two feet was 13%. For the top two feet the CBR values ranged from 6% to 10%. At the surface, the CBR values ranged from 3% to 28. At test points 7 and 8, the CBR values decreased with depth. This Figure does not provide conclusive evidence that compacting around the trench improved the

DCP values. Figure 77 plots the CBR values for each point as a function of depth for the test points outside the trench.

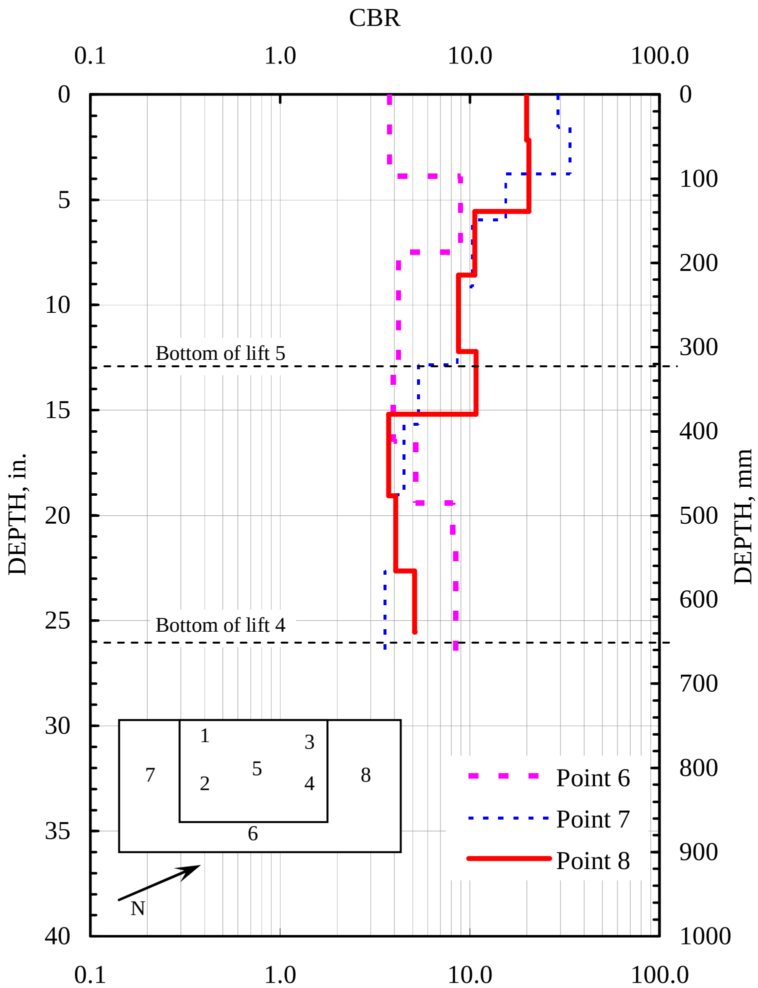


Figure 77 -- CBR profiles from the DCP tests for test points in the soil adjacent to Trench A on August 10, 2007

Clegg Hammer Test Results

Table 26 summarizes the impact values from the Clegg Hammer tests for Trench A and Table 27 summarizes the CBR results from the Clegg Hammer tests for Trench A. The CBR value for each point was calculated using the equations in Section 2.0 and then the CBR values were averaged.

For the fifth (top), the average CBR value for the test points within the trench was 85%. The CBR values ranged from 58% to 112%. For the soil adjacent to the trench, the average CBR value for the test points within the trench was 42%. The CBR values ranged from 17% to 60%. When comparing the CBR values from the Clegg Hammer and the DCP tests, the CBR values from the Clegg Hammer are higher than from the DCP test.

Table 26 -- Impact value results from the Clegg Hammer tests for Trench A

Location	Number of test points	Average IV reading	Min/Max IV readings	Standard deviation	Coefficient of variance (%)
Third lift	5	N/A	N/A	N/A	N/A
Fifth lift test points within the trench tested on August 8, 2007	5	N/A	N/A	N/A	N/A
Fifth lift test points within the trench tested on August 10, 2007	5	33.8	27.6 / 40.0	6.0	17.7
Test points in the soil adjacent to the trench on August 10, 2007	3	22.1	13.0 / 28.0	80.0	36.2

Table 27 -- CBR results from the Clegg Hammer tests for Trench A

Location	Number of test points	Average CBR (%)	Min/Max CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	5	N/A	N/A	N/A	N/A
Fifth lift test points within the trench tested on August 8, 2007	5	N/A	N/A	N/A	N/A
Fifth lift test points within the trench tested on August 10, 2007	5	85	58 / 112	22.3	31.2
Test points in the soil adjacent to the trench on August 10, 2007	3	42	17 / 60	22.3	53.0

Table 28 shows a comparison of the DCP test results and the Clegg Hammer test results and the percent difference between the two tests. The large difference was the result of the DCP testing measuring the CBR values for the about 25 inches of backfill. While the Clegg Hammer measures the CBR values for the top 4 to 6 inches of the backfill, which experiences better compaction. For the second comparison of the DCP test results to Clegg Hammer test results, the CBR was recalculated for the top 4 to 6 inches of the DCP profiles.

The recalculation of CBR values for the top 4 to 6 inches of the DCP profiles reduced the difference between the Clegg Hammer and DCP test results (136.1% to 80.8% and 223.1% to 121.0%). Although the difference between the CBR values calculated from the Clegg Hammer and from the DCP test for the top 4 to 6 inches are smaller than those reported for the total depth of the lift, the values are still significantly (greater than 5%) higher. This could be the attributed to the empirical correlations used to calculated CBR values from the Clegg Hammer and DCP tests which were developed for general soil types and not specifically for 3/8-inch minus limestone.

Table 28 -- Average CBR results from the DCP and Clegg Hammer tests for Trench A

Location	Average CBR values from Clegg Hammer (%)	Average CBR values from DCP for the depth of the profile (approximately 2 feet) (%)	Percent difference between the Clegg Hammer and the DCP test for the depth of the profile (%)	CBR values from DCP for the upper most 4 to 6 inches profile (%)	Percent difference between the Clegg Hammer and the DCP test for the upper most 4 to 6 inches (%)
Third lift	---	8	---		
Fifth lift test points within the trench tested on August 8, 2007	---	17	---	22.8	---
Fifth lift test points within the trench tested on August 10, 2007	85	36	136.1	47	80.8
Test points in the soil adjacent to the trench on August 10, 2007	42	13	223.1	19	121.0

FWD Test Results

To monitor the long-term performance of the constructed trenches, FWD testing was conducted. The FWD tests were performed to detect the "zone of influence" around the trench and associated weakening of the pavement and subgrade as well as to monitor the change in trench response as a function of time. The surveys were conducted to measure the overall settlement of the trenches.

The Iowa DOT performed FWD testing for Trench A on November 5, 2007 (three months after construction). This was the only FWD testing performed on the trench at the completion of these thesis. Figure 72 shows the field-testing locations for Trench A and Figure 78 shows the FWD testing locations for Trench A. On Figure 79, the deflections for the 6 kip and 15 kip loads were labeled for key points. The backfill had a stiffer response than the surrounding subgrade soil. This is the result of the lift's thicknesses being smaller. The "zone of influence" was still present for Trench A. Figure 79 shows that the "zone of influence" was detected on the northeast side of the trench with no distinct "zone of influence" on the southwest side. Based on Figures 45 and 46 (see above) construction equipment was located on both the northeast and southwest sides of the trench. This was the result of the soil 10 feet further southwest of the trench having a softer response than the soil to the northeast of the trench as seen by soil on the higher deflection of 60.32 mils for the soil southwest of the trench and 45.05 mils of the soil northeast the trench. The deflection from the 15 kip load at the center of the trench was 20.36 mils. The average deflection at the inside edges of the trench was 29.10 mils. The backfill within the trench was placed stiffer than the surrounding subgrade soils. The deflections of the subgrade within the trench averaged 26.09 mils. The surrounding soil that was compacted before the placement of the patch had an average deflection of 40.32 mils compared with the soil at FWD test points 2 and 8, which were outside the area that was compacted; whose average deflection was 57.56 mils. This showed that compacting the soil surrounding the trench increased its strength. However, the compaction did not extend far enough to eliminate the "zone of influence" that formed when the lateral support was lost during excavation. The "zone of influence" extended about 4 feet beyond the trench (2 feet beyond the patch limits).

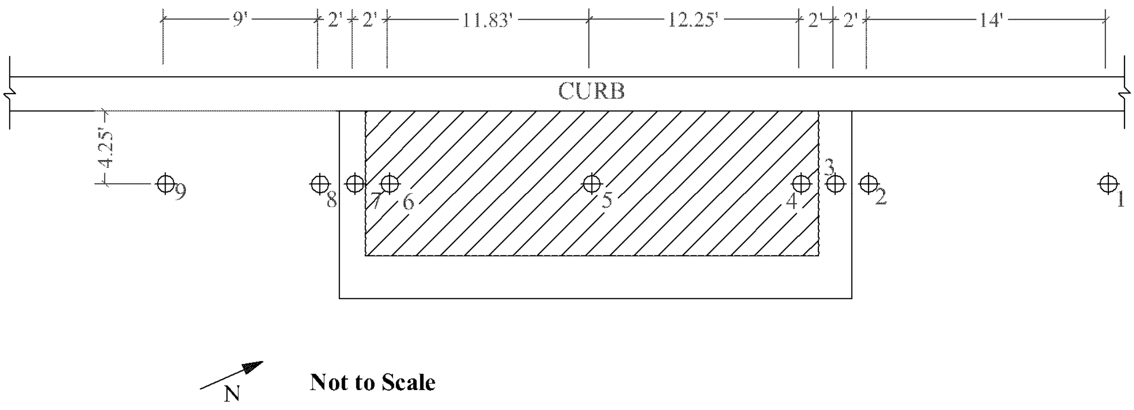


Figure 78 -- FWD testing locations for Trench A

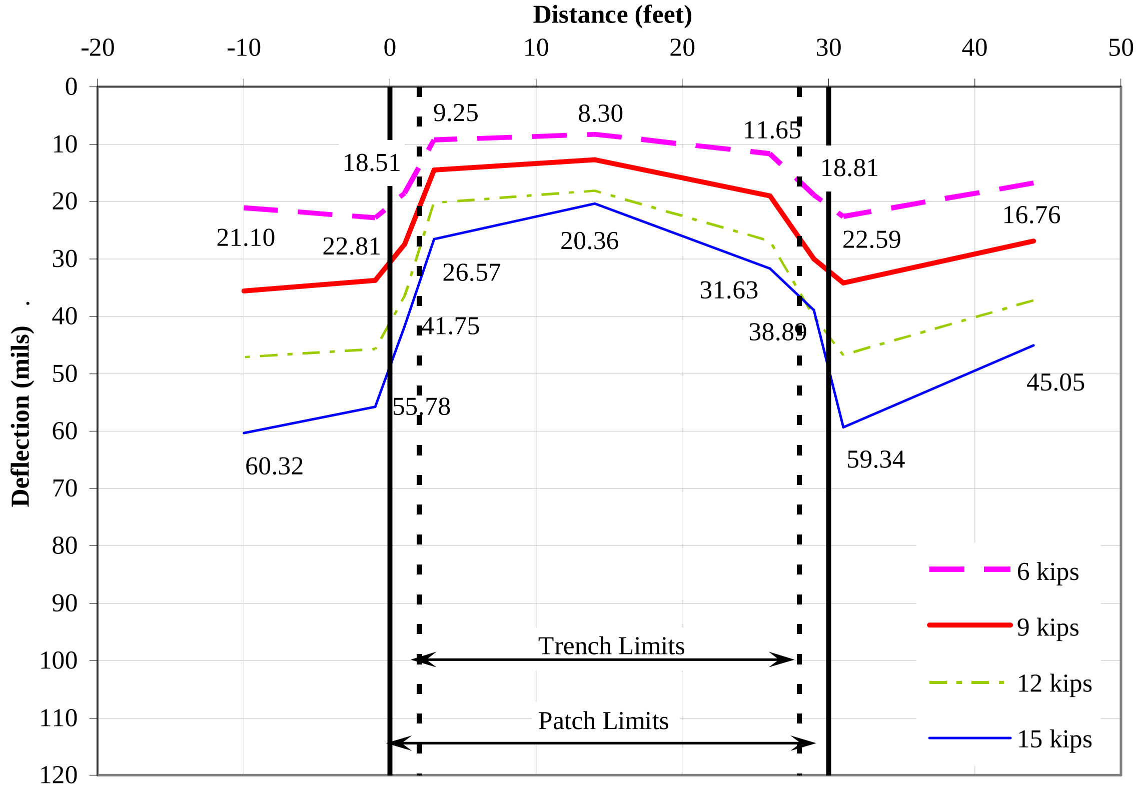


Figure 79 -- FWD testing results for Trench A testing in November 5, 2007

Post Construction Elevation Survey

The post construction elevations were measured and 3D surfaces were constructed using survey data collected on September 25, 2007 and March 20, 2008.

A grid was placed across the trenches and then selected grid lines were extended outward from the trenches onto the original pavement. The extended lines were to monitor the settlement of the original pavement. The elevations were determined at each point.

The results from the surveys were used to construct a 3-dimensional surface. When the future surveys are completed, additional surfaces can be constructed to monitor the pavement settlement.

At all sites, the dome bolt on fire hydrants were used for the benchmark (see Figure 80), which was given an elevation of 100 feet.

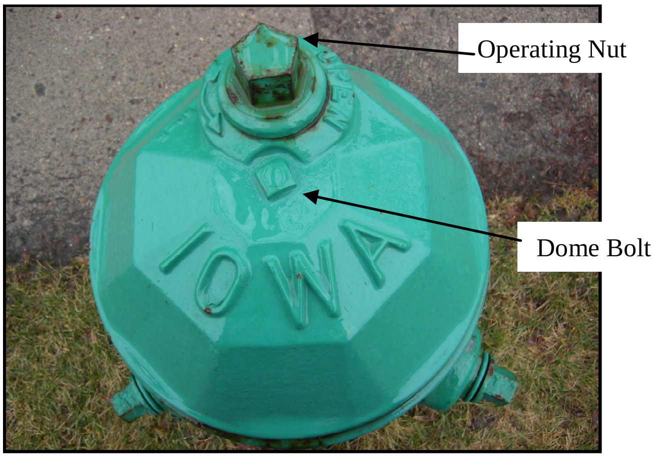


Figure 80 -- Dome bolt on fire hydrants

Trench A was surveyed with 43 grid points. The hydrant was located northeast of the restoration at the intersection of McKinley Drive and Van Buren Avenue. From the elevation survey on September 25, 2007, the highest pavement elevation was 94.90 feet (survey point 33) and the minimum elevation was 94.2 feet (survey point 6) across the pavement patch. The average elevation was 94.56 feet. From the elevation survey on March 20, 2008, the highest pavement elevation was 94.94 feet (survey point 33) and the minimum elevation was 94.23 feet (survey point 6) and the average elevation was 94.60 feet.

When the patch was originally placed the difference between the highest and lowest elevation was 8.4 inches. During the March survey, the difference between the highest and lowest elevation increased to 8.54 inches. The patches had increased the difference between the highest and lowest elevations. The maximum uplift was 0.72 inches at survey points 2 and 13. The minimum uplift was 0.12 inches at survey points 26, 30 and 35.

Figure 81 shows the location of the grid points for Trench A and Figure 82 shows the pavement surface for Trench A from September 25, 2007. Figure 83 shows the settlement as a function of time for the trench.

Figure 84 shows the elevation profiles and the settlement of Trench A. This shows that the southwest edge of the trench experienced more uplift than other portions of the trench.

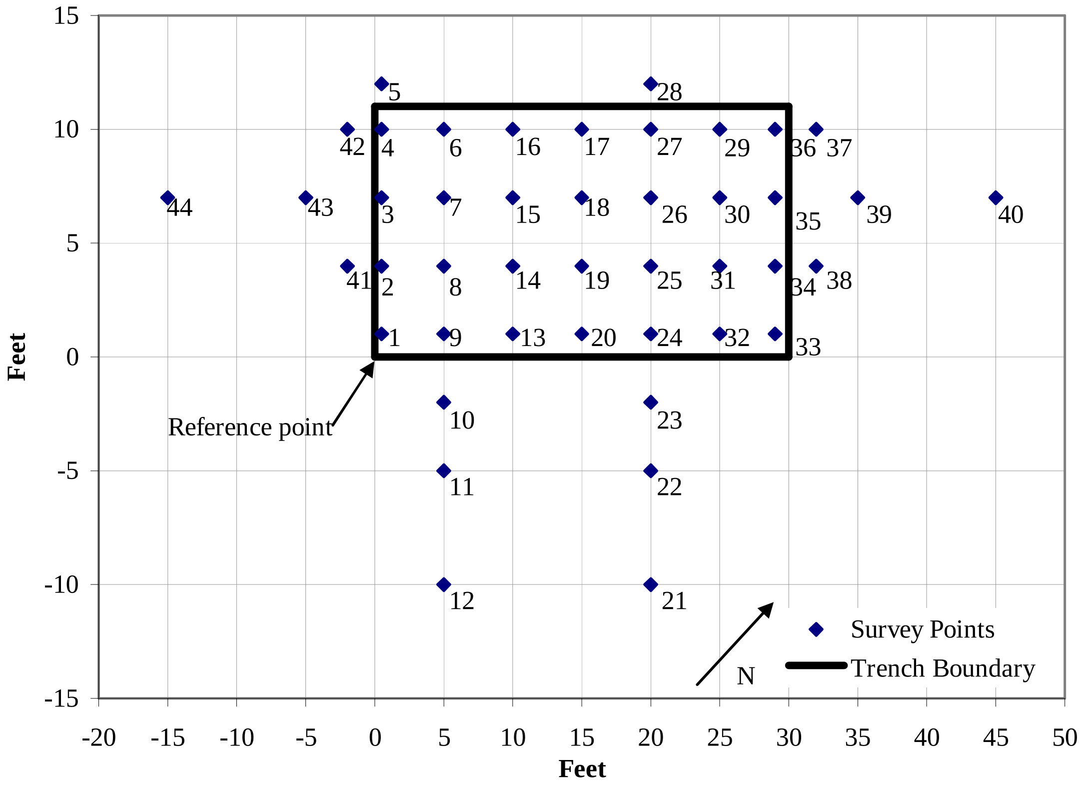


Figure 81 –Trench A survey locations

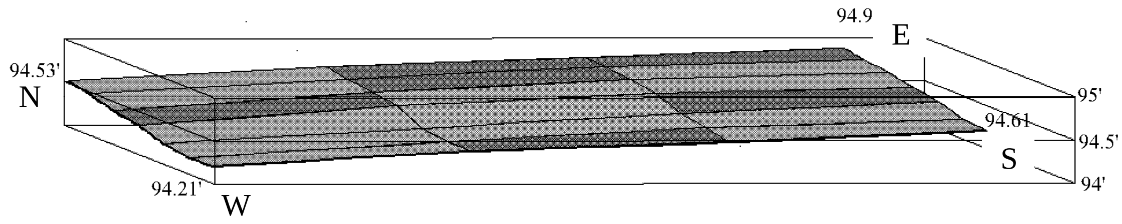


Figure 82 – Pavement surface elevations of Trench A

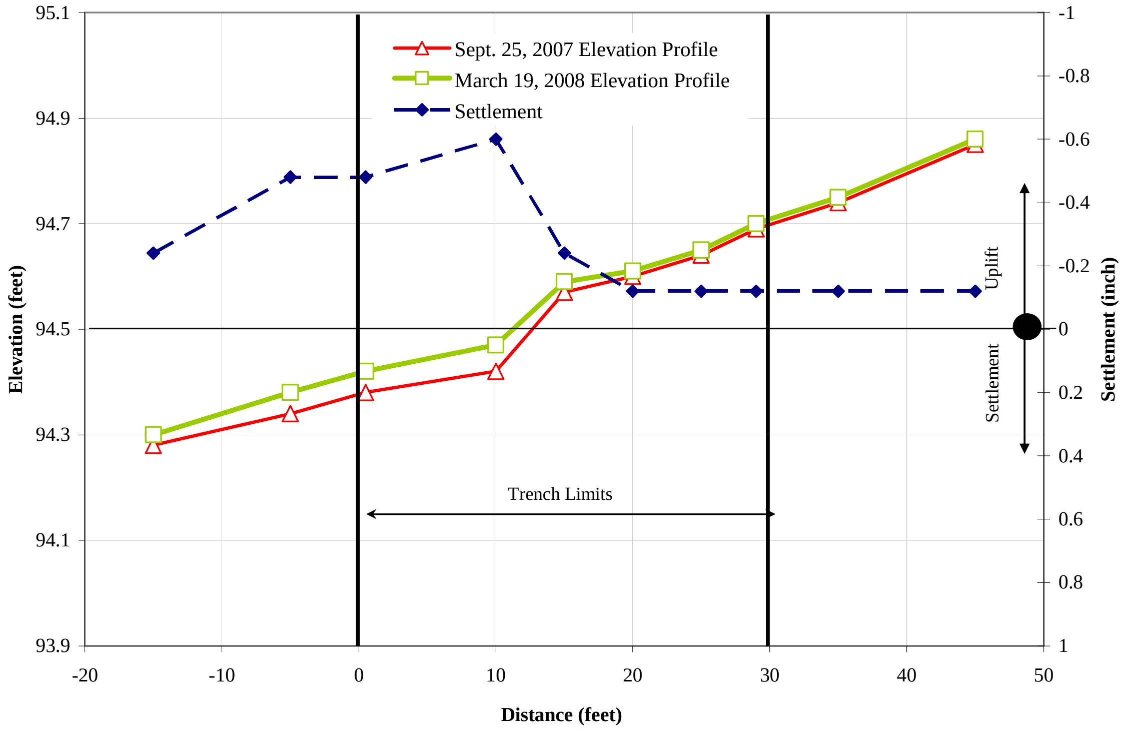


Figure 83 – Settlement along the centerline of the trench

Comparison of Field-testing Results to Long Term Monitoring

Figure 84 shows the FWD test locations with the field-testing locations superimposed and the averaged field-testing data for test points near the FWD test locations. At the center of the trench, the backfill and patch system provided the stiffest response (20.36 mils for the 15 kip load). This point corresponded to test point 5 for the field tests performed during construction. At test point 5, the average dry unit weight was 127.4 pcf and the CBR for the top two to three feet was 22%. At the southwest edge of the trench, test points 1 and 2 were in the vicinity of FWD test point number 6. The average dry unit weight was 120.4 pcf and the CBR value was 25% for the depth of the profiles (top two feet). At the northeast edge of the patch, test points 3 and 4 were near the FWD test point 4. The average dry unit weight was 123.1 pcf and the average CBR value was 12% for the top two feet.

For the test points located in the soil adjacent to the trench, (test points 7 and 8 in Figure 84), the deflections were 41.17 mils at test point 7 and 38.89 mils test point 8. The average dry unit weights at tests points 7 and 8 were 125.4 pcf at a moisture content of 9.7% and 122.3 pcf at a moisture content of 5.0%, respectively.

The CBR values calculated for the top two feet of the backfill and subgrade soil correspond with the response of the FWD response of patch for Trench A. The same conclusion can be drawn when comparing the CBR values for the backfill and the subgrade soil surrounding the trench, where DCP show an average value of 36% for backfill and the surrounding soil had an average value of 13%.

Further, to explore the relationship between FWD deflections and field-testing data, Figure 85 plots the CBR values and the dry unit weights measured in the field for the top two feet of the trench. This shows that there is no correlation between the FWD deflections and the field-testing results.

In Figure 86, the settlements measured between the summer survey after construction and the early survey were plotted with the FWD deflections. This shows that on the southwest side of the uplift occurred where there were smaller deflections and on the northeast side of the trench, the uplift was smaller than on the southwest side of the trench. This does not provide a correlation between settlement and FWD testing results.

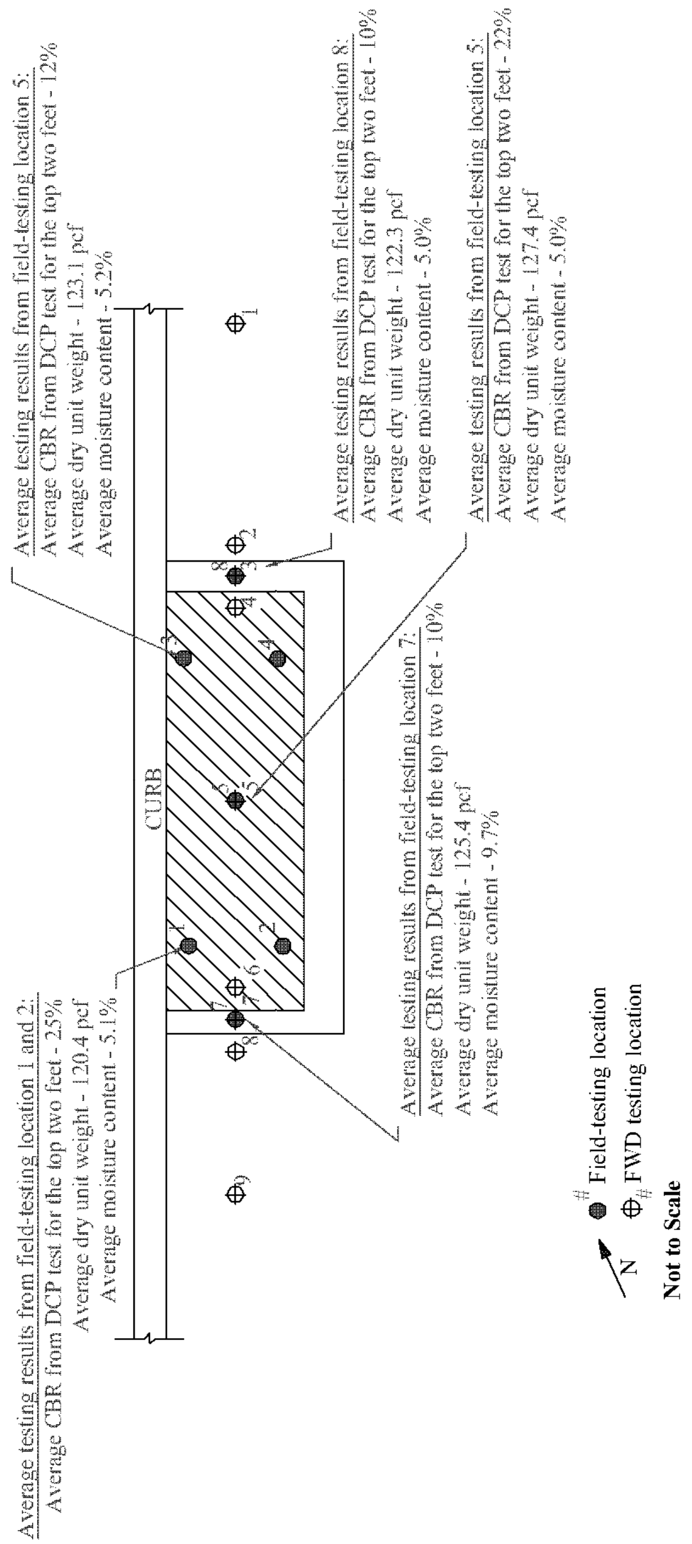


Figure 84 – Comparison of CBR values, dry unit weights and FWD testing results

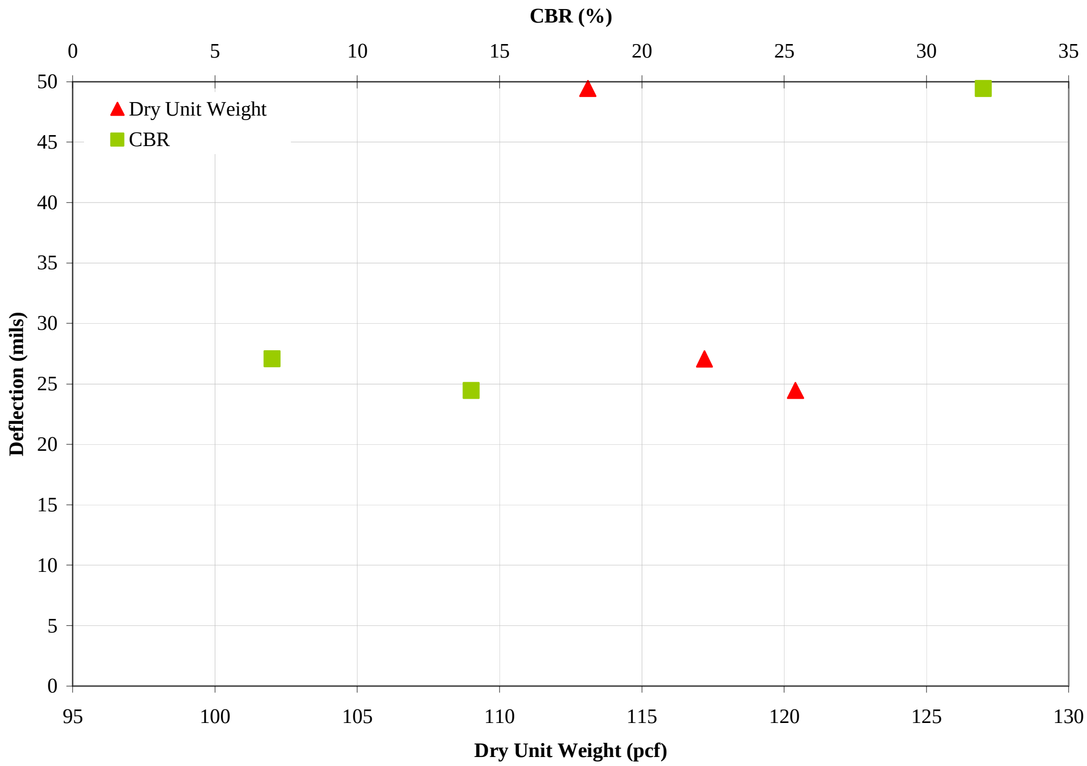


Figure 85 - Comparison of CBR and dry unit weights to the deflections from the 15 kip FWD

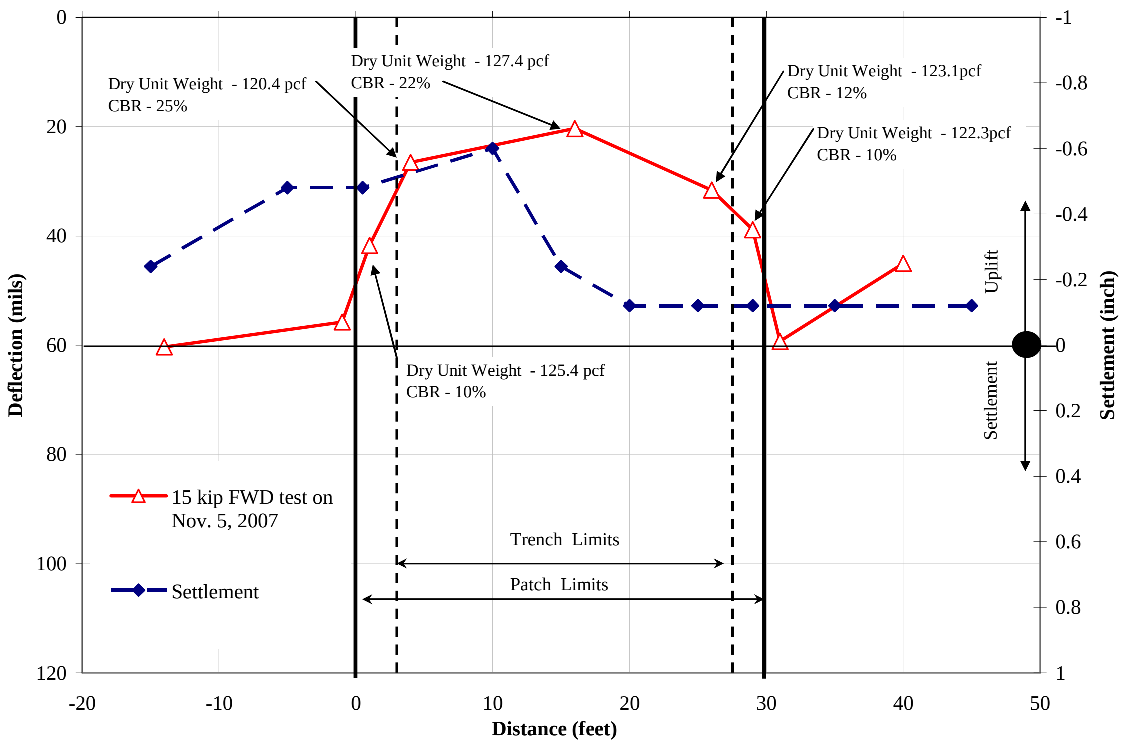


Figure 86 – 15 kip FWD test with settlement for Trench A

Key Results

1. The granular backfill was placed at moisture contents ranging from 5.0% to 8.3%, which was mostly within the bulking moisture content range (i.e., 4.0% to 8.0%) for 3/8-inch minus backfill.
2. The dry unit weights of the backfill within the trench ranged from 107.8 pcf to 124.7 pcf. For the soil surrounding the trench, the dry units ranged from 122.3 pcf to 122.5 pcf.
3. The relative density of the 3/8-inch minus backfill within the trench ranged from 34% to 65% between the loose and dense compaction.
4. The CBR values calculated from the DCP test for the top two feet ranged from 20% at test point 2 along the southwest edge of the trench to 35% at test point 5 at the center of the trench. The CBR values of the surrounding soil for the

top two feet ranged from 13% at test point 6 along the southeast edge of the patch to 21% at test point 7 along the southwest edge of the patch.

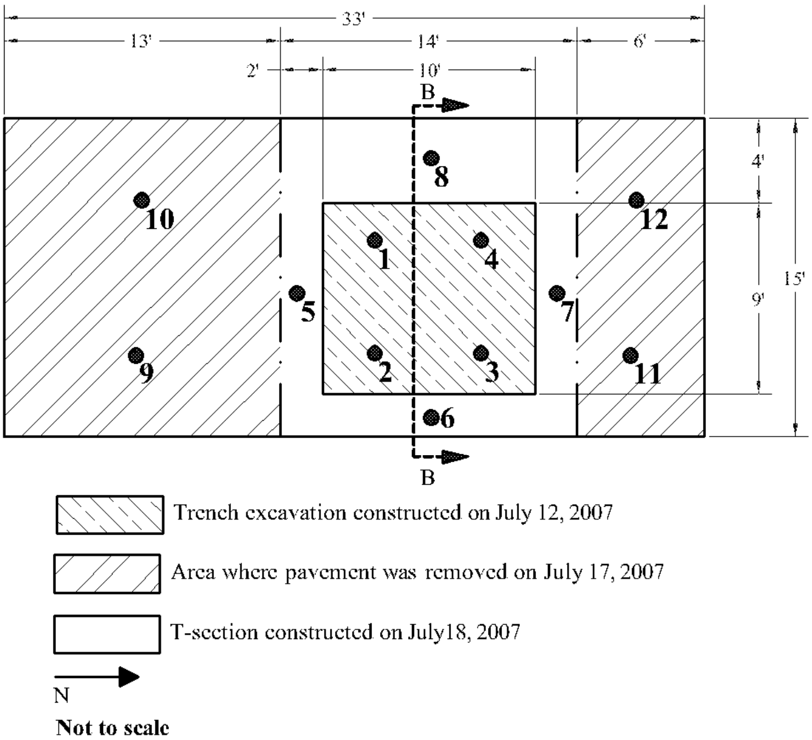
5. Leaving the trench open for two days resulted in a 1.7% increase in the density of the backfill.
6. The FWD response and measured deflections across the trench and adjacent soil reflected the CBR values using the DCP test. Locations with higher CBR values show smaller deflections on the FWD test.
7. The FWD testing indicated that the “zone of influence” extended 4 feet beyond the trench (2 feet beyond the patch). Compacting the soil around the trench helped recover some of the strength lost when the trench was excavated; however, the compaction needs to be extended further to 4 feet beyond the excavation which is greater than the recommended distance provide in Schaefer et al.. (2 feet).
8. Compared with the trenches constructed in Phase I, the backfill provided a stiffer response; however, the “zone of influence” was still present.

4.5.2 - Recommended Trench B

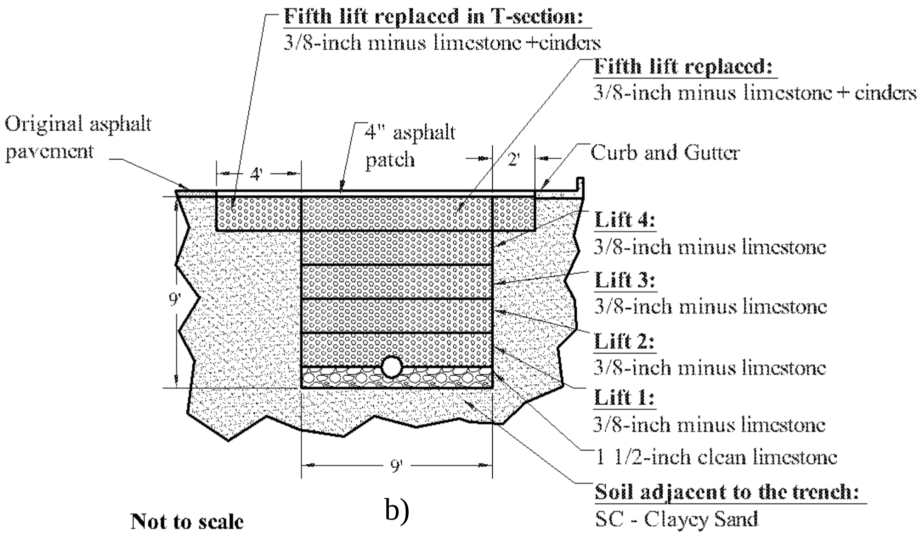
At this site, Nuclear Gauge, Clegg Hammer, and DCP tests were performed during construction. On July 13, 2007, the tests were performed at four test points (points 1, 2, 3, and 4 on Figure 87) within the trench on the third and fifth (top) lifts. The trench was then left open for five days. On July 17, 2007, the pavement around the trench was removed. The pavement was removed beyond the extent of the trench, because the surrounding pavement was damaged.

On July 18, 2007, the fifth lift was removed during the construction of the T-section. The T-section was completely backfilled with one lift. The replaced fifth (top) lift was tested at the same four points as the previous lifts as well as at four additional points (5, 6, 7, and 8 on Figure 87) in the T-section for a total of eight points. A patch was not placed on the trench on July 18, 2007 because of time constraints. During the evening of July 18, 2007, the City of Ames received 1½ inches of rain. The trench was left open for an additional seven days after the T-section was constructed to allow the backfill to dry.

On July 25, 2007, the replaced fifth lift was retested at the same eight points used in previous testing as well as four additional points (9, 10, 11, and 12 on Figure 87) in the soil adjacent to the trench, for a total of 12 test points. This testing was performed to compare the changes in the backfill properties before it rained to after it rained and dried for seven days.



a)



b)

Figure 87 –Testing locations for Trench B, a) Plan view with test points, and b) Cross-section B-B

Nuclear Density Test Results

Table 29 summarizes the dry unit weights from the Nuclear Density testing results for Trench B and Table 30 summarizes the moisture content results from the Nuclear Density tests for Trench B. The probe depth was six inches.

Figure 88 plots the relative density test results for 3/8- inch minus limestone with the average field-testing results for lifts 3 and 5. Figures 89 and 90 plot the Standard Proctor testing results for Backfill No. 1 and Backfill No. 2 along with fielding testing results for the replaced fifth (top) lift on July 18, 2007 and July 25, 2007.

The third and fifth lift was constructed with 3/8-inch minus limestone. The limestone backfill was classified as SP-SM – poorly graded sand and silt. The typical values of dry unit weights from NAVFAC were 110 pcf to 130 pcf with optimum moisture contents ranging from 9% to 16%.

The replaced fifth (top) lift was constructed with two mixtures of 3/8-inch minus limestone, Backfill No. 1 and Backfill No. 2. The backfill was classified as SC – Clayey sand. The typical range of maximum dry unit weights after compaction according to NAVFAC was 105 pcf to 125 pcf with an optimum moisture content ranging from 11% to 19%.

The third lift for the four test points (1, 2, 3, and 4) had an average moisture content of 6.6% and a dry unit weight of 112.9 pcf. According to NAVFAC (1986) in Table 5, the dry unit weights were within the maximum dry unit weights for a SP-SM soil. Lift 3 was placed at 41% relative density. This material was medium dense. The moisture content of the backfill was below the range of optimum moisture contents suggested by NAVFAC. According to laboratory testing, all backfill was placed at upper boundary of the bulking moisture content.

The fifth (top) lift four test points had an average dry unit weight of 118.2 pcf and a moisture content of 5.1%. According to NAVFAC, the dry unit weights were within the suggested maximum dry unit weights after compaction. This backfill was medium dense. The moisture content during placement was below the suggested range of optimum moisture contents for compaction. Based on laboratory testing, the fifth lift was compacted to 54%

relative density. The backfill was placed within the bulking moisture content found in laboratory testing. This lift was removed when the T-section was constructed.

The four test points for the replaced fifth (top) lift within the trench *before it rained* had an average dry unit weight of 107.5 pcf and an average moisture content of 7.9%. According to NAVFAC in Table 5, average dry unit weight of the backfill was within typical values for clayey sands. Because it is not known, if Backfill No. 1 or Backfill No. 2 was used in this area, two relative compactions were calculated. For Backfill No. 1, the field placement was 96.8% of the Standard Proctor and for Backfill No. 2; the field placement was 87.5% for the Standard Proctor. The moisture content during placement was below the suggested optimum moisture content suggested by NAVFAC. Based on laboratory testing the moisture content during placement of the backfill was below optimum water content.

The four test points in the T-sections of the replaced fifth (top) lift *before it rained* (July 18, 2007) had an average moisture content of 10.3% and an average dry unit weight of 102.5 pcf. According to NAVFAC in Table 5 the dry unit weights were below the typical range of values. Based on laboratory results the backfill was placed at 92% of the Standard Proctor Backfill No. 1 and 83% of the Standard Proctor for Backfill No. 2. The moisture content was below typical moisture content given by NAVFAC. The moisture content of the backfill at placement was below the optimum moisture content found with the Standard Proctor test.

The four test points within the trench for the replaced fifth (top) lift *after* it rained (July 25, 2007) had an average moisture content of 7.0% and an average dry unit weight of 115.3 pcf. According to NAVFAC in Table 5, the dry unit weights were below the suggested values given by NAVFAC. Based on laboratory testing results, for Backfill No. 1 the field placement was at 104% of Standard Proctor and for Backfill No. 2, the field placement was at 94% of Standard Proctor. This was an increase from 96.8% and 87.5% of Standard Proctor from before it rained for Backfill No. 1 and Backfill No. 2, respectively. The total increase in the dry unit weights was 7.3%. This increase was larger than in other trenches, which were left open for several days. This large increase was the result of the trench becoming saturated during the rain event. The moisture content at placement was also below the suggested moisture contents for optimum compaction from NAVFAC in Table 5.

The four test points in the T-section of the replaced fifth (top) lift *after it rained* had an average moisture content of 7.9% and an average dry unit weight of 108.7 pcf. The dry unit weights measured in the trench was within the suggested range provided by NAVFAC in Table 5. Based on laboratory testing results, the backfill was placed at 98% of Standard Proctor for Backfill No. 1 and 88.5% of Standard Proctor for Backfill No. 2. These values were an increase of 92% and 83% of Standard Proctor for Backfill No. 1 and Backfill No. 2, respectively. The total increase in the dry unit weight was 7.2% for the backfill within the trench. The moisture content after it rained and dried out were below the suggested values provided by NAVFAC.

The four test points in the soil adjacent to the trench *after it rained* had an average moisture content of 8.6% and an average dry unit weight of 117.5 pcf. The soil was at 91% of Standard Proctor. Leaving the trench open resulted in a 6.1% increase in the dry unit weight of the soil in the T-section. The moisture content was below the optimum moisture content. However, the soil adjacent to the trench was consolidating over time (since the road was previously paved).

Table 29 -- Dry unit weight results from the Nuclear Density tests for Trench B

Location	Number of test points	Average dry unit weight (pcf)	Min/Max dry unit weight from field-testing (pcf)	Relative density (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	112.9	110.0 / 116.0	41.16	2.3	2.0
Fifth lift	4	118.2	114.9 / 120.9	54.35	1.7	1.4
Replaced fifth lift *before rain event* for tests within the trench	4	107.5	102.6 / 117.7	N/A	3.8	3.5
Replaced fifth lift *before rain event* for tests in the T-section	4	102.5	97.0 / 107.9	N/A	4.7	4.6
Replaced fifth lift *after rain event* for tests within the trench	4	115.3	111.0 / 117.0	N/A	2.4	2.0
Replaced fifth lift *after rain event* for tests in the T-section	4	108.7	106.7 / 110.8	N/A	2.1	1.9
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	117.5	115.1 / 123.0	N/A	3.7	3.1

Table 20 -- Moisture content results from the Nuclear Density tests for Trench B

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Bulking moisture content (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	6.6	6.2 / 7.1	4.0 to 8.0	2.3	34.8
Fifth lift	4	5.1	4.8 / 5.5	4.0 to 8.0	0.2	2.9
Replaced fifth lift *before rain event* for tests within the trench	4	7.9	6.0 / 9.1	N/A	1.4	17.6
Replaced fifth lift *before rain event* for tests in the T-section	4	10.3	8.0 / 12.6	N/A	2.0	18.4
Replaced fifth lift *after rain event* for tests within the trench	4	7.0	5.6 / 8.2	N/A	1.2	17.1
Replaced fifth lift *after rain event* for tests in the T-section	4	7.9	7.4 / 8.6	N/A	0.5	6.8
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	8.6	7.0 / 11.0	N/A	1.7	19.8

Figure 88 shows the relative density testing with the field-testing results. The figure shows that both lifts constructed with 3/8-inch minus limestone were at a medium density. The circles indicate the lift the various test points were on and shows that the test points were similar across the trench.

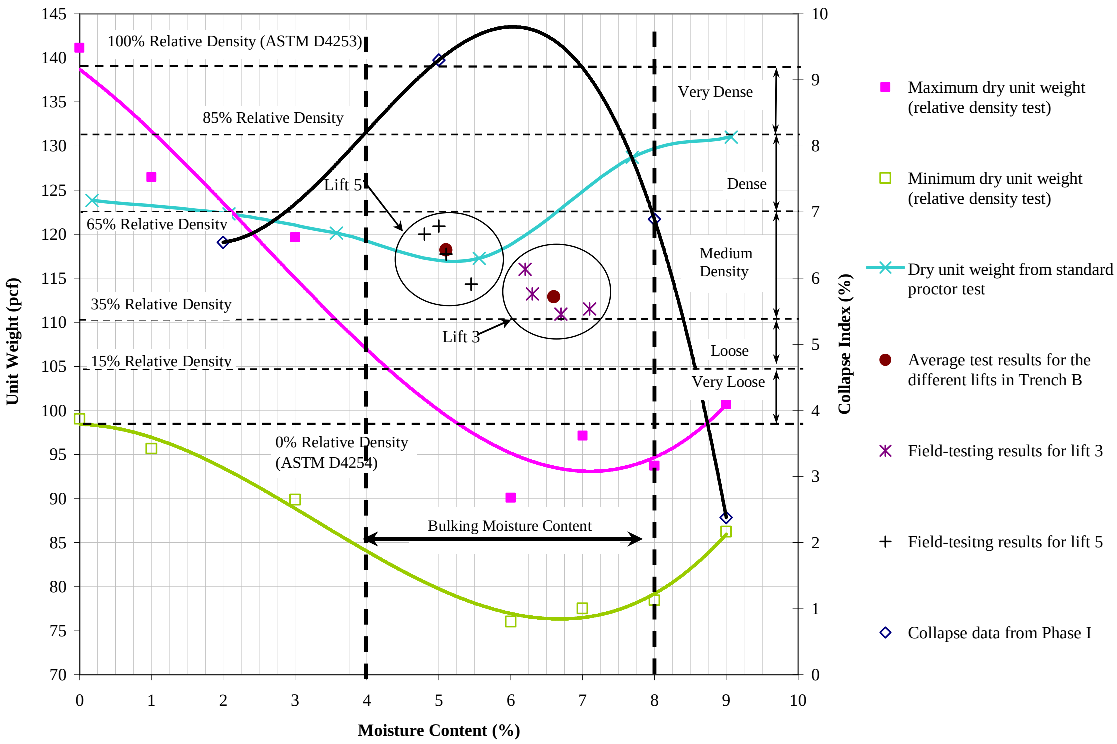


Figure 88 -- Relative density testing results for 3/8-inch minus limestone with field-testing results for Trench B

Figure 89 shows, that all of the lifts constructed with a mixture of 3/8 - inch minus limestone and cinders, were placed below the optimum moisture content and were not compacted to the maximum dry unit weight. Also, shown on the graph are the average results from the two test dates. The Figure shows that the dry unit weights increased because of the rain events. For quick reference, the 90% and 95% Standard Proctor density for the averaged results were plotted.

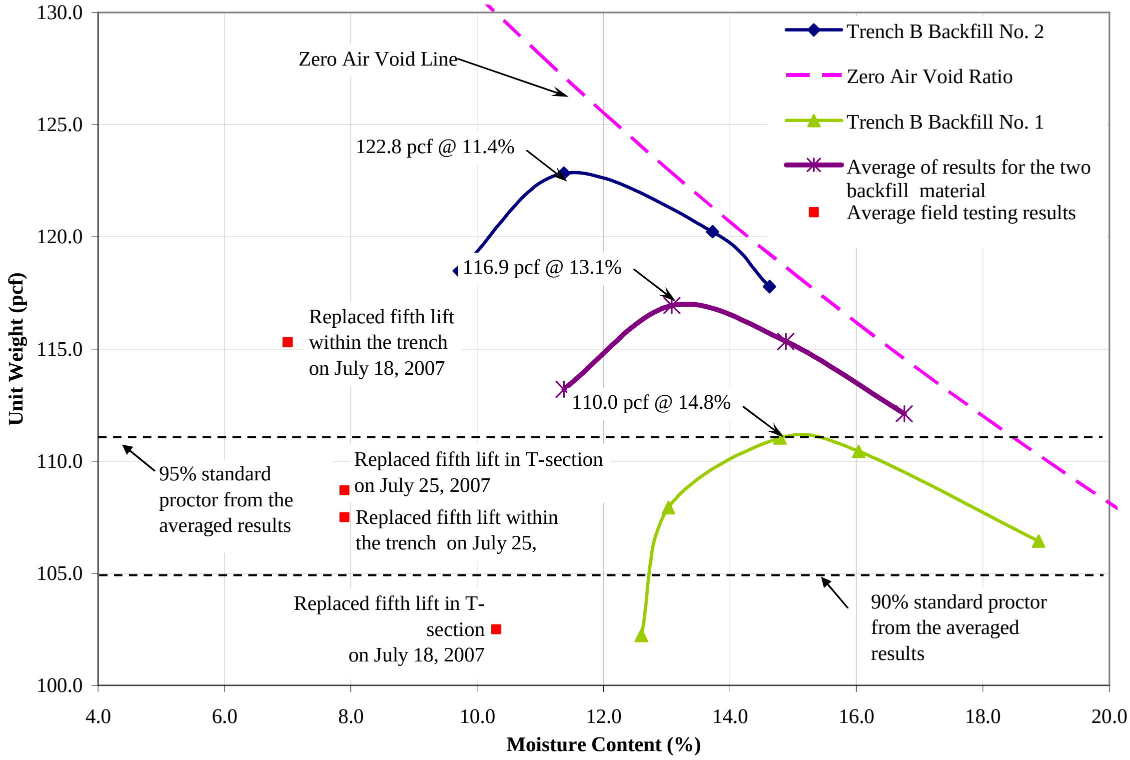


Figure 89 -- Standard Proctor test results for Backfill No. 1 and Backfill No.2 with the averaged results and the field-testing results from Trench B

Figure 90 shows the Standard Proctor test results for soil excavated from the trench. The bulk sample collected from the soil excavated from the trench was assumed representative of the soil surrounding the trench. On the plot were the dry unit weights measured in the field for the top lift (points 9, 10, 11, and 12). Points 9 and 10 plotted below the 90% Standard Proctor line.

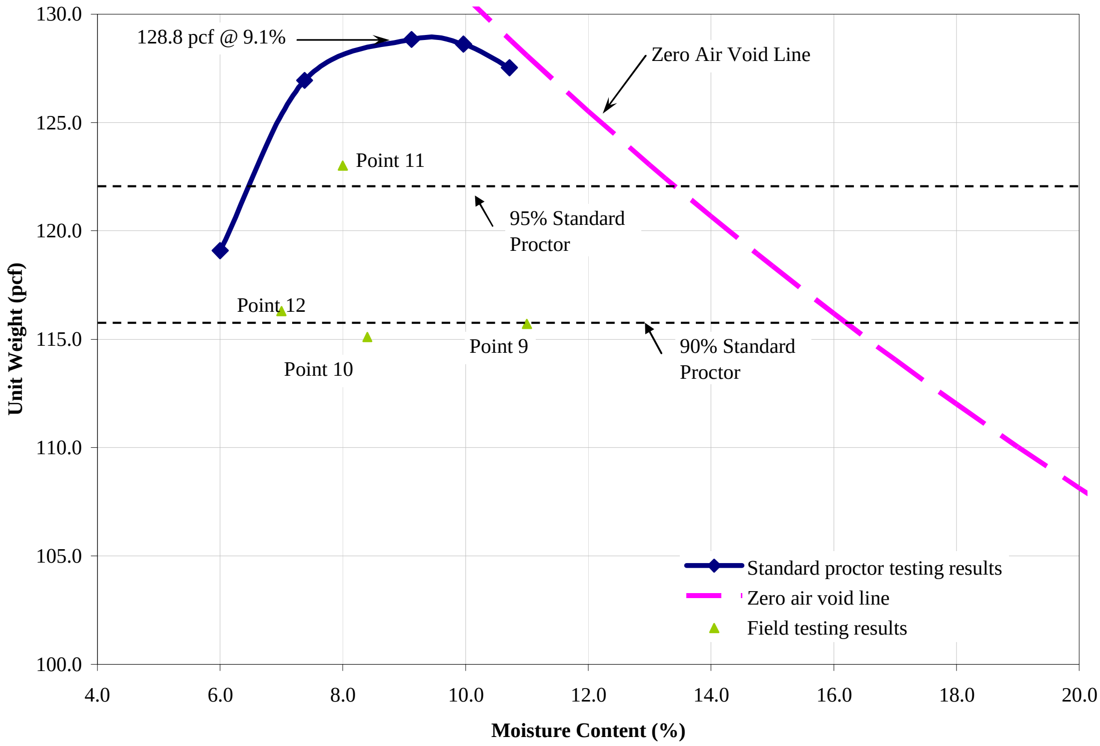


Figure 90 -- Standard Proctor test results for the soil excavated from Trench B with field-testing results for the soil adjacent to the trench

DCP Test Results

Table 30 summarizes the DCPI readings from the DCP tests for Trench B and Table 31 summarizes the average CBR results from the DCP tests for Trench B.

The third and fifth lift was constructed with 3/8-inch minus limestone. The limestone backfill was classified as SP-SM – poorly graded sand and silt. The typical range of CBR values from NAVFAC (1986), in Table 5 were 10% to 40%.

The replaced fifth (top) lift was constructed with two mixtures of 3/8-inch minus limestone, Backfill No. 1 and Backfill No. 2. The backfill was classified as SC – Clayey sand. The typical range of CBR values from NAVFAC (1986), in Table 5 were 5% to 20%.

Table 30 -- DCPI results from the DCP tests for Trench B

Location	Number of test points	Average depth of tests (inches)	Average DCPI	Standard deviation	Coefficient of variance (%)
Third lift	4	27.0	15.0	7.3	48.7
Fifth lift	4	26.7	16.6	9.0	54.2
Replaced fifth lift *before rain event* for tests within the trench	4	27.5	24.6	16.4	66.7
Replaced fifth lift *before rain event* for tests in the T-section	4	31.1	61.8	18.2	29.4
Replaced fifth lift *after rain event* for tests within the trench	4	27.1	56.2	49.3	87.7
Replaced fifth lift *after rain event* for tests in the T-section	4	33.6	48.0	53.6	111.7
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	32.3	63.2	34.7	54.9

Table 31 – Average CBR results from the DCP tests for Trench B

Location	Number of test points	Average depth of tests (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	27.0	16	7.4	46.3
Fifth lift	4	26.7	20	8.0	40.0
Replaced fifth lift *before rain event* for tests within the trench	4	27.5	15	11.9	79.3
Replaced fifth lift *before rain event* for tests in the T-section	4	31.1	4	1.7	42.5
Replaced fifth lift *after rain event* for tests within the trench	4	27.1	8	48.7	608.7
Replaced fifth lift *after rain event* for tests in the T-section	4	33.6	1	2.6	260.0
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	32.3	4	3.6	90.0

Figure 91 plots the CBR values for four-test point as a function of depth for the third lift. The third lift had an average CBR value from the DCP was 16% for an average depth of 27.0 inches. At the surface, the CBR values ranged from 4% to 8%. These were below and at the lower boundary of typical range of values given by NAVFAC. At the termination of the tests, the CBR values ranged from 15% to 26%. These values were within the typical values provided by NAVFAC. As the DCP test penetrated into the lift, the CBR values increased. The CBR profile for the third lift for the four tests points, increased slightly with depth. This indicates that there was an increase in strength with depth. The four test points had lower standard deviations and were banded over a narrow range throughout the depth of the test.

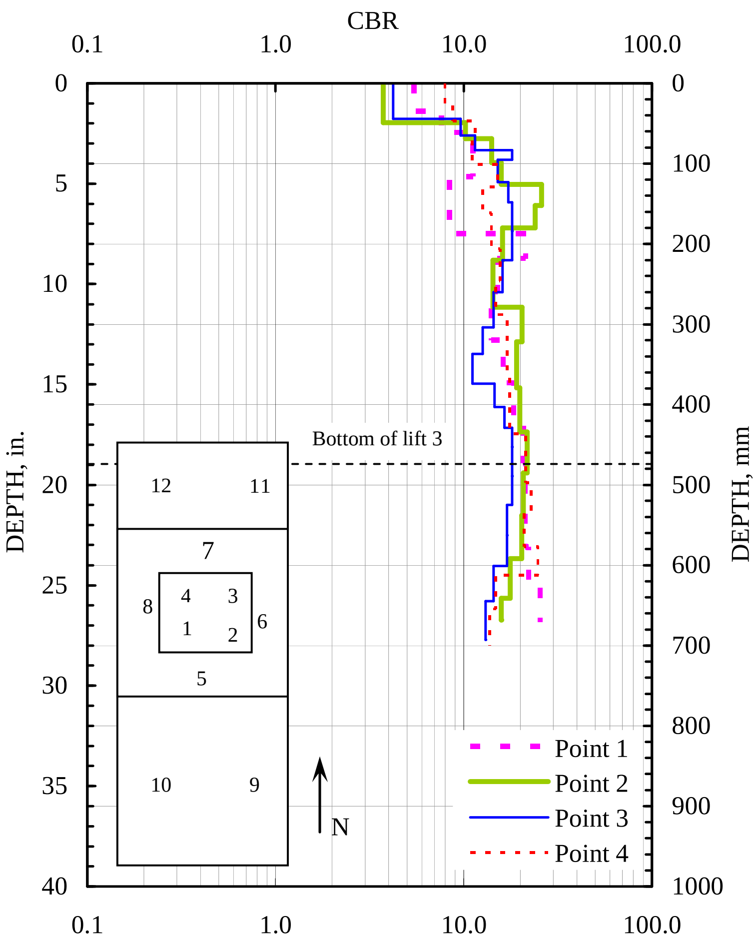


Figure 91 -- CBR profiles from DCP tests for lift 3 for Trench B

Figure 92 plots the calculated CBR values as function of depth for the fifth lift. The DCP test had an average CBR value of 20%. At the surface, the CBR values ranged from 3% to 6%. These CBR values were below the typical CBR values from NAVFAC. At the termination of the tests, the CBR values ranged from 6% to 23%. These CBR values were within and above the typical CBR values from NSVFAC. The CBR values increased with depth and each test point followed the same generalized pattern over the depth of the profile.

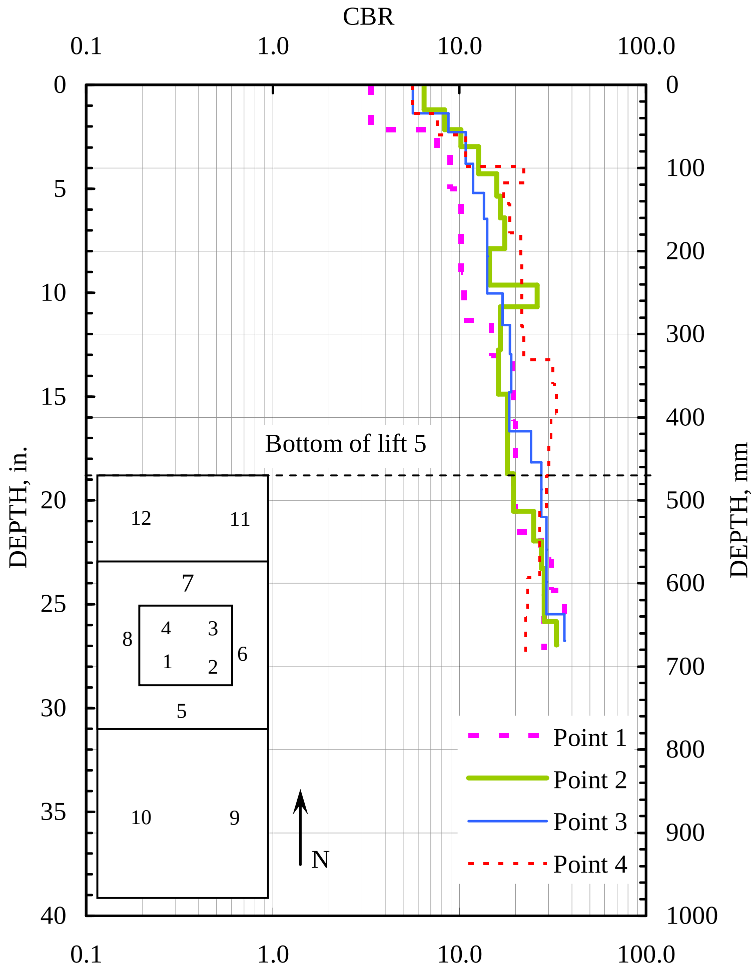


Figure 92 -- CBR profiles from DCP tests for lift 5 for Trench B

Figure 93 shows the profiles of the CBR values for replaced fifth lift *before* it rained for the four test points located within the trench. The DCP test had an average CBR value of 15% for 27.5 inches. The CBR values at the surface ranged from 3% to 6%. These values were below the typical values given by NAVFAC. The CBR values at the termination of the test ranged from 23% to 46%. These values were within the typical CBR values from NAVFAC. For test point 3, at a depth of 1 to 2 inches, the CBR values spiked. The spike was the result of the Penetrometer encountering a larger piece of aggregate. The low standard deviation shows that through depth of the profile the CBR values were banded and followed a similar pattern.

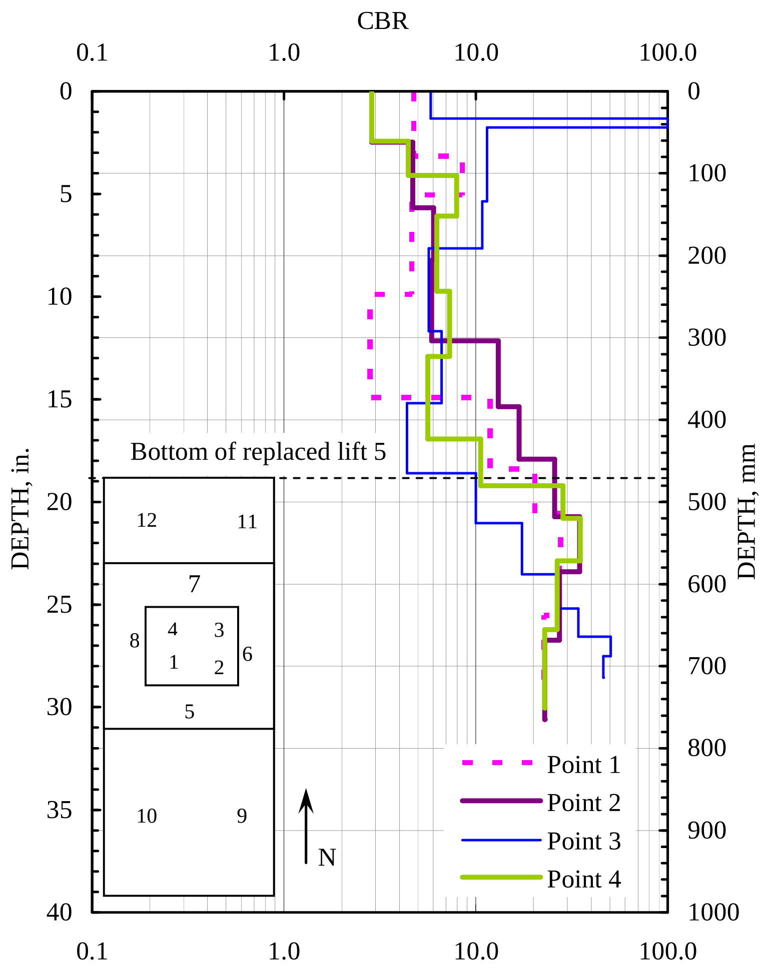


Figure 93 -- CBR profiles from the DCP tests for Trench B for test points within the trench for the replaced fifth lift before it rained

Figure 94 shows the profiles of the CBR values for the four test points located in the T-section before it rained. The replaced fifth lift *before* it rained had an average CBR value of 3% for 30.1 inches. At the surface, the CBR values ranged 2% to 3%. These values were below and at the lower boundary of CBR values for clayey sand from NAVFAC. At the termination of the test, the CBR values ranged from 2% to 3%. The profiles of the CBR values did not show an increase in strength. The standard deviation shows that the profiles were banded and do not vary with depth.

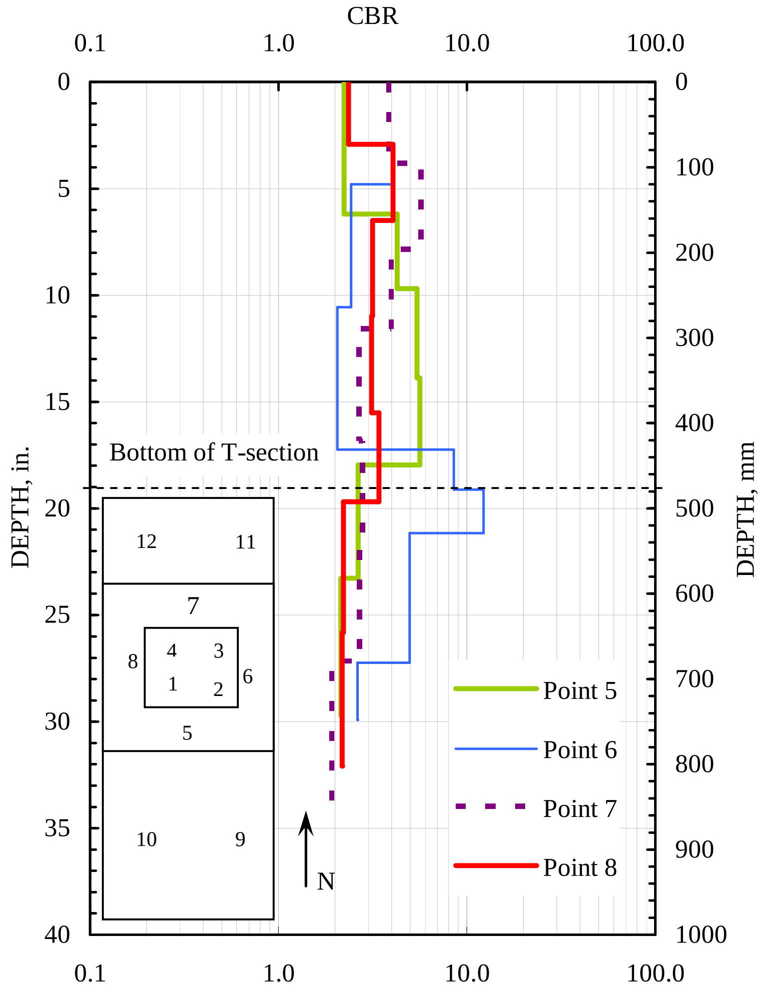


Figure 94 -- CBR profiles from the DCP tests for Trench B for test points in the T-section before it rained

Figure 95 plots the CBR values for each point as a function of depth for the test four points within the trench for the replaced fifth lift *after it rained*. The four test points in the T-section region had an average CBR of 8% for 27.1 inches. At the surface of the lift the CBR values ranged from 1% to 3%. These values were below the typical CBR values from NAVFAC. At the termination of the tests, the CBR values were ranged from 13% to 20%. Test point 3 encountered a zone of increased strength at about 4 to 6 inches. This anomaly could be the result of encountering a larger piece of aggregate in the backfill. The CBR profile for the test points within the trench had the same shape throughout the depth of the profile.

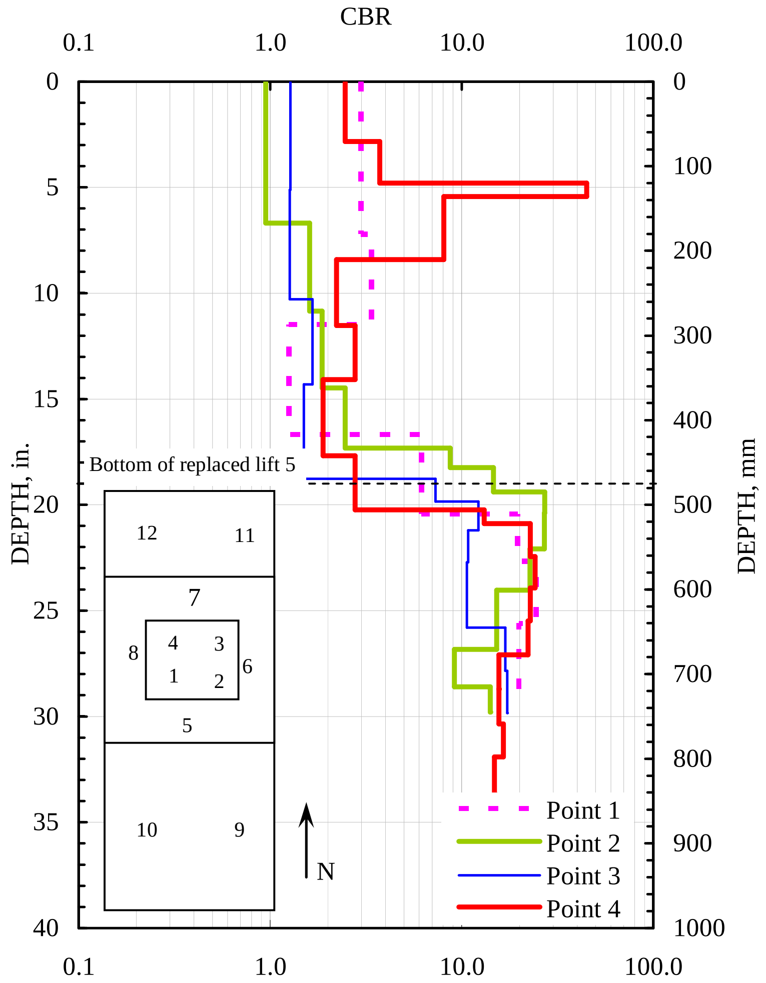


Figure 95 -- CBR profiles from the DCP tests for Trench B for test points within the trench for replaced lift 5 after it rained

Figure 96 plots the CBR profiles for the four test points as a function of depth for the test points in the T-section for the final lift *after it rained*. For the replaced fifth lift after it rained, the four the test points in the T-section had an average CBR value of 1% for 33.6 inches. At the surface of lift, the CBR values ranged from 1% to 2%. These values were below the typical values for clayey sand by NAVFAC. At the termination of the test, the CBR values ranged from 1% to 5%. The CBR profiles for test points 5 and 6 increased for until a depth of about 20 inches. After 20 inches, the CBR profiles decreased. This shows that the compaction had no affect deeper in the lift.

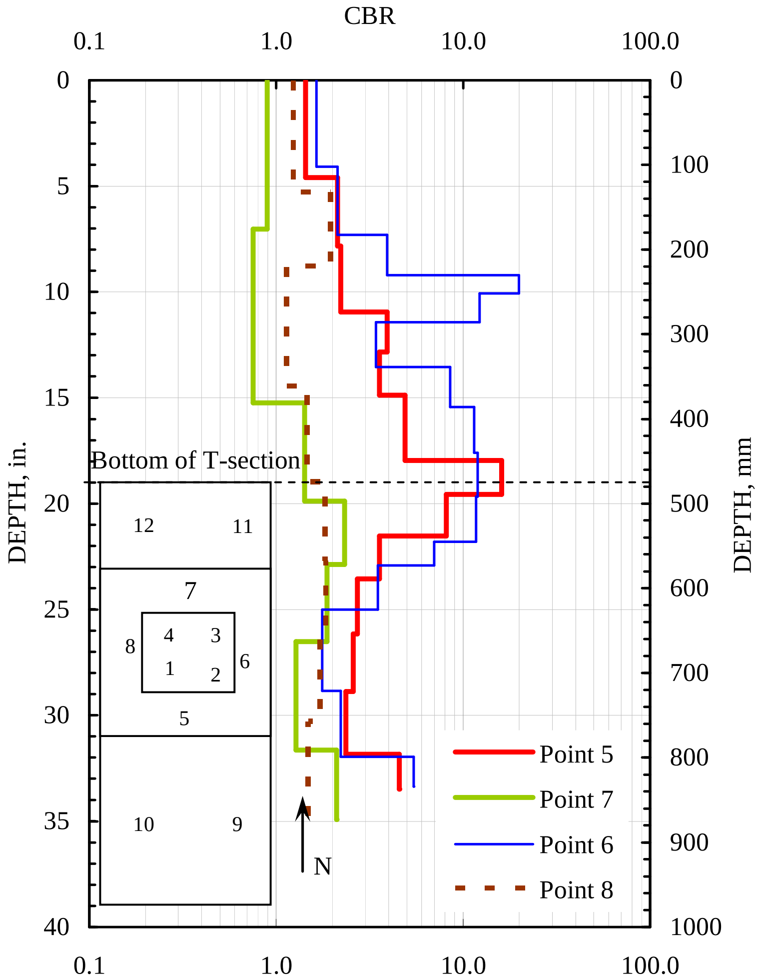


Figure 96 -- CBR profiles from the DCP tests for Trench B for test points in the T-section for replaced lift 5 after it rained

Figure 97 plots the CBR values for each point as they vary with depth for the test points in soil adjacent to the trench *after it rained*. After it rained, the four the test points in the soil adjacent to the trench had an average calculated CBR value of 4% for 32.3 inches. At the surface the CBR values ranged from 1% to 5%. At the termination of the tests, the CBR values ranged from 2% to 8%. These values were below the typical values for well graded sand.

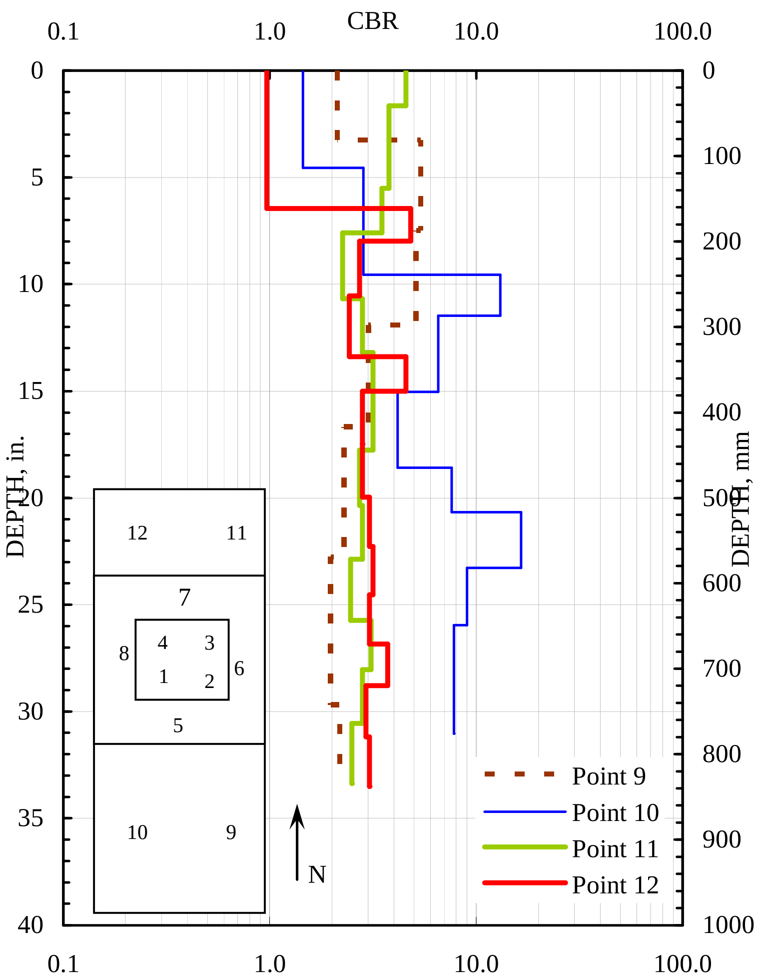


Figure 97 -- CBR profiles from the DCP tests for the four test points in soil adjacent to the trench after it rained

Clegg Hammer Test Results

Table 32 summarizes the impact values from the Clegg Hammer tests for Trench B and Table 33 summarizes the CBR results from the Clegg Hammer tests for Trench B. The CBR value for each point was calculated using Equation 2-3 and then the CBR values were averaged.

The third lift had a Clegg Hammer CBR values ranged from 8% to 25% with an average CBR value of 14%. The fifth lift had CBR values ranging from 15% to 42% with an average CBR value of 28%. These CBR values were within the typical values from NAVFAC.

The CBR values for the replaced fifth lift *before* the rain event for four test points within the trench ranged from 3% to 6% with an average CBR value of 5%. The CBR values for the four test points in the T-section ranged from 3% to 5% with the average CBR value of 4%. These CBR values were below and within the typical values from NAVFAC for clayey sand.

The CBR values for the four test points within the trench *after* the rain event ranged from 6% to 21% with an average of 15%. The CBR values for the four test points T-section *after* it rained ranged from 5% to 8% with an average value of 7%. These values were within the values provided by NAVFAC. These values increased from *before* it rained. This was the result of the trench becoming saturated and the backfill increasing in density.

The four test points in the soil adjacent to the trench *after* it rained the CBR values ranged from 5% to 15% with an average calculated CBR value of 11%. These values were below the typical values from NAVFAC.

Table 32 -- Impact value results from the Clegg Hammer tests for Trench B

Location	Number of test points	Average IV reading	Min/Max IV readings	Standard deviation	Coefficient of variance (%)
Third lift	4	14.2	7.9 / 16.6	3.8	33.6
Fifth lift	4	17.9	12.0 / 22.9	5.9	32.9
Replaced fifth lift *before rain event* for tests within the trench	4	4.8	3.9 / 6.4	1.6	33.3
Replaced fifth lift *before rain event* for tests in the T-section	4	4.2	3.4 / 5.1	0.7	16.7
Replaced fifth lift *after rain event* for tests within the trench	4	8.8	5.8 / 15.1	4.3	48.9
Replaced fifth lift *after rain event* for tests in the T-section	4	6.6	7.3 / 5.1	1.2	17.1
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	9.2	5.1 / 12.0	3.1	33.7

Table 33 -- CBR results from the Clegg Hammer tests for Trench B

Location	Number of test points	Average CBR (%)	Min/Max CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	14	8 / 25	7.3	51.3
Fifth lift	4	28	15 / 42	14.8	50.4
Replaced fifth lift *before rain event* for tests within the trench	4	5	3 / 6	1.6	34.6
Replaced fifth lift *before rain event* for tests in the T-section	4	4	3/ 5	0.7	17.5
Replaced fifth lift *after rain event* for tests within the trench	4	15	6 / 21	7.4	74.0
Replaced fifth lift *after rain event* for tests in the T-section	4	7	5 / 8	1.2	17.1
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	11	5 / 15	4.5	40.9

To compare the CBR values obtained from the DCP and Clegg Hammer tests, Table 34 was made. The first comparison was to compare the average CBR values from the Clegg Hammer with the average CBR value over the depth of the DCP test for each lift. The difference between CBR values from the Clegg Hammer tests and the DCP test ranged from 0% to 400%. The large difference was the result of the Clegg Hammer testing only the surface of the lift. To compensate for the difference in the thickness of the material being tested, to 4 to 6 inches of the DCP test results were averaged together. Since the Clegg Hammer was broken in the fall 2007 and it is not known when the Clegg Hammer broke, the difference in the between the Clegg Hammer results and the DCP tests were subject to debate.

Table 34 -- CBR comparison for Trench B

Location	Average CBR values from Clegg Hammer (%)	Average CBR values from DCP for the depth of the profile (%)	Percent difference between the Clegg Hammer and the DCP test for the depth of the profile (%)	CBR values from DCP for the upper most 4 to 6 inches profile (%)	Percent difference between the Clegg Hammer and the DCP test for the upper most 4 to 6 inches (%)
Third lift	14	16	12.5	5	180
Fifth lift	28	20	40	5	460
Replaced fifth lift *before rain event* for tests within the trench	5	15	66.7	16	68.7
Replaced fifth lift *before rain event* for tests in the T-section	4	4	0	3	25.0
Replaced fifth lift *after rain event* for tests within the trench	15	8	87.5	2	650
Replaced fifth lift *after rain event* for tests in the T-section	5	1	400	1	400
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	11	4	175	2	450

FWD Test Results

Trench B was not tested because a car was parked on the trench for the two days that the Iowa DOT FWD equipment was available for testing.

Post Construction Elevation Survey

The post construction elevations were measured and 3D surfaces were constructed using survey data collected on July 30, 2007 and March 19, 2008.

Trench B was surveyed with 51 grid points (see Figure 98). The benchmark was located at the dome bolt (see Figure 80) located on the fire hydrant northwest of the trench at the intersection of 9th Street and Carroll. Figure 99 shows the pavement surface for Trench B when it was surveyed on July 30, 2007. The 3D model of the surface shows that the patch when it was originally placed was not level. Patch it ungulates across the surface. The highest elevation was 97.62 feet (survey point 41) and the lowest elevation was 97.11 feet (survey point 10). This was a difference of 6.12 inches at the placement of the patch. From the survey on March 19, 2008, the highest elevation was 97.88 feet (survey point 41) and the minimum elevation was 97.02 feet (survey point 44). The difference in the highest and lowest elevation was 6.72 inches.

The average uplift at the site was 0.01 inches and the maximum settlement was 5.64 inches at survey points 43 and 44. The maximum settlement occurred on the north edge of the patch in the soil adjacent to the trench. Figure 100 shows the elevation profiles of the trench and the settlement profile of the trench. This Figure shows that the settlement occurred at the north edge of the trench.

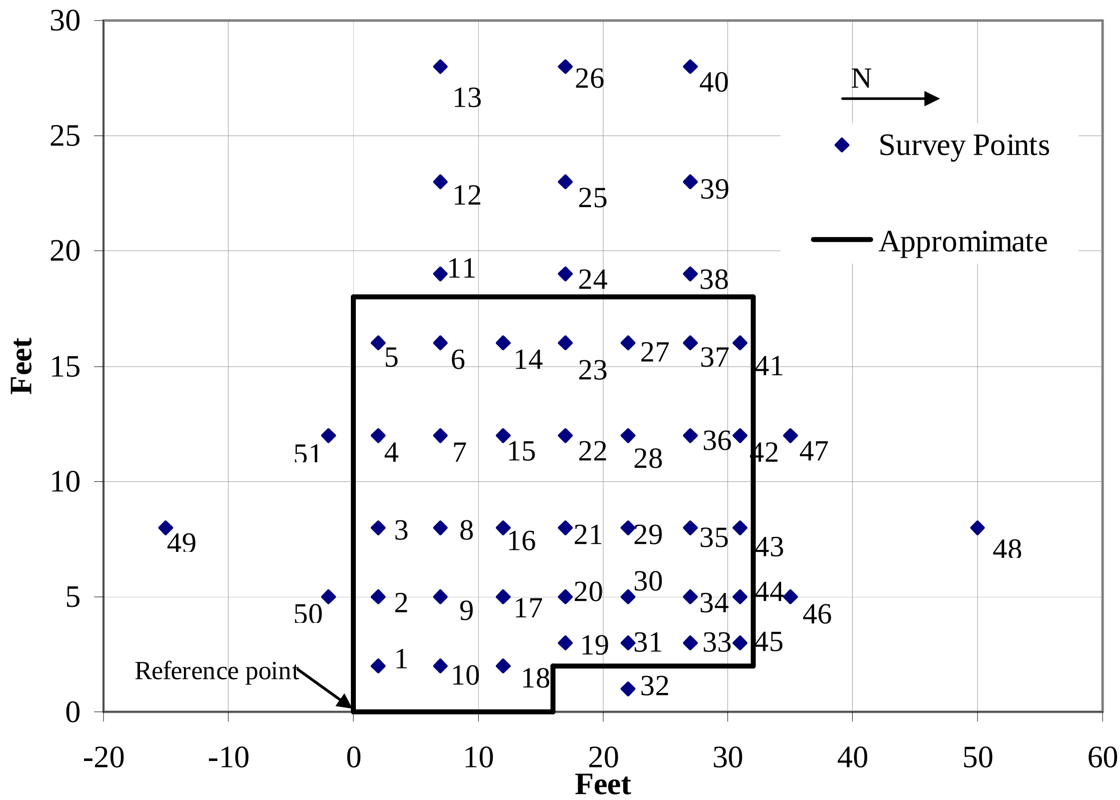


Figure 98 -- Survey points for Trench B

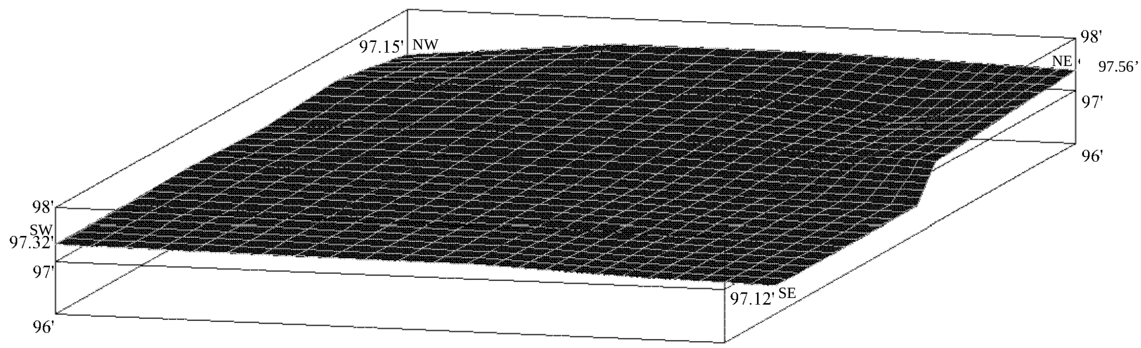


Figure 99 -- Pavement surface elevations of Trench B

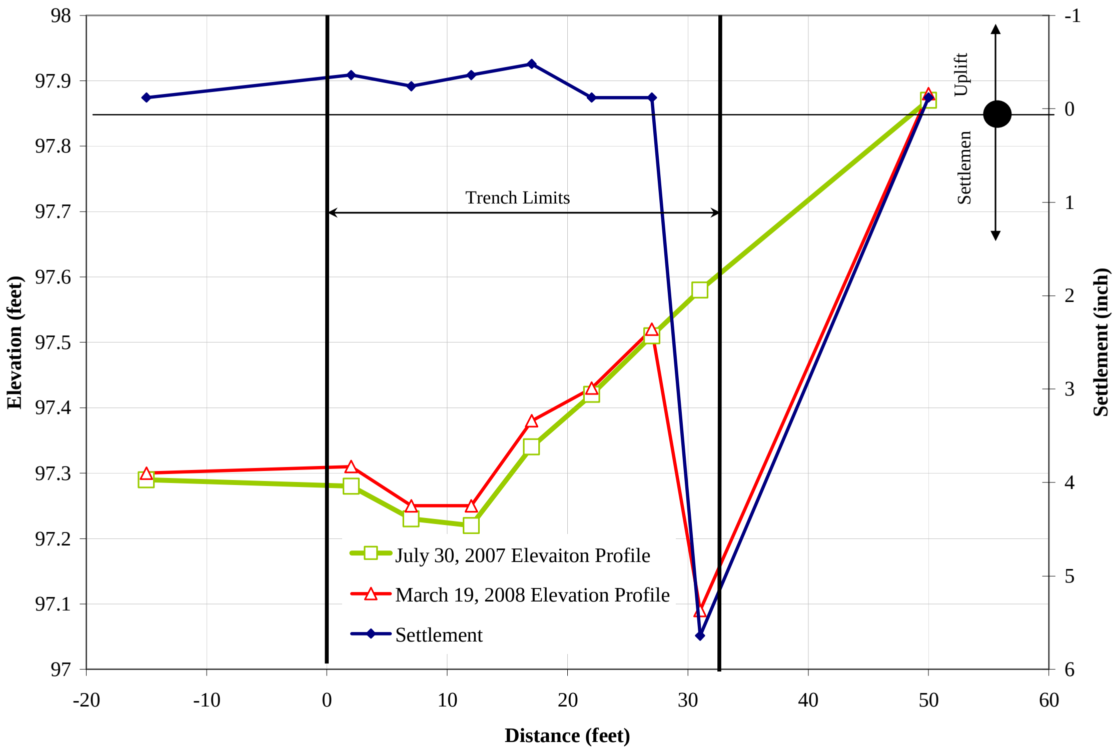


Figure 100 -- Settlement along centerline of Trench B

Comparison of Field-testing Results to Long Term Monitoring

On the north side of the trench where the maximum settlement occurred, test points 11 and 12 (see Figure 87) were within the vicinity. The dry unit weights at points 11 and 12 were 123.0 pcf and 116.3 pcf, respectively. The CBR values at the surface were 5% and 1% for points 11 and 12, respectively. The average CBR values for the depth of the test for both test points was 3%. These soils were extremely weak even though, the densities for the soils were within the accepted range from NAVFAC. The CBR values from the DCP tests on the north edge of the trench at test point 11 showed a softening response with depth and test point 12 showed the stiffness increasing with depth.

Key Results

- The 3/8-inch minus limestone used in lift 3 was placed within the bulking moisture content of 5.0% to 9.0%.
- During initial compaction of the upper lifts, the moisture content of the backfill was below the optimum moisture content from the Standard Proctor test. Compacting the soil below the optimum moisture content causes the trench to be more susceptible to collapse behavior.
- The 1½ inches of rain saturated the backfill and caused the density to increase.
- When the patch was originally placed there was a 6.12 inches difference in elevation across the patch.
- The maximum settlement was 5.64 inches and occurred in the soil adjacent to the trench where there were low CBR values.
- The location of the maximum settlement corresponded to the location of lower dry unit weights and CBR values.

4.5.3 - Recommended Trench C

Nuclear Density, Clegg Hammer, and DCP tests were performed on the Trench C located at McKinley Drive and Fillmore Avenue. Four different test points were used to test the third and final lifts on May 18, 2005. The locations of test points for the third and final lift are shown on Figure 101.

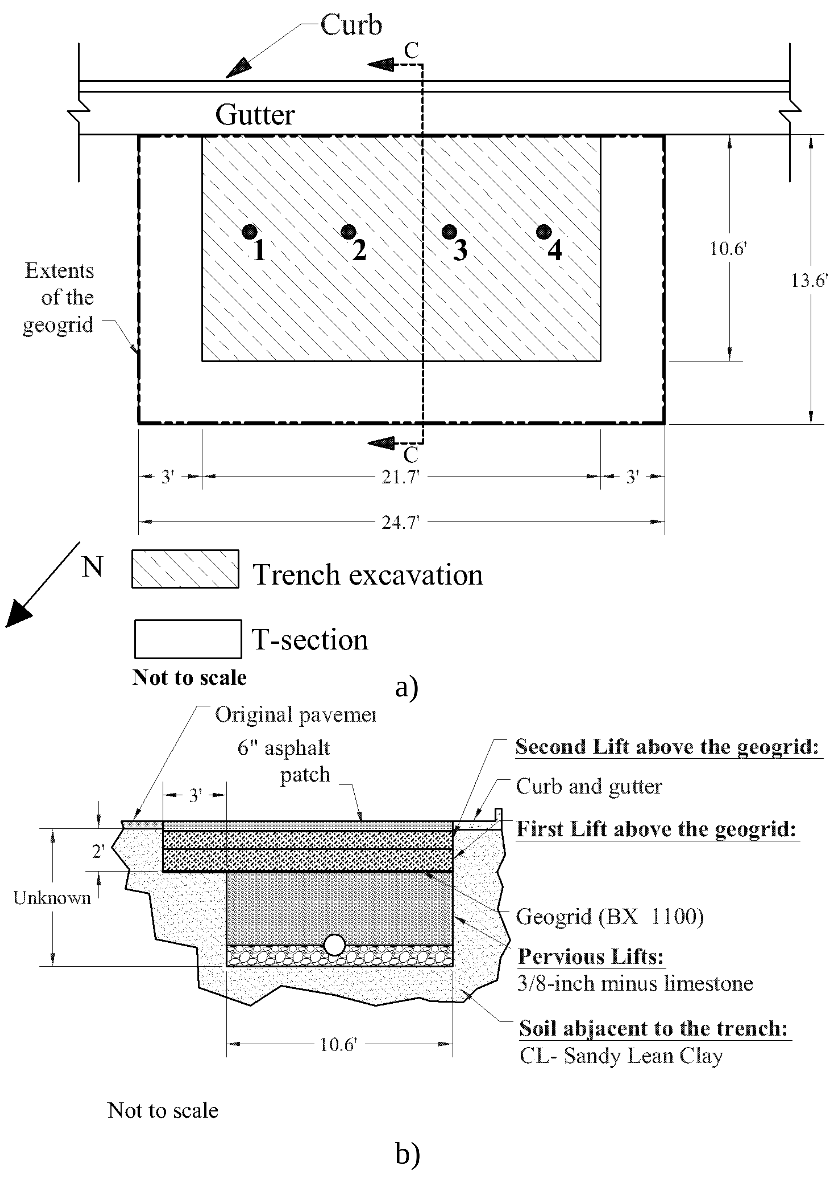


Figure 101 -- Testing locations for Trench C, a) Plan view with test points, b) Cross-section C-C

Nuclear Density Test Results

Table 35 summarizes the dry unit weights from the Nuclear Density testing results for Trench C and Table 36 summarizes the moisture content results from the Nuclear Density tests for Trench C. The probe depth was six inches.

The Nuclear Density tests on the first lift above the Geogrid had, for the four test points, an average moisture content of 11.3% and a dry unit weight of 111.0 pcf. The Nuclear Density tests on the final lift for the four test points had an average moisture content of 10.0% and a dry unit weight of 117.8 pcf. The Phase I report did not present field data for the 3/8-inch minus material placed below the geogrid or laboratory data for the backfill used for the lifts above the geogrid.

Table 35 -- Dry unit weight results from the Nuclear Density tests for Trench C

Location	Number of test points	Average dry unit weight (pcf)	Min/Max dry unit weight (pcf)	Standard deviation	Coefficient of variance (%)
First lift above the geogrid	4	111.0	101.2 / 116.8	6.9	6.2
Second lift above the geogrid	4	117.8	113.1 / 121.2	3.5	3.0

Table 36 -- Moisture content results from the Nuclear Density tests for Trench C

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Standard deviation	Coefficient of variance (%)
First lift above the geogrid	4	11.3	9.7 / 12.5	1.4	12.4
Second lift above the geogrid	4	10.0	8.9 / 11.0	1.0	3.0

DCP Test Results

Table 39 summarizes the DCPI readings from the DCP tests for Trench C and Table 40 summarizes the average CBR results from the DCP tests for Trench C. No comparisons between the typical values and the field values were made because classification of the backfill used above the geogrid was not performed in Phase I.

Table 37 -- DCPI results from the DCP tests for Trench C

Location	Number of test points	Average depth of Tests (inches)	Average DCPI	Standard deviation	Coefficient of variance (%)
First lift above the geogrid	4	30.6	6.2	8.7	140.3
Second lift above the geogrid	4	30.4	46.1	56.7	127.3

Table 38 – Average CBR results from the DCP tests for Trench C

Location	Number of test points	Average depth of tests (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
First lift above the geogrid	4	30.6	55	66.2	120.4
Second lift above the geogrid	4	30.4	9	10.9	121.1

Figure 102 plots the CBR values for each test point as a function of depth for the first lift above the geogrid. The first lift above the geogrid for the four test points had an average CBR value of 55%. At the surface, the CBR values ranged from 4% to 8%. At the termination of the tests, the CBR values ranged from 1% to 18%. The anomaly in test point 4's profile was the result of encountering a larger piece of arrogate during the driving of the DCP testing device.

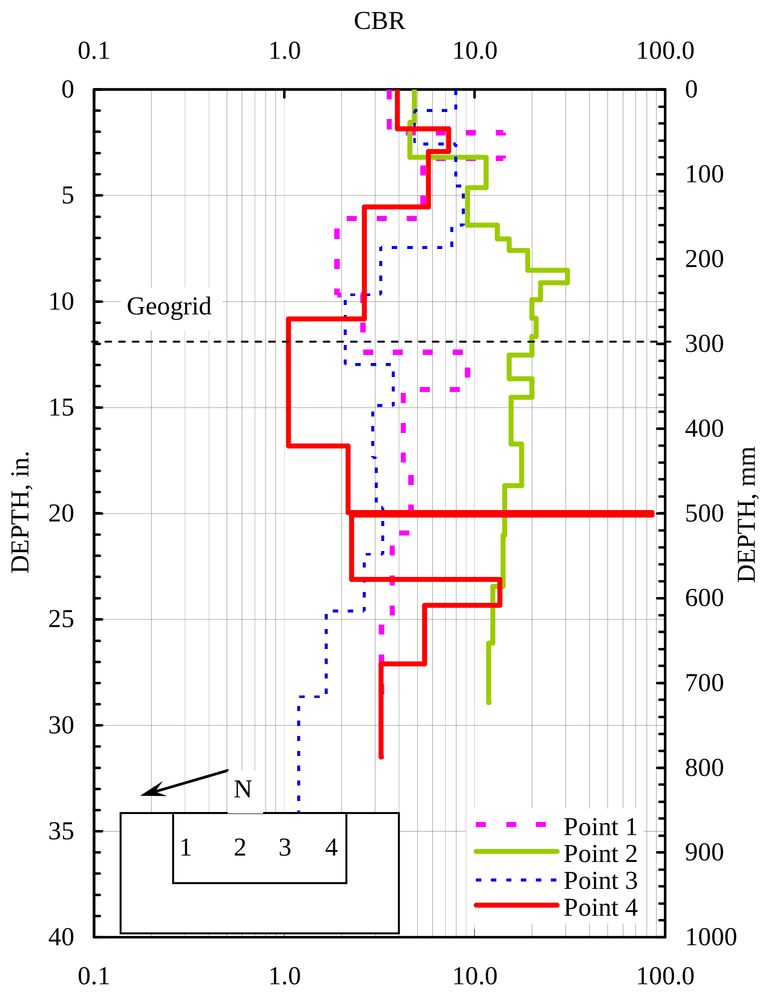


Figure 102 -- CBR profiles from the DCP tests for the first lift above the geogrid in Trench C

Figure 103 plots the CBR values as a function of depth for the test points within the trench for the second lift above the geogrid. For the final lift, the DCP test points had an average DCPI of 46.11. The average calculated CBR value within the trench was 9%, with a variance equal to 118.8 and a standard deviation of 10.9. The coefficient of variance was 121.1%. At the surface, the CBR values ranged from 3% to 6%. At the termination of the test, the CBR values ranged from 3% to 21%. At a depth of about 19 inches, test points 2, 3, and 4 show a large decrease in CBR values. The decrease in CBR values identified a boundary between either lifts or material types.

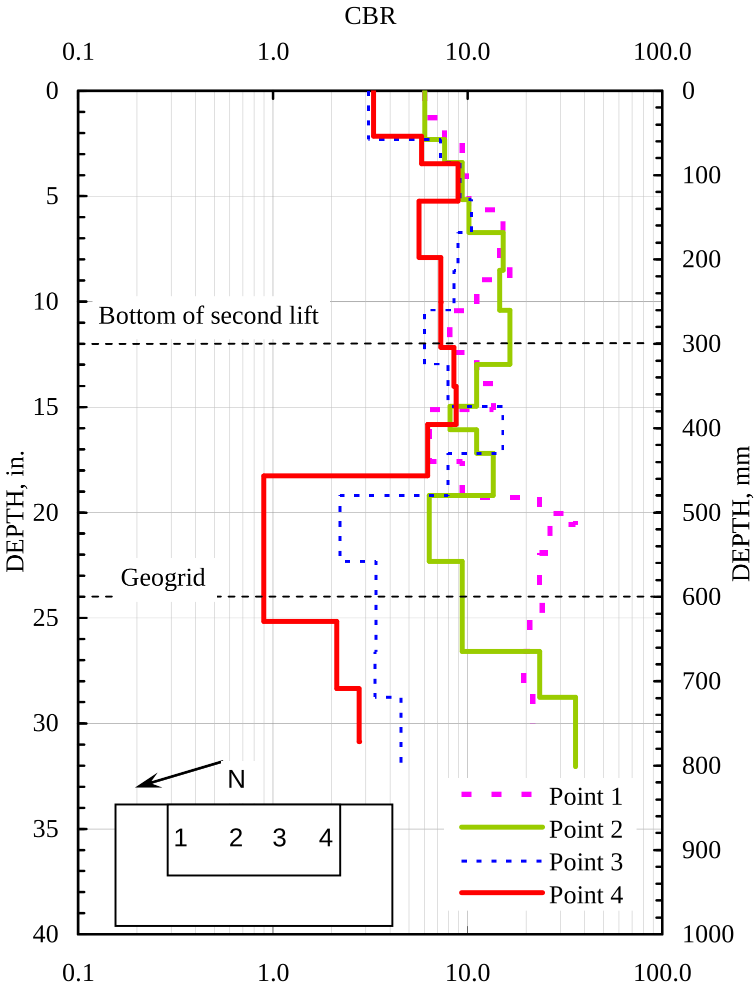


Figure 103 -- CBR profiles from the DCP tests for the second lift above the geogrid of Trench C

Clegg Hammer Test Results

Table 39 summarizes the impact values from the Clegg Hammer tests for Trench C and Table 40 summarizes the CBR results from the Clegg Hammer tests for Trench C. The CBR value for each point was calculated and then the CBR values were averaged.

For the four test points on the first lift above the geogrid for four test points the CBR values ranged from 5% to 14% with an average CBR value of 9%.

The second lift above the geogrid, for the four test points, the CBR values ranged from 8% to 11% with an average CBR value of 9%.

Table 39 -- Impact value results from the Clegg Hammer tests for Trench C

Location	Number of test points	Average IV reading	Min/Max IV readings	Standard deviation	Coefficient of variance (%)
First lift above the geogrid	4	8.0	5.4 / 11.5	2.6	32.5
Second lift above the geogrid	4	8.7	7.9 / 9.7	0.9	10.3

Table 40 -- CBR results from the Clegg Hammer tests for Trench C

Location	Number of test points	Average CBR (%)	Min/Max CBR (%)	Standard deviation	Coefficient of variance (%)
First lift above the geogrid	4	9	7 / 14	3.9	43.3
Second lift above the geogrid	4	9	8 / 11	1.3	13.7

Table 41 compares the differences between the CBR values from the DCP and Clegg Hammer test. In this table, the average CBR values from the entire depth of the DCP test and the CBR from the top 4 to 6 inches from the DCP test were compared with the average CBR values from the Clegg Hammer test. From this comparison it is seen that the there is a substantial (greater than 5%) difference between the Clegg Hammer results and the DCP testing.

Table 41 -- Comparison of average CBR results for Trench C

Location	Average CBR values from Clegg Hammer (%)	Average CBR values from DCP for the depth of the profile (%)	Percent difference between the Clegg Hammer and the DCP test for the depth of the profile (%)	CBR values from DCP for the upper most 4 to 6 inches profile (%)	Percent difference between the Clegg Hammer and the DCP test for the upper most 4 to 6 inches (%)
First lift above the geogrid	14	55	74.5	5	180
Second lift above the geogrid	14	9	55.6	5	180

FWD Test Results

The FWD testing locations are shown in Figure 104. FWD testing was performed on June 2005 and June 2007. The June 2007 testing results are shown in Figure 105. Figure 106 shows the comparison between the two tests.

During, the June 2007 FWD testing, the "zone of influence" was not present. The soil within the trench was stiffer than the surrounding soil. The deflection in the trench for the 15 kip load was 37.7% less than the deflection outside the trench. The deflections for the 15 kip load show for the testing points furthest from both sides of the trench, the deflections were less than the deflections for the 12 kip load.

Figure 106 compares the FWD testing from June 2005 and June 2007 and shows that the backfill within the trench had stiffened over time. This could be the result of the backfill collapsing and increasing in density.

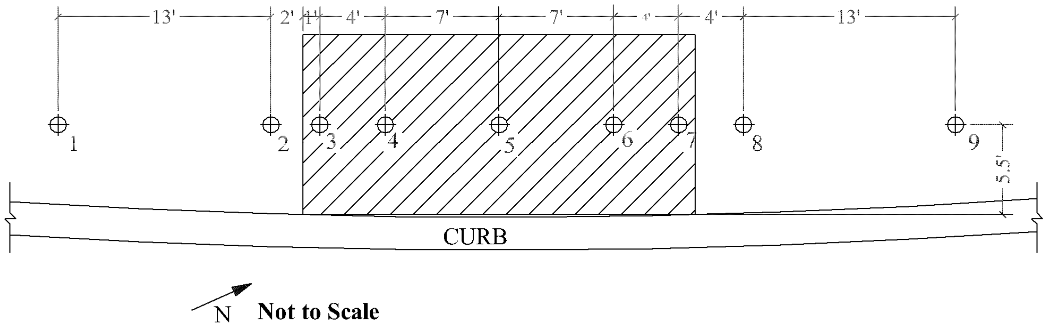


Figure 104 -- FWD testing locations for Trench C

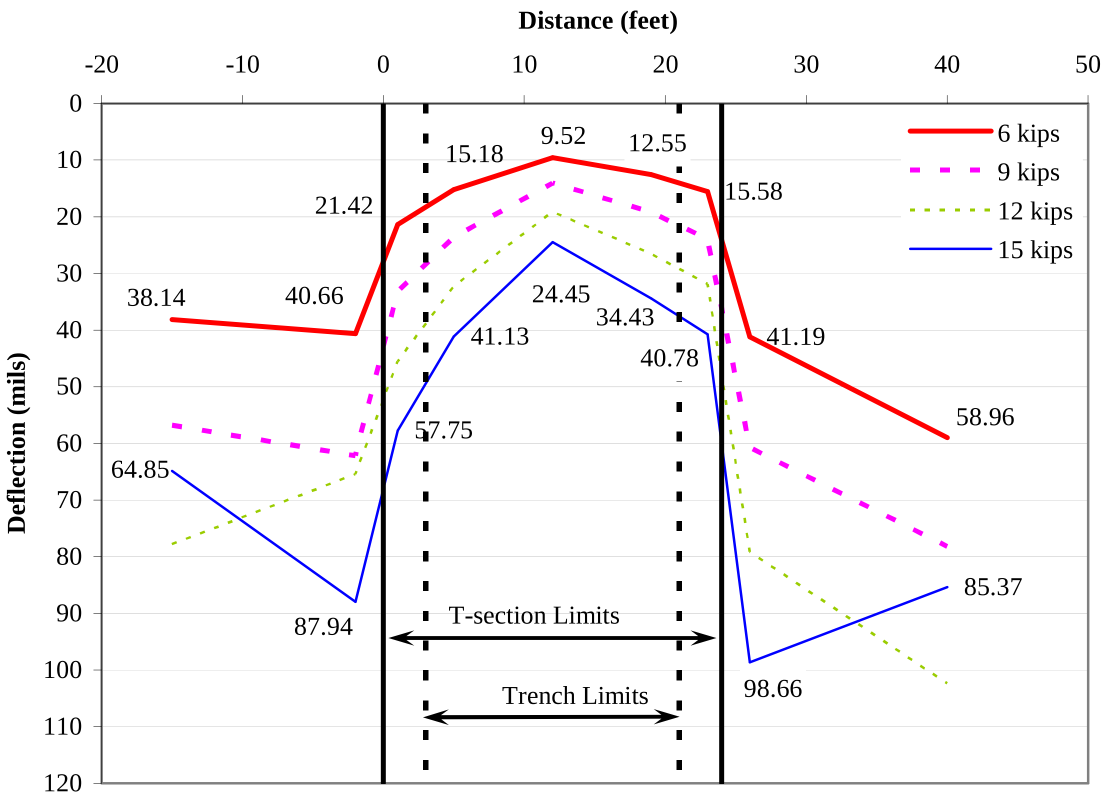


Figure 105 – June 2007 FWD results for Trench C

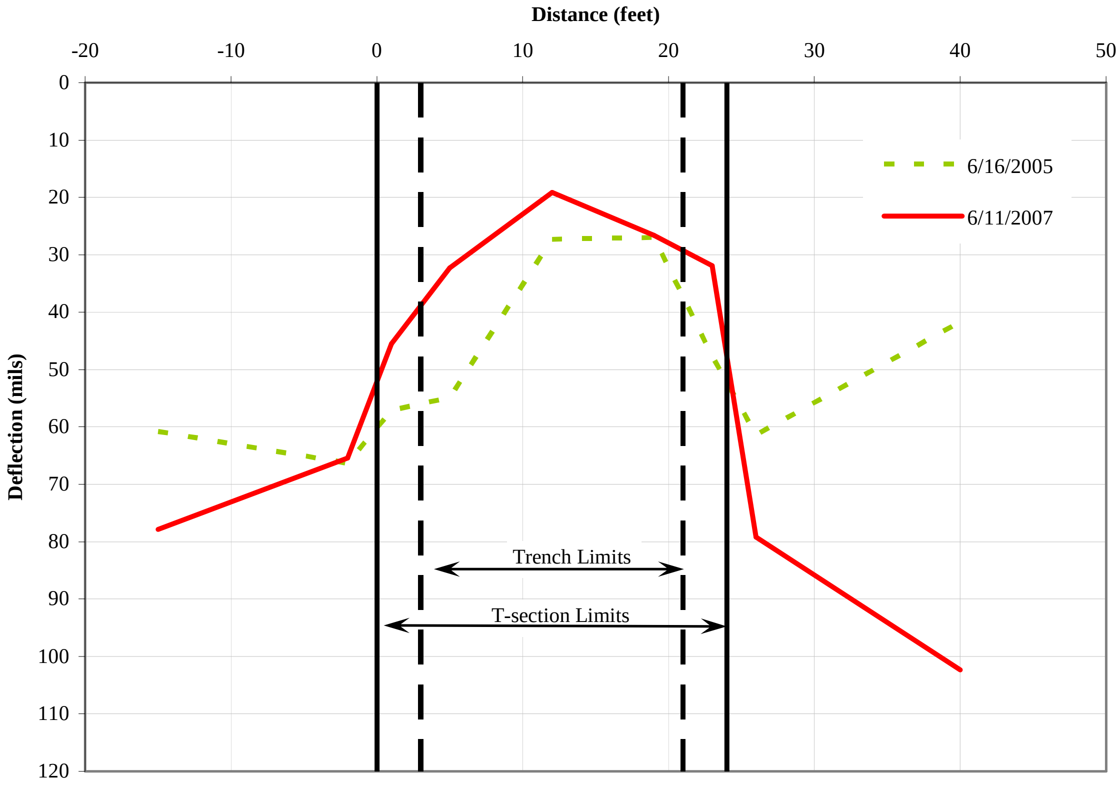


Figure 106 -- Comparison of the 12 kip load deflections for June 16, 2005 and June 11, 2007

Post Construction Elevation Survey

The post construction elevation surfaces were constructed using survey data collected on May 11, 2007 and March 20, 2008. No survey data earlier than May 11, 2007 was available.

Trench C was surveyed with 51 grid points (see Figure 107). The benchmark was dome bolt (see Figure 80) on the hydrant northeast of the trench located at the intersection of McKinley Drive and Van Buren Avenue. From the elevation survey on May 11, 2007, the highest pavement elevation was 94.97 feet (survey point 1) and the minimum pavement elevation was 94.50 feet (survey point 30). The difference in the elevation of the pavement was 5.64 inches when the patch was initially placed.

From the elevation survey on March 20, 2008, the highest elevation was 95.63 feet (survey point 30) and lowest elevation was 95.08 feet (survey point 1). The difference in the maximum and minimum elevations was 5.40 inches. The average uplift of the trench was 2.05 inches and the maximum settlement was 1.7 inches (survey point 17). The maximum settlement occurred in the west corner of the patch. Figure 107 shows the location of the elevation points and Figure 108 shows the pavement surface for Trench C. Figure 109 presents the elevation profiles and settlement profiles fro Trench C. This Figure shows that the middle of the trench did not experience the same magnitude of uplift during the winter as the area surrounding it. Because of this, the patch had a bump it in.

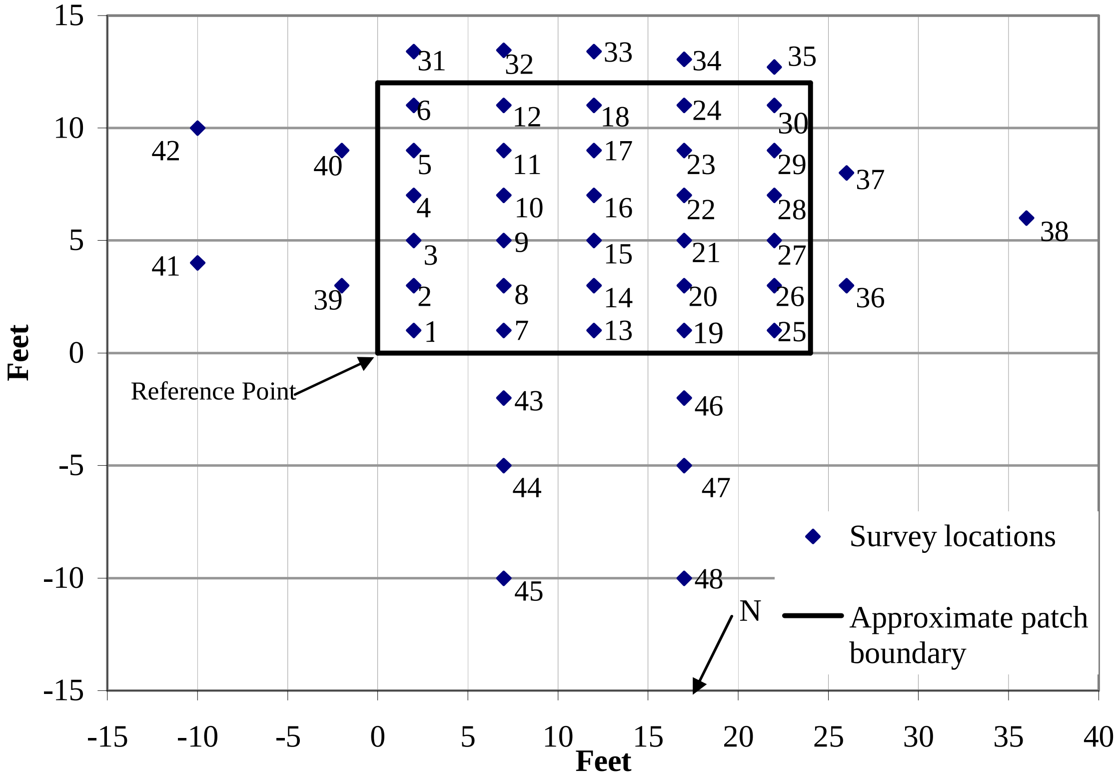


Figure 107 -- Survey locations for Trench C

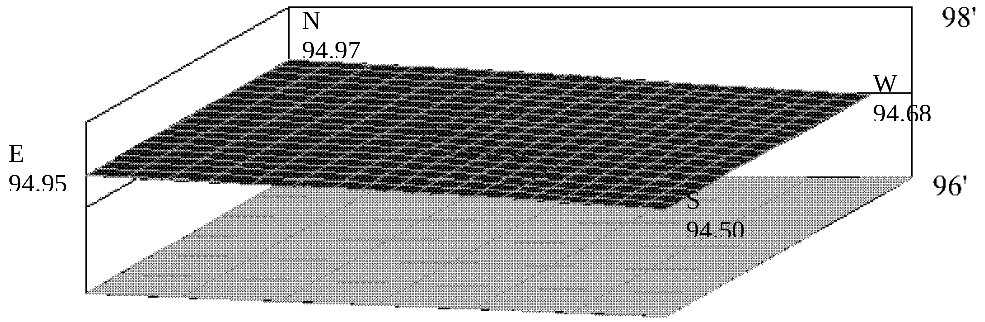


Figure 108 -- Pavement surface elevations of Trench C

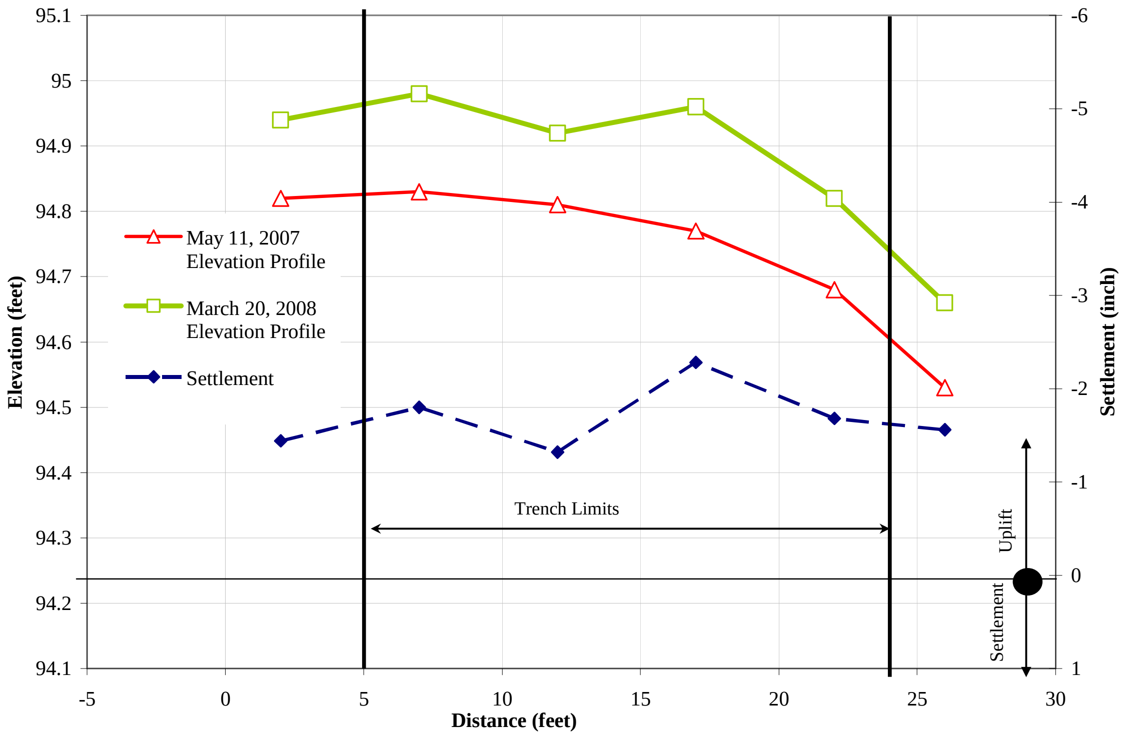


Figure 109 -- Settlement along centerline of Trench C

Comparison of Field-testing Results to Long Term Monitoring

Figure 110 shows the FWD testing locations with the field-testing locations superimposed with the averaged field-testing results fro various points. The deflection in the middle of the trench was 24.25 mils. At the edge of the trench, the deflections ranged from 40.78 mils to 41.13 mils. Test point 1 (see Figure 101) was in the near the FWD test point 7 that yielded the 34.43 mils. At this test point, the dry unit weight of the backfill after compaction was 117.2 pcf. The average CBR values for the depth of the DCP test was 7%. The CBR value at the surface was 6%. Test point 4 was located in the near the FWD test point 5with the deflection of 41.13 mils. At this test point, the dry unit weight was 113.1 pcf. The CBR average value for the depth of the DCP test was 32% and the CBR value at the surface of the trench was 3%. In the center of the trench, test points 2 and 3 (see Figure 101) were averaged together. The averaged dry unit weight was 120.4 pcf. The averaged CBR value at these points over the depth of the DCP tests was 14%. At the surface, the averaged CBR value was 5%. Since no bulk sample of the backfill was collected and its classification is not known, no other comparisons can be drawn.

Figure 111 shows a plot with the FWD deflections verses CBR values and dry unit weights measured in the field during construction. This Figure shows that there is no empirical correlation between the FWD deflections and the field-testing results.

Figure 112 shows a plot with FWD deflections and settlement. This shows that the settlements are independent of the FWD deflections. On the chart, it can be seen that the higher dry unit weights measure within the trench are occur where there were lower deflections. It also shows that the CBR values did not predict the FWD testing results.

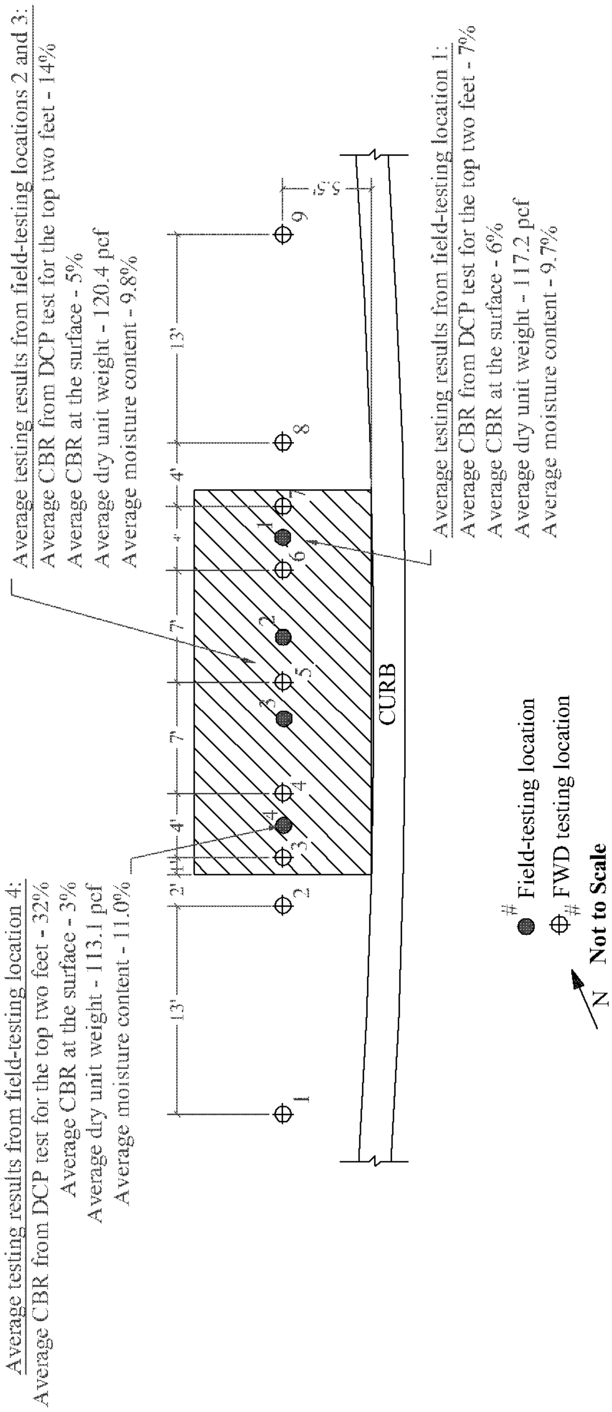


Figure 110 – Comparison of CBR values, dry unit weights and FWD testing results

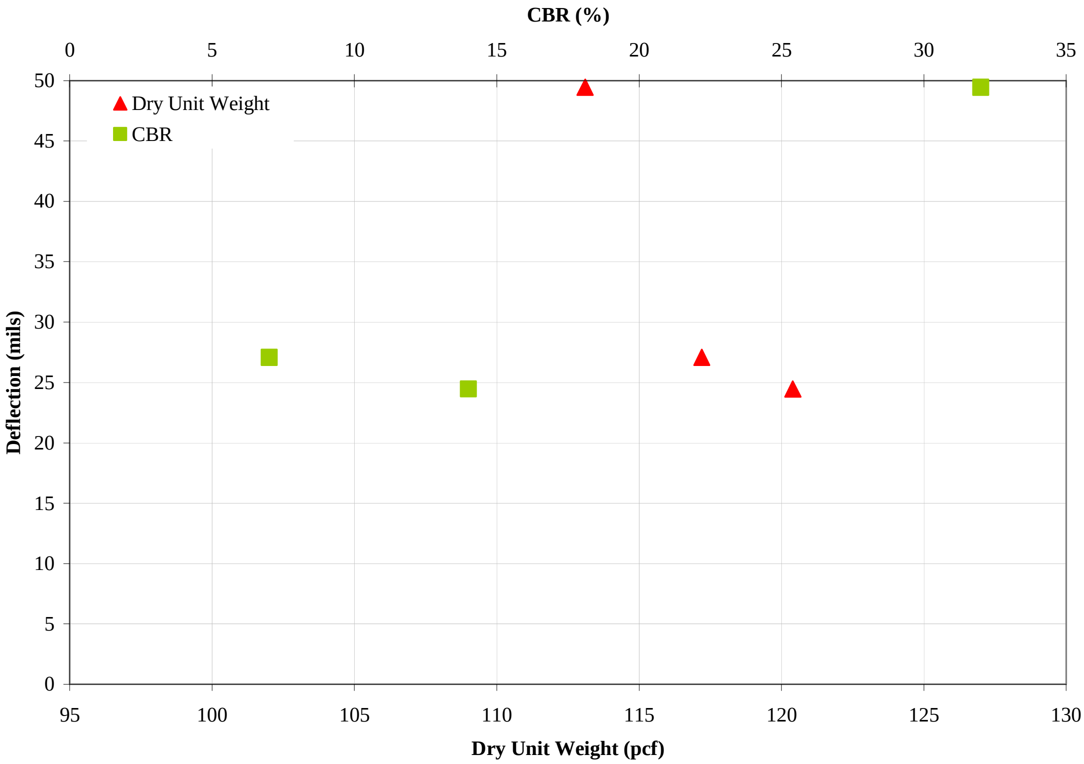


Figure 111 - Comparison of CBR and dry unit weights to the deflections from the 15 kip FWD

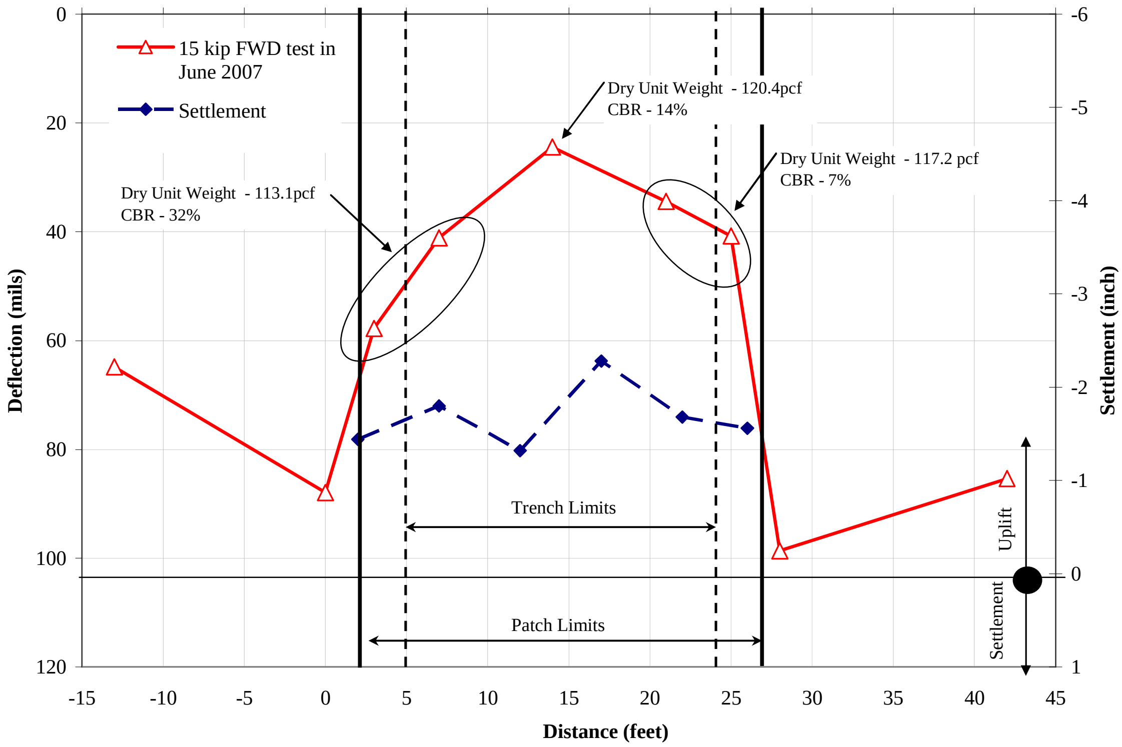


Figure 112 – 15 kip FWD test with settlement for Trench C

Key Results

- The trench settled 1.70 inches between the Spring 2007 survey and March 2008 survey.
- The FWD test results showed that the backfill within the trench had stiffened over time.
- The “zone of influence” was present on both sides of the trench.
- FWD deflections did not correlate with CBR results or settlements. The FWD results showed that lower deflections occurred where there were higher dry unit weights.

4.5.4 - Recommended Trench D

Nuclear Density, Clegg Hammer, and DCP tests were performed on Trench D. On July 23, 2007, the backfill was tested at four test points on the third lift. On July 25, 2007, the final lift was tested at the same four points and four additional test points in the T-section for a total of eight test points (see Figure 113).

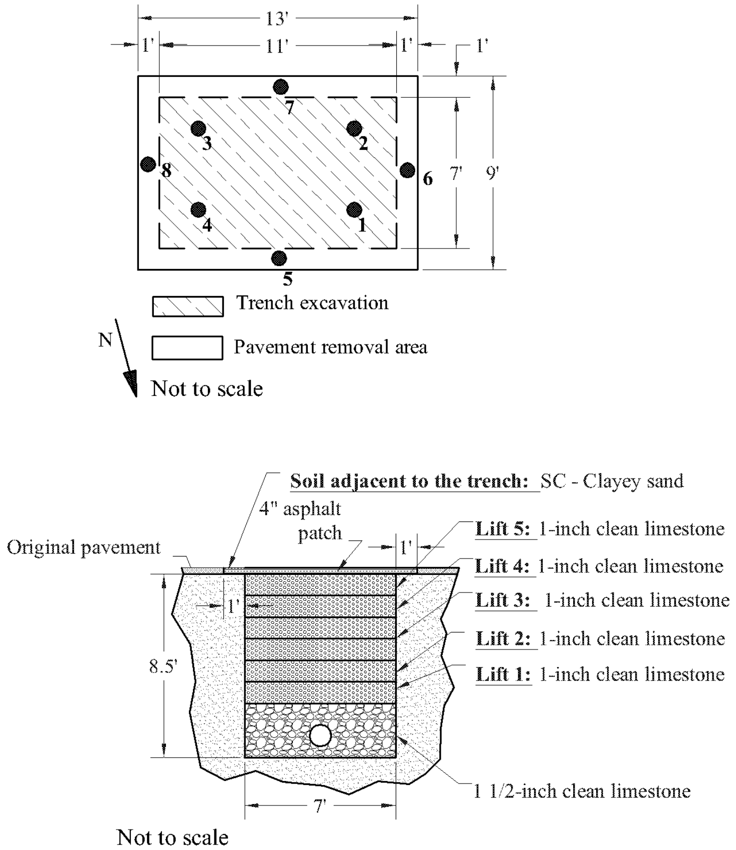


Figure 113 -- Testing locations for Trench D a) Plan view b) Cross-section

Nuclear Density Test Results

Table 42 summarizes the dry unit weights from the Nuclear Density testing results for Trench D and Table 43 summarizes the moisture content results from the Nuclear Density tests for Trench D. The probe depth was six inches.

The backfill within the trench was classified as GP – poorly graded gravel. The typical range of dry unit weights for compacted poorly graded gravel from NAVFAC of 115 to 125 pcf. The typical moisture content ranged from 11% to 14% from NAVFAC (1986) in Table 5. From laboratory testing in Phase I, the maximum dry unit weight was 132.2 pcf. There was no bulking moisture content because it was free draining and the particle size was too large.

The maximum dry unit weight within the trench was 114.5 pcf and the minimum dry unit weight within the trench was 104.3 pcf. All the dry unit weights measured within the trench were within the typical values from NAVFAC. The average moisture contents ranged from 2.0% to 3.0%. The moisture contents were below the typical values from NAVFAC.

The Nuclear Density tests for the third lift at the four test points had an average dry unit weight of 106.9 pcf and average moisture content of 3.0%. Based on the laboratory testing, the backfill was compacted to 57% relative density, which corresponded to a medium dense compaction.

The fifth lift average dry unit weight from the Nuclear Density tests for the four test points within the trench was 110.0 pcf and the moisture content was 2.0%. Based on the laboratory testing this lift was placed at 63% relative density, which corresponds to medium dense compaction.

The four test points in the adjacent soil where the pavement was removed had an average moisture content of 5.1% and an average dry unit weight of 118.5 pcf. The average dry unit weight of the soil was 98% of the maximum from the Standard Proctor test. This corresponded to very dense compaction.

Table 42 -- Dry unit weight results from the Nuclear Density tests on Trench D

Location	Number of test points	Average dry unit weight (pcf)	Min/Max dry unit weight from field-testing (pcf)	Relative density (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	106.9	104.3 / 108.6	57	19	1.8
Fifth lift test points within the trench	4	110.0	107.1 / 114.0	63	2.9	2.6
Soil adjacent to the trench	4	118.5	107.1 / 122.5	N/A	7.6	6.4

Table 43 -- Moisture content results from the Nuclear Density tests for Trench D

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	3.0	2.5 / 3.0	0.3	10
Fifth lift test points within the trench	4	2.0	1.8 / 2.8	0.2	10.2
Soil adjacent to the trench	4	5.1	2.5 / 7.3	2.0	39.2

Figure 114 shows the relative density testing results for Phase I and the average testing results from Trench D. On the Figure the boundary between the different relative densities are shown as dashed lines. The collapse index of the material is also shown. The moisture content that the backfill was placed at was within the range of maximum collapse potential. This Figure shows that the average dry unit weight for each lift corresponded to medium dense compaction density. The test points for each lift are encompassed in a circle. The individual test points were closely grouped.

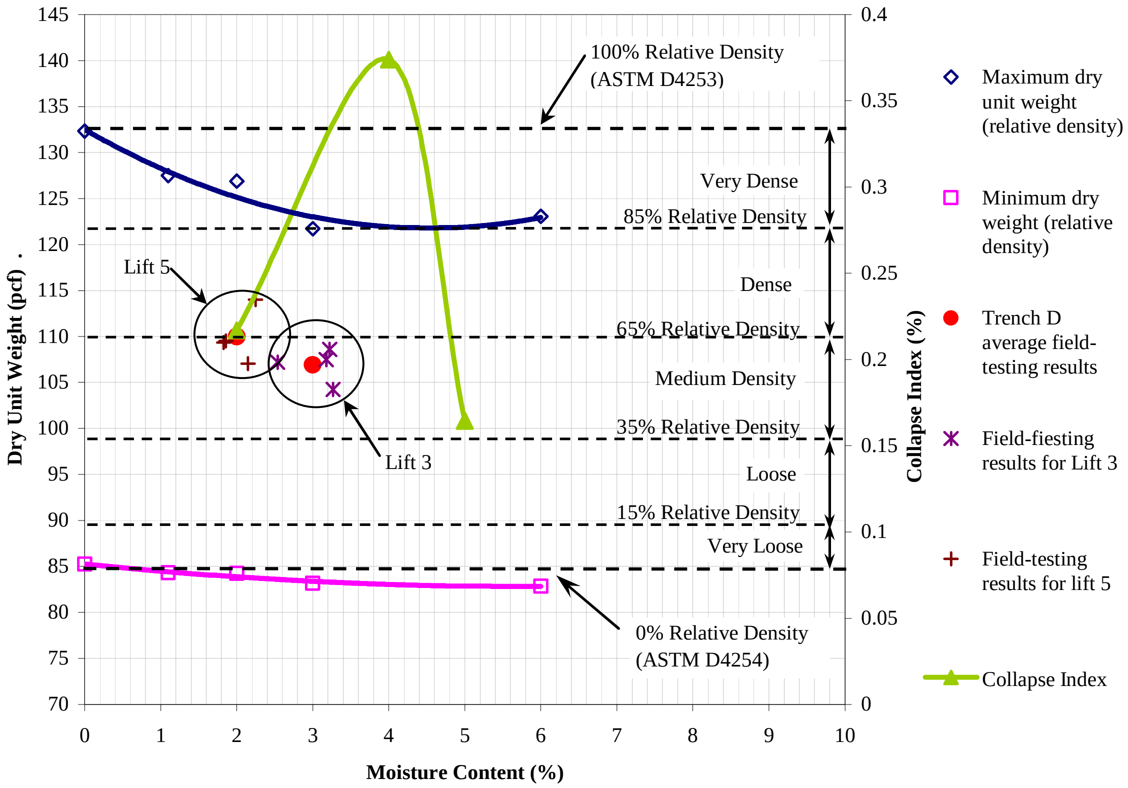


Figure 114 -- Result of relative density testing results from Phase I with the field-testing results from Trench D

Figure 115 shows the Standard Proctor testing results for the soil excavated from Trench D. Plotted on the chart is the average field-testing result for the soil adjacent to the trench. The soil adjacent to the trench was above 95% of the Standard Proctor maximum.

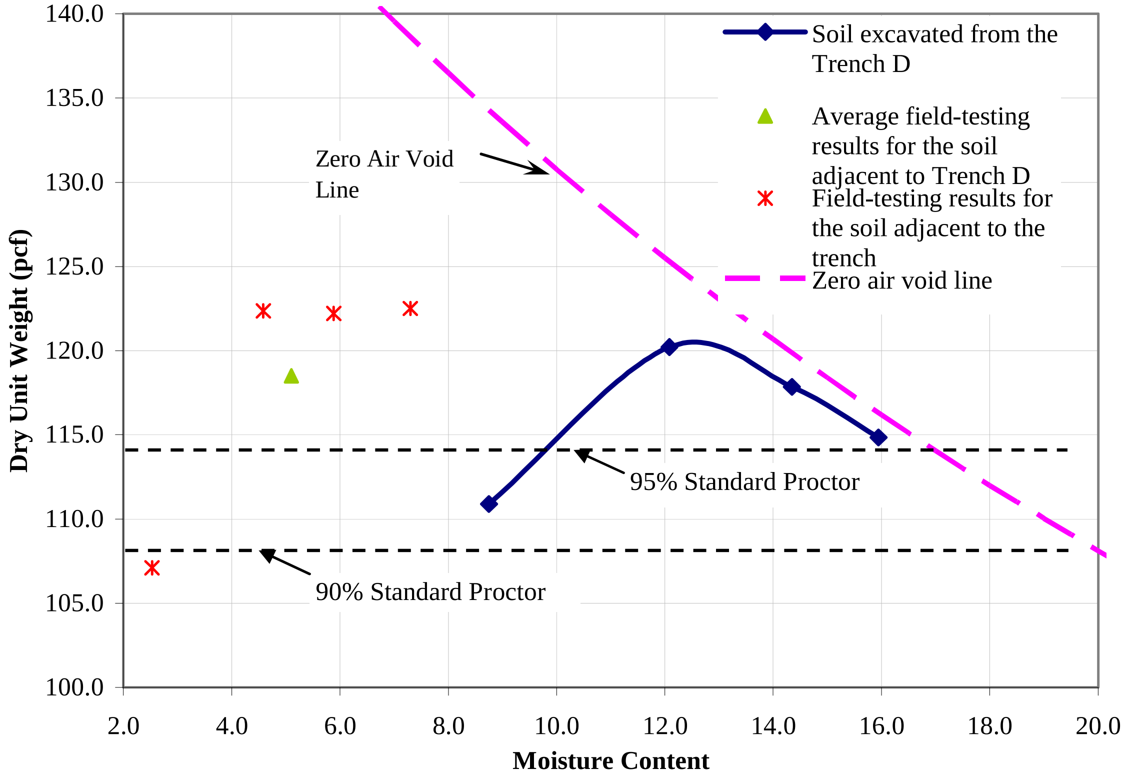


Figure 115 -- Standard Proctor testing results with the average field-testing results for the soil adjacent to the trench

DCP Test Results

Table 44 summarizes the DCPI readings from the DCP tests for Trench D and Table 45 summarizes the average CBR results from the DCP tests for Trench D. Trench D was constructed with 1-inch clean limestone. This backfill was classified as GP - poorly graded gravel. The reported CBR values for poorly graded gravel were from 30% to 60% by NAVFAC are presented in Table 5. The average values for the trench were below the typical values from NAVFAC.

Table 44 -- DCPI results from the DCP tests for Trench D

Location	Number of test points	Average depth of tests (inches)	Average DCPI	Standard deviation	Coefficient of variance (%)
Third lift	4	27.3	33.2	34.6	103.0
Fifth lift test points within the trench	4	29.4	15.9	16.7	105.0
Soil adjacent to the trench	4	29.8	40.5	30.8	76.0

Table 45 – Average CBR results from the DCP tests for Trench D

Location	Number of test points	Average depth of tests (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	27.3	26	26.8	64.6
Fifth lift test points within the trench	4	29.4	23	12.7	55.2
Soil adjacent to the trench	4	29.8	11	9.7	88.2

Figure 116 plots profiles of the CBR values as a function of depth for the third lift. The third lift for the four test points within the trench had an average CBR value of 26% extending 27.3 inches. At the surface of the lift, the CBR values ranged from 2% to 5%. These CBR values were below the typical values from NAVFAC At the termination of the DCP tests, the CBR values ranged from 24% to 34%. The CBR profiles increased slightly with depth. This indicates that there was an increase in strength with depth. The four test points were tightly banded through the profile. This indicates that the lift was placed consistently over the trench.

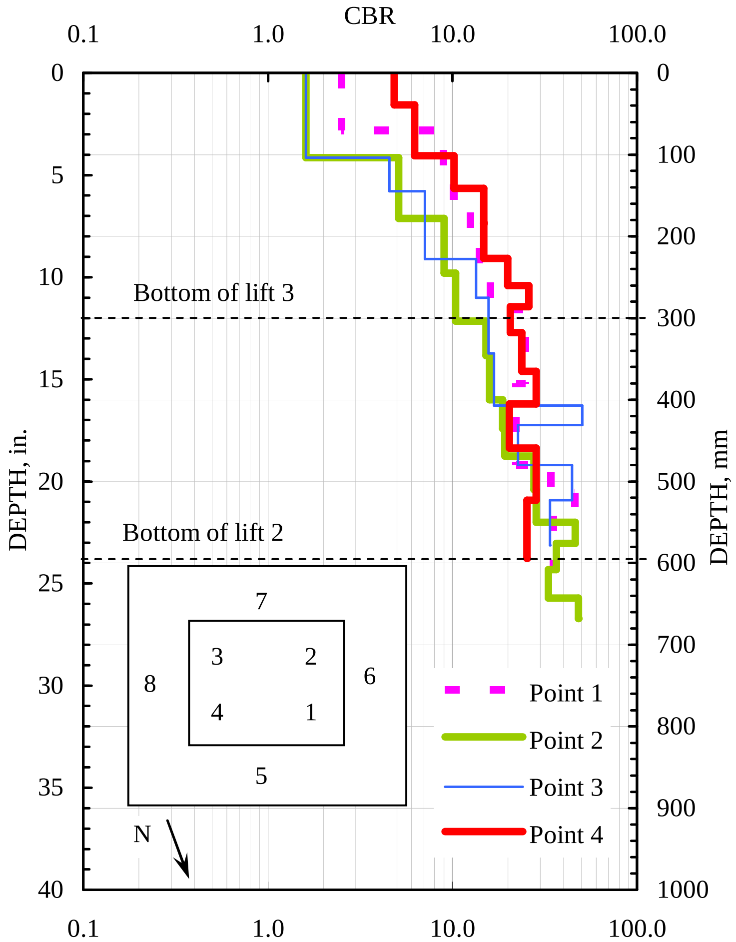


Figure 116 -- CBR profiles from the DCP tests for Lift 3 of Trench D

Figure 117 plots profiles of the CBR values as a function of depth for the fifth lift. The four test points within the trench had an average CBR of 23% extending 29.4 inches. The average CBR value was below the typical values from NAVFAC. At the surface of the CBR values ranged from 2% to 4%. At the termination of the DCP tests, the CBR values ranged from. The CBR profile increased with depth. The profiles were tightly banded for the entire profile; however, the profile for test point 1 had a higher CBR value for depths of 8 inches to 10 inches. This outlying point was possibly the result of encountering a larger piece of aggregate during penetration.

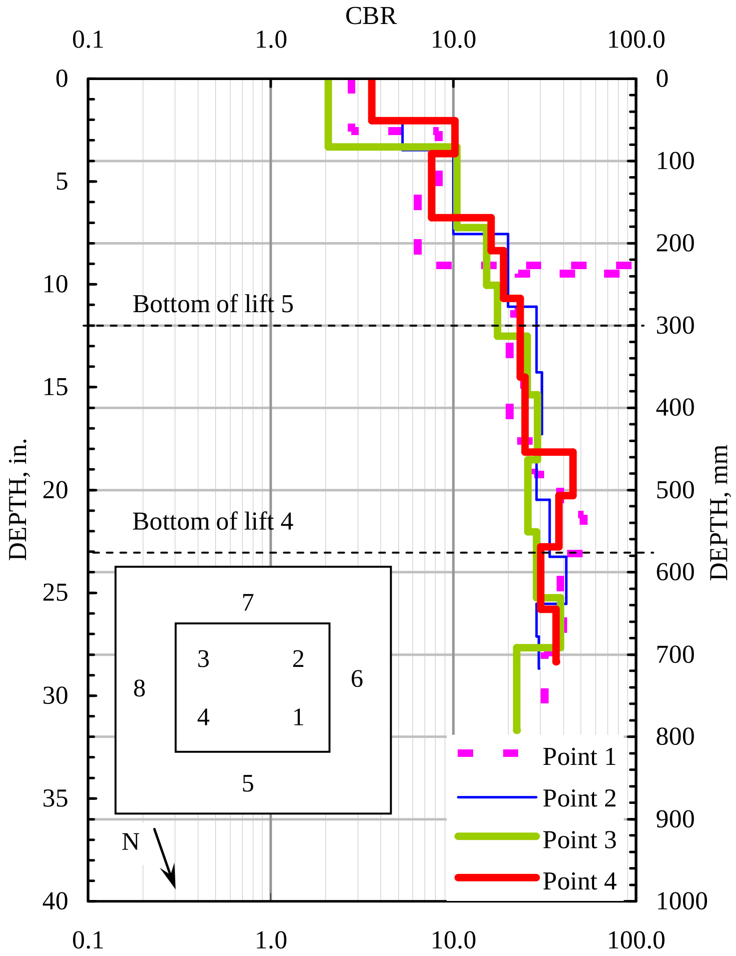


Figure 117 - CBR profiles from the DCP tests for the test points within the trench for Lift 5 in Trench D

Figure 118 plots profiles of the CBR values as a function of depth in soil adjacent to Trench D. The four test points had an average CBR of 11%. The average was within the typical values from NAVFAC. At the surface, the CBR results ranged from 1% to 9%. At the termination of the of the DCP tests the CBR values ranged from 2% to 20%. The CBR profiles for the four test points in the soil adjacent to the trench were widely varied. This indicates that soil surrounding the trench was varied and was inconsistent. This could lead to differential settlement. The profiles also show that test points 7, and 8 soften with depth and test points 5 and 6 show that they strength with depth.

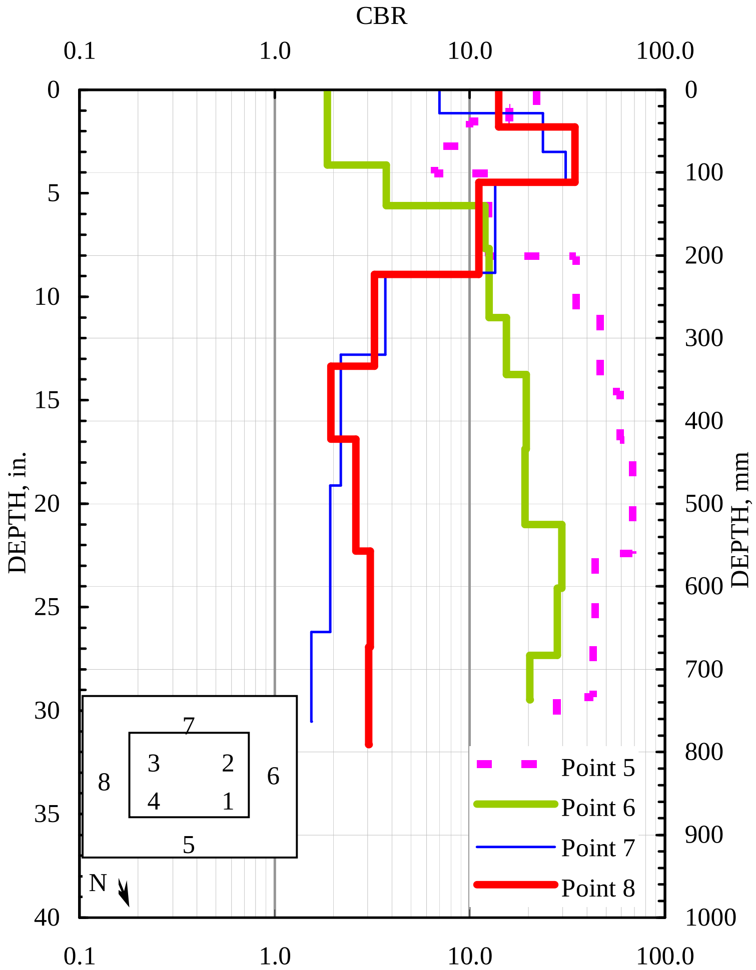


Figure 118 -- CBR profiles from the DCP tests for the test points in soil adjacent to Trench D

Clegg Hammer Test Results

Table 46 summarizes the impact values from the Clegg Hammer tests for Trench D and Table 47 summarizes the CBR results from the Clegg Hammer tests for Trench D. The CBR value for each point was calculated and then the CBR values were averaged.

The third lift had CBR values ranging from 17% to 35% with an average CBR value of 22%. The CBR values were below the typical values by NAVFAC. The fifth (top) lift, for the four test points within the trench, the CBR values ranged from 13% to 66% with an average CBR of 41%. The average CBR value was within the typical CBR values from NAVFAC. The minimum CBR value was below the typical values.

The soil adjacent to the trench had CBR values ranging from 43% to 316% with an average calculated CBR in the soil adjacent to the trench was 36.9. The average CBR value was above the typical by NAVFAC.

The large CBR values could be the result two problems. First, the Clegg Hammer does not work accurately on large sized aggregate and there was no laboratory correlation made to adjust the CBR correlation equation for the Clegg Hammer to 1-inch clean limestone. Second, Clegg Hammer could have been broken.

Table 46 -- Impact value results from the Clegg Hammer tests for Trench D

Location	Number of test points	Average IV reading	Min/Max IV readings	Standard deviation	Coefficient of variance (%)
Third lift	4	15.5	13.0 / 20.6	3.4	21.9
Fifth lift test points within the trench	4	21.7	29.7 / 10.9	5.5	25.3
Soil adjacent to the trench	4	36.9	23.3 / 70.0	22.4	60.6

Table 47 -- CBR results from the Clegg Hammer tests for Trench D

Location	Number of test points	Average CBR (%)	Min/Max CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	22	17 / 35	8.8	40.0
Fifth lift test points within the trench	4	41	13 / 66	25.6	62.4
Soil adjacent to the trench	4	37	43 / 316	132.7	115.5

Comparing the CBR results from the Clegg Hammer and the DCP tests shows that there were large differences between the two tests was present for Trench D similar to the other trenches. Table 51 present the results of the comparisons.

Table 48 -- Comparison of average CBR results for Trench D

Location	Average CBR values from Clegg Hammer (%)	Average CBR values from DCP for the depth of the profile (%)	Percent difference between the Clegg Hammer and the DCP test for the depth of the profile (%)	CBR values from DCP for the upper most 4 to 6 inches profile (%)	Percent difference between the Clegg Hammer and the DCP test for the upper most 4 to 6 inches (%)
Third lift	22	26	15	3	633
Fifth lift test points within the trench	41	23	78	3	1267
Soil adjacent to the trench	57*	11	418	5	1040

* This value has been adjusted not to include the outlier points in data.

FWD Test Results

Figure 119 shows the testing locations for Trench D. Figure 120 shows the results from the November 5, 2007 FWD testing results. The FWD testing shows the shows the "zone of influence" on the west side of the trench. On the east edge of the trench, the zone of influence was not present. The response of the pavement on the east and west sides of the trench are similar because both sides of the trench were exposed to construction equipment loads. However, on the east side of the trench the "zone of influence" was not percent. 15 feet further east the pavement provided a soft response than the soil adjacent to the trench. Based on the literature review, the zone that is affected by excavation should extend to about 3 feet. The softer response 15 feet to the east of the trench was not the result of construction activities. The deflection at the center of the trench was 15.36 mils and the average deflection at the inside edge of the trench was 20.68 mils for the 15 kips loads. This Figures shows that the trench was placed stiffer than the surrounding soils.

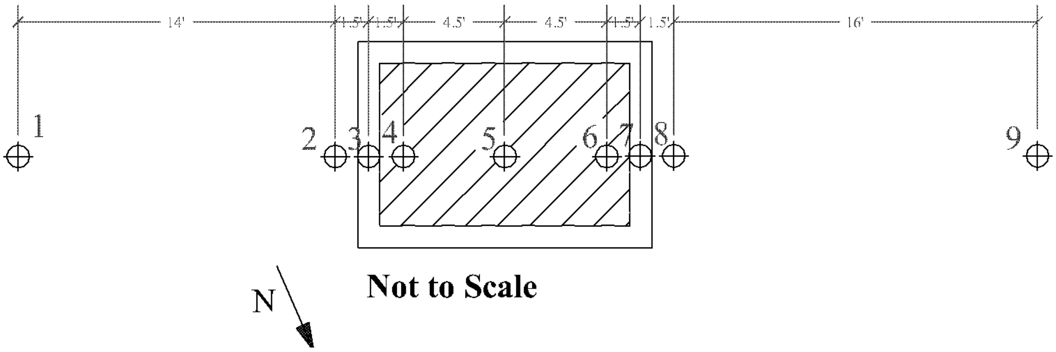


Figure 119 -- FWD test locations from Trench D

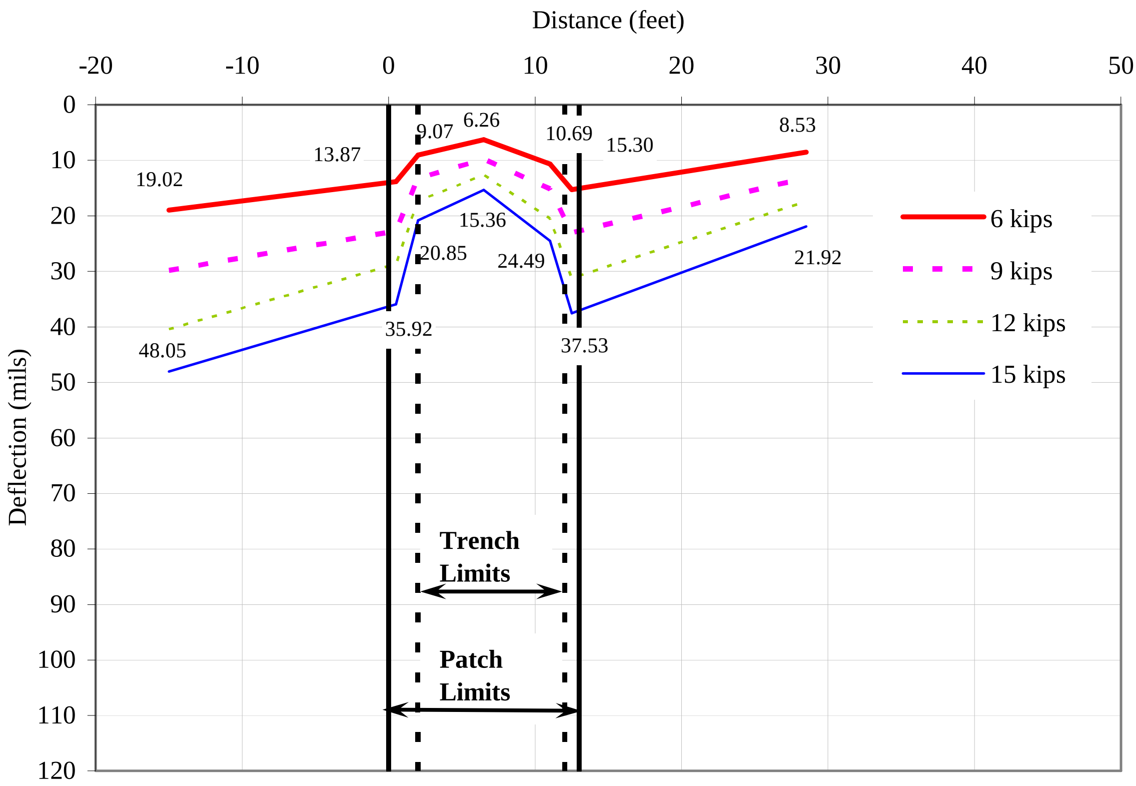


Figure 120 -- FWD test from Trench D

Post Construction Elevation Survey

The post construction surfaces were constructed using survey data collected on July 30, 2007 and March 19, 2008. Figure 121 shows the location of the grid points and Figure 122 shows the pavement surface for Trench D.

Trench D was surveyed with 27 grid points. The benchmark was the dome bolt (see Figure 80) on hydrant northeast of the trench. From the elevation survey on July 3, 2007, the highest elevation was 97.38 feet (at survey points 4, 8, 15 and 16) and the lowest elevation was 96.25 feet (at survey point 1). The difference between the highest and lowest elevation was 1.58 inches. From the elevation survey on March 20, 2007, the highest pavement elevation was 97.42 feet (at survey point 16) and lowest elevation was 96.3 feet (at survey point 1). The difference between the maximum and lowest elevation was 1.44 inches. This was a reduction in the total difference between the highest and lowest level. The uplift was 0.08 feet (0.96 inches) and the maximum settlement was 0.02 feet (0.24 inches) at survey point 15 along the south edge of the trench in the soil adjacent to the trench.

Figure 123 shows the elevation profiles and settlement profiles for Trench D. This shows that the larger uplifts during the winter occurred outside the trench. This would result in the patch to appear like a dip in the road.

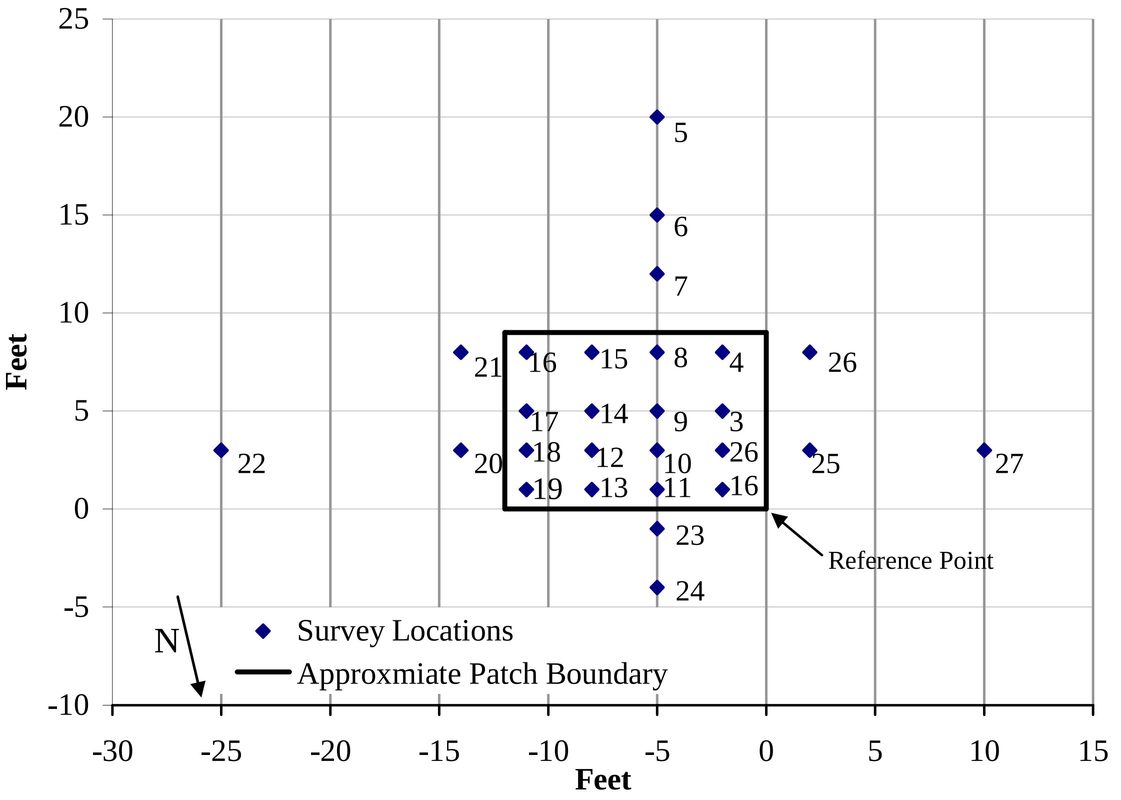


Figure 121 -- Survey locations for Trench D

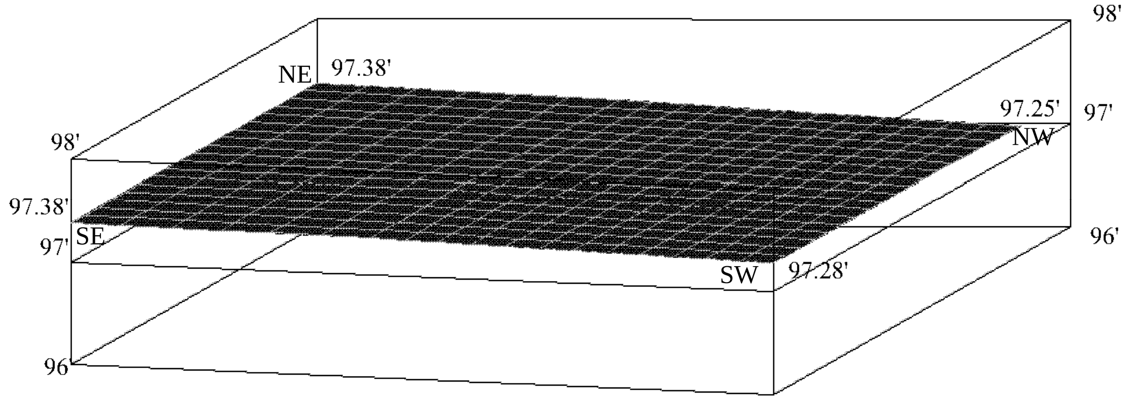


Figure 122 -- Pavement surface elevations of Trench D

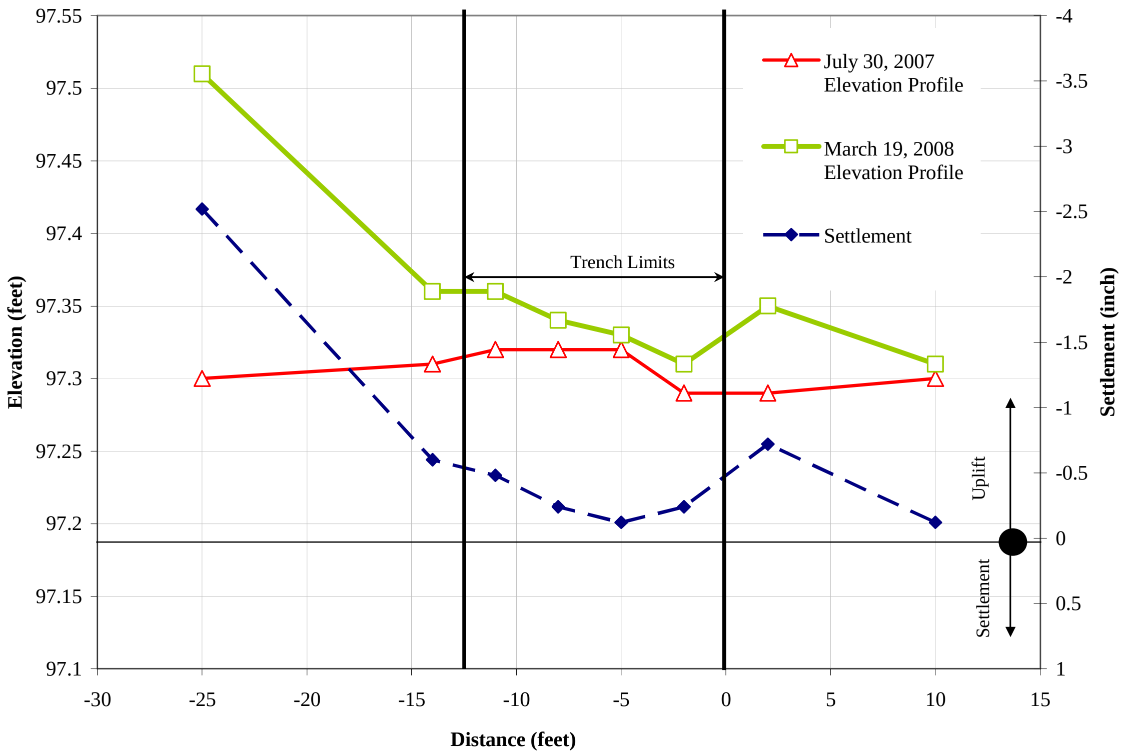


Figure 123 -- Settlement along centerline of Trench D

Comparison of Field-testing Results to Long Term Monitoring

Test point 7 (see Figure 113) was near the maximum settlement. The dry unit weight was 122.4 pcf. The CBR values at the surface and the over the depth of the trench was 7%. Comparing these values to other places in the trench, the dry unit weights were higher and the CBR values were below the CBR values at other test points in the soil adjacent to the trench.

To compare the field-testing results during construction from the four test points within the trench were compared with the FWD testing. Figure 127 shows the FWD and field-testing locations superimposed. Also on the Figure are the average field-testing results for field-testing points that correspond to FWD testing locations. The average dry unit weight was 110 pcf. The CBR value at the surface was 3% and the average CBR values for the depth of the test was 23%. At the west edges of the trench, test points 3 and 4 (see Figure

127) were within the vicinity of FWD testing point 4 (see Figure 124) had an average dry unit weight 108.3 pcf. The CBR value at the surface was 3% and the average CBR value for the depth of the test was 22%. On the east side of the trench test points 1 and 2 (see Figure 113), were in the vicinity of FWD test point 6 (see Figure 124). The dry unit weight was 111.7 pcf. The CBR value at the surface was 3% and the average CBR results was 24%.

The dry unit weight of the soil adjacent to the trench on the west side (FWD point 7) of the trench at test point 6 (see Figure 124) was 107.1 pcf at 2.5% moisture content. The average CBR value for the length of the test was 17% and at the surface, the CBR was 2%

The dry unit weight of the soil adjacent to the trench on the east side (FWD point 3) of the trench at test point 8 (see Figure 124) was 122.2 pcf at 5.9% moisture content. The average CBR value for the length of the test was 7% and at the surface, the CBR was 2%

To compare if there was a trench between CBR values and FWD deflects and/or dry unit weights and FWD deflections they were plotted on Figure 125. The field-testing data points were for the top two feet of backfill. Figure 125 shows that for this trench there was not distinct empirical correlation between the FWD results and the field-testing results.

Figure 126 shows an overlay of the pavement settlement between the summer and early spring surveys with the FWD testing results. Stiffer responses to FWD testing correlate to reduced movement during the freeze/thaw cycle. The higher deflections from the FWD testing were located where the backfill was had lower CBR values.

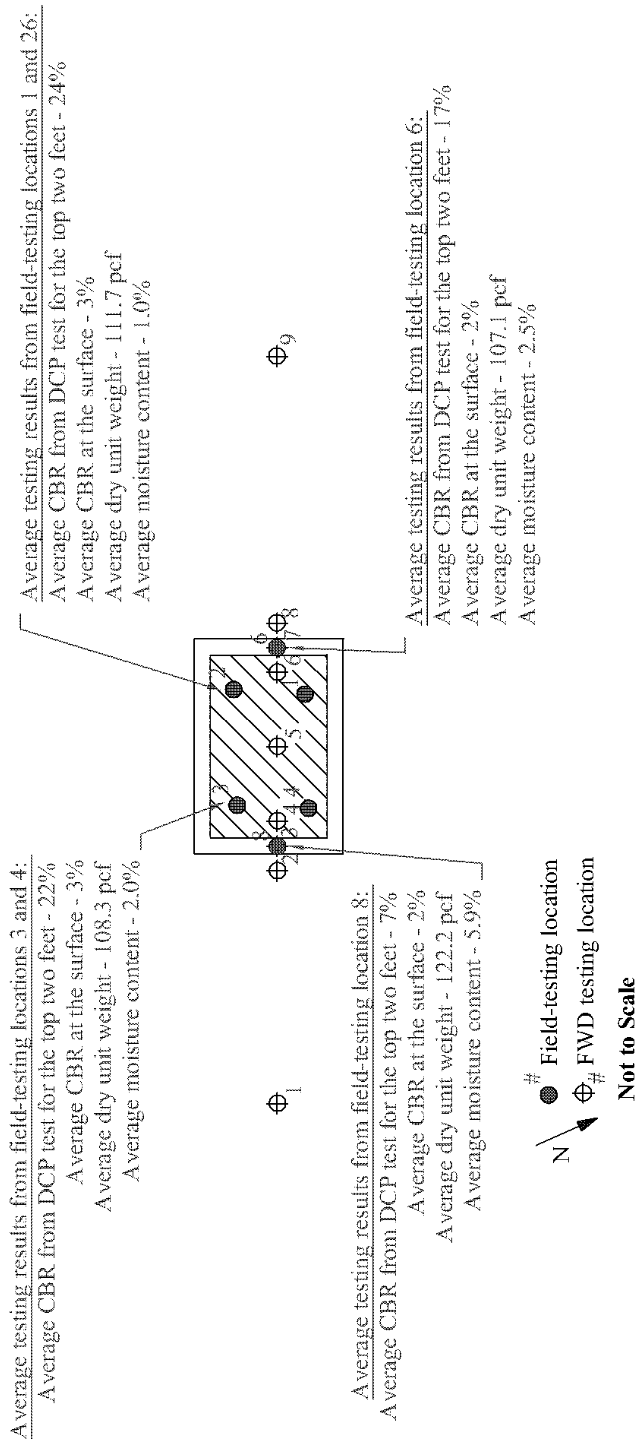


Figure 124 – Comparison of CBR values, dry unit weights and FWD testing results

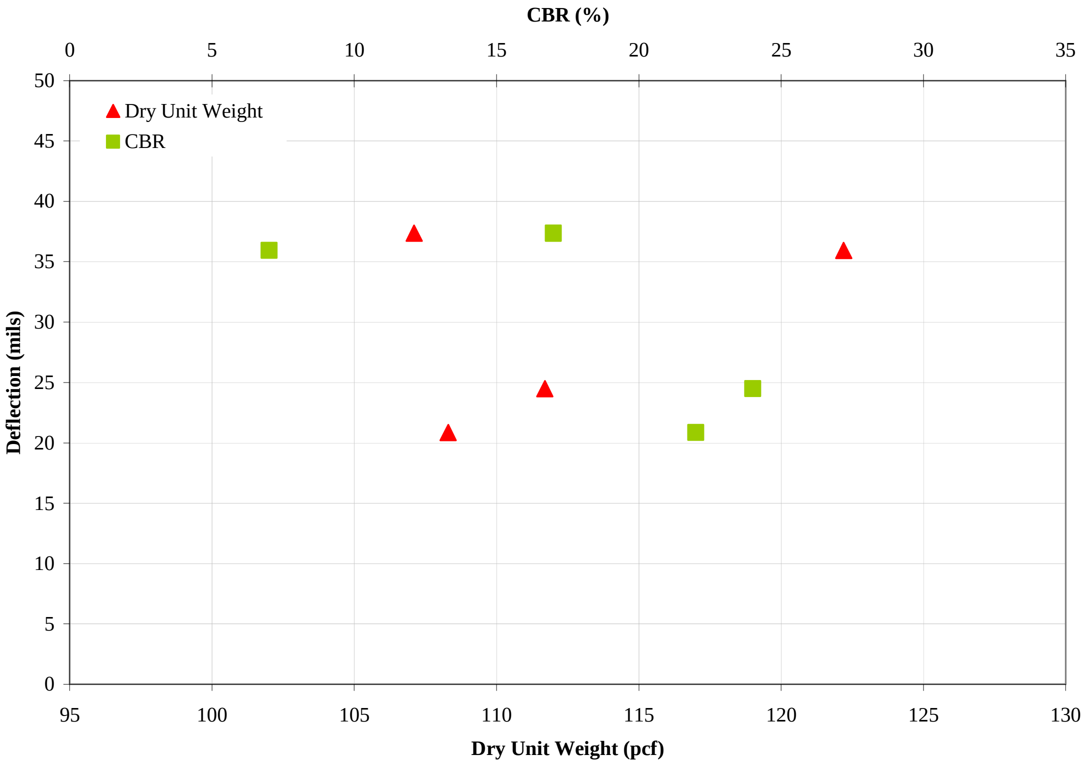


Figure 125 - Comparison of CBR values and dry unit weights to the deflections from the 15 kip FWD

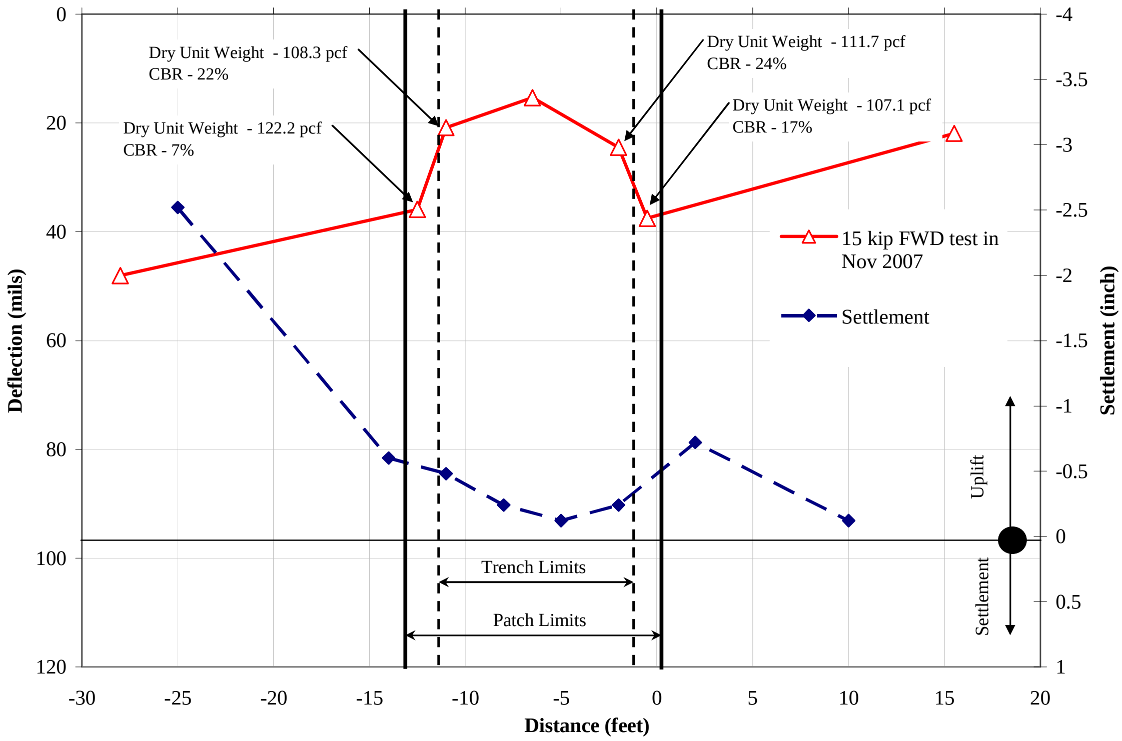


Figure 126 – 15 kip FWD test and settlement for Trench D

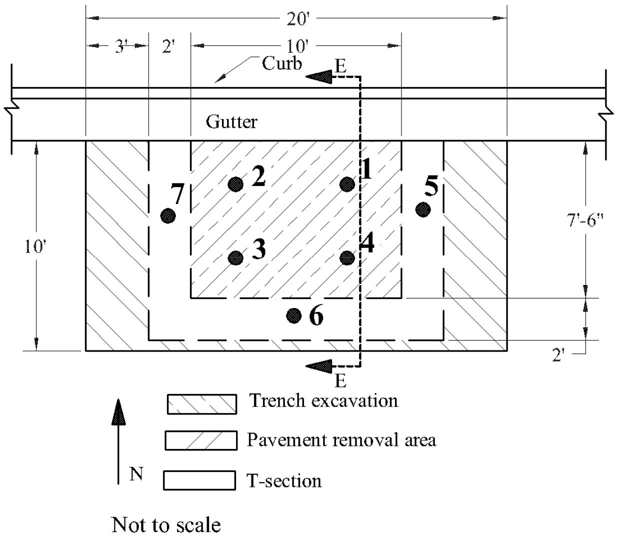
Key Results

- The backfill was placed at medium to dense relative densities ranging from 57% to 63%.
- The average CBR values were below the typical values from NAVFAC.
- The maximum settlement was 0.24 inches in the soil adjacent to the trench on the south side of the trench. At this location, there were low CBR values.
- The patch moved independent of the surrounding pavement during the winter. The patch experienced less uplift than the surrounding pavement. Even though the patch was performing better during winter conditions, it would still be perceived as a dip in the road during the winter.

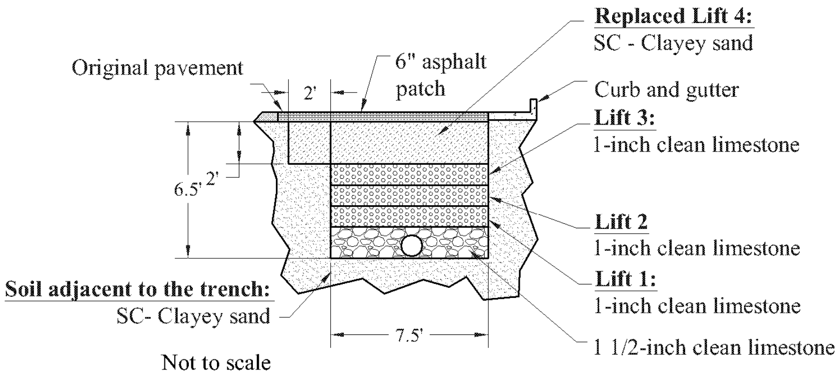
- The FWD test results showed high deflections occurred where the dry unit weights for the trench were the largest. The low FWD deflections occurred where the CBR values were higher in the trench.

4.5.5 - Recommended Trench E

Nuclear Density Gauge, Clegg Hammer, and DCP tests were performed in Trench E located on 7th Street and Carroll Avenue. On July 12, 2007 the third and fifth lift was tested at four points (see Figure 127). The trench was left open for six days. On July 18, 2007, the T-section was excavated two feet. This removed the fifth lift. Testing was performed on the same four points used to test the third and fifth lift, and then three additional test points in the T-section.



a)



b)

Figure 127 -- Testing locations for Trench E a) Plan view, b) Cross-section E- E

Nuclear Density Test Results

Table 49 summarizes the dry unit weights from the Nuclear Density testing results for Trench E and Table 50 summarizes the moisture content results from the Nuclear Density tests for Trench E. The probe depth was six inches.

The third and fifth lifts were constructed with 1-inch clean limestone. The classification was GP – poorly graded gravel. According to NAVFAC in Table 5, the range maximum dry unit weight of the compacted material is 115 pcf to 125 pcf. The optimum moisture content for the compacted material was 11% to 14%. From laboratory testing in Phase I, the maximum dry unit weight was 132.2 pcf. There was no bulking moisture content because it was free draining and the particle size was too large.

The replaced fifth lift was constructed with two mixtures of 1-inch clean limestone and soil from the City of Ames soil supply piles. These backfills were classified as SC-clayey sand. According to NAVFAC in Table 5, the range of maximum dry unit weights for compacted values was 105 pcf to 125 pcf. From laboratory testing, the maximum dry unit weight of Additional Backfill No. 1 was 108.4 pcf at a moisture content of 17.5% and the maximum dry unit weight for Additional Backfill No. 2 was 105.4 at a moisture content of 19.1%. Because the placement of the backfills was not known, the Standard Proctor results were averaged together; therefore the maximum dry unit weight was 106.2 pcf at a moisture content of 17.0%. The range of optimum moisture content was 11% to 19%.

On July 12, 2007, the third lift, for the four test points, had an average dry unit weight was 105.6 pcf (54% relative density) and an average moisture content was 5.6%. The fifth lift, for four test points, had an average dry unit weight of 102.2 pcf (47% relative density) and an average moisture content of 3.4%. Both lifts were at a medium density after compaction. The range of dry unit weights measured in the field was below NAVFAC typical values. The moisture contents for the third and fifth lift were below the typical moisture content from NAVFAC. The fifth lift was removed during the construction of the T-section.

On July 18, 2007, replaced fifth lift, for the four test points within the trench, had an average dry unit weight of 99.8 pcf and an average moisture content of 10.6%. The dry unit weights were below the typical values from NAVFAC in Table 5. The average dry unit weight was placed at 94% of the maximum from the Standard Proctor test. The moisture content of the backfill for all test points was below the optimum moisture content.

The replaced fifth lift, for the test three points located in the T-section, had an average dry unit weight of 98.7 pcf and an average moisture content of 12.2%. The dry unit weights measured in the field was below the typical values from NAVFAC. Based on laboratory testing, the backfill in the T-section was placed at 93% of the Standard Proctor. The moisture content of the backfill during placement was below the optimum moisture content which increases the collapse potential of the backfill.

Table 49 -- Dry unit weight results from the Nuclear Density tests on Trench E

Location	Number of test points	Average dry unit weight (pcf)	Relative density (%)	Min/Max Dry unit weight (pcf)	Standard deviation	Coefficient of variance (%)
Third lift	4	105.6	54%	103.3 / 111.3	3.8	3.6
Fifth lift tested on July 12, 2007	4	102.2	47%	99.5 / 104.6	2.3	2.3
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	99.8	N/A	94.5 / 102.7	5.0	5.0
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	98.7	N/A	95.5 / 104.5	5.0	5.1

Table 50 -- Moisture content results from the Nuclear Density tests for Trench E

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	3.0	4.9 / 6.0	0.5	16.6
Fifth lift tested on July 12, 2007	4	3.4	3.2 / 3.5	0.2	5.9
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	10.6	6.8 / 12.9	2.7	25.5
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	12.2	8.8 / 14.7	3.1	25.4

Figure 128 shows the relative density results from Phase I. Plotted on the chart were the average field placement results and the collapse index. The average field placement was in the medium density and at the moisture contents with the highest collapse index. The Figure shows the averaged field-testing results for the third and fifth lifts. These lifts were placed at a medium density. The field-testing results are circled and show that the test points were uniform within the trench.

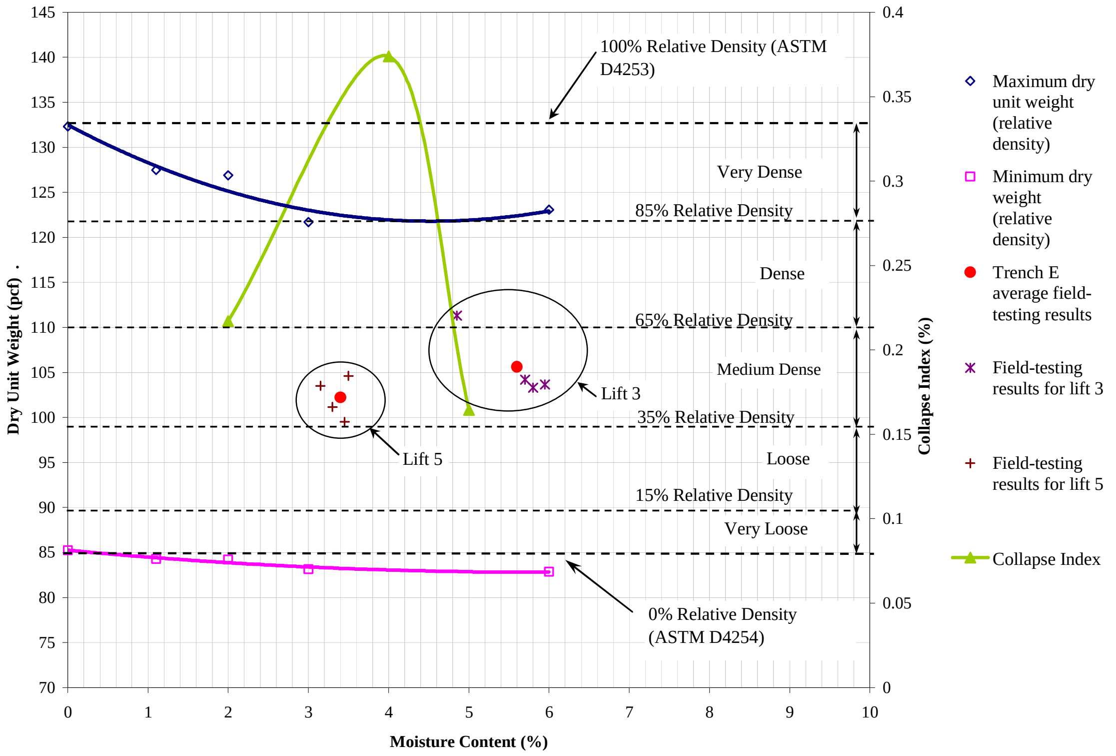


Figure 128 -- Relative density testing results from Phase I with the field-testing results from lifts 3 and 5

Figure 129 shows the Standard Proctor testing results for Addiction Backfills No. 1 and Additional Backfill No.2 used in Trench E. The results were averaged together for making comparisons for the field placement of the backfill. The backfill was placed above 90% of the Standard Proctor test. The Figure shows that the field-testing results were scattered.

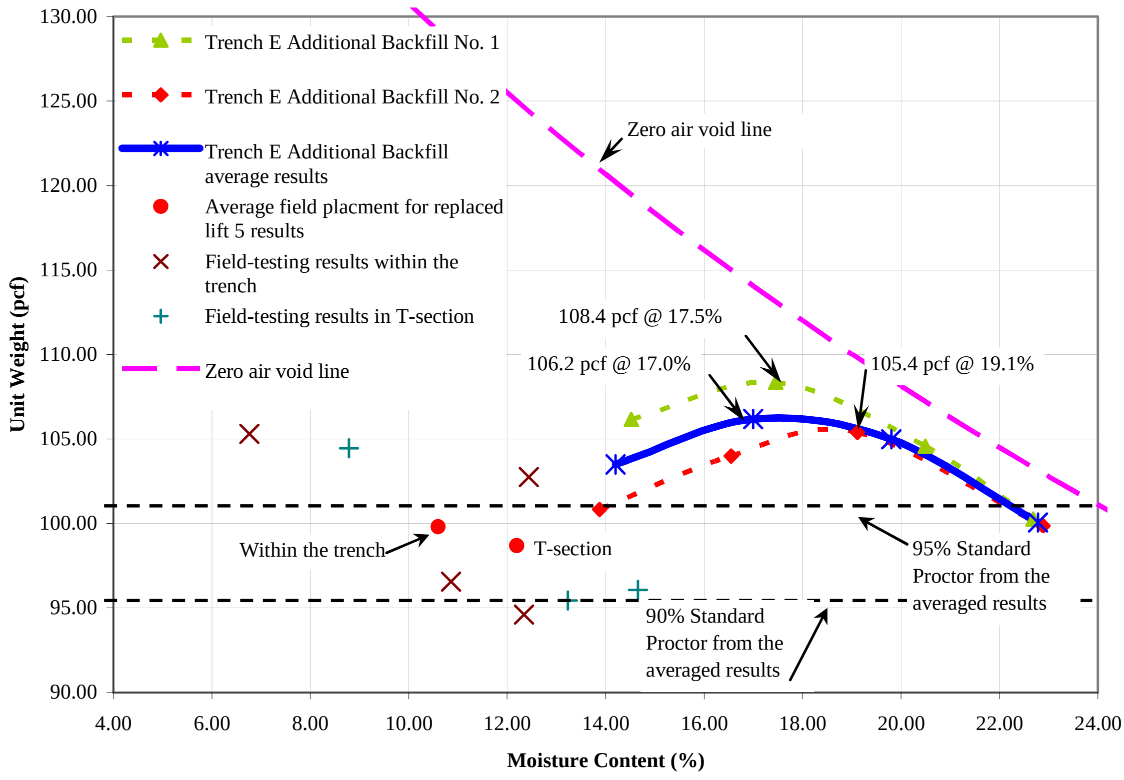


Figure 129 -- Standard Proctor testing results for the backfills used in the upper two feet of Trench E with the average field-testing results

DCP Test Results

Table 51 summarizes the DCPI readings from the DCP test for Trench E and Table 52 summarizes the average CBR results from the DCP test for Trench E. The third and fifth lifts were constructed with 1-inch clean limestone. The classification was GP – poorly graded gravel. According to NAVFAC, typical range of CBR values was 30% to 60

The replaced fifth lift was constructed with two mixtures of 1-inch clean limestone and soil from the City of Ames soil supply piles. These backfills were classified as SC-clayey sand. According to NAVFAC in Table 5, the range of typical CBR values was 5% to 20%.

Table 51 -- DCPI results from the DCP tests for Trench E

Location	Number of test points	Average depth of tests (inches)	Average DCPI	Standard deviation	Coefficient of variance (%)
Third lift	4	22.7	14.3	9.2	
Fifth lift tested on July 12, 2007	4	24.5	19.8	9.3	47.0
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	27.1	44.5	29.7	66.7
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	28.5	74.2	16.1	21.7

Table 52 – Average CBR results from the DCP tests for Trench E

Location	Number of test points	Average depth of tests (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	22.7	28	12	
Fifth lift tested on July 12, 2007	4	24.5	16	12.7	79.4
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	27.1	13	17.6	135.4
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	28.5	3	0.8	26.7

The third lift, for the four test points, the CBR values had an average CBR value of 28% for an average depth of 22.7 inches. It should be noted that the DCP test at point 1 was terminated at 12.6 inches. The average CBR value was below the typical values from NAVFAC. At the surface of the lift, the CBR values ranged from 4% to 10%. At the termination, of the DCP tests the CBR values ranged from 12% to 56%. The CBR values at the surface were below typical values from NAVFAC. At the termination the test, the CBR values at test points 1, 3, and 4 were within the range of typical values by NAVFAC and test point 2 was below the typical values from NAVFAC. The average CBR value as the termination of the tests was 42%, which was within the typical range of values from NAVFAC. The profile shows that backfill follows the same generalized pattern through the depth of the profiles. This indicated that the backfill was placed and compacted in a uniform manner. The profiles increased with depth, indicating the backfill increased in strength with depth. Figure 130 plots profiles of the CBR values as a function of depth.

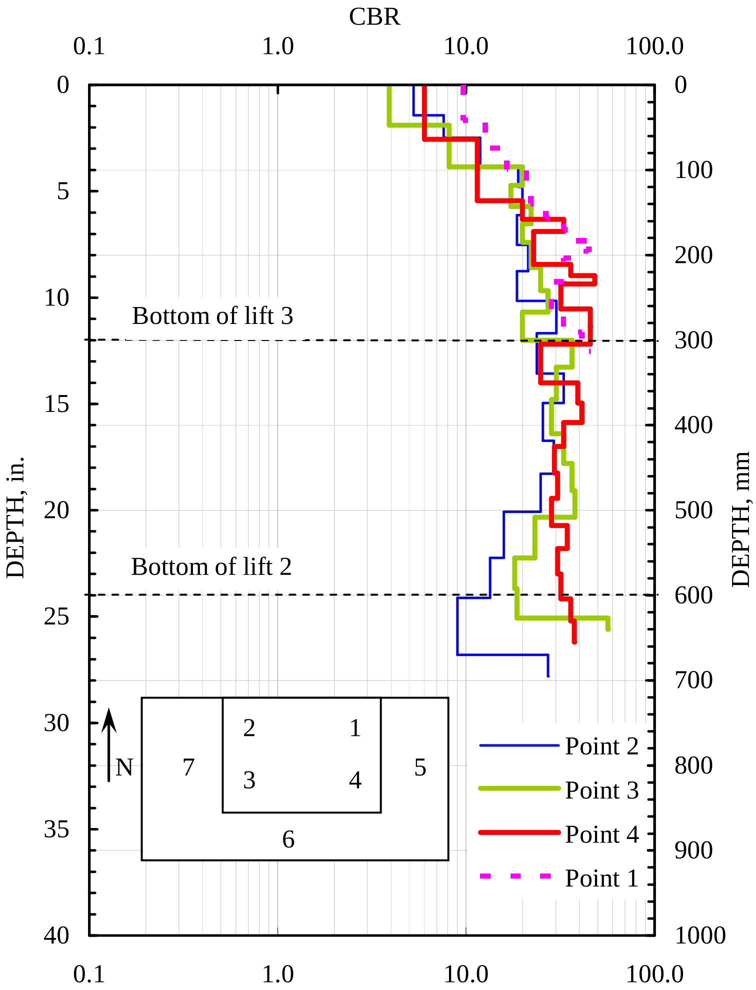


Figure 130 -- CBR from the DCP tests profiles for lift 3 in Trench E

The fifth lift, tested on July 12, 2007 for the four test points within the trench, had an average CBR of 16% extending 24.5 inches. At the surface of the lift, the CBR values ranged from 3% to 5%. These values were below the typical values from NAVFAC. The CBR values at the termination of the DCP tests ranged from 22% to 53%. All of the test points were within the typical values from NAVFAC, except for test point 4. The profiles all followed the same pattern thought the lift, suggesting that the lifts were compacted in an even manner. All the CBR profiles increased with depth indicating that the backfill increases with strength. Figure 131 shows the CBR profiles for the four test points within the trench on the fifth lift on July 12, 2007.

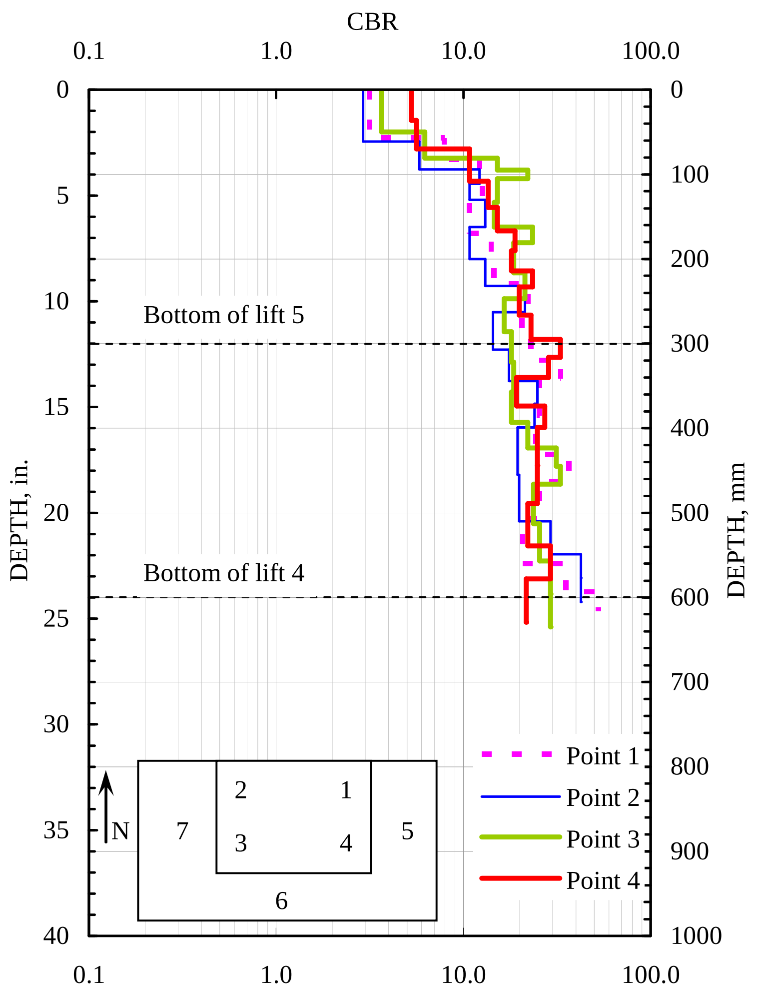


Figure 131 -- CBR profiles for lift 5 in Trench E tested on July 12, 2007

The replaced fifth lift, tested on July 18, 2007, for the four test points within the trench, had an average CBR of 13% extending 27.1 inches. At the surface of the lift, the CBR values ranged from 2% to 3%. These values were below the typical values provided by NAVFAC in Table 5. At the termination of the test, the CBR values ranged from 4% to 65%. Point 4 was below the typical values and points 1 and 2 were above the typical values. At a depth of between 17 and 20 inches for tests points 2, 3, and 4, the CBR values increased from 12% to 13% to a range of 32% to 54%. This indicated that the DCP probe penetrated to the 1-inch clean limestone below. Figure 132 shows CBR profile for the four test points within the trench on the replaced fifth lift.

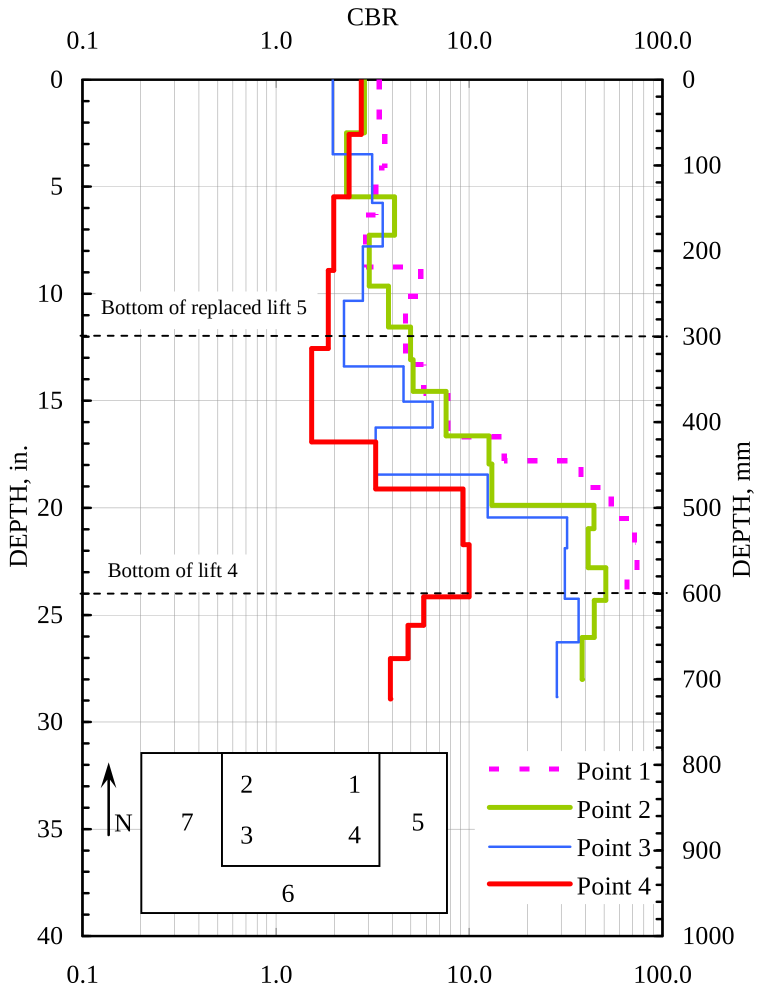


Figure 132 -- CBR profiles for test points within Trench E for replaced lift 5 tested on July 18, 2007

Figure 133 shows the CBR profiles for the three test points test on July 18, 2007 in the T-section. The replaced fifth lift, tested on July 18, 2007 at three test points in the T-section, had an average CBR of 13% extending 28.5 inches. The average CBR values for the top two feet ranged from 2% to 3%. These average values were below the typical values from NAVFAC. At the surface and termination of the lift, the CBR values ranged from 2% to 3%. The CBR values did not reflect the penetration into previous lifts or the subgrade below the T-section. This shows that the backfill in the T-section was not compacted sufficiently.

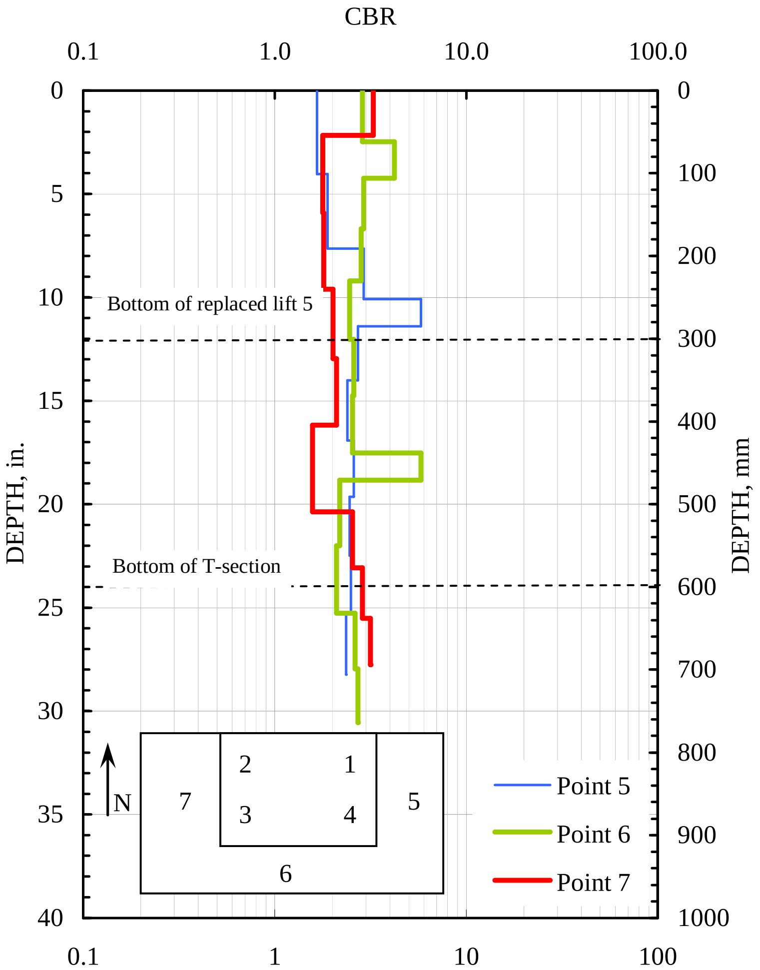


Figure 133 -- CBR profiles for test points in the T-section for the lift 5 tested on July 18, 2007

Clegg Hammer Test Results

Table 53 summarizes the impact values from the Clegg Hammer tests for Trench E and Table 54 summarizes the CBR results from the Clegg Hammer tests for Trench E. The CBR value for each point was calculated and then the CBR values were averaged.

For the third lift, for the four test points, the CBR values ranged from 18% to 22% with an average CBR value of 22%. These values were below the typical CBR values were from NAVFAC. For the fifth lift, tested at four points on July 12, 2007, The CBR values ranged from 11% to 16% with an average CBR value 14%. These CBR values were below the typical values from NAVFAC.

The replaced fifth lift, for the four test points within the trench and tested on July 18, 2007, had CBR values ranging from 3% to 5% with an average CBR value of 4%. These values were below the typical values from NAVFAC. The replaced fifth lift, for three test points in the T-section and tested on July 18, 2007, had CBR values ranging from 3% to 5% with an average CBR value of 5%. The average CBR value was within the recommend values from NAVFAC.

Table 53 -- Impact value results from the Clegg Hammer tests for Trench E

Location	Number of test points	Average IV reading	Min/Max IV readings	Standard deviation	Coefficient of variance (%)
Third lift	4	15.2	13.6 / 17.3	1.7	11.2
Fifth lift tested on July 12, 2007	4	11.2	9.9 / 12.3	1.0	9.0
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	4.3	3.3 / 5.3	0.9	20.9
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	4.7	3.5 / 5.8	1.2	25.5

Table 54 -- CBR results from the Clegg Hammer tests for Trench E

Location	Number of test points	Average CBR (%)	Min/Max CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	22	18 / 27	3.8	17.0
Fifth lift tested on July 12, 2007	4	14	11 / 16	1.8	13.2
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	4	3 / 5	0.8	20.0
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	5	3 / 6	1.2	26.1

Table 55 compares CBR values obtained from the DCP and Clegg Hammer tests. The first comparison was to compare the average CBR values from the Clegg Hammer with the average CBR value over the depth of the DCP test for each lift. The difference between CBR values from the Clegg Hammer tests and the DCP test ranged from 21.4% to 75%. The large difference is the result of the Clegg Hammer testing only the surface of the lift. To compensate for the difference in the thickness of the material being tested, to 4 to 6 inches of the DCP test were average together. However, comparing the surface CBR values from the DCP test did not improve the difference between the Clegg Hammer test and the DCP test.

Because the Clegg Hammer was broken in the fall 2007 and it is not known when the Clegg Hammer broke, the difference in the between the Clegg Hammer results and the DCP tests were inconclusive.

Table 55 -- CBR results from the Clegg Hammer and DCP test in Trench E

Location	Average CBR values from Clegg Hammer (%)	Average CBR values from DCP for the depth of the profile (%)	Percent difference between the Clegg Hammer and the DCP test for the depth of the profile (%)	CBR values from DCP for the upper most 4 to 6 inches profile (%)	Percent difference between the Clegg Hammer and the DCP test for the upper most 4 to 6 inches (%)
Third lift	22	28	21.4	6	367
Fifth lift tested on July 12, 2007	16	13	23.1	4	300
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	16	75	3	33.3
Replaced fifth lift at test points in the T-section tested on July 18, 2007	5	3	66.7	3	66.7

FWD Test Results

FWD testing was performed on November 5, 2007. Figure 134 shows the testing locations for Trench E. Figure 135 shows the FWD testing results for Trench E on November 5, 2007. The FWD testing for Trench E showed that the “zone of influence” was present on both the east and west sides of the trench. The FWD tests within the trench showed that the backfill was placed relatively even across the trench without the peak stiffness seen in the other trenches.

For the 15 kip load the deflection in the middle of the trench was 14.74 mils. The center of the trench did not exhibit the decrease in deflection as the other trenches. Compared to other trenches, the backfill in this trench gives a rather uniform response. At the edge of the trench at FWD, testing locations 5 and 7 the deflections were 14.74 mils and 18.73 mils, respectively. At FWD testing location 1, the deflection was 15.80 mils. The T-section on the west side had a higher deflection than on the east side of the trench.

The FWD diagram shows that on the east side of the trench, the “zone of influence” is present. The “zone of influence” was beyond the outer limits of the T-section. On the west side of the trench, the deflections were high in comparison to other location. Figure 136 shows that there was no visible cracking in the pavement. Based on the photographs taken during construction of the trench, equipment was only located on the east side of the trench (see Figure 60). This does not account for the difference in the response to the FWD testing.

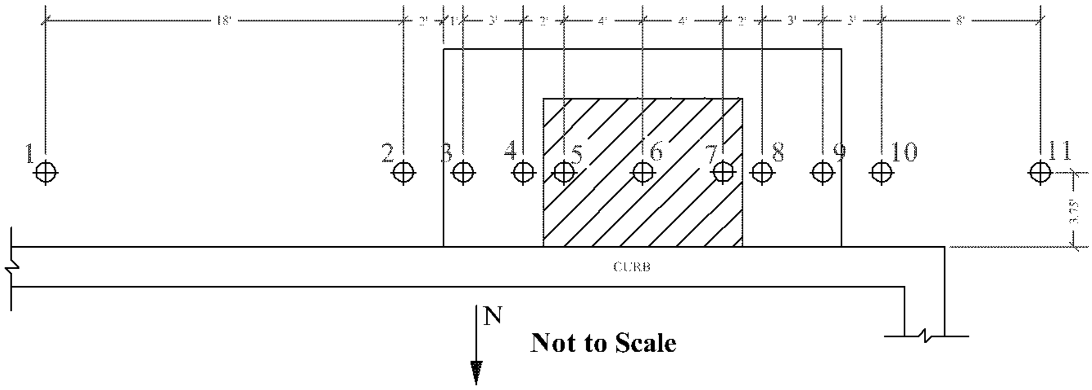


Figure 134 -- FWD test locations for Trench E

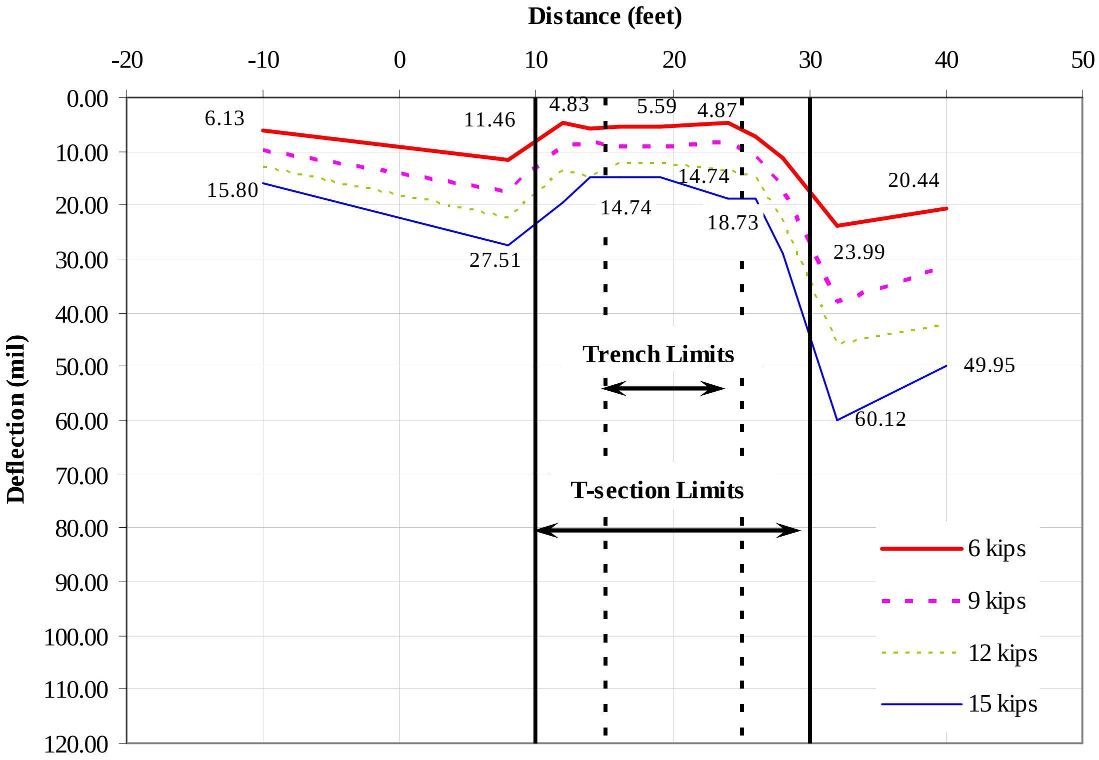


Figure 135 -- FWD test results for Trench E

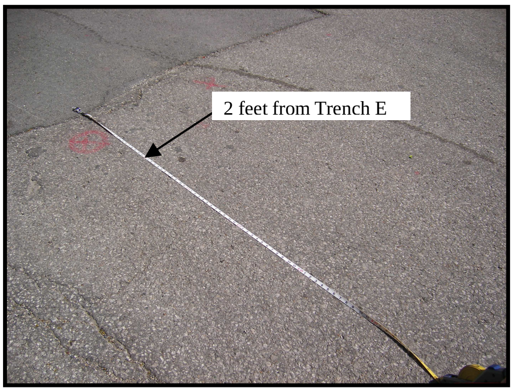


Figure 136 – Condition of the pavement 2 feet west of Trench E at FWD testing location 10

Post Construction Elevation Survey

The post construction elevation surface was constructed using survey data collected on July 20, 2007 and March 19, 2008.

Trench E was surveyed at 46 grid points. The benchmark was the hydrant northwest of the trench at the intersection of 6th Street and Carroll Avenue. From the elevation survey on July 20, 2007, the highest elevation was 97.73 feet at survey point 16 and the lowest elevation was 97.24 feet at survey point 12. From the elevation survey March 19, 2008, the highest pavement elevation was 97.68 feet at survey point 37 and the lowest elevation was 97.23 feet at survey point 12. The average settlement was 0.03 feet (0.36 inches) and the maximum settlement was 0.06 feet (0.72 inches) along the south edge of the trench at survey points 22 and 26. Figure 137 shows the location of the grid points and Figure 138 shows the pavement surface for Trench E.

Figure 139 shows that settlement and elevation profiles for Trench E. This shows the Trench had settled since construction. Five feet west of the trench, the pavement was in a state of uplift. This caused the settlement of the patch to appear greater.

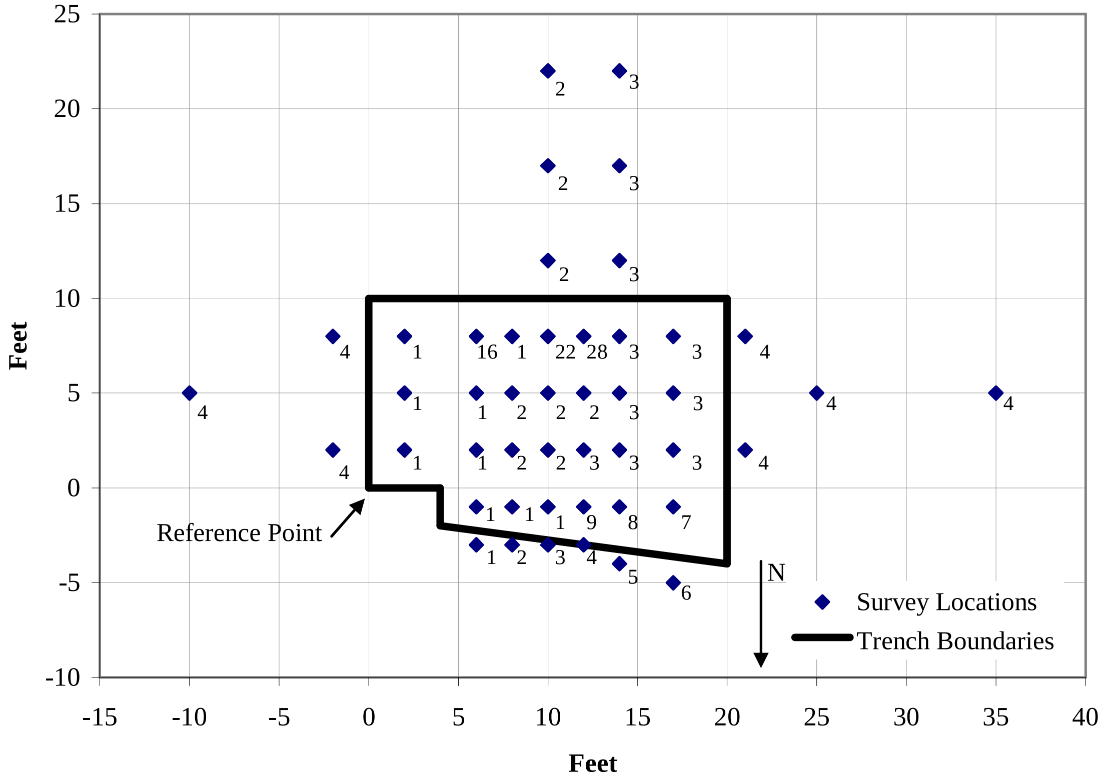


Figure 137 -- Pavement surface elevations of Trench E

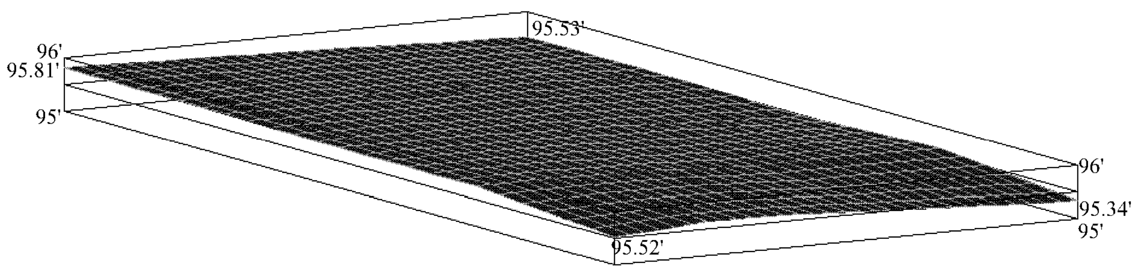


Figure 138 – Surface of Trench E

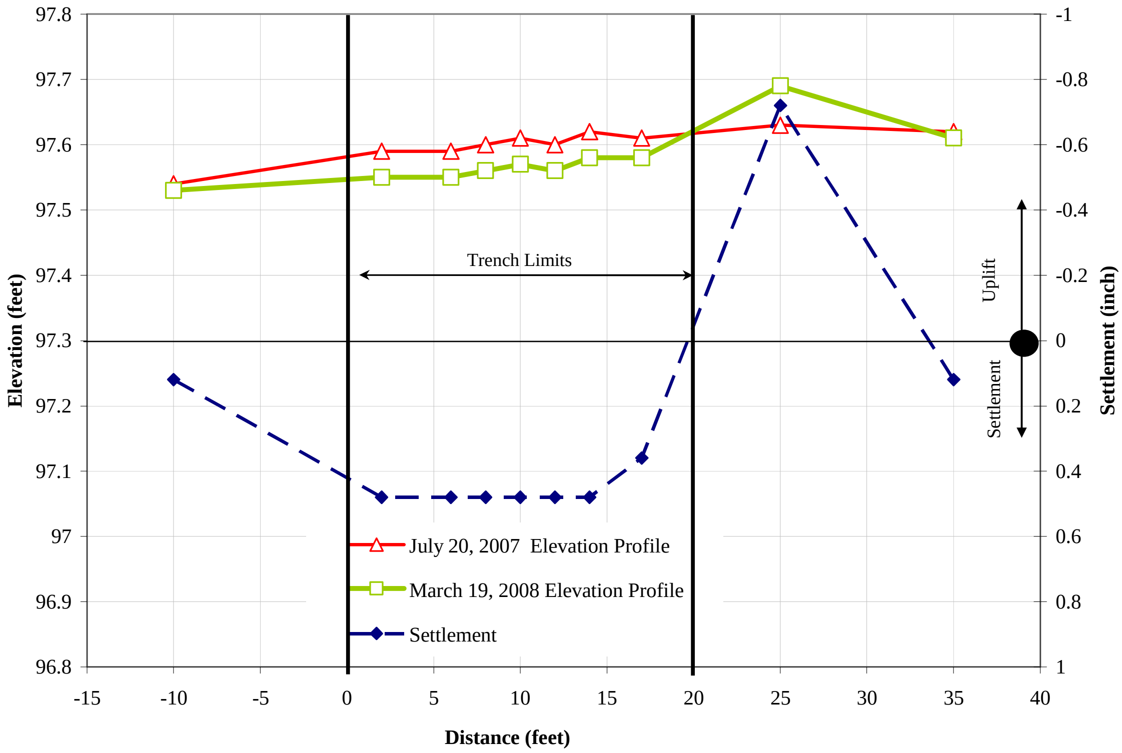


Figure 139 -- Settlement along centerline of Trench E

Comparison of Field-testing Results to Long Term Monitoring

Figure 140 shows the FWD locations and the field-testing locations superimposed with field-testing results averaged. The dry unit weights at test point 5 (west side) and 7 were 104.5 pcf and 95.5 pcf, respectively. The average CBR values for test point 5 and 7 was 2% for both test points. At the top of the fifth lift, the CBR value was 2% and 3% for test points 5 and 7, respectively. The higher deflection on the west side of the trench was the result of the backfill not being compacted to a dense state.

Figure 141 shows the FWD deflection plotted verses the dry unit weight and CBR values. This Figure shows that there was no empirical relationship between the CBR values, dry unit weights and the FWD deflections.

Figure 141 shows the settlement of the trench with the FWD deflections and field-testing results. The maximum settlement of Trench E was 0.72 inches along the south edge of the trench. The dry unit weight at test point 6 on the south side of the trench was 96.1 pcf at a moisture content of 14.7%. The CBR values from the DCP tests were constant with depth. This Figure shows that where the FWD deflections were lowest, the settlement was the highest. Outside the trench, the highest deflection on the FWD results occurred where the trench was uplift during the winter.

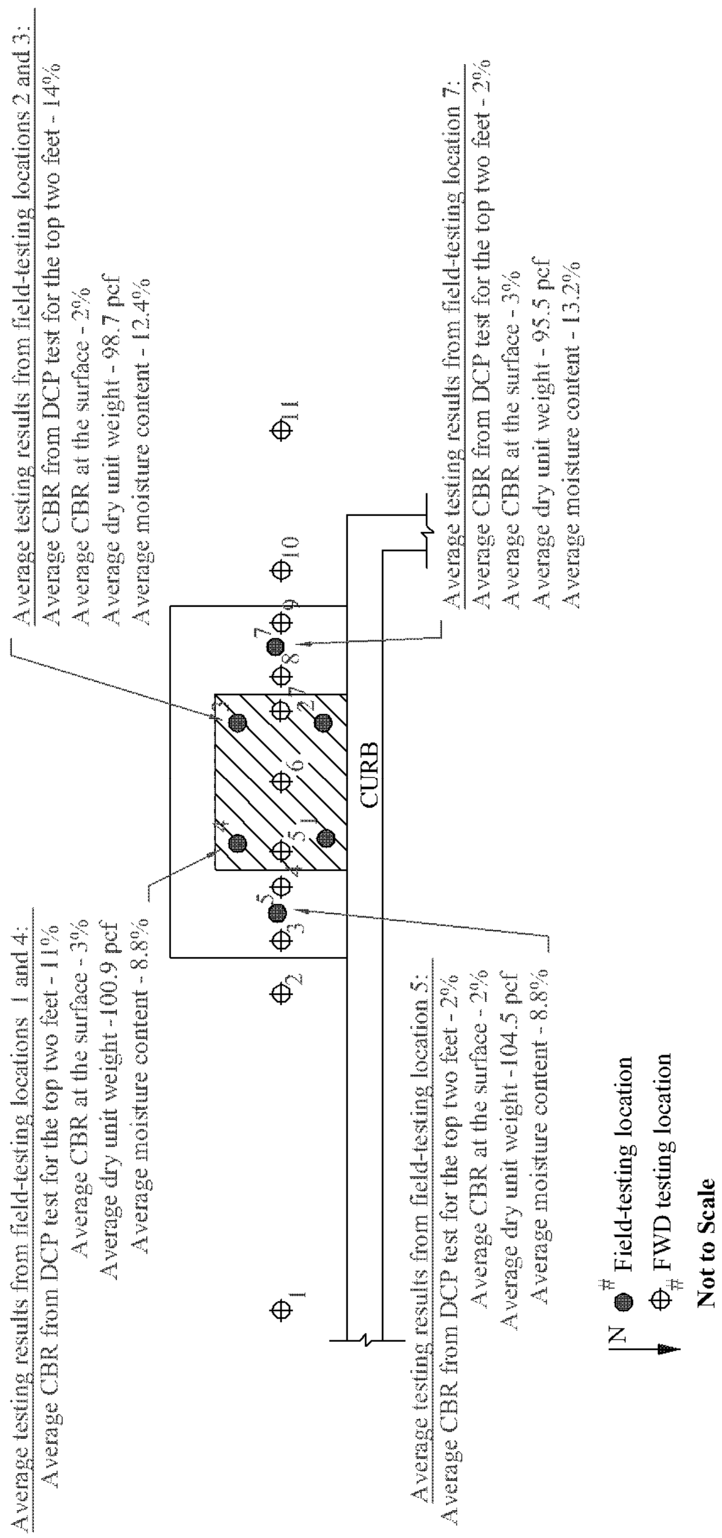


Figure 140 – Comparison of CBR values, dry unit weights and FWD testing results

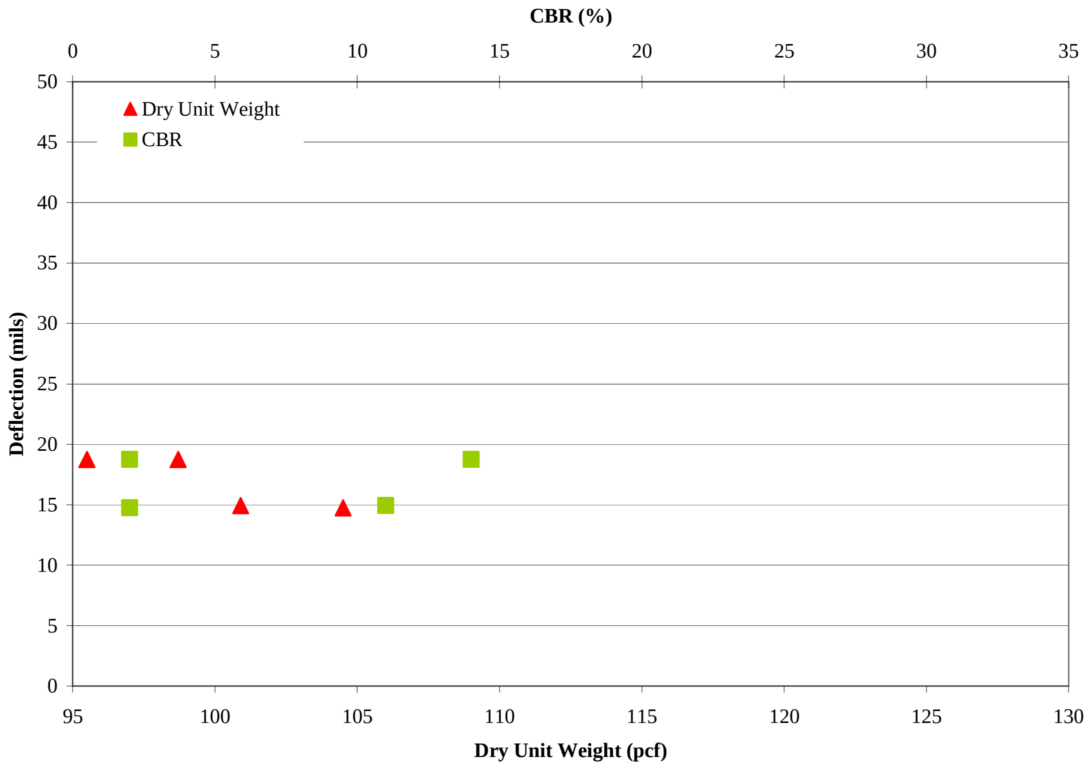


Figure 141 - Comparison of CBR and dry unit weights to the deflections from the 15 kip FWD

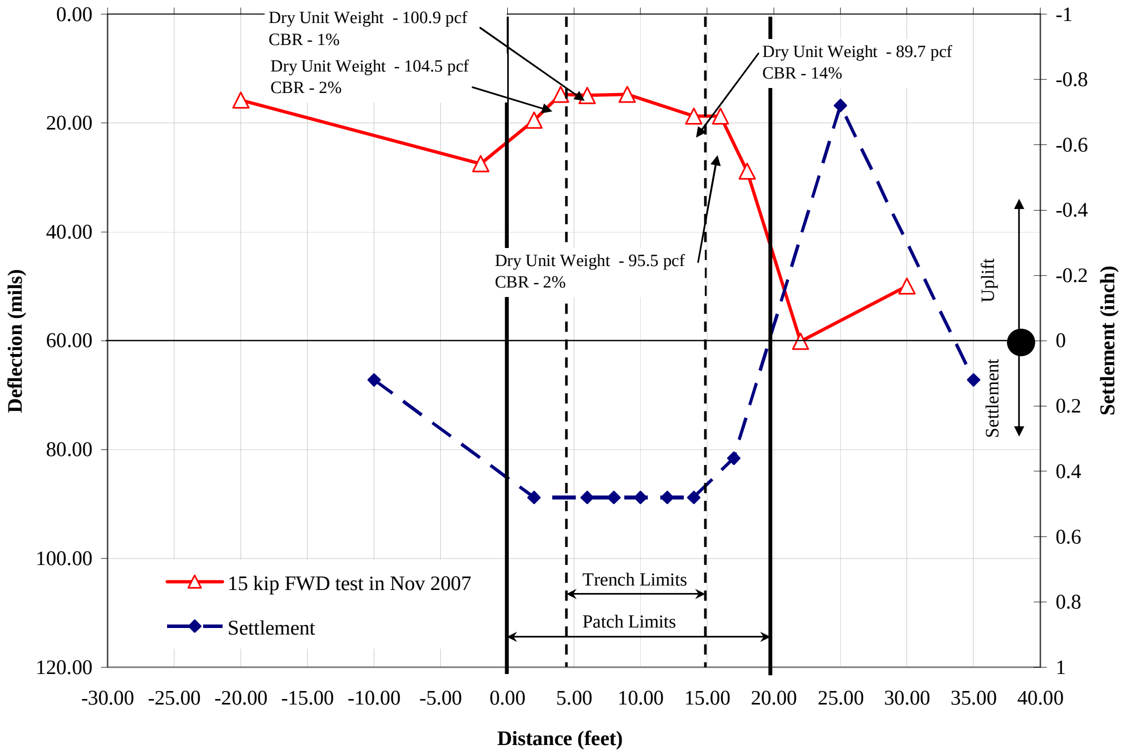


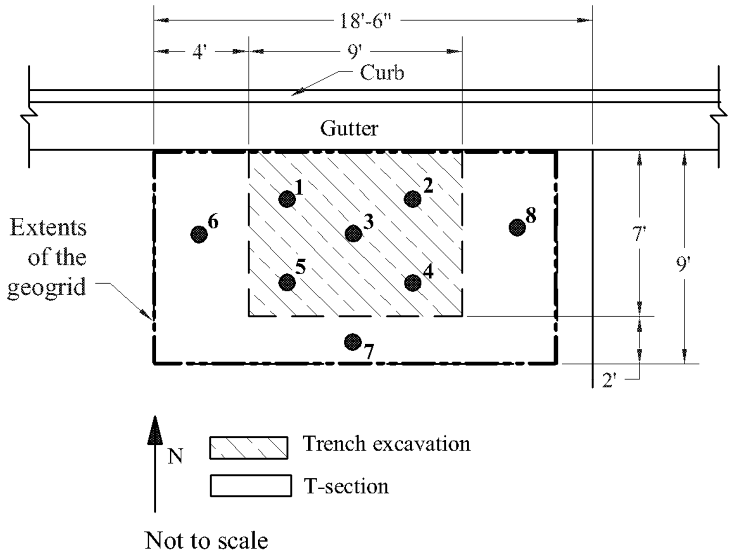
Figure 142 – 15 kip FWD test and settlement for Trench E

Key Results

- The third lift was placed at a medium dense compaction density.
- The backfill used in for the T-section was placed at 93 to 94 percent of the Standard Proctor. The backfill was dry of optimum, which will increase its collapse potential.
- The CBR values in the replaced fifth lift were below the typical values indicated by NAVFAC.
- The T-section was not compacted to the same dry unit weights as the backfill within the trench. The CBR values in this T-section were also below the CBR values in the center of the trench.
- The CBR values were consistently below the typical values from NAVFAC
- The highest deflection in the trench from the FWD testing was the result the low density of the backfill during construction.
- The "zone of influence" was present on both sides of the trench outside of the T-section.
- The highest settlement was located on the south edge of the trench where the backfill was placed at a low density.
- West of the trench the pavement was uplift during the winter causing the settlement of the patch to be perceived as greater than what it actual was.

4.5.6 - Recommended Trench F

Nuclear Density, Clegg Hammer, and DCP tests were performed on Trench F located on 6th Street and Carroll Avenue. On July 12, 2007, the second and fourth lifts were tested at five points (points 1, 2, 3, 4, and 5). On July 18, 2007, after the excavation of the fourth lift and additional soil to from the T-section, the trench was tested at the same five test points within the trench as well as three additional points in the T-section for a total of eight test points (see Figure 143).



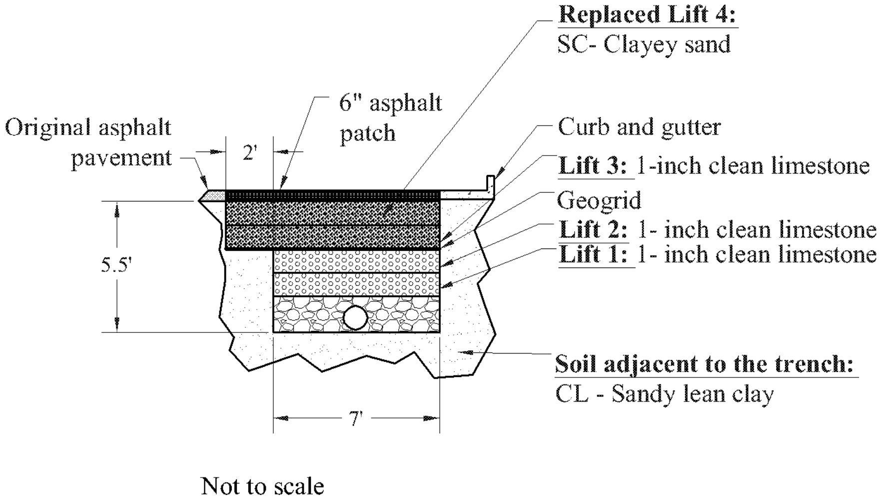


Figure 143 -- Testing locations for Trench F a) Plan view b) Cross-section

Nuclear Density Test Results

Table 56 summarizes the dry unit weights from the Nuclear Density testing results for Trench F and Table 57 summarizes the moisture content results from the Nuclear Density tests for Trench F. The probe depth was six inches.

The second and fourth lifts were constructed with 1-inch clean limestone. The classification was GP – poorly graded gravel. According to NAVFAC, the range maximum dry unit weight of the compacted material is 115 pcf to 125 pcf. The optimum moisture content for the compacted material was 11% to 14%. From laboratory testing in Phase I, the maximum dry unit weight was 132.2 pcf. There was no bulking moisture content because it was free draining and the particle size was too large.

The replaced fourth lift was constructed with two mixtures of 1-inch clean limestone and soil from the City of Ames soil supply piles. According to NAVFAC, the range of maximum dry unit weights for compacted values was 105 pcf to 125 pcf. The range of optimum moisture content was 11% to 19%. The typical CBR values from NAVFAC were 5% to 20%. To evaluate the placement of the backfill, the Standard Proctor test results from the two backfills was averaged together. Laboratory testing found that the maximum dry unit weight was 106.2 pcf at a moisture content of 17.0%.

On July 12, 2007, the second lift, at the five test points on second lift, had an average dry unit weight of 95.2 pcf and an average moisture content of 5.2%. The dry unit weights were below the typical values from NAVFAC. Based on laboratory testing the backfill was placed at 29% relative density. This corresponded to loose compaction from Table 6. The moisture contents were below the typical values from NAVFAC. The fourth lift, tested at five test points, had an average dry unit weight of 99.0 pcf and an average moisture content of 3.6%. The dry unit weights were below the typical values from NAVFAC. Based on laboratory testing, the backfill was placed at 39% relative density. This corresponded to medium dense compaction from Table 6. This lift was removed for the construction of the T-section.

The replaced fourth lift, for the five test points within the trench, had an average dry unit weight of 108.8 pcf and an average moisture content of 12.3%. The dry unit weights were within the typical range of values from NAVFAC. The moisture contents were below typical moisture contents from NAVFAC. Based on laboratory testing the backfill was placed at 92% of the Standard Proctor. The moisture content was below the optimum moisture content.

The replaced fourth lift, for the three test points located in the T-section, had an average dry unit weight of 110.6 pcf and an average moisture content of 12.6%. The dry unit weights were within the typical values from NAVFAC. The moisture content was below the typical values from NAVFAC. Based on laboratory testing the backfill was placed at 93% of the Standard Proctor test.

Table 56 -- Dry unit weight results from the Nuclear Density tests on Trench F

Location	Number of test points	Average dry unit weight (pcf)	Relative density (%)	Min/Max dry unit weight (pcf)	Standard deviation	Coefficient of variance (%)
Second Lift	5	95.2	29	90.7 / 99.1	4.2	4.4
Fourth Lift tested on July 12, 2007	5	99.0	39	85.7 / 104.1	3.5	12.1
Replaced Fourth Lift for test points within the trench tested on July 18, 2007	5	108.8	N/A	99.7 / 114.3	5.7	5.2
Replaced Fourth Lift for test points in the T-section tested on July 18, 2007	3	110.6	N/A	108.1 / 112.3	5.1	2.1

Table 57 -- Moisture content results from the Nuclear Density tests for Trench F

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Standard deviation	Coefficient of variance (%)
Second Lift	5	5.6	3.4 / 7/3	1.0	18.8
Fourth Lift tested on July 12, 2007	5	3.6	3.5 / 4.0	0.2	5.4
Replaced Fourth Lift for test points within the trench tested on July 18, 2007	5	12.3	9.3 / 14.5	1.8	14.5
Replaced Fourth Lift for test points in the T-section tested on July 18, 2007	3	12.6	9.3 / 12.3	3.0	23.8

Figure 144 shows the field placement results of for second and fourth lift for Trench F. The backfill was placed at loose density. The averaged field-testing results were plotted along with the individual testing results for each lift. The testing results for the individual testing points are scattered. This indicates the lifts were not uniformly placed.

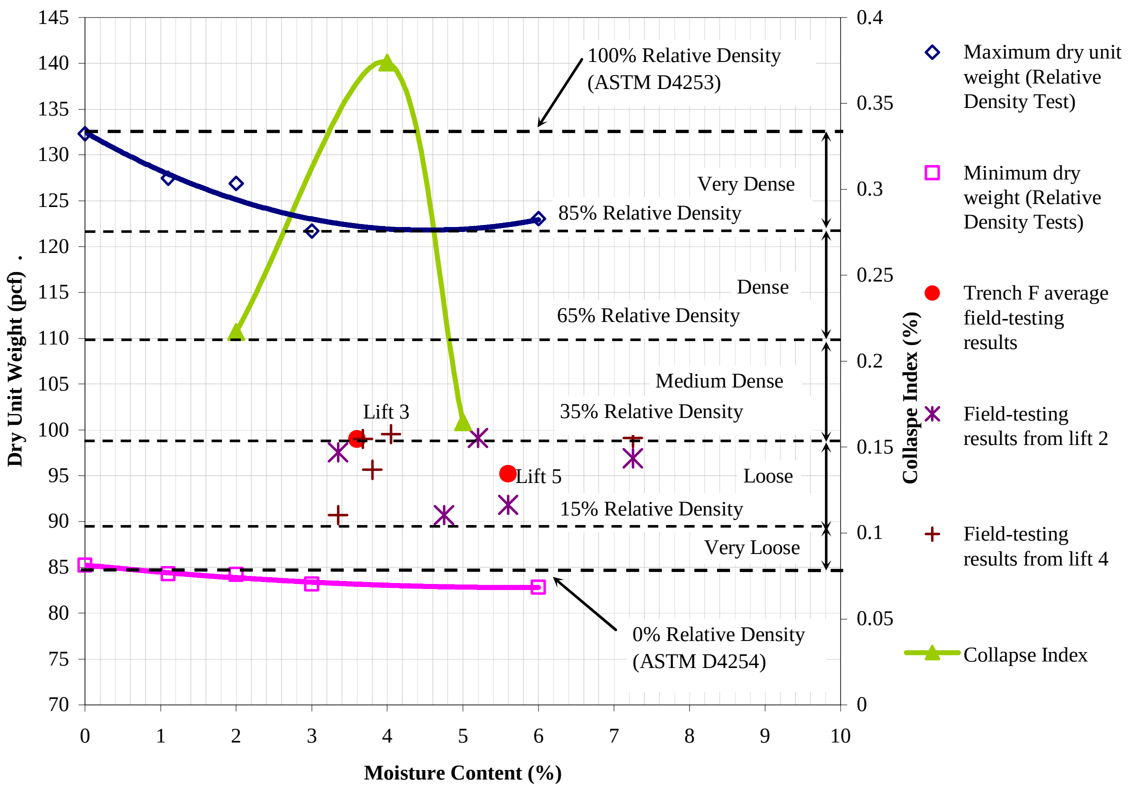


Figure 144 -- Relative density testing results for Trench F with field-testing results

Figure 145 shows the Standard Proctor test results for the backfill used in the top two feet of the trench. The Figure shows that the field placement of the backfill was between 90% and 95%. The backfill within the T-section was placed at a higher dry unit weight than within the trench. This is the only trench with a T-section compacted to a highest dry unit weight compared to the other trenches.

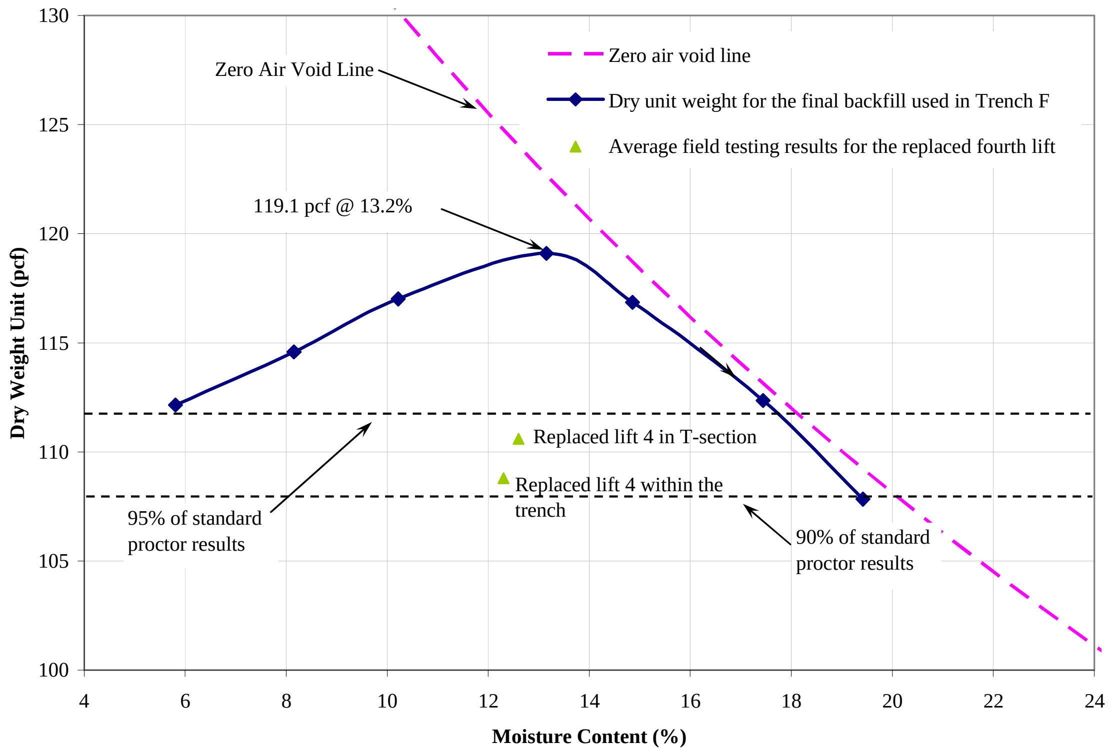


Figure 145 -- Standard Proctor test results for the backfill used in the top two feet of the trench with the field-testing results for the replaced fourth lift

DCP Test Results

Table 58 summarizes the DCPI readings from the DCP tests for Trench F and Table 59 summarizes the average CBR results from the DCP tests for Trench F. The second and fourth lifts were constructed with 1-inch clean limestone. The classification was GP – poorly graded gravel. According to NAVFAC, typical range of CBR values was 30% to 60. The replaced fifth lift was constructed with two mixtures of 1-inch clean limestone and soil from the City of Ames soil supply piles. According to NAVFAC, the typical range of CBR values was 5% to 20%. To evaluate the placement of the backfill, the Standard Proctor test results from the two backfills was averaged together. Laboratory testing found that the maximum dry unit weight was 106.2 pcf at a moisture content of 17.0%.

Table 58 -- DCPI results from the DCP tests for Trench F

Location	Number of test points	Depth of test (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Second Lift	5	24.6	30.6	22.7	74.9
Fourth Lift tested on July 12, 2007	5	24.5	22.1	9.6	43.2
Replaced Fourth Lift for test points within the trench tested on July 18, 2007	5	30.5	2.4	11.6	493.6
Replaced Fourth Lift for test points tested in the T-section on July 18, 2007	3	30.2	58.4	21.7	37.2

Table 59 -- CBR results from the DCP tests for Trench F

Location	Number of test points	Depth of test (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Second Lift	5	24.6	11	7.0	63.6
Fourth Lift tested on July 12, 2007	5	24.5	15	7.1	47.3
Replaced Fourth Lift for test points within the trench tested on July 18, 2007	5	30.5	13	0.4	3.1
Replaced Fourth Lift for test points in the T-section tested on July 18, 2007	3	30.2	3	1.7	45.8

Figure 146 has the CBR profiles for the five test points within the trench for the second lift. The second lift, tested on July 12, 2007, for the five test points within the trench, had an average CBR value of 11% extending 24.6 inches. The average CRB value was below the typical values from NAVFAC. At the surface of the lift, the CBR values ranged from 2% to 3% and at the termination of the tests the CBR values ranged from 2% to 19%. These values were below the recommend values from NAVFAC. At the start of the test, the CBR values were similar however, at the termination of the test the CBR values were scattered. At a depth of 10 inches, the profiles diverge. This is the interface between the 1-inch clean and 1½-inch clean limestone, which was used as bedding for the pipe.

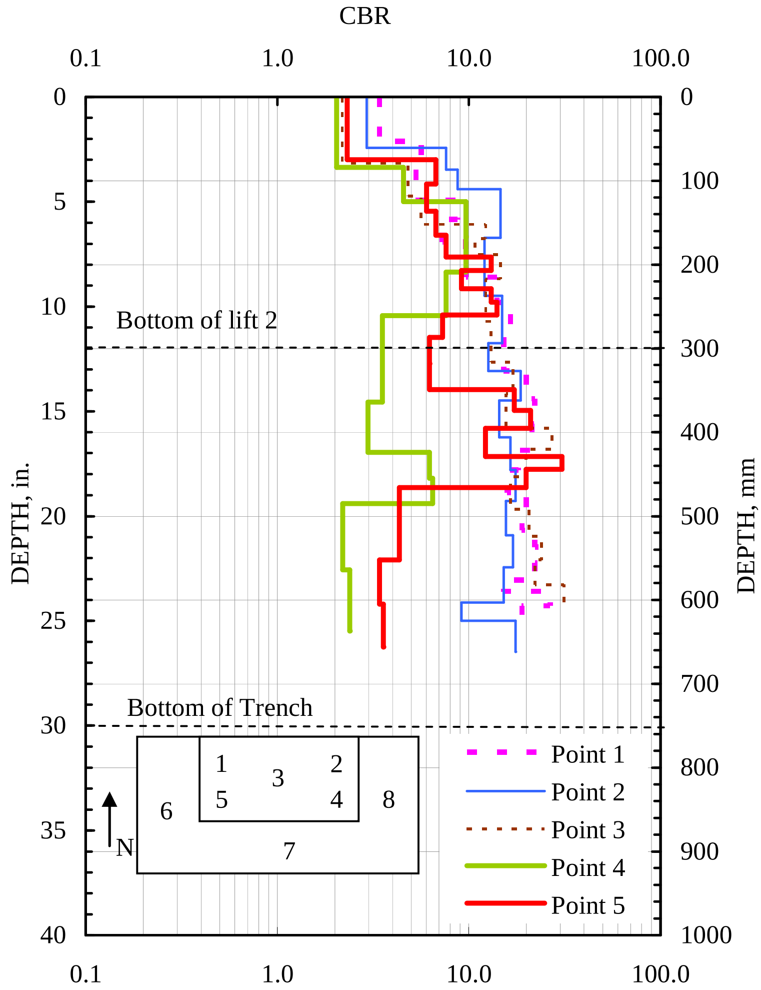


Figure 146 -- CBR from the DCP tests profiles for lift 2 in Trench F

Figure 147 shows the CBR profiles for five test points tested on July 12, 2007 within the trench for the fourth lift. The fourth lift, tested on July 12, 2007, had for the five test points within the trench an average CBR of 15% extending 24.5 inches. At the surface of the lift the CBR values ranged from 2% to 3% and at the termination of the test the CBR values ranged from 16% to 25%. These values were below the typical CBR values from NAVFAC.

The CBR profiles increased with depth. The profiles also followed the same pattern throughout the profile. This indicated that the lift was evenly compacted.

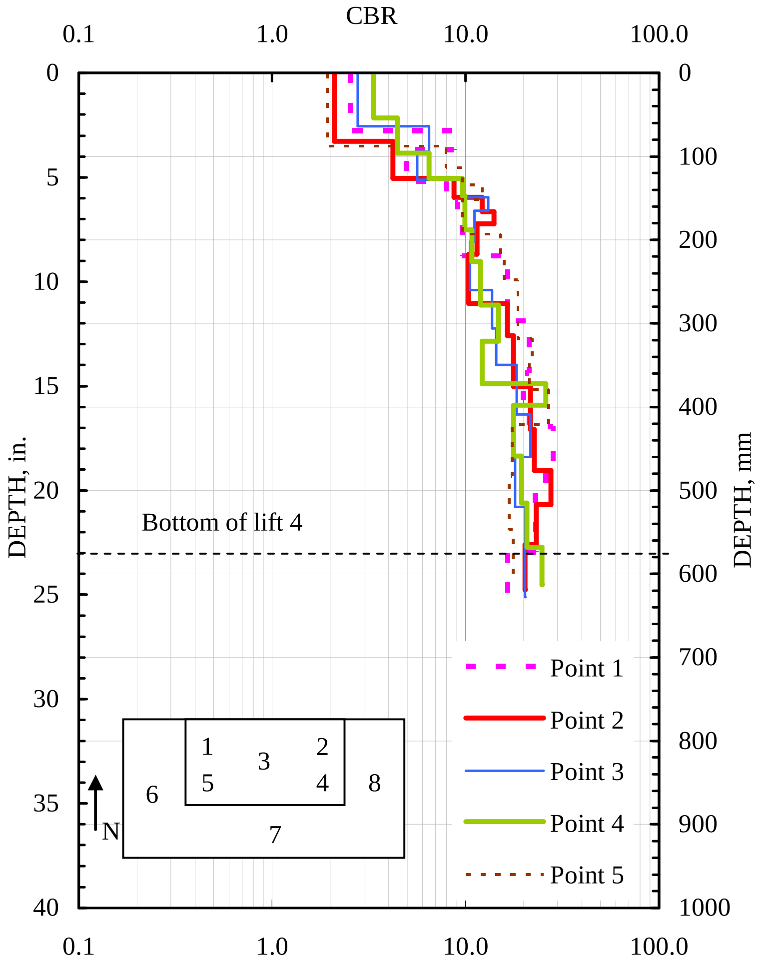


Figure 147 -- CBR profiles for fourth lift in Trench F tested on July 12, 2007

The replaced fourth lift, tested on July 18, 2007, had for the five test points within the trench an average CBR of 13% extending 30.5 inches. The average value was within the average values suggested by NAVFAC. At the surface of the lift, the CBR values ranged from 2% to 5%. At the termination of the DCP tests, CBR values ranged from 22% to 34%. All the CBR profiles start below the typical CBR values from NAVFAC. However, as the depth increases the CBR values increase. The CBR profiles do not follow the same generalized pattern showing that the compaction was not applied evenly across the trench. Figure 148 shows the CBR profile for the test five points within the trench for the replaced fourth lift.

Figure 149 shows the CBR profile for the three-test points test on July 18, 2007 in the T-section. The replaced fourth lift, tested on July 18, 2007, for the three test points in the T-section, had an average CBR of 3% extending 32.0 inches. The average CBR value was not within the typical range of CBR values from NAVFAC. At the start of the test, the CBR values ranged from 2% to 4%. At the termination of the test, the CBR values ranged from 1% to 4%. The T-section was not compacted enough to obtain the typical CBR values from NAVFAC.

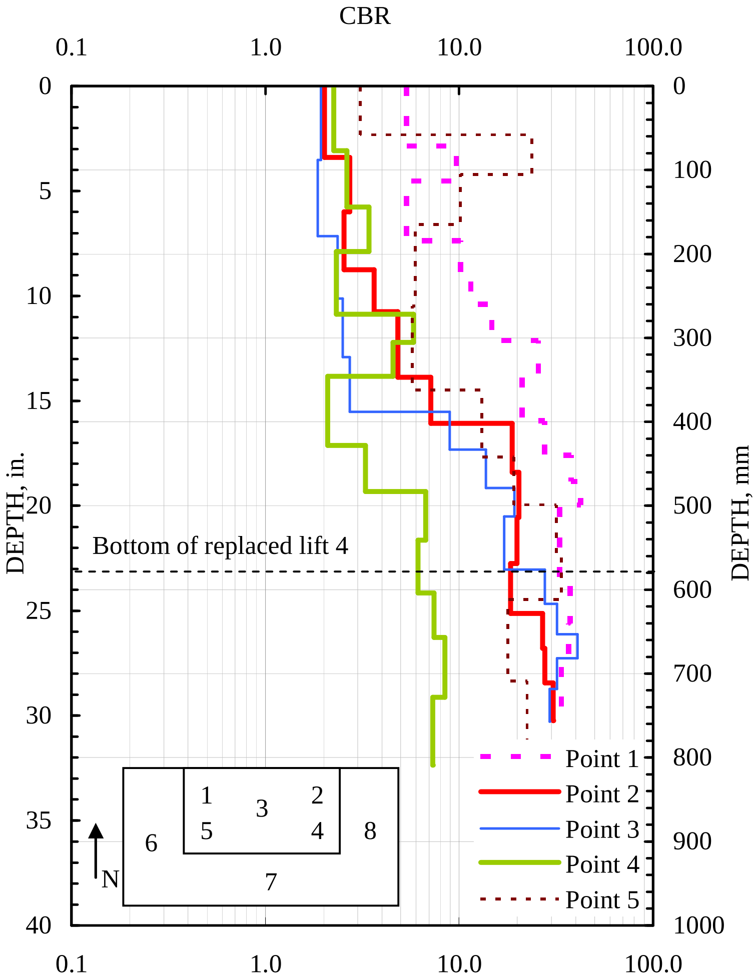


Figure 148 -- CBR profiles for test points within Trench F for replaced lift 4 tested on July 18, 2007

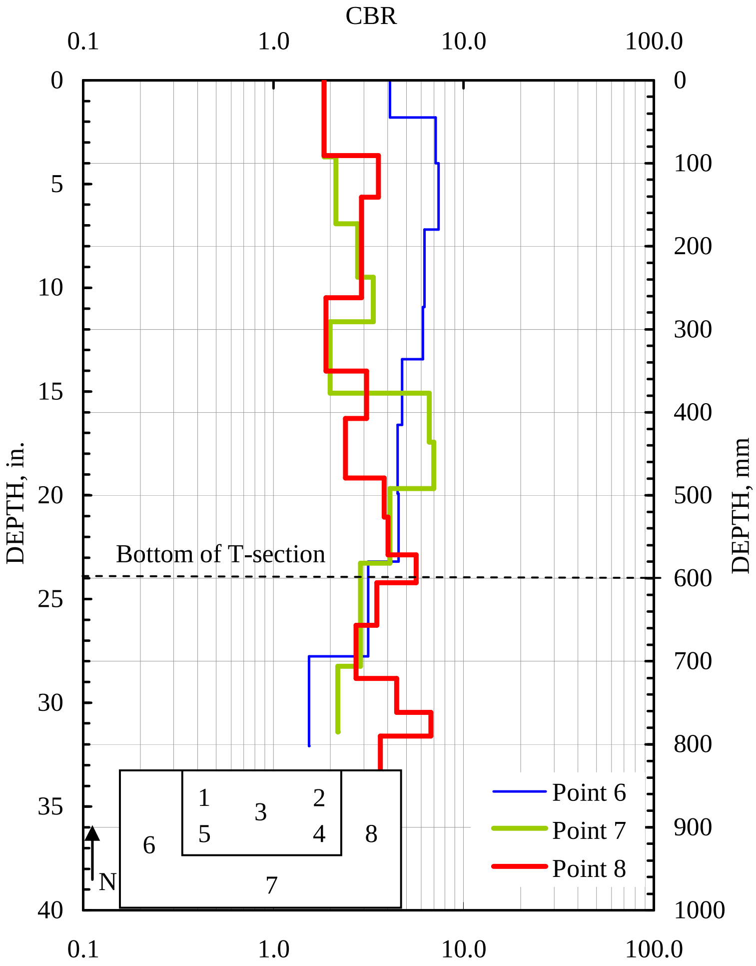


Figure 149 -- CBR profiles for test points within the trench of the replaced fourth lift for the T-section tested on July 18, 2007

Clegg Hammer Test Results

Table 60 summarizes the impact values from the Clegg Hammer tests for Trench F and Table 61 summarizes the CBR results from the Clegg Hammer tests for Trench F. The CBR value for each point was calculated and then the CBR values were averaged.

The second lift for the five test points had CBR values ranging from 10% to 29% with an average CBR value of 18%. The fourth lift for the five test points had CBR values ranging from 10% to 27% with an average CBR value of 16%. These values were below the typical values from NAVFAC.

The replaced fourth lift for the five test points within the trench had CBR values ranging from 6% to 12% with an average CBR value of 9%. The replaced fourth lift for the three test points in the T-section had CBR value ranging from 5% to 31% with an average CBR value of 18%. The CBR values were within the typical values from NAVFAC.

Table 60 -- Impact value results from the Clegg Hammer tests for Trench F

Location	Number of Test Points	Average IV reading	Min/Max IV readings	Standard Deviation	Coefficient of Variance (%)
Second Lift	5	13.4	9.2 / 18.2	3.5	26.1
Fourth Lift tested on July 12, 2007	5	11.2	9.9 / 12.3	1.0	9.0
Replaced Fourth Lift for test points within the trench tested on July 18, 2007	5	12.2	6.4 / 10.3	1.8	22.2
Replaced Fourth Lift for test points in the T-section tested on July 18, 2007	3	12.6	4.9 / 13.8	7.1	56.3

Table 61 -- CBR results from the Clegg Hammer tests for Trench F

Location	Number of Test Points	Average CBR (%)	Min/Max CBR (%)	Standard Deviation	Coefficient of Variance (%)
Second lift	5	18	1 / 29	7.1	38.6
Fourth lift tested on July 12, 2007	5	16	27 / 10	6.5	40.6
Replaced fourth lift for test points within the trench tested on July 18, 2007	5	9	6 / 12	2.6	29.2
Replaced fourth lift for test points in the T-section tested on July 18, 2007	3	18	5 / 31	13.1	72.4

Table 62 shows the difference between the Clegg Hammer test and the DCP tests. The difference between the Clegg Hammer test and the DCP test for the entire depth of the test ranged from 6.7% to 500%. The difference between the Clegg Hammer test and the DCP tests at the surface ranged from 200% and 800%.

Table 62 -- CBR results for the Clegg Hammer and DCP tests

Location	Average CBR values from Clegg Hammer (%)	Average CBR values from DCP for the depth of the profile (%)	Percent difference between the Clegg Hammer and the DCP test for the depth of the profile (%)	CBR values from DCP for the upper most 4 to 6 inches profile (%)	Percent difference between the Clegg Hammer and the DCP test for the upper most 4 to 6 inches (%)
Second lift	18	11	63.6	5	260
Fourth lift tested on July 12, 2007	16	15	6.7	3	433
Replaced fourth lift for test points within the trench tested on July 18, 2007	9	13	30.7	3	200
Replaced fourth lift for test points in the T-section tested on July 18, 2007	18	3	500	2	800

FWD Test Results

Figure 150 shows the FWD testing locations and Figure 151 shows the FWD testing results. FWD testing was performed on the trench on November 5, 2007. The deflection from the 15 kip load in the center of the trench was 11.64 mils. The deflections at the edges of the trench were 15.02 mils and 13.03 mils. On the east side of the trench, the "zone of influence" was in the T-section. On the west side of the trench, the "zone of influence" was outside the T-section. To the west of the trench, there were no visible cracks in the pavement. However, the deflections to the west of the trench corresponded to the same approximate location within the intersection with Carroll Avenue. Figure 152 shows that there was no visible cracking of the pavement where the high FWD deflections occurred. Figures 64 and 65 show that construction equipment was located on the both the east and west sides of the trench. The construction equipment does not account for the difference in the FWD responses between the east and west sides of the trench. The pavement away from the trench deflected 8.45 mils. The backfill in the trench was not placed as stiff as the surrounding soil.

The FWD testing on Trench F shows that the zone of influences was in the T-section on the east side of the trench; however, the "zone of influence" was present in the soil adjacent to the trench on the west side of the trench. The deflection from the FWD test at the 15 kip load was 11.64 mils in the center of the trench and the average deflection at the edge of the trench was 14.02 mils at the 15 kip load.

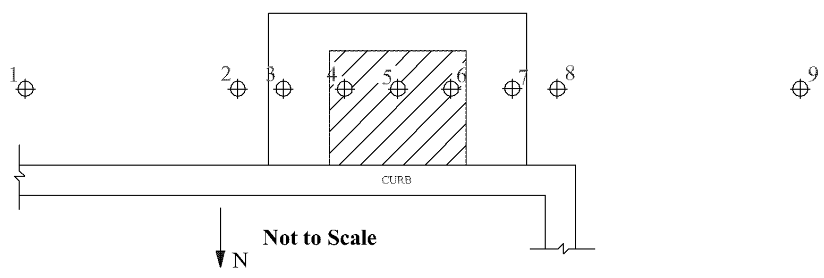


Figure 150 -- FWD test locations for Trench F

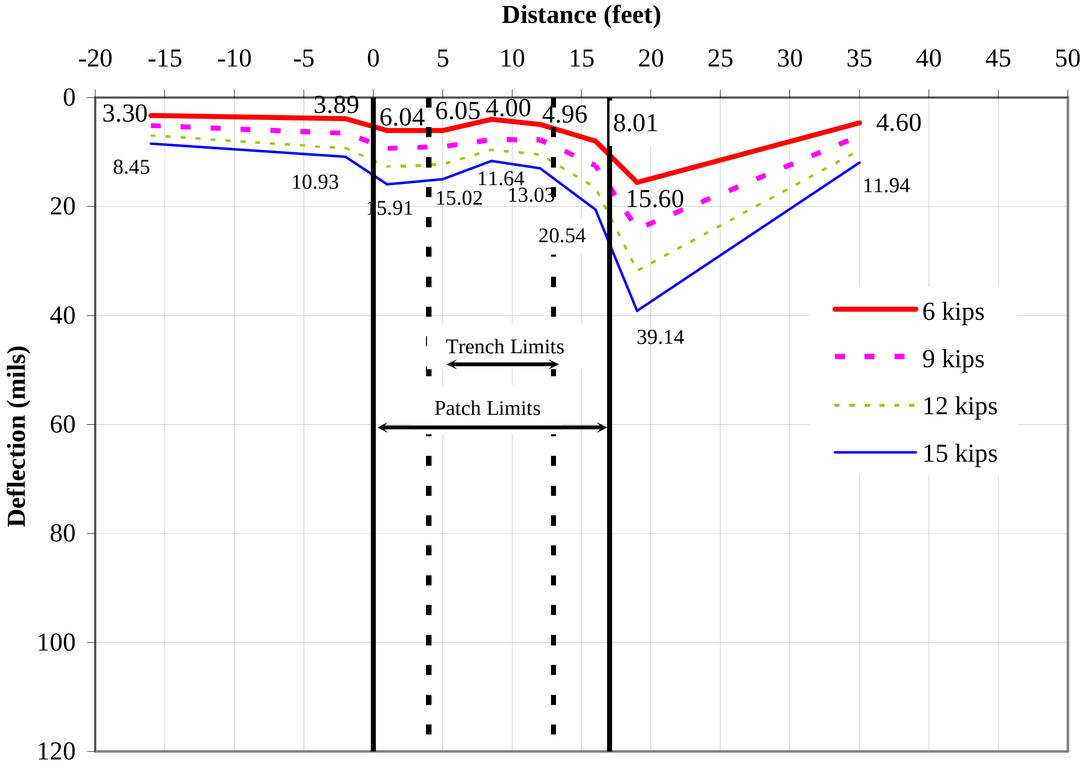


Figure 151 -- FWD testing results for Trench F

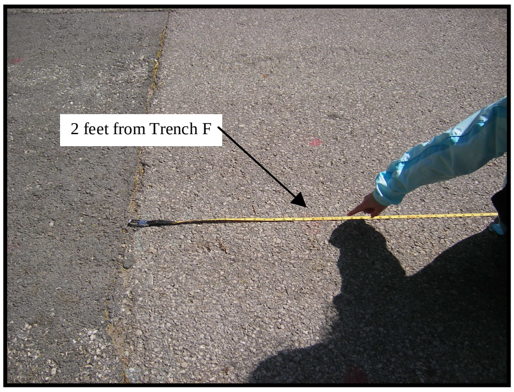


Figure 152 – Condition of pavement two feet west of Trench F at FWD testing location 8

Post Construction Elevation Survey

The post surface models were constructed using survey data collected on July 20, 2007 and March 19, 2008.

Trench F was surveyed at 36 points. The benchmark was the dome bolt on the hydrant northwest of the trench at the intersection of 6th Street and Carroll Avenue. From the elevation survey, the highest elevation was 97.36 feet and the lowest elevation was 96.94 feet. The difference between the highest and the lowest elevation was 5.04 inches. This shows that the patch was placed in uneven fashion. From the elevation survey on March 19, 2008, the highest elevation was 97.35 feet and the lowest elevation was 96.93 feet. The average settlement was 0.02 feet (0.24 inches) and the maximum settlement was 0.21 feet (2.51 inches) along the southwest corner of the patch. The difference between the highest elevation and the lowest elevation was 5.04 inches. Figure 153 shows the location of the grid points and Figure 154 shows the pavement surface for Trench F.

Figure 155 shows the elevation profiles and settlement for Trench F. This shows that the trench had settled since its construction.

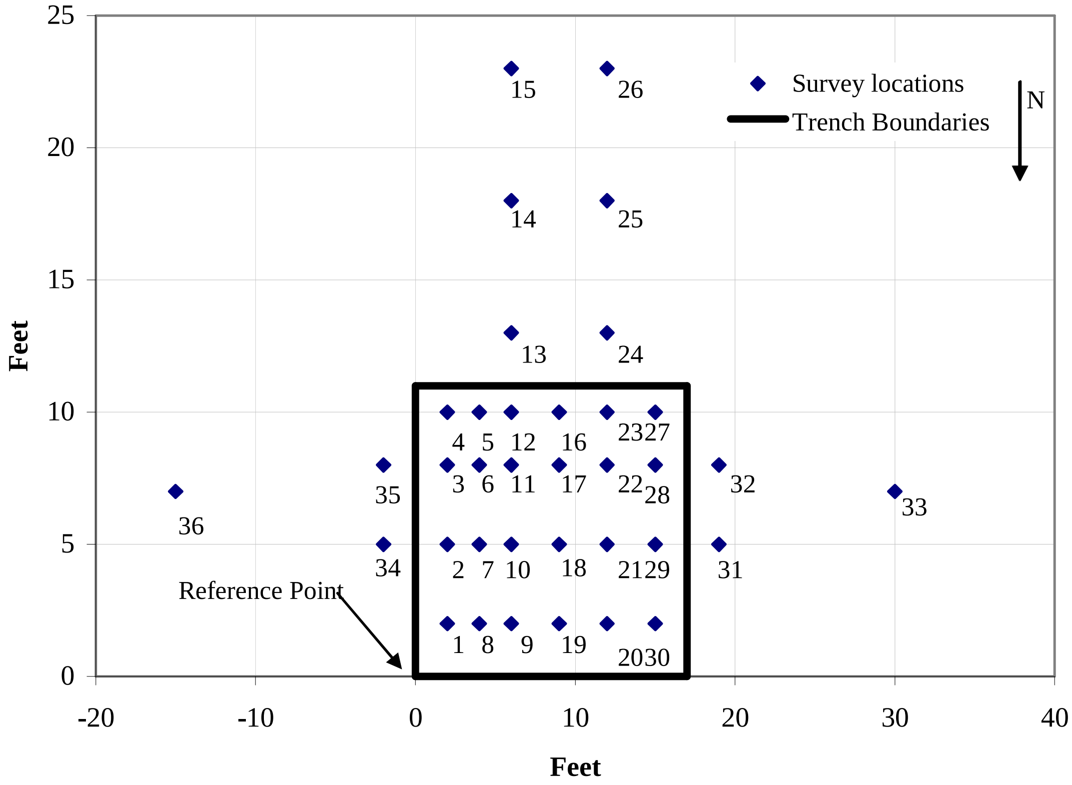


Figure 153 -- Survey locations for Trench F

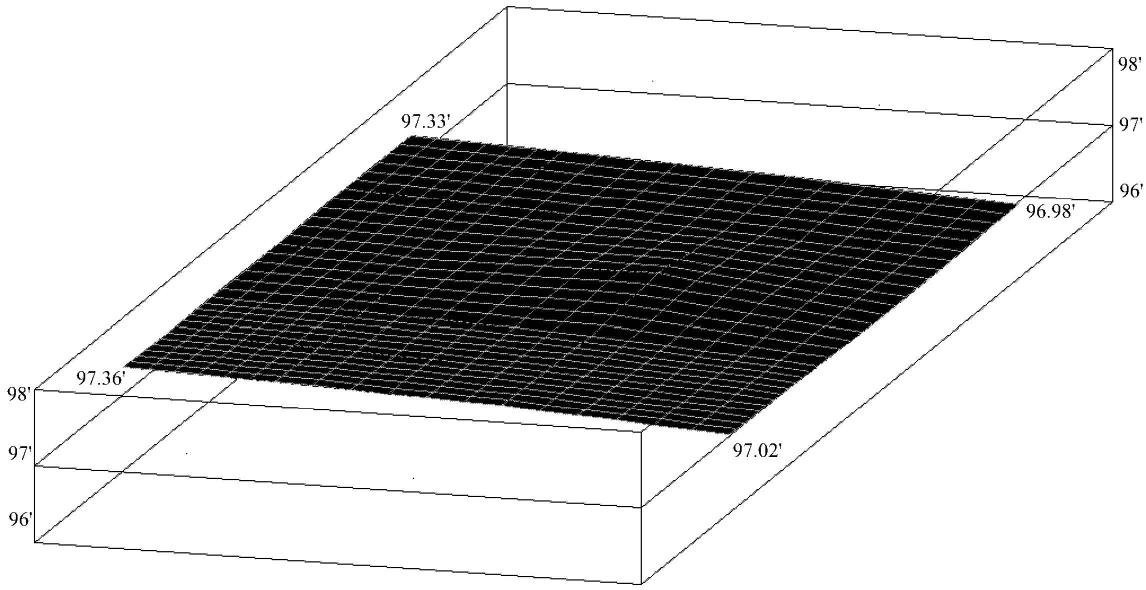


Figure 154 -- Pavement surface elevations of Trench F

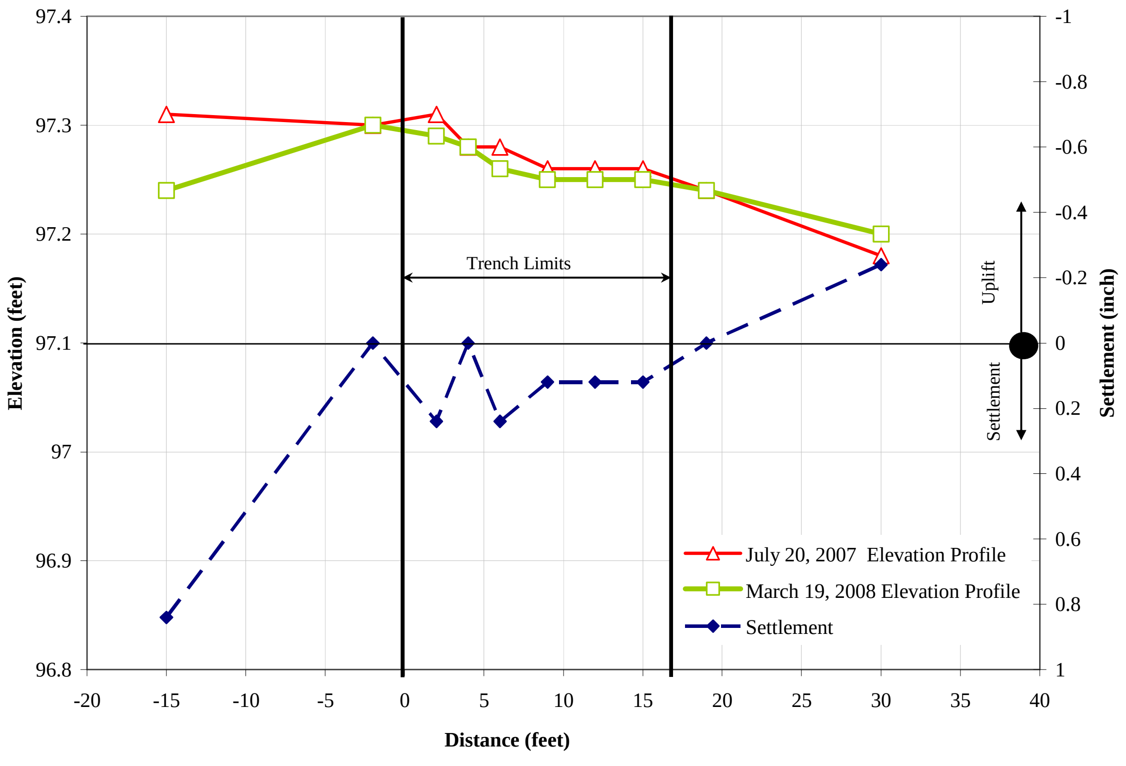


Figure 155 -- Settlement along centerline of Trench F

Comparison of Field-testing Results to Long Term Monitoring

Figure 156 shows the FWD locations and the field-testing locations with the average field-testing results corresponding test points. On the east side of the trench, test point 8 (see Figure 143) corresponds to FWD location 3. The Nuclear Density test at test point 8, the dry unit weight was 112.3 pcf at a moisture content of 13.4%. The DCP test at point 8 shows that the soil stiffness increased with depth. The CBR value at the surface was 4% and the average CBR value was 3%. In the center the trench, test point 3 corresponded to FWD location 5. The Nuclear Density test measured a dry unit weight of 107.1 pcf. The CBR value at the surface was 2% and the average CBR value was 12%. On the west side of the trench, test point 6 corresponds to FWD location 7. The dry unit weight was 111.6 pcf. The CBR value at the surface was 4% and the average CBR value was 5%. This shows that the higher deflections occurred were there where lower CBR values. The dry unit weights did not correspond to the FWD deflections.

Figure 157 shows the FWD deflections plotted with the CBR values and dry unit weights. This Figure shows that there was no empirical relationship between the CBR values or the dry unit weights and the FWD deflections.

Figure 158 shows the settlement profile of the trench with the FWD test results. The maximum settlement of the trench was 2.51 inches in the southwest corner of the trench (not shown on Figure 158). The Nuclear Density test on the backfill on the T-section at test point 6 on the west side of the trench was 111.6 pcf at a moisture content of 9.3%. The DCP test at point 6 was shows that the soil softens with depth. The Nuclear Density test on the backfill on the east side of the trench at test point 8, the dry unit weight was 112.3 pcf at a moisture content of 13.4%. The DCP test at point 8 shows that the soil stiffness with depth. The Nuclear Density test on the backfill on the south side of the trench at test point 7 on the south side of the trench had a dry unit weigh of 108.1 pcf at a moisture content of 15.3%. The DCP test for this point shows that the soils CBR values were constant over the depth of the trench. The maximums settlement occurred where the FWD testing showed the softest response and the lowest dry unit weights.

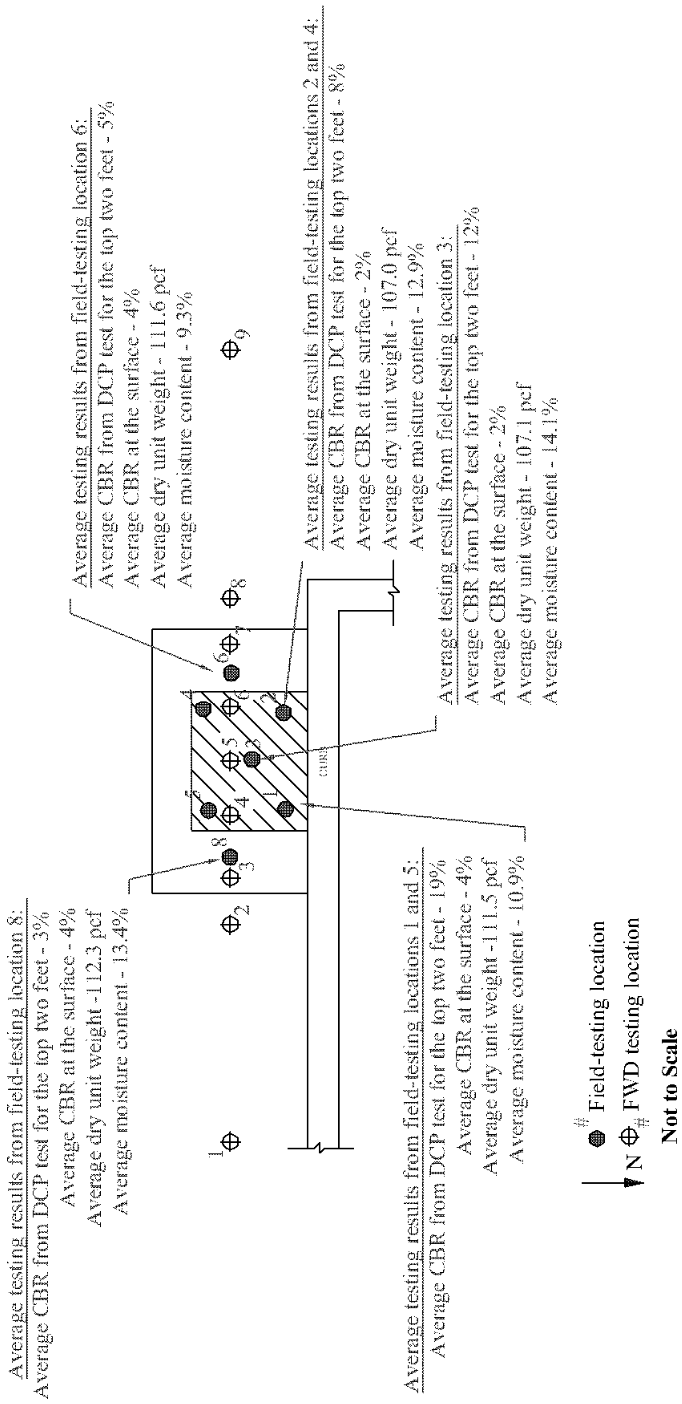


Figure 156 – Comparison of CBR values, dry unit weights and FWD testing results

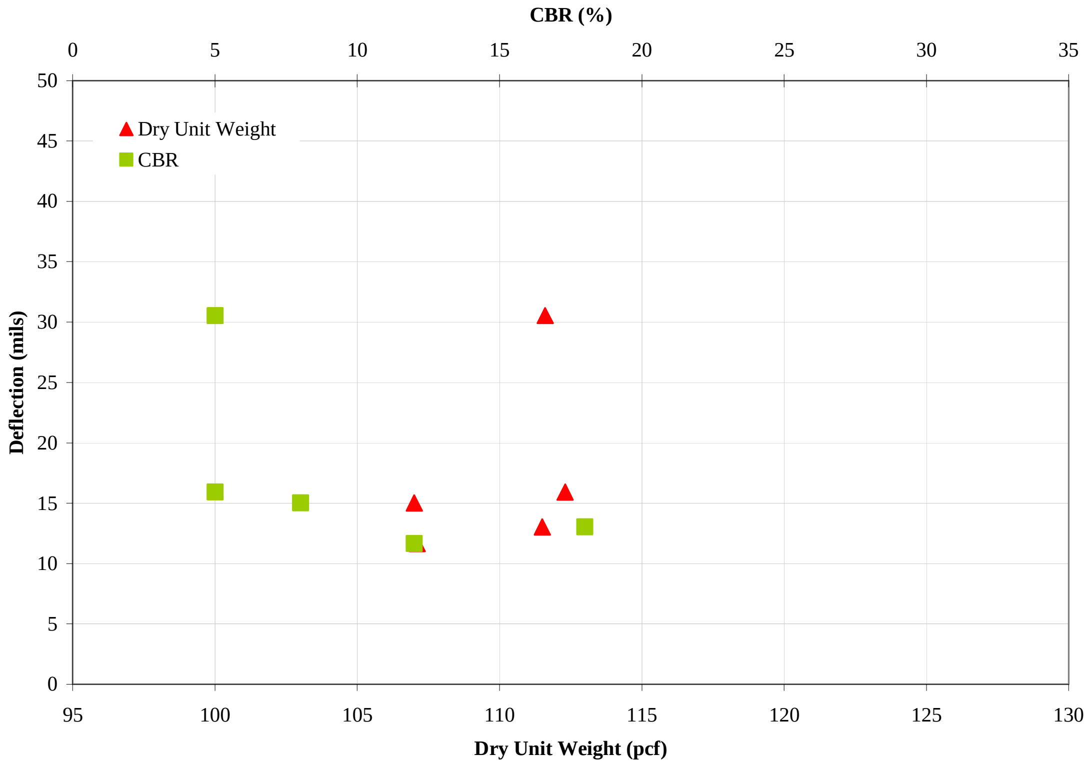


Figure 157 - Comparison of CBR and dry unit weights to the deflections from the 15 kip FWD

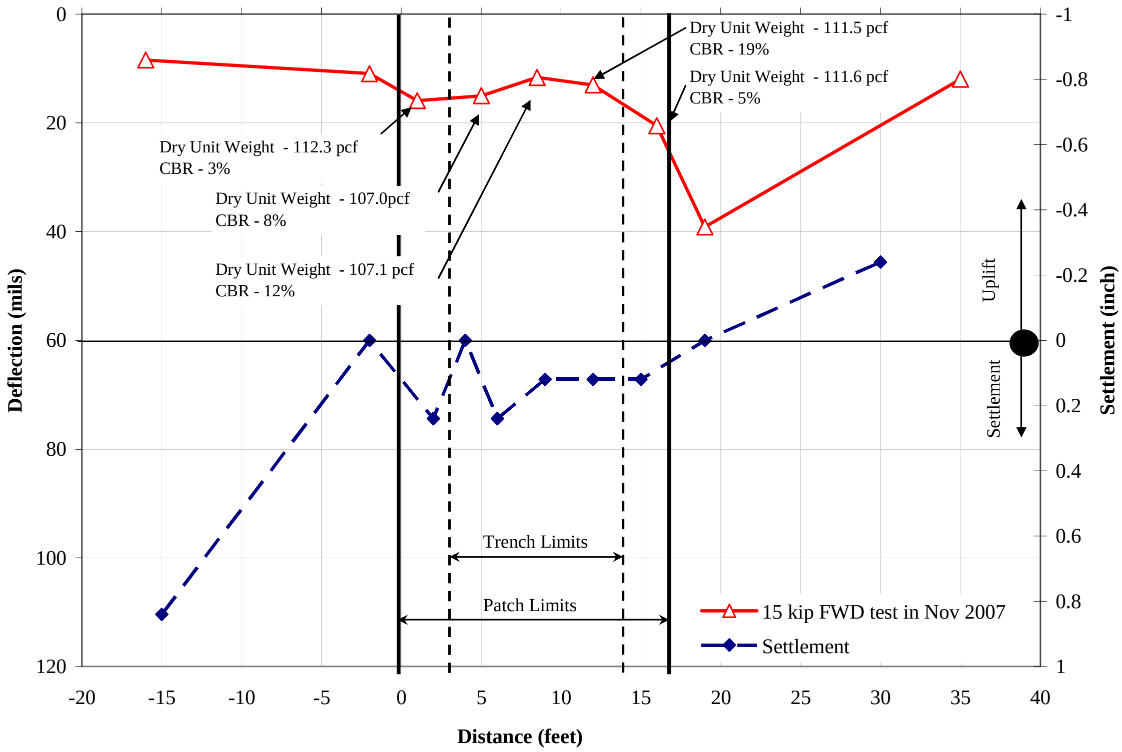


Figure 158 – 15 kip FWD test and survey data for Trench F

Key Results

- The 1-inch clean backfill fill was placed at low dry unit weights.
- The upper lifts were placed above 90% of the Standard Proctor.
- The maximum settlement was 2.51 inches.
- The maximum settlement occurred where lowest dry unit weights were measured.
- The “zone of influence” was present in the T-section on the east side of the trench and the on the west side the trench the “zone of influence” was present outside the trench.
- The maximums settlement occurred where the FWD testing showed the softest response and the lowest dry unit weights.

4.6 - Comparison of the Trenches

Three different trench designs were tested with two different primary backfills: 3/8-inch minus and 1-inch clean limestone. Table 63 summarizes the backfill used in the top two feet of each trench. The top two feet of Trenches A and D were constructed with granular limestone backfill. The top two feet of Trenches B, C, E, and F were constructed with granular backfill mixed with various other soils. The backfills in Trenches B, E, and F were classified as SC-clayey sand. In Trench C, no bulk sample of the backfill used in the top two feet was collected for laboratory testing; therefore, there are no typical values from NAVFAC or laboratory data to compare the field-testing results.

Table 63 summarizes the field-testing results for the top two feet of the trenches. In trenches with T-sections, the test points within the trench and in the T-section were averaged together. The dry unit weights of the backfills were all placed within the typical range of dry unit weights from NAVFAC, except for Trench E. The moisture content of the backfills were all below the typical values, except for Trenches E and F. Trench A had the highest average dry unit weights and the highest CBR values.

In Table 64, the settlement the results from Spring/Summer 2007 to March 2008. Trench C was first surveyed in May 2007 and no survey data from before 2007 is available for comparisons. The settlement data presented for Trench C spanned from May 2007 to March 2008.

In Table 65, FWD testing results from the tests performed after construction is presented.

Table 63 -- Backfills used in the top two feet of each trench with typical NAVFAC values

Trench	Backfill	Typical dry unit weights from NAVFAV	Typical moisture content from NAVFAC	Typical CBR values from NAVFAC
Trench A	SP-SM	100 to 120	12 to 21	10 to 40
Trench B	SC	105 to 125	11 to 19	5 to 20
Trench C*	N/A	N/A	N/A	N/A
Trench D	GP	115 to 125	11 to 14	30 to 60
Trench E	SC	105 to 125	11 to 19	5 to 20
Trench F	SC	105 to 125	11 to 19	5 to 20

*No soil classification was available for the top two feet of backfill

Table 64 – Field compared with laboratory testing results for the top 2 ft.

Trench	Average dry unit weight (pcf)	Relative density (%)	% of Standard Proctor	Average moisture content (%)	Bulking moisture content (%)	Optimum moisture content (%)	Average CBR (%) from DCP
Trench A	122.3	64	---	5.1		---	29
Trench B	112.0	---	96	7.4	---	13.1	5
Trench C*	117.8	N/A	N/A	10.1	N/A	N/A	9
Trench D	118.5	63	----	5.1	---	---	23
Trench E	99.3	---	94	11.3	---	17.0	8
Trench F	109.5	---	92	12.5	---	13.2	10

*No laboratory data is available for the backfill used in the top two feet of Trench 2

Table 65 -- Summary of the settlement for each trench

Trench	Date of construction	Dates of testing	Average displacement within the trench (inches)	Maximum/ Minimum displacement within the trench (inches)	Average displacement adjacent to the trench (inches)	Maximum/ Minimum displacement adjacent to the trench (inches)
Trench A	08/10 2007	09/25/2007 & 03/20/2008.	-0.40	-0.72/ -.012	-0.38	0.24/ -0.84
Trench B	07/25/2007	07/30/2007 & 03/19/2008	-0.06	5.64 / -2.16	-0.55	0 / -1.68
Trench C	05/16/2005	05/11/2007 & 03/20/2008	-1.36	2.40 / -4.44	-1.45	-2.54 / -0.72
Trench D	07/18/2007	07/30/2007 & 03/19/2008	-0.36	0.24 / -0.82	-0.96	-2.25 / -0.12
Trench E	07/25/2007	07/20/2007 & 03/19/2008	0.38	0.72 / 0.12	-0.53	0.48 / -3.36
Trench F	07/18/2007	07/20/2007 & 03/19/2008	0.19	2.52 / -0.84	0.11	0.96 / -0.36

*Negative values indicate uplift

Table 66 -- Summary of the deflections from the 15 kip load from the FWD test after construction

Trench	Date of construction	Dates of testing	Deflection at the center of the trench (mils)	Average deflection at the edges of the trench (mils)	Deflection of the surrounding soils (mils)
Trench A	08/10 2007	11/05/2007	20.36	29.10	52.68
Trench B	07/25/2007	11/05/2007	N/A	N/A	N/A
Trench C*	05/16/2005	06/16/2005	27.29	40.92	51.23
Trench C	05/16/2005	06/11/2007	24.45	37.78	75.11
Trench D	07/18/2007	11/05/2007	15.36	20.68	34.97
Trench E	07/25/2007	11/05/2007	14.92	14.74	32.51
Trench F	07/18/2007	11/05/2007	11.64	14.02	10.20

*The maximum load used in 2005 for FWD testing was 12 kips

Trench A and Trench D were constructed using the vertical wall cross-section, with two different backfills. Trench A was constructed using 3/8-inch minus limestone and Trench D was constructed using 1-inch clean limestone. Trench A was uplifted during the winter survey by 0.12 inches and Trench D had experienced a maximum settlement of 0.24

inches. The difference in the settlements measure was the result of 3/8 inch minus backfill being frost susceptible and the 1-inch clean limestone being non-frost susceptible. The deflections from the 15 kip load in the FWD tests were higher in Trench A than in Trench D and both trenches were stiffer than the surrounding soil. Smaller settlement in these two trenches was associated with higher CBR values. However, the higher CBR values did not correlate to lower deflections from the FWD test.

Trenches B and E were constructed using the T-section cross-section. No FWD testing was performed on Trench B. The maximum settlement in Trench B was larger than the settlement in Trench E. However, the average settlement in Trench B was less than the average settlement in Trench E. The backfill in the top two feet of the trenches were placed at similar percent relative densities. The larger differential settlements in Trench B could be the result of using cinders from the Ames power plant in the top two feet.

Trench C and Trench F were constructed using the T-section with geogrid cross-section. The maximum settlement since the May 2007 in Trench C was larger than in Trench F. The total settlement of Trench C is not known because there was no survey data from before May 2007. The FWD testing results show that Trench F provided a stiffer response.

Trenches A, B, and C were constructed using various cross-sections and the same 3/8-inch minus backfill. Trench A was the best performing trench of the three trenches constructed with 3/8 inch minus limestone. It experienced the smallest settlements and had the stiffest response from the FWD tests. The backfill in Trench A had higher average dry unit weight, and CBR values than in Trenches B and C.

Trenches B and C were T-sections, except Trench C had geogrid placed across the bottom of the T-section. During field-testing, these trenches had similar CBR values. Trench B had a maximum settlement of 5.64 inches and Trench C had a maximum settlement of 2.40 inches. The average settlement in Trench B was less than the average settlement in Trench C. However, the settlements measured in Trench C were form June 2007 to March 2008 and started 2 years after the construction of the trench was complete. There was no survey data for Trench C dating before May 2007.

Trenches D, E, and F were constructed using the same cross-section and 1-inch minus limestone backfill. Trench D is the best performing trench of these three trenches. Trench D experienced the smallest settlements. The FWD deflections were higher than the other three trenches; however, the surrounding soils for Trench D were also softer than the soil surrounding trenches.

Trenches B, C, E, and F were constructed with limestone backfill mixed with other cohesive materials in the top two feet of the trench. Based on the settlement criteria for performance, these four trenches performed poorly with settlements ranging form 0.72 inches to 5.64 inches. All backfill used in the top two feet, was classified as a cohesive material, and therefore, the Standard Proctor test results apply. When comparing the field-testing results for the top two feet of these trenches, the backfill was placed either below optimum moisture content or at low dry unit weights. Placing backfill below the optimum moisture content caused the backfill to have collapse behavior and high settlements. The reason the backfill was at low moisture content, was that the granular material, which was at low moisture contents, was mixed with cohesive material that was allowed to air dry during construction. These two factors resulted in moisture contents lower than optimum.

Figure 159 plots average settlement as a function of time for the six trenches. The trench with the largest rate of movement (both settlement and uplift) was Trench C. The slopes of the trenches constructed in 2007 are similar, except for Trenches A and B, which had the smallest average settlement. However, this is misleading because Trench B had a range of settlement from -2.16 to 5.64 inches.

Figure 160 shows the FWD deflections verse the dry unit weights and CBR values measured for the six trenches. This Figure shows that there was no correlation between dry unit weights and CBR values with FWD deflections.

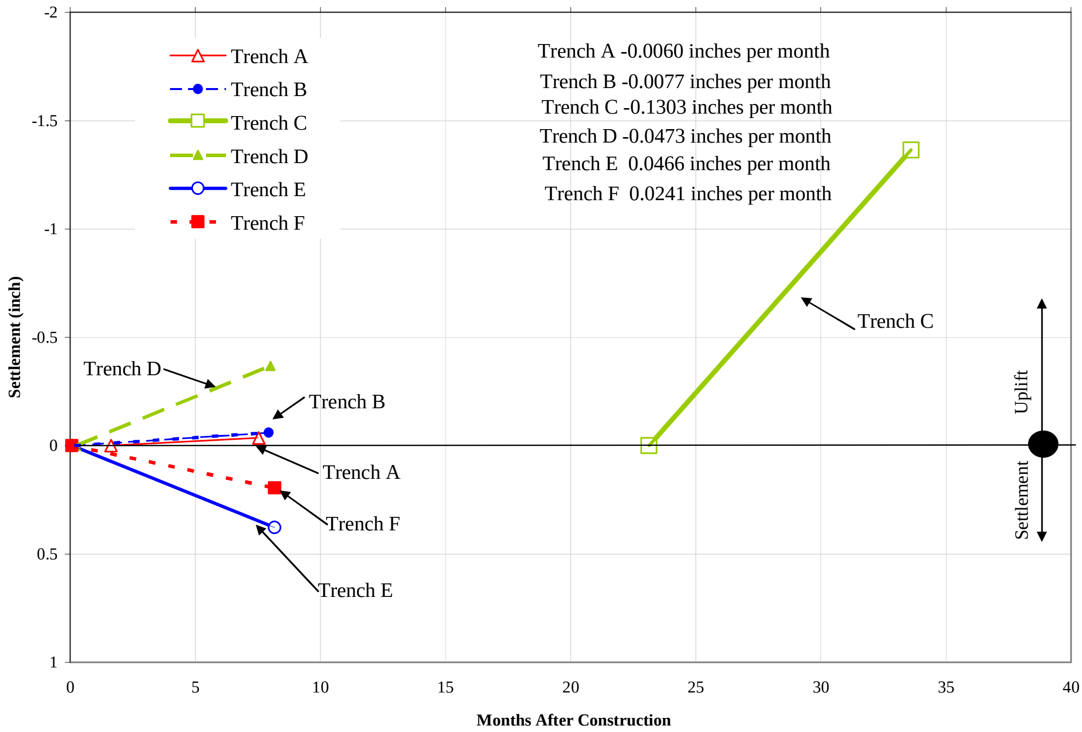


Figure 159 -- Settlement as a function of time for the six recommended trenches

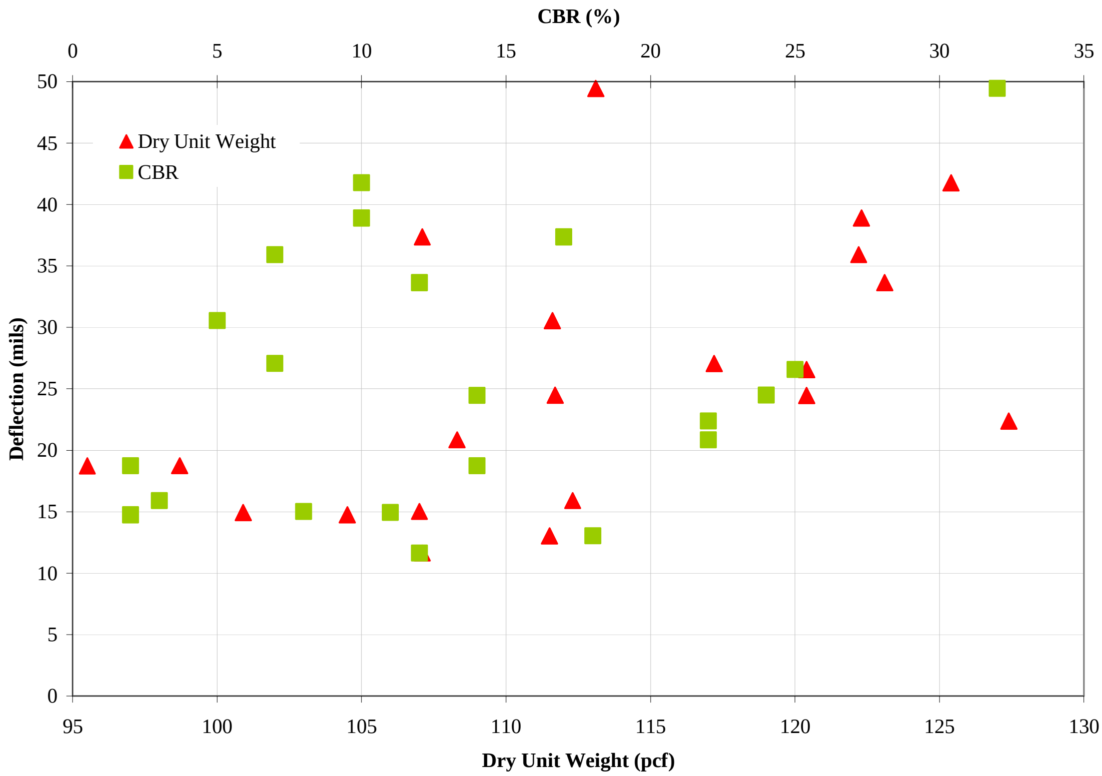


Figure 160 - Comparison of CBR and dry unit weights to the deflections from the 15 kip FWD

4.7 - Conclusion

Based on the monitoring results the following conclusions can be drawn:

- The use of 1- inch clean limestone improves the performance of the trenches. It stiffens the response of the trench in FWD testing and the settlement within the trenches is less than in trenches constructed with 3/8-inch minus limestone.
- Mixing the soil excavated from the trench with the backfill was not proven to be a successful construction practice, which could be attributed to the low compaction levels achieved during construction and minimal moisture control of the fine grained materials.
- The use of geogrid in the trenches did not improve the performance of the trenches compared to the trenches constructed without the geogrid for the trenches using 3/8-inch minus limestone. The geogrid appears to have stiffened the response of the trench the FWD testing; however, these trenches had larger settlements than trenches A and D.

- The T-section did not abate the "zone of influence" on the trenches. Rather, the "zone of influence" moved outside of the T-section for all trenches, except Trench E where it was in the T-section only on one side.
- The T-section did not reduce the settlement in the trenches. The trenches without the T-section (Trenches A and D) performed better. During the construction of the T-section, a larger area of the road was disturbed and a large volume of backfill had to be evenly compacted. Because, there was no quality management of the placement of the backfill to ensure that it was compacted to appropriate relative densities across the trenches, uneven settlements occurred. Another reason for the poor performance of the T-sections trenches could be the result of mixing the limestone backfills with other soils.
- The increased effort and resources used to construct the T-section trenches did not yield a better trench performance.

4.8 - Recommendations

Based on the performance of the six trenches the following recommendations were made:

- The standard vertical walled cross-section with 1-inch clean limestone is recommended as a construction practice.
- Soils excavated from the trenches or other soils should not be mixed with the granular backfills unless previous laboratory testing yielding range of recommended moisture content and densities to be achieved in the field are conducted.
- Pavement should be removed from four feet around the parameter of the trench and the area should be re-compacted if a T-section is not constructed.
- The T-section should be modified to use walls that are beveled outward to facilitate compaction of backfill. Beveled edges will reduce the amount of disturbance to the surrounding soil and also eliminate the vertical excavation, which makes compacting the backfill more difficult.
- Quality control measures should be implemented in the field to ensure that compaction requirements are met. This includes achieving at least medium relative density with

moisture contents above the bulking moisture content for cohesionless soils and above 95% of Standard Proctor and +/- 2% of optimum moisture content for cohesive soils.

- Cities should implement moisture control practices. The construction industry has implemented practice of wetting or dry soil before compaction to insure that it meets specifications for performance.

4.9 - Further Research

After the completion of this thesis, the following research is recommended:.

- Reconstruct the T-section trenches with beveled edges without mixing the soil excavated from the trench with granular backfill. Quality control management should be used on each lift (i.e. ensure that each lift is placed with moisture control and at the appropriate relative density for the backfill being used). This will provide more conclusive results that the T-section trench works to reduce the "zone of influence" or the "zone of influence" moves further outside the trench.
- Continue FWD testing and settlement monitoring on the existing six recommended trenches.

CHAPTER 5.0 - INSTRUMENTED TRENCHES

Three instrumented trenches were constructed at 2709 Kellogg Avenue between Luther Drive and 28th Street of north Ames to monitor the effects of different utility cut construction techniques. One trench (trench 2) was constructed using the current City of Ames standard construction practices and the other two trenches (trench 1 and trench 3) were constructed using the recommended construction practices. Figure 161 shows the site before trench construction. This location was selected because the City of Ames planned to conduct routine resurfacing of this road.

5.1 - Site Conditions of Kellogg Avenue

The asphalt pavement was sawed around the trenches. The existing asphalt pavement ranged from 1 to 3 inches in thickness across the site. A layer of about 6 inches of fly ash treated soil was found beneath the asphalt.

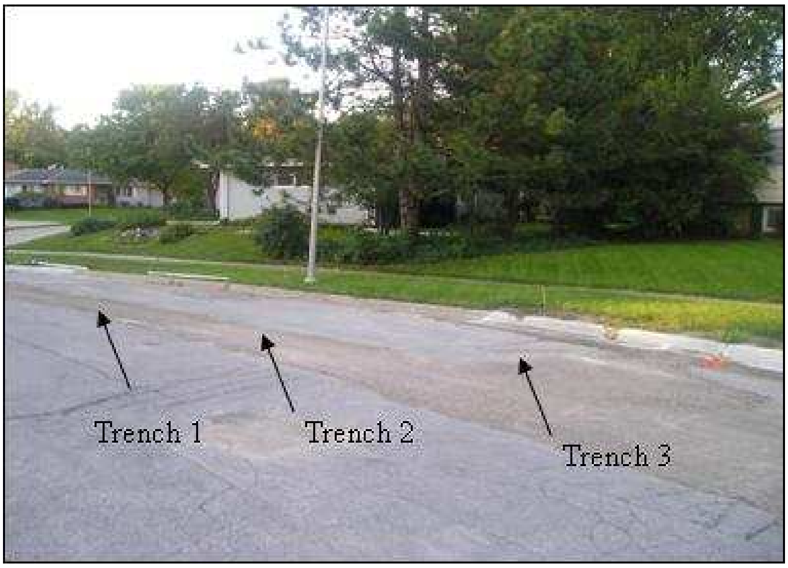


Figure 161 -- Kellogg Avenue before construction the instrumented trenches

Three Shelby tube samples were collected from a boring made north of Trench 1 on Kellogg Avenue. Six unconfined compression tests were conducted on these samples using ASTM D2166, 2006 "Standard Test Method for Unconfined Compressive Strength of Cohesive Soil." The samples were then classified using sieve and hydrometer testing.

Figure 162 shows the boring log of the subgrade soils at the instrumented trenches. The moisture content of the samples ranged from 15.5% to 21.5%. The dry unit weights ranged from 105.9 pcf to 120.6 pcf. The undrained shear strengths ranged from 1179.3 psf to 7911.2 psf.

Table 67 and Figure 163 show the gradations of the soil on Kellogg Avenue. More than 30% of the particles are smaller than 0.02 mm (see Figure 163). This high percentage of small particles increased the soil's susceptibility to frost heave (see Figure14). This along with the soils classification of SC, allowed for a frost heave classification of F3 by the Army Corps of Engineering in Table 9. The frost suitability of the soils is Medium to High according to Figure 14 by the Army Corps of Engineers. The frost suitability rating accounted for the rate of frost heave per day. This means that this soil was expected to experience 2.0 mm/day to 8.0 mm/day of heave when temperatures were below freezing. These soils were classified using the USCS and AASHTO standards (see Tables 2, 3, and 4).

Log of Boring 1											
Site: Instrumented Trenches on Kellogg Avenue					**Project:** Phase II:						
	Description		**USCS Symbol**	**AASHTO Symbol**	**Sample**			**Tests**			
	Approximate Surface Elevation:	97.6 ft			**Number**	**Type**	**in**	**Content**	**Dry Unit Weight, pcf**	**Compressive Strength, psf**	**Other**
0.3	Pavement	95.7				PA					
	Sandy Lean Clay		CL	A-6							
	Brown										
1.3											
		94.7			1	ST	30.0	19.5	111.0	7911.2	LL=37 PL=14 PI=23
2.6		93.4			2			19.1	106.7	3331.0	
						PA					
3.6											
	Clayey Sand	92.4	SC	A-6	3	ST	20.0	19.1	111.6	1526.7	LL=30 PL=13 PI=17
	Brown										
					4			19.5	107.0	1526.7	
5.0											
5.3	**Sandy Lean Clay**	91.0	CL	A-6		PA					
	Brown				5	ST	22.0	21.5	105.9	1665.5	LL=29 PL=13 PI=16
6.0											
6.5		89.5			6			15.5	120.6	1179.3	
7.0		89.0									
10.0		86.0									
	Bottom of Boring										

Figure 162 -- Boring Log for trenches on Kellogg Avenue

Table 67 -- Particle distribution in soils removed from Kellogg Avenue trenches and 3/8-inch minus backfill

Sieve/ Opening Size (mm)	Bulk sample from 0.0 feet to 3½ feet	Bulk sample from 3½ to 5.0 feet	Bulk sample from 5.0 to 10.0 feet
1½ in (38.1)	100	100	100.0
1 in (25.4)	100	100	100.0
3/4 in (19.05)	97	99	100.0
1/2 in (12.7)	---	---	---
3/8 in (9.525)	96.8	98.6	98.3
No.4 (4.75)	95.0	98.6	98.3
No.10 (2.0)	91.6	97.9	97.4
No.20 (0.85)	83.6	83.3	95.9
No.40 (0.425)	77.1	73.0	90.5
No.60 (0.25)	70.7	66.3	81.1
No. 80 (0.1778)	65.0	59.2	71.3
No.100 (0.15)	61.2	54.5	67.0
No.200 (0.075)	53.4	45.4	65.6

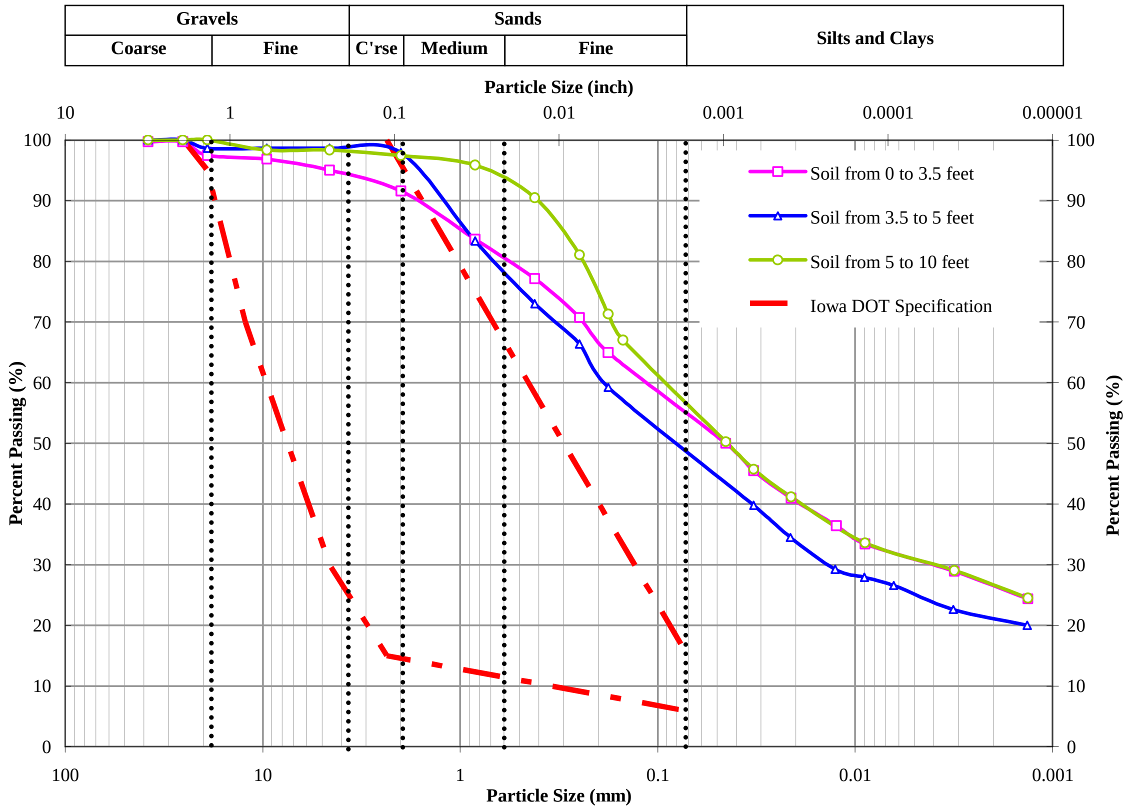


Figure 163 -- Gradation of soils excavated from the Kellogg Avenue trenches

Table 68 -- Classification of the soils removed from the trenches in Kellogg Avenue and the 3/8-inch minus backfill

Sample	Soil Classification			
	USCS		AASHTO	
Kellogg bulk sample from 0 to 3½ feet	CL	Sandy lean clay	A-6	Clayey soil
Kellogg bulk sample from 3½ to 5 feet	SC	Clayey sand	A-6	Clayey soil
Kellogg bulk sample from 5 to 10 feet	CL	Sandy lean clay	A-6	Clayey soil

5.2 - Design of the Instrumented Trenches

Trench 1 was constructed using the Trench A technique shown in Figure 42 along with instrumentation. Trench 2 used the City of Ames standard trench restoration practices. Trench 3 was constructed using the Trench B technique; except that it included instrumentation and all backfill was 3/8-inch minus limestone, (no soil excavated from the trench was placed back in the trench). General description of the Instrumented Trenches 1, 2, and 3 are summarized below:

Trench 1 characteristics:

- Vertical side walls with no T-section for the trench excavation
- Placing 3/8-inch minus limestone in lifts of 1 foot or less
- Moisture control
- Compaction using a impact rammer

Trench 2 characteristics (using City of Ames practices):

- Vertical side walls with no T-section for the trench excavation
- Placing 3/8-inch minus limestone in lifts of 2 feet or greater
- No moisture control
- Compaction using a vibratory plate compactor attached to a backhoe

Trench 3 characteristics:

- Vertical side walls with the T-section for the trench excavation
- Placing 3/8-inch minus limestone in lifts of 1 foot or less
- Moisture control
- Compaction using an impact rammer (except the first two lifts were compacted using a vibratory plate compactor attached to a backhoe.)

As shown in Figure 164, the trenches were instrumented to measure settlement, earth pressure, and moisture content within the trenches and to measure the temperature within the trenches and adjacent soil. The trenches had instrumentation installed vertically every 2 feet in the loose backfill placement. The data logger synchronized instrumentation readouts.

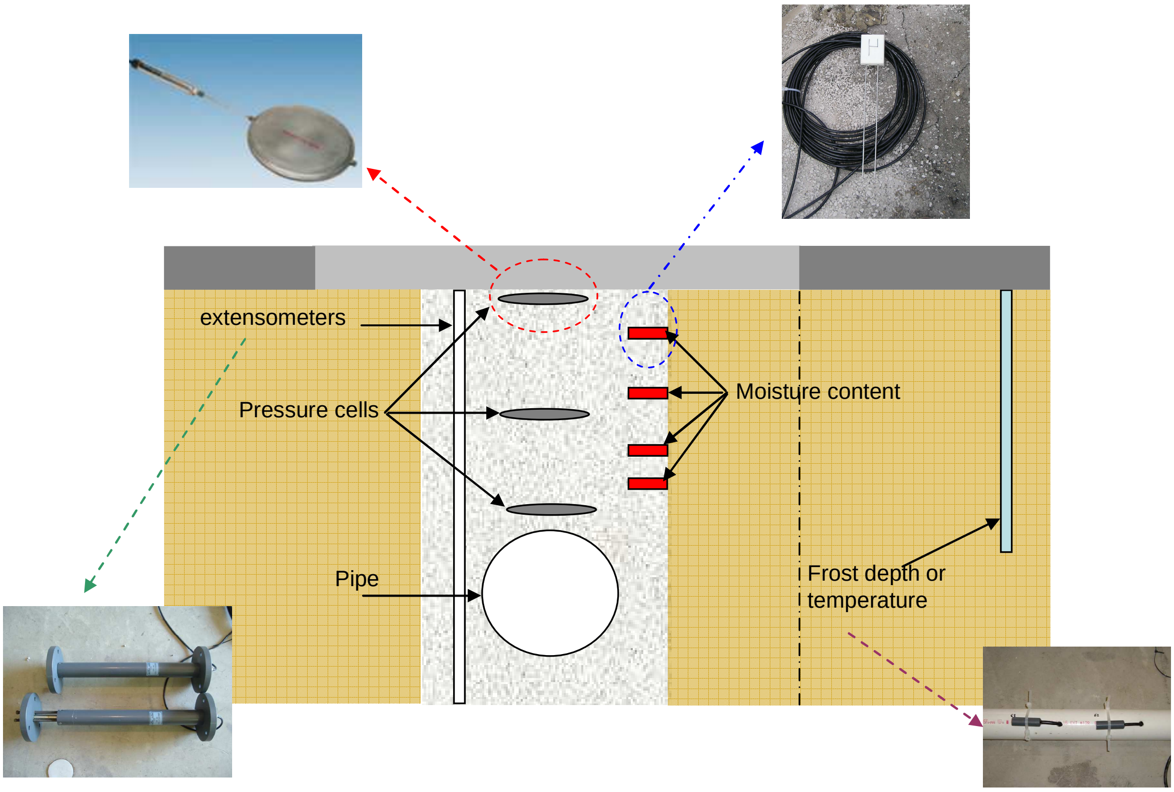


Figure 164 -- General configuration of instrumentation in trenches (modified from project proposal)

5.2.1 - Instrumentation

The extensometers, moisture sensors, pressure cells, and temperature sensors were supplied by RocTest.

Extensometers

ERI vibrating wire fill extensometers manufactured by RocTest were used to evaluate settlement in the trenches. Each extensometer spanned approximately 1 to 2 feet of compacted soil. The extensometers measured the settlement in each lift. The total backfill settlement was calculated by adding the output of all the extensometers.

The extensometers were vibrating wire instruments that measure output data in Linear Units (LU). The LU was then entered into equation 5-1 as recommended by the RocTest

Manual E1117A-050708 to determine the absolute displacement reading (D). Relative displacement (D_r) was calculated by subtracting the absolute displacement reading (D) from the first extensometer reading after installation D_o (see Equation 4).

$$D = A*LU^2 + B*LU + C$$ **Equation 4**

Where:

D = Absolute displacement (mm)

A, B, and C = Calibration factors specific to each instrument supplied by RocTest

LU = Reading from the extensometer (LU)

$$D_r = D - D_o$$ **Equation 5**

Where:

D_o = First reading from the extensometers after installation (mm)

D = Absolute displacement (mm)

D_r = Relative displacement (mm)

Moisture Sensors

CS615 Water Content Reflectometer manufactured by Campbell Scientific measured the change in the moisture content of the backfill. The water content reflectometer was a time domain reflectometer (TDR). This instrument calculated the backfill moisture content using the voltage difference between two metal prongs. Without material specific calibration, the sensors were accurate to within 3% of the actual moisture content (Campbell Scientific 1996). With calibration, the moisture sensors can be accurate to within 2% of the actual moisture content. In the laboratory, the sensors were calibrated at three different moisture levels for 3/8-inch minus limestone from the City of Ames stockpile. It was assumed that the limestone gradation from the stockpile was similar to that of the backfill soil used in the trenches.

The moisture sensors output data as the period (microseconds). The period can be converted into a volumetric moisture content using Equation 6 (CS 615):

$$\theta_v = C_o + C_1{*}\tau + C_2{*}\tau^2$$ **Equation 6**

Where:

θ_v = Volumetric moisture content

τ = Period (microseconds)

C_o, C_1, and C_2 = Constraints found from laboratory testing

The soil moisture content was calculated using the equation provided by Campbell Scientific, CS 516 (see Equation 7). This equation used the volumetric moisture content and the specific gravity of the backfill found during Phase I.

$$\theta_v / G.S. \times 100 = w(\%)$$ **Equation 7**

Where:

$w(\%)$ = Moisture content (%)

G.S. = Specific Gravity

Pressure Cells

Model TPC pressure cells monitored the pressures induced in the trench by the backfill, traffic, and weather. The pressure cells also measured the temperatures at different levels within the trench. The pressure cells were vibrating wire instruments that output data in Linear Units (LU). The output was then converted into a pressure reading using the polynomial equations from the RocTest manual E1078E-050708 (see Equations 8, 9, and 10)

$$P = A \times L^2 + B \times L + (-AL_o^2 - B \times L_o)$$ **Equation 8**

Where:

P = Calculated pressure using Linear Units without correction factors applied (kPa)

L_o = Initial Linear Unit reading from pressure cell(LU)

L = Current reading in Linear unit from pressure cell (LU)

A and B = Calibration factor for each instrument supplied by RocTest

$$C_{TO} = C_T \text{ x } (T\text{-}T_o)$$ **Equation 9**

Where:

C_{TO} = Correction factor to account for the coefficient of thermal expansion of the fuild inside the pressure cell (P) (kPa)

C_T = Calibration factor supplied by RocTest

T = Current Temperature (C)

T_o = Initial temperature during calibration (C)

$$C_{SO} = (S\text{-}S_O)$$ **Equation 10**

C_{SO} = Correction for changes in atmospheric pressure between time of calibration and time of reading

S_o = Initial barometric pressure reading when the calibration constants were calculated (kPa)

S = Barometric pressure at the time of the pressure reading (kPa)

$$P_C = P - C_{TO} - (C_{SO})$$ **Equation 11**

Where:

P_C = Pressure corrected for temperature and barometric affects (kPa)

The corrected pressure was not used to monitor the pressure within the trenches. Because the barometric pressure was not measured as a function of time, it was assumed that the barometric pressure measured during calibration was the same barometric pressure during the length of the trial.

Temperature Sensors

Model TH-T temperature sensors manufactured by Campbell Scientific were used to monitor subgrade soil temperatures. The temperature sensors were synchronized with the other sensors to correlate freeze/thaw cycles. The temperature sensors output data in degrees Celsius.

5.2.2 - Instrumentation Installation Procedure

The extensometers were partially extended during installation to allow for both extension and retraction. Bolts secured the position of the partially extended extensometer (Figures 165) and prevented them from fully retracting (Figures 165) before installation. A concrete base extending 1 foot below the base of the trench, which acted as an anchoring point for the extensometers (see Figure 166). This concrete anchoring point was assumed to be immovable and at offset zero. The extensometers were installed in a series by bolting the top of one extensometer to the bottom of the extensometer above it. After the extensometers were connected, the spacing bolts were removed.

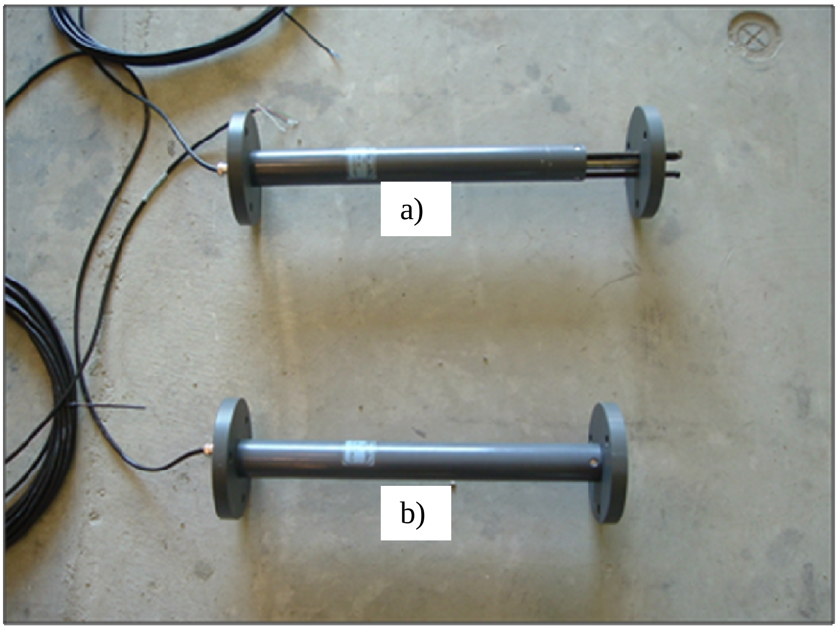


Figure 165 – Extensometers used in instrumented trenches (a) with temporary bolts maintaining the extended head and (b) fully retracted head

Figure 166 – Concrete based at the bottom of the trench

The pressure cells were installed in the trenches using a lens of sand. The maximum sand particle was less than 1/8 of the total thickness of the pressure cell (less than 4.7 mm, No. 4 sieve). The lens of sand was installed to protect the pressure cells from being punctured or dented by the 3/8-inch minus limestone backfill (Figure 167). During construction, the pressure cells were protected by not compacting the 3/8-inch minus limestone backfill above the cells until the lift thickness was about 2 feet (Figure 168).

Figure 167 -- Pressure cell being placed within a lens of sand, a) sand lens below the pressure cell and b) sand lens covering the pressure cells

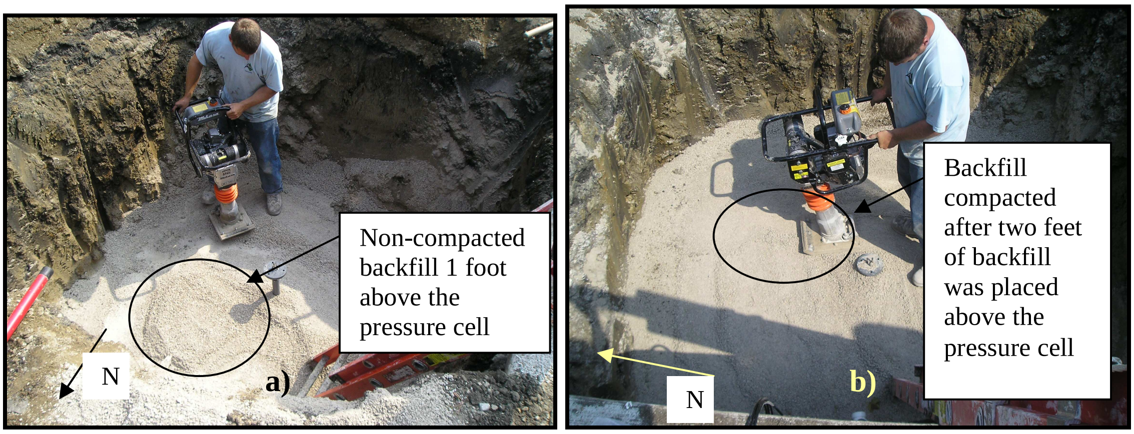


Figure 168 -- Procedure for compacting backfill over the pressure cells a) 1 foot above the pressure cells the backfill was not compacted and b) 2 feet above the pressure cell the backfill was compacted

At each layer of instrumentation, moisture sensors were installed lying flat on the surface to avoid bending the sensors' prongs (see Figure 169). Then, 3/8-inch minus limestone was placed on top of the sensors by hand.

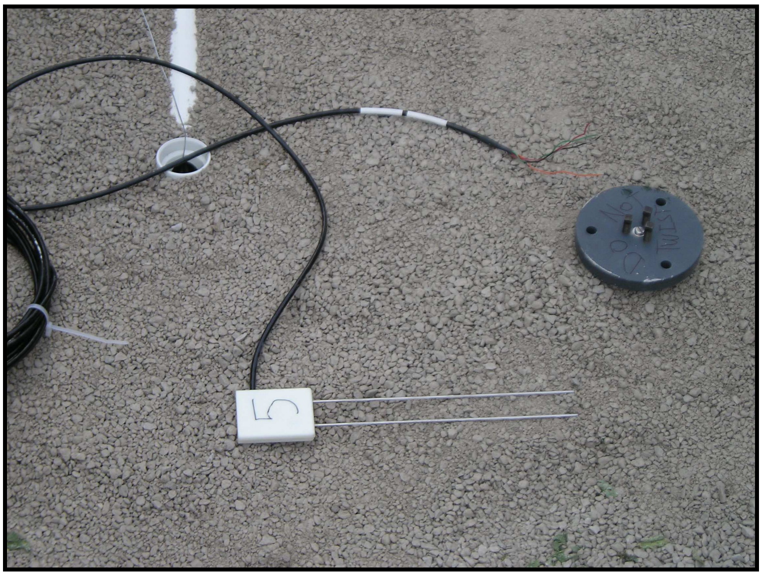


Figure 169 – TDR Moisture sensor used in instrumenting all trenches

Eight temperature sensors were mounted to a PVC pipe in a configuration consisting of increasing interval lengths with increasing depth. The four most superficial sensors were mounted at 6-inch intervals followed by two sensors placed at 1-foot intervals. The deepest two sensors were mounted at 2-foot intervals (see Figure 170). The PVC pipe was installed vertically in a soil boring north of Instrumented Trench 1 (Figure 170) so that the first temperature sensor was located 11½ inches below the newly paved surface.

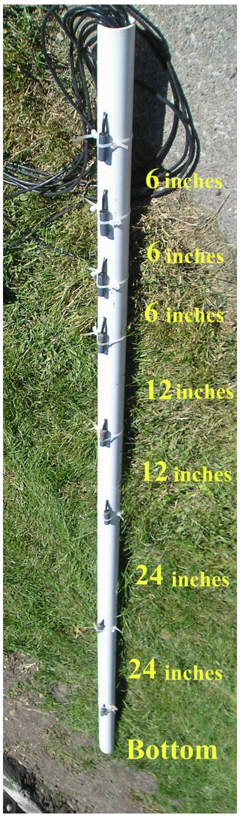


Figure 170 -- Temperature sensors mounted on the PVC pipe.

Four multiplexers connected each type of instrument to the data logger, which collected the data (Figure 171). The system was powered by a solar panel and a battery pack. Data from the data logger was downloaded approximately every ten days.

Initially, the data logger was programmed to begin scanning at one-minute intervals; however, a complete scan of all the multiplexers required 1 minute and 10 seconds. This caused the scans to repeatedly abort before data was recorded in temporary storage. Once RocTest modified the programming to scan every two minutes, the data logger was able to record the maximum, minimum, and average readings in two-hour intervals.

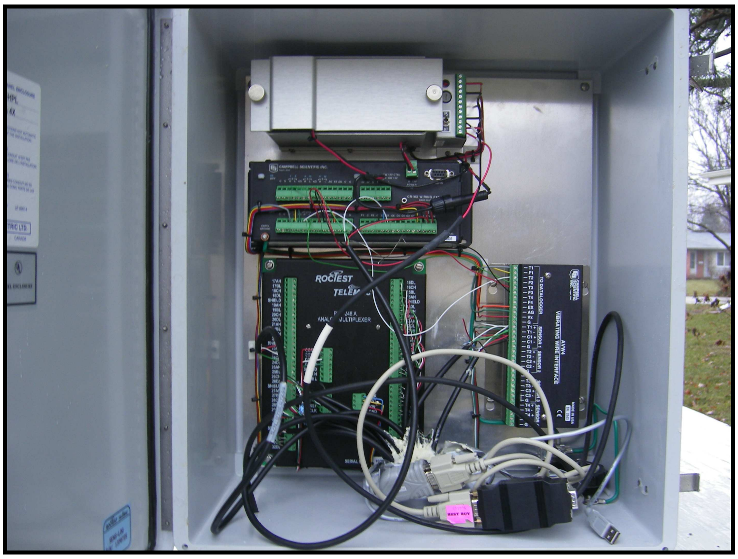


Figure 171 – Multiplexer, vibrating wire interface and data logger used to read the instruments

5.3 - Construction of Instrumented Trenches

The City of Ames, in conjunction with the Iowa State Research Team, completed the excavation and construction of the instrumented trenches. The Iowa State Research Team monitored and documented each step in the trench construction.

The benchmark for the site was the dome bolt (see Figure 172) on a fire hydrant located 100 feet southeast of the site. The dome bolt, which holds the cap of the hydrant in place, was assigned an elevation of 100.0 ft. This benchmark was used throughout the elevation monitoring of the site. The elevation of the pre-excavation asphalt road ranged from 97.2 feet to 98.5 feet.

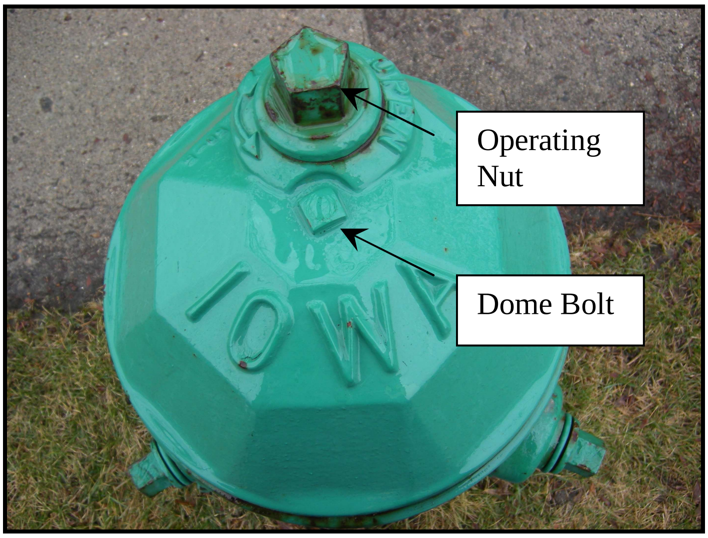


Figure 172 -- Top of the Iowa valve fire hydrant in Ames, Iowa with Dome Bolt.

Figure 173 shows the location of the boring for the temperatures sensors and the trenches along Kellogg Avenue. Also illustrated are site features including existing sewers, laterals, power pole, and fire hydrant.

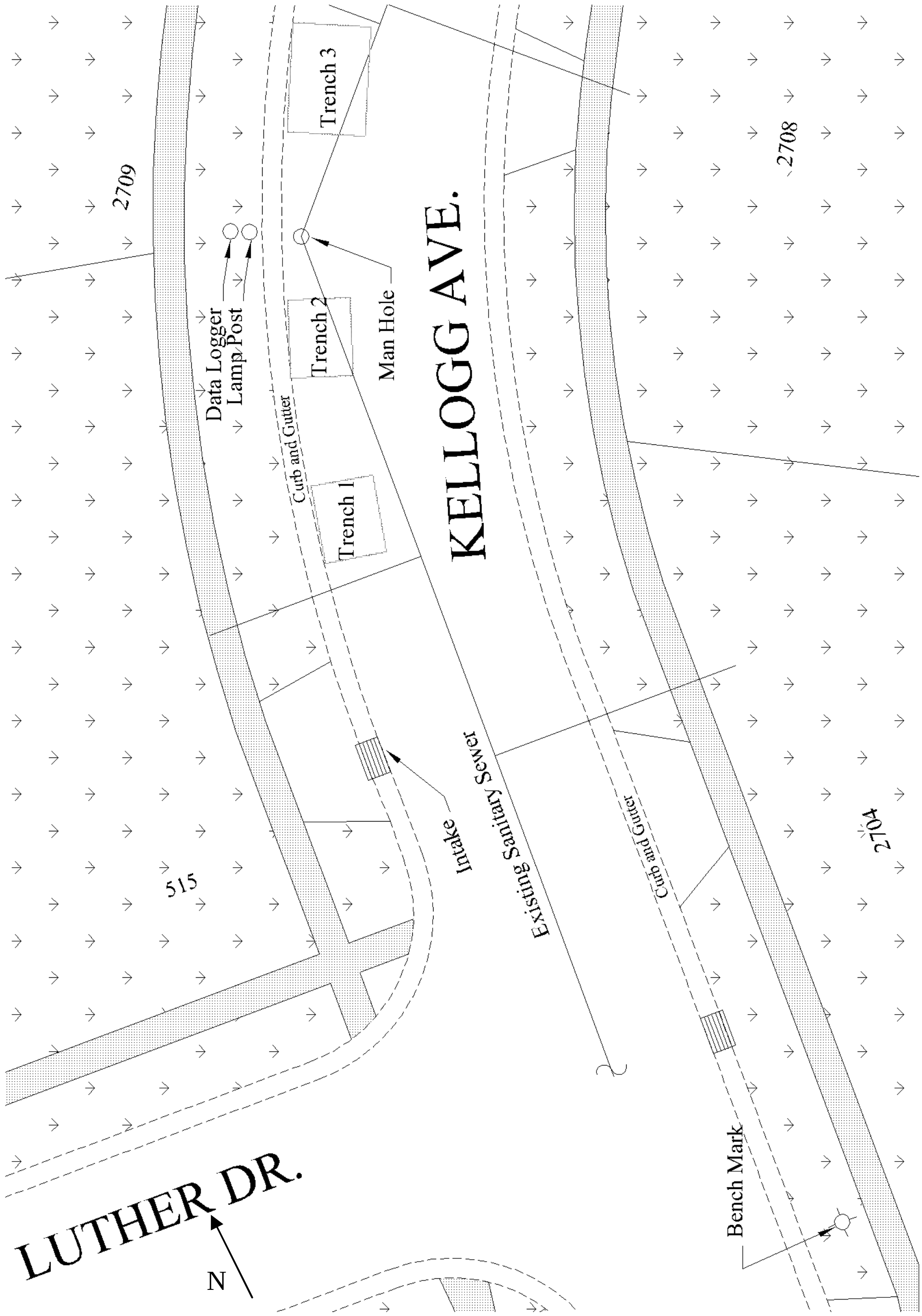


Figure 173 – Plan view of the instrumented trench site showing the location of the trenches and the temperature sensors

5.3.1 - Construction Summary: Trench 1

Trench 1 was constructed on September 27, 2007. The following is a summary of the construction process:

- The trench was excavated using a backhoe to the elevation of about 89.8 feet (about 7.25 feet below existing pavement). The trench dimensions were about 10 feet long paralleling the curb and 8 feet wide extending from the edge of the concrete curb gutter pan (see Figure 174).
- After the trench was excavated, a section of ductile iron pipe was placed horizontally at the base of the trench to simulate an underground utility. The ductile iron pipe was filled with 3/8-inch minus limestone, and the ends of the pipe were capped with clay.
- The first extensometer was installed next to the iron pipe.
- The first lift was 2 feet of loose backfill to cover the pipe and compacted with a impact rammer compactor.
- The remaining eight lifts were about 1 foot thick and consisted of loose 3/8-inch minus limestone backfill.
- An impact rammer compactor was used to compact each lift (see Figure 175).
- Each lift was moisture conditioned by sprinkling water from a hose attached to a watering truck.
- After completing lift compaction, four Nuclear Density tests were performed to verify that each lift met moisture content and dry unit weight requirements (moisture content greater than 8 percent and above 65% percent relative density). Figure 176 shows a Nuclear Density test about to be performed in Trench 1. Results from the field-testing are summarized in Section 5-4.
- DCP tests were also performed on lifts 2, 4, 6, 7, and 8 to estimate the CBR of the compacted backfill (see Figure 177).
- The instruments were installed on lifts 2, 4, 6, and 8. On the upper-most instrumented lift (lift 8) an additional moisture sensor was inserted into the wall of the trench to measure the moisture content of the soil adjacent to the trench.

- Upon the completion of the trench, a temporary asphalt patch was placed over the trench (see Figure 178).
- On September 31, 2007, the asphalt was stripped from the road for repaving. The trenches were left with only a partial patch. During that afternoon, the City of Ames experienced a large amount of rain. The runoff free flowed into the trenches (see Figure 179)
- On October 1, 2007, the street was resurfaced with about 6 inches of asphalt.

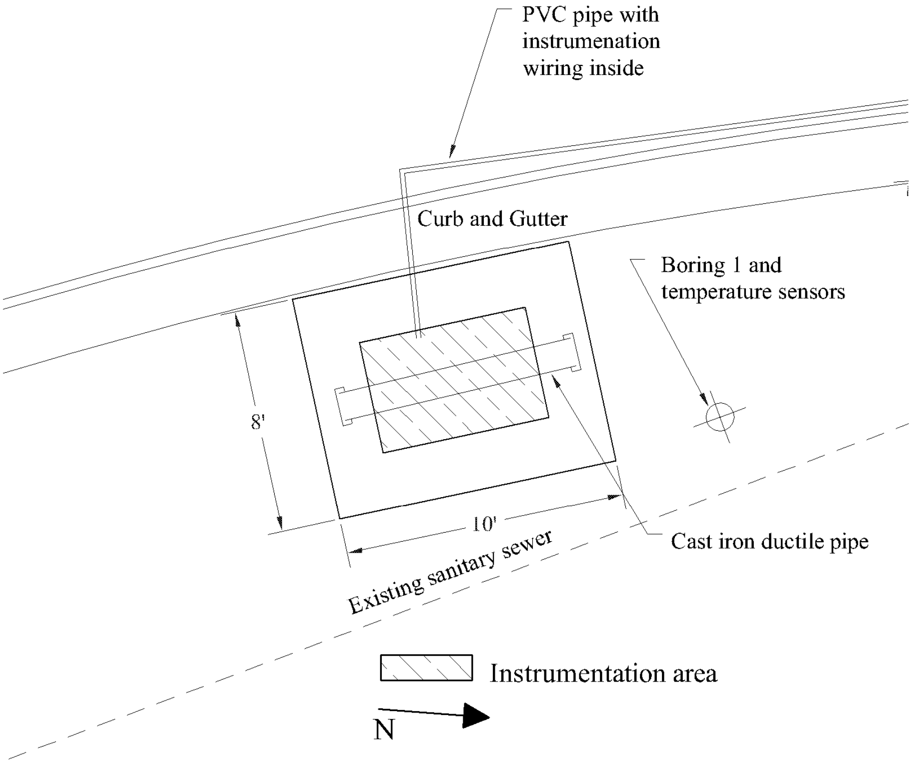


Figure 174 – Plan view showing details of Trench 1

Figure 175 -- Impact rammer used to compact the backfill in Trench 1

Figure 176 -- Nuclear density gauge used in Trench 1

Figure 177 -- DCP test performed in Trench 3, (similar procedure for all trenches)

Figure 178 – The placement of the temporary patch on Trench 1

Figure 179 -- Runoff flowing into the trench around the temporary patch

5.3.2 - Construction Summary: Trench 2

The installation of Trench 2 took place on September 20, 2007 by the City of Ames. The Iowa State Research Team documented the construction process. Observations include the following:

- The trench was excavated using a backhoe to the approximate elevation of 90.3 feet (7.8 feet below existing pavement). The trench dimensions were about 10 feet long paralleling the curb and 8 feet wide extending from the edge of the concrete curb gutter (Figure 180).

- A clay drain line lined with a plastic tube was broken while excavating the north end of the trench. According to the City of Ames, this drain line was not marked as an active utility. Thus, the hole in the clay pipe was filled with packaged concrete.
- A City of Ames worker probed to find the exact location of the sewer line in the northwest corner of the trench. The sewer line was below the trench floor.
- A drainpipe located between lifts 2 and 3 on the west side of the trench was also broken. This pipe was also filled with packaged concrete, but it is possible that water was entering the trench through this pipe during rain events.
- A section of ductile iron pipe was placed horizontally at the base of the trench to simulate an underground utility. The ductile iron pipe was filled with 3/8-inch minus limestone, and the ends of the pipe were capped with clay.
- The first extensometer was installed was installed next to the ductile iron pipe.
- Each lift was approximately 2 feet of loose 3/8-inch minus limestone backfill.
- A plate compactor attached to a backhoe was used to compact each lift (see Figure 181).
- The City of Ames personnel were responsible for placing the backfill material in Trench 2, with no requirements for moisture control or density. The Iowa State Research Team performed four Nuclear Density tests in each lift after compaction. Results from these tests are in Section 5-3.
- The Iowa State Research Team performed DCP tests on lifts 1, 2, 3, and 4 to estimate the CBR of the compacted backfill. Lift 5 (the top lift) was not tested using the DCP tests.
- Extensometers were installed to span center of lifts 1, 2, 3, and 4. An extensometer spanning lift 1 was also installed on the side of the trench. This additional extensometer does not work.
- On lifts 1, 2, 3, and 4, pressure cell, and moisture sensor were installed. An additional moisture sensor was installed on the side of the trench on lift 1. This moisture sensor does not work.
- The City of Ames placed a temporary asphalt patch was placed over the trench after completion.
- On October 1, 2007, the City of Ames resurfaced the street with about 6 inches of asphalt pavement.

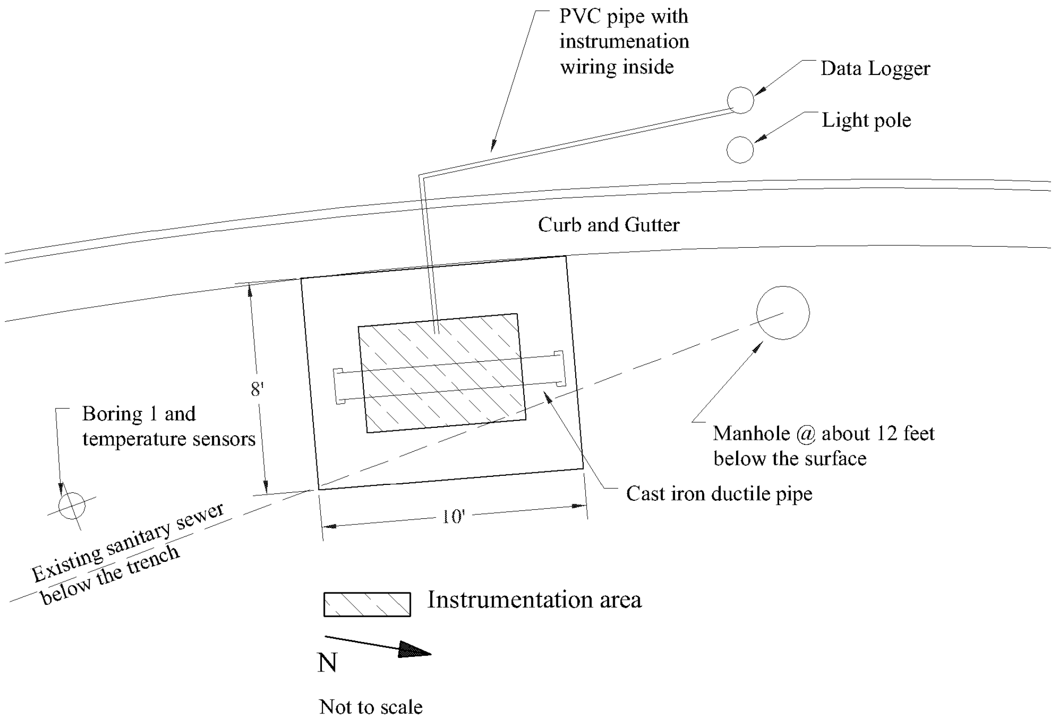


Figure 180 – Plan view showing details of Trench 2

Figure 181 -- Vibratory plate compactor attached to the backhoe used compact the backfill in Trench 2

5.3.3 - Construction Summary: Trench 3

Trench 3 was constructed on September 21, 2007. The following was documented by the Iowa State Research Team:

- The trench was excavated using a backhoe to the elevation of about 91.3 feet (7.25 feet below existing pavement). The trench dimensions were about 10 feet long paralleling the curb (including the cutbacks) and 8 feet wide extending from the edge of the concrete curb gutter (see Figure 182).
- An unused drain tile was broken during excavation, and it was patched with packaged concrete.
- After the excavation was completed, water seepage was present in the northwest corner of the trench. The water prevented the concrete anchor of the extensometer from curing. This resulted in about an hour delay before the trench could be backfilled.
- Lifts were performed by placing about 1 foot of loose 3/8-inch minus limestone fill.
- A vibratory plate compactor was initially used to compact the first lift until the workers noticed that the vibrations caused the extensometer to tip off vertical. An impact rammer compactor was then used to adjust the extensometer back to vertical alignment (Figure 183) and to complete this and all subsequent lift compactions. No further problems occurred with the extensometers during this process.
- Each lift was moisture conditioned with a hose (see Figure 184).
- The Iowa State Research Team performed Nuclear Density tests in each lift after compaction to verify that they met moisture content and dry unit weight requirements (moisture content greater than 8 percent and a relative density greater than 65%).
- The Iowa State Research Team performed DCP tests on lifts 3, 4, 5, 7, and 9 to estimate the CBR of compacted backfill.
- At the completion of lift 6, the T-section was constructed by removing 2 feet of soil on each side of the trench (see Figure 185). Additional Nuclear Density and DCP tests were performed on the T-section.

- The completed trench contained nine lifts with a column of extensometer extending from a depth of about 8.30 feet to 2.42 feet and pressure cells, and moisture sensors were installed on top of lifts 2, 4, 6, and 7.
- On the T-section, a pressure cell and moisture sensor was installed.
- The City of Ames placed a temporary asphalt pavement patch over the completed trench.
- On October 1, 2007, the City of Ames resurfaced the street with about 6 inches of asphalt pavement.

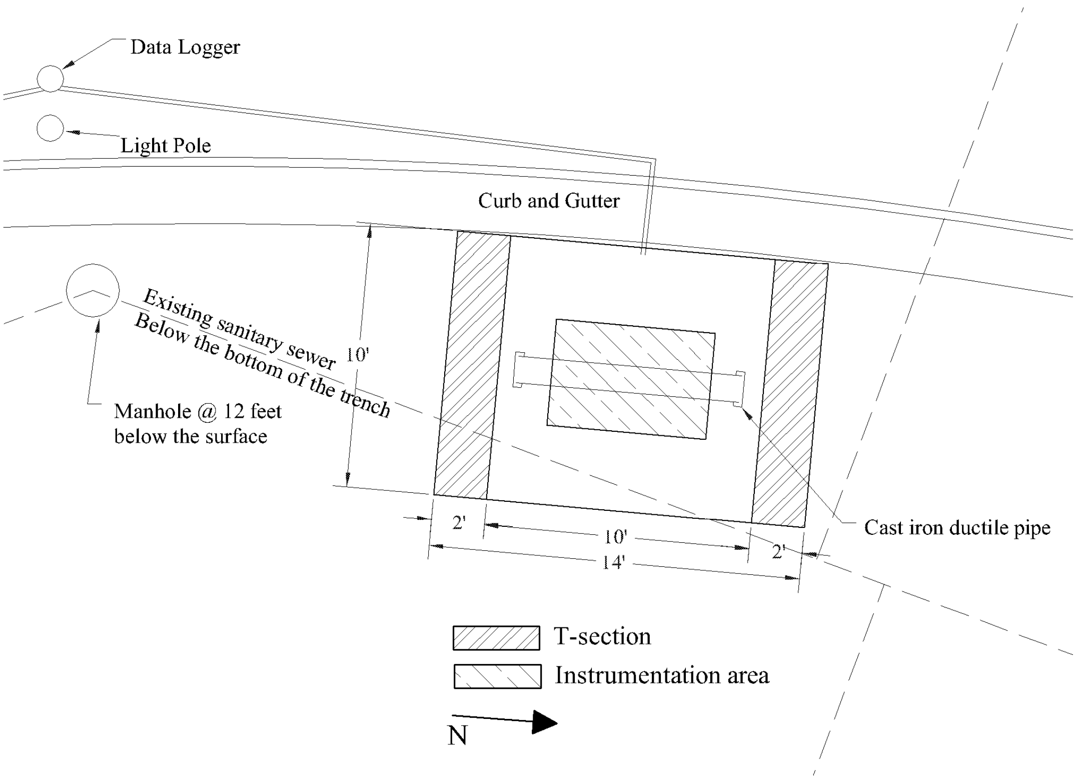


Figure 182 – Plan view showing details of Trench 3

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Figure 183 – a) Extensometer being moved back to vertical alignment and b) final compaction around the extensometer after being re-aliened with vertical

Figure 184 – Adding water to the 3/8-inch minus backfill being from above in Trench 3.

Figure 185 – The excavation of the T-section being constructed for Trench 3

5.4 - Laboratory Testing Results

Laboratory tests were conducted on the backfill from the instrumented trenches on Kellogg Avenue. These tests included particle size distribution with sieve and hydrometer analyses, Atterberg limits, water content, Standard Proctor, and minimum and maximum relative density. All tests were performed according to the corresponding ASTM standards. For descriptions of these laboratory tests refer to Section 4.4. Complete laboratory and classification information is located in Appendix B.

5.4.1 - Soil Classification

The gradations for soils excavated from the trench and the backfill are shown in Table 5-13. The 3/8-inch minus backfill has 3.0% of the particle by mass passing 0.02 mm. This along with the soils classification of SP-SM, allows for a frost heave classification of F2 by the Army Corps of Engineering in Table 6. The frost susceptibility of the soils was Negligible to Medium according to Figure 14 by the Army Corps of Engineers. The frost susceptibility rating accounts for the rate of frost heave per day. This means that these soils were expected to experience 0.5 mm/day to 4.0 mm/day of temperatures below freezing. The gradation chart in Figure 186 presents the gradations of the backfill used in the instrumented trenches and the soils excavated from the trenches.

Table 69 -- Particle distribution in soils removed from Kellogg Avenue and 3/8-inch minus backfill

Sieve/ Opening Size (mm)	3/8-inch minus limestone
1½ in (38.1)	100
1 in (25.4)	100
3/4 in (19.05)	100
1/2 in (12.7)	---
3/8 in (9.525)	98.3
No.4 (4.75)	53.2
No.10 (2.0)	19.8
No.20 (0.85)	12.0
No.40 (0.425)	10.2
No.60 (0.25)	9.3
No. 80 (0.1778)	---
No.100 (0.15)	8.8
No.200 (0.075)	7.4

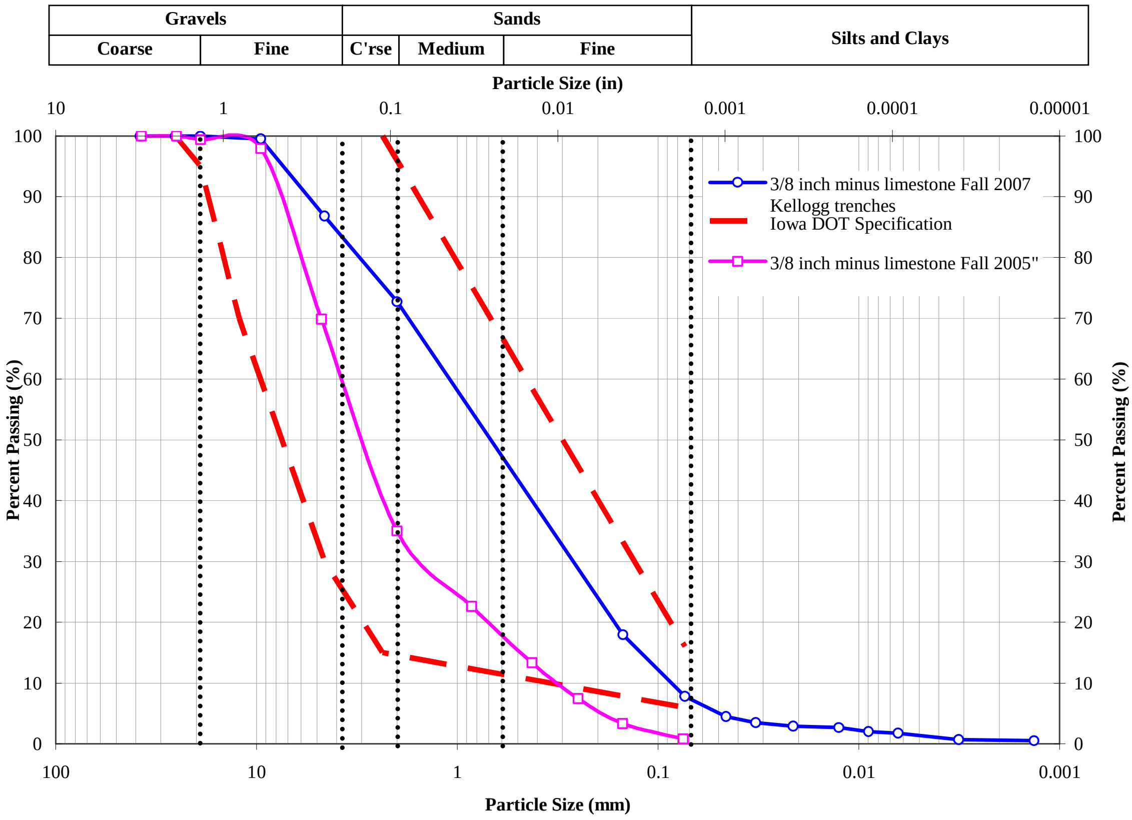


Figure 186 -- Gradation of backfill and soils excavated from the trenches

All soils were classified using the USCS and AASHTO standards. The soil classification results are summarized in Table 70. This table shows that the backfill was classified as SP-SM – Poorly graded sand with silt with the USCS and the AASHTO classification was A-1-B stone fragments, gravel and sand.

Table 70 -- Classification of the soil removed from the trenches on Kellogg Avenue and the 3/8-inch minus backfill

Sample	Soil Classification			
	USCS		AASHTO	
3/8-inch minus backfill for from 2007	SP-SM	Poorly graded sand with silt	A-1-b	Stone fragment, gravel and sand
3/8-inch minus backfill for from 2005	SM	Sand/silt	A-1-a	Stone fragment, gravel and sand

5.4.2 - Soil Compaction

Figure 187 compares the relative density testing results from Phase I and Phase II. The difference in the values results from errors during laboratory testing in Phase II. Thus, the Phase II field measurements of the backfill were compared with the Phase I relative density data instead of the Phase I laboratory data. Phase I reported that the bulking moisture content lowest dry unit weight occurred at 7% and that the bulking moisture content ranged from 6% to 8%. Based on the literature review and additional review of the data from Phase I, the bulking moisture content was determined to be from 4% to 8%.

Based on the classification of the 3/8-inch minus limestone in Phase II as SP-SM, the recommended maximum dry unit weight from the standard proctor tests 110 pcf to 125 pcf. The optimum moisture content was from 11% to 16%.

Figure 188 shows the relative density testing results from Phase I with the bulking moisture content.

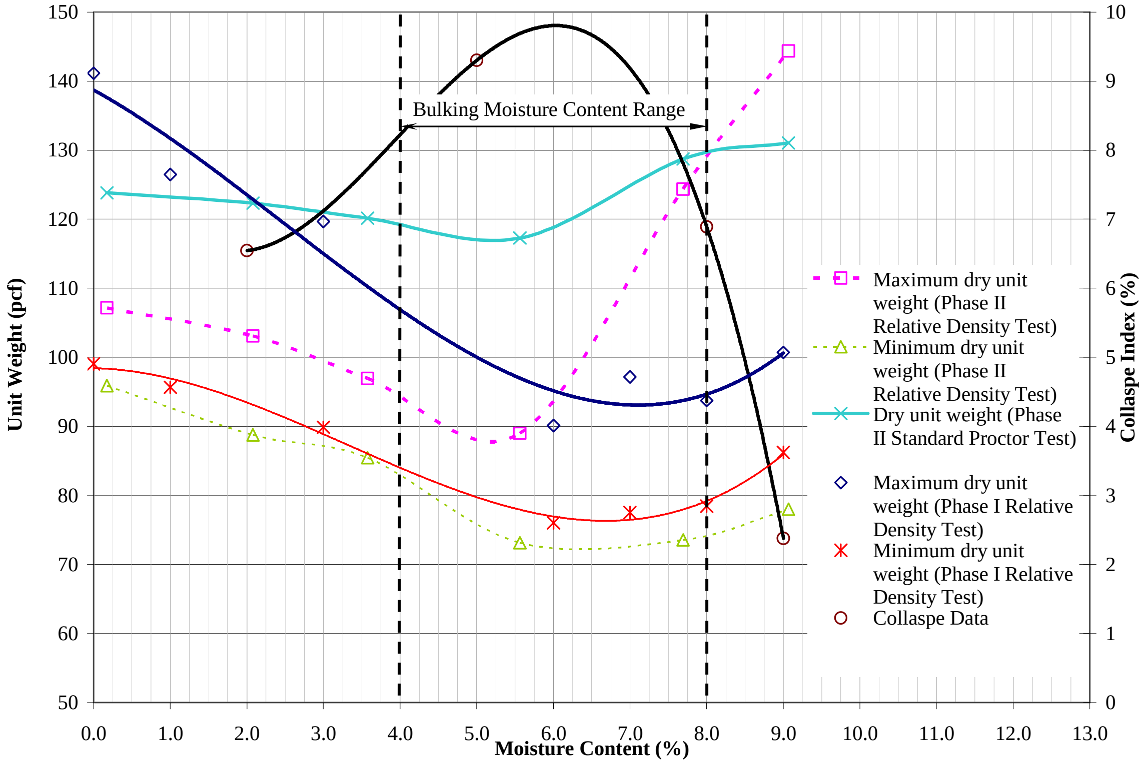


Figure 187 -- Comparison of the Relative Density testing from Phase I and Phase II

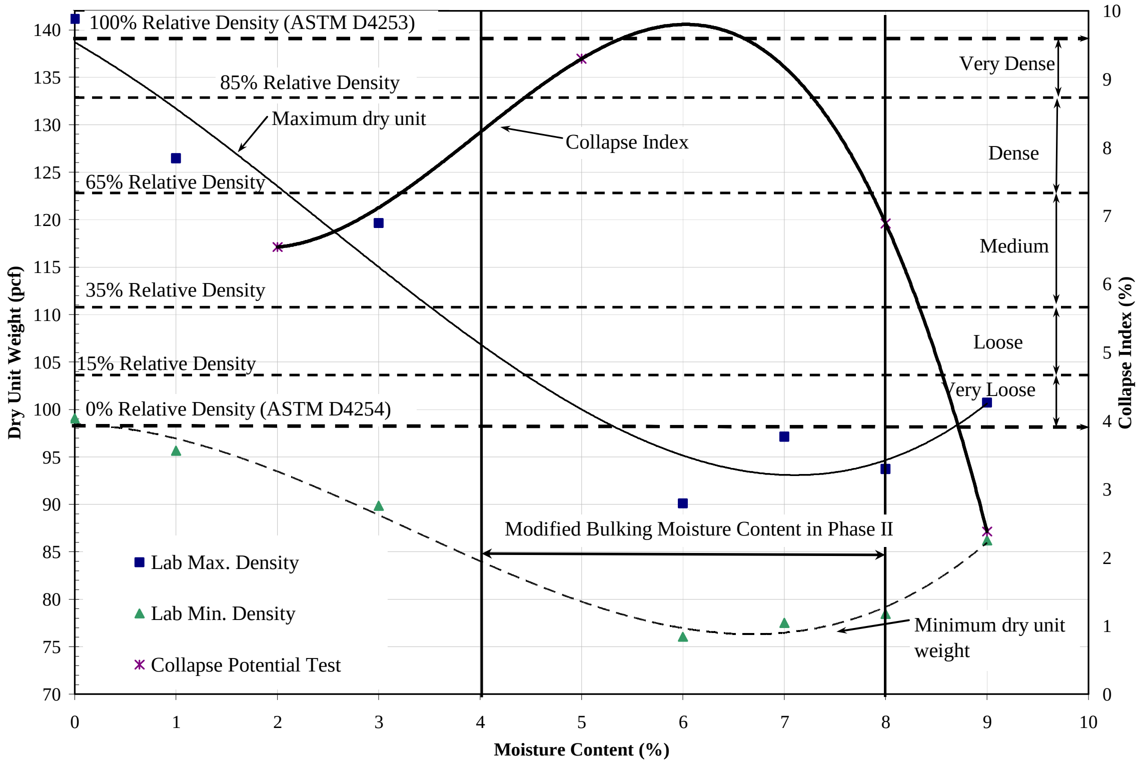


Figure 188 - Relative Density testing results with the bulking moisture content and collapse index

5.5 - Field-Testing During Site Construction

Nuclear Density and DCP tests were conducted on the three instrumented trenches. Testing results for each test point on the lifts are in Appendix B.

The trenches were constructed with 3/8-inch minus limestone that was classified as SP-SM – poorly graded sand and silt. The field test results of the backfill used in Phase II were compared to the following NAVFAC recommendations for silty soils: 1) dry unit weights range from 110 pcf to 125 pcf, 2) optimum moisture contents range from 11% to 16%, and 3) CBR values range from 5% to 30%. The field test results were also compared to values obtained during laboratory testing of the backfill used in Phase II: a) maximum dry unit weight of 140 pcf, b) minimum dry unit weight of 99.0 pcf and c) the bulking moisture content ranging from 4% to 8%.

5.5.1 - Instrumented Trench 1

The two tests were performed at four different test points for all lifts. The location of the test points are shown in Figure 189. Test points 1 through 4 were used to test all lifts. Figure 190 shows the trench cross-section with the average testing results.

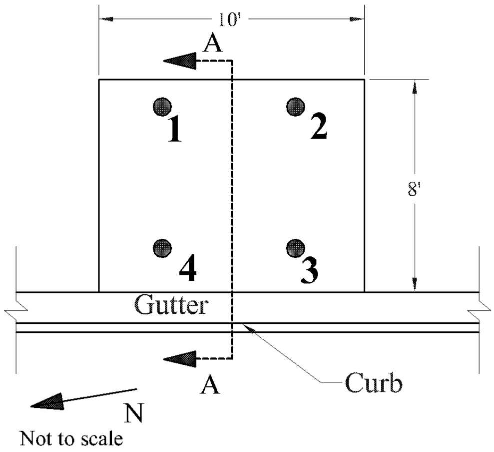


Figure 189 -- Location of test points in Trench 1

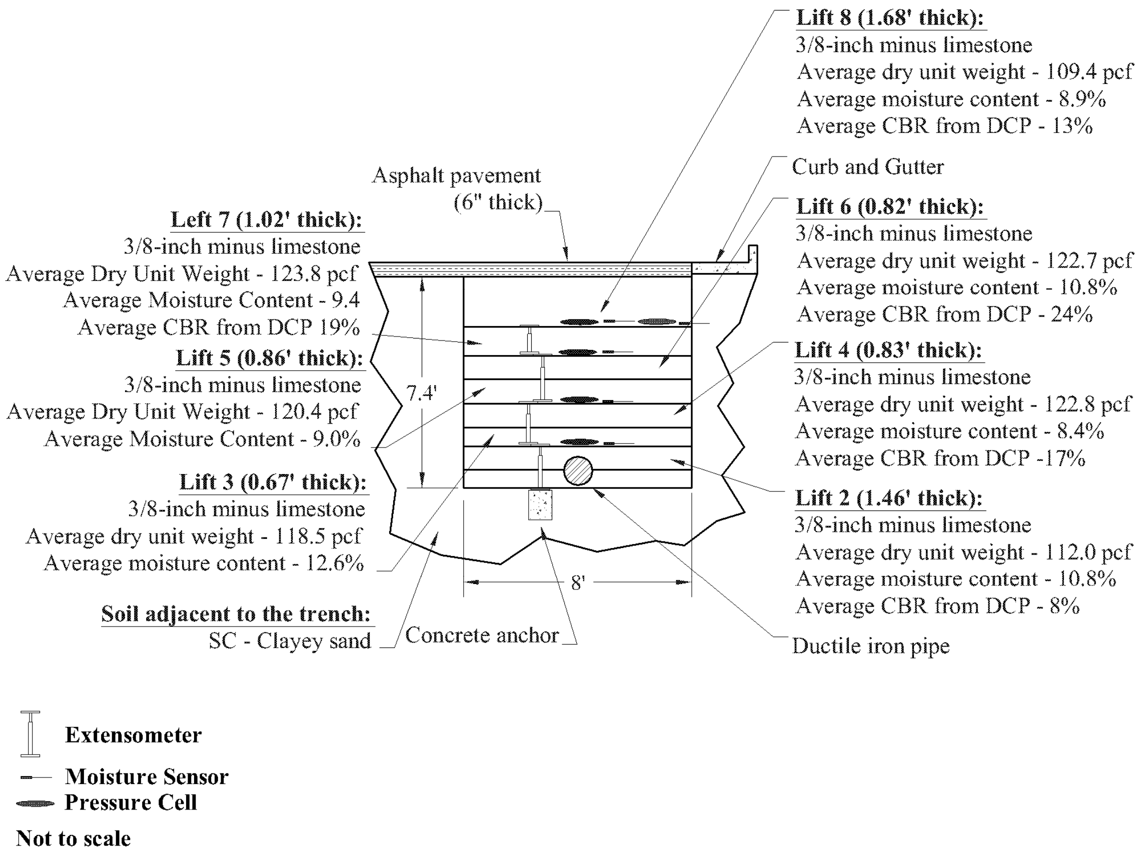


Figure 190 – East-west cross-section A-A of completed Trench 1 with testing results

Nuclear Density Test Results

Table 5-3 summarizes of the average dry unit weight results from the Nuclear Density tests for each layer in Trench 1. Table 5-4 summarizes the moisture content results from the Nuclear Density tests for the various lifts in Trench 1. The probe depth during testing was 4 inches. As reported in the laboratory testing section, the maximum dry unit weight was 140 pcf and the bulking moisture content ranged from 4.0% to 8.0%

The average dry unit weights for lifts 2, 3, 4, 5, 6, and 7 ranged from 112.0 pcf to 123.8 pcf and fell within the NAVFAC recommendations. The average dry unit weight for lift 8 was 109.4 pcf, which was below the NAVFAC recommendations. The average relative densities for lifts 2, 3, 4, 5, 6, and 7 ranged from 39% to 67%, which corresponds to medium dense to dense compaction. The relative density of lift 8 was 32%, which corresponded to loose compaction density.

The average moisture contents for lifts 2, 3, 4, 5, 6, 7, and 8, ranged from 8.4% to 12.6%. These values were below the recommended optimum moisture content for compaction from NAVFAC. All the moisture contents were above the bulking moisture content.

The second lift dry unit weights ranged form 115.1 pcf to 123.4 pcf. The relative densities ranged from 47% to 66%. These values were all at a medium dense compaction density. The moisture contents ranged from 9.4% to 12.6%. These moisture contents were above the bulking moisture content range. Figure 191 shows the field-testing results for lift 2 superimposed on the laboratory testing data from Phase I.

The third lift dry unit weights ranged form 113.2 pcf to 121.4 pcf. The relative densities ranged from 41% to 62%. These values were all at a medium dense compaction density. The moisture contents ranged from 11.7% to 14.4%. Test points 2 and 3 were within the bulking moisture content and test points 1 and 4 were above the bulking moisture content. These moisture contents were above the bulking moisture content range. Figure 192 shows the field-testing results for lift 3 superimposed on the laboratory testing data from Phase I.

The fourth lift dry unit weights ranged 120.0 pcf to 123.5 pcf. The relative densities ranged from 58% to 68%. These values ranged from a medium dense to a dense compaction density. The moisture contents ranged from 7.7% to 9.1%. These moisture contents were above the bulking moisture content range. Figure 193 shows the field-testing results for lift 4 superimposed on the laboratory testing data from Phase I.

The fifth lift dry unit weights ranged 111.4 pcf to 125.2 pcf. The relative densities ranged from 37% to 70%. These values ranged from a loose to a dense compaction density. The moisture contents ranged from 8.6% to 9.0%. These moisture contents were above the bulking moisture content range. Figure 194 shows the field-testing results for lift 5 superimposed on the laboratory testing data from Phase I.

The sixth lift dry unit weights ranged 121.2 pcf to 124.8 pcf. The relative densities ranged from 61% to 69%. These values ranged from a loose to a dense compaction density. The moisture contents ranged from 9.2% to 11.7%. These moisture contents were above the bulking moisture content range. Figure 195 shows the field-testing results for lift 6 superimposed on the laboratory testing data from Phase I.

The seventh lift dry unit weights ranged 121.4 pcf to 125.8 pcf. The relative densities ranged from 61% to 71%. These values ranged from a loose to a dense compaction density. The moisture contents ranged from 8.2% to 10.8%. These moisture contents were above the bulking moisture content range. Figure 196 shows the field-testing results for lift 7 superimposed on the laboratory testing data from Phase I.

The eighth lift the dry unit weights ranged 106.4 pcf to 111.0 pcf. The relative densities ranged from 61% to 71%. These values ranged from a loose to a dense compaction density. The moisture contents ranged from 8.4% to 9.6%. These moisture contents were above the bulking moisture content range. Figure 197 shows the field-testing results for lift 8 superimposed on the laboratory testing data from Phase I.

The lower lifts were placed were compacted to medium dense to dense compactions. The upper lift was loose at 32% relative density. Figure 198 shows the field-testing results for each lift. The average dry unit weight for all the lifts was 118.5 pcf. This is a 55% relative density or medium dense compaction. The average moisture content for all lifts was 9.7%. The moisture content was above the bulking moisture content.

Table 71 – Dry unit weights measured using Nuclear Density testing for Trench 1

Lift	Average dry unit weight (pcf)	Relative density (%)	Relative compaction	Minimum and maximum dry unit weights from field-testing (pcf)	Standard deviation	Coefficient of variance (%)
Lift 2	120.0	59	Medium	115.1 / 123.4	3.6	3.2
Lift 3	118.5	55	Medium	113.2 / 121.4	3.8	3.2
Lift 4	122.8	65	Dense	120.0 / 123.5	1.9	1.5
Lift 5	120.4	59	Medium	111.4 / 125.2	6.2	5.1
Lift 6	122.7	65	Dense	121.2 / 124.8	1.5	1.2
Lift 7	123.8	67	Dense	121.4 / 125.8	1.1	1.9
Lift 8	109.4	32	Loose	106.4 / 111.0	2.2	2.0
Average for entire Trench	119.6	58	Medium	---	5.5	

Table 72 – Average moisture contents measured using Nuclear Density testing for Trench 1

Lift	Average moisture content (%)	Degree of saturation (%)	Minimum and maximum moisture contents (%)	Standard deviation	Coefficient of variance (%)
Lift 2	10.8	74.2	9.4 / 12.6	1.3	12.0
Lift 3	12.6	49.6	11.7 / 14.4	1.3	10.3
Lift 4	8.4	28.6	7.7 / 9.1	0.8	9.5
Lift 5	9.0	26.3	8.6 / 9.0	0.3	3.3
Lift 6	10.8	30.1	9.2 / 11.7	1.1	11.7
Lift 7	9.4	25.2	8.2 / 10.8	1.5	16.0
Lift 8	8.6	18.9	8.4 / 9.6	0.6	7.0
Average for entire Trench	10.0	23.9	---	1.7	

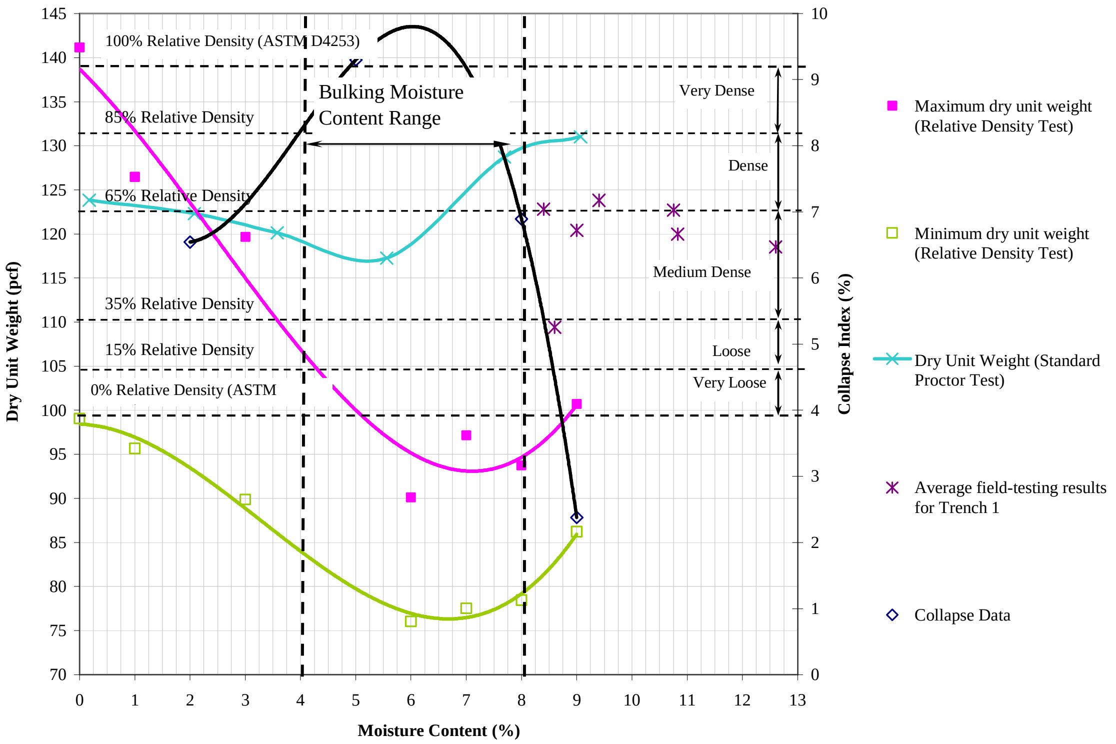


Figure 191 -- Dry unit weights and moisture contents measured during the construction of Trench 1 lift 2 compared with the relative density, and Standard Proctor testing results with the collapse index

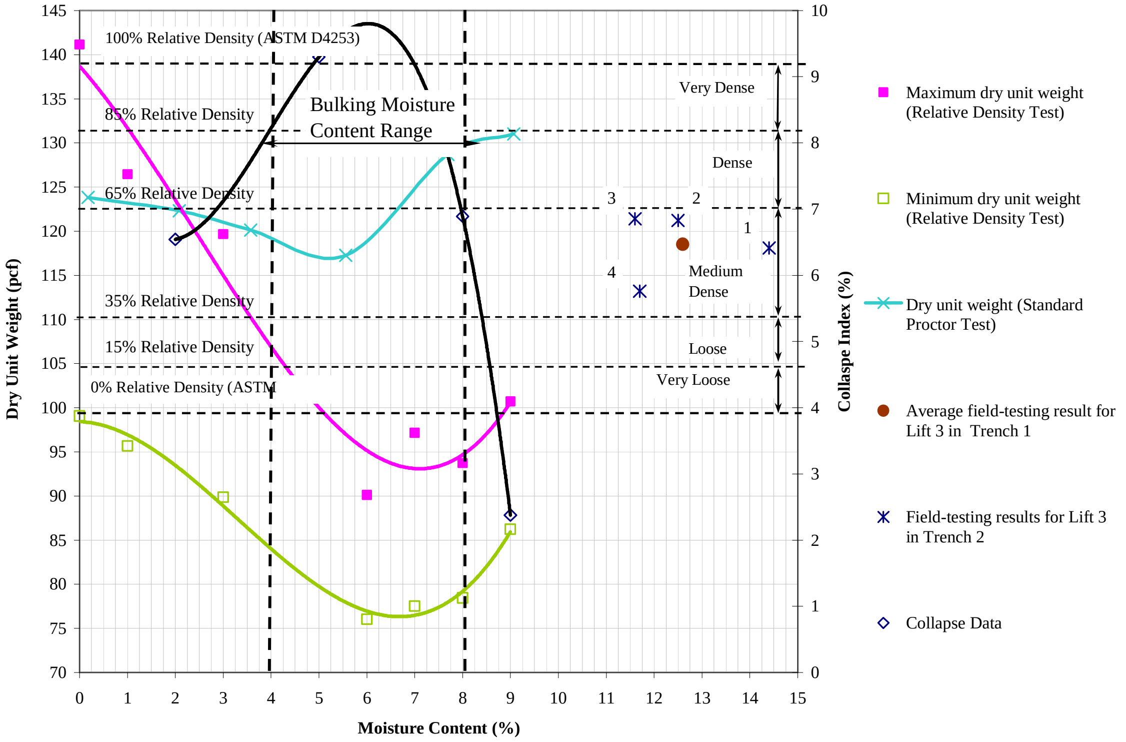


Figure 192 -- Dry unit weights and moisture contents measured during the construction of Trench 1 lift 3 compared with the relative density, and Standard Proctor testing results with the collapse index

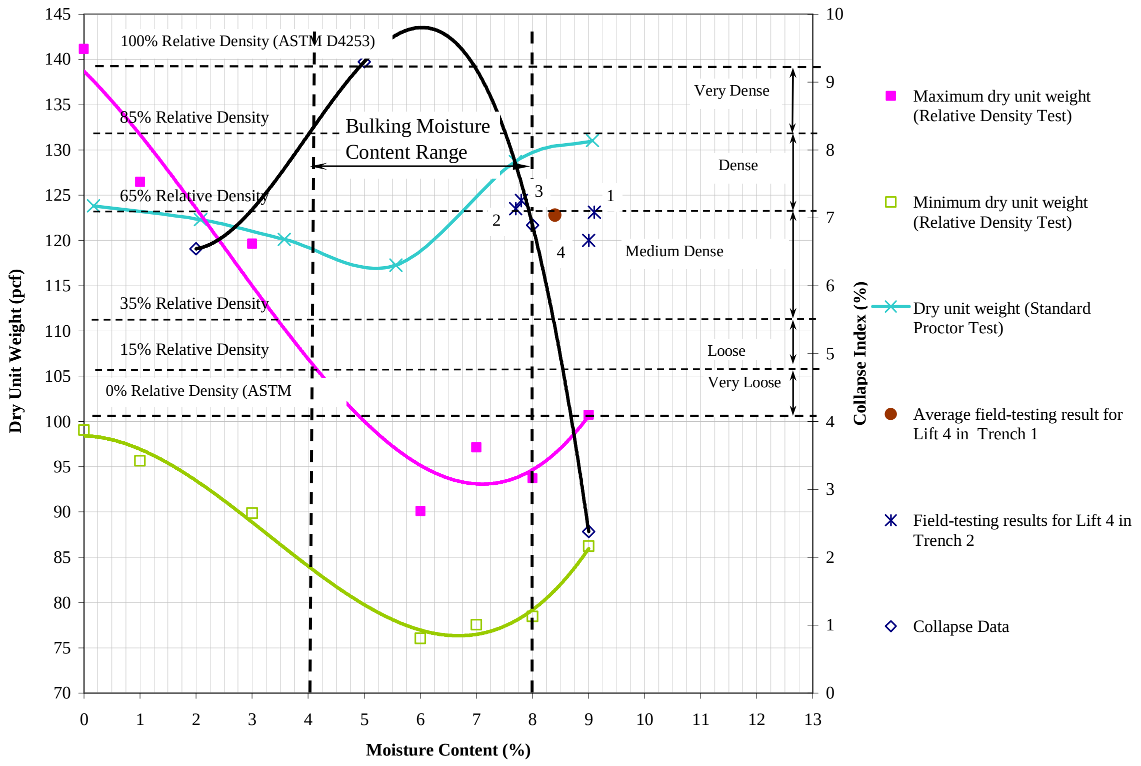


Figure 193 -- Dry unit weights and moisture contents measured during the construction of Trench 1 lift 4 compared with the relative density, and Standard Proctor testing results with the collapse index

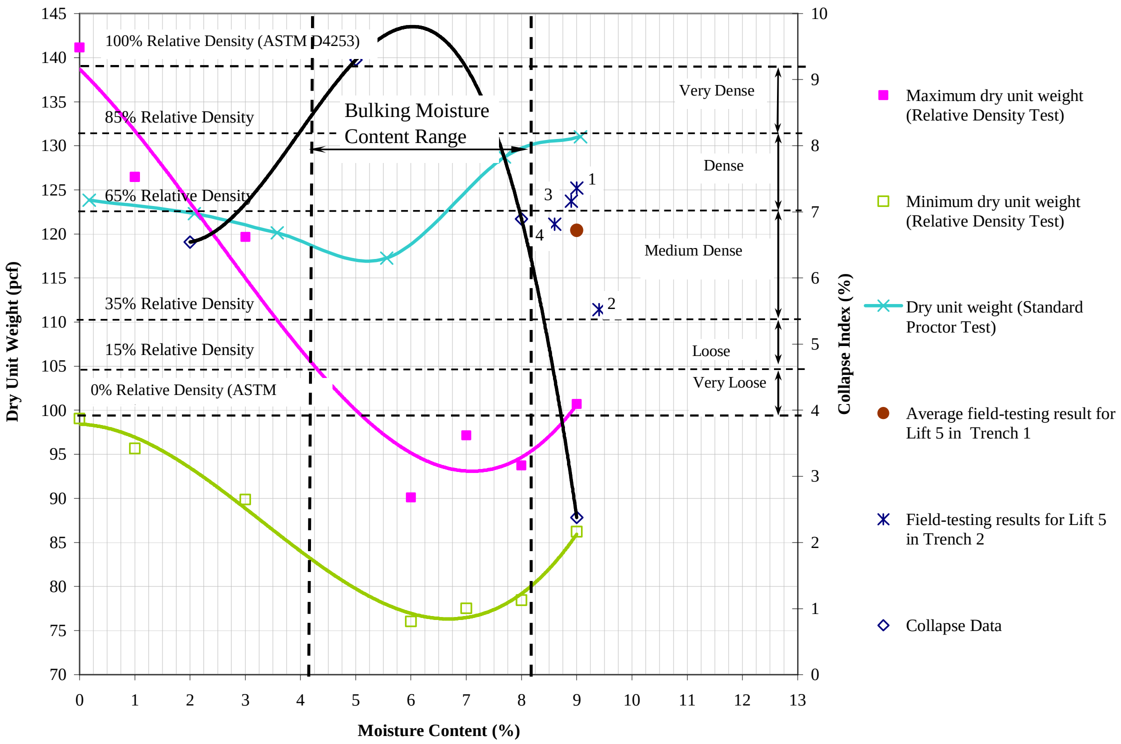


Figure 194 -- Dry unit weights and moisture contents measured during the construction of Trench 1 lift 5 compared with the relative density, and Standard Proctor testing results with the collapse index

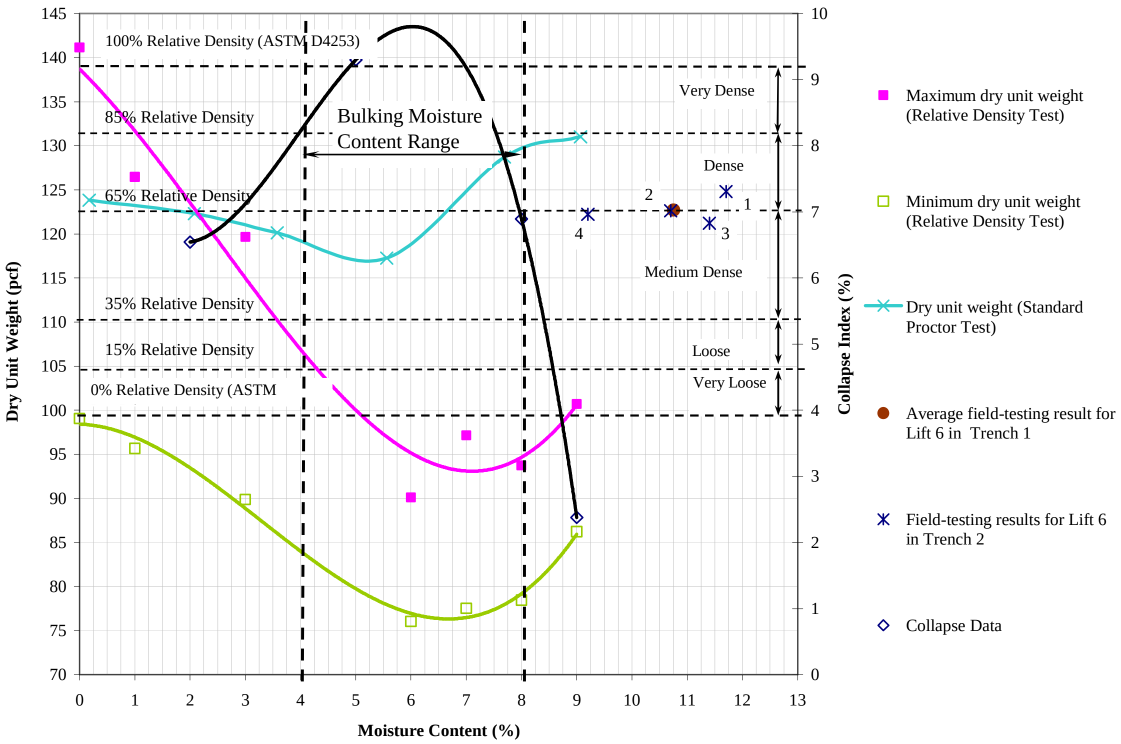


Figure 195 -- Dry unit weights and moisture contents measured during the construction of Trench 1 lift 6 compared with the relative density, and Standard Proctor testing results with the collapse index

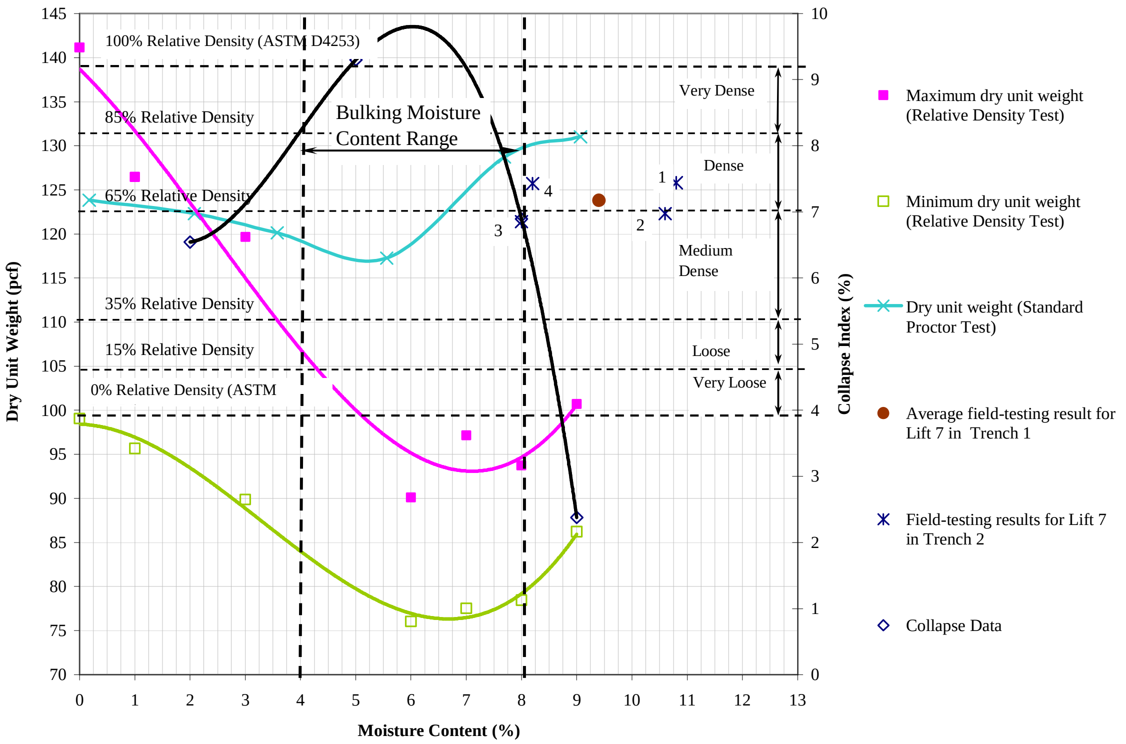


Figure 196 -- Dry unit weights and moisture contents measured during the construction of Trench 1 lift 7 compared with the relative density, and Standard Proctor testing results with the collapse index

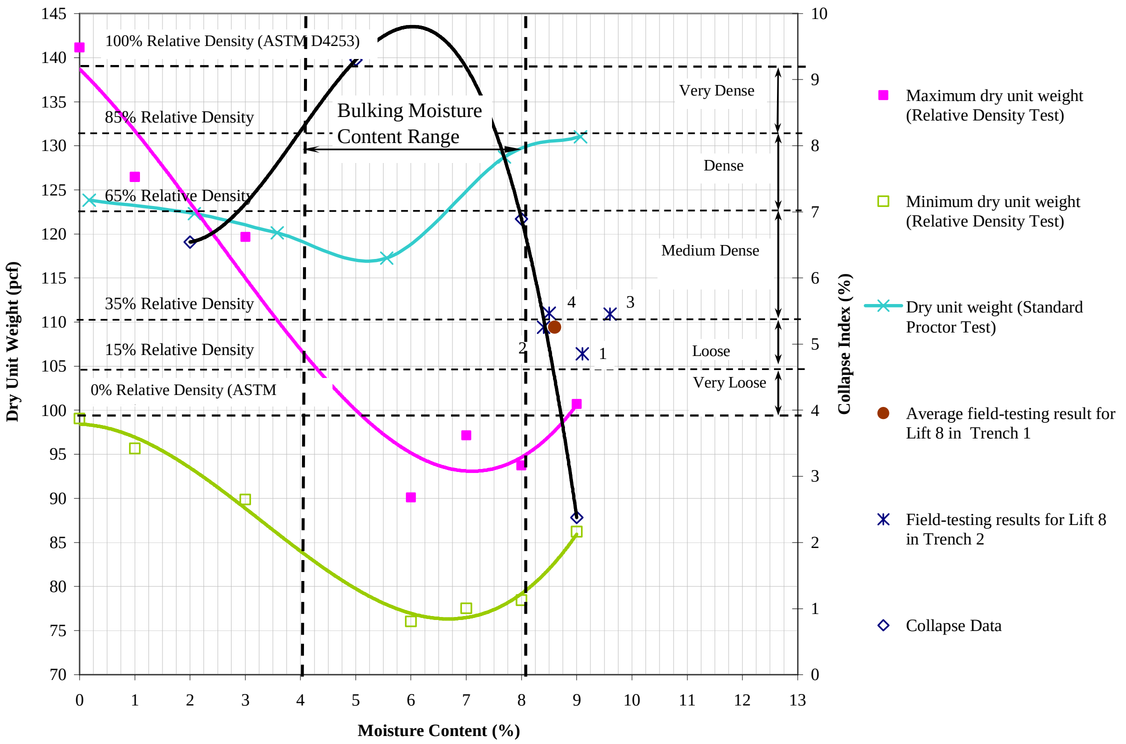


Figure 197 -- Dry unit weights and moisture contents measured during the construction of Trench 1 lift 8 compared with the relative density, and standard proctor testing results with the collapse index

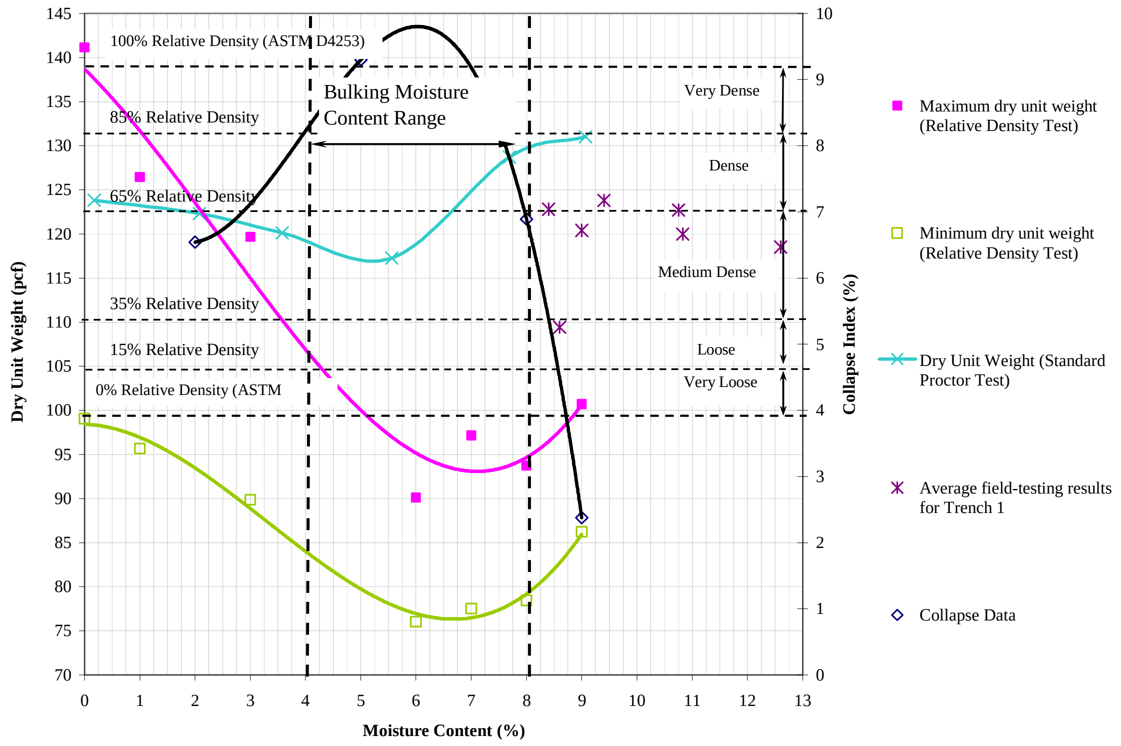


Figure 198 – Summary of average dry unit weights and moisture contents measured for different lifts during the construction of Trench 1 compared with the relative density, and Standard Proctor testing results with the collapse index

DCP Test Results

Table 73 summarizes the DCPI results from the DCP tests for the various lifts and Table 74 summarizes the CBR results from the DCP tests for the various lifts. The fifth lift was not tested using the DCP. The average CBR value for lift 2 was below the typical values from NAVFAC. The remaining lifts had CBR values that were within the recommend CBR values from NAVFAC.

Table 73 – Average DCPI calculated from DCP testing for Trench 1

Lift	Average DCPI	Average depth of test (inch)	Standard deviation	Coefficient of variance (%)
Lift 2	42.5	25.5	46.5	108.3
Lift 3	N/A	N/A	N/A	N/A
Lift 4	16.2	19.5	8.3	51.2
Lift 6	18.7	19.5	8.7	46.5
Lift 7	13.4	19.1	26.6	19.8
Lift 8	23.8	20.7	17.0	73.1

Table 74 – Average CBR results calculated using DCP test results for Trench 1

Lift	Average CBR	Average depth of test (inch)	Standard deviation	Coefficient of variance (%)
Lift 2	8	25.5	4.9	62.6
Lift 3	N/A	N/A	N/A	N/A
Lift 4	17	19.5	9.1	54.2
Lift 6	24	19.5	12.4	51.7
Lift 7	19	19.1	8.8	78.2
Lift 8	13	20.7	8.2	61.6

Figure 199 shows the CBR profiles for the test points within the trench for lift 2. The second lift had an average CBR of 8% extending 25.5 inches. At the surface of the lift, the CBR values ranged from 5% to 8%. These values were not within the range of typical from NAVFAC. At the termination of the tests, the CBR values ranged from 16% to 23%. These values are within the recommend range from NAVFAC. The compactor was effective up to a depth of 10 inches.

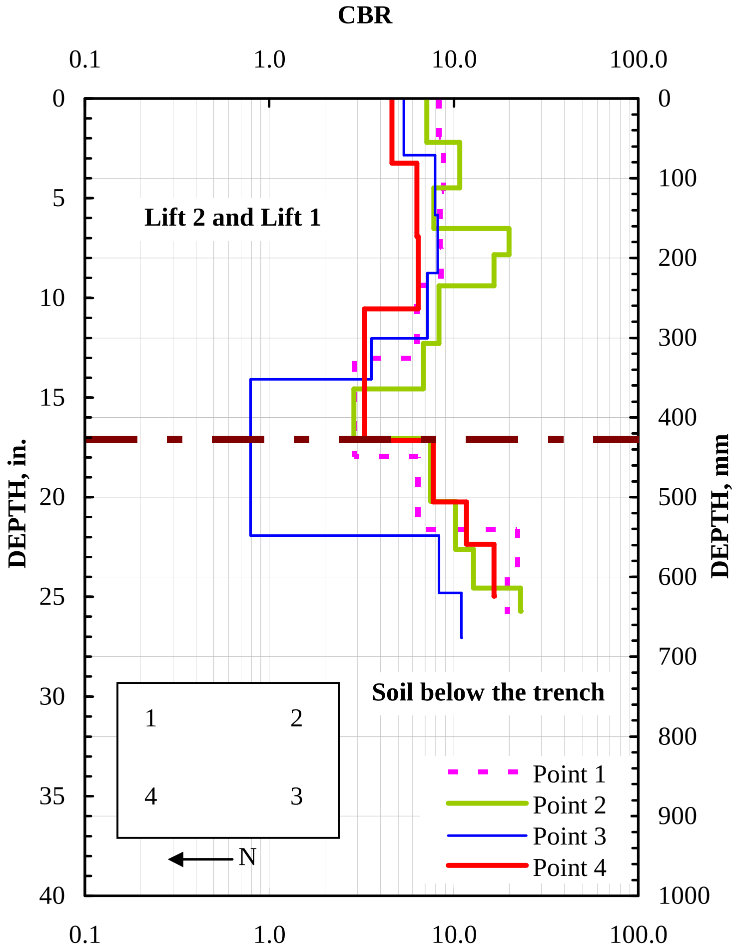


Figure 199 -- CBR profiles calculated using the DCP results for lift 2 in Trench 1

Figure 200 shows the CBR profiles for the test points within the trench for lift 4. On the fourth lift, the four test points had an average depth of 19.5 inches and an average CBR of 17%. These average values were within the NAVFAC recommendations. At the surface of the lift, the CBR values ranged from 5% to 10%. These values were not within the typical range of values from NAVFAC. At the termination of the tests, the CBR values ranged from 18% to 48%. The CBR values were within the typical range for test points 2, 3, and 4. The CBR value at the termination of the DCP test was above the recommend range of values from NAVFAC. As the depth increased, the CBR values increased. In addition, the four tests followed the same generalized pattern through the lift. This indicated that the backfill was evenly compacted across the lift.

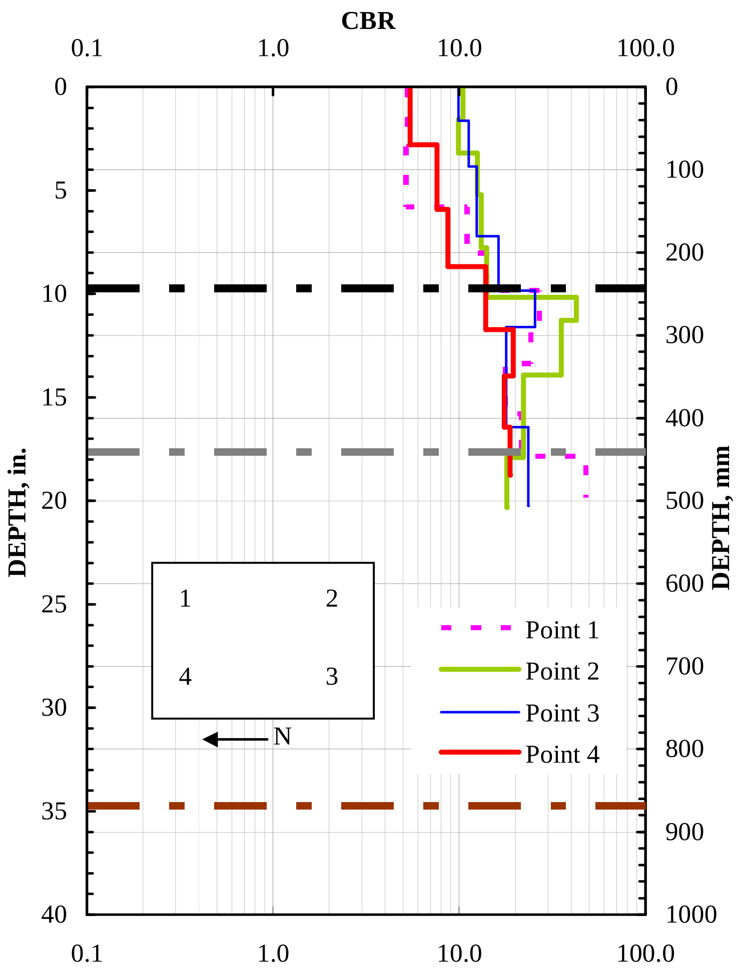


Figure 200 -- CBR profiles calculated using DCP results for lift 4 of Trench 1

Figure 201 shows the CBR profiles for the test points within the trench for lift 6. The average CBR was 24% extending 19.5 inches. The average CBR value was within the typical range of values from NAVFAC. At the surface of the lift, the CBR values ranged from 6% to 11%. These values were not within the typical range of values from NAVFAC. At the termination of the DCP test, the CBR values ranged from 15% to 28%. These values were within the typical range of values from NAVFAC. The CBR values increased with depth. At a depth of about 10 inches, the CBR values uniformly increased. This was at the boundary between lift 6 and lift 7.

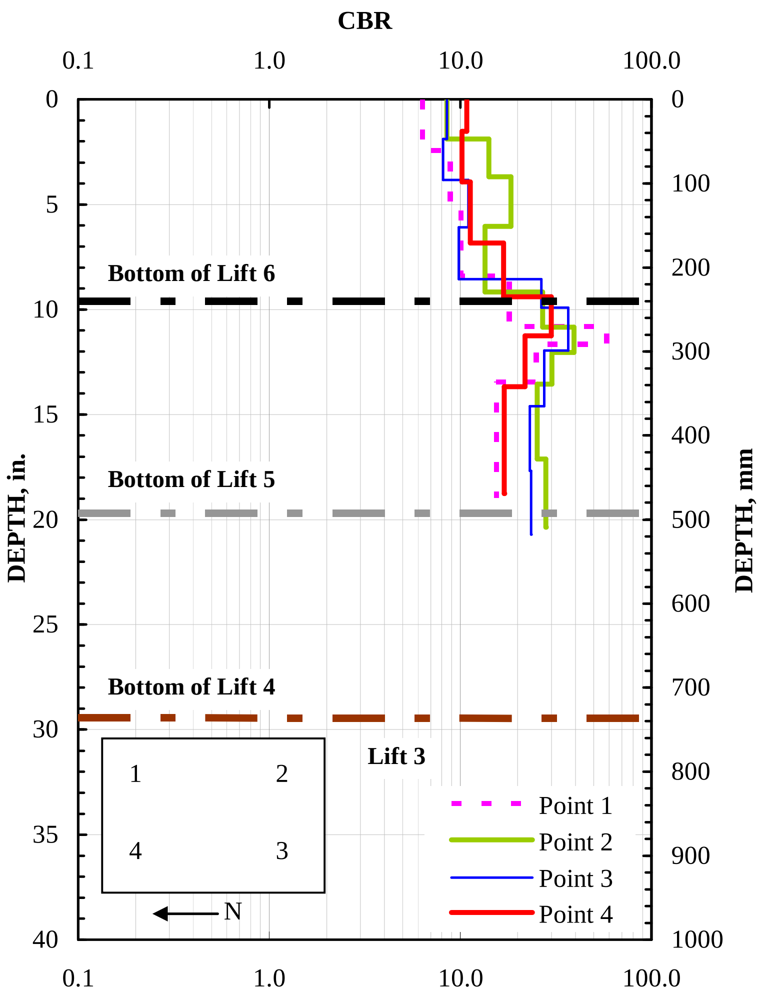


Figure 201 -- CBR profiles calculated using DCP results for lift 6 in Trench 1

Figure 202 shows the CBR profiles for the test points within the trench for lift 7. The average CBR was 19% extending 19.1 inches. This value was within the typical range from NAVFAC. At the surface of the lift, the CBR values ranged from 7% to 11%. These values were not within the typical range of values from NAVFAC, except test point 4 where the CBR value was within the typical range. At the termination of the DCP tests, the CBR values ranged from 19% to 26%. These CBR values were within the typical range of values from NAVFAC. The CBR values increased with depth and they also followed the same generalized pattern.

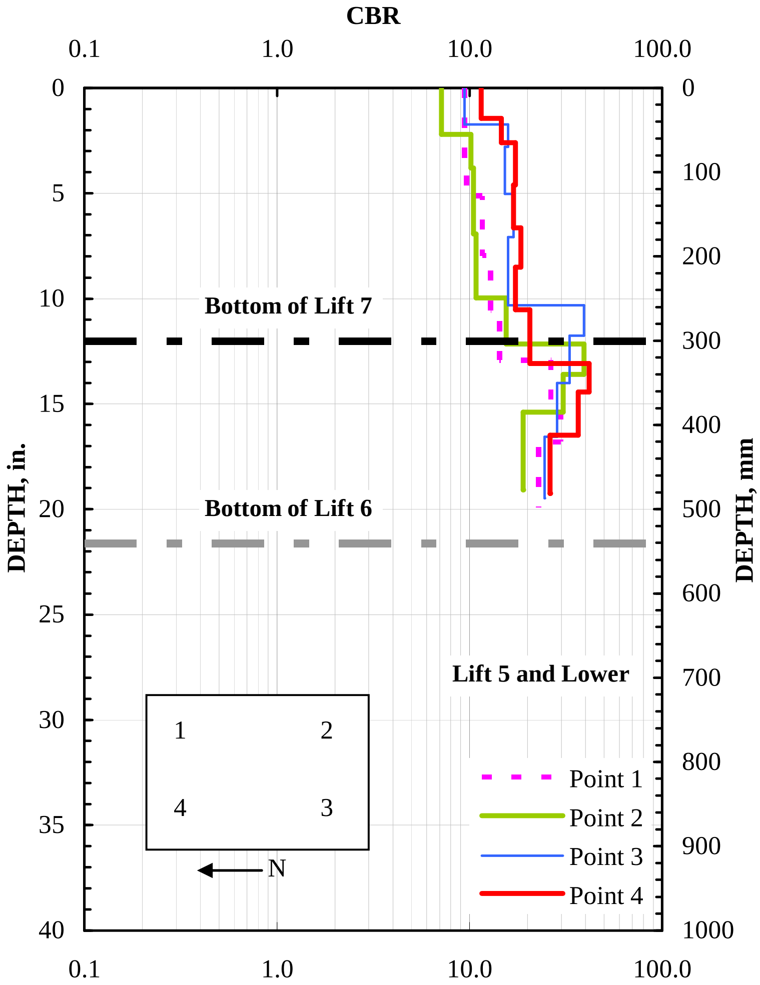


Figure 202 -- CBR profiles calculated using DCP results for lift 7 in Trench 1

Figure 203 shows the CBR profiles for the test points within the trench for lift 8. Average CBR was 13% extending 20.7 inches. This value was within the typical values from NAVFAC. The average CBR value at the surface for all tests was 3%. This was below the typical range of values from NAVFAC. At the termination of the tests, the CBR values ranged from 24% to 42%. These values were within the typical range of values from NAVFAC. The CBR profiles followed the same generalized pattern through the depth of the profile and increased in value with depth. This shows that the lift was evenly compacted.

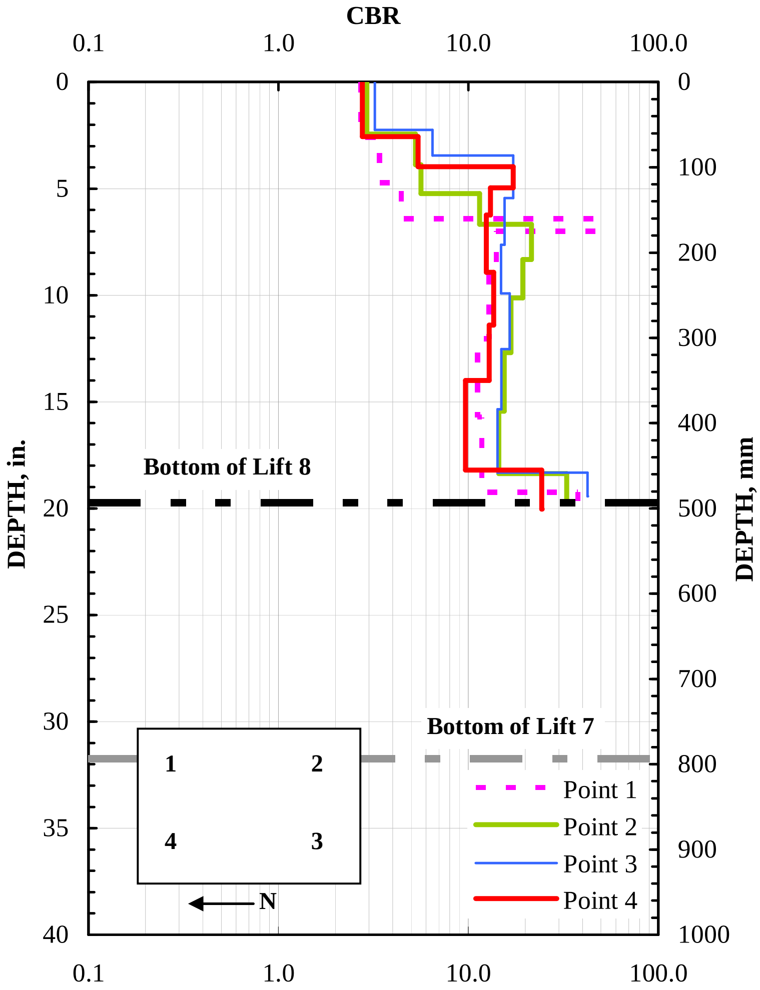


Figure 203 -- CBR profiles calculated using DCP results for lift 8 in Trench 1

5.5.2 - Instrumented Trench 2

The location of the test points in Trench 2 are shown in Figure 204. The first lift was tested at points 2, 3, and 5 because the bottom of the trench was uneven. In lift 3 the Nuclear Density tests was performed at all five test points (1 through 5) and the DCP test was performed at test points 1, 2, 3, and 4. Lifts 2 and 4 were tested at test points 1, 2, 3, and 4 (did not use test point 5). Lift 5 was only tested using the Nuclear Density test at points at field-testing points 2, 3, and 4. The fifth lift was not tested using DCP testing. Figure 205 shows the trench cross-section with the average testing results.

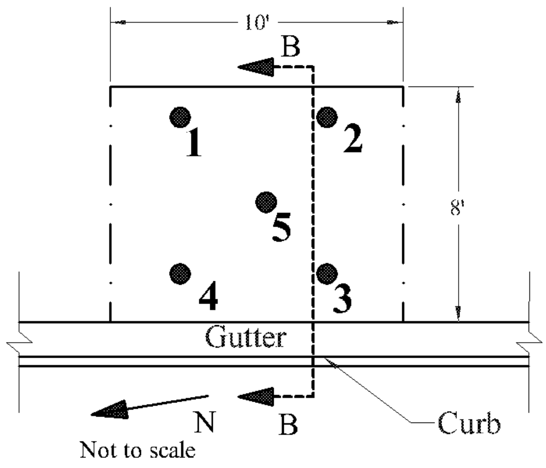


Figure 204 -- Location of test points in Trench 2

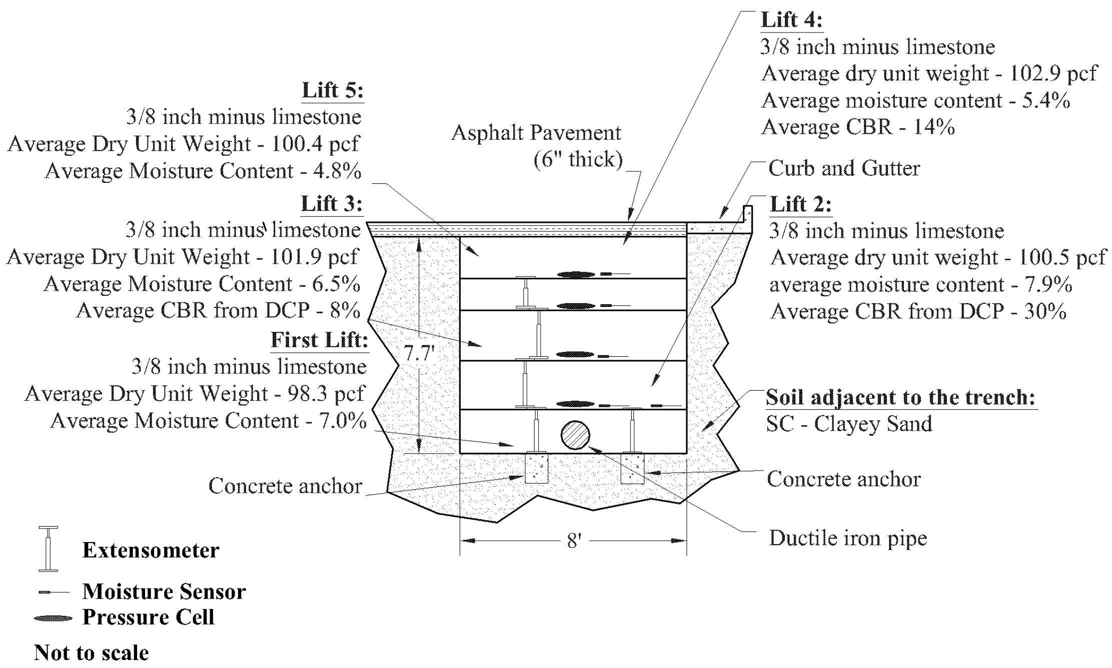


Figure 205 – East-west cross-section B-B of completed Trench 2 with testing

Nuclear Density Test Results

Table 75 summarizes the average dry unit weight results from the Nuclear Density tests for each layer. Table 76 summarizes the moisture content results from the Nuclear Density tests for the various lifts in Trench 2. The probe depth was 4 inches.

The average dry unit weight measured for all the lifts were below the recommended values from NAVFAC. The measured dry unit weights all correspond to very loose compaction densities. The average moisture contents measured in the trench for all lifts were within the bulking moisture content range. The average dry unit weights and moisture contents for each lift are plotted on Figure 206. This Figure illustrates that all the lifts were placed at very loose relative densities and within the bulking moisture content range of 4% to 8%.

The first lift dry unit weights ranged form 92.3 pcf to 104.1 pcf. The relative densities ranged from -25% to 16%. These values were between very loose and loose compaction density. The moisture contents ranged from 5.2% to 8.3%. These moisture contents were within the bulking moisture content range. Figure 207 shows the field-testing results for lift 1 superimposed on the laboratory testing data from Phase I. This illustrates that the lift was not evenly compacted across the lift and was poorly compacted.

The second lift dry unit weights ranged form 97.4 pcf to 105.1 pcf. The relative densities ranged from-6% to 18%. (The minimum relative density from laboratory testing was 99.0 pcf). These values ranged between very loose and very loose compaction density. The moisture contents ranged from 7.0% to 10.1%. These moisture contents were within the bulking moisture content range. Figure 208 shows the field-testing results for lift 2 superimposed on the laboratory testing data from Phase I. This illustrates that the lift was not evenly compacted across the lift and was poorly compacted.

The third lift dry unit weights ranged form 96.7 pcf to 106.9 pcf. The relative densities ranged from -8% to 16%. These values were between loose and very loose compaction density. The moisture contents ranged from 5.1% to 9.8%. The moisture contents were within the bulking moisture content, except for test point 2. Figure 209 shows the field-testing results for lift 3 superimposed on the laboratory testing data from Phase I.

This illustrates that the lift was not evenly compacted across the lift and was poorly compacted.

The fourth lift dry unit weights ranged 97.6 pcf to 107.3 pcf. The relative densities ranged from -5% to 25%. These values ranged from a very loose to loose compaction density. The moisture contents ranged from 4.9% to 5.7%. These moisture contents were within the bulking moisture content range. Figure 210 shows the field-testing results for lift 4 superimposed on the laboratory testing data from Phase I. This illustrates that the lift was not evenly compacted across the lift and was poorly compacted.

The fifth lift dry unit weights ranged 97.1 pcf to 102.6 pcf. The relative densities ranged from -7% to 12%. These values ranged from a very loose to loose compaction density. The moisture contents ranged from 3.9% to 6.3%. These moisture contents were within the bulking moisture content range. Figure 211 shows the field-testing results for lift 5 superimposed on the laboratory testing data from Phase I. This illustrates that the lift was not evenly compacted across the lift and was poorly compacted.

Table 75 –Dry unit weights measured using Nuclear Density tests for Trench 2

Lift	Average dry unit weight (pcf)	Relative density (%)	Relative compaction	Minimum and maximum dry unit weights from field-testing (pcf)	Standard deviation	Coefficient of variance (%)
Lift 1	98.3	0	Very Loose	92.3 / 104.1	5.9	6.0
Lift 2	100.5	5	Very Loose	97.4 / 105.1	3.5	3.4
Lift 3	101.9	9	Very Loose	96.7 / 106.9	4.1	4.0
Lift 4	102.9	13	Very Loose	97.6 / 107.3	4.1	4.0
Lift 5	100.4	4	Very Loose	97.1 / 102.6	2.9	2.9
Average for all lifts	101.0	7	Very Loose	---	4.9	---

Table 76 – Average moisture contents measured using Nuclear Density tests for Trench 2

Lift	Average moisture content (%)	Degree of saturation (%)	Minimum and maximum moisture contents (%)	Standard deviation	Coefficient of variance (%)
Lift 1	7.0	12.9	5.2 / 8.3	1.6	22.9
Lift 2	7.9	14.8	7.0 / 10.1	1.5	7.0
Lift 3	6.5	12.2	5.1 / 9.8	1.9	29.8
Lift 4	5.4	10.1	4.9 / 5.7	0.4	27.9
Lift 5	4.8	8.7	3.9 / 6.3	1.3	3.9
Average for all lifts	6.3	11.4	---	1.7	---

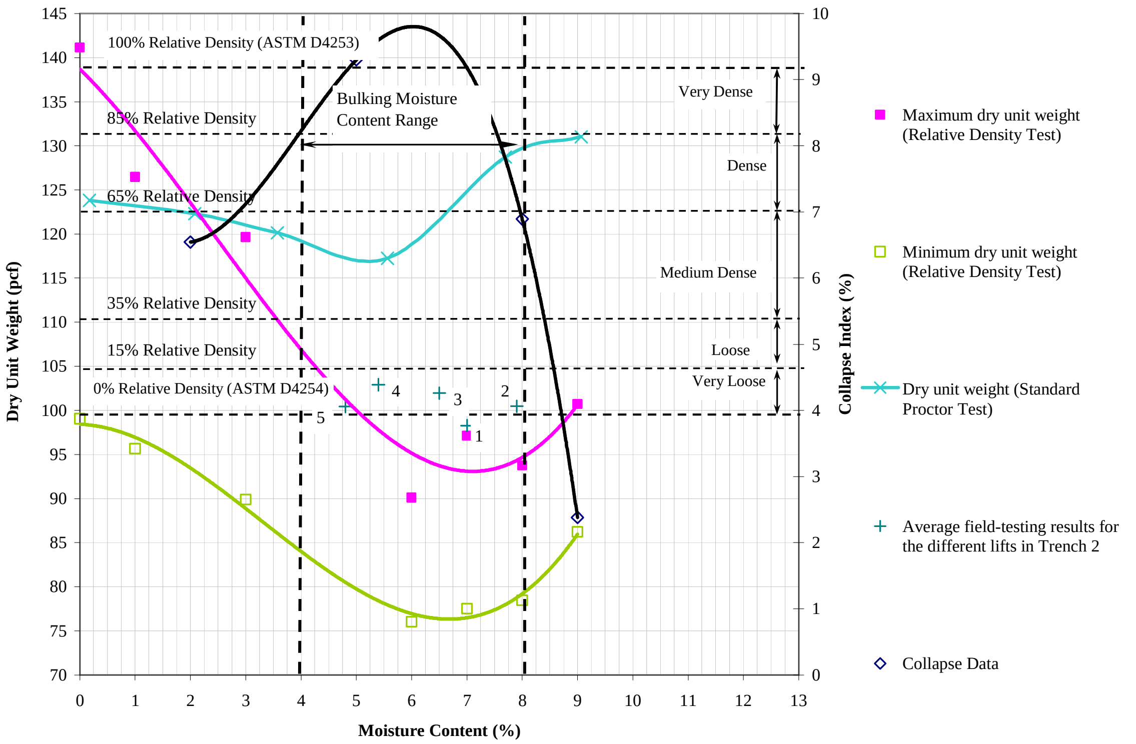


Figure 206 -- Dry unit weights and moisture contents measured during the construction of Trench 2 compared with the relative density, and Standard Proctor testing results with the collapse index

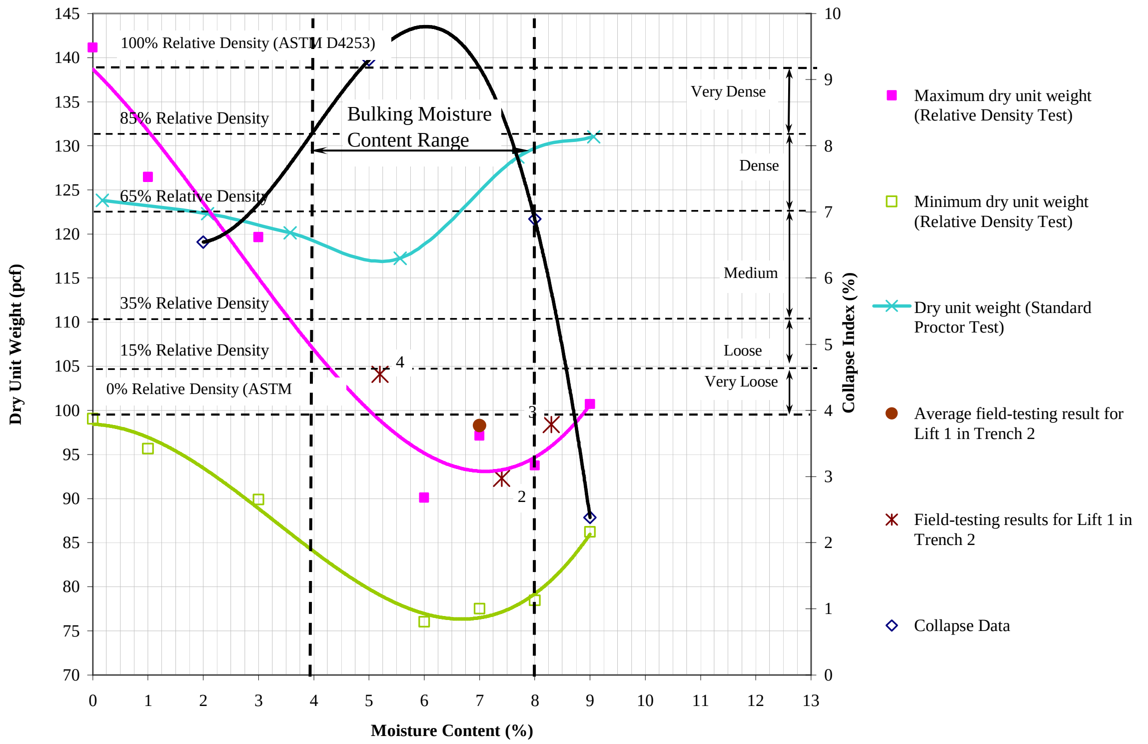


Figure 207 -- Dry unit weights and moisture contents measured during the construction of Trench 2 lift 1 compared with the relative density, and standard proctor testing results, with the collapse index

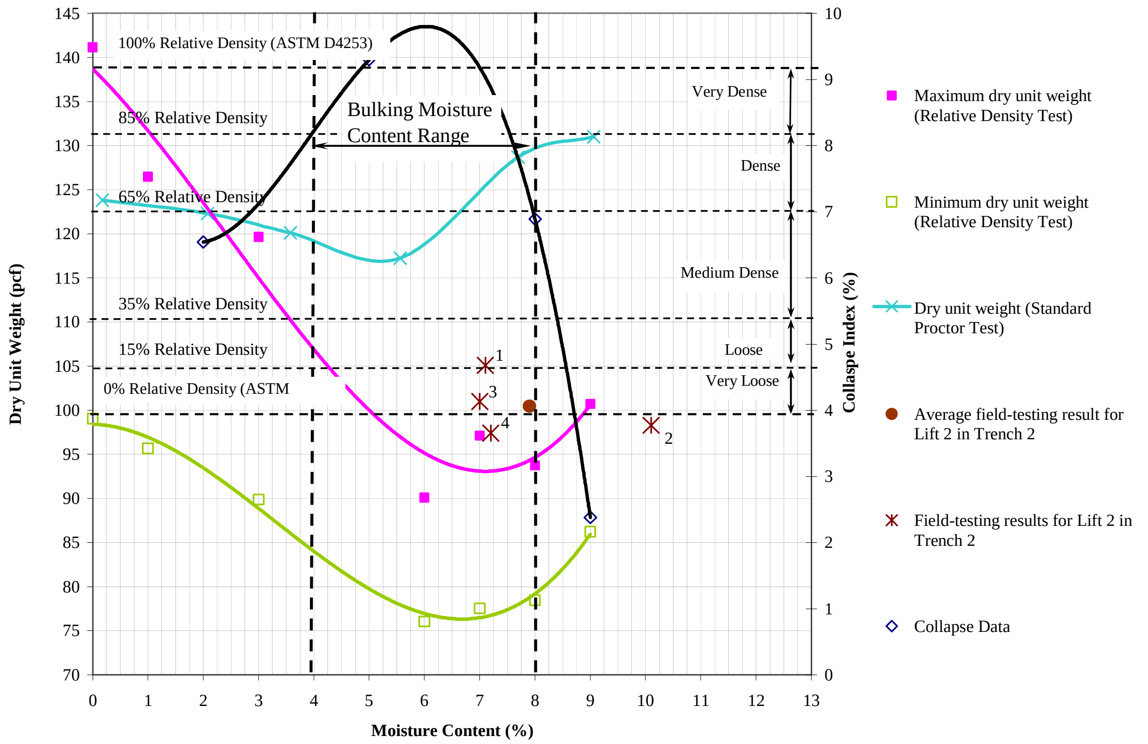


Figure 208 - Dry unit weights and moisture contents measured during the construction of Trench 2 lift 2 compared with the relative density, and standard proctor testing results, with the collapse index

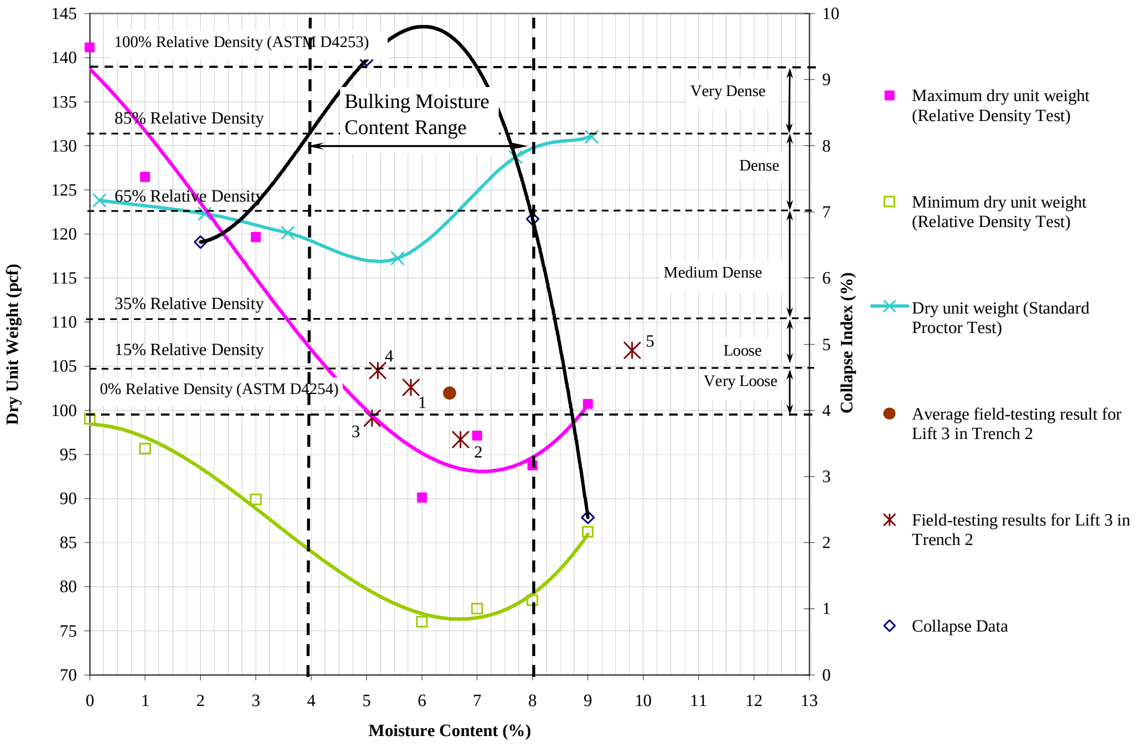


Figure 209 -- Dry unit weights and moisture contents measured during the construction of Trench 2 lift 3 compared with the relative density, and Standard Proctor testing results with the collapse index

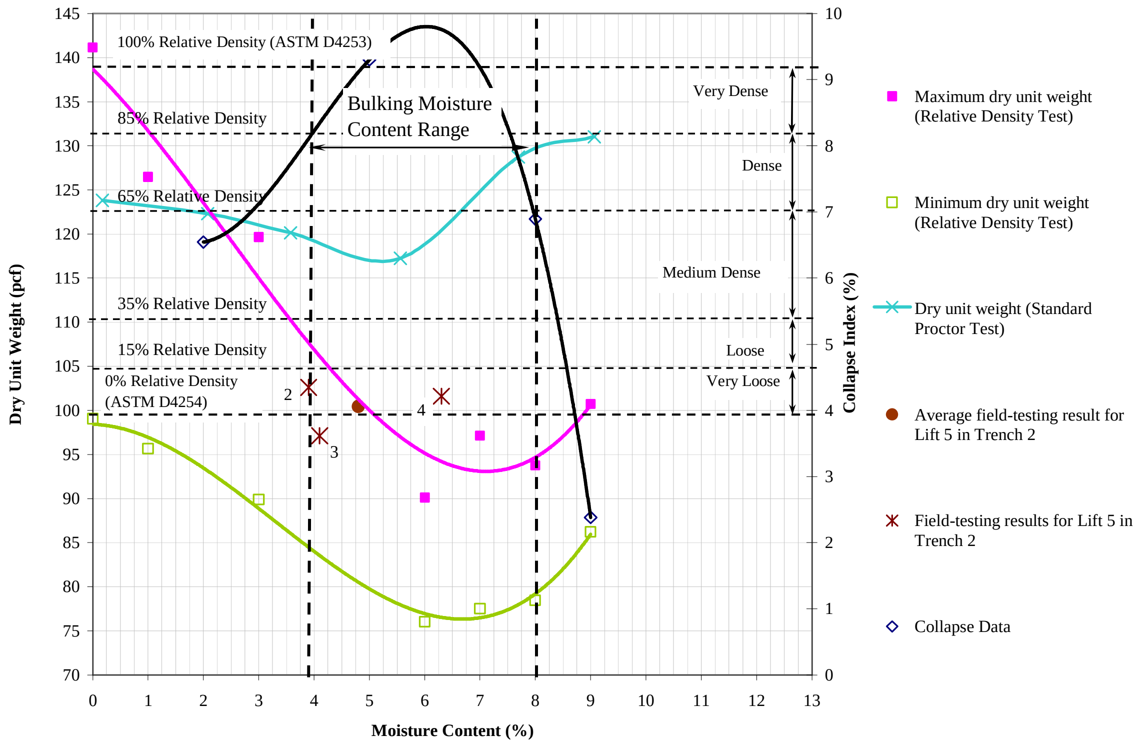


Figure 210 -- Dry unit weights and moisture contents measured during the construction of Trench 2 lift 4 compared with the relative density, and Standard Proctor testing results with the collapse index

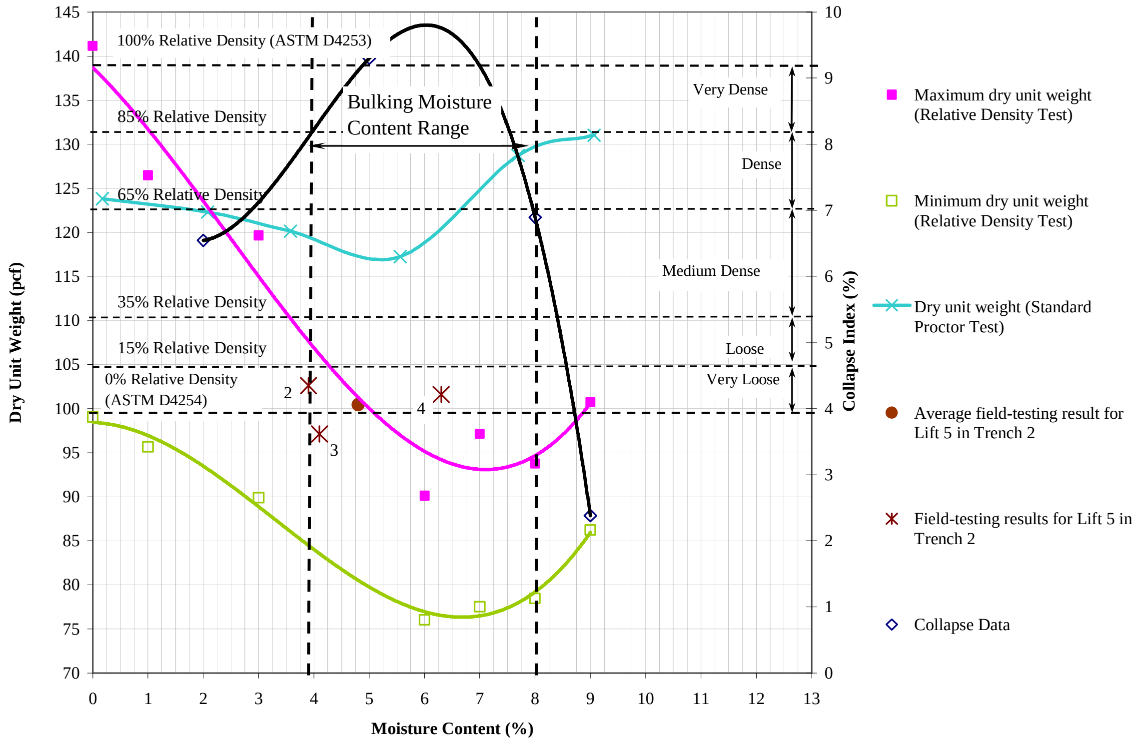


Figure 211 -- Dry unit weights and moisture contents measured during the construction of Trench 2 lift 5 compared with the relative density, and Standard Proctor testing results with the collapse index

DCP Test Results

Table 77 summarizes the DCPI results from the DCP tests for the various lifts and Table 78 summarizes the CBR results from the DCP tests for the various lifts. The typical values from CBR values range from 10% to 40% according to NAVFAC in Table 5. The CBR values for lifts 1 and 4 were within the recommended ranged from NAVFAC. However, lifts 2 and 3 had CBR values below the recommended values from NAVFAC. The low and high average CBR values do not corresponded to the maximum and minimum dry unit weights measured during construction.

Table 77 – Average DCPI calculated from DCP test results for Trench 2

Lift	Average DCPI	Average depth of DCP tests (inch)	Standard deviation	Coefficient of variance (%)
Lift 1	43.2	13.9	37.8	87.3
Lift 2	35.1	19.6	24.9	70.9
Lift 3	31.8	21.2	14.0	43.9
Lift 4	19.7	26.1	13.4	67.9
Lift 5	N/A	N/A	N/A	N/A

Table 78 – Average CBR calculated used DCP test results for Trench 2

Lift	Average CBR (%)	Average depth of DCP tests (inch)	Standard deviation	Coefficient of variance (%)
Lift 1	30	13.9	27.8	92.6
Lift 2	9	19.6	6.0	68.2
Lift 3	8	21.2	4.1	49.3
Lift 4	14	26.1	7.2	49.8
Lift 5	N/A	N/A	N/A	N/A

Figure 212 shows the CBR profiles for the test points within the trench for lift 1. The average CBR value was 30% extending 13.9 inches. At the surface of the lift, the CBR values for all test points ranged from 2% to 3%. This CBR values were below the recommend values from NAVFAC. The CBR values increased until a depth of about 10 inches. After 10 inches, the CBR values decrease. This is the result of penetrating into the soil below the trench at the test points. The line on the graph was based on the elevation at the center of the trench and the base of the trench was uneven.

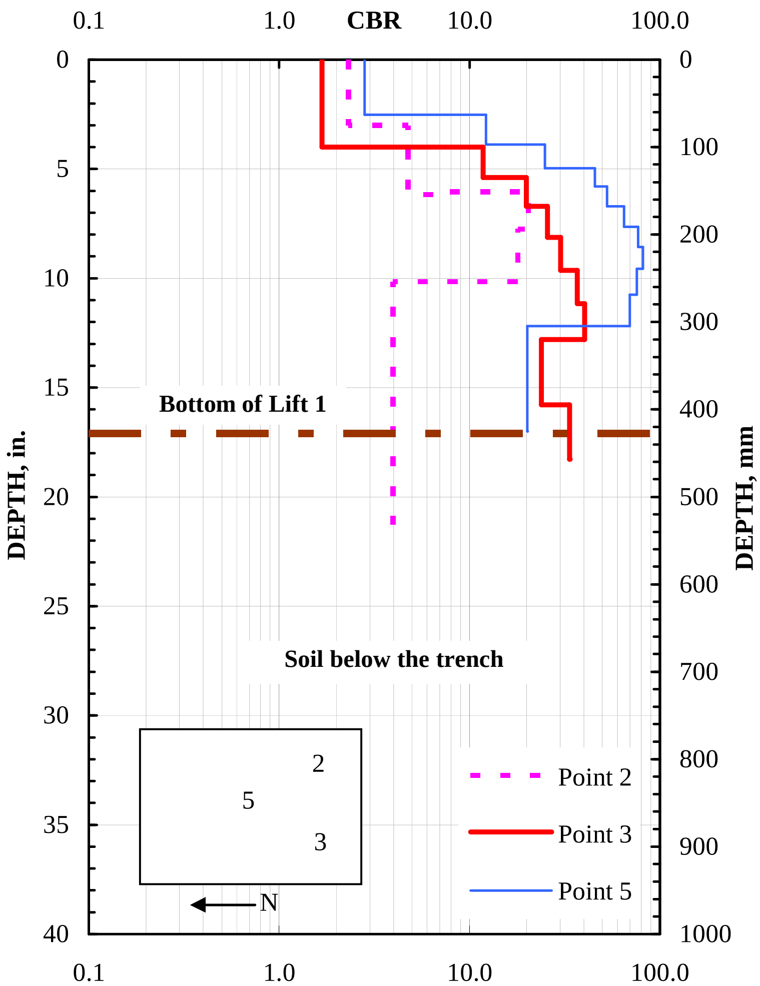


Figure 212 -- CBR profiles calculated using DCP results for lift 1 in Trench 2

Figure 213 shows the CBR profiles for the test points within the trench for lift 2. The second lift, for the four test points within the trench, had an average CBR was 9% extending 19.6 inches. The average CBR value was within the typical range of CBR values from NAVFAC. At the surface of the trench, the CBR values ranged from 2% to 3%. At the termination of the tests, the CBR values ranged from 3% to 14%. The CBR values increased through the depth of the tests until a depth of about 13 inches. After this depth, the CBR values decrease. This was the result of the compaction not being effective deeper into the lift.

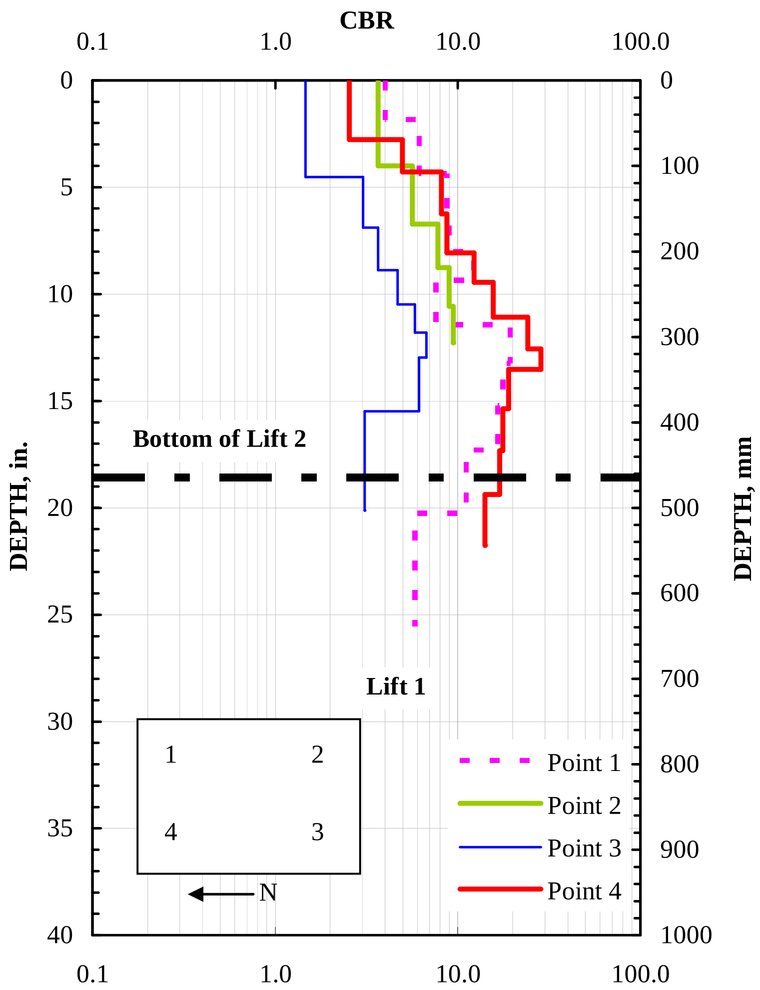


Figure 213 -- CBR profiles calculated using DCP results for lift 2 in Trench 2

Figure 214 shows the CBR profiles for the test points within the trench for lift 3. The average CBR value was 8% extending 21.2 inches, within the recommended range of values from NAVFAC. At the surface of the lift, the CBR values ranged from 1% to 4%. At the termination of the DCP tests, the CBR values ranged from 5% to 17%. The CBR values increased until the boundary between lift 3 and lift 2.

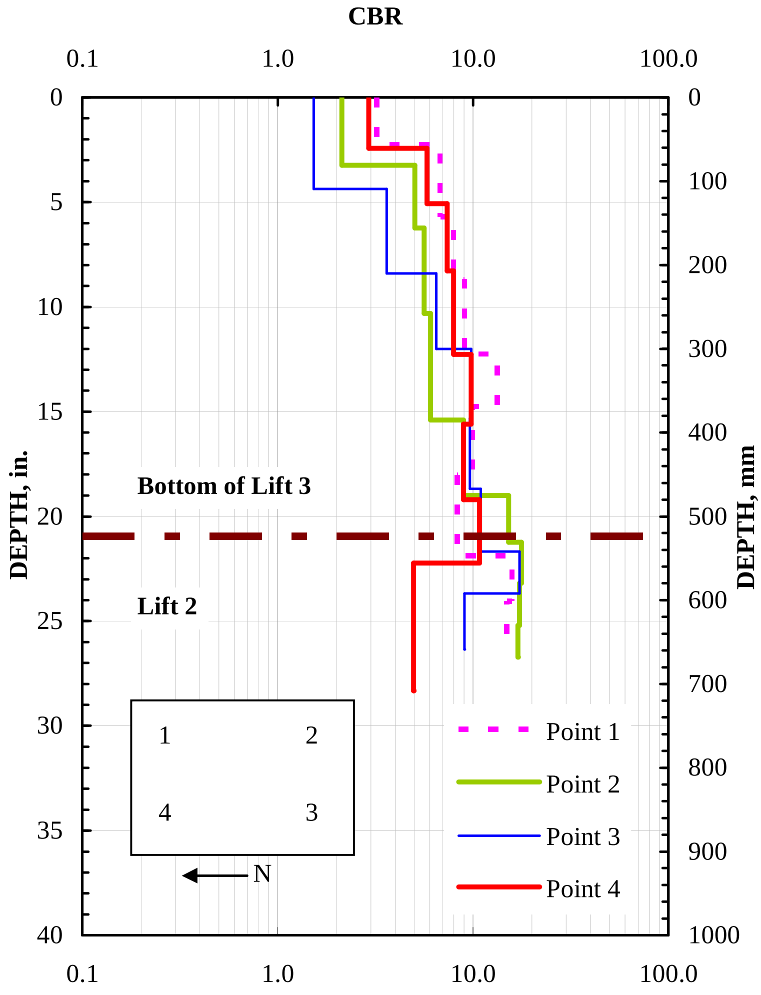


Figure 214 -- CBR profiles calculated using DCP results for lift 3 in Trench 2

Figure 215 shows the CBR profiles for the test points within the trench for lift 4. The CBR value was 14%. This value was within the range of typical values from NAVFAC in Table 5. This lift was the only lift to have an average CBR value within the typical range from NAVFAC. At the surface of the lift the CBR values ranged from 3% to 5% and at the termination of the tests, the CBR values increased to 10% to 22%.

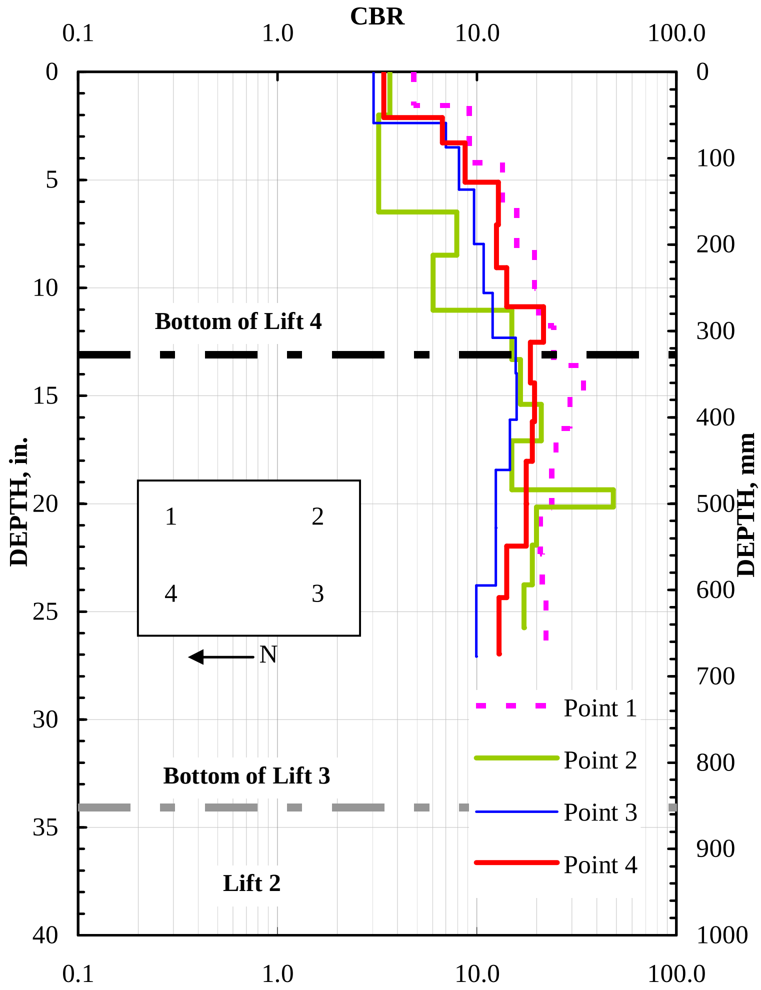


Figure 215 -- CBR profiles calculated using DCP results for lift 4 in Trench 2

5.5.3 - Instrumented Trench 3

The location of the test points in the trench is shown in Figure 216. Figure 217 shows the trench cross-section with the average testing results.

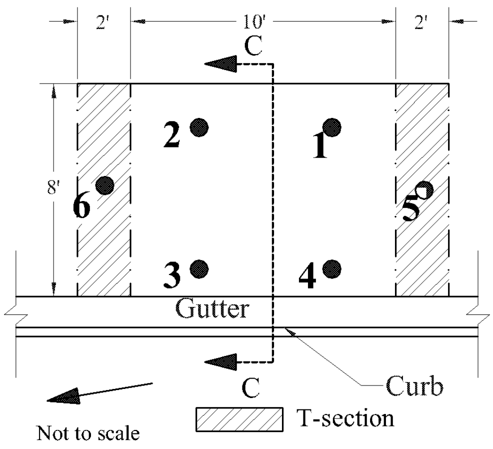


Figure 216 -- Location of test points in Trench 3

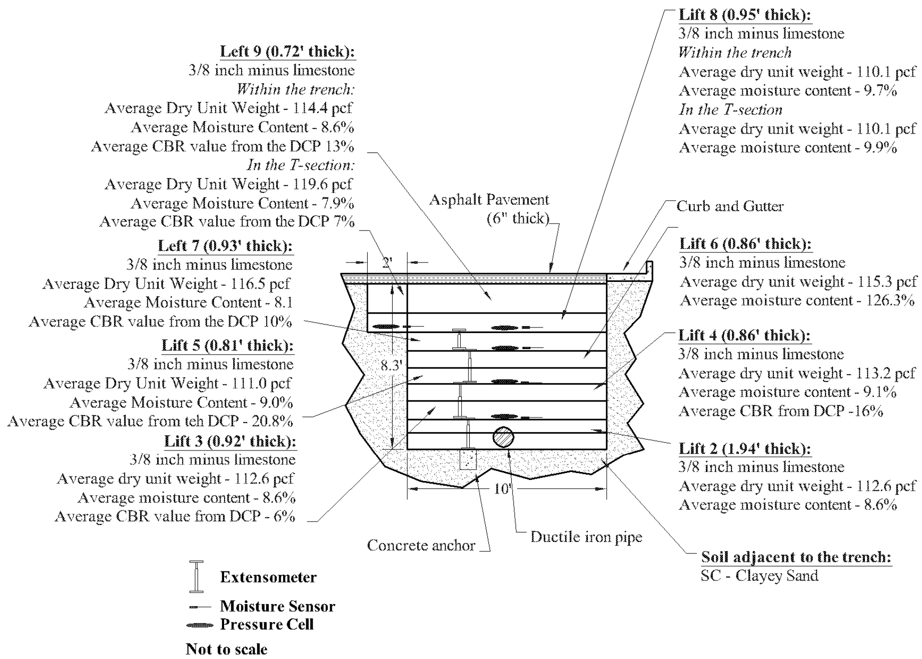


Figure 217 -- Cross-section c-c of completed Trench 3

Nuclear Density Test Results

Table 79 summarizes the average dry unit weight results from the Nuclear Density tests for each layer. Table 80 summarizes the moisture content results from the Nuclear Density tests for the various lifts in Trench 3. The typical dry unit weights from NAVFAC ranged from 110 pcf to 125 pcf and the typical optimum moisture content ranged from 11% to 16%. From laboratory testing, the maximum dry unit weight was 140 pcf and the minimum dry unit weight was 99.0 pcf. The range of the bulking moisture contents was from 4% to 8%. The probe depth of the nuclear density gauge was 4 inches.

Figure 218 illustrates the average dry unit weights and moisture contents for each tested lift. The average dry unit weights for all tested lifts, ranged from 109.4 pcf to 123.8 pcf. The average dry unit weights for all the lifts were within the recommended values by NAVFAC, except for lift 9 in the T-section. The relative densities ranged from 32% to 67%, which corresponded to medium dense and dense compaction densities.

The average moisture contents ranged 8.4% to 12.6% for all tested lifts. The average moisture contents for all tested lifts were below recommended values from NAVFAC. All lifts had average moisture contents above the range of bulking moisture contents.

The second lift dry unit weights ranged form 104.4 pcf to 127.6 pcf. The relative densities ranged from 18% to 75%. These values corresponded to loose to dense compaction densities. Test point 1 had the lowest dry unit weight of 104.4 pcf. The moisture contents ranged from 7.3 % to 9.4%. These moisture contents were within and above the bulking moisture content range. At test points 3 and 4, the backfill was placed within the bulking moisture content range. Figure 219 shows the field-testing results for lift 2 superimposed on the laboratory testing data from Phase I.

The third lift dry unit weights ranged form 107.4 pcf to 118.7 pcf. The relative densities ranged from 26% to 58%. These values correspond to loose to medium dense compaction density. The moisture contents ranged from 7.0% to 10.1%. Test points 1 and 2 were within the bulking moisture content and test points 3 and 4 were above the bulking moisture content. These moisture contents were above the bulking moisture content range. Figure 220 shows the field-testing results for lift 3 superimposed on the laboratory testing data from Phase I.

The fourth lift dry unit weights ranged 96.7 pcf to 106.9 pcf. The relative densities ranged from 26% to 57%. These values ranged from a loose to medium dense compaction density. The moisture contents ranged from 7.3% to 9.5%. These moisture contents were above the bulking moisture content range. Figure 221 shows the field-testing results for lift 4 superimposed on the laboratory testing data from Phase I.

The fifth lift dry unit weights ranged 107.4 pcf to 118.4 pcf. The relative densities ranged from 21% to 46%. These values ranged from a loose to a medium dense compaction density. The moisture contents ranged from 8.4% to 10.1%. These moisture contents were above the bulking moisture content range. Figure 222 shows the field-testing results for lift 5 superimposed on the laboratory testing data from Phase I.

The sixth lift dry unit weights ranged 105.9 pcf to 114.9 pcf. The relative densities ranged from 34% to 56%. These values ranged from a loose to a medium dense compaction density. The moisture contents ranged from 8.0% to 10.0%. These moisture contents were above the bulking moisture content range. Figure 223 shows the field-testing results for lift 6 superimposed on the laboratory testing data from Phase I.

The seventh lift dry unit weights ranged 114.3 pcf to 119.0 pcf. The relative densities ranged from 45% to 56%. These values correspond to a medium dense compaction density. The moisture contents ranged from 9.4% to 9.9%. These moisture contents were above the bulking moisture content range. Figure 224 shows the field-testing results for lift 7 superimposed on the laboratory testing data from Phase I.

The eighth lift, within the trench dry unit weights ranged 107.8 pcf to 112.8 pcf. The relative densities ranged from 37% to 41%. These values ranged from a loose to a medium dense compaction density. The moisture contents ranged from 9.1% to 11.0%. These moisture contents were above the bulking moisture content range. Figure 225 shows the field-testing results for lift 8 superimposed on the laboratory testing data from Phase I.

The eighth lift, in the T-section dry unit weights ranged 107.5 pcf to 112.7 pcf. The relative densities ranged from 26% to 41%. These values ranged from a loose to a medium dense compaction density. The moisture contents ranged from 9.9% to 10.1%. These moisture contents were above the bulking moisture content range. Figure 226 shows the field-testing results for lift 8 superimposed on the laboratory testing data from Phase I.

The ninth lift, within the trench dry unit weights ranged 113.3 pcf to 117.1 pcf. The relative densities ranged from 42% to 51%. These values ranged from a loose to a medium dense compaction density. The moisture contents ranged from 8.3% to 9.0%. These moisture contents were above the bulking moisture content range. Figure 227 shows the field-testing results for lift 9 superimposed on the laboratory testing data from Phase I.

The ninth lift, in the T-section dry unit weights ranged 119.2 pcf to 119.9 pcf. The relative densities ranged from 57% to 58%. These values ranged from a loose to a dense compaction density. The moisture contents ranged from 7.9% to 9.5%. These moisture contents were above the bulking moisture content range. Figure 228 shows the field-testing results for lift 9 superimposed on the laboratory testing data from Phase I.

Table 79 –Dry unit weights measured using Nuclear Density tests for Trench 3

Lift	Average dry unit weight (pcf)	Relative density (%)	Relative compaction	Minimum and maximum dry unit weights	Standard deviation	Coefficient of variance (%)
Lift 2	115.1	47	Medium	104.4 / 127.6	9.5	8.2
Lift 3	112.6	40	Medium	107.4 / 119.7	5.2	4.6
Lift 4	113.2	42	Medium	96.7 / 106.9	5.1	4.5
Lift 5	111.0	36	Medium	107.4 / 119.4	4.1	3.7
Lift 6	115.3	47	Medium	105.9 / 114.9	3.7	3.2
Lift 7	116.5	50	Medium	114.3 / 119.0	2.1	1.8
Lift 8 within the trench	110.1	34	Loose	107.8 / 112.8	2.3	2.1
Lift 8 in the T-section	110.1	45	Medium	107.5 /112.7	3.7	3.3
Lift 9 within the trench	114.4	34	Loose	113.3 / 117.1	1.8	1.6
Lift 9 in the T-section	119.6	57	Medium	119.2 / 119.9	0.5	0.4
Average for all lifts	113.7	43	Medium	---	4.8	

Table 80 – Average moisture contents measured using Nuclear Density tests for Trench 3

Lift	Average moisture content (%)	Degree of saturation (%)	Minimum and maximum moisture contents (%)	Standard deviation	Coefficient of variance (%)
Lift 2	7.8	16.2	7. 3 / 9.4	1.4	17.5
Lift 3	8.6	17.3	7.0 / 10.1	0.9	10.9
Lift 4	9.1	18.3	7.3 / 9.5	0.8	9.1
Lift 5	9.0	17.6	8.4 / 10.1	0.8	9.1
Lift 6	9.6	19.5	8.0 / 10.0	0.2	2.3
Lift 7	8.1	16.5	9.4 / 9.9	0.4	5.4
Lift 8 within the trench	9.7	18.6	9.1 / 11.0	0.9	9.4
Lift 8 in the T-section	9.9	18.9	9.9 / 10.1	0.1	1.4
Lift 9 within the trench	8.6	17.0	8.3 / 9.0	0.3	4.0
Lift 9 in the T-section	7.2	14.9	7.9 / 8.5	1.9	11.7
Average for all lifts	8.8	17.2	---	1.0	

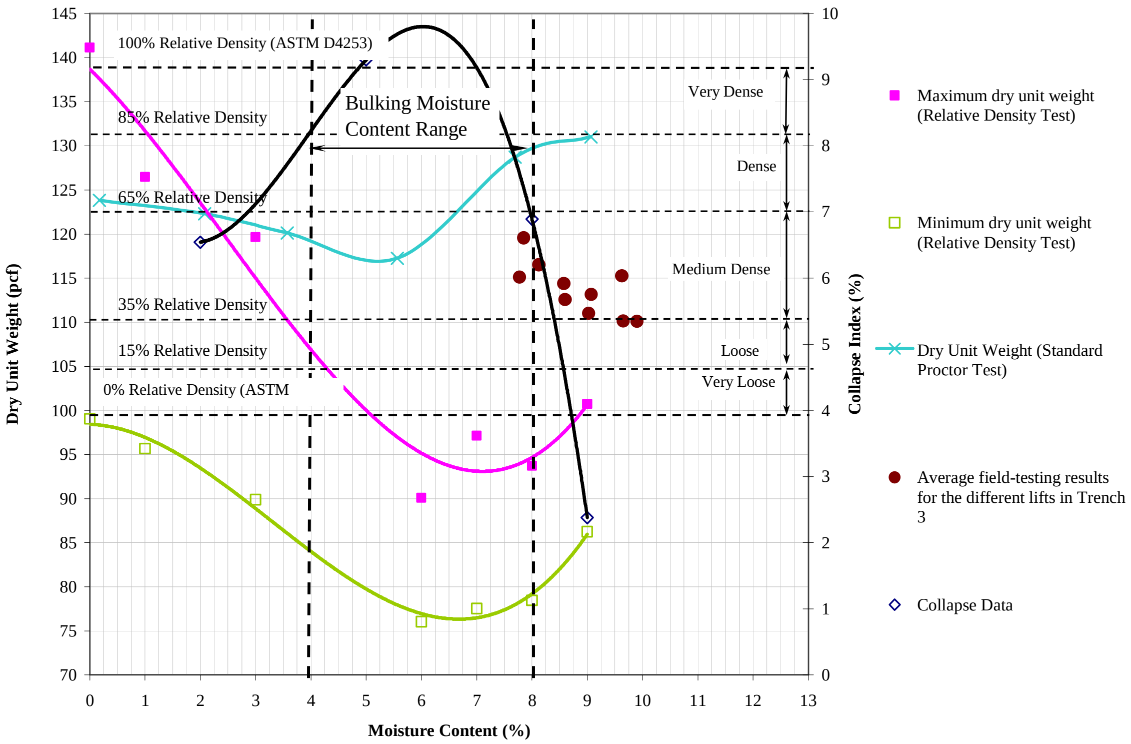


Figure 218 -- Dry unit weights and moisture contents measured during the construction of Trench 3 compared with the relative density, and Standard Proctor testing results with the collapse index

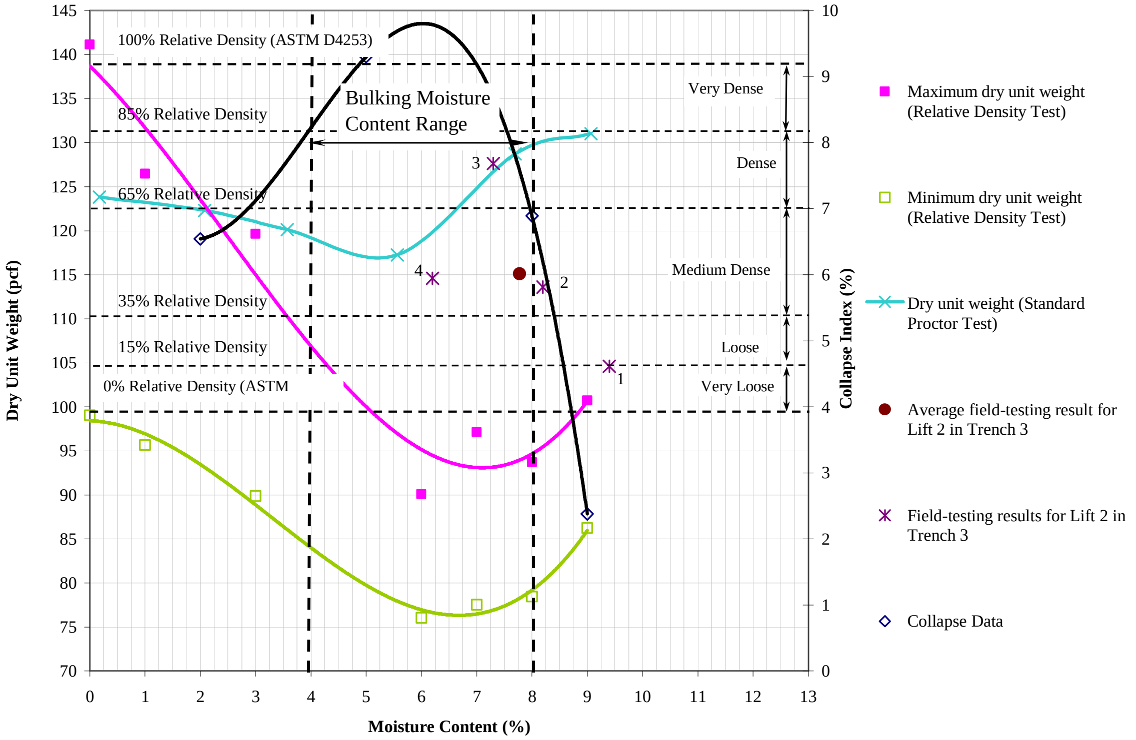


Figure 219 -- Dry unit weights and moisture contents measured during the construction of Trench 3 lift 2 compared with the relative density, and Standard Proctor testing results with the collapse index

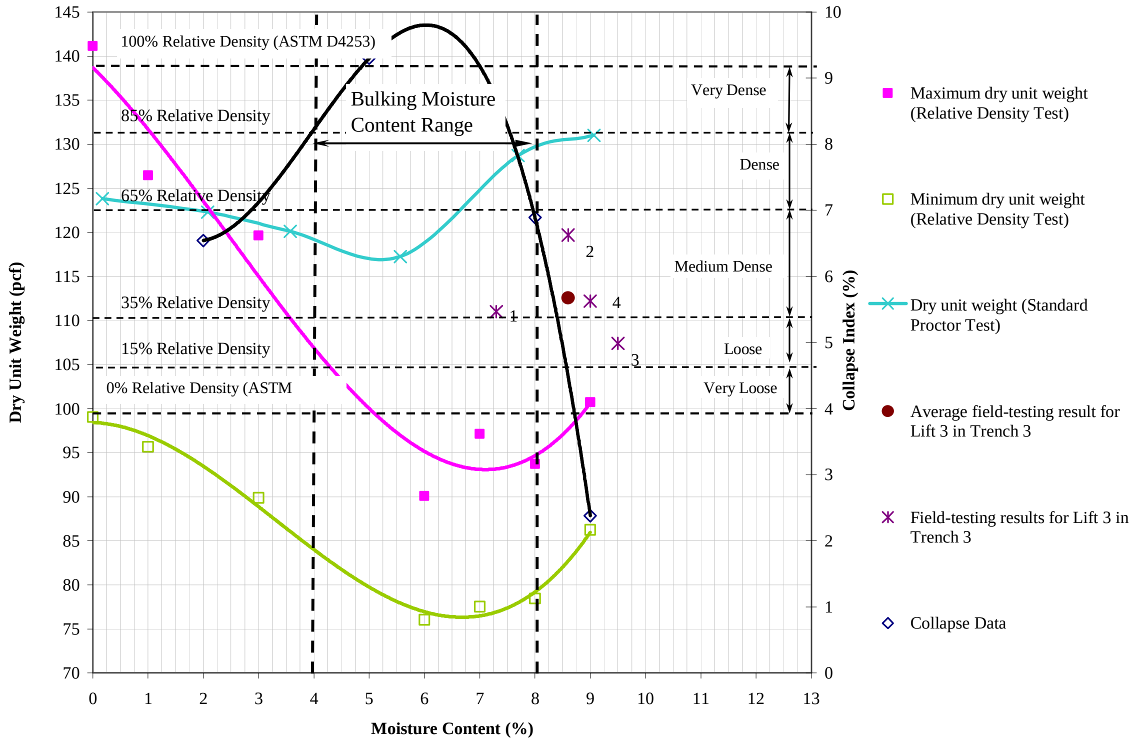


Figure 220 -- Dry unit weights and moisture contents measured during the construction of Trench 3 lift 3 compared with the relative density, and Standard Proctor testing results with the collapse index

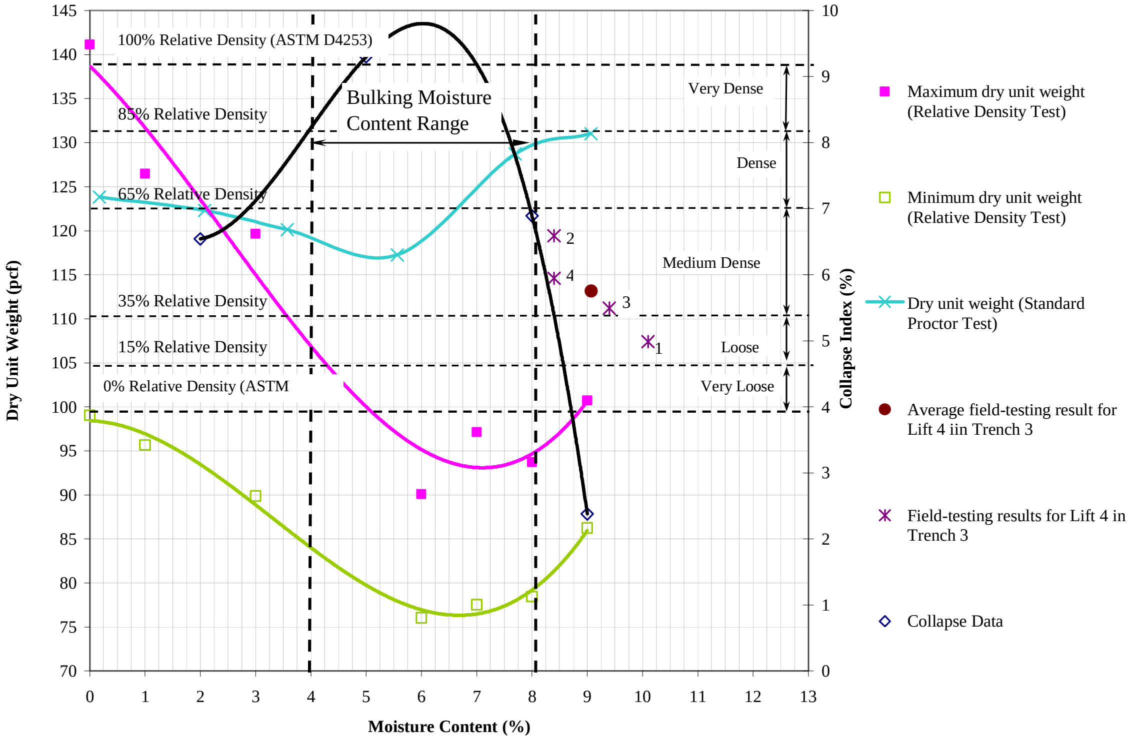


Figure 221 -- Dry unit weights and moisture contents measured during the construction of Trench 3 lift 4 compared with the relative density, and Standard Proctor testing results with the collapse index

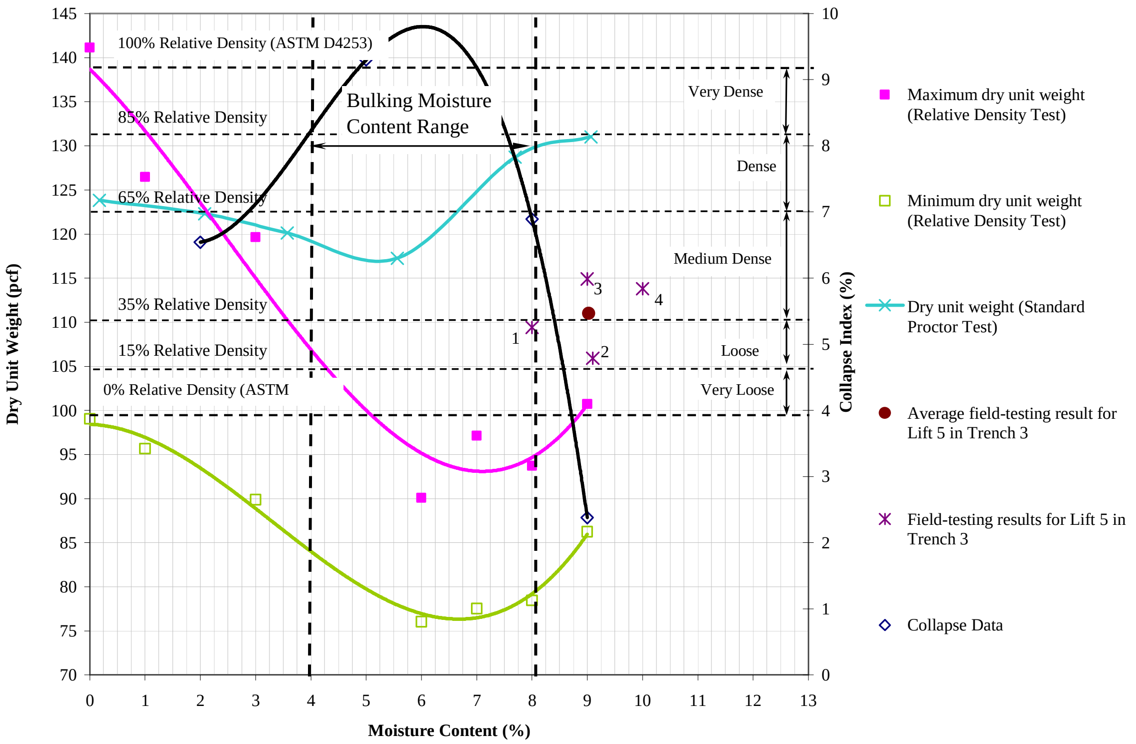


Figure 222 -- Dry unit weights and moisture contents measured during the construction of Trench 3 lift 5 compared with the relative density, and Standard Proctor testing results with the collapse index

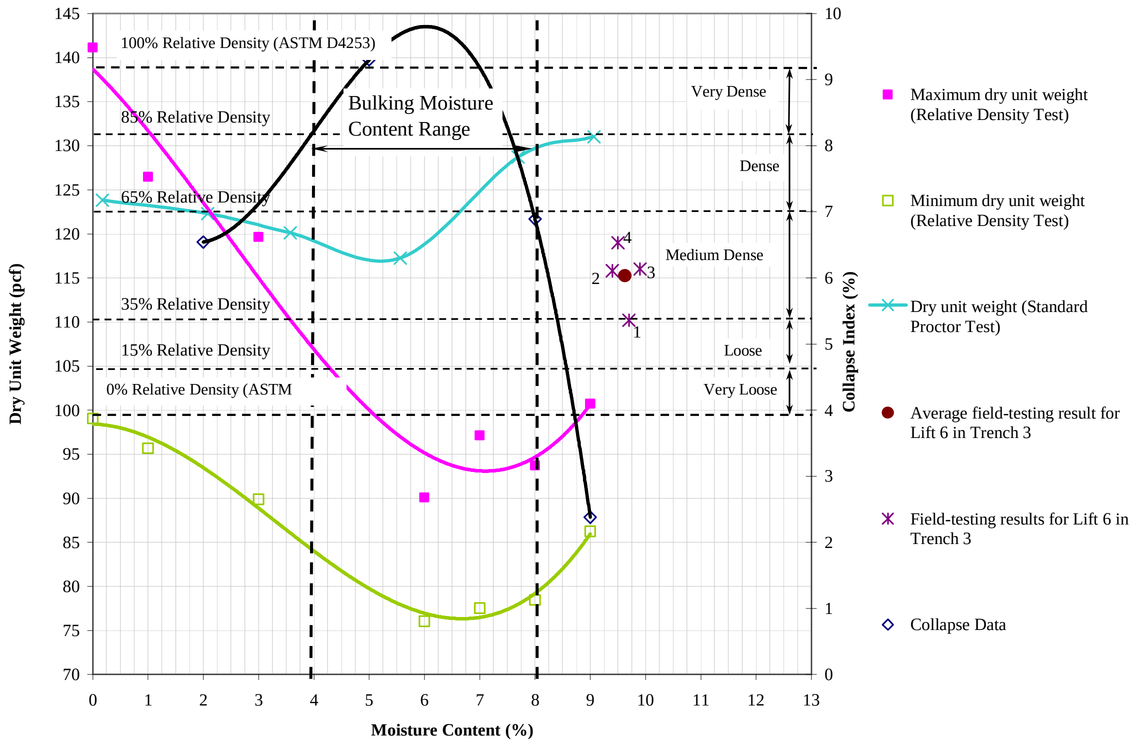


Figure 223 -- Dry unit weights and moisture contents measured during the construction of Trench 3 lift 6 compared with the relative density, and Standard Proctor testing results with the collapse index

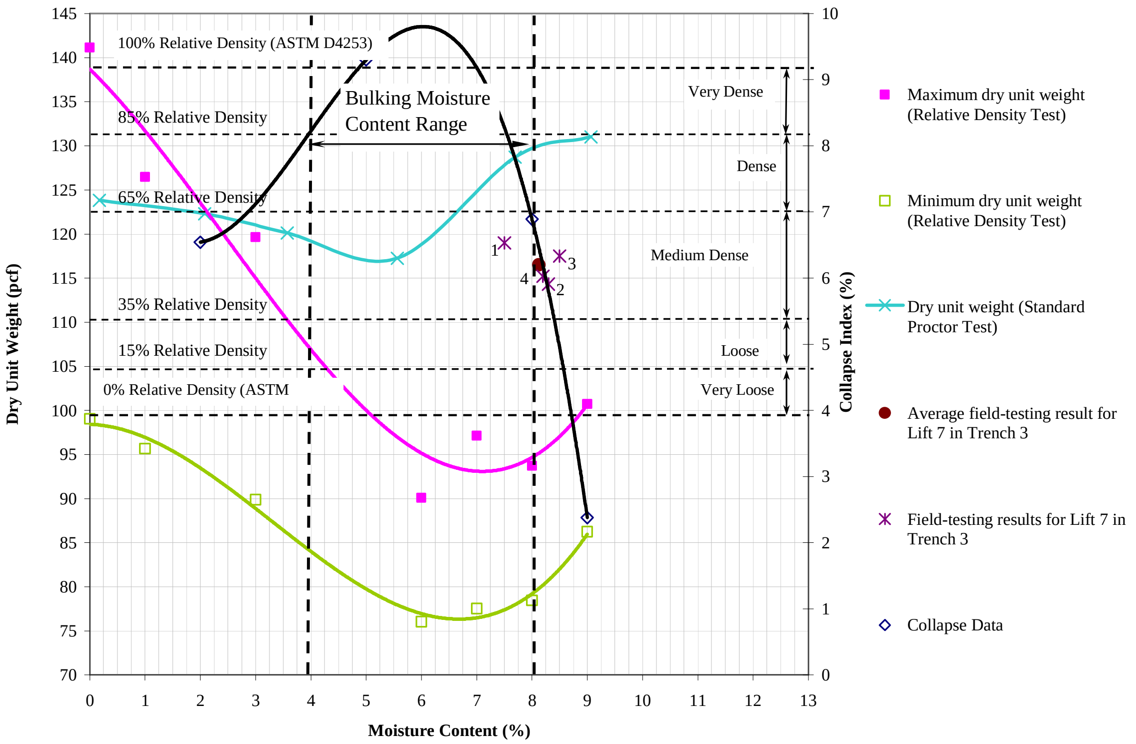


Figure 224 -- Dry unit weights and moisture contents measured during the construction of Trench 3 lift 7 compared with the relative density, and Standard Proctor testing results with the collapse index

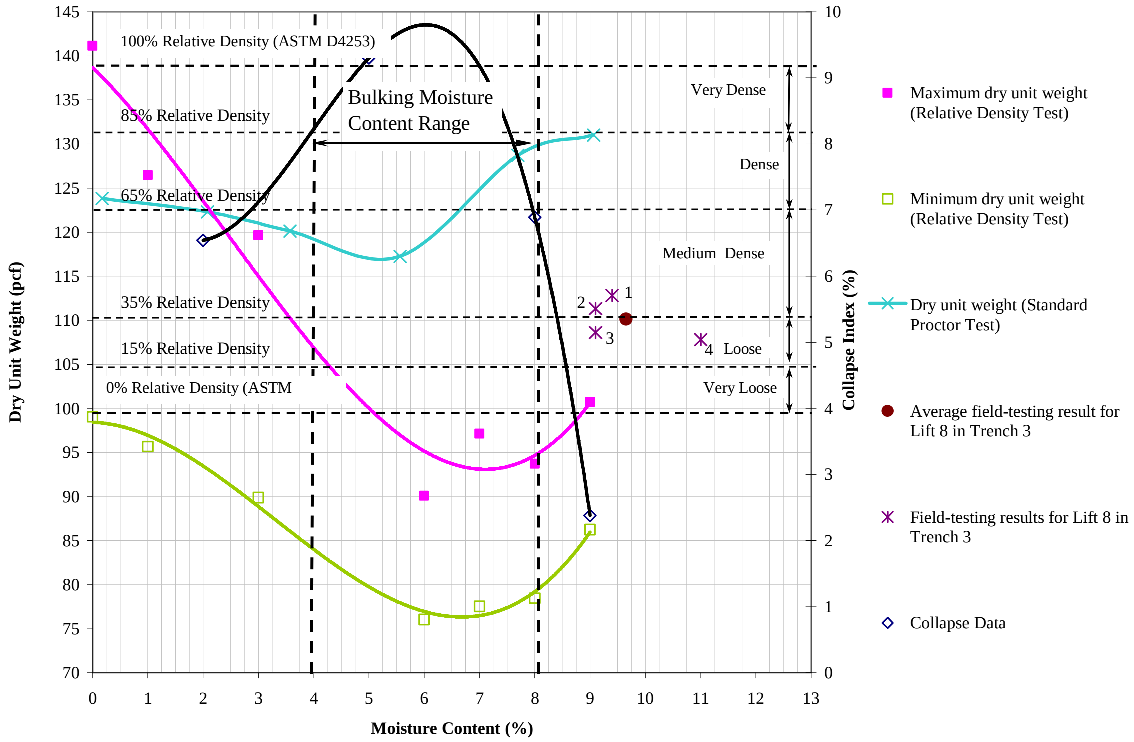


Figure 225 -- Dry unit weights and moisture contents measured during the construction of Trench 3 lift 8 within the trench compared with the relative density, and Standard Proctor testing results with the collapse index

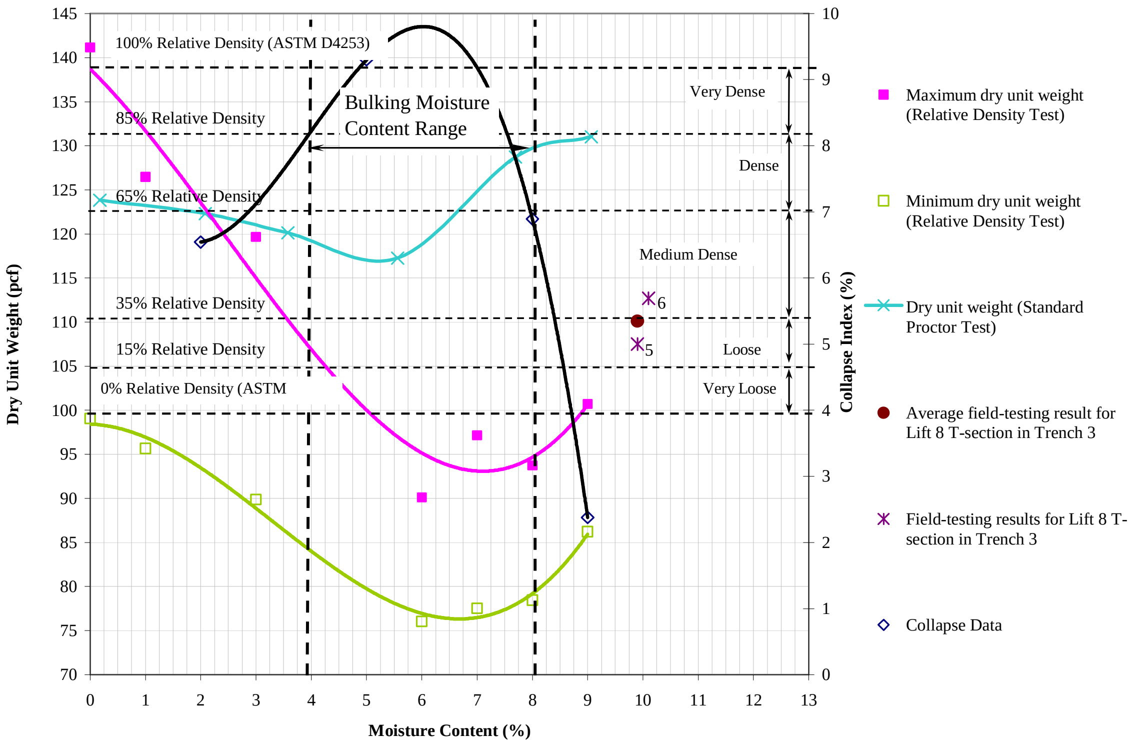


Figure 226 -- Dry unit weights and moisture contents measured during the construction of Trench 3 lift 8 in the T-section compared with the relative density, and Standard Proctor testing results with the collapse index

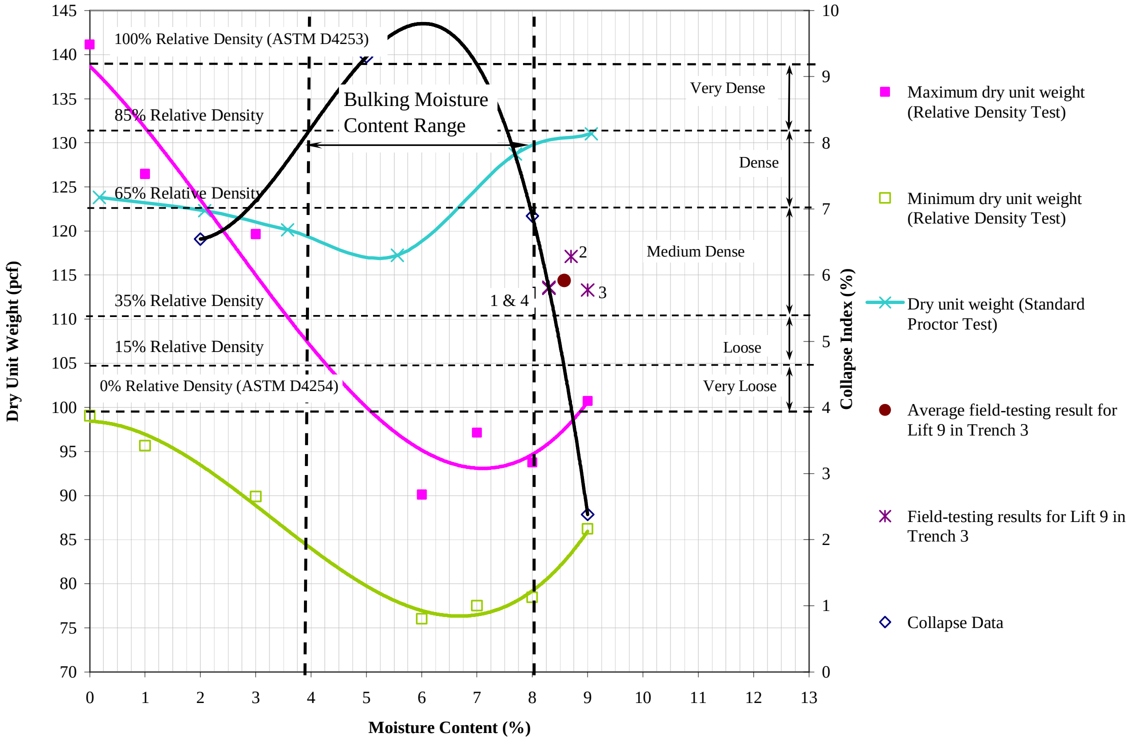


Figure 227 -- Dry unit weights and moisture contents measured during the construction of Trench 3 lift 9 within the trench compared with the relative density, and Standard Proctor testing results with the collapse index

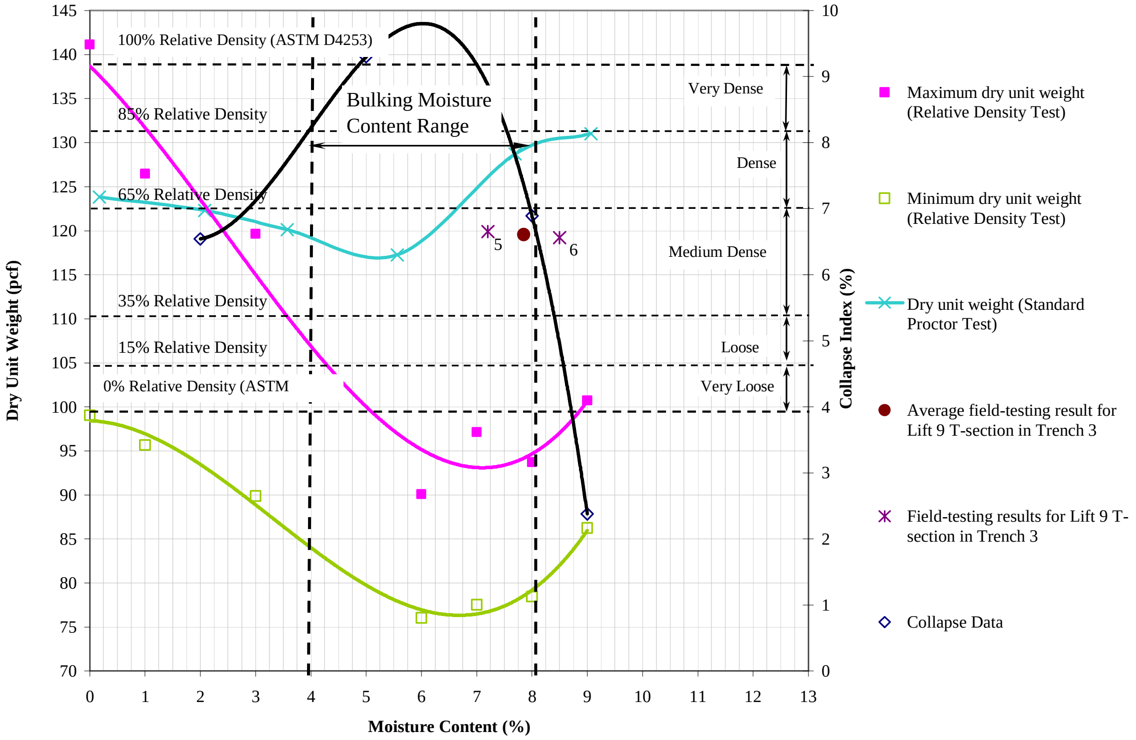


Figure 228 -- Dry unit weights and moisture contents measured during the construction of Trench 3 lift 9 in the T-section compared with the relative density, and Standard Proctor testing results with the collapse index

DCP Test Results

Table 81 summarizes the DCPI results from the DCP tests for the various lifts and Table 82 summarizes the CBR results from the DCP tests for the various lifts. The typical CBR values for compacted soil from NAVFAC range from 10% to 40%.

The average CBR values for lifts 2, 3, and 9 in the T-section were below the recommended values from NAVFAC. The average CBR values from lifts 4, 5, 7, and 9 within the trench were within the recommended range of values from NAVFAC.

Table 81 – Average DCPI results from DCP testing for Trench 3

Lift	Average DCPI	Average depth of DCP test	Standard deviation	Coefficient of variance (%)
Lift 2	78.0	22.6	72.3	
Lift 3	87.8	22.3	107.2	112.2
Lift 4	18.2	23.5	10.9	60.1
Lift 5	20.8	22.2	15.5	74.5
Lift 7	23.1	21.6	13.1	57.1
Lift 9 within the Trench	20.6	25.5	10.5	51.0
Lift 9 in T-section	32.9	18.6	14.9	45.4

Table 82 – Average CBR results from DCP testing for Trench 3

Lift	Average CBR (%)	Average depth of DCP test	Standard deviation	Coefficient of variance (%)
Lift 2	3	22.6	2.4	
Lift 3	6	22.3	5.8	91.8
Lift 4	16	23.5	9.7	59.1
Lift 5	16	22.2	10.5	64.6
Lift 7	10	21.6	6.5	63.3
Lift 9 within the Trench	13	25.5	6.1	48.2
Lift 9 in T-section	7	18.6	3.9	53.7

Figure 229 presents the CBR profiles for the first lift in the trench. The first lift, for the four test points within the trench, had an average CBR of 3% extending 22.6 inches. At the surface of the lift, the CBR values ranged from 4% to 7%. At the termination of the tests, the CBR values ranged from 1% to 6%. The CBR values were below the typical values from NAVFAC. The DCP tests penetrated into the soil below the trench. This lift was compacted using a vibratory plate compactor attached to a backhoe. The plate compactor was not able to compact the backfill in the confined area and did not evenly compact the backfill.

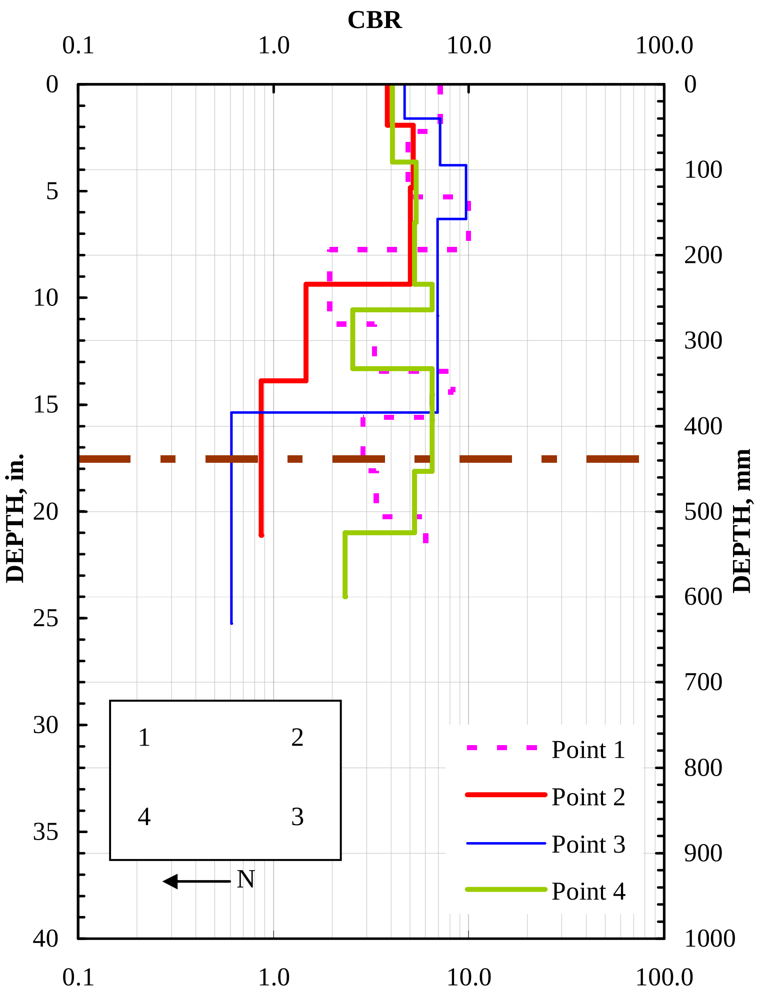


Figure 229 -- CBR profiles calculated using DCP results for lift 2 in Trench 3

Figure 230 shows the CBR profiles for the test points within the trench for lift 3. The average CBR value was 6% extending 22.3 inches. At the surface of the lift, the CBR values ranged from 2% to 8% and at the termination of the tests, the CBR values ranged from 0% to 15%. The CBR values were below the typical range of values from NAVFAC. This lift was the final lift compacted with the vibratory plate compactor. The lift was not evenly compacted and the backfill below the interface of lift 3 and lift 2 was also not completely compacted.

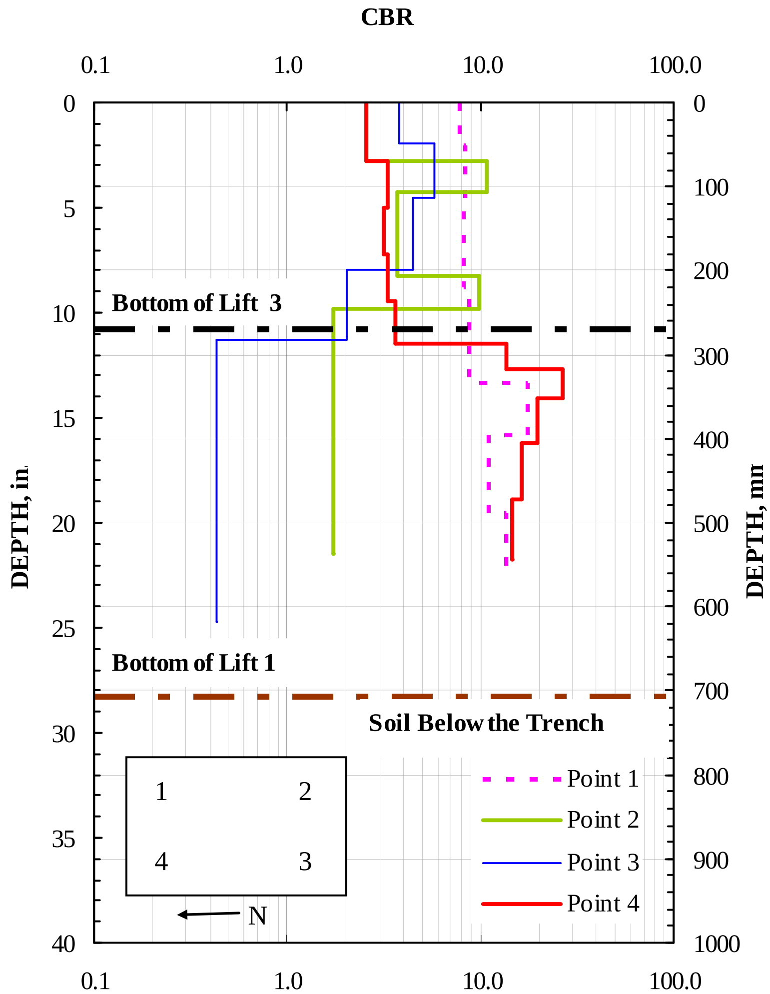


Figure 230 -- CBR profiles calculated using DCP results for lift 3 in Trench 3

Figure 231 shows the CBR profiles for the test points within the trench for lift 4. The average CBR value was 16% extending 23.5 inches. At the surface of the lift, the CBR values ranged from 3% to 8%. At the termination of the tests, the CBR values ranged from 10% to 41%. Test points 1 and 4 did not have CBR values increasing for the entire depth of the test. These points were not evenly compacted during previous lifts.

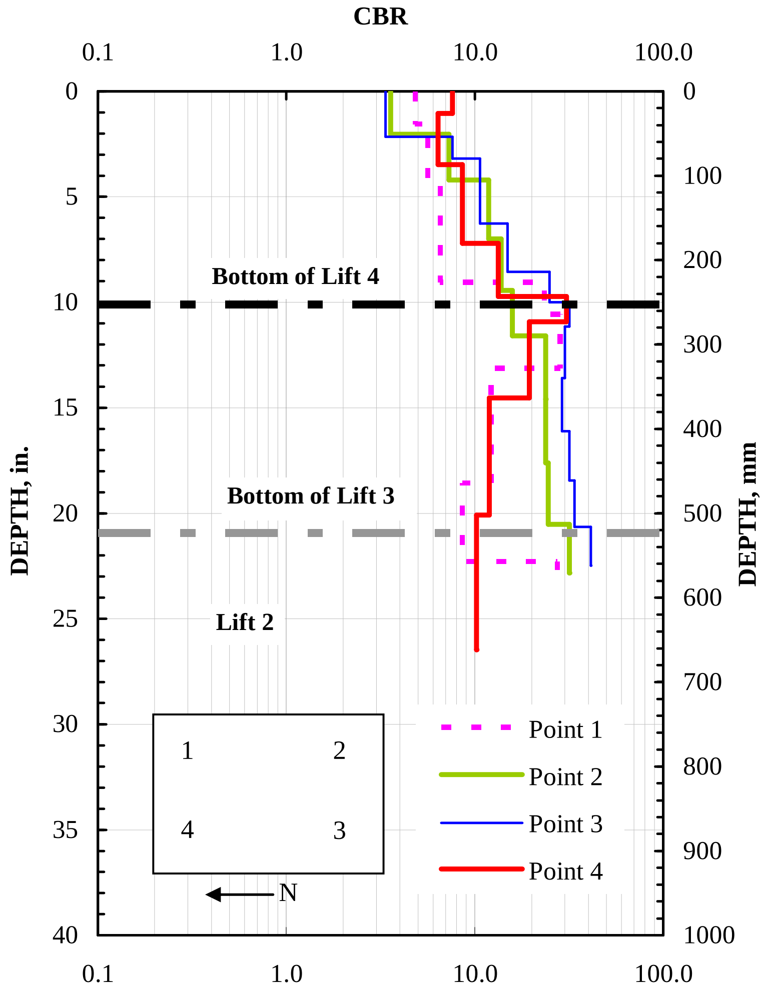


Figure 231 -- CBR profiles calculated using DCP results for lift 4 in Trench 3

Figure 232 shows the CBR profiles for the test points within the trench for lift 5. The average CBR value was 16% extending 22.2 inches. At the surface, the CBR values ranged from 3% to 4%. The CBR values increased with depth, until at termination the CBR values ranged from 19% to 58%. The average value was within the typical range of values from NAVFAC. When the DCP tests penetrated into the previous lift, the CBR values rate of increased decreased.

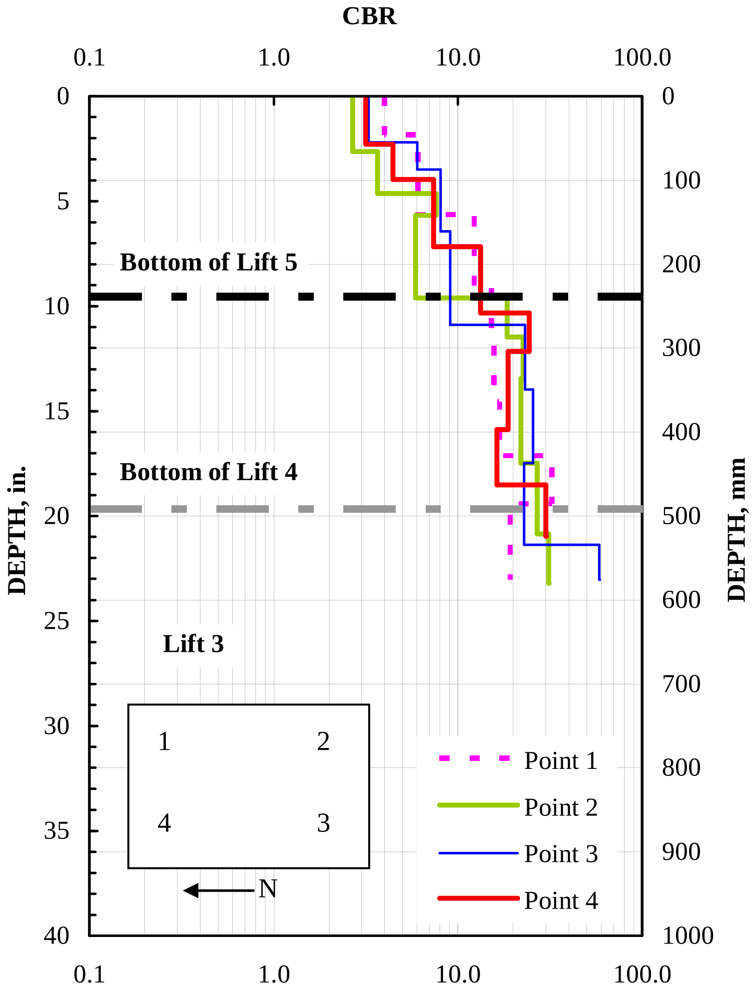


Figure 232 -- CBR profiles calculated using DCP results for lift 5 in Trench 3

Figure 233 shows the CBR profiles for the test points within the trench for lift 7. The average CBR value was 11% extending 21.6 inches. At the surface of the lift the CBR values ranged from 3% to 6% and at the termination of the tests, the CBR values ranged from 11% to 28%. The CBR values were within the typical range of values from NAVFAC. At the interface between the lifts, the rate of increase of the CBR values decreased.

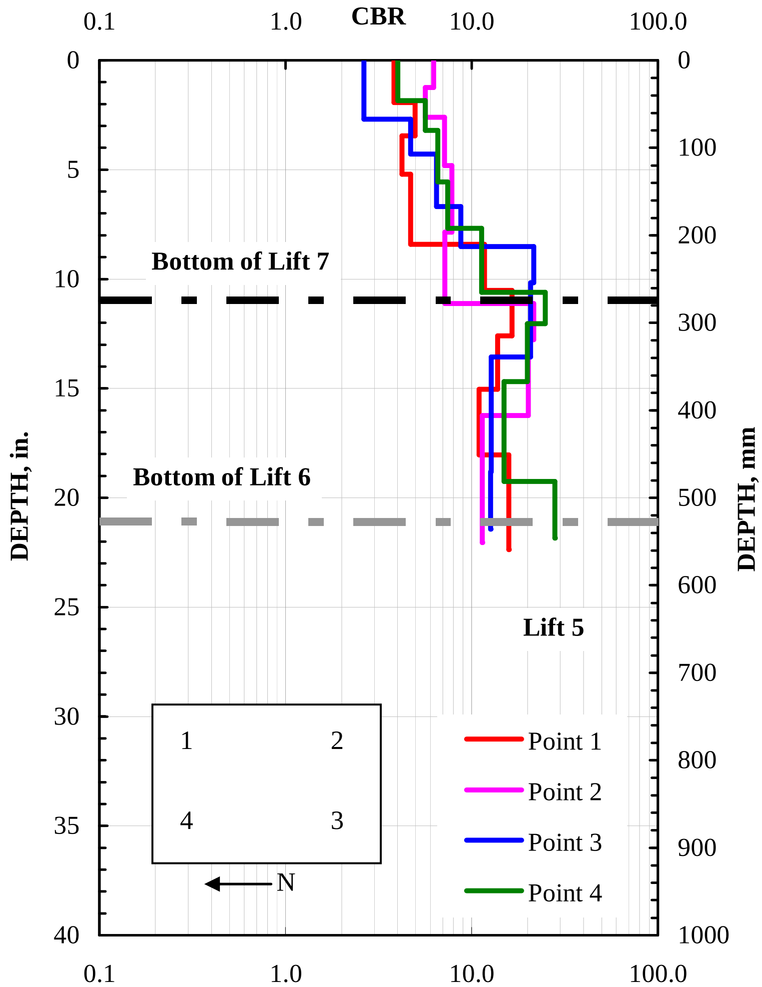


Figure 233 -- CBR profiles calculated using DCP results for lift 7 in Trench 3

Figure 234 shows the CBR profiles for the test points within the trench for lift 9. The average CBR value was 13% extending 25.5 inches. The average CBR value was within the typical values provided by NAVFAC. At the surface of the lift, the CBR values ranged from 3% to 5%. At the termination of the test, the CBR values ranged from 2% to 19%. The CBR values from test point 4 decrease in value after penetrating into the previous lift.

Figure 235 shows the CBR profiles for the test points in the T-section. The average CBR value was 7% extending 18.3 inches. The CBR values at the surface were 5%. At the termination of the test, the CBR value ranged from 2% to 5%.

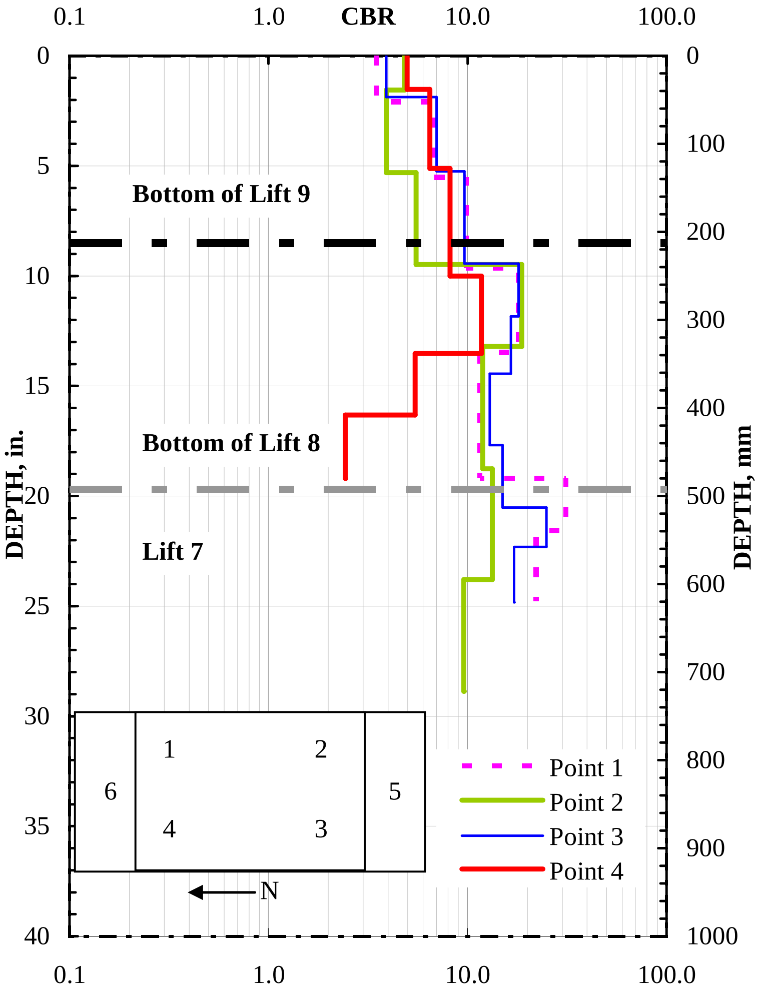


Figure 234 -- CBR profiles calculated using DCP results for lift 9 in Trench 3

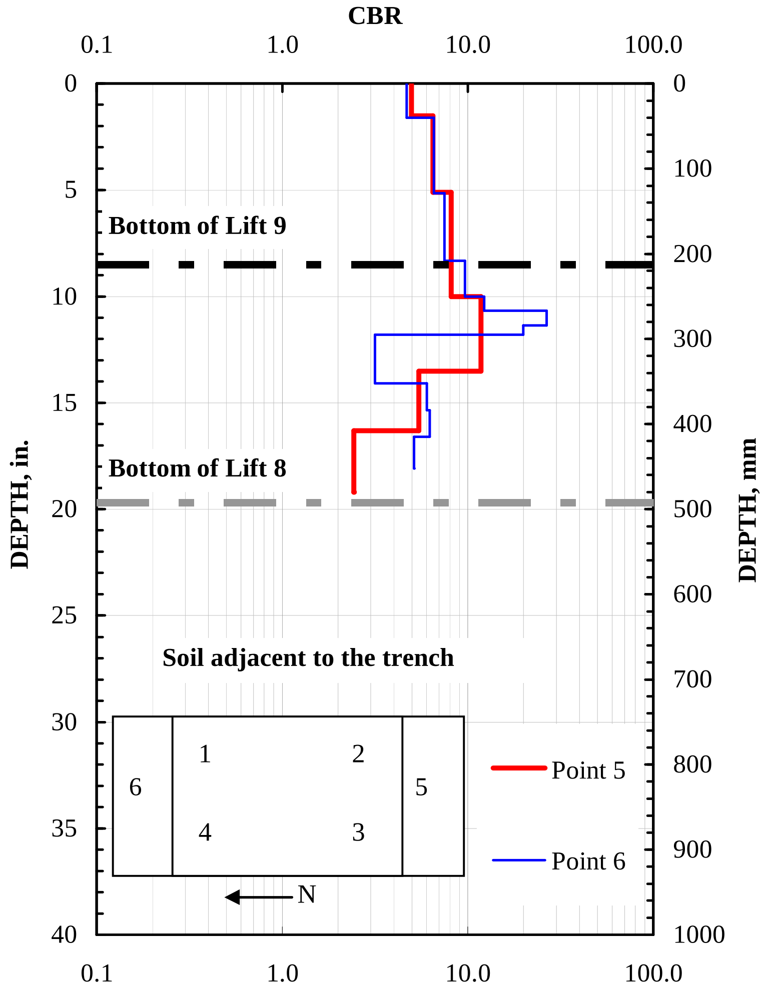


Figure 235 -- CBR profiles calculated using DCP results for the T-section of lift 9 in Trench 3

5.6 - FWD Monitoring and Elevation Surveys of Trenches

5.6.1 - Instrumented Trench 1

To monitor the long-term performance of Trench 1, FWD testing and elevations surveys were conducted on the site. Trench 1 was tested using FWD testing on November 5, 2007. This was 38 days after the construction of the trench.

FWD Test Results

FWD tests were performed on the trenches on November 11, 2007. Forces of 6 kips, 9 kips, 12 kips, and 15 kips were applied to each test point along the trenches. The deflections of the pavement were measured at eight points across each trench. The locations of the test points are shown on Figure 236.

Figure 237 shows the deflections at the test points for Trench 1. This Figure shows that the trench had a stiffer response than the surrounding soil. As monitoring of the site continues, the settlement of surrounding soil should be compared to the settlement of the backfill within the trench. The 15 kip load had a deflection of 18.60 mils in the center of the trench. During the construction of the trench, no testing was performed in the center of the trench because of the instrumentation.

At the south edge of the trench, the deflection was 21.41 mils at FWD testing point 4. The average dry unit weight of test points 2 and 3 on the south edge of the trench for the top lift was 110.1 pcf at a moisture content of 9.0%. The CBR value at the surface was 3% and the average CBR value for the top two feet was 15%. Figure 236 shows the average testing results for the top two feet of backfill on the south side of the trench with the FWD testing locations.

At the north edge of the trench, the deflection from the 15 kips load was 23.21 at FWD testing point 6. Within the vicinity of this deflection were test points 1 and 4. The average dry unit weight was 108.7 pcf at 8.8%. The CBR value at the surface was 3% and the average for the top two feet was 12%. Figure 236 shows the average testing results for the top two feet of backfill on the north side of the trench with the FWD testing locations..

The higher deflections corresponded to lower dry unit weighs and CBR values. As the load increased, the difference between the backfill within the trench and the surrounding soil increased. This was the result of the difference in the soil density and stiffness.

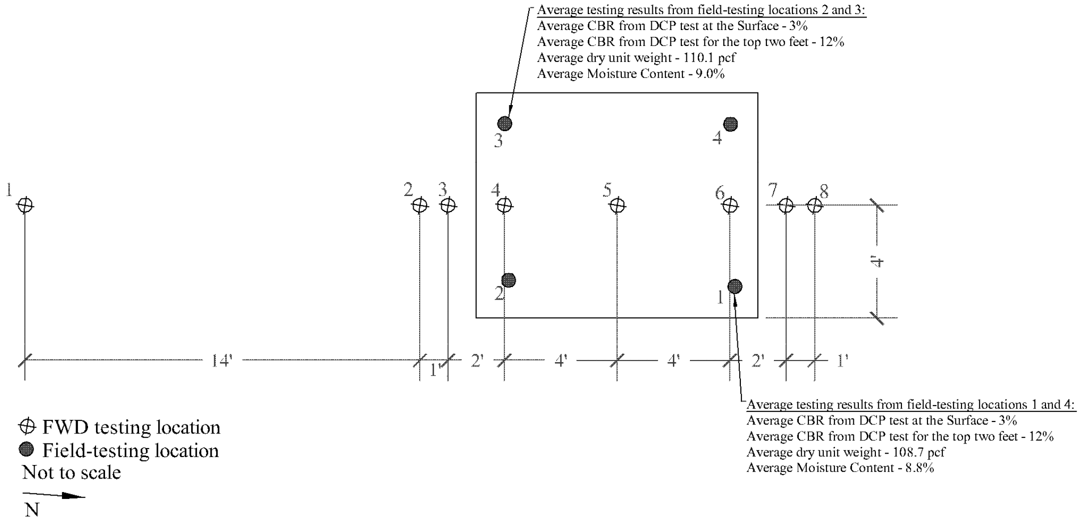


Figure 236 -- FWD testing locations for Trench 1 and average field-testing results for the upper most lift for the north and south edges of the trench

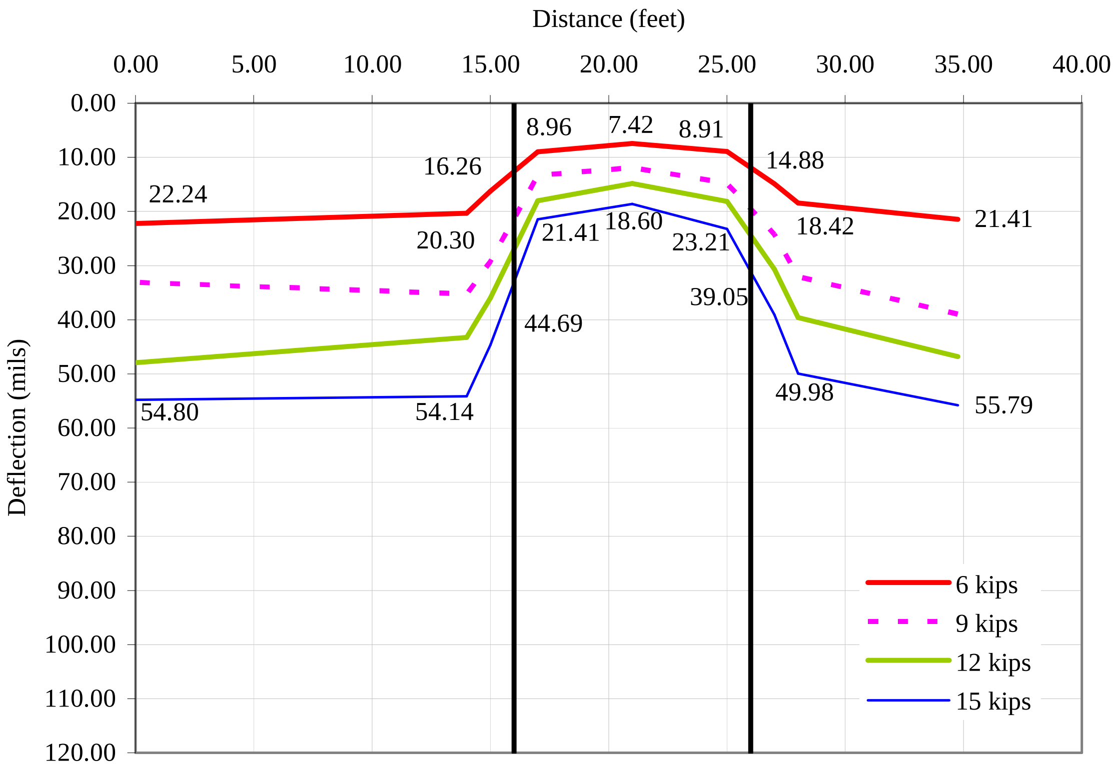


Figure 237 – Results of FWD tests conducted on Trench 1 showing the maximum deflections measured at the points where the load was dropped

Post Construction Elevation Survey

Trench 1 was surveyed on October 27, 2007 and on March 19, 2008. The site survey contained 41 grid points. Figure 238 shows the location of the grid points across the trench. In October 27, 2007, the site elevations ranged from 97.79 feet (at survey point 38) to 97.35 feet (at survey point 4). The difference between the maximum and minimum elevation was 5.28 inches.

On March 19, 2008, the elevation ranged from 97.82 feet (at survey point 38) to 97.38 feet (at survey point 4). The difference between the maximum and minimum elevation was 5.28 inches. The difference between the maximum and minimum elevation did not change between the two surveys. This showed that the trench behaved in a uniform manner and differential movement was not occurring. The average uplift between the two surveys was 0.32 inches, the maximum uplift was 0.48 inches (at survey points 15, 25, and 39), and the minimum uplift was 0.12 inches (at survey points 8, 19, and 29). The pavement across the trench sloped from north to south and from the center of the road to the curb.

Figure 239 shows the elevation profiles along the centerline of Trench 1 for the two surveys. The trench moved up uniformly, except at the north edge of the trench. This shows that the soil adjacent to the trench had not moved in a uniform manner during frost conditions.

Figure 239 also shows the settlement between the fall and spring survey. Superimposed on the graph is the deflection measured from the 15 kip load in the fall. This shows that location of the highest deflections from the FWD testing correspond to the smallest uplifts. This was a result of frost heave effect. The soils with lower stiffness were classified as clayey sand, which was less susceptible to frost heave than the 3/8-inch minus limestone.

At the inside edges of the trench, the FWD deflection increased. The FWD deflections are large at 2 feet south of the trench and at 2 feet north of the trench, the soil experienced smaller uplifts during frost conditions. This was a function of the soil type and the density of the surrounding soil.

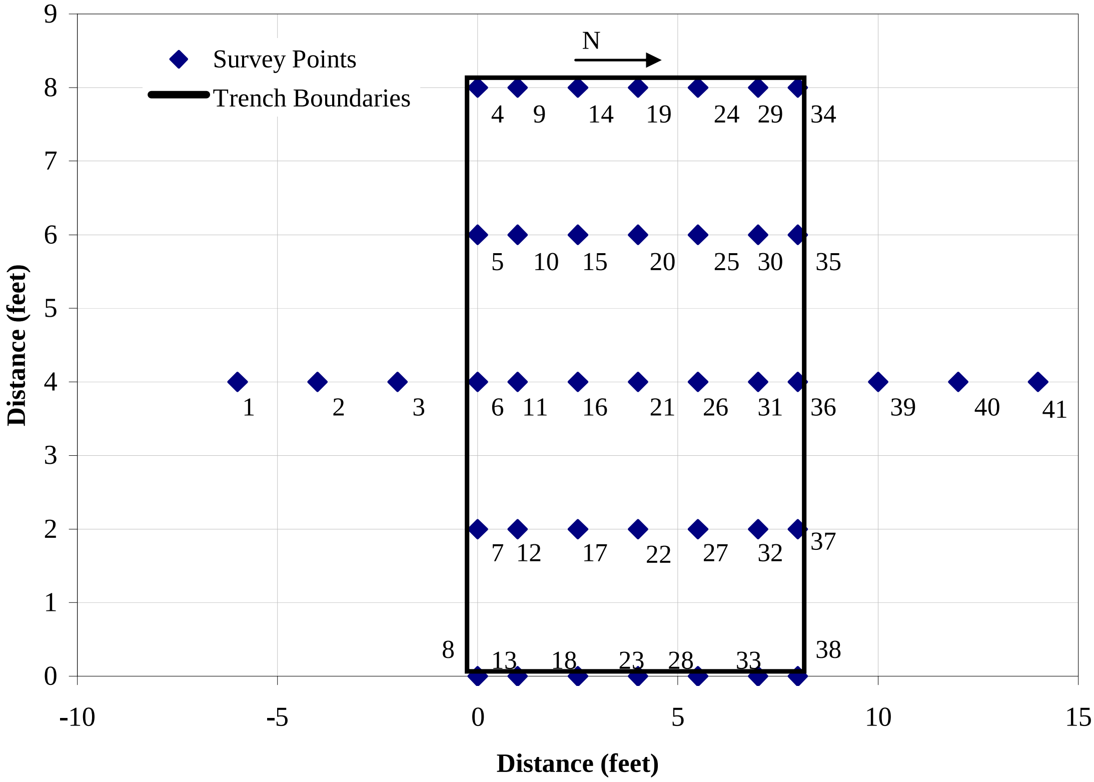


Figure 238 – Location of points used to survey the elevation of the surface of the pavement on top of the trench and surrounding area

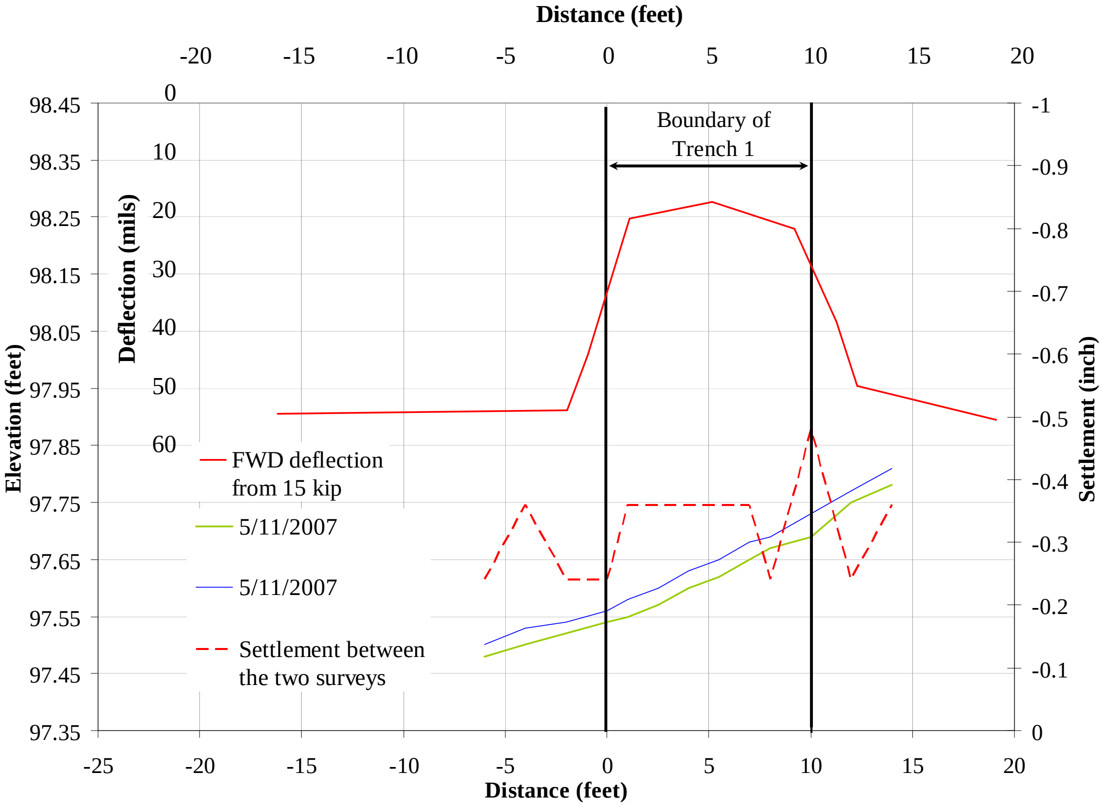


Figure 239 – Elevation profiles of Trench 1 along the centerline of the trench with the total settlement difference with settlement and the 15 kip load superimposed

5.6.2 - Instrumented Trench 2

To monitor the long-term performance of Trench 2, FWD testing and elevations surveys were conducted on the site. Trench 2 was tested using FWD testing on November 5, 2007. This was 45 days after the construction of the trench.

FWD Test Results

Figure 240 shows the location of the FWD testing points for Trench 2.

Figure 241 shows the deflections at the test points for Trench 2. The backfill in the trench had smaller deflections than the surrounding soil. This shows that the backfill was placed stiffer than the surrounding soil. North of the trench, because there was a sewer crossing the site points further out from the trench could not be tested.

At FWD testing point 5 in the center of the trench, the deflection was 16.76 mils from the 15 kip load. The average dry unit weight for the fifth lift was 100.4 pcf at an average moisture content of 3.9%. No DCP testing was performed on the top lift (lift 5). The average CBR value calculated for lift 4 from the DCP test was 14%.

At FWD testing point 12 on the south side of the trench, the deflection was 23.03 mils under a 15 kip load. Near this deflection were test points 2 and 3 (see Figure 240). The average dry unit weight (for lift 5) at test points 2 and 3 was 99.8 pcf at a moisture content of 4.0%. The CBR at the surface of lift 4 (1.5 feet below the surface) was 3% and the average CBR for lift 4 value was 12%.

At FWD testing point 14 on the north edge of the trench, the deflection was 19.59 mils. Near this deflection was test point 4 (see Figure 240) on the fifth lift; test point 1 was not test on the fifth lift. The dry unit weight at test point 4 was 101.6 pcf at a moisture content of 6.3%. The CBR values at the surface of lift 4 (1.5 feet below the surface) was 4% and the average CBR for lift 4 value was 17%. The lower deflections from the FWD testing occurred where there were lower dry unit weights and CBR values.

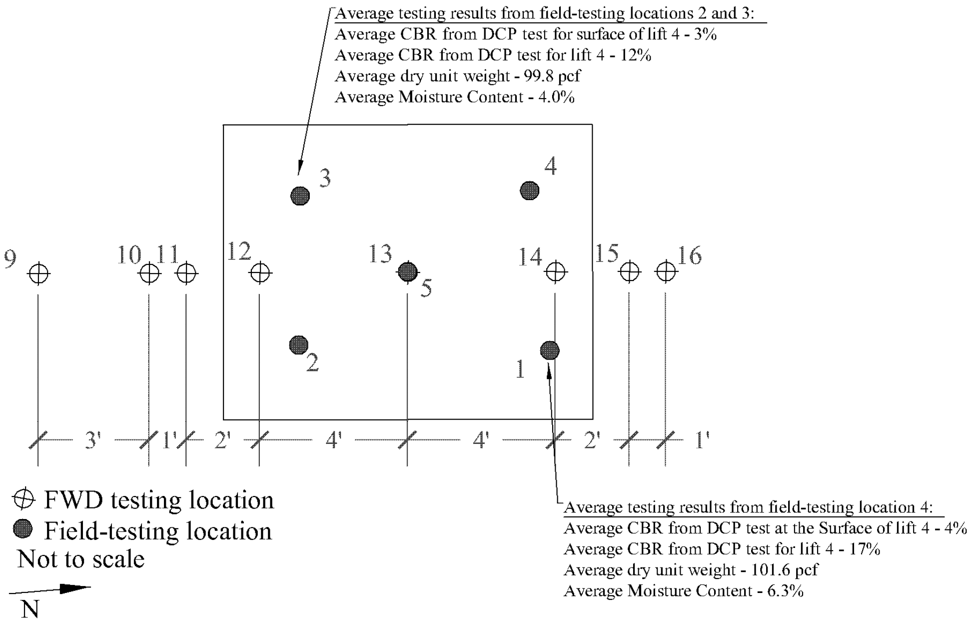


Figure 240 -- Location of FWD testing for Trench 2 with the field-testing locations and average field-testing results

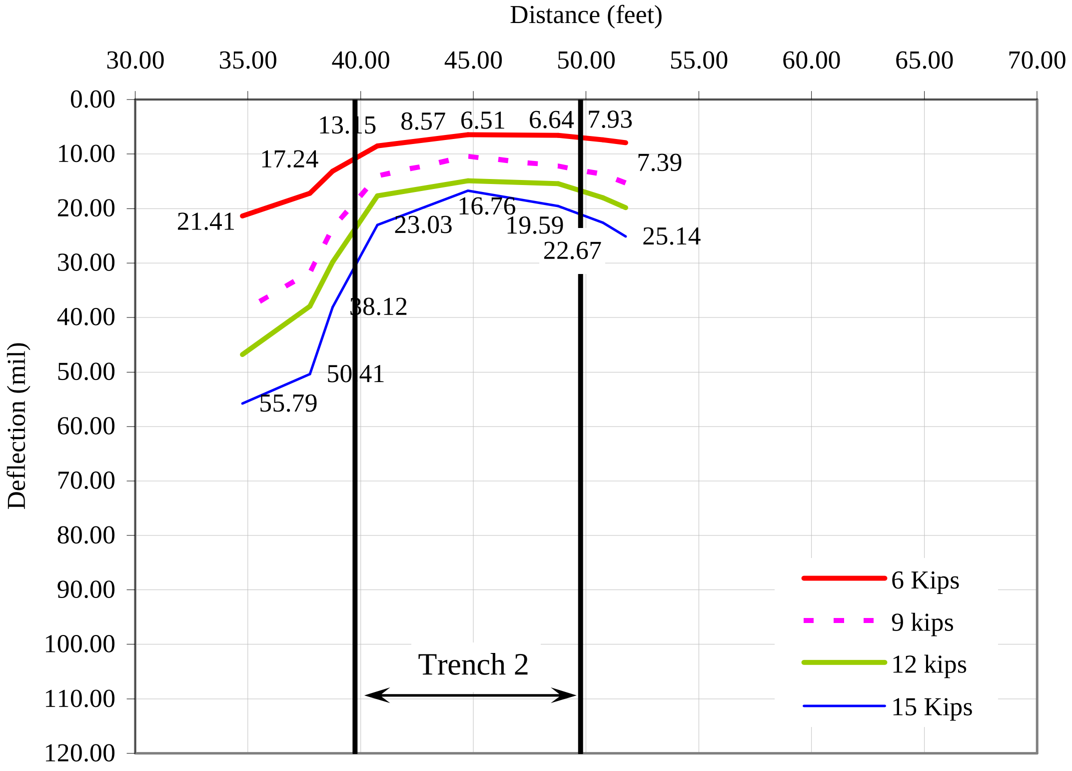


Figure 241 – Results of FWD tests conducted on Trench 2 showing the maximum deflections measured at the points were the load was dropped

Post Construction Elevation Survey

Trench 2 was surveyed in October 27, 2007 and on March 19, 2008. The site survey contained 41 grid points. Figure 242 shows the location of the grid points across the trench.

On October 27, 2007, the site had elevations ranging from 97.73 feet (survey point 4) to 98.18 feet (survey point 38). The difference between the minimum and maximum elevations was of 0.36 inches. On March 19, 2008 the elevation ranged from 97.76 feet (survey point 4) to 98.20 feet (survey point 38). The difference between the minimum and maximum elevations was of 0.24 inches. The difference between maximum and minimum elevations between the surveys decreased. This shows that there was differential settlement. The pavement across the trench slopes from north to south and from the center of the road to the curb.

The average uplift between the two surveys was 0.31 inches and the maximum uplift was 0.48 inches at survey point 2. The minimum uplift between the two surveys was 0.12 inches at survey points 27 and 33. Figure 243 shows the elevation profile for the two surveys. Superimposed on the chart is the total movement of the trench. This shows that the trench moved upward uniformly. It also shows that the soil adjacent to the trench has not moved up uniformly. This was also seen in Trench 1.

Figure 243 also shows the centerline profiles of Trench 2 on the two survey dates with the settlement and the FWD deflections for the 15 kip load. This shows that the trench had a uniform response to the FWD test. The uplift was uniform. This also shows that where the FWD shows softer soils the uplift during the winter was uneven.

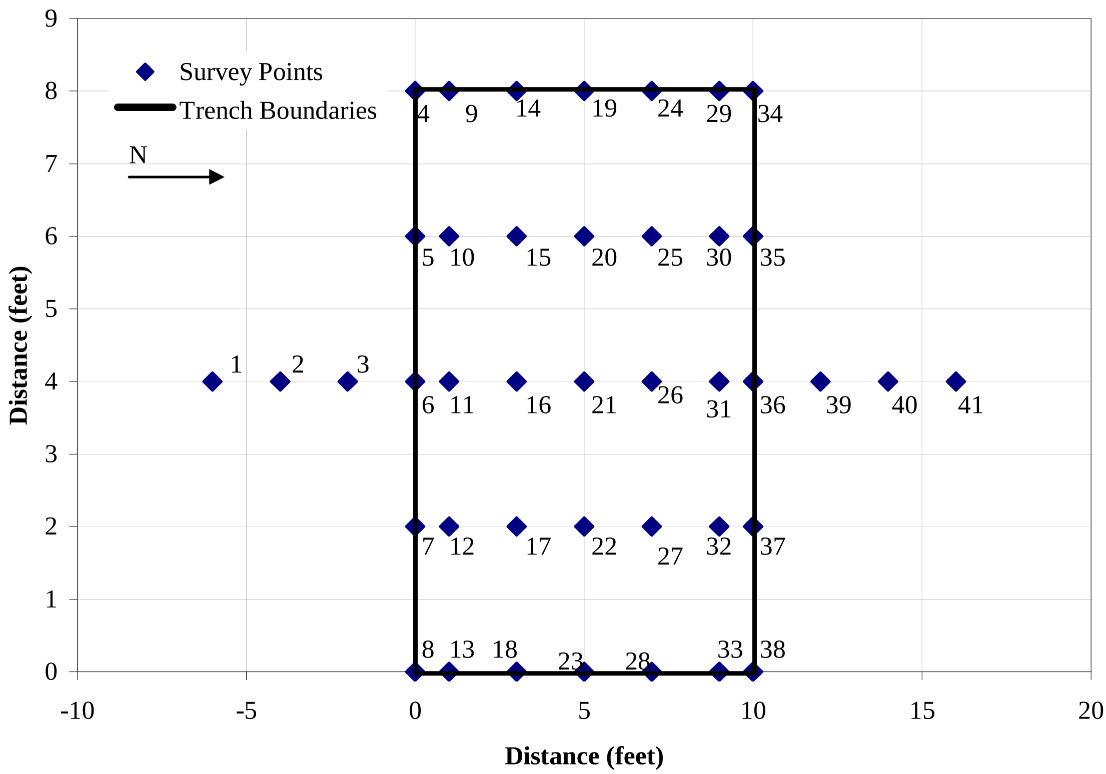


Figure 242 – Location of points used to survey the elevation of the surface of the pavement on top of the trench and surrounding area

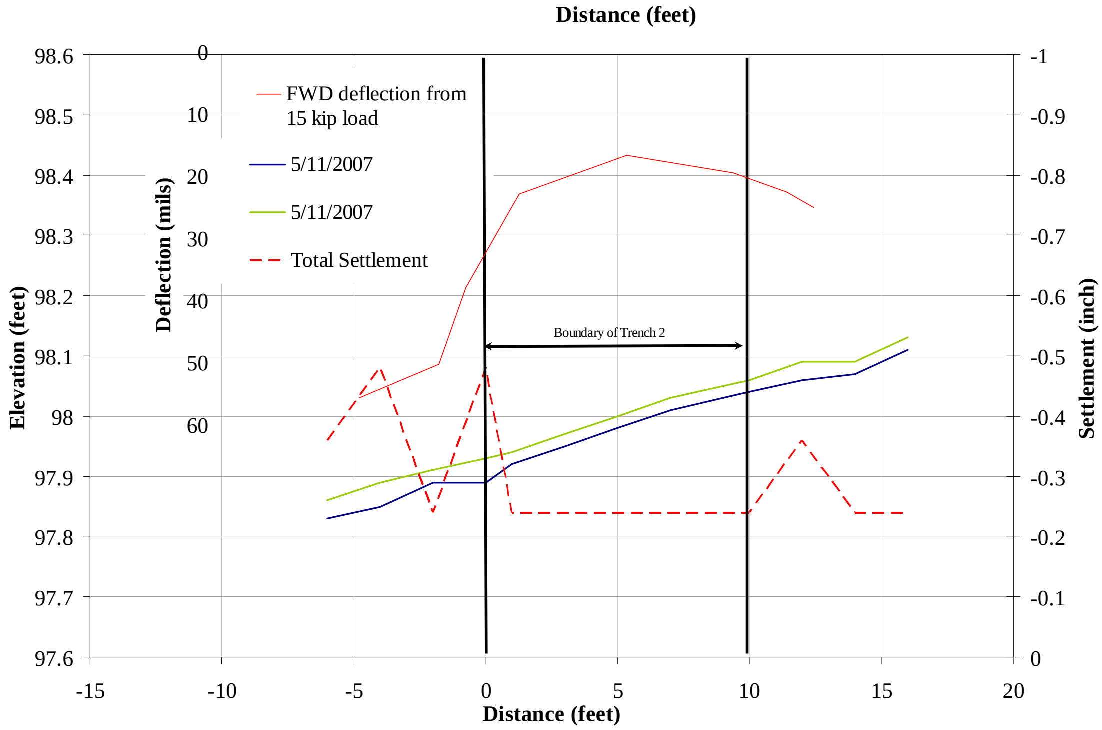


Figure 243 -- Elevation profile along the centerline of Trench 2 with the total difference in settlement between the two surveys with the FWD deflections from the 15 kip load superimposed

5.6.3 - Instrumented Trench 3

To monitor the long-term performance of Trench 3, FWD testing and elevations surveys were conducted on the site. Trench 3 was tested using FWD testing on November 5, 2007. This was 44 days after the construction of the trench.

FWD Test Results

Figure 244 shows the deflections at the test points across Trench 3. In the trenches, the deflections were smaller than the deflections in the surrounding soil. This indicates that backfill was stiffer than the surrounding soils. The sewer prevented the test from being extended on the south side of the trench.

At the edge of the trench was FWD testing points 20 and 22. At FWD test point 20, the deflection from the 15 kip load was 16.74 mils. Near this point were FWD testing points

1 and 4 (see Figure 245). The average dry unit weight was 113.6 pcf at a moisture content of 8.3%. The CBR value at the surface was 4% and the average was 14%. At FWD testing point 22, the deflection was 19.49 mils. Near this point were testing points 2 and 3 (see Figure 244). The average dry unit weight was 115.2 pcf at a moisture content of 8.9%. The CBR value at the surface was 4% and the average CBR value for the top two feet was 12%.

In the T-sections of the trench were FWD testing points 19 and 23. At FWD test point 19, the deflection from the 15 kip load was 18.82 mils. At this location, was test point 5 (see Figure 244). The dry unit weight was 119.9 pcf at a moisture content of 7.2%. The CBR value at the surface was 5% and the average CBR value was 7%. At FWD test point 23, the deflection was 26.45 mils. At this location, was test point 6 (see Figure 244). The dry unit weight was 119.2 pcf at a moisture content of 8.5%. The CBR value at the surface was 1% and the average CBR value was 7%.

The lower CBR values and the dry unit weights measure during construction corresponded to higher deflections from the FWD testing.

The “zone of influence” was present on both sides of the trench. The “zone of influence” extended one foot beyond the trench.

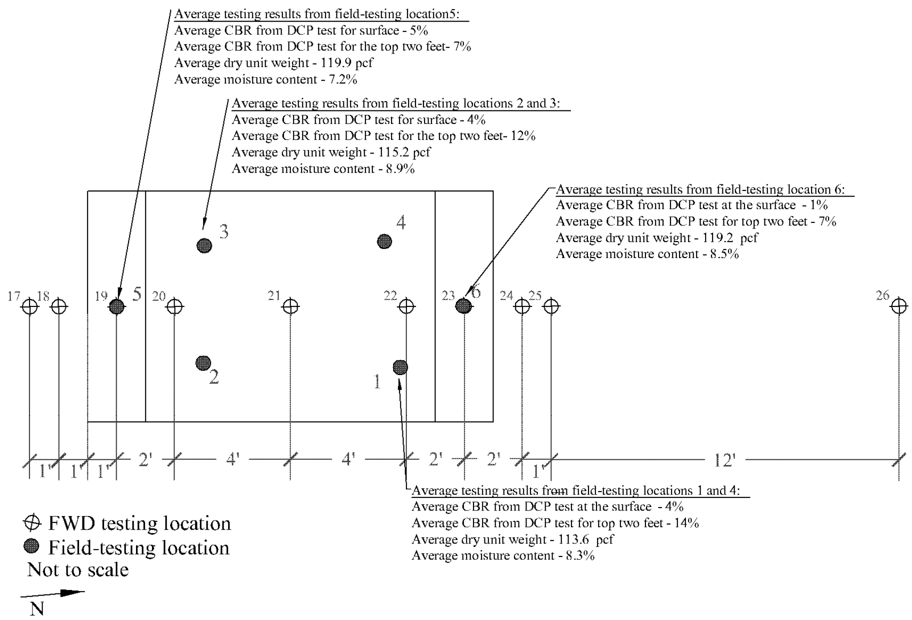


Figure 244 -- Location of FWD testing locations for Trench 3

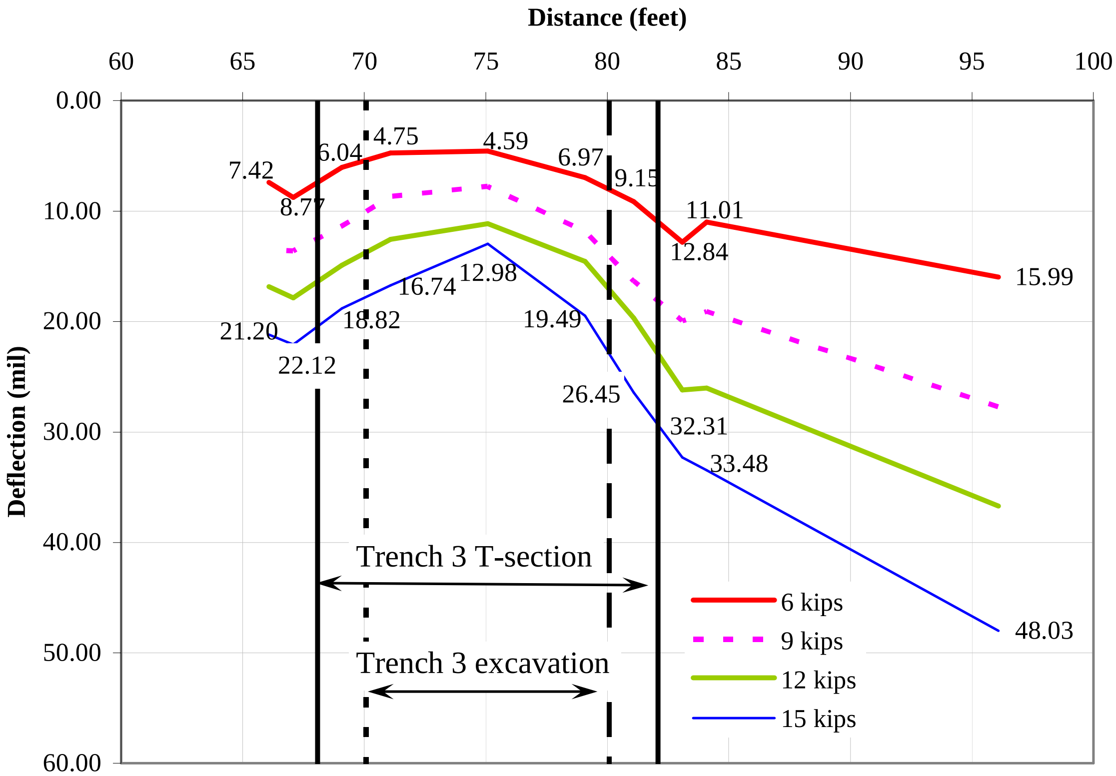


Figure 245 -- FWD testing result for Trench 3

Post Construction Elevation Survey

Trench 3 was surveyed on October 27, 2007 and on March 19, 2008. The site survey contained 43 grid points. Figure 246 shows the location of the grid points across the trench.

On October 27, 2007, the site had elevations ranging from 98.19 feet (survey point 4) to 98.62 feet (survey point 43). This was a difference between the maximum and minimum elevation of 0.41 inches. On March 19, 2008, the elevation ranged from 98.23 feet (survey point 4) to 98.64 feet (survey point 43). The difference between the maximum and minimum elevation was 0.41inches. This shows that the trench was not experiencing differential settlement.

The average uplift between the two surveys was 0.34 inches and the maximum uplift was 0.60 inches (survey point 9). The pavement across the trench slopes from north to south and from the center of the road to the curb.

Figure 247 shows the centerline profiles for Trench 3 with the settlement along the centerline. The south edge of the trench settled evenly, while the north edge of the trench did not settle evenly. These settlement values do not correspond with in-field measurements of dry unit weights and moisture contents.

Figure 247 shows the centerline profiles and settlement between the two surveys, with the FWD 15 kip testing results. This shows that on the south edge of the trench, where the zone of influence were larger settlements.

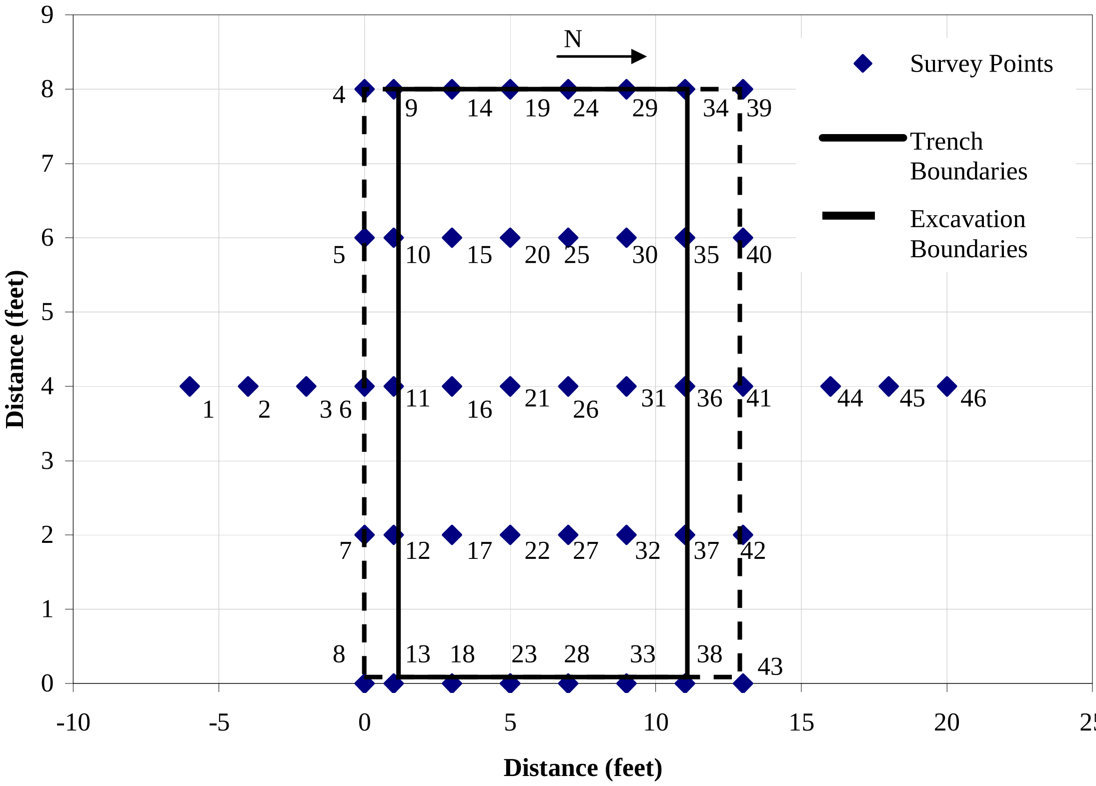


Figure 246 – Survey locations for Trench 3

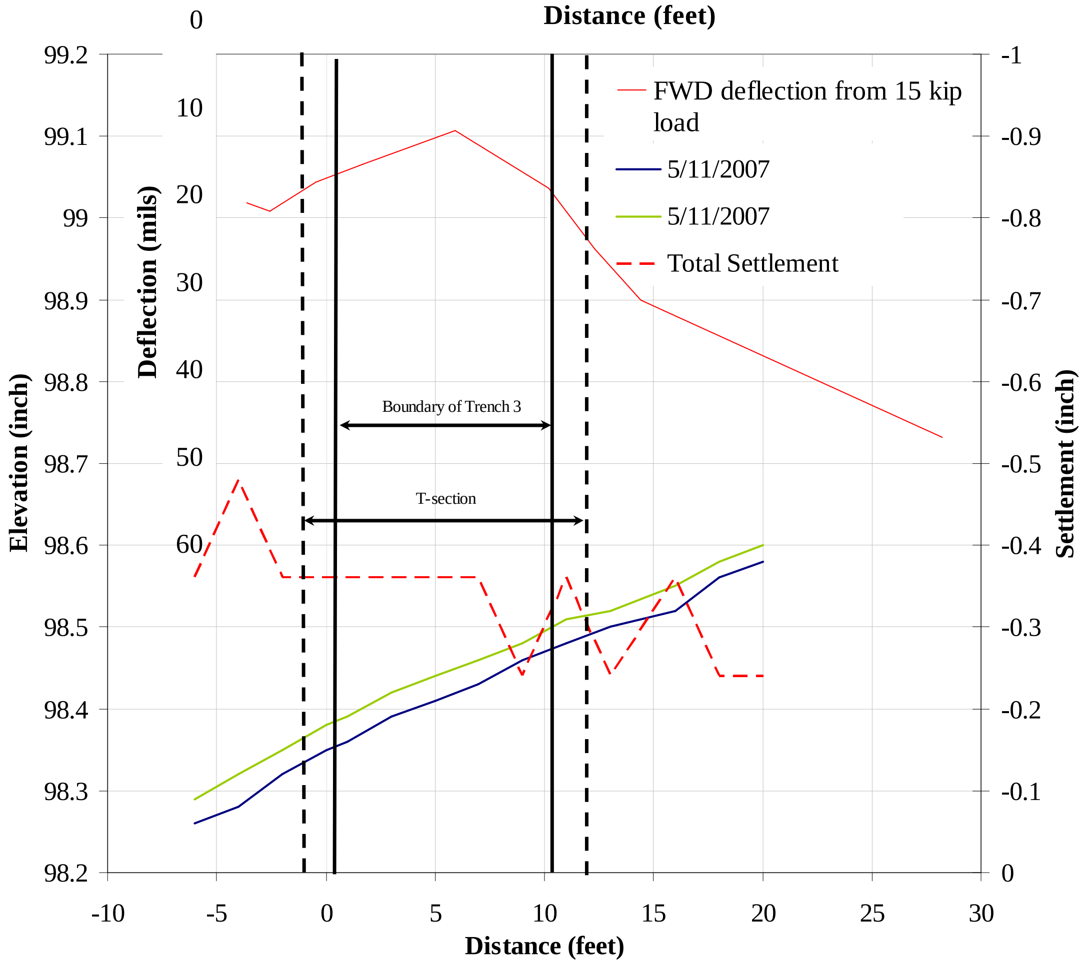


Figure 247 -- Centerline profiles with settlement between the two surveys and the FWD deflections from the 15 kip load superimposed

5.7 - Comparison of the Trenches.

The backfill used in the trenches was classified as SP-SM – poorly graded sand with silt. According to Table 5, the typical CBR values for this backfill range from 10% to 40%. The typical dry unit weights for compacted soil are 100 pcf to 120 pcf. The optimum moisture content for compacted backfill was 12% to 20% according to Table 5.

The top lift of Trench 1 was placed at 39% relative density and in the upper range of the bulking moisture content. The average CBR value was 13%. The top lift of Trench 2 was placed at 4% relative density and was in the bulking moisture content. The average CBR value was 14%. The top lift of the Trench 3 was placed at 49% relative density and was at the upper end of the bulking moisture content. The average CBR value was 11%.

The backfill for Trench 1 and Trench 3 for all lifts was above the bulking moisture content obtained in the relative density testing. The backfill in Trench 2 was at or below the bulking density of the backfill. The results from the field-testing are plotted on Figure 248. This Figure shows that the trench constructed using the City of Ames standard method without moisture control yielded lifts with lower densities and moisture contents.

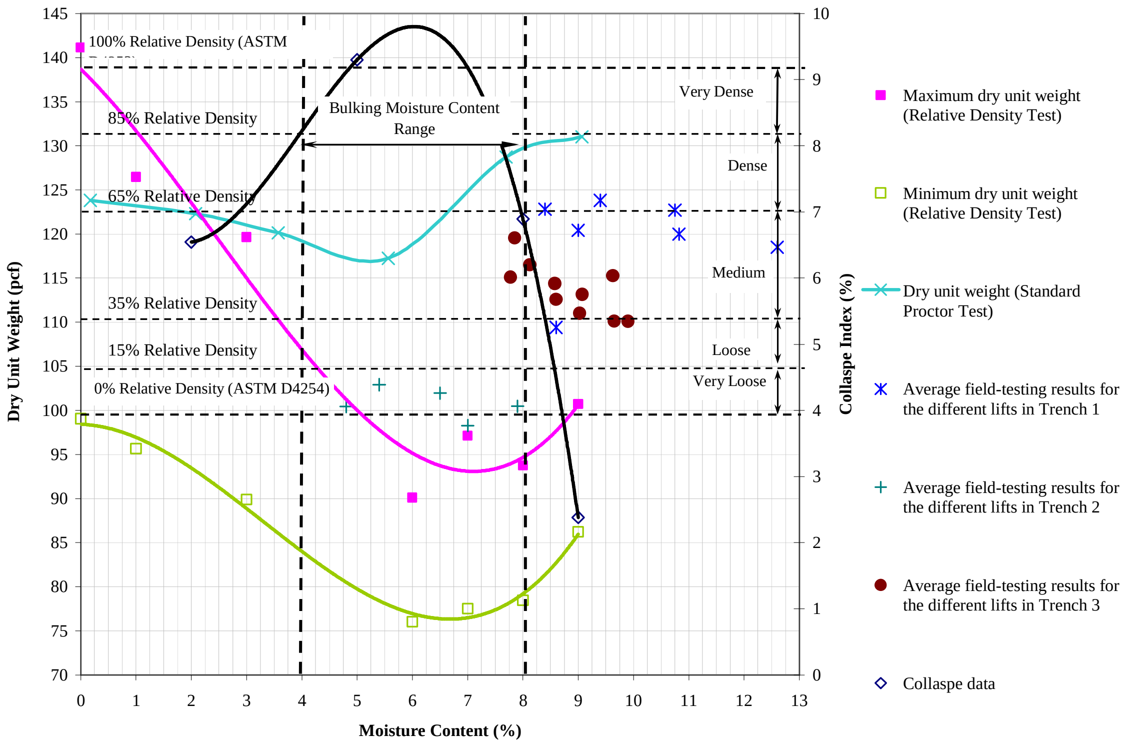


Figure 248 – Results from relative tests with the average nuclear density testing results for the three instrumented trenches

Figure 249 shows a comparison of the trenches with a 12 kip loading. This Figure shows that Trench 3 provided the stiffness (smallest deflections) response to the FWD test. Trench 3 was placed at the highest relative density during compaction; however, the CBR values from Trench 3 were lower than in the other trenches. Figure 250 shows the FWD profile across the entire Kellogg Avenue site. Outside of Trenches 1 and 2, the deflections are larger that the deflections outside of Trench 3. However, at the test point further from the trenches, the subgrade had similar high deflections from the FWD testing. This shows that the effect of the "zone of influence" was minimal using the T-section construction. However, Trench 3 was the trench where the "zone of influence" was most evident. A manhole located between Trenches 2 and 3 did not allow the research team to conduct FWD testing to measure the deflection of the subgrade away from the trench.

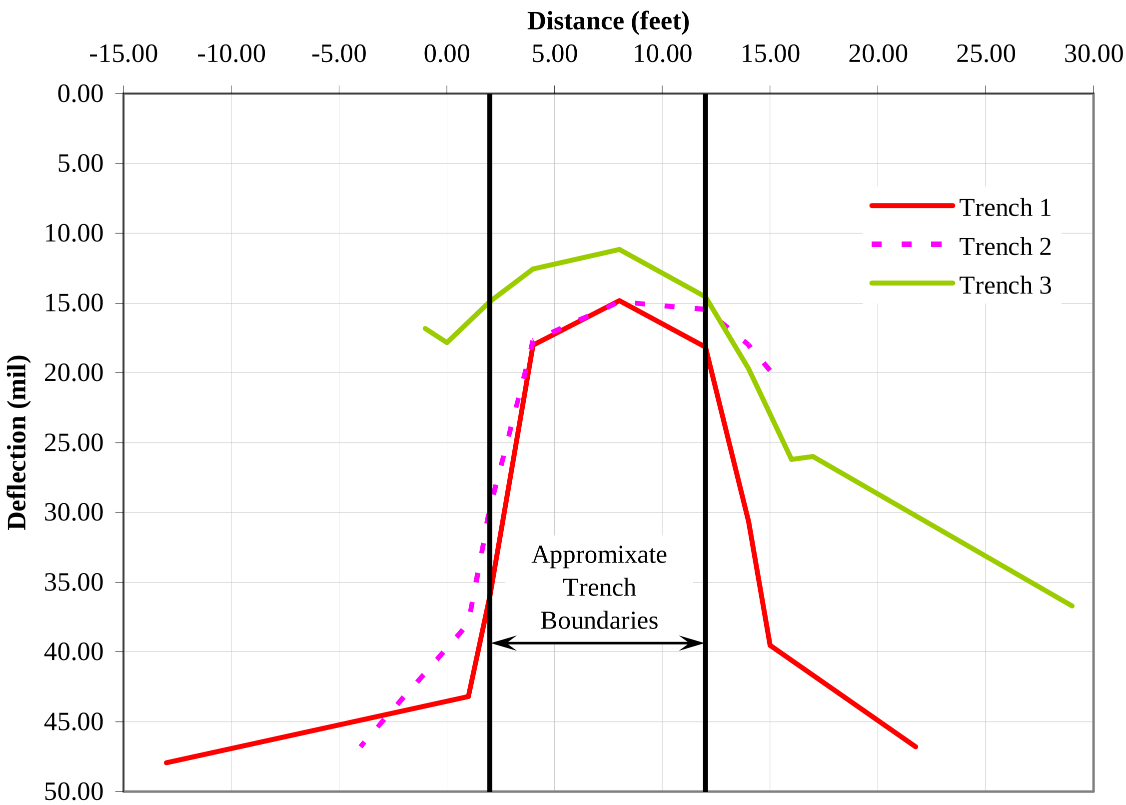


Figure 249 -- Comparison of the three-instrumented trenches response at the 12 kip FWD loading

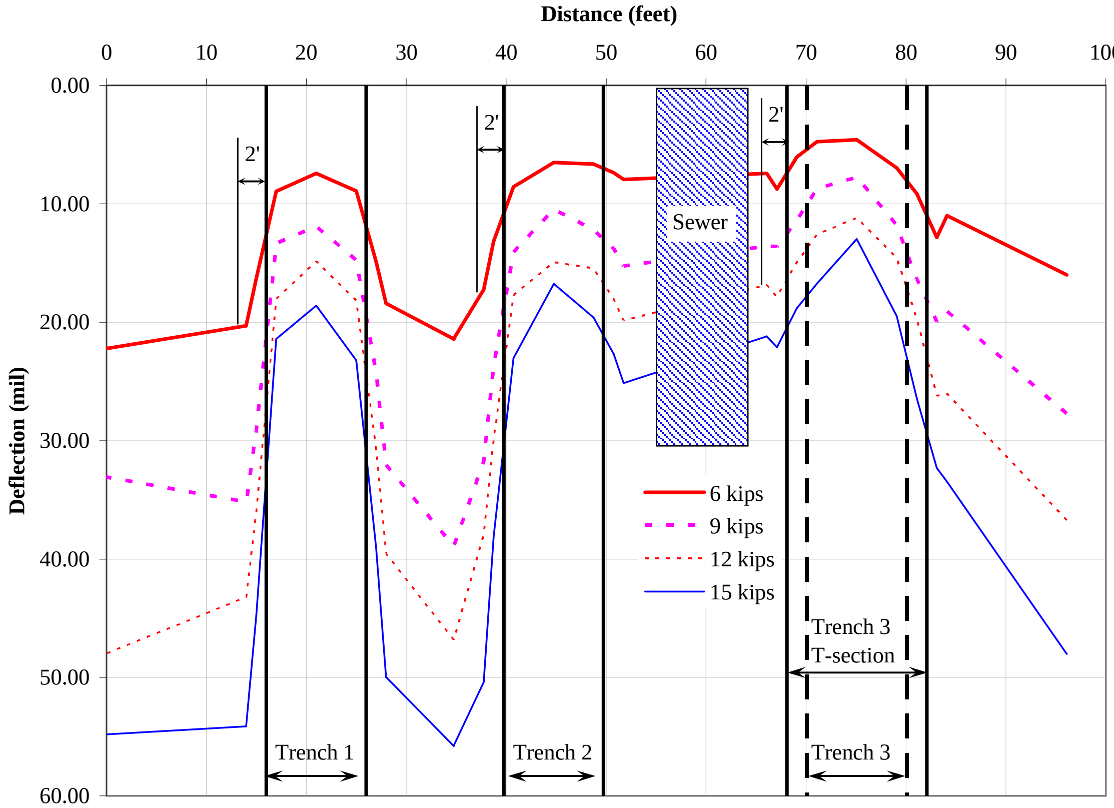


Figure 250 -- FWD results across the three-instrumented trenches Kellogg Avenue site

5.8 - Instrumentation Results

The instrumented trenches on Kellogg Avenue were monitored from November 2007 to March 2008. The performance of the trenches was monitored with instrumentation.

Figures 251, 252, and 253 show the cross sections of the trenches with the instruments installed on each layer.

In Trench 1, there was an additional pressure cell installed on the side of the trench on the top lift. In Trench 2, additional extensometer and moisture sensor were installed at the base of the trench. The extensometer and moisture sensor 1 was not working during monitoring. In Trench 3, an extra pressure cell and moisture sensor were installed on the T-section.

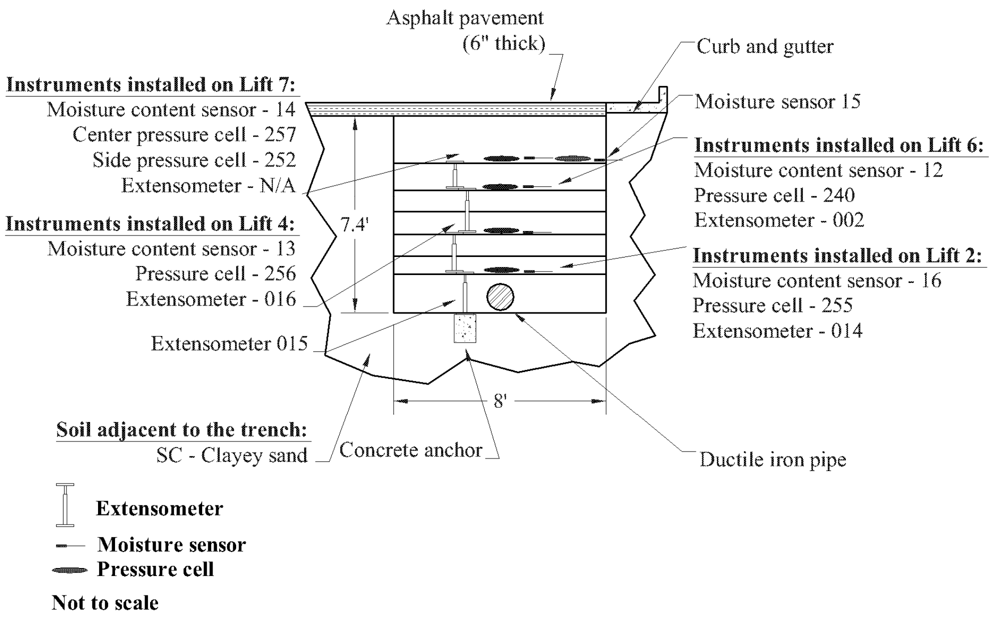


Figure 251 -- Cross-section of Trench 1 showing the location of the instrumentation

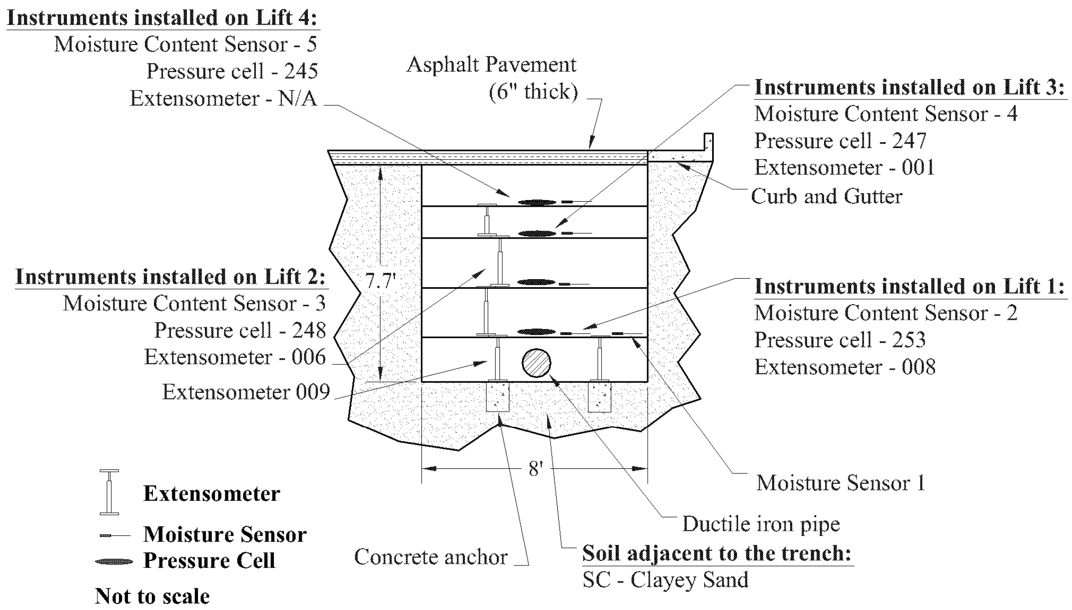


Figure 252 – Cross-section of Trench 2 with showing the location of the instrumentation

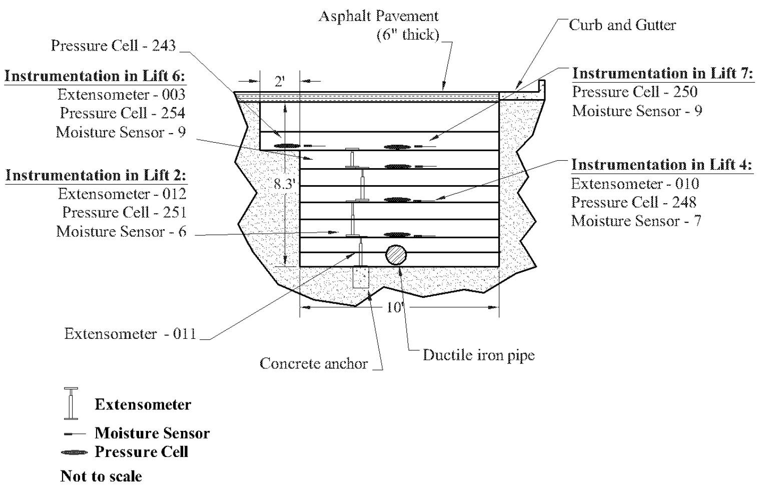


Figure 253 -- Cross-section of Trench 3 showing the location of instrumentation

All instrument readings began on November 4, 2007 except for the extensometers, which began on September 25, 2007. The delay from the time of installation to the beginning of data collection occurred because of several factors, including missing multiplexers, wiring difficulties and appropriate code to scan all equipment.

The flat line gap in the instrumentation data from December 7, 2007 to December 13, 2007 occurred because the data on the December 20, 2007 was downloaded and saved directly over the file from the previous week. The gap in the March data was the result of the same problem.

To compare temperature and pressure as a function of depth, eight dates were selected for comparison. Table 83 shows the justification for the selection of each date.

Table 83 -- Dates used for comparing temperatures and pressures as a function of depth

Date	Justification
11/14/07	Construction was completed, all instruments were providing read-outs and no freezing has occurred in the trench
12/25/07	The ambient air temperature was below freezing, and temperatures were measured in the soil adjacent to the trench and the temperatures in the trenches were just above freezing
1/13/08	The temperature in the trenches was dropping to coldest temperatures in the trench
1/30/08	The temperatures and pressures in the trench reached the lowest values
2/10/08	Temperatures in the trench briefly increased towards freezing and there was an increase in pressures in the trench
2/28/08	Temperatures in the trench began to decrease again and pressures decreased in all the trenches
3/10/08	Temperatures in the trench began to raise above freezing and the pressures in the trench were increasing
5/14/08	All temperatures measured in the trench were above freezing and the pressures had stabilized

5.8.1 - Temperature Readings in Boring 1

Figure 254 shows the readout from the temperature sensors installed in Boring 1 located north of Trench 1 (see Figure 173). This figure illustrates the delay between the changes in average ambient air temperature verse the temperature in the soil. The upper region of soil experienced larger changes in temperature in response to changes in the ambient air temperature than soils in deeper regions of the trench. The temperature in the soil adjacent to the trench decreased until late February and then began to increase again. Freezing temperatures were measured to a depth of 2.45 feet during the winter. The upper most stratum of soil experienced freezing temperatures from December16, 2007 to March 13, 2008 to a depth of about 2.45 feet and January 27, 2008 to January 30, 2008 to a depth of 2.45 feet. During spring warming, the upper layers of soil responded sooner to raising air temperatures than deeper regions of the trench. This was seen by the temperatures in the upper region of the soil becoming warmer than temperatures in the deeper soils. The deeper soils in the trench experienced smaller changes in temperature over the winter season.

Figure 255 shows the temperature profiles for eight selected dates from Table 83 (above). The profiles of the temperatures varied linearly through the profile as the ambient air temperature deceased until January 30, 2008. After January 30, 2008, the upper layer of the trench was affected by the increases in ambient air temperatures. During this time, the lower region of the soil profile continued to decrease in temperature. At the completion of the data collection for this thesis, there were not frozen temperatures measured in the trench.

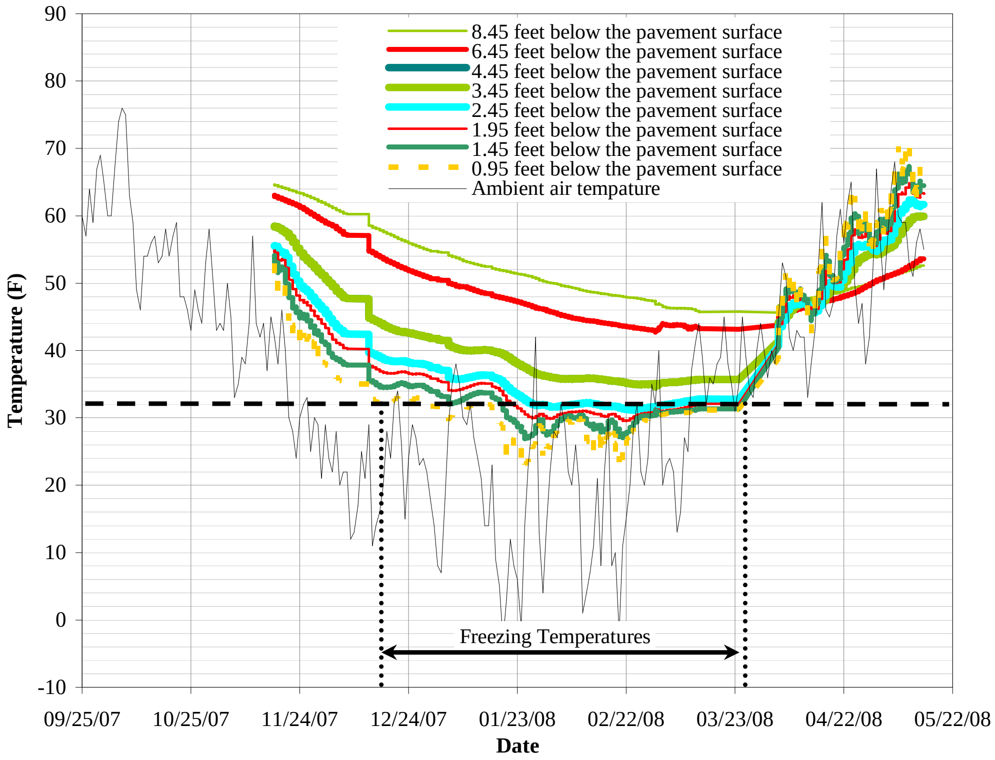


Figure 254 -- Variation of temperature over time at various depths

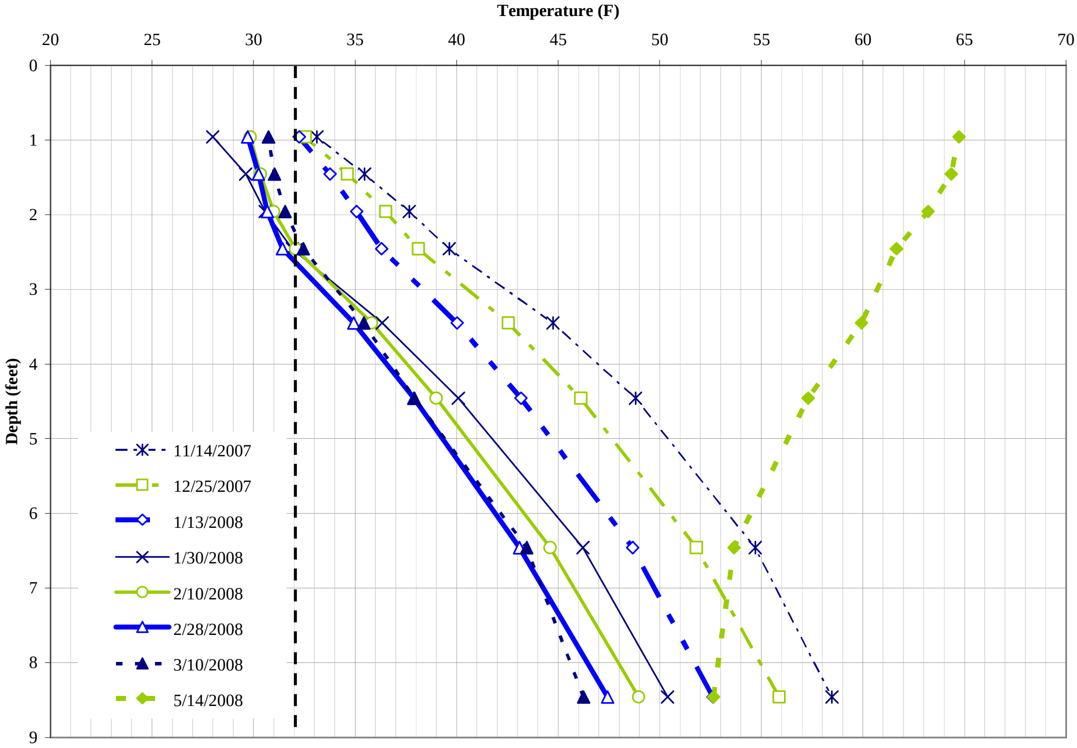


Figure 255 -- Temperature profiles for various dates (11/14/07, 12/25/07. 1/13/08, 1/30/08, 2/10/08, 2/28/08, and 5/14/08)

5.8.2 - Instrumented Trench 1

The temperature readings from Trench 1 are plotted on Figure 256. The temperatures in the trench follow a similar pattern as the temperature sensors in the soil adjacent to the trench. The Figure shows that freezing temperatures in the trench reached a depth of 1.02 feet (the top lift) on the side of the trench between January 1, 2008 and March 13, 2008 and at a depth of 1.02 feet in the center of the trench from January 20, 2008 and March 3, 2008. The trench did not experience freezing temperatures to the same depth as measured in Boring 1. This is a function of the soils thermal conductivity. Granular materials have lower thermal conductivities than cohesive soils as discussed in Section 2.0.

The temperature measured at the side of the trench was constantly lower by various magnitudes during the winter. This was the result of the granular soil at the side of the trench being adjacent to a heat sink (i.e. the cohesive soil adjacent to the trench). The colder cohesive soils adjacent to the trench caused a thermal gradient to occur between the center of the trench and the side of the trench.

The temperature measured at the bottom of the trench (at depths of about 5.98 feet and 4.48 feet) were similar. This was different that what would have been typically expected (linear varying temperatures with depth through a constant media). The relative densities measured at these elevations in trench were uniform. The discontinue measured at a depth of is a reflection of the pressure cell at a depth of 4.48 feet possibly not providing accurate temperatures and pressure measurements.

Figure 257 shows the temperature profiles for the trench as function of depth for the selected dates in Table 83 (see above). The temperature profiles in the trench show that as the ambient air temperature was decreasing, the backfill decreased in temperature uniformly until January 30, 2008. After January 30, 2008, the lower region continues to decrease steadily, while the upper region of the trench fluctuates with the ambient air temperature. This is similar to in the soil adjacent to the trench. However, the temperature profiles were not linear. The non-linearity of the profiles was caused by the pressure cell at 4.48 feet not working properly. During the spring warming, the upper region of the trench experienced increased temperature and the temperature was above the temperature measured after installation on November 14, 2007.

Figure 258 plots the pressures measurements in the trench. The highest pressure was at the bottom of the trench. This was expected. At a depth of 4.48 feet, the pressure measurements were similar to measurements at depths of about 2.81 feet. These readings were not expected because typically pressures vary linearly as a function of depth. However, the pressure sensor at a depth of about 4.48 feet was also not measuring temperatures that were expected. The pressure measured in the trench was a function of temperature measured in the trench (see Instrumentation Summary for complete description of the equations). Based on Equations 9 and 10, and because the sensor was reading temperatures that were higher than expected, the pressure reading was then lower than expected. The spring temperature reading was lower than expected (similar to the fall temperatures), however, the spring pressure readings were similar to in the fall pressure readings. This pressure cell was not accurate.

At a depth of 1.02 feet, a pressure cell was installed in the center of the trench and at the side of the trench. The pressure cell on the side of the trench reads pressures that are lower than pressures in the center of the trench. Initially, the interaction between the side of the trench with the backfill resulted in lower pressures at the side of the trench.

During the winter, the difference in pressures between the side of the trench and the center of the trench was the result of adjacent soil freezing to a deeper depth than the backfill in the trench. Using linear interpolation on Figure 257, freezing temperatures were experienced to a depth of about 2.5 feet in the adjacent soil and 1.9 feet in the trench. Because there was no FWD testing done during the winter, it is hypothesized that soil adjacent to the trench during the winter became stiffer than the backfill. This was the reverse of the stiffness measured during the fall 2007 FWD testing.

Figure 259 compares the pressures measured in the top two lifts of instrumentation with the temperatures measured by the pressure cells on the side of the trench and in the center of the trench. During the winter, all the pressure cells experienced a reduction in the pressures during freezing. The pressure cells were installed with a lens of clean sand. The clean sand, according to the literature review was less susceptible to frost action than the 3/8 inch minus limestone. In addition to the sand lens, the 3/8 inch minus backfill was not compacted until 2 feet above the instrument. As shown by the CBR tests on the six recommended trenches (Section 4.0), when the lift thickness exceeded 12 inches, the compaction was no longer effective. When the non-compacted backfill was freezing, the larger void space allowed the ice lenses to form without displacing the surrounding particles. Because of the sand and the loosely placed backfill, the compacted 3/8 inch minus limestone surrounding the instruments pulled water up to the freezing fringe (shown in Figure11) more effectively and formed ice lenses to a deeper depth than where the instruments were located. The result was that the backfill surrounding the instrumentation was stiffer than the backfill covering the instrumentation. As loads (overburden and heave) were applied, using the beam on elastic foundation theory, the stiffer surrounding backfill carried the load. This accounts for the lower pressures experienced during freezing and until the first thaw about January 29, 2008 (varies slightly by instrument).

In January, the pressure decreased as freezing temperatures penetrated deeper into the trench. However, from about January 29, 2008 to February 12, 2008 the pressure cells in the top two lifts experienced an increase in pressures (see Figure 258). This is shown in Figure 258, on February 10, 2008. Figure 260 shows the pressure profiles for various dates selected in Table 83 above. During this period, the trench experienced freezing temperatures; however, for the top lift, the temperatures rose above freezing at the center of the trench and approached freezing along the side of the trench. The lower temperature measured at the side of the trench was a result of the soil adjacent to the trench being colder than the soil towards the middle of the trench. As the backfills above the pressure cell warmed and the ice lens receded, the stiffness of the backfill adjacent to the instruments decreased. As the stiffness the backfill adjacent and above to the instrument became similar to the stiffness of the material surrounding the instrument, the pressure cells experienced pressures that were similar to when they were initially installed. In addition, during this time, the pressure cell on the side of the trench did not experience the same magnitude of increase in pressure because the soil adjacent to the trench was still frozen, even though the frozen fringe was migrating upward.

About February 12, 2008, the temperatures in the trench began to decrease again. As the temperature of the soil decreased, the frozen fringe migrated downward. In addition, the backfill surrounding the instruments became stiffer relative to the backfill above the pressure cells and the loads were distributed around the pressure cells.

These pressure cell results do not support, Moser (1990) that pressures on underground utilities can double during the winter. However, the method of installing the instruments could affect the pressure results.

Figure 261 shows the moisture sensor readings. Plotted on the chart are the Nuclear Density test results from the field-testing during construction. The field-testing results are plotted as the first moisture content on the figure. The range for error determined using the specification of the instruments (Campbell Scientific 1996). The difference between the moisture sensors and the field measures was small and could also be affected by the nuclear density gauges accuracy and time delay from installation and the first reading (6 days). The moisture sensor located in the soil adjacent to the trench recorded higher moisture contents than the moisture sensor in the center of the trench. This was expected because the soil adjacent to the trench was cohesive and therefore did not drain as quickly as the granular backfill. The moisture sensor at a depth of 5.89 feet had readings that were above 100% saturation. This indicates that water was freely flowing and pooling at the bottom of the trench.

After the first day of readings, the moisture sensors were offline until November 14, 2008. Valid readings continued until early to mid-December. During this time, the temperature fell below 50 F in the backfill and surrounding soils. This lasted until April. The data collected when the instruments were operating out of designed parameters, were lighter than when there were data points. However, even though the instruments were operating out of design specifications, it can be seen that the moisture sensors in the top center (1.02 feet) of the trench and in the soil adjacent to the trench both showed moisture content decrease. The decrease in the moisture content was the result of frost formation and water being drawn upward away from the sensors.

Figure 262 plots the settlement data from the trench. Initially, when the extensometers were installed, the elevation was assigned a reference value of zero. After installation, the trench experienced maximum settlement of 0.04 inches. This initial settlement was the result of rain infiltrating into the trench from around the temporary patch. The total settlement initially measured decreased as the soil froze and ice lens formed and pushed the backfill upwards. Data indicates that the trench remained in an uplifted condition from January 23, 2008 to April 8, 2008. During the winter months, the extensometers measured a total uplift of 0.13 inches from February 4, 2008 to March 4, 2008. This movement was controlled by the top lift. The larger rate of uplift during this time was the result of the temperature of the backfill being closer to the freezing point. Temperatures closer to the freezing point increased the backfill's ability to draw water upwards to form an ice lens. This increased the amount of lensing in the upper lift of the trench, resulting in larger uplifts. This uplift was reflected in the elevation survey performed on March 19, 2008. As the soil thawed, the backfill in the trench began to settle again.

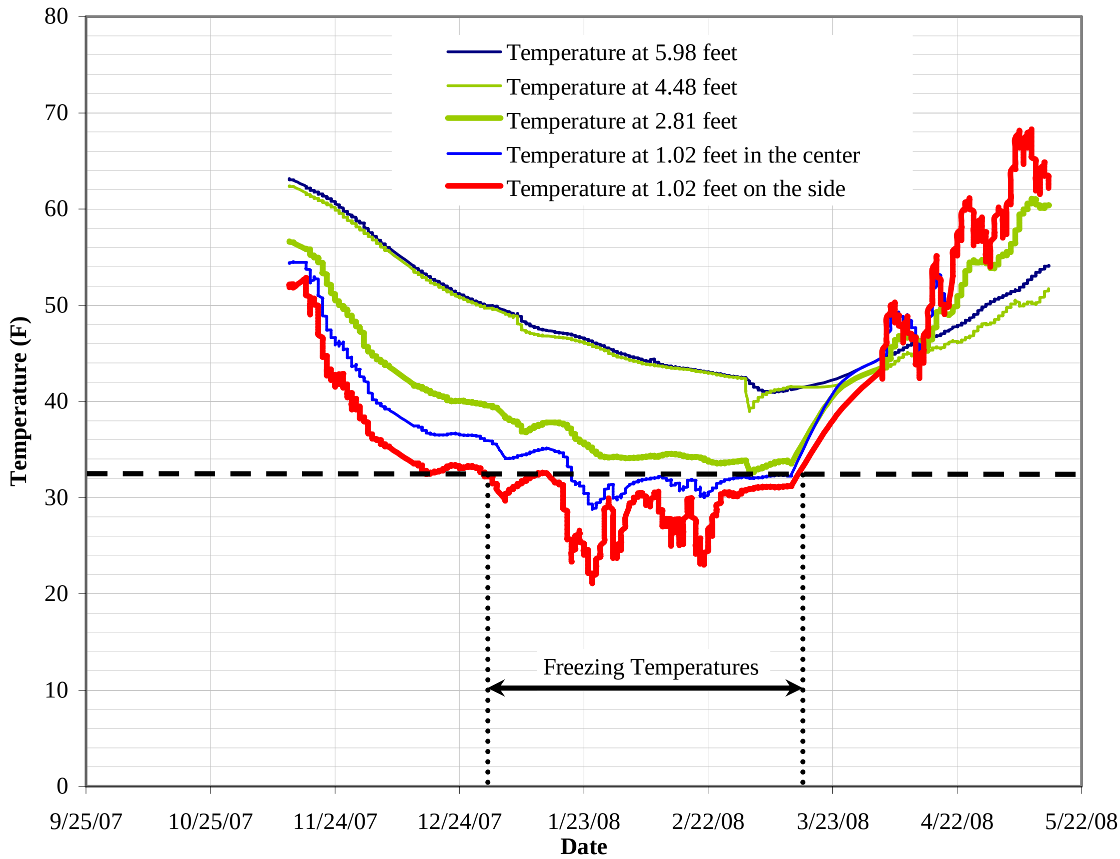


Figure 256-Temperature in Trench 1

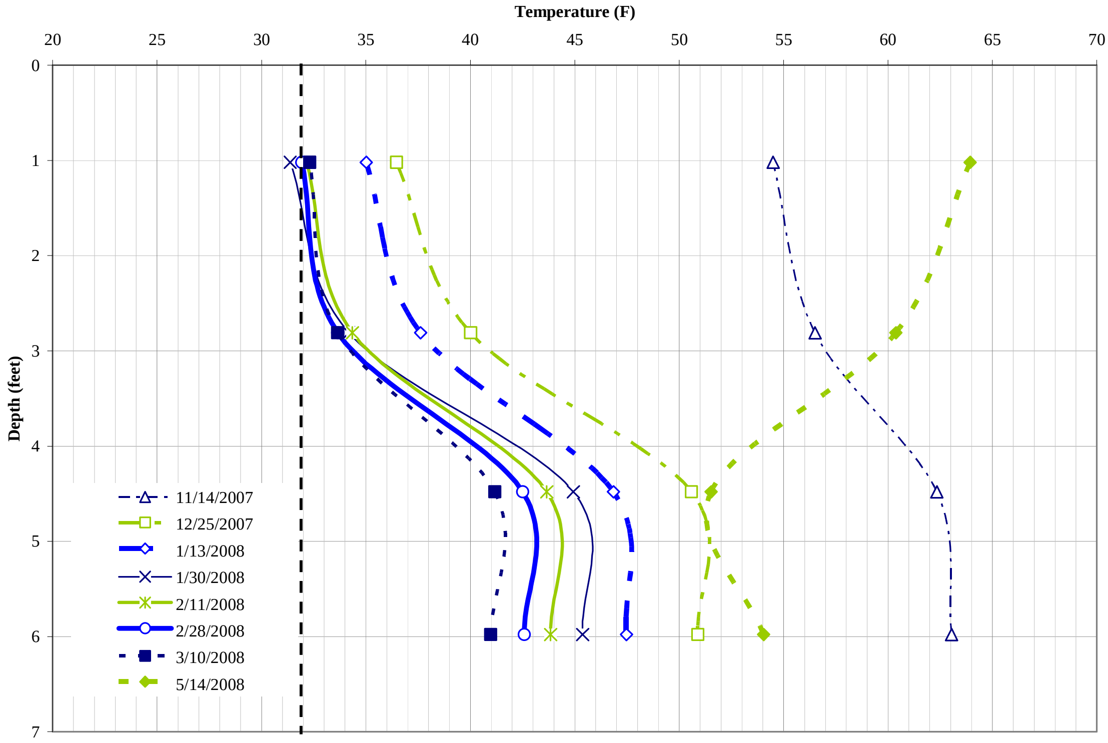


Figure 257 -- Temperature profiles for selected dates (11/14/07, 12/25/07. 1/30/08, 2/10/08, 2/28/08, and 5/14/08) in Trench 1

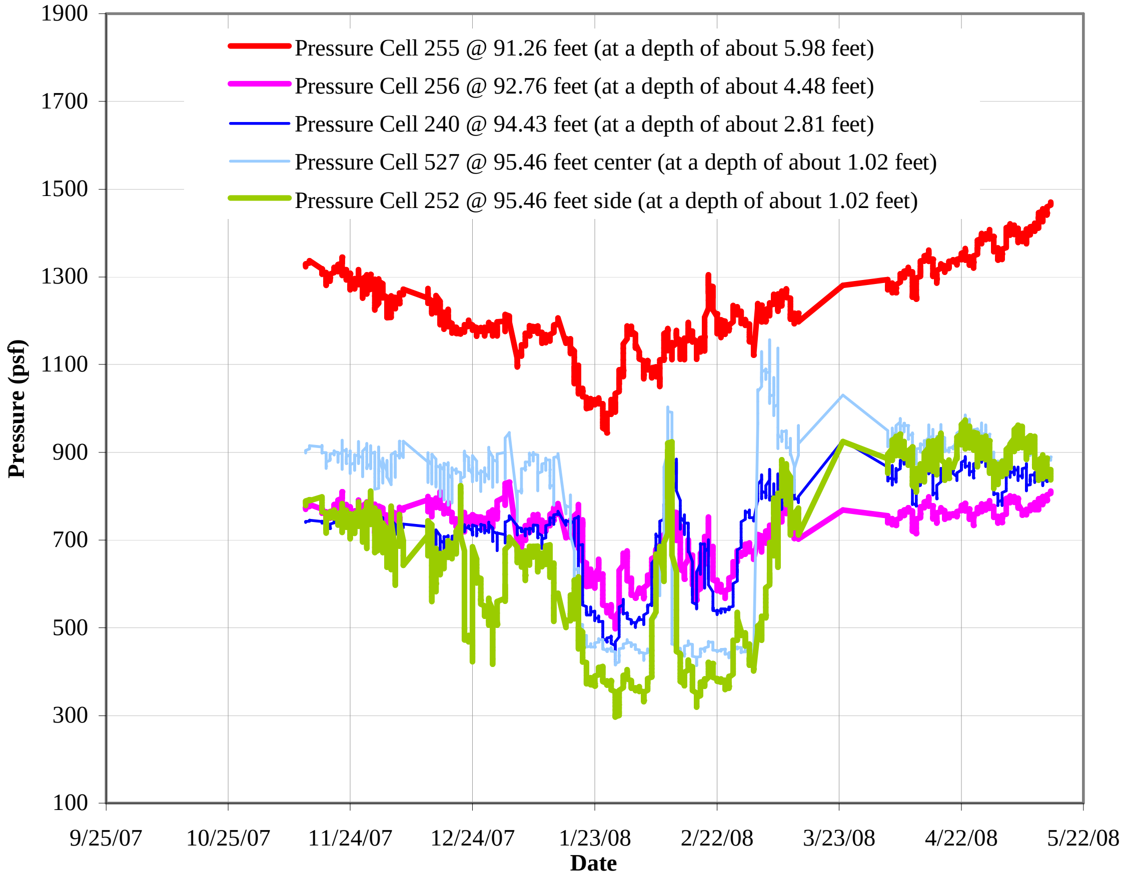


Figure 258 -- Pressure readings for Trench 1

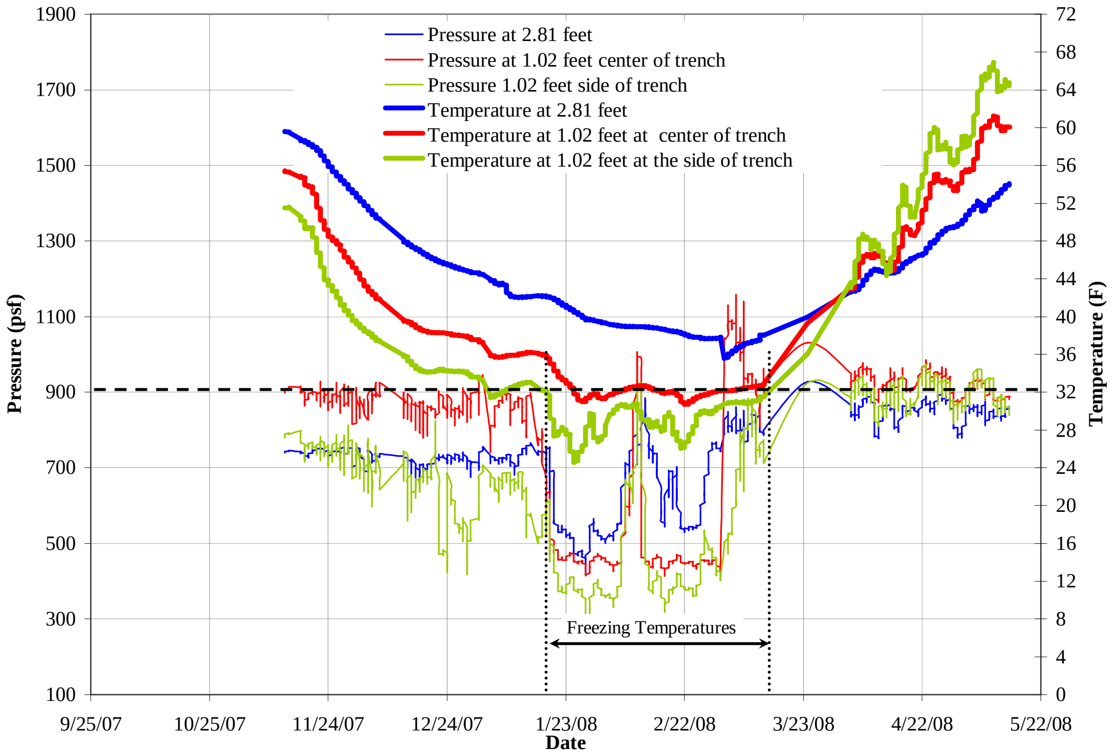


Figure 259-Temperature and pressure comparison for the top lift of Trench 1

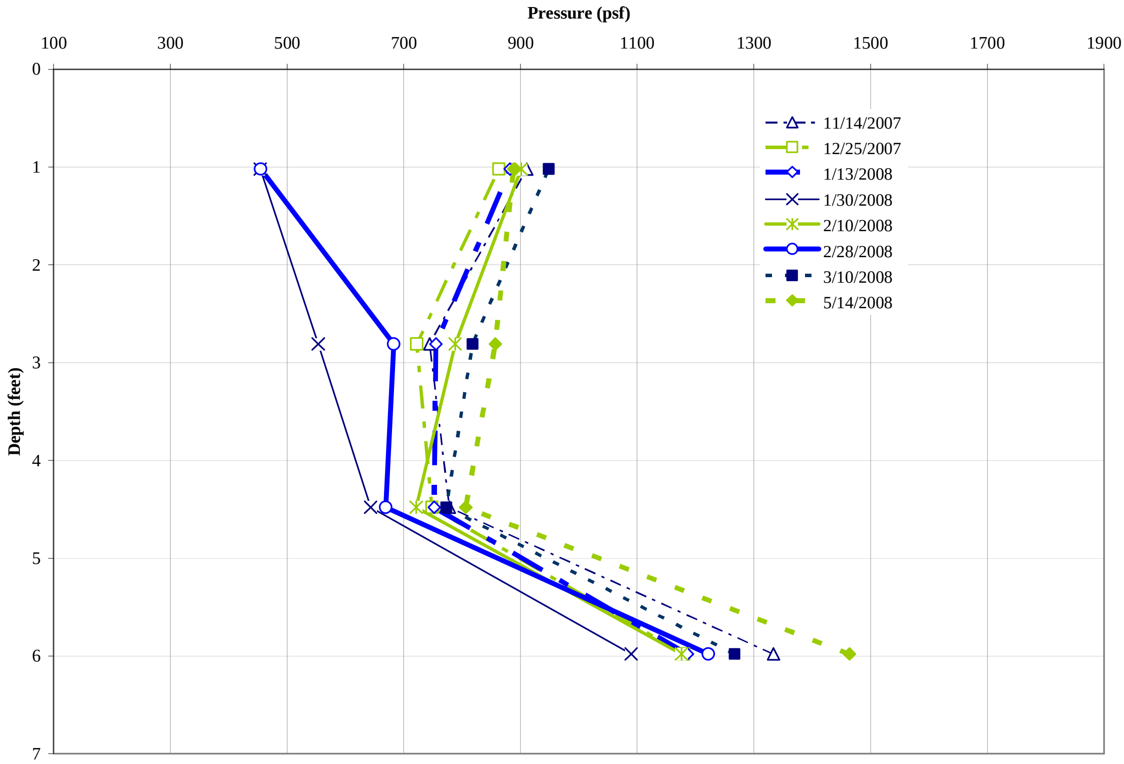


Figure 260-Pressure profiles for selected dates (11/14/07, 12/25/07. 1/30/08, 2/10/08, 2/28/08, and 5/14/08) for Trench 1

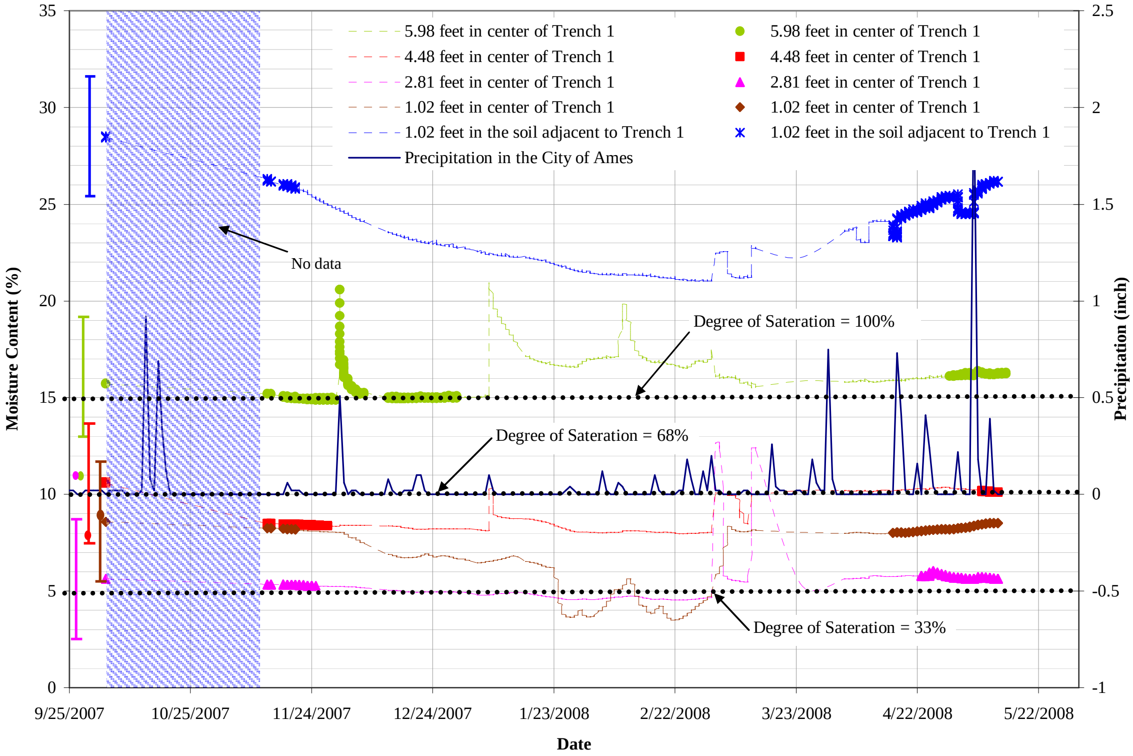


Figure 261 -- Moisture content in Trench 1

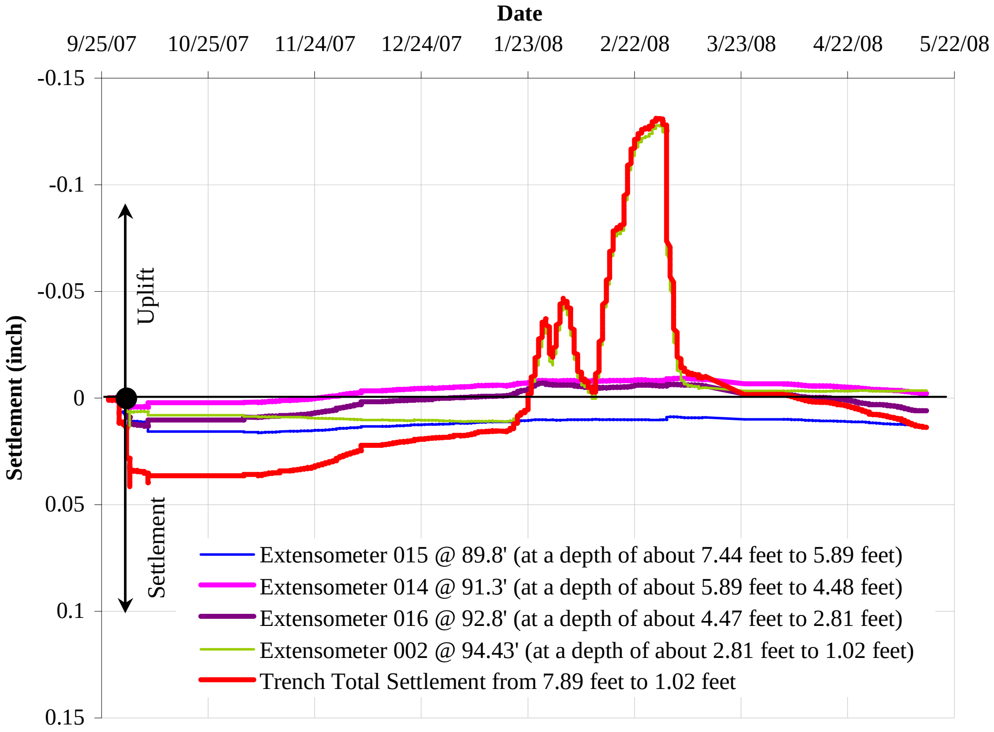


Figure 262 -- Extensometer readings for Trench 1

5.8.3 - Instrumented Trench 2

The temperature readings for Trench 2 are plotted in Figure 263. Figure 264 shows the temperature profiles in Trench 2 for the dates selected in Table 83. The temperatures in the trench followed a similar pattern as the temperature sensors in the soil adjacent to the trench. The figure shows that freezing temperatures in the trench were to a depth of 2.67 feet from January 25, 2008 to February 5, 2008 and February 29, 2008 to March 13, 2008 and at a depth of 1.56 feet in the trench from January 4, 2008 and March 13, 2008. The trench experienced freezing temperatures to a depth greater than the subgrade soil adjacent to the trench. The thermal conductivity of this trench was higher because of the voids in the backfill.

Figure 265 plots the pressure readings for Trench 2. This figure shows that the top pressure cell did not experience decreased and increased pressure, as did the upper pressure cells in Trench 1. However, the pressure cell placed at a depth of about 2.67 feet followed a similar pattern to Trench 1. In Trench 2, the backfill was placed at about 4% relative density. The lower relative density correlates to larger voids in the backfill.

The larger voids caused two things to happen. First, the larger voids in the backfill allowed the ice lens to form without displacing the backfill or causing it to stiffen. Second, the larger voids prevented water from moving to the frozen fringe. These two factors caused the upper lift of the trench to have relative constant pressures through the winter. The constant pressure was contrary to Moser (1990) about pressures in a frozen trench. However, the soil was frozen or just above the frozen fringe during most of the winter. Once the region was above the frozen fringe, no ice lens could form. The pressure cell was then encapsulated by frozen soils. As the frozen fringe migrated downward, there was sufficient void space that the expansion of the soil below did not cause the pressure to increase at the top. This was also reflected in the lack of upper movement in the upper extensometer.

The pressure cell at elevation 2.65 feet below the surface did experience the fluctuation in pressure like those seen in Trench 1. This was caused by the temperature in this region being at or just below the freezing point for several weeks. When the temperature is close to freezing, more ice lens will form. Because the fringe remained below the pressure cell at 1.56 feet but above or at the pressure cell at 2.67 feet for several weeks, larger ice lens in this region formed (see Figure 266). This resulted in the compacted soil between 1.56 feet and 2.67 to become stiffer than the backfill above it and the backfill covering the instrumentation. The pressure cells at 4.45 feet and 6.91 feet also experienced a decrease in pressure because of the frozen fringe being below the upper most pressure cell. The frozen fringe was in the region of the pressure cell at 2.65 feet. The pressure fluctuations at a depth of 2.67 feet can be seen on Figure 267.

Figure 268 shows the moisture contents at various depths in Trench 2. Similar to Trench 1, the moisture contents measured during the field-testing were within the error bars of the moisture sensors at depths of 1.56 feet and 2.57 feet. The lowest moisture sensors had a higher reading than the field-testing point because the backfill was free draining, the surrounding soil was cohesive, and had a lower permeability rate, thus the moisture pooled at the bottom of the trench. The moisture sensor at the bottom of the trench was above 68% saturation for the duration of monitoring. This indicated that water was freely flowing to the bottom of the trench. During the spring, the moisture sensors, recorded rapid fluctuation in the moisture content of the soil. These fluctuations in moisture content correlate to precipitation events in Ames, Iowa.

Trenches 1 and 3 data did not indicate similar fluctuations during the spring. The moisture sensors at depths of 2.67 feet and the moisture sensor at a depth of 1.56 feet did not have these fluctuations in moisture content associated with precipitation. It was hypothesized that the drain tiles that were broken and patched with packaged concrete were acting as conduits to draw water directly into the trench at depths of 2.67 feet and 4.45 feet.

The settlement measurements are shown in Figure 269. The maximum settlement in the trench was 0.67 inches. This settlement occurred after rain infiltrated the trench from around the temporary patch. During the winter, as the frozen fringe penetrated to depths of between 1.56 feet and 2.67 feet, the extensometer spanning these depths experienced uplift. This showed that an ice lens was forming between the two pressure cells. The net movement upward from the frost heave was not sufficient to cause the trench to be in an uplifted state. The elevation survey measured uplift at this trench. However, the extensometers did not account for the movements of the upper most lift of backfill.

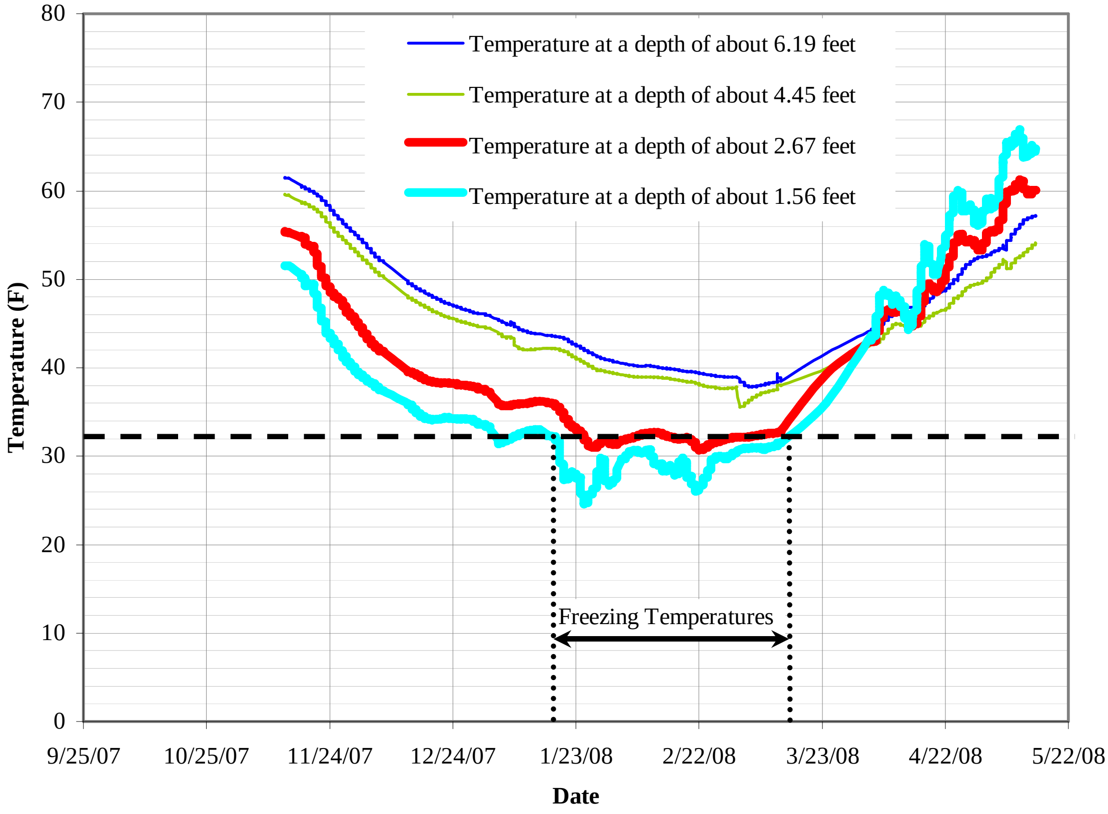


Figure 263 -- Temperature in Trench 2

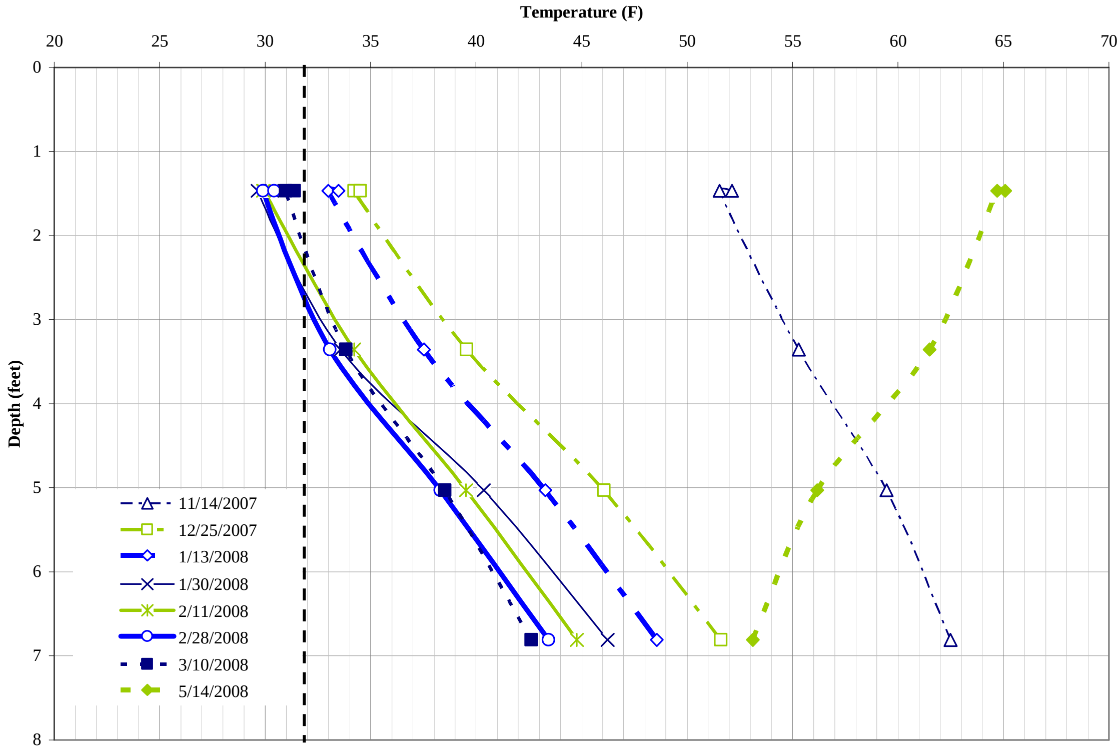


Figure 264 -- Temperature profiles for selected dates in Table 83 for Trench 2

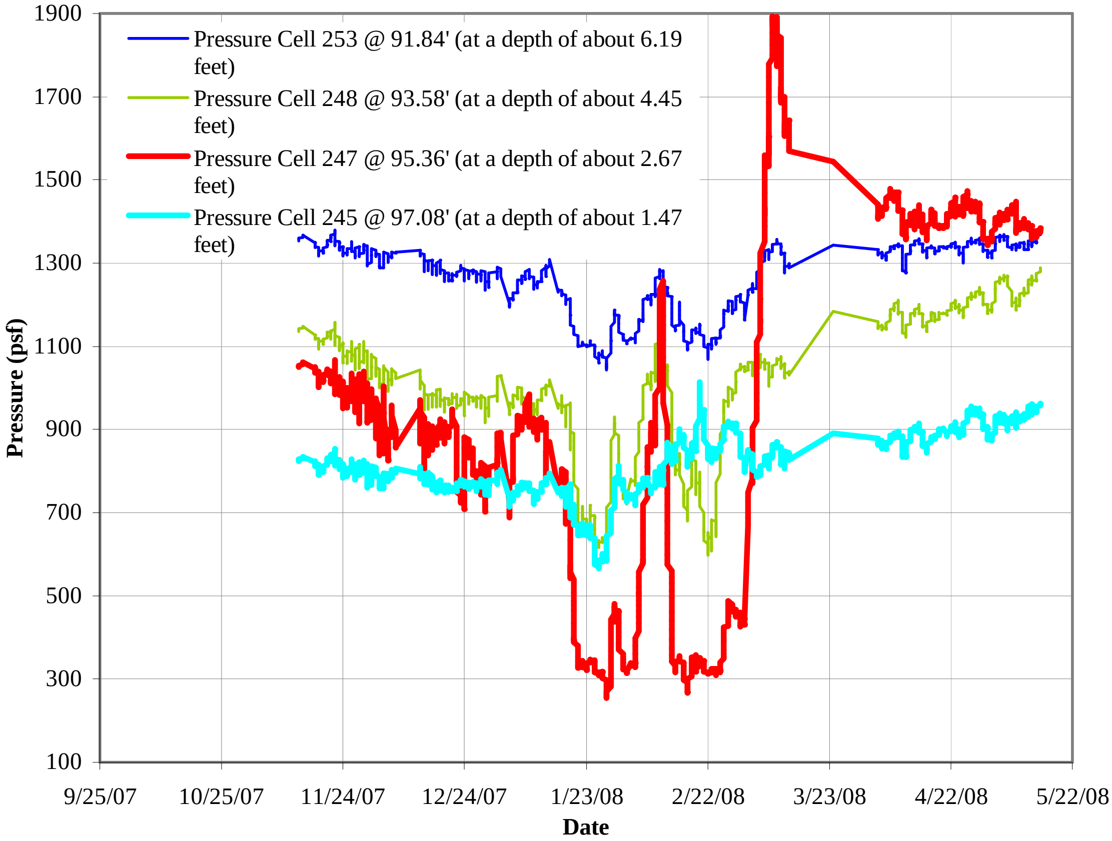


Figure 265 -- Pressures measured in Trench 2

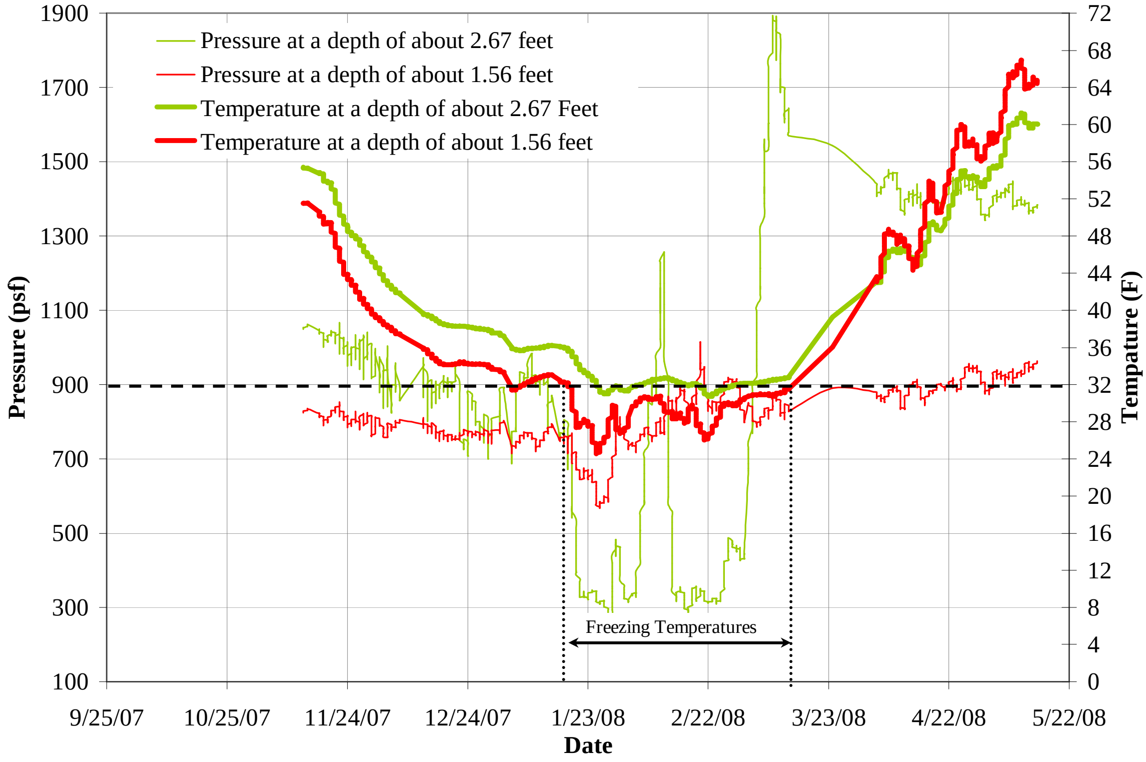


Figure 266 -- Comparison of temperatures and pressures in the upper two lifts of Trench 2

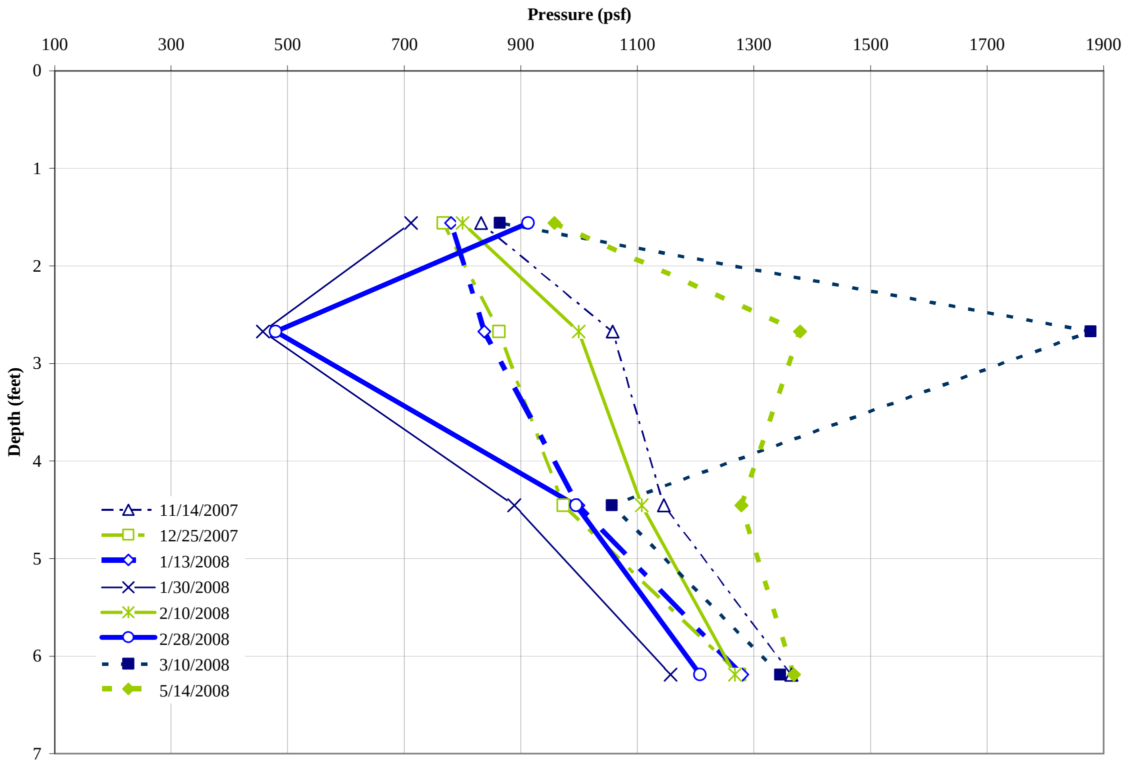


Figure 267 - Pressure profiles for selected dates in Table _ for Trench 2

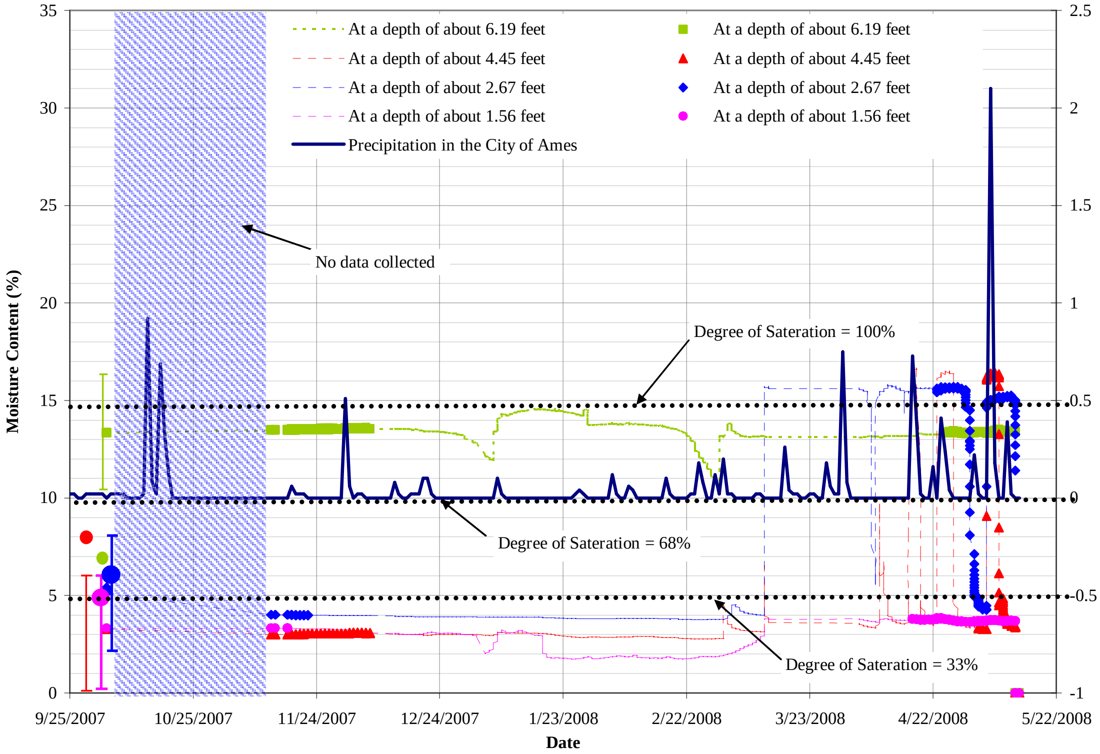


Figure 268 – Moisture content data for Trench 2 with error percent error bars for the instrumentation and results from field-testing results

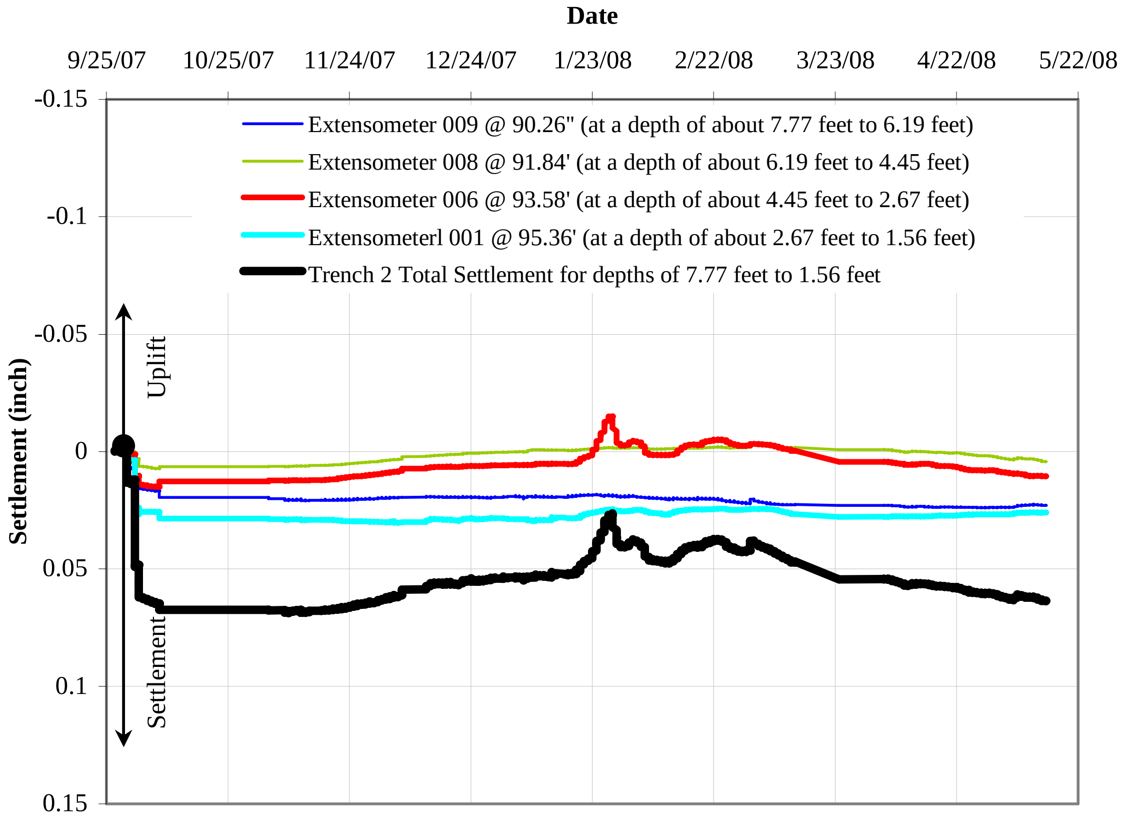


Figure 269 -- Extensometer readings for Trench 2

5.8.4 - Instrumented Trench 3

The temperature readings for Trench 3 are plotted on Figure 270. Figure 271 shows the temperature profile in Trench 3 for the dates selected in Table 83. The temperatures in the trench followed a similar pattern as the temperature sensors in the soil adjacent to the trench. The figure shows that freezing temperatures in the trench went to a depth of 1.37 feet from January 4, 2008 to March 13, 2008 for both the sensors on the side and in the center of the trench. However, based on the temperature profiles, freezing temperatures may have penetrated deeper into the trench (up to 2.8 feet below the surface). The trench experienced freezing temperatures to a depth less than the subgrade soil adjacent to the trench. The temperature profiles were linear, which was expected. The temperatures measured in the T-section and in the center of the trench were similar. This indicates that the pressure cell in the T-section was far enough away from the edge of the trench so that the cohesive soil did not affect its readings.

Figure 272 shows the pressures in Trench 3. Figure 273 shows the pressures compared with the temperatures measured in the trench for the top two lifts. The pressure cells in the middle of the trench experienced the same pattern of pressure increases and decreases as Trench 1. However, the pressure cell in the T-section had the inverse pressure readings during the winter. This resulted because of the T-section being cut into the cohesive material adjacent to the trench. The cohesive material below the T-section had a lower permeability than the granular backfill. This prevented the upward movement of water in this area, which in turned prevented frost from forming and the surrounding soil from stiffening. When comparing the pressure cell in the T-section to the pressure cell in the center of the trench, the pressure cell in the T-section had lower pressure readings than the pressure cell in the center of the trench. This difference was not as large as the difference between pressures in Trench 1. The smaller pressure difference was the result of the pressure cell being placed further away from the edge of the trench than the pressure cell in Trench 1.

Figure 274 shows the pressure profiles for the dates selected in Table 83. This Figure illustrates that during February when the frozen fringe was shifting vertically in the trench, that the pressure profiles were not linear. The upper regions of the trench were affected more than lower regions of trench. This indicates that even though there is a spike in the pressures at the surface, the effect of the spike decreased with depth. This was contrary to Moser (1990) about the pressure increasing on utility cuts because of frost heave.

Figure 275 shows the reading from the moisture sensors. The field-testing results are shown as dots at the beginning of the monitoring period. The difference between the moisture sensor readings was the result of instrument error (moisture sensor and Nuclear Density), infiltration of rain around the temporary patch, and time delay between field-testing and initial readings. As in Trenches 1 and 2, the deepest moisture sensor had the highest values. This indicates that water was freely flowing through the trench and pooling at the bottom of the trench. During the spring, the moisture sensors did not measure variations in the trench despite the rain events in early spring in Ames.

Figure 276 shows the settlement in Trench 3. The initial settlement in Trench 3 was smaller than in the other trenches because less water infiltrated into the trench around the temporary patch. The maximum settlement was 0.02 inches. The maximum uplift in the trench was 0.11 inches. The uplift in the trench was controlled by the upper two extensometers extending from depths of about 5.04 feet to 2.42 feet. This indicated that the frozen fringe extended below a depth 3.36 feet and the frozen fringe caused heave on the extensometer spanning from 5.04 feet to 3.36 feet.

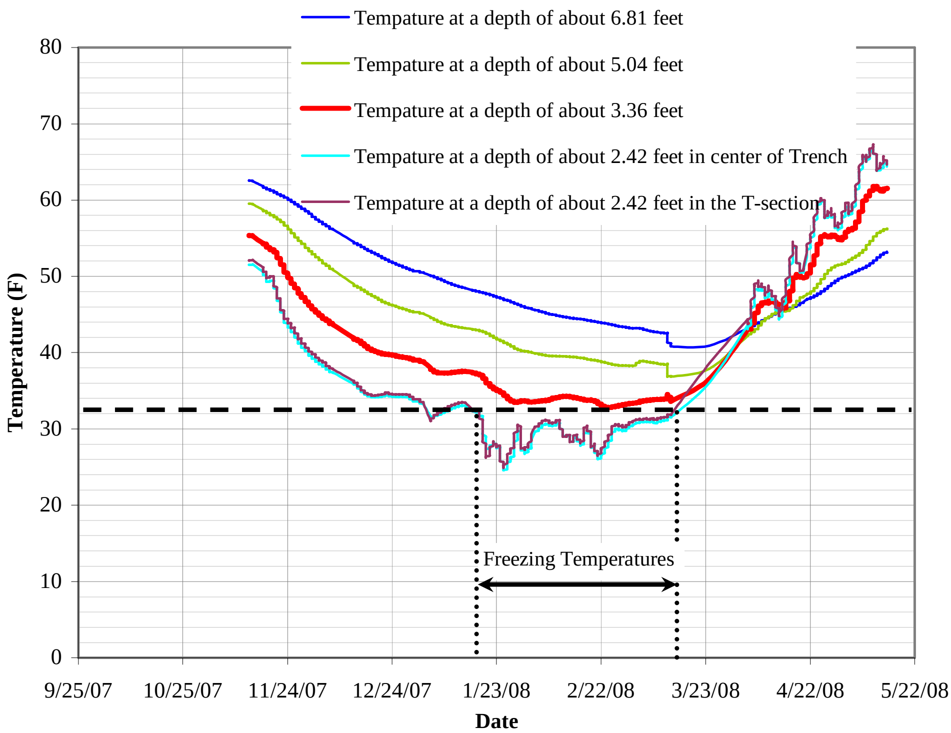


Figure 270 -- Temperatures in Trench 3 at various depths

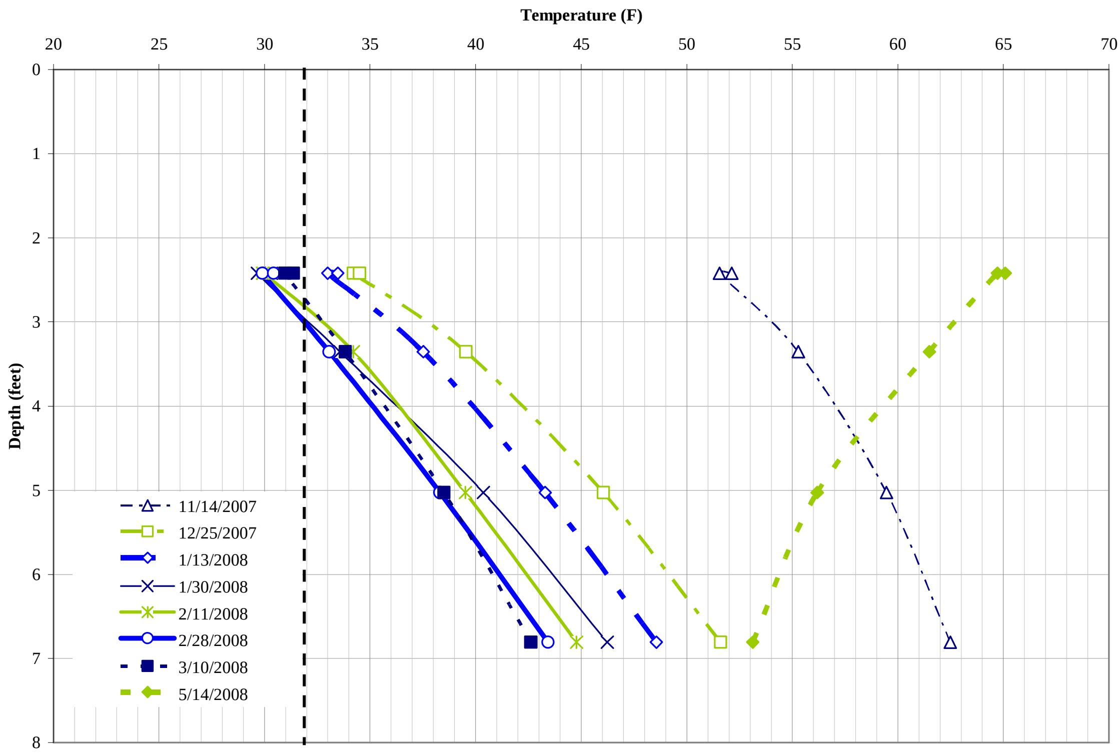


Figure 271 -- Temperature profiles for selected dates in Table 83 for Trench 3

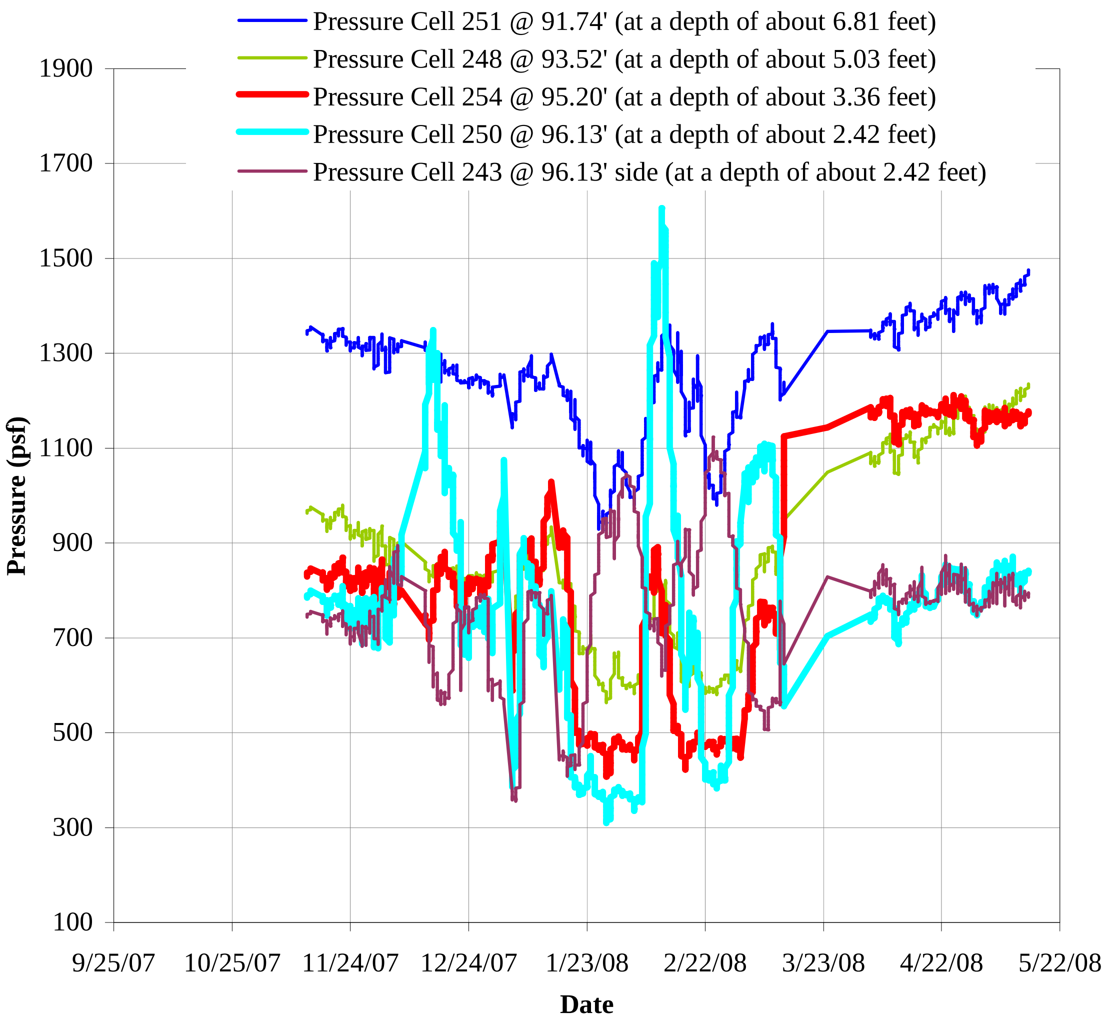


Figure 272 -- Pressures in Trench 3

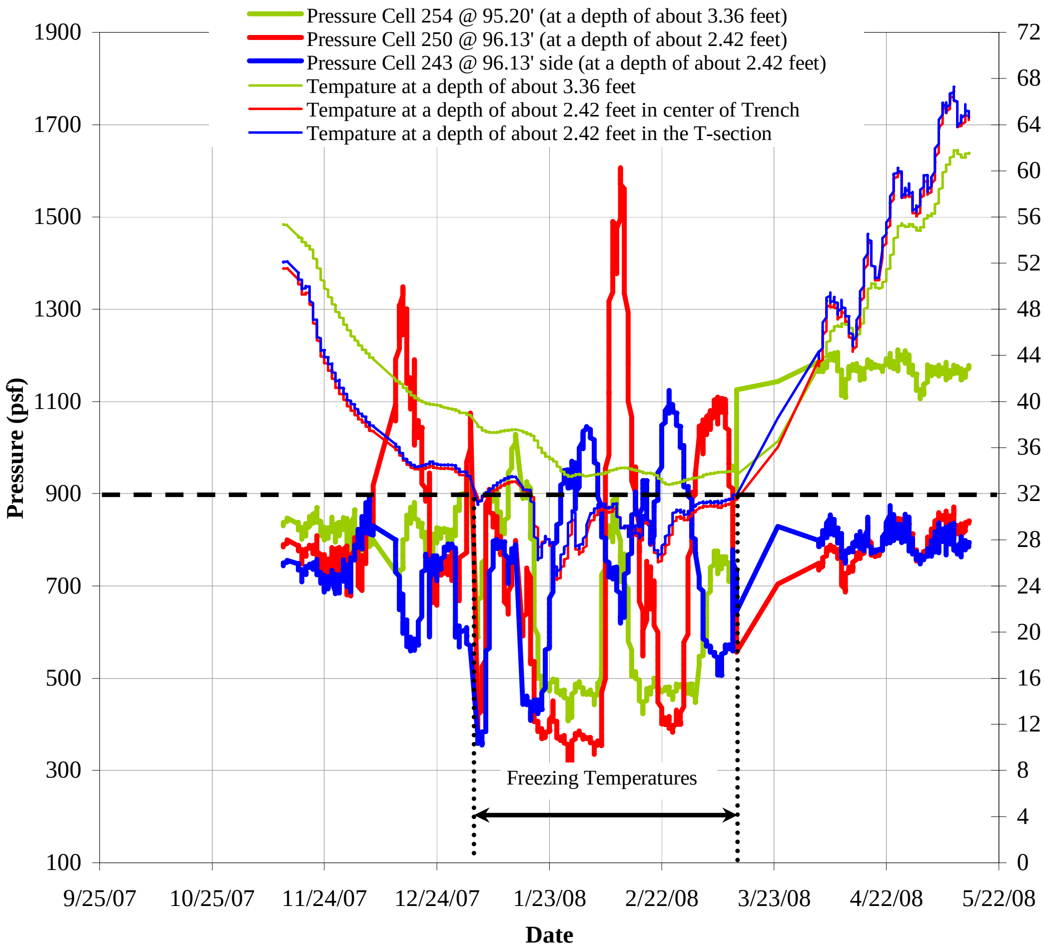


Figure 273 -- Pressure and Temperature readings for the top two lifts in Trench 3

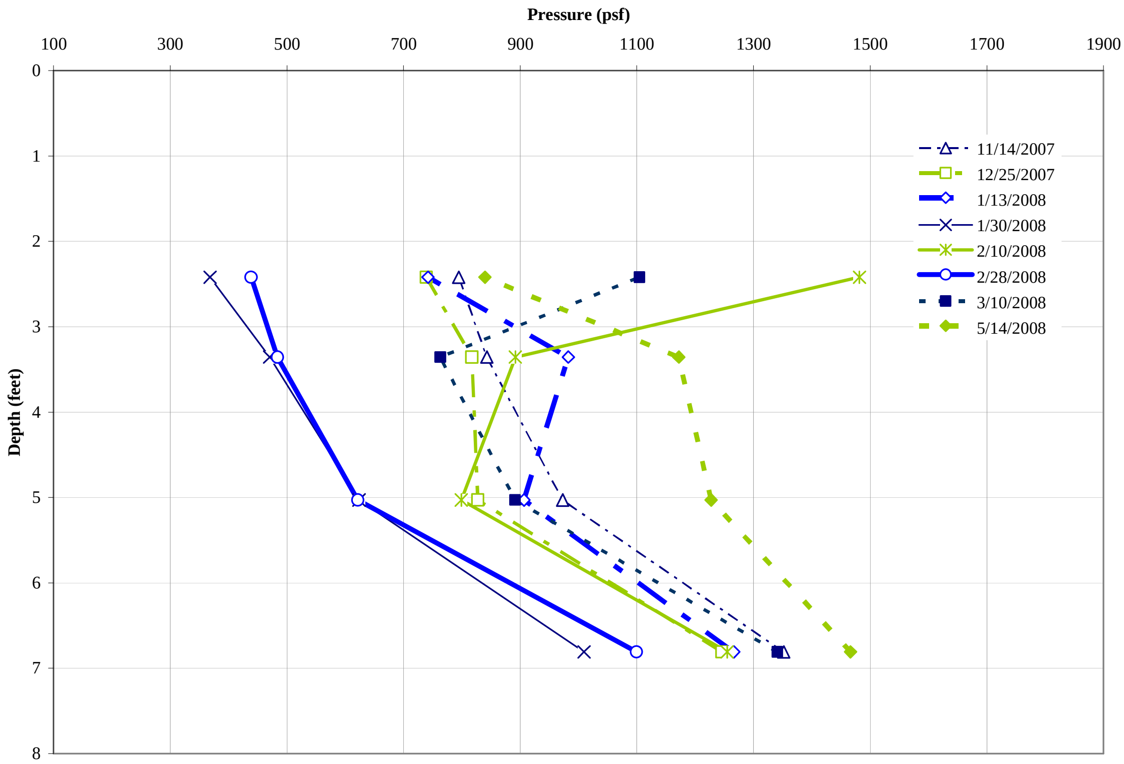


Figure 274 - Pressure profiles for selected dates in Table 83 for Trench 3

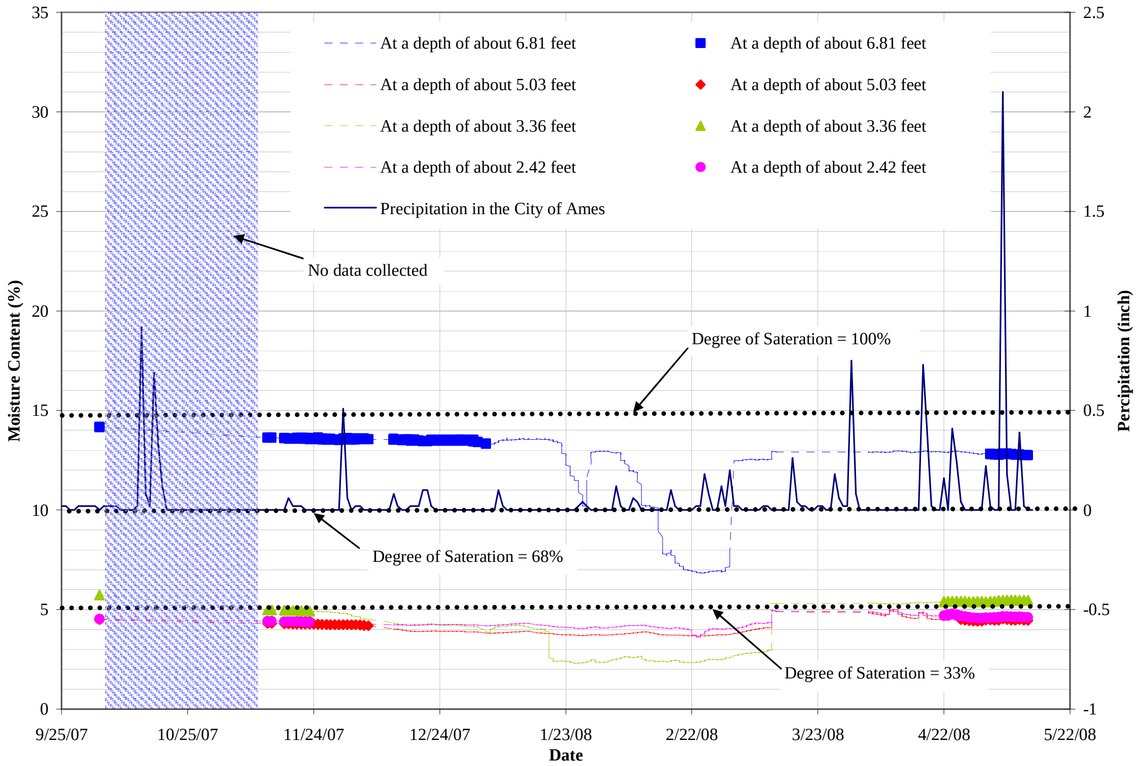


Figure 275 - Moisture date for Trench 3 with percent error bars for the instrumentaiton and the field-testing results

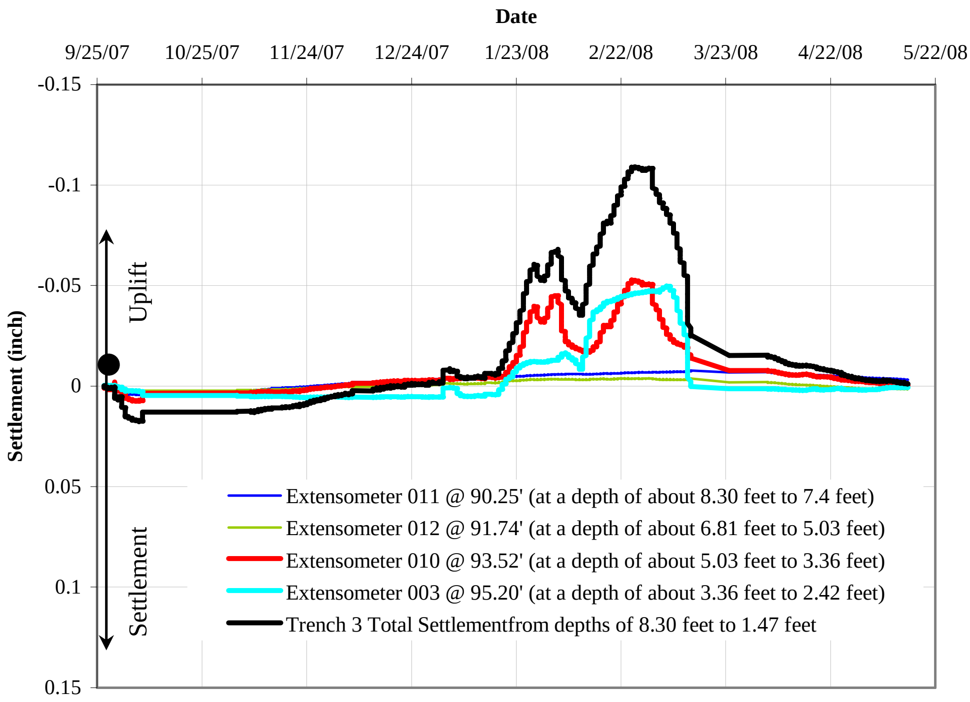


Figure 276 -- Extensometer reading for Trench 3

5.8.5 - Comparison of Instrumented Trenches

Figure 277 shows the pressures in the center of the top lifts of the trenches. Trench 3 experienced the largest pressure change when the frozen fringe migrated in February. Trench 2 the upper lifts did not show same pressure changes as Trenches 1 and 3 because instrumentation it was above the frozen fringe for the duration of the winter. During non-freezing temperatures, the readings are similar.

Figure 278 shows the pressure readings from the side of Trench 1 and the T-section in Trench 3. This shows that in the T-section the pressures were not affected by the stiffening of the cohesive materials adjacent to the trench like the pressure cell in Trench 1.

Figure 279 shows the total settlements for all three trenches. Trench 1 had the largest uplifts during the winter. This was a result of the Trench 1 being placed at the highest relative density. Because the backfill had silts in it, the higher relative density resulted in smaller voids that were most susceptible to frost heave. Trench 2 had the greatest settlements. This was the result of the backfill being at the lowest relative density. This caused the backfill to collapse when water infiltrated into the trench.

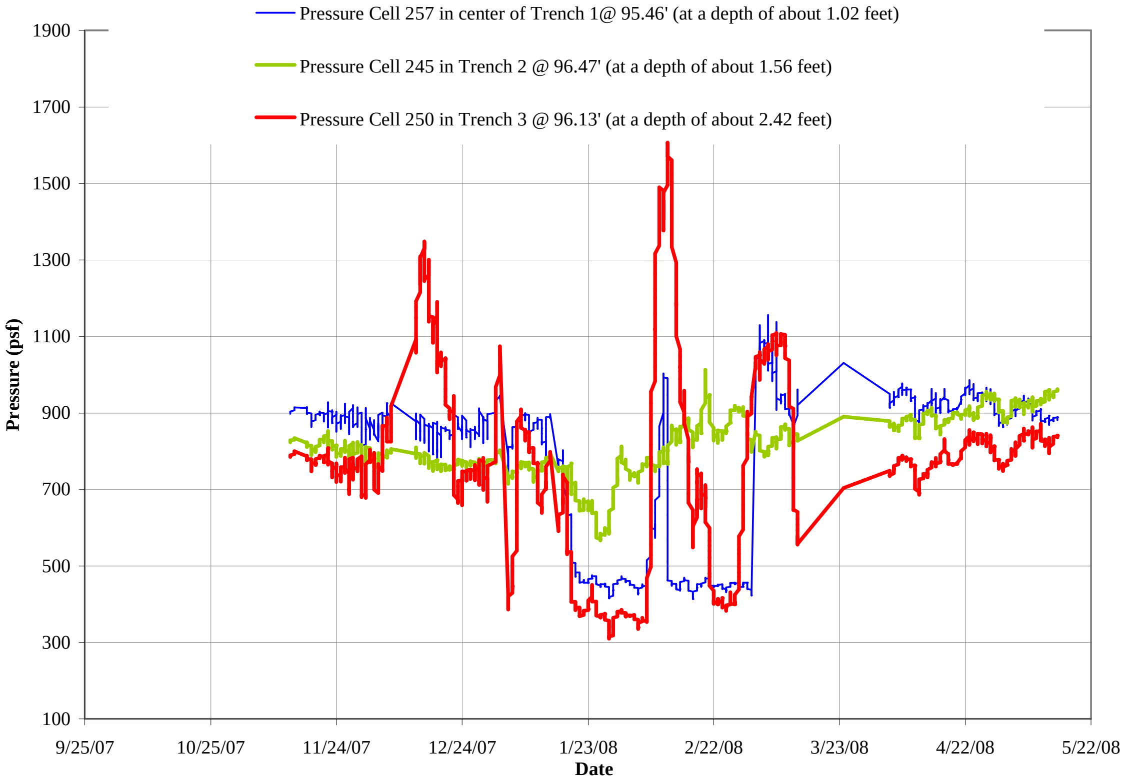


Figure 277 - Pressures in the center of the top lift with instrumentation of the Instrumented Trenches

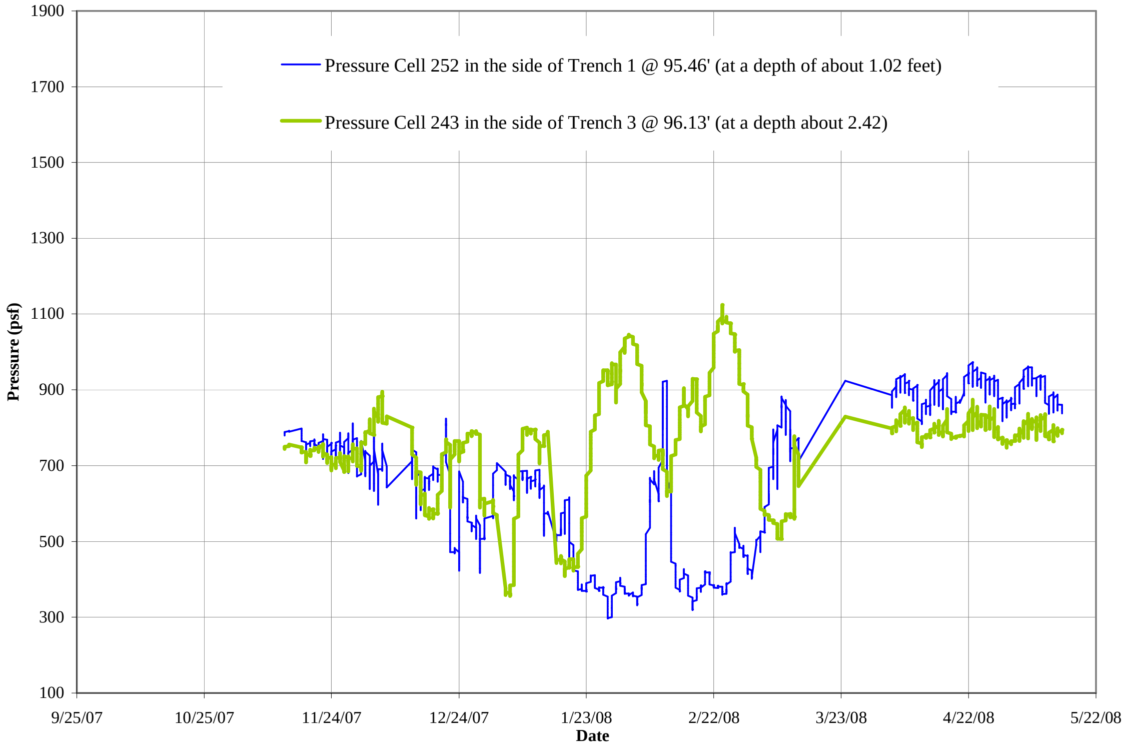


Figure 278 - Pressures in the side of Trenches 1 and 3 for the upper-instrumented lifts

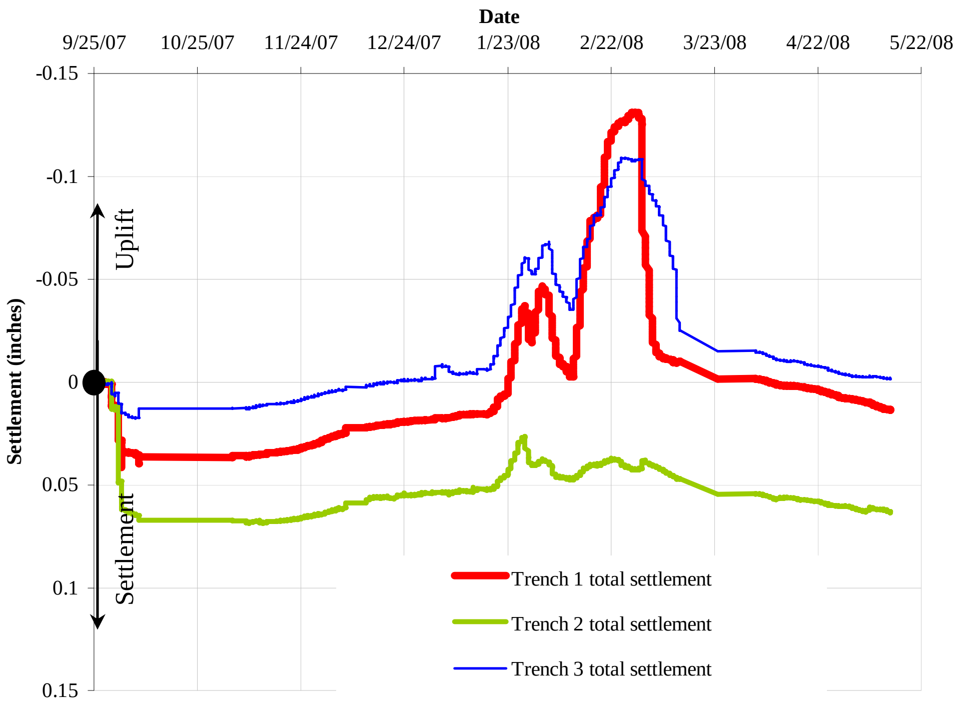


Figure 279 - Total settlements measured in each trench

5.9 - Summary of Results and Discussion

The followings are the findings from the three-instrumented trenches:

- After the trenches were constructed, water infiltrated into the trenches around the temporary patch causing the backfill to collapse. The largest collapse occurred in Trench 2, where the backfill was placed at the lowest relative density and at moisture content within the range of bulking moisture content. Trench 1 had the second largest collapse even though it had a higher relative density than Trench 3. This occurred because, during the rain event, water drained around Trench 3 rather than over the trench, like Trench 1. Also, the collapse in Trench 3 was smaller than in Trench 1 because as the water entered the utility cut, the T-section helped to keep the water from affecting the center of the trench where the extensometers were located.
- 3/8 inch minus backfill is susceptible to collapse behavior as shown in the laboratory testing results and results from the instrumented trenches
- 3/8 inch minus backfill material is susceptible to frost heave potential as shown by the heave in Trenches 1 and 3 during the winter
- The measured frost heaves occurred where the frozen fringe was located (at about 32 degrees Fahrenheit). In Trench 2, the frozen fringe was located below the uppermost pressure cell and at the bottom of the uppermost extensometer. This resulted in the pressure cell and the extensometer moving as a unit within the upper region of frozen backfill and thus, not measuring changes in pressures and uplift movements.
- When frost was present in the trenches the pressures in the top of the trenches increased when the frozen fringe mirage in February. The increase in pressures was measured deeper into the trenches. However, this pressure increase did not double the pressure in the bottom of the trench as Moser (1990) stated.
- When there was frost in the trenches, the extensometers measured uplift in the trenches. In Trenches 1, and 3 the maximum uplift was experienced in the lift

and Trench 2 experienced uplift in lift second from the top surface; however, the trench's overall settlement was still downward. In Trench 2, the greatest increase in pressure during the winter months was experienced in the second lift from the surface.

- After the trench construction, water infiltrated into the trenches from around the temporary patch and caused initial settlements. Trench 2, which was placed at the lowest relative densities, experienced the greatest settlements when the water infiltrated. Trenches 1 and 3 experienced uplift during the winter months. Trench 3, which was placed at the highest dry unit weights, experienced the smallest settlements and uplifts.

5.10 - Conclusions

Based on the field-testing results, continued monitoring, and measurements with the instruments the following conclusions can be draw:

- 3/8 inch minus backfill exhibits collapse behavior when wetted, as seen when water infiltrated around the temporary patch into the trenches and is frost susceptible and undergoes heave during freezing conditions. 3/8 inch minus limestone is not an acceptable backfill material.
- Trench 3 was the best performing trench. Placing the backfill with moisture control decreased the settlement and uplift. The FWD testing showed that Trench 3 provided the stiffest response. Constructing the T-section reduced the effects of the "zone of influence" next to the trench.
- Temperature sensors installed in the soil adjacent to the trench, confirmed that cohesive soils have higher thermal conductivity than granular soils used in trenches. This caused pressure and temperature gradients in the trenches from the edges to the center.
- Pressure measured in the trenches did not confirm Moser's theory that frost heave cause the pressures in trenches to double. Rather, as the frozen fringe migrated downward, the voids above the frozen fringe were sufficient to prevent the build-up of pressures. However, during the next frost cycle, the trenches will have undergone more settlement, the voids spaces will be

smaller, and pressure could increase. The pressure readings in the trench during the winter were affected by the installation process. As the trench settles, the errors in the pressure cell will decrease.

- The extensometers and pressure cells were able to detect the movement of the frozen fringe within the trenches; however, the exact location of the fringe could not be determined with the current instrumentation arrangement.
- The moisture sensors in the trenches were operating below the design operation temperatures during most of the monitoring. The moisture sensors did show that the cohesive soils adjacent to the trench had higher moisture contents than the granular backfill. The sensors also showed that water was pooling in the bottom of the trenches.

CHAPTER 6.0 - CONCLUSIONS AND RECOMMENDATIONS

Based on the continued monitoring of the trenches constructed during Phase I (Section 3.0), the six recommended trenches during Phase II (Section 4.0), and the three-instrumented trenches constructed during Phase II (Section 5.0) the following conclusions and recommendations can be made:

6.1.1 - Material Selection

- 3/8 inch minus backfill is not an acceptable backfill material, it exhibits collapse behavior when wetted, as seen when water infiltrated around the temporary patch into the trenches, and is frost susceptible, and undergoes heave during freezing conditions as shown in Trenches 1 and 3 where the backfill was placed with moisture control and proper compaction techniques.
- Soils containing silt-sized particles are most susceptible to frost heave.
- 1-inch clean limestone or other clean backfill with limited fines do not experience collapse and are least susceptible to frost-heave. The use of 1-inch clean limestone improved the performance of the trenches. It stiffened the response of the trench in FWD testing and the settlement within the trench is less than in trenches constructed with 3/8-inch minus limestone.
- Soils excavated from the trenches could be mixed with granular backfill if laboratory tests indicating the range of moisture content and densities that the material need to be placed at were conducted and appropriate quality control measures are used. Mixing a cohesive material and the granular backfill reduces the moisture content. The soils were placed at moisture contents that were below optimum moisture content.

6.1.2 - Construction Practices

- The use of a concrete patch with dowels performed the best over the long-term. This was documented with the Des Moines trench patch.
- Pavement should be removed from four feet around the perimeter of the trench and the area should be re-compacted if a T-section is not constructed. This is supported by the results in Trench A.

- The T-section did not abate the “zone of influence” on the trenches. Rather, the “zone of influence” moved outside of the T-section for all trenches, except Trench E where “the zone of influence” was evident on only one side of the T section.
- The T-section did not reduce the settlement in the trenches. The trenches without the T-section (Trenches A and D) performed better. During the construction of the T-section, a larger area of the street was disturbed and a large volume of backfill had to be evenly compacted. Because there was no quality management of the placement of the backfill to ensure that it was compacted to appropriate relative densities across the trenches, uneven settlements occurred.
- Another reason for the poor performance of the T-sections trenches could be the result of mixing the limestone backfills with other soils.
- The increased effort and resources used to construct the T-section trenches did not yield better trench performance.
- The T-section could be modified to use walls that are beveled outward to facilitate compaction of backfill. Beveled edges may reduce the amount of disturbance to the surrounding soil and eliminate the vertical excavation, however, it may make compacting the backfill at the edges difficult. This is expected to prevent the “zone of influence” from migrating outside of the T-section.
- Construction equipment should be kept away from the edges of the trench. FWD testing on the Cedar Rapids trench showed that damage caused by equipment during construction had a long-term impact on the performance of the trench.
- The FWD tests showed similar response of the trenches based on the season of the tests. According to the literature reviewed, this was the result of differences in the moisture content and stiffness of the soil during the spring and fall (Andersland and Landanyi 2004).
- The use of geogrid in the trenches did not improve the performance of the trenches compared to the trenches constructed without the geogrid for the trenches using 3/8-inch minus limestone. The geogrid appears to have stiffened the response of the trench based on FWD testing; however, it did not reduce settlement in the trenches.
- Cities should implement moisture control practices.

Quality Management

- Quality control measures should be implemented in the field to ensure that compaction requirements are met. This includes achieving at least medium to dense relative density with moisture contents above the bulking moisture content for cohesionless soils and above 95% of Standard Proctor and +/- 2% of optimum moisture content for cohesive soils.
- An educational program should be established to educate city maintenance crews of the importance of proper construction practices. Based on the experience with the City of Ames, a program including demonstrations will help solidify the importance of moisture control during the construction of trenches.

6.1.3 - Future Research Needs

- Reconstruct the T-section trenches with 1-inch clean backfill. Several T-sections should be constructed to permit evaluating the performance of the trenches. (i.e. ensure that each lift is placed with moisture control at the appropriate relative density for the backfill being used).
- Construct trenches with a beveled cross section at the top to facilitate the compaction of the backfill at the perimeter of the trench.
- Continue FWD testing on the trenches.
- Continue to monitor the settlement of the trenches.
- Continue to monitor the instrumented trenches.

APPENDIX A.0 LABORATORY TESTING RESULTS

APPENDIX A.0 – LABORATORY TESTING RESULTS

A.1 - Primary Backfills

A.1.1 - Trench A and B and Instrumented Trenches 3/8 inch minus limestone

Classification

Liquid Limit	n/a
Plastic Limit	n/a
Plastic Index	n/a

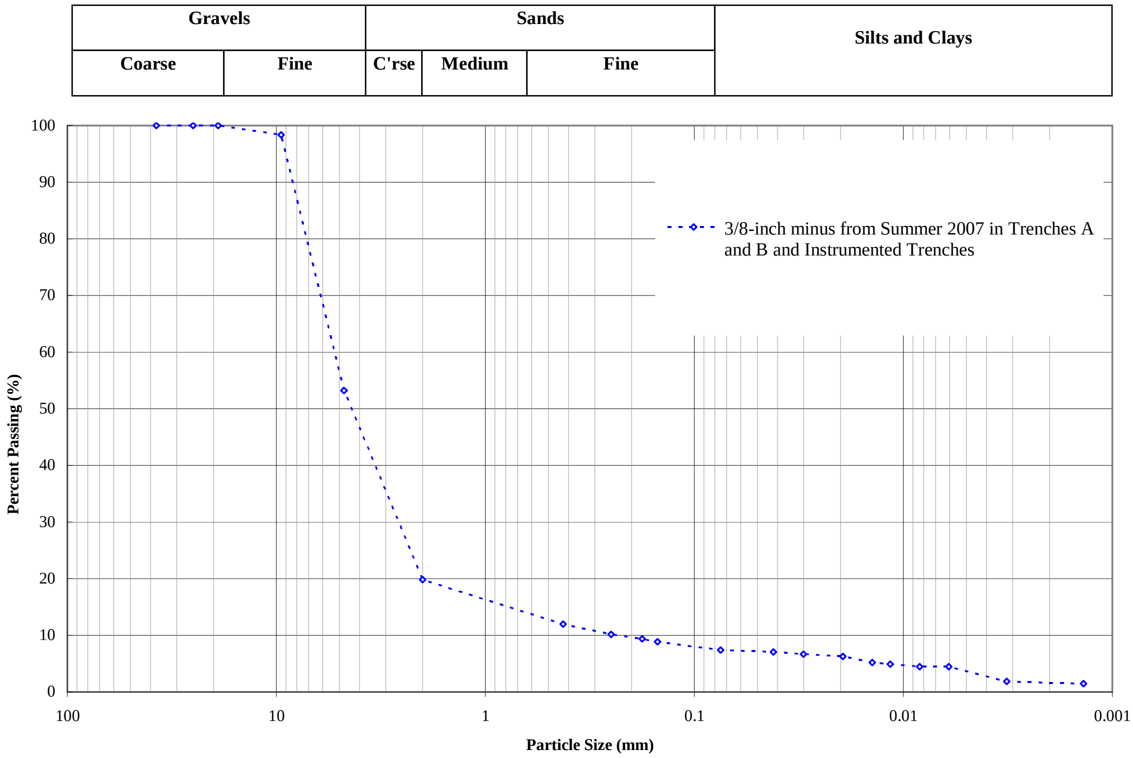


Figure A 1 -- Gradation curve for 3/8 inch minus limestone used in Trenches A, and B and the Instrumented Trenches

Percent Passing #4	53.21%
Percent Passing #10	19.84%
Percent Passing #40	11.97%
Percent Passing #200	8.83%

D60	5.445
D30	2.84
D10	0.24
CU	22.69

Cc	6.17
USCS Soil Classification	SP-SM Poorly grade sand with silts
AASHTO Soil Classification	A-1-a Stone fragments, gravel and sand

Standard Proctor Test Results

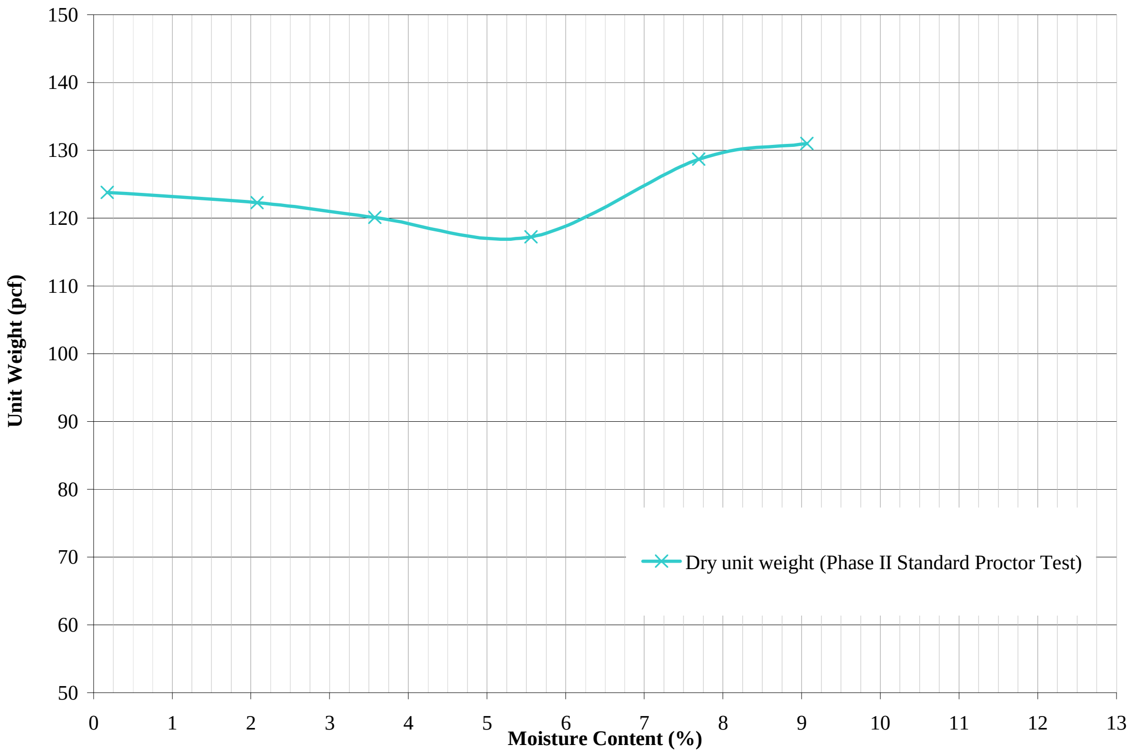


Figure A 2 -- Standard Proctor test results for 3/8 inch minus limestone used in Trenches A, and B and the Instrumented Trenches

Relative Density Test Results

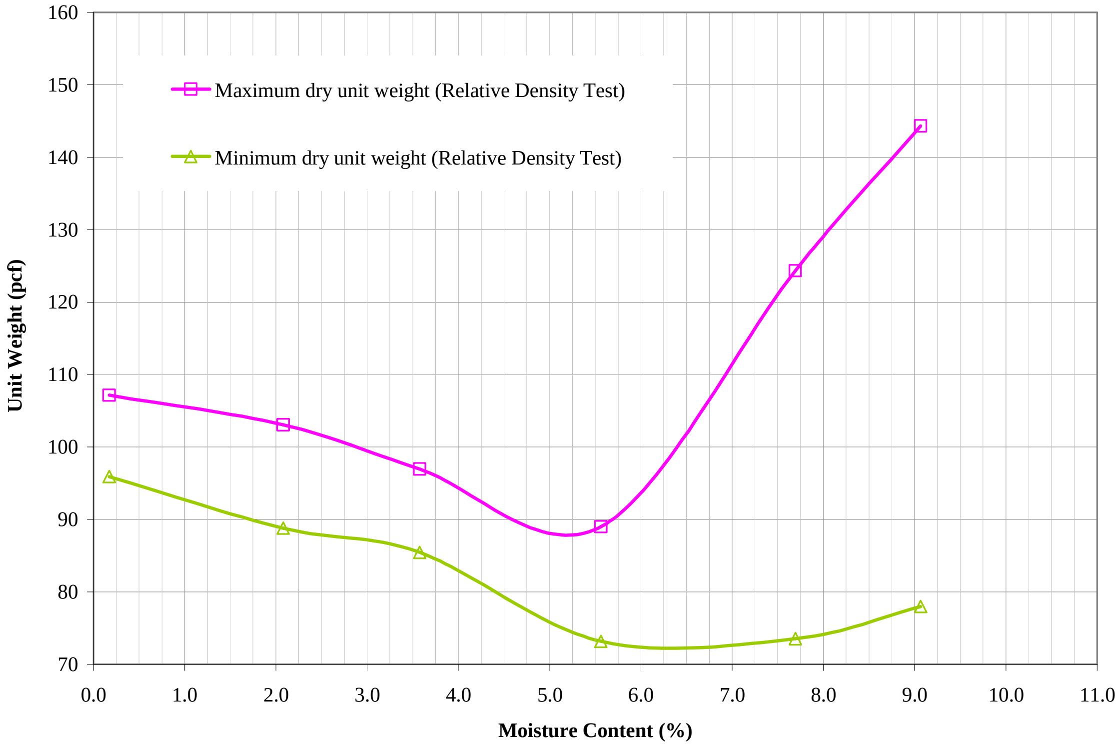


Figure A 3 -- Relative Density test results for3/8 inch minus limestone used in Trenches A, and B and the Instrumented Trenches

Note: These results were not used in the body of the thesis

A.1.2 - Trench D 1-inch clean limestone

Classification

Liquid Limit	n/a
Plastic Limit	n/a
Plastic Index	n/a

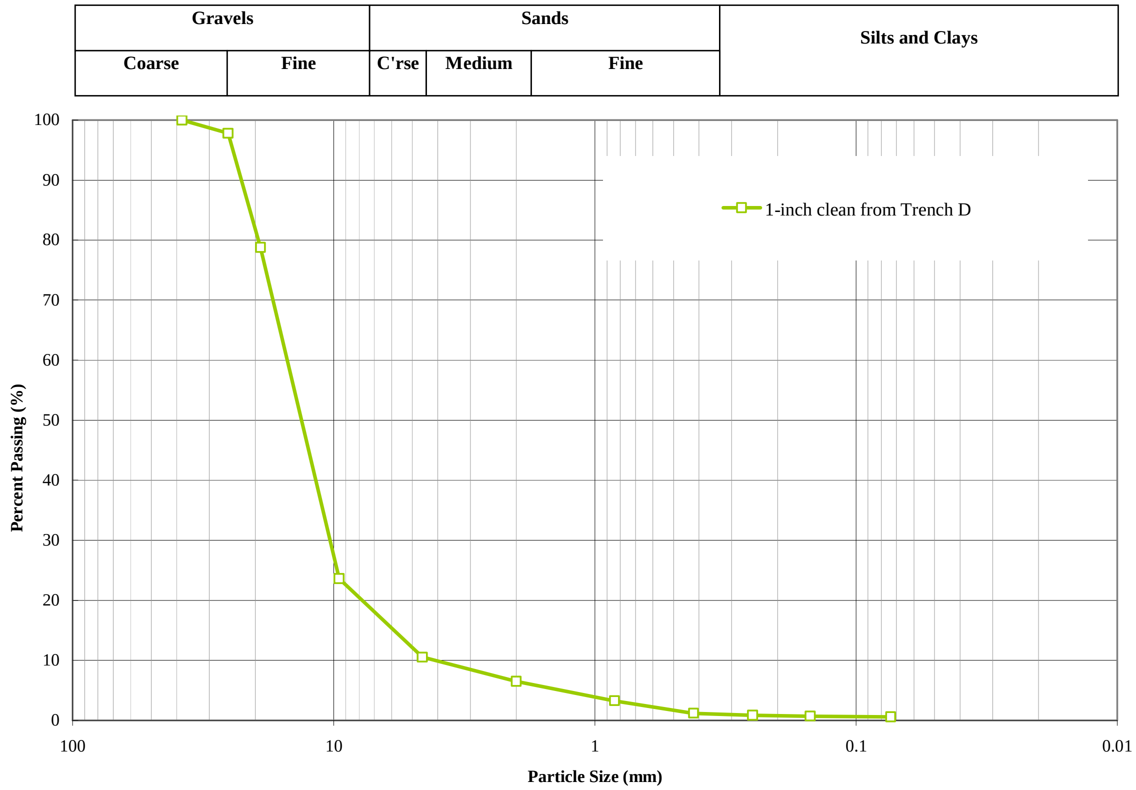


Figure A 4 -- Gradation curve for 1-inch clean limestone used in Trenches E, and F

Percent Passing #4	10.53%
Percent Passing #10	8.33%
Percent Passing #40	1.17%
Percent Passing #200	0.61%
D60	15.7
D30	10.75
D10	4.3
CU	3.65
Cc	1.7
USCS Soil Classification	GP- Poorly graded gravel
AASHTO Soil Classification	A-1-a Stone fragments, gravel and sand

Standard Proctor Test Results

Not available

Relative Density Test Results

N/A

A.1.3 - Trench E and F 1-inch clean limestone

Classification

Liquid Limit	n/a
Plastic Limit	n/a
Plastic Index	n/a

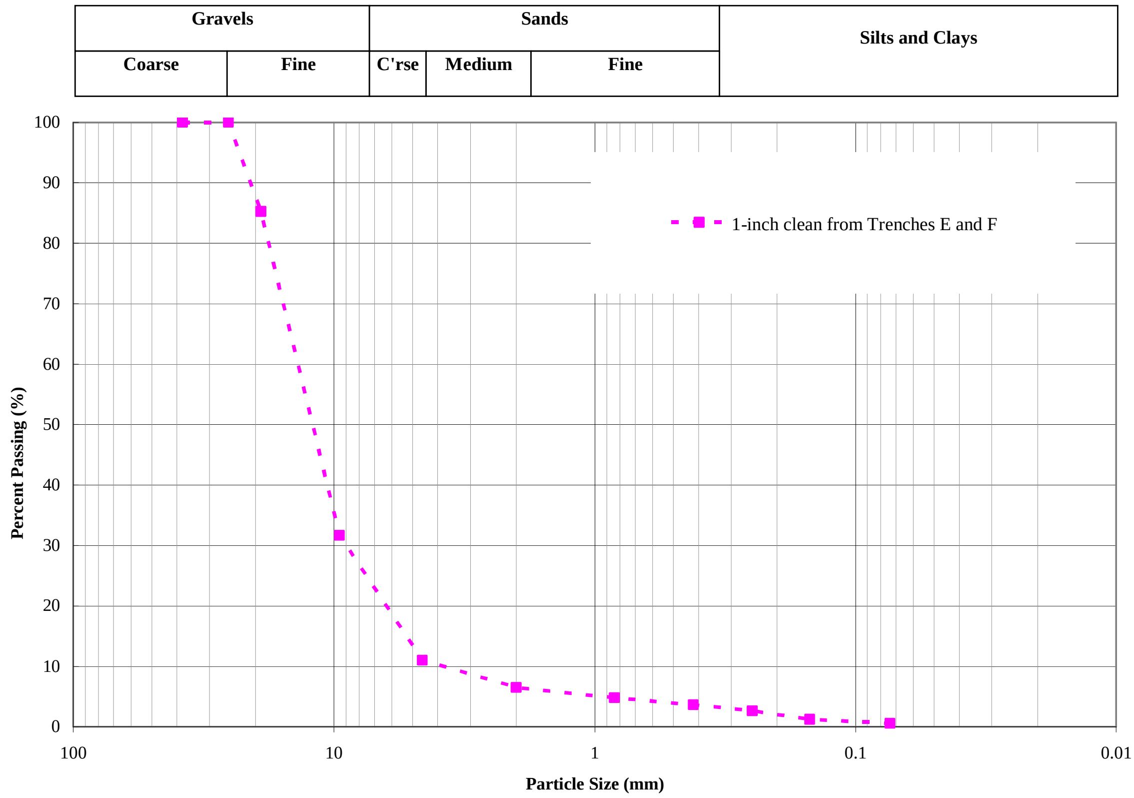


Figure A 5 -- Gradation curve for 1-inch clean limestone used in Trenches E, and F

Percent Passing #4	14.4%
Percent Passing #10	9.2%
Percent Passing #40	3.63%
Percent Passing #200	0.59%
D60	14.4
D30	9.2
D10	4.26
CU	3.38
Cc	1.38
USCS Soil Classification	GP- Poorly graded gravel
AASHTO Soil Classification	A-1-a Stone fragments, gravel and sand

Standard Proctor Test Results
Not available

Relative Density Test Results
N/A

A.2 - Secondary Backfills

A.2.1 - Trench B Backfill No. 1

Classification

Liquid Limit 39
Plastic Limit 18
Plastic Index 21

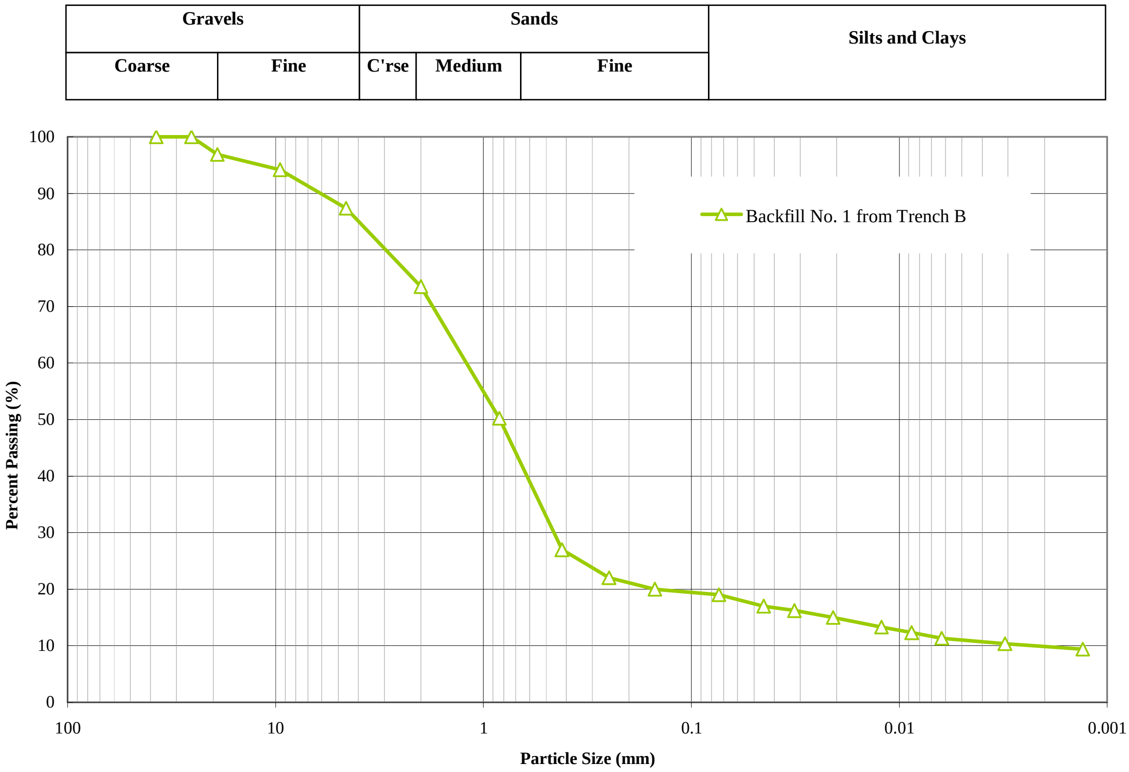


Figure A 6 -- Gradation curve for Trench B Backfill No. 1

Percent Passing #4 79.0%
Percent Passing #10 73.5%
Percent Passing #40 26.4%
Percent Passing #200 16.01%
D60 1.1
D30 0.484
D10 0.005
CU 220
Cc 42.6
USCS Soil Classification SC – Clayey Sand
AASHTO Soil Classification A-2-6 Silty and Clayey gravel and sand

Standard Proctor Test Results

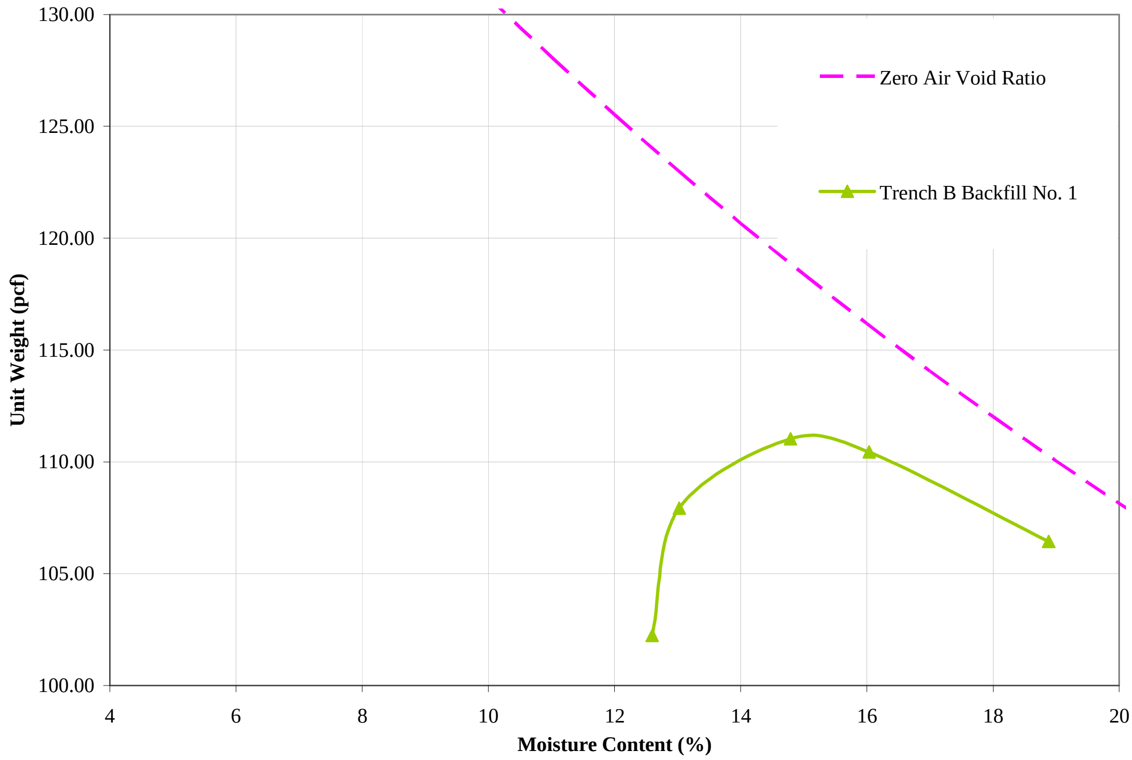


Figure A 7 -- Standard Proctor test results for Trench B Backfill No. 1

Relative Density Test Results

N/A

A.2.2 - Trench B Backfill No. 2

Classification

Liquid Limit	48
Plastic Limit	20
Plastic Index	28

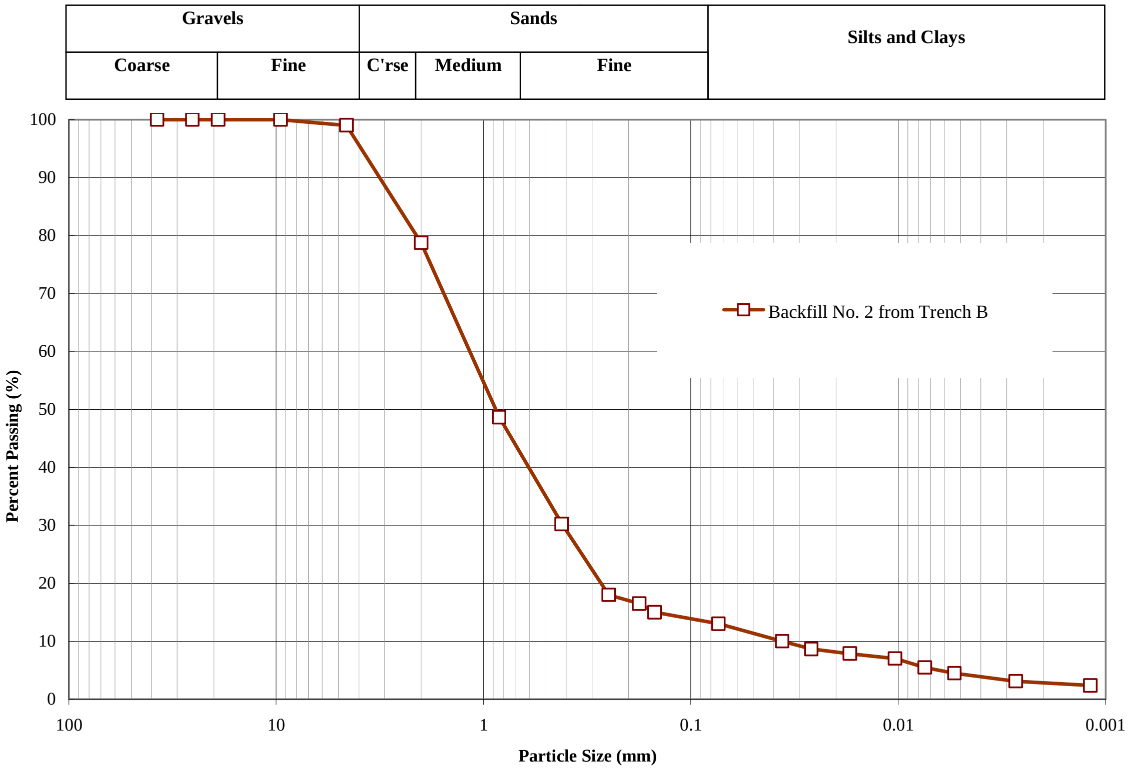


Figure A 8 -- Gradation curve for Trench B Backfill No. 2

Percent Passing #4	86.67%
Percent Passing #10	80.14%
Percent Passing #40	33.00%
Percent Passing #200	20.29%
D60	1.1
D30	0.484
D10	0.005
CU	220
Cc	42.6
USCS Soil Classification	SC – Clayey Sand
AASHTO Soil Classification	A-2-6 Silty and Clayey gravel and sand

Standard Proctor Test Results

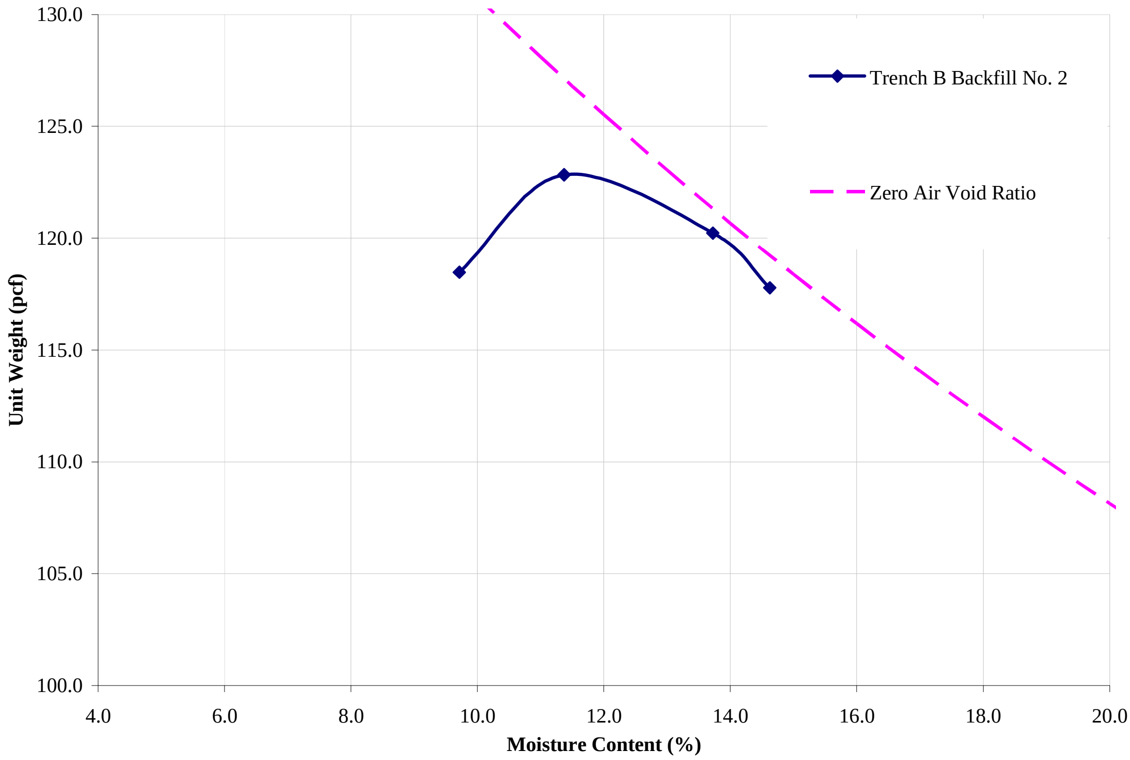


Figure A 9 -- Standard Proctor test results for Trench B Backfill No. 2

Relative Density Test Results

N/A

A.2.3 - Trench E Backfill No. 1

Classification

Liquid Limit	36
Plastic Limit	19
Plastic Index	17

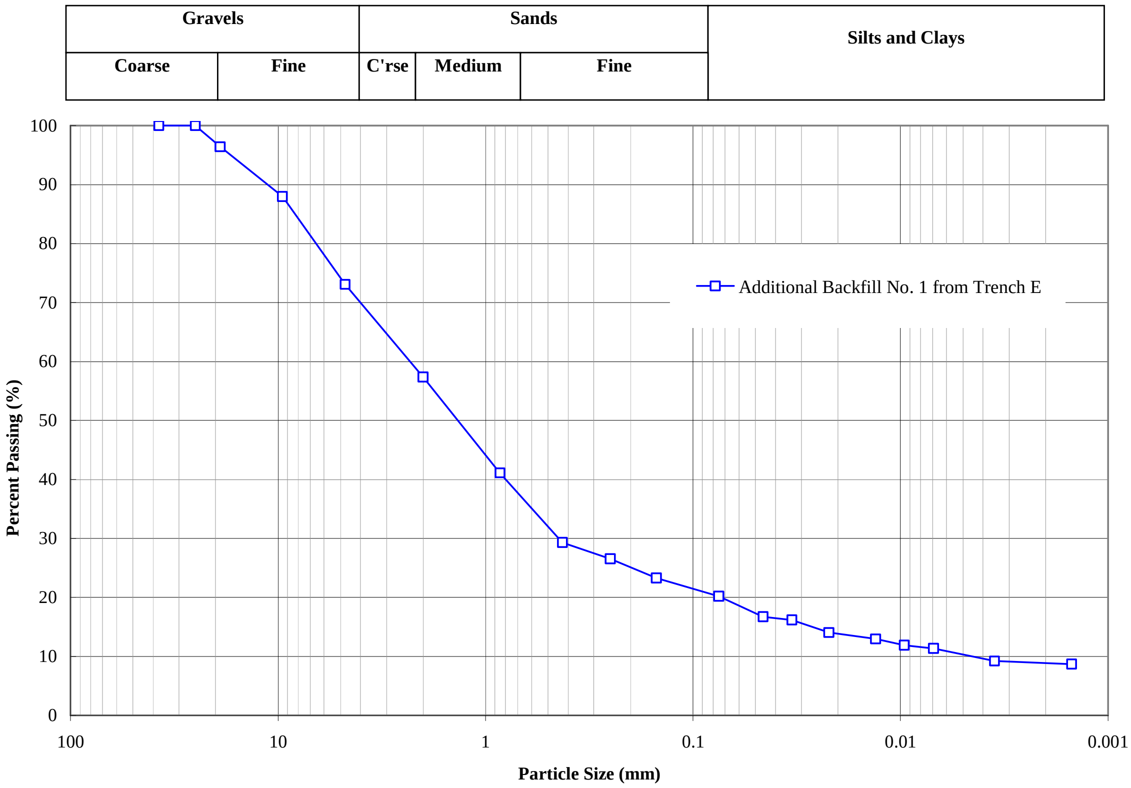


Figure A 10 -- Gradation curve for Trench E Backfill No. 1

Percent Passing #4	73.09%
Percent Passing #10	57.38%
Percent Passing #40	29.3%
Percent Passing #200	20.19%
D60	2.34
D30	0.45
D10	0.0048
CU	487.5
Cc	18.03
USCS Soil Classification	SC – Clayey Sand
AASHTO Soil Classification	A-2-6 Silty and Clayey gravel and sand

Standard Proctor Test Results

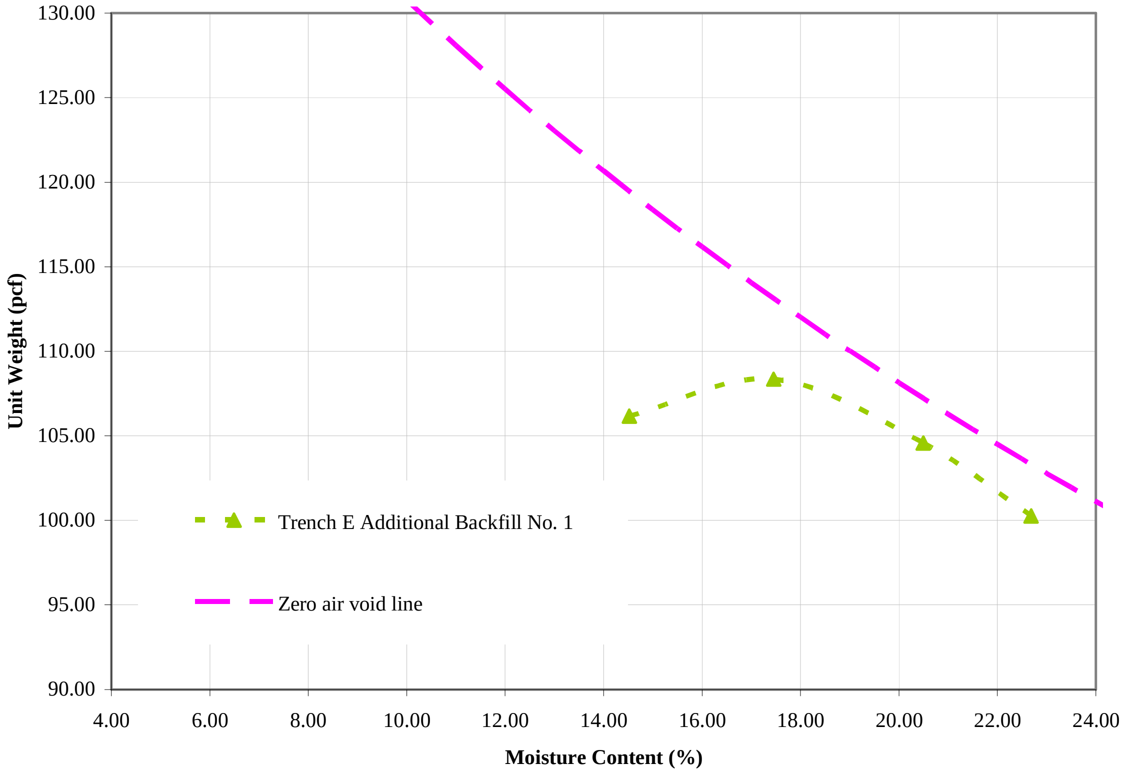


Figure A 11 -- Standard Proctor test results for Trench E Backfill No. 1

Relative Density Test Results

N/A

A.2.4 - Trench E Backfill No. 2

Classification

Liquid Limit	40
Plastic Limit	17
Plastic Index	23

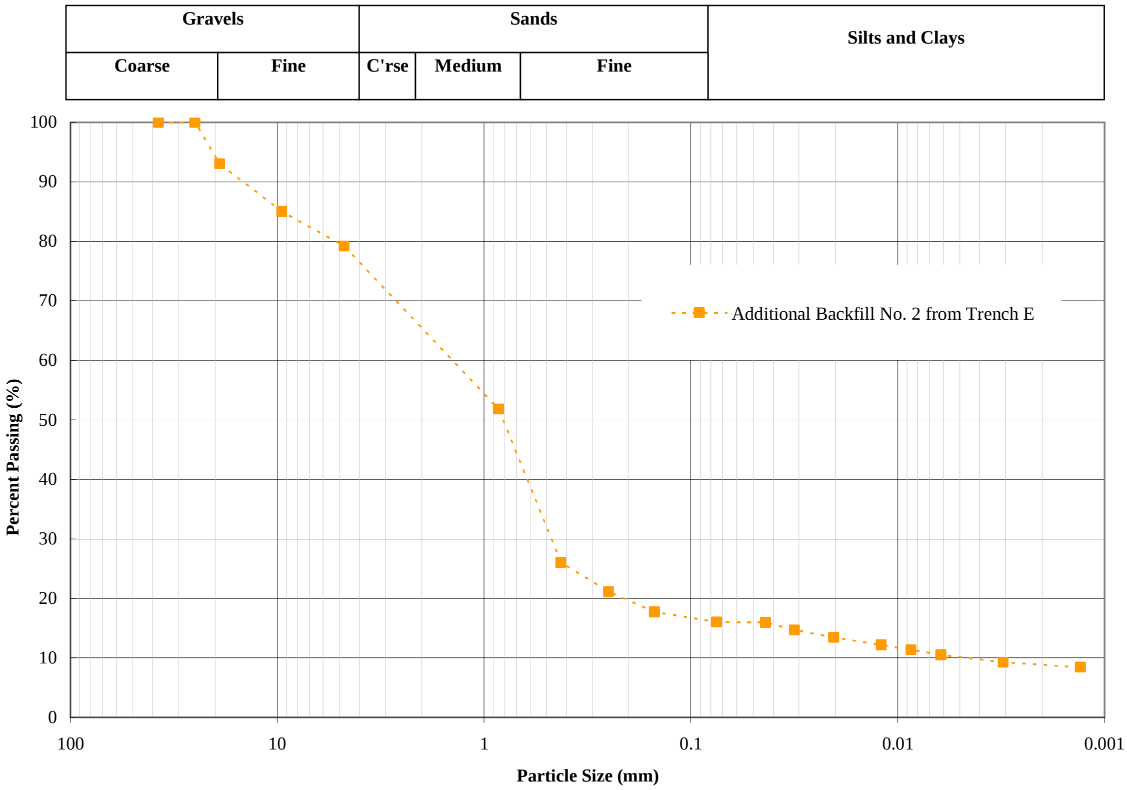


Figure A 12 -- Gradation curve for Trench E Backfill No. 2

Percent Passing #4	79.20%
Percent Passing #10	76.5%
Percent Passing #40	26.0%
Percent Passing #200	16.0%
D60	1.1
D30	0.48
D10	0.049
CU	224.48
Cc	42.74
USCS Soil Classification	SC – Clayey Sand
AASHTO Soil Classification	A-2-6 Silty and Clayey gravel and sand

Standard Proctor Test Results

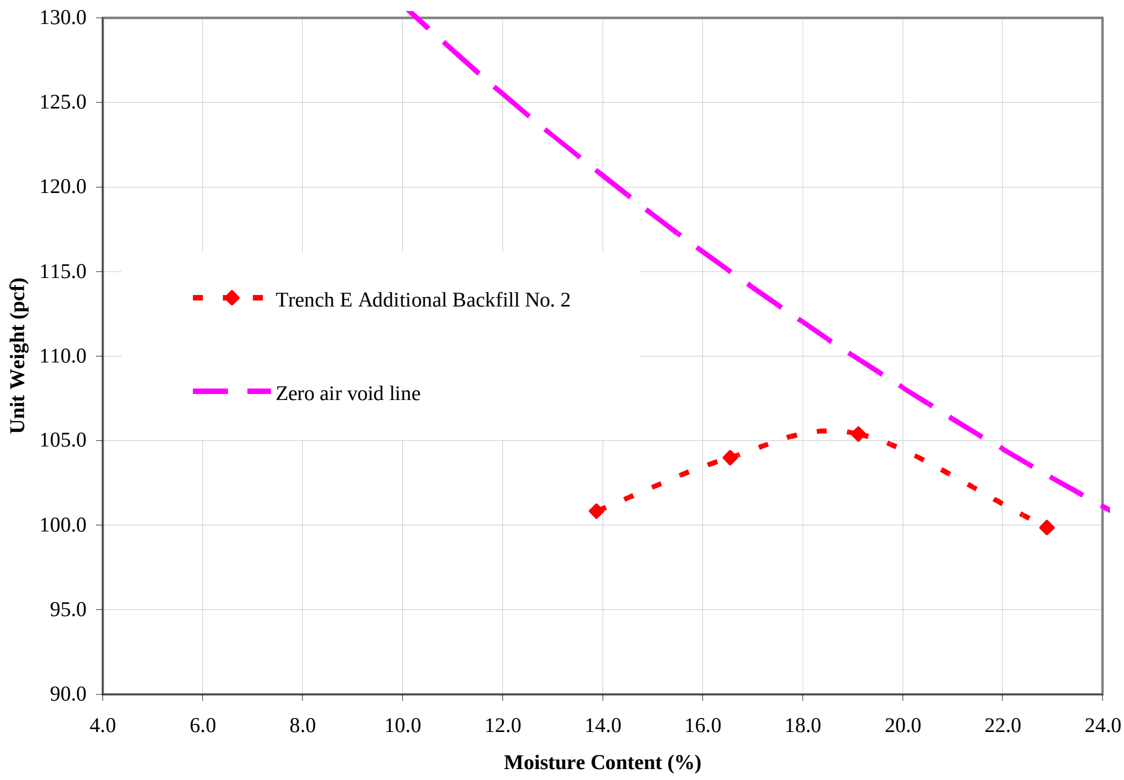


Figure A 13 -- Standard Proctor test results for Trench E Backfill No. 2

Relative Density Test Results

N/A

A.2.5 - Trench F Final Backfill

Classification

Liquid Limit	26
Plastic Limit	15
Plastic Index	11

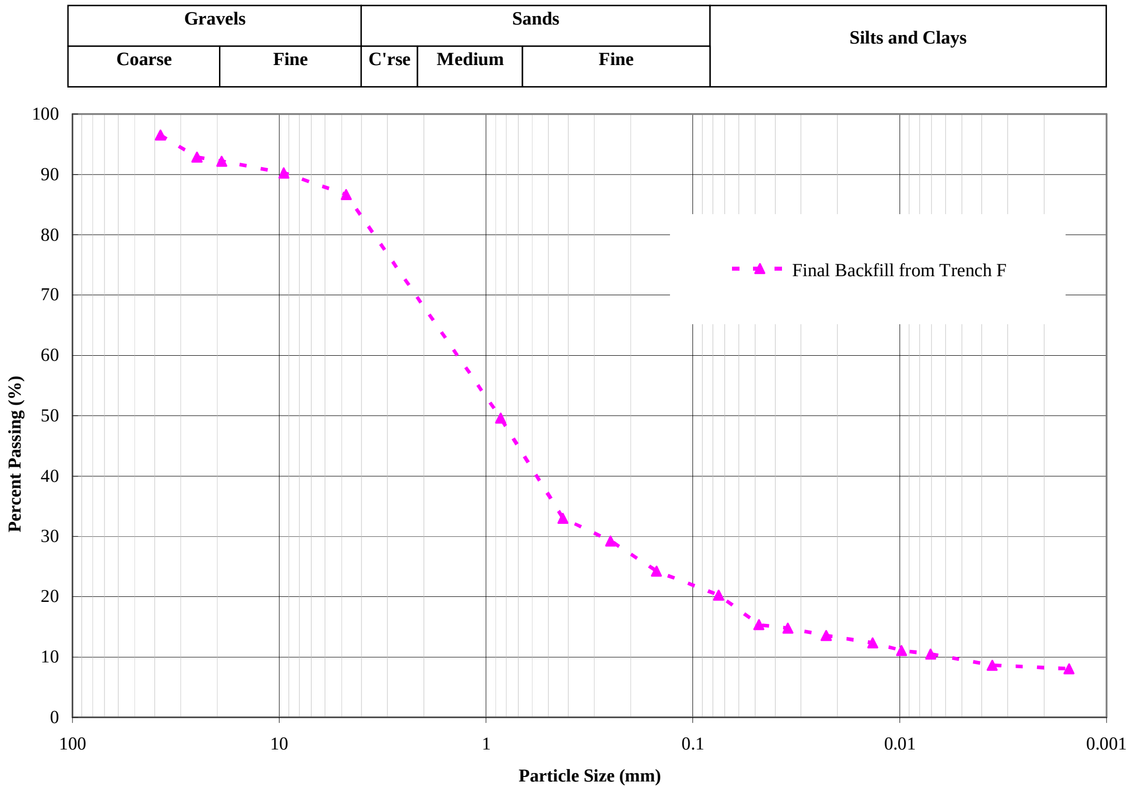


Figure A 14 -- Gradation curve for Trench F Final Backfill

Percent Passing #4	86.67%
Percent Passing #10	80.1%
Percent Passing #40	33.0%
Percent Passing #200	20.29%
D60	1.1
D30	0.3
D10	0.006
CU	187.5
Cc	13.33
USCS Soil Classification	SC – Clayey Sand
AASHTO Soil Classification	A-2-6 Silty and Clayey gravel and sand

Standard Proctor Test Results

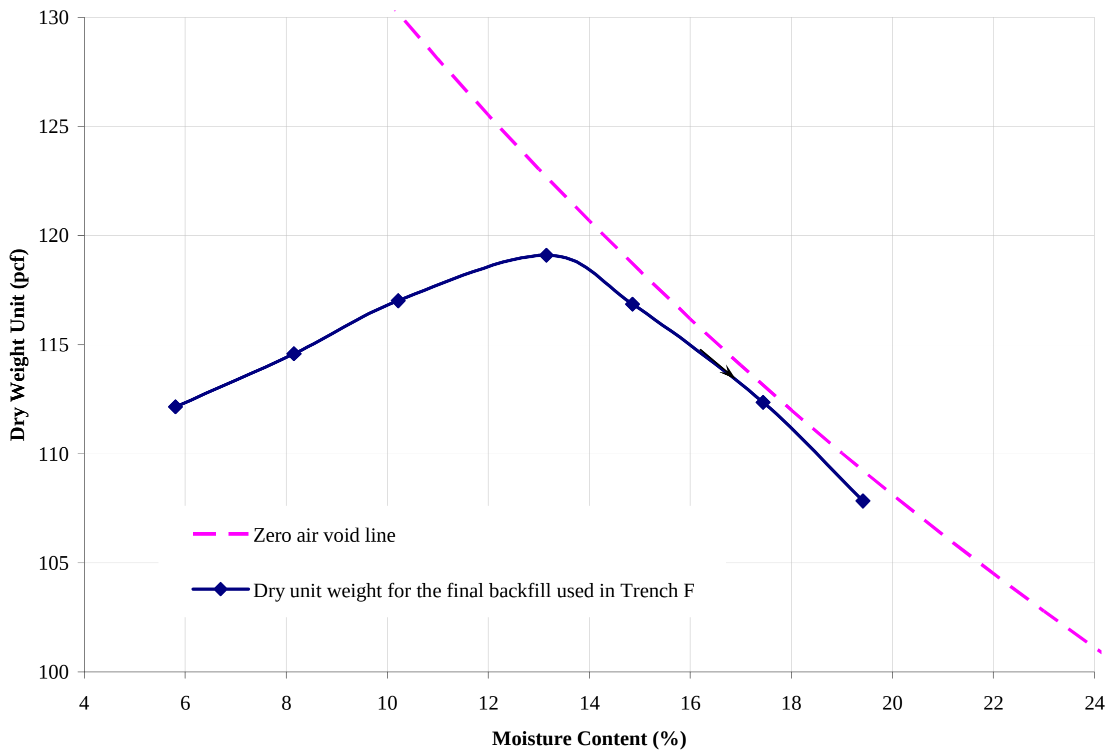


Figure A 15 -- Standard Proctor test results for Trench F Final Backfill

Relative Density Test Results

N/A

A.3 - Soils Excavated from the Trenches

A.3.1 - Trench A Sand from Previous Cut

Classification

Liquid Limit	N/A
Plastic Limit	N/A
Plastic Index	N/A

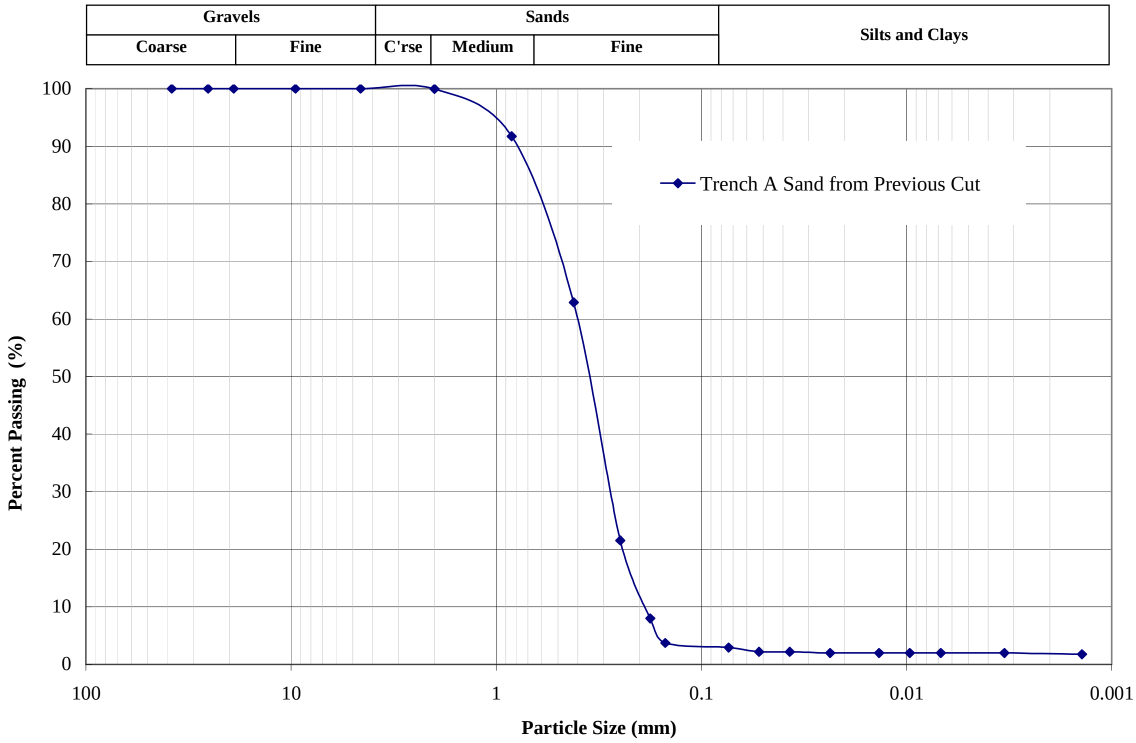


Figure A 16 -- Gradation curve for Trench A sand from previous cut

Percent Passing #4	100%
Percent Passing #10	100%
Percent Passing #40	62.8%
Percent Passing #200	3.0
D60	0.4
D30	0.275
D10	0.18
C_u	13.34
C_c	1.05
USCS Soil Classification	SW – Well graded sand
AASHTO Soil Classification	A-3 Fine sand

Standard Proctor Test Results
N/A

Relative Density Test Results
N/A

A.3.2 - Trench B

Classification

Liquid Limit	39
Plastic Limit	20
Plastic Index	19

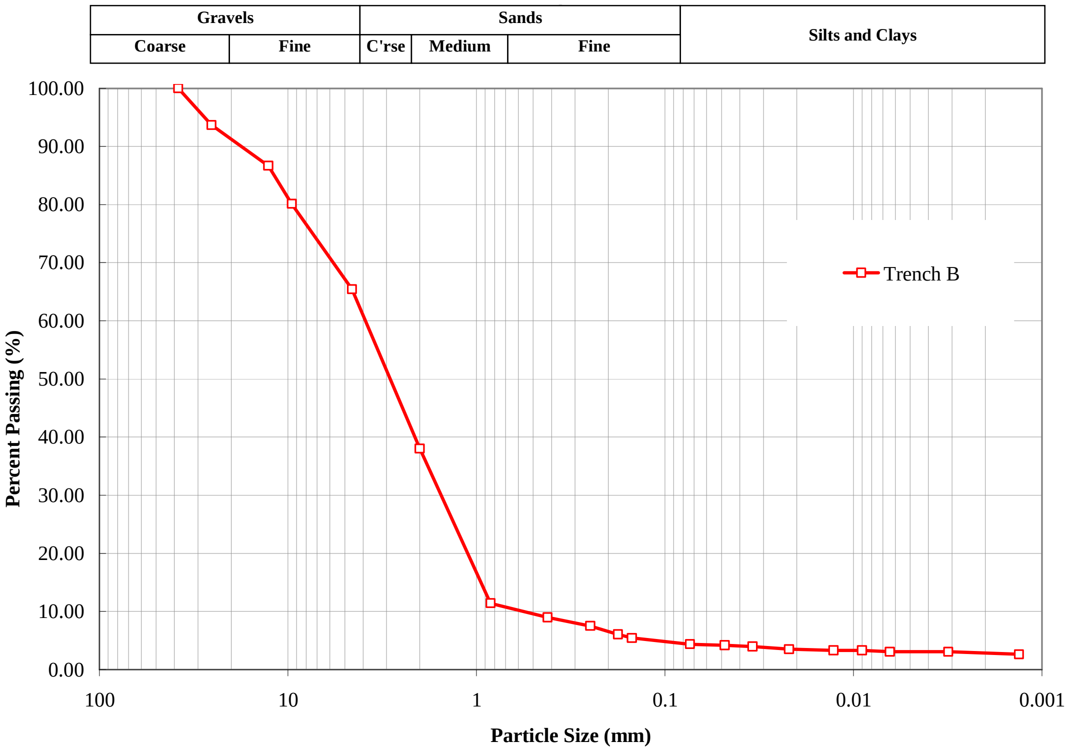


Figure A 17 -- Gradation curve for Trench B

Percent Passing #4	65.44%
Percent Passing #10	38.0%
Percent Passing #40	11.4%
Percent Passing #200	4.36
D60	3.8
D30	1.552
D10	0.3253
C_u	11.68
C_c	1.95
USCS Soil Classification	SW – Well graded sand with gravel
AASHTO Soil Classification	A-1-b Stone fragments, gravel and sand

Standard Proctor Test Results

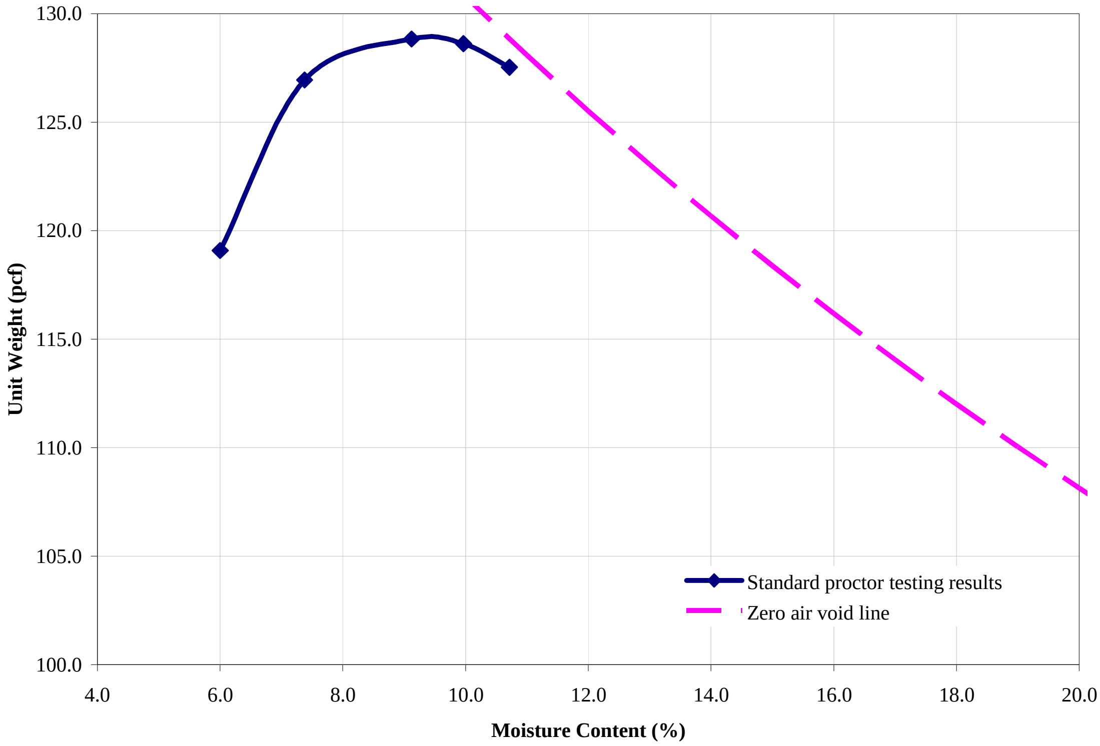


Figure A 18 -- Standard Proctor test results for Trench B

Relative Density Test Results

N/A

A.3.3 - Trench D

Classification

Liquid Limit	N/A
Plastic Limit	N/A
Plastic Index	N/A

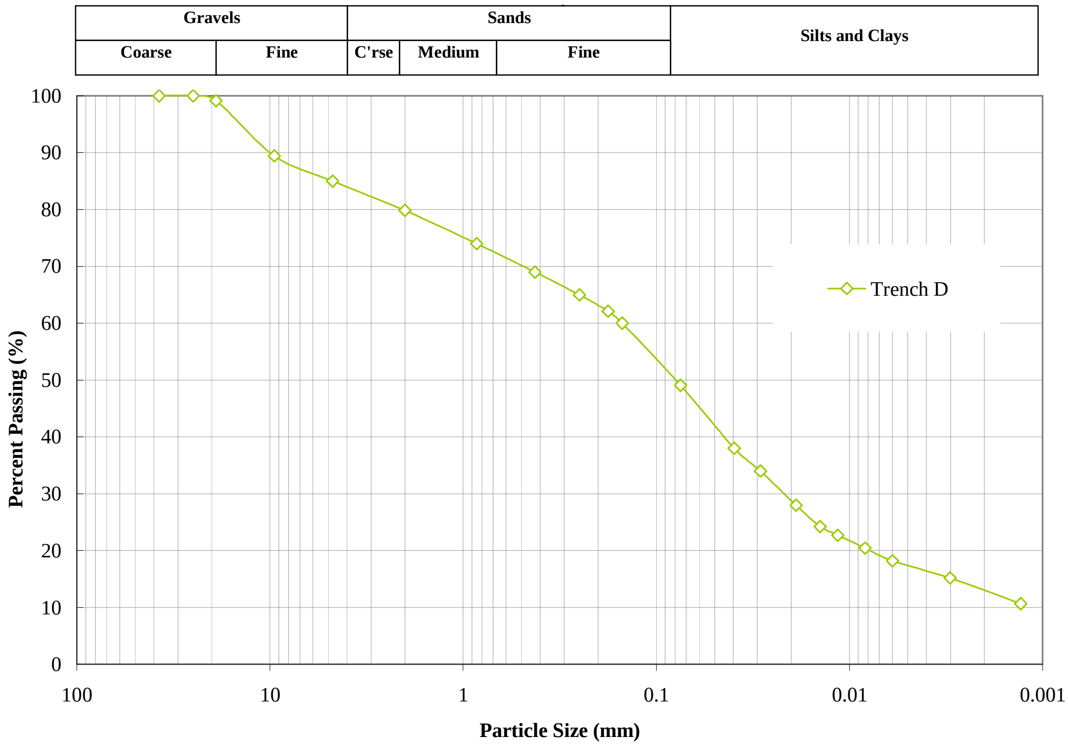


Figure A 19 -- Gradation curve for Trench D

Percent Passing #4	98.5%
Percent Passing #10	79.8%
Percent Passing #40	69%
Percent Passing #200	49.1%
D60	
D30	
D10	
C_u	3.88
C_c	161
USCS Soil Classification	SC – Clayey Sand
AASHTO Soil Classification	A-6 Clayey Soils

Standard Proctor Test Results

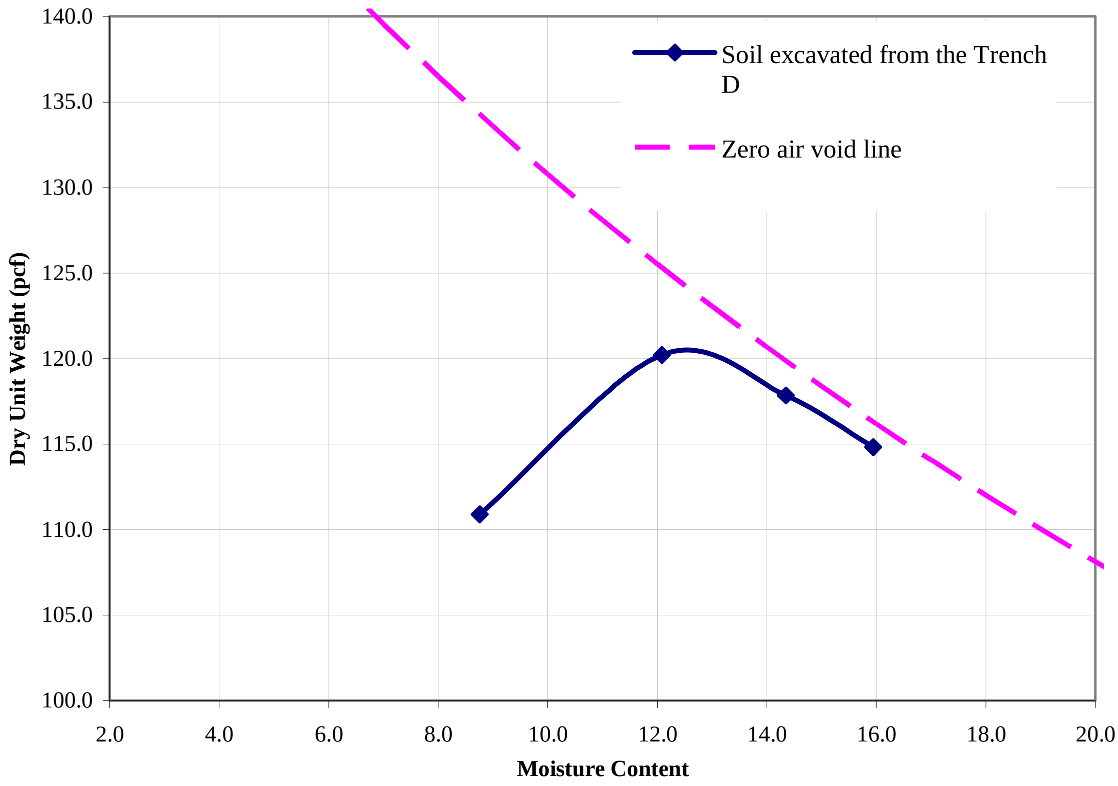


Figure A 20 -- Standard Proctor test results for Trench D

Relative Density Test Results

N/A

A.3.4 - Trench E

Classification

Liquid Limit	26
Plastic Limit	16
Plastic Index	10

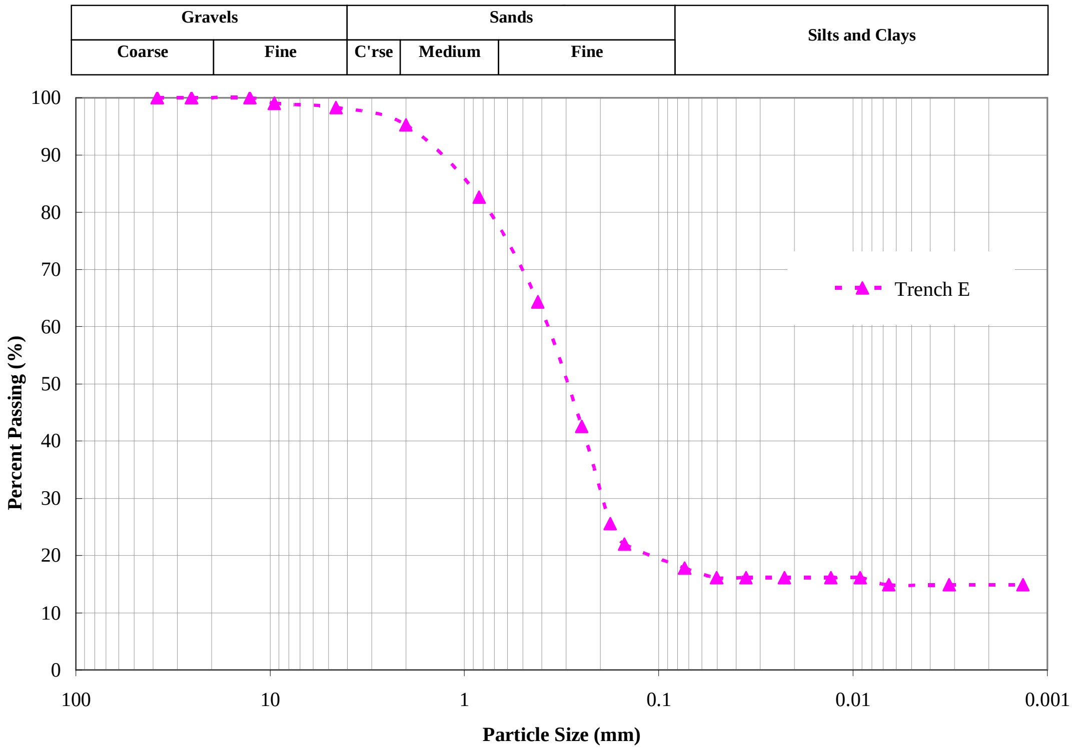


Figure A 21 -- Gradation curve for Trench E

Percent Passing #4	98.26%
Percent Passing #10	95.24%
Percent Passing #40	64.2%
Percent Passing #200	18.06
D60	0.366
D30	0.196
D10	0.001
C_u	366
C_c	104.9
USCS Soil Classification	SM – Silty Sand
AASHTO Soil Classification	A-2-4 Stone fragments, gravel and sand

Standard Proctor Test Results

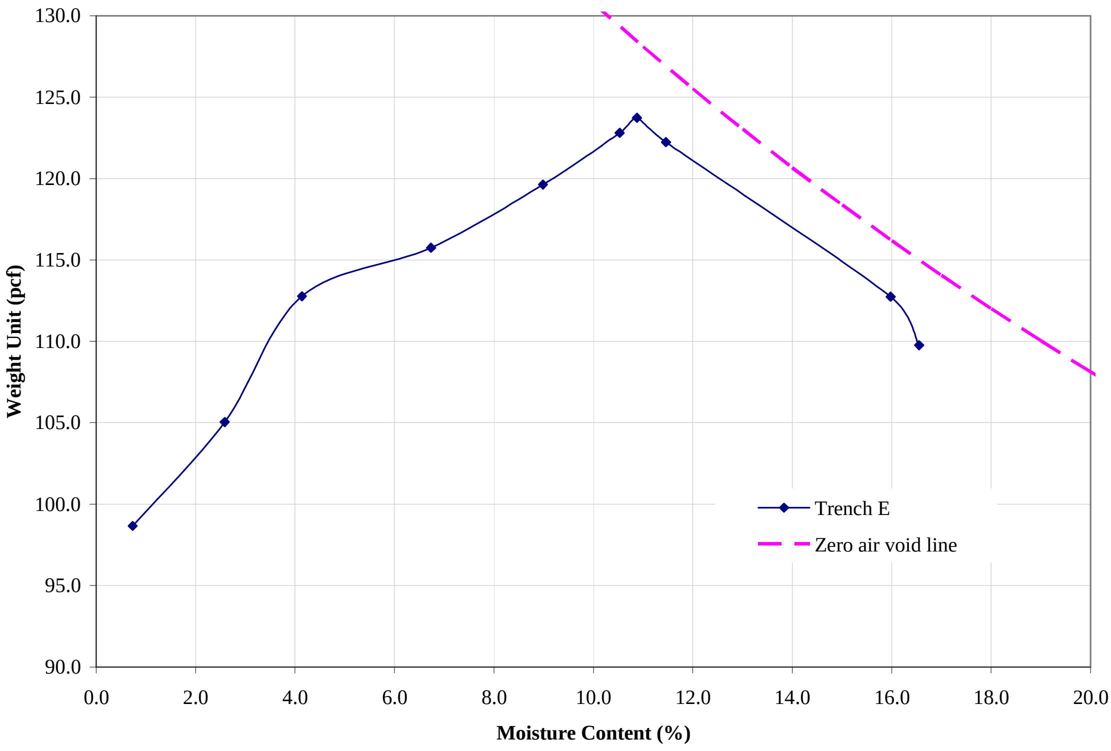


Figure A 22 -- Standard Proctor test result for Trench E

Relative Density Test Results

N/A

A.3.5 - Trench F

Classification

Liquid Limit	40
Plastic Limit	17
Plastic Index	23

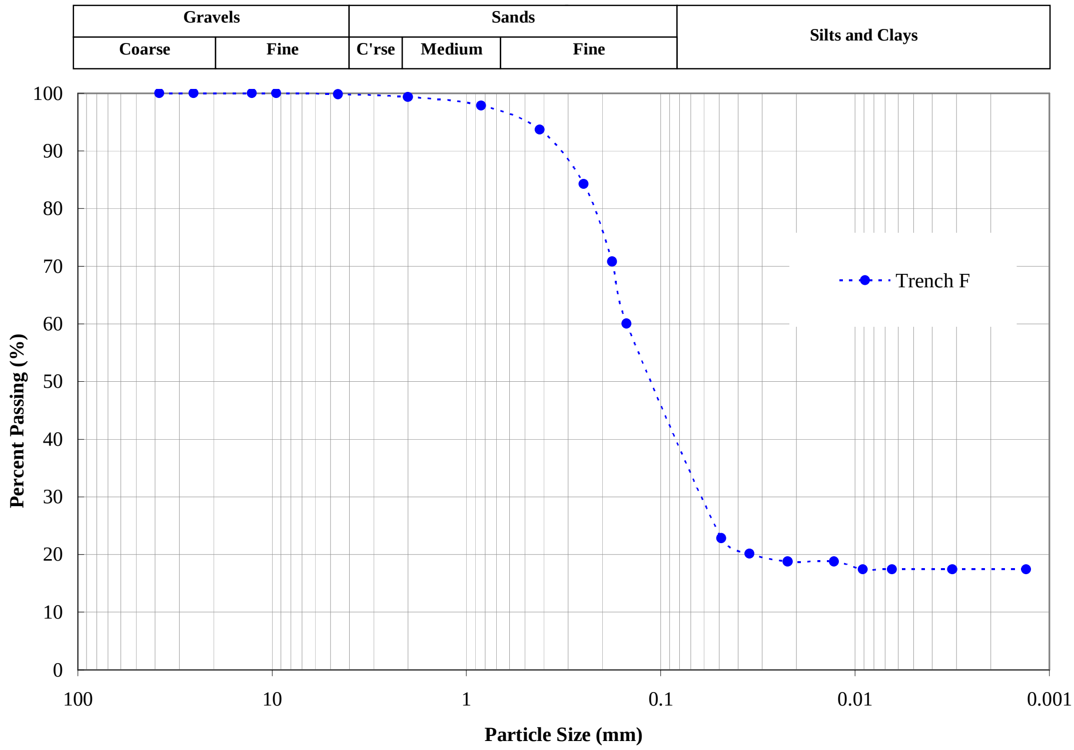


Figure A 23 -- Gradation curve for Trench F

Percent Passing #4	99.81%
Percent Passing #10	99.4%
Percent Passing #40	93.4%
Percent Passing #200	52.9
D60	0.148
D30	0.054
D10	0.001
C_u	---
C_c	---
USCS Soil Classification	CL- Sandy Lean Clay
AASHTO Soil Classification	A-6 Clayey soil

Standard Proctor Test Results

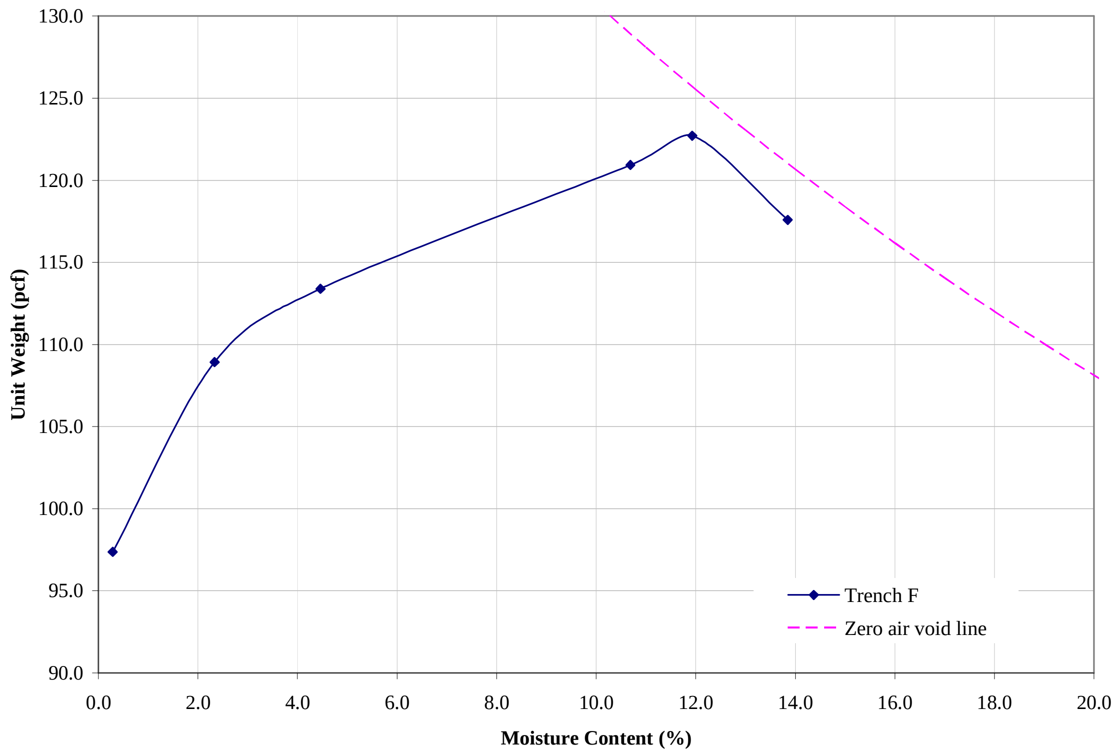


Figure A 24 - Standard proctor test resutls for Trench F

Relative Density Test Results

N/A

A.3.6 - Instrumented Trenches from 0 feet to 3.5 feet

Classification

Liquid Limit 37
Plastic Limit 14
Plastic Index 23

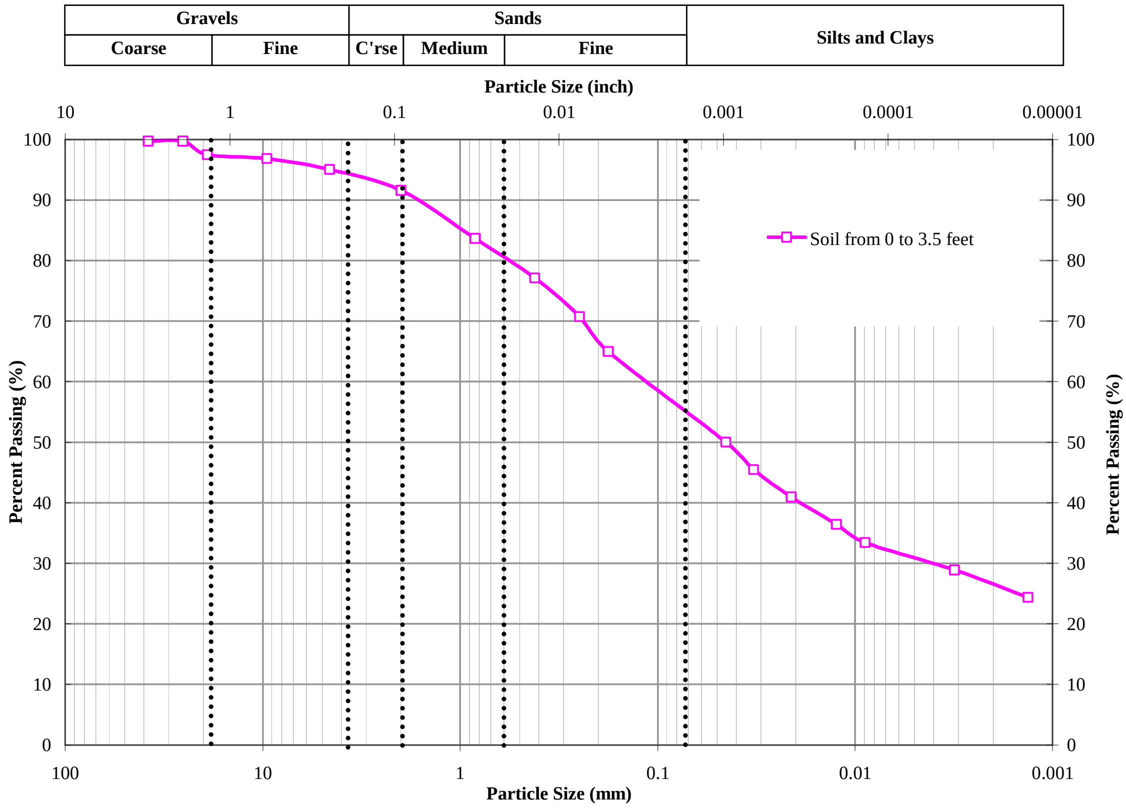


Figure A 25 -- Gradation curve for instrumented trenches from 0 feet to 3.5 feet

Percent Passing #4	95.0%
Percent Passing #10	91.6%
Percent Passing #40	77.1%
Percent Passing #200	53.4
D60	---
D30	---
D10	--
C_u	---
C_c	---
USCS Soil Classification	CL- Sandy Lean Clay
AASHTO Soil Classification	A-6 Clayey soil

Standard Proctor Test Results
N/A

Relative Density Test Results
N/A

A.3.7 - Instrumented Trenches from 3.5 feet to 5.0 feet

Classification

Liquid Limit	30
Plastic Limit	13
Plastic Index	17

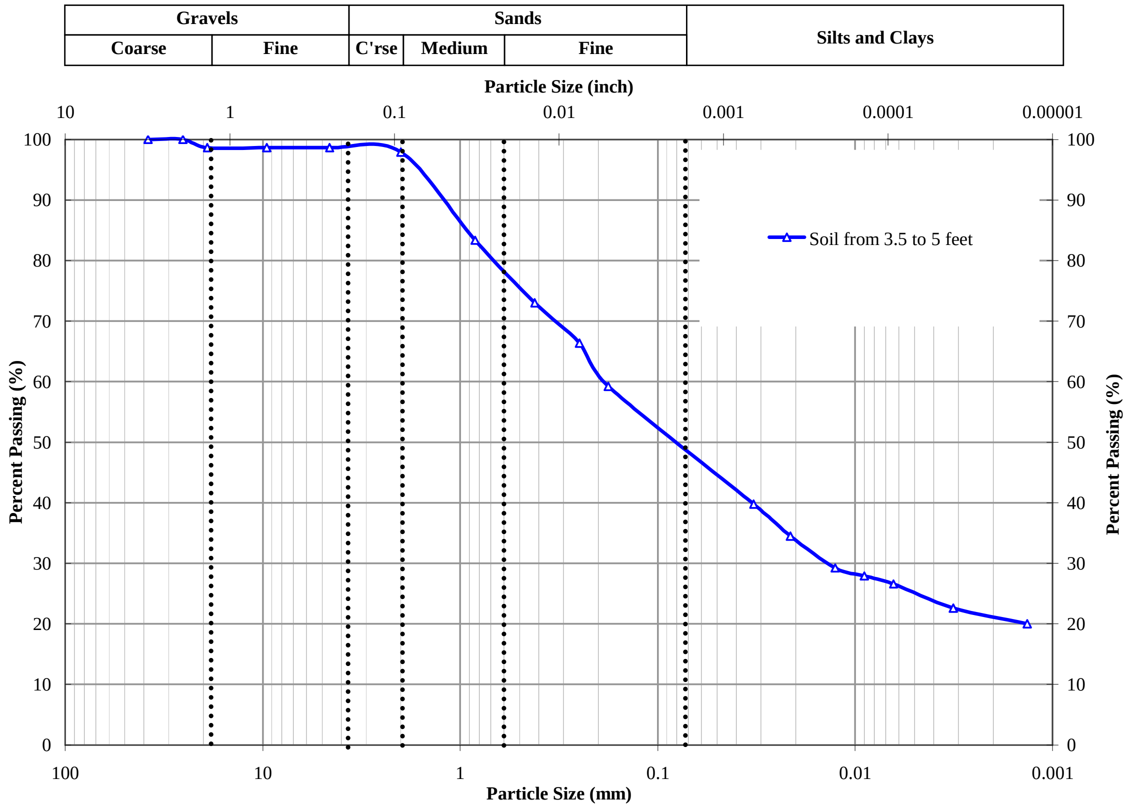


Figure A 26 -- Gradation curve for instrumented trenches from 3.5 feet to 5.0 feet

Percent Passing #4	98.63%
Percent Passing #10	97.91%
Percent Passing #40	73.00%
Percent Passing #200	54.57
D60	---
D30	---
D10	--
C_u	---
C_c	---
USCS Soil Classification	CL- Sandy Lean Clay
AASHTO Soil Classification	A-6 Clayey soil

Standard Proctor Test Results
N/A

Relative Density Test Results
N/A

A.3.7 - Instrumented Trenches from 5.0feet to 10.0 feet

Classification

Liquid Limit 29
Plastic Limit 13
Plastic Index 16

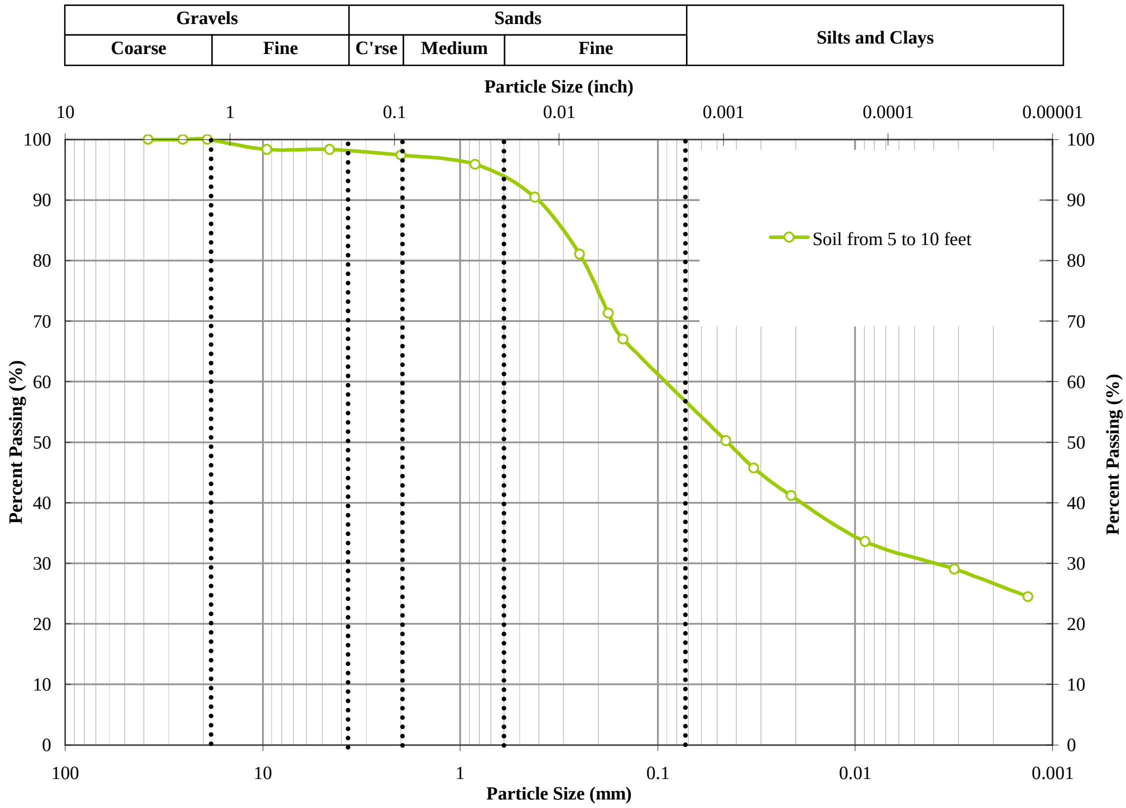


Figure A 27 -- Gradation curve for instrumented trenches from 3.5 feet to 5.0 feet

Percent Passing #4	98.3%
Percent Passing #10	98.3%
Percent Passing #40	97.4%
Percent Passing #200	65.5
D60	---
D30	---
D10	--
C_u	---
C_c	---
USCS Soil Classification	CL- Sandy Lean Clay
AASHTO Soil Classification	A-6 Clayey soil

Standard Proctor Test Results

N/A

Relative Density Test Results

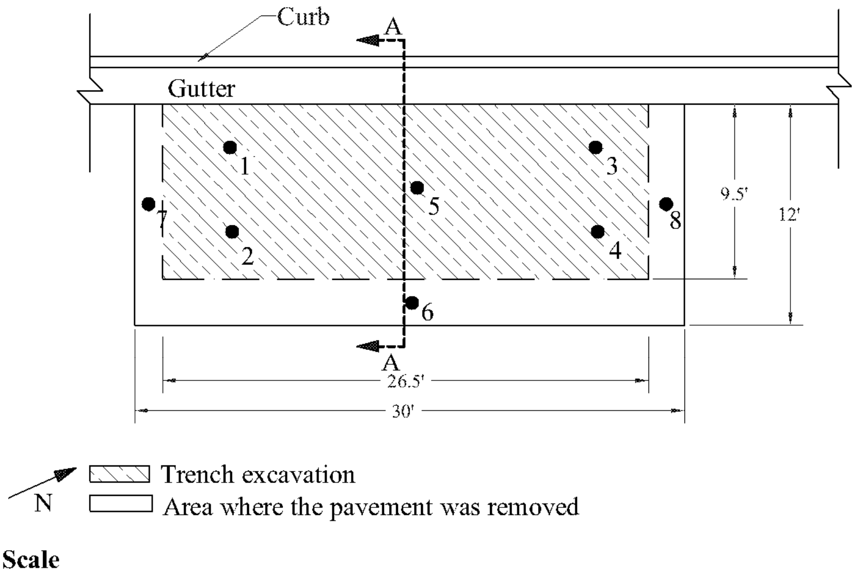
N/A

APPENDIX B.0 FIELD TESTING RESULTS

APPENDIX B.0 – FIELD-TESTING RESULTS

B.1 – Recommended Trenches

B.1.1 - Trench A



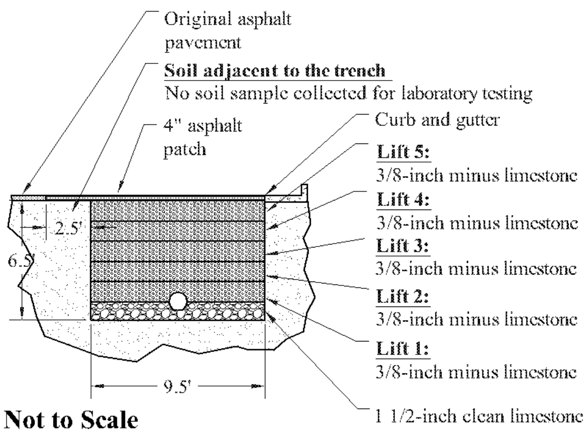


Figure B 1 -- Field-testing locations for Trench A

Nuclear Density Test Results

Table B 1– Moisture contents from the Nuclear Density testing results for lift 3 for Trench A

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	7.9	8.6	8.3	0.5	0.1
2	6.0	6.0	6.0	0.0	0.0
3	5.6	6.8	6.2	0.8	0.1
4	5.2	6.6	5.9	1.0	0.2
5	5.6	6.6	6.1	0.7	0.1
Average			6.5		
Standard deviation			1.0		
Coefficient of variance			15.3		

Table B 2– Dry unit weight from the Nuclear Density testing results for lift 3 for Trench A

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	108.6	111.9	110.3	2.3	0.02
2	112.6	109.1	110.9	2.5	0.02
3	109.2	106.3	107.8	2.1	0.02
4	111.0	111.3	111.2	0.2	0.00
5	113.5	108.5	111.0	3.5	0.03
Average			110.2		
Standard deviation			1.4		
Coefficient of variance			1.3		

Table B 3 -- Moisture contents from the Nuclear Density testing results for lift 5 on August 8, 2007 for Trench A

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	6.0	5.7	5.9	0.2	3.6
2	5.1	7.1	6.1	1.4	23.2
3	5.8	5.3	5.6	0.4	6.4
4	5.9	6.5	6.2	0.4	6.8
5	6.2	6.3	6.3	0.1	1.1
Average			6.0		
Standard deviation			0.3		
Coefficient of variance			4.8		

Table B 4 -- Dry unit weight from the Nuclear Density testing results for lift 5 on August 8, 2007 for Trench A

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	119.2	117.6	118.4	1.1	1.0
2	119.7	114.4	117.1	3.7	3.2
3	123.4	123.7	123.6	0.2	0.2
4	120.0	119.6	119.8	0.3	0.2
5	124.9	124.2	124.6	0.5	0.4
Average			120.7		
Standard deviation			3.3		
Coefficient of variance			2.7		

Table B 5– Moisture contents from the Nuclear Density testing results for lift 5 on August 10, 2007 for test points within Trench A

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	4.2	5.9	5.1	1.2	23.8
2	4.8	5.1	5.0	0.2	4.3
3	5.1	5.1	5.1	0.0	0.0
4	5.1	5.2	5.2	0.1	1.4
5	4.7	5.3	5.0	0.4	8.5
Average			5.1		
Standard deviation			0.1		
Coefficient of variance			1.6		

Table B 6– Dry unit weight from the Nuclear Density testing results for lift 5 on August 10, 2007 for test points within Trench A

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	119.2	117.6	120.7	1.4	1.2
2	119.7	114.4	120.1	0.9	0.8
3	123.4	123.7	123.1	2.3	1.8
4	120.0	119.6	123.1	0.2	0.2
5	124.9	124.2	124.7	2.7	2.2
Average			122.3		
Standard deviation			1.9		
Coefficient of variance			1.6		

Table B 7– Moisture contents from the Nuclear Density testing results for lift 5 on August 10, 2007 for test points in the soil adjacent to Trench A

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
7	9.6	8.6	9.1	0.7	7.8
8	10.3	9.0	9.7	0.9	9.5
9	5.2	4.8	5.0	0.3	5.7
Average			5.1		
Standard deviation			0.1		
Coefficient of variance			1.6		

Table B 8 -- Dry unit weight from the Nuclear Density testing results for lift 5 on August 10, 2007 for test points in soil adjacent to Trench A

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
7	124.8	120.1	122.5	3.3	2.7
8	125.8	124.9	125.4	0.6	0.5
9	122.0	122.5	122.3	0.4	0.3
Average			120.7		
Standard deviation			3.3		
Coefficient of variance			2.7		

Table B 9 – Summary of moisture content results from the Nuclear Density tests for Trench A

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Bulking moisture content (%)	Standard deviation	Coefficient of variance (%)
Third lift	5	6.5	5.9 / 8.3	4.0 to 8.0	1.0	15.4
Fifth lift test points within the trench tested on August 8, 2007	5	6.0	5.6 6.2	4.0 to 8.0	0.3	5.0
Fifth lift test points within the trench tested on August 10, 2007	5	6.1	5.0 / 9.7	N/A	2.0	32.8
Test points in the soil adjacent to the trench on August 10, 2007	3	5.0	5.0 / 9.7	N/A	2.5	32.1

Table B 10 – Summary of dry unit weight results from the Nuclear Density tests on Trench A

Location	Number of test points	Average dry unit weight (pcf)	Min/Max dry unit weight from field-testing (pcf)	Relative density (%)	Standard deviation	Coefficient of variance (%)
Third lift	5	110.2	107.8 / 111.2	34	1.4	1.3
Fifth lift test points within the trench tested on August 8, 2007	5	120.7	117.1 / 124.5	60	3.3	2.7
Fifth lift test points within the trench tested on August 10, 2007	5	122.3	120.1 / 125.7	65	1.8	1.5
Test points in the soil adjacent to the trench on August 10, 2007	3	123.4	122.3 / 125.4	N/A	1.7	1.4

DCP Test Results

Table B 11 -- DCP test results for lift 3 test point 1 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	390.0	0.0
1	3.0	486.0	96.0
1	5.0	633.0	243.0
1	5.0	710.0	320.0
1	5.0	779.0	389.0
1	8.0	845.0	455.0
1	4.0	909.0	519.0
1	3.0	992.0	602.0
1	4.0	1099.0	709.0

Table B 12 -- DCP test results for lift 3 test point 2 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	397.0	0.0
2	3.0	490.0	93.0
2	5.0	577.0	180.0
2	5.0	651.0	254.0
2	8.0	784.0	387.0
2	5.0	856.0	459.0
2	4.0	921.0	524.0
2	5.0	999.0	602.0
2	6.0	1061.0	664.0
2	5.0	1108.0	711.0

Table B 13 -- DCP test results for lift 3 test point 3 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	389.0	0.0
3	2.0	531.0	142.0
3	1.0	685.0	296.0
3	3.0	752.0	363.0
3	5.0	826.0	437.0
3	8.0	921.0	532.0
3	8.0	1009.0	620.0
3	8.0	1106.0	717.0

Table B 14 -- DCP test results for lift 3 test point 4 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	388.0	0.0
4	4.0	570.0	182.0
4	1.0	649.0	261.0
4	1.0	791.0	403.0
4	1.0	880.0	492.0
4	1.0	959.0	571.0

Table B 15 -- DCP test results for lift 3 test point 5 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
5	0.0	394.0	0.0
5	2.0	505.0	111.0
5	1.0	589.0	195.0
5	1.0	721.0	327.0
5	1.0	930.0	536.0
5	1.0	1049.0	655.0
5	2.0	2003.0	1609.0

Table B 16 -- DCP test results for lift 5 test point 1 on August 8, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	377.0	0.0
1	2.0	451.0	74.0
1	5.0	546.0	169.0
1	5.0	605.0	228.0
1	8.0	705.0	328.0
1	10.0	828.0	451.0
1	10.0	932.0	555.0
1	10.0	1014.0	637.0
1	10.0	1095.0	718.0

Table B 17 -- DCP test results for lift 3 test point 2 on August 8, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	374.0	0.0
2	3.0	469.0	95.0
2	5.0	569.0	195.0
2	8.0	755.0	381.0
2	8.0	869.0	495.0
2	8.0	970.0	596.0
2	8.0	1056.0	682.0

Table B 18 -- DCP test results for lift 3 test point 3 on August 8, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	363.0	0.0
3	3.0	446.0	83.0
3	5.0	524.0	161.0
3	8.0	648.0	285.0
3	8.0	781.0	418.0
3	8.0	874.0	511.0
3	10.0	971.0	608.0
3	10.0	1075.0	712.0

Table B 19 -- DCP test results for lift 3 test point 4 on August 8, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	361.0	0.0
4	3.0	461.0	100.0
4	5.0	545.0	184.0
4	10.0	671.0	310.0
4	10.0	792.0	431.0
4	10.0	877.0	516.0
4	10.0	940.0	579.0
4	10.0	994.0	633.0

Table B 20 -- DCP test results for lift 5 test point 1 on August 10, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	377.0	0.0
1	2.0	451.0	74.0
1	5.0	546.0	169.0
1	5.0	605.0	228.0
1	8.0	705.0	328.0
1	10.0	828.0	451.0
1	10.0	932.0	555.0
1	10.0	1014.0	637.0
1	10.0	1095.0	718.0

Table B 21 -- DCP test results for lift 5 test point 2 on August 10, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	364.0	0.0
2	5.0	432.0	68.0
2	8.0	515.0	151.0
2	8.0	612.0	248.0
2	8.0	746.0	382.0
2	8.0	851.0	487.0
2	8.0	956.0	592.0
2	8.0	991.0	627.0
2	8.0	1029.0	665.0

Table B 22 -- DCP test results for lift 5 test point 3 on August 10, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	374.0	0.0
3	5.0	420.0	46.0
3	15.0	510.0	136.0
3	15.0	644.0	270.0
3	15.0	833.0	459.0
3	8.0	905.0	531.0
3	10.0	989.0	615.0
3	10.0	1065.0	691.0

Table B 23 -- DCP test results for lift 5 test point 4 on August 10, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	364.0	0.0
4	5.0	419.0	55.0
4	15.0	495.0	131.0
4	15.0	585.0	221.0
4	15.0	694.0	330.0
4	15.0	790.0	426.0
4	15.0	913.0	549.0
4	15.0	1005.0	641.0

Table B 24 -- DCP test results for lift 5 test point 5 on August 10, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
5	0.0	359.0	0.0
5	5.0	402.0	43.0
5	15.0	477.0	118.0
5	15.0	547.0	188.0
5	15.0	628.0	269.0
5	15.0	701.0	342.0
5	10.0	790.0	431.0
5	10.0	886.0	527.0
5	10.0	966.0	607.0
5	10.0	1058.0	699.0

Table B 25 -- DCP test results for lift 5 test point 6 on August 10, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
6	0.0	379.0	0.0
6	2.0	476.0	97.0
6	4.0	566.0	187.0
6	3.0	698.0	319.0
6	2.0	791.0	412.0
6	2.0	864.0	485.0
6	2.0	913.0	534.0
6	3.0	984.0	605.0

Table B 26 -- DCP test results for lift 5 test point 7 on August 10, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
7	0.0	353.0	0.0
7	5.0	392.0	22.0
7	8.0	447.0	77.0
7	4.0	502.0	132.0
7	4.0	581.0	211.0
7	4.0	674.0	304.0
7	2.0	745.0	375.0
7	2.0	828.0	458.0

Table B 27 -- DCP test results for lift 5 test point 8 on August 10, 2007 for Trench A

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
8	0.0	369.0	0.0
8	5.0	424.0	55.0
8	8.0	510.0	141.0
8	4.0	587.0	218.0
8	4.0	679.0	310.0
8	4.0	755.0	386.0
8	2.0	853.0	484.0
8	2.0	944.0	575.0
8	2.0	1018.0	649.0

Table B 28 – Summary of DCPI results from the DCP tests for Trench A

Location	Number of test points	Depth of test (inches)	Average DCPI	Standard deviation	Coefficient of variance (%)
Third lift	5	26.5	61.1	58.6	96.1
Fifth lift test points within the trench tested on August 8, 2007	5	27.5	15.2	7.0	46.1
Fifth lift test points within the trench tested on August 10, 2007	5	26.6	8.7	3.0	33.8
Test points in the soil adjacent to the trench on August 10, 2007	3	26.1	47.7	26.3	55.1

Table B 29 – Summary of Average CBR results from the DCP tests for Trench A

Location	Number of test points	Depth of test (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	5	26.5	8%	79.0	975.3
Fifth lift test points within the trench tested on August 8, 2007	5	27.5	17%	7.3	42.7
Fifth lift test points within the trench tested on August 10, 2007	5	26.6	29%	20.7	70.9
Test points in the soil adjacent to the trench on August 10, 2007	3	26.1	13%	20.4	156.9

Clegg Hammer Test Results

Table B 30 -- Clegg Hammer test results for lift 5 on August 10, 2007 for test within Trench A

Location #	IV Value	CBR (%)
1	27.6	58.1
2	27.9	59.2
3	34.0	83.9
4	39.7	110.8
5	40.0	112.4
Average	33.8	84.9
Standard Deviation	6.1	26.5
Coefficient of variance	0.2	0.3

Table B 31 -- Clegg Hammer test results for lift 5 on August 10, 2007 for test adjacent to Trench A

Location #	IV Value	CBR (%)
7	13.0	17.0
8	28.0	59.6
9	25.2	49.7
Average	22.1	42.1
Standard Deviation	8.0	22.3
Coefficient of variance	0.4	0.5

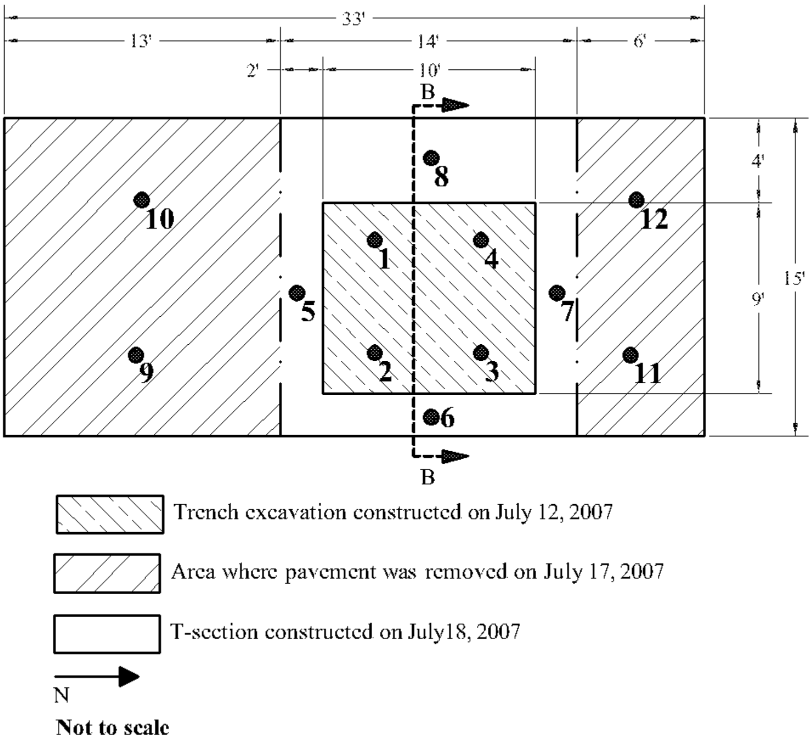
Table B 32 – Summary of impact value results from the Clegg Hammer tests for Trench A

Location	Number of test points	Average IV reading	Min/Max IV readings	Standard deviation	Coefficient of variance (%)
Third lift	5	N/A	N/A	N/A	N/A
Fifth lift test points within the trench tested on August 8, 2007	5	N/A	N/A	N/A	N/A
Fifth lift test points within the trench tested on August 10, 2007	5	33.8	27.6 / 40.0	6.0	17.7
Test points in the soil adjacent to the trench on August 10, 2007	3	22.1	13.0 / 28.0	80.0	36.2

Table B 33 – Summary of CBR results from the Clegg Hammer tests for Trench A

Location	Number of test points	Average CBR (%)	Min/Max CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	5	N/A	N/A	N/A	N/A
Fifth lift test points within the trench tested on August 8, 2007	5	N/A	N/A	N/A	N/A
Fifth lift test points within the trench tested on August 10, 2007	5	85	58 / 112	22.3	31.2
Test points in the soil adjacent to the trench on August 10, 2007	3	42	17 / 60	22.3	53.0

B.1.2 - Trench B



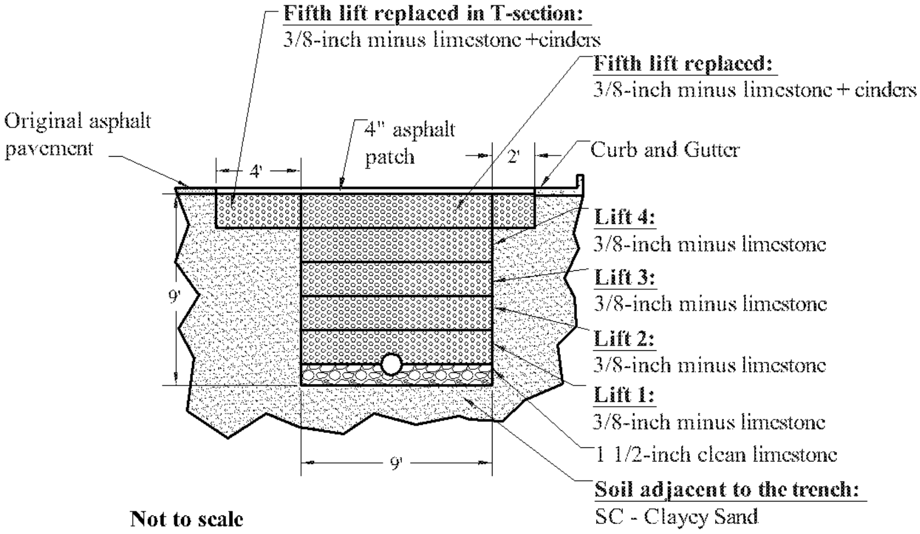


Figure B 2 -- Field-testing locations for Trench B

Nuclear Density Test Results

Table B 34 -- Moisture contents from the Nuclear Density testing results for lift 3 for Trench B

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	7.2	7.0	7.1	0.1	2.0
2	5.9	7.4	6.7	1.1	15.8
3	6.0	6.3	6.2	0.2	3.4
4	6.2	6.4	6.3	0.1	2.2
5	7.2	7.0	6.6	0.1	2.0
Average			6.6		
Standard deviation			0.4		
Coefficient of variance			6.2		

Table B 35 -- Dry unit weight from the Nuclear Density testing results for lift 3 for Trench B

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	111.0	112.0	111.5	0.7	0.6
2	113.6	108.1	110.9	3.9	3.5
3	117.3	114.7	116.0	1.8	1.6
4	113.6	112.7	113.2	0.6	0.6
5	111.0	112.0	111.5	0.7	0.6
Average			112.9		
Standard deviation			2.3		
Coefficient of variance			2.0		

Table B 36 -- Moisture contents from the Nuclear Density testing results for lift 5 for Trench B

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	5.3	4.9	5.1	0.3	5.5
2	5.1	4.9	5.0	0.1	2.8
3	4.9	4.7	4.8	0.1	2.9
4	5.6	5.3	5.5	0.2	3.9
Average			5.1		
Standard deviation			0.3		
Coefficient of variance			5.3		

Table B 37 -- Dry unit weight from the Nuclear Density testing results for lift 5 for Trench B

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	117.8	117.5	117.7	0.2	0.2
2	121.1	120.6	120.9	0.4	0.3
3	118.5	121.4	120.0	2.1	1.7
4	111.2	117.3	114.3	4.3	3.8
Average			118.2		
Standard deviation			2.9		
Coefficient of variance			2.5		

Table B 38 -- Moisture contents from the Nuclear Density for Replaced fifth lift before rain event for tests within the trench for Trench B

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	5.8	6.2	6.0	0.2	4.0
2	8.2	7.4	7.8	0.6	7.5
3	9.7	8.5	9.1	0.9	9.9
4	8.7	8.7	8.7	0.0	0.1
Average			7.9		
Standard deviation			1.4		
Coefficient of variance			17.4		

Table B 39 -- Dry unit weight from the Nuclear Density testing results for Replaced fifth lift before rain event for tests within the trench for Trench B

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	111.7	111.7	111.7	0.0	0.0
2	101.6	103.6	102.6	1.4	1.4
3	108.7	108.8	108.8	0.1	0.1
4	107.0	107.0	107.0	0.0	0.0
Average			107.5		
Standard deviation			3.8		
Coefficient of variance			3.5		

Table B 40 -- Moisture contents from the Nuclear Density for Replaced fifth lift before rain event for tests in the T-section for Trench B

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	9.6	11.5	10.5	1.4	12.9
2	9.0	10.9	9.9	1.3	13.6
3	6.8	9.2	8.0	1.7	21.1
4	13.2	12.1	12.6	0.8	6.2
Average			10.3		
Standard deviation			1.9		
Coefficient of variance			18.4		

Table B 41 -- Dry unit weight from the Nuclear Density testing results for Replaced fifth lift before rain event for tests in the T-section for Trench B

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	101.4	97.2	99.3	3.0	3.0
2	106.7	102.8	104.8	2.8	2.6
3	110.4	105.3	107.9	3.6	3.3
4	96.2	99.7	97.9	2.4	2.5
Average			102.5		
Standard deviation			4.7		
Coefficient of variance			4.6		

Table B 42 -- Moisture contents from the Nuclear Density for replaced fifth lift after rain event for tests within Trench B

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	5.0	6.3	5.6	1.4	12.9
2	6.4	6.6	6.5	1.3	13.6
3	7.7	8.7	8.2	1.7	21.1
4	7.6	8.0	7.8	0.8	6.2
Average			7.0		
Standard deviation			1.2		
Coefficient of variance			17.0		

Table B 43 -- Dry unit weight from the Nuclear Density testing results for replaced fifth lift after rain event for tests within Trench B

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	117.4	116.5	117.0	0.6	0.5
2	111.5	112.0	111.8	0.4	0.3
3	117.8	114.2	116.0	2.5	2.2
4	116.7	115.8	116.3	0.6	0.5
Average			115.3		
Standard deviation			2.4		
Coefficient of variance			2.0		

Table B 44 -- Moisture contents from the Nuclear Density for replaced fifth lift after rain event for tests in the T-section for Trench B

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	7.1	8.7	7.9	1.1	14.5
2	7.5	7.3	7.4	0.2	2.3
3	8.9	8.2	8.6	0.5	5.3
4	8.1	6.9	7.5	0.8	11.1
Average			7.9		
Standard deviation			0.5		
Coefficient of variance			6.9		

Table B 45 -- Dry unit weight from the Nuclear Density testing results for replaced fifth lift after rain event for tests in the T-section for Trench B

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	109.4	103.9	106.7	3.9	3.6
2	112.5	109.0	110.8	2.5	2.2
3	109.6	110.7	110.2	0.8	0.7
4	109.5	104.9	107.2	3.3	3.0
Average			106.7		
Standard deviation			110.8		
Coefficient of variance			110.2		

Table B 46 -- Moisture contents from the Nuclear Density for replaced fifth lift after rain event for tests in the T-section for Trench B

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	11.4	10.6	11.0	1.1	14.5
2	7.8	9.1	8.4	0.2	2.3
3	8.0	7.9	8.0	0.5	5.3
4	6.7	7.2	7.0	0.8	11.1
Average			8.6		
Standard deviation			1.7		
Coefficient of variance			19.8		

Table B 47 -- Dry unit weight from the Nuclear Density testing results for replaced fifth lift after rain event for tests in the T-section for Trench B

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	114.8	116.6	115.7	1.3	1.1
2	118.0	112.2	115.1	4.1	3.6
3	123.9	122.0	123.0	1.3	1.1
4	114.7	117.9	116.3	2.3	1.9
Average			117.5		
Standard deviation			3.7		
Coefficient of variance			3.1		

Table B 48 – Summary of moisture content results from the Nuclear Density tests for Trench B

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Bulking moisture content (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	6.6	6.2 / 7.1	4.0 to 8.0	2.3	34.8
Fifth lift	4	5.1	4.8 / 5.5	4.0 to 8.0	0.2	2.9
Replaced fifth lift *before rain event* for tests within the trench	4	7.9	6.0 / 9.1	N/A	1.4	17.6
Replaced fifth lift *before rain event* for tests in the T-section	4	10.3	8.0 / 12.6	N/A	2.0	18.4
Replaced fifth lift *after rain event* for tests within the trench	4	7.0	5.6 / 8.2	N/A	1.2	17.1
Replaced fifth lift *after rain event* for tests in the T-section	4	7.9	7.4 / 8.6	N/A	0.5	6.8
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	8.6	7.0 / 11.0	N/A	1.7	19.8

Table B 49 – Summary of dry unit weight results from the Nuclear Density tests for Trench B

Location	Number of test points	Average dry unit weight (pcf)	Min/Max dry unit weight from field-testing (pcf)	Relative density (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	112.9	110.0 / 116.0	41.16	2.3	2.0
Fifth lift	4	118.2	114.9 / 120.9	54.35	1.7	1.4
Replaced fifth lift *before rain event* for tests within the trench	4	107.5	102.6 / 117.7	N/A	3.8	3.5
Replaced fifth lift *before rain event* for tests in the T-section	4	102.5	97.0 / 107.9	N/A	4.7	4.6
Replaced fifth lift *after rain event* for tests within the trench	4	115.3	111.0 / 117.0	N/A	2.4	2.0
Replaced fifth lift *after rain event* for tests in the T-section	4	108.7	106.7 / 110.8	N/A	2.1	1.9
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	117.5	115.1 / 123.0	N/A	3.7	3.1

DCP Test Results

Table B 50 -- DCP test results for lift 3 test point 1 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	251.0	0.0
1	1.0	286.0	35.0
1	1.0	312.0	61.0
1	3.0	367.0	116.0
1	3.0	438.0	187.0
1	3.0	469.0	218.0
1	3.0	511.0	260.0
1	4.0	571.0	320.0
1	4.0	624.0	373.0
1	4.0	671.0	420.0
1	5.0	724.0	473.0
1	5.0	776.0	525.0
1	5.0	828.0	577.0
1	5.0	878.0	627.0
1	5.0	922.0	671.0

Table B 51 -- DCP test results for lift 3 test point 2 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	273.0	0.0
2	1.0	322.0	49.0
2	1.0	342.0	69.0
2	2.0	372.0	99.0
2	2.0	399.0	126.0
2	3.0	425.0	152.0
2	3.0	453.0	180.0
2	3.0	493.0	220.0
2	4.0	552.0	279.0
2	4.0	595.0	322.0
2	5.0	652.0	379.0
2	5.0	707.0	434.0
2	5.0	758.0	485.0
2	5.0	811.0	538.0
2	5.0	865.0	592.0
2	4.0	914.0	641.0
2	2.0	941.0	668.0

Table B 52 -- DCP test results for lift 3 test point 3 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	245.0	0.0
3	1.0	289.0	44.0
3	1.0	310.0	65.0
3	1.0	328.0	83.0
3	1.0	340.0	95.0
3	2.0	368.0	123.0
3	2.0	393.0	148.0
3	3.0	429.0	184.0
3	3.0	465.0	220.0
3	3.0	505.0	260.0
3	3.0	549.0	304.0
3	2.0	582.0	337.0
3	2.0	619.0	374.0
3	2.0	648.0	403.0
3	2.0	674.0	429.0
3	2.0	698.0	453.0
3	3.0	734.0	489.0
3	3.0	770.0	525.0
3	3.0	808.0	563.0
3	3.0	846.0	601.0
3	3.0	890.0	645.0
3	3.0	938.0	693.0

Table B 53 -- DCP test results for lift 3 test point 4 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	256.0	0.0
4	1.0	281.0	25.0
4	1.0	304.0	48.0
4	1.0	322.0	66.0
4	2.0	359.0	103.0
4	2.0	387.0	131.0
4	2.0	420.0	164.0
4	3.0	465.0	209.0
4	3.0	506.0	250.0
4	3.0	549.0	293.0
4	3.0	587.0	331.0
4	3.0	625.0	369.0
4	3.0	662.0	406.0
4	3.0	699.0	443.0
4	3.0	730.0	474.0
4	3.0	761.0	505.0
4	4.0	800.0	544.0
4	4.0	842.0	586.0
4	4.0	878.0	622.0
4	3.0	921.0	665.0
4	3.0	967.0	711.0

Table B 54 -- DCP test results for lift 5 test point 1 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	268.0	0.0
1	1.0	322.0	54.0
1	1.0	348.0	80.0
1	2.0	393.0	125.0
1	2.0	433.0	165.0
1	3.0	493.0	225.0
1	3.0	551.0	283.0
1	3.0	594.0	326.0
1	3.0	628.0	360.0
1	4.0	673.0	405.0
1	4.0	717.0	449.0
1	4.0	762.0	494.0
1	4.0	806.0	538.0
1	4.0	839.0	571.0
1	5.0	876.0	608.0
1	5.0	908.0	640.0
1	5.0	948.0	680.0

Table B 55 -- DCP test results for lift 5 test point 2 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	1.0	287.0	30.0
2	1.0	311.0	54.0
2	1.0	331.0	74.0
2	2.0	364.0	107.0
2	2.0	391.0	134.0
2	2.0	417.0	160.0
2	3.0	454.0	197.0
2	3.0	498.0	241.0
2	3.0	524.0	267.0
2	4.0	576.0	319.0
2	4.0	629.0	372.0
2	4.0	677.0	420.0
2	4.0	725.0	468.0
2	4.0	770.0	513.0
2	4.0	806.0	549.0
2	4.0	839.0	582.0
2	4.0	871.0	614.0
2	4.0	903.0	646.0
2	4.0	931.0	674.0
2	1.0	287.0	30.0

Table B 56 -- DCP test results for lift 5 test point 3 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	243.0	0.0
3	1.0	277.0	34.0
3	1.0	300.0	57.0
3	2.0	338.0	95.0
3	2.0	373.0	130.0
3	2.0	404.0	161.0
3	3.0	449.0	206.0
3	3.0	494.0	251.0
3	3.0	532.0	289.0
3	3.0	567.0	324.0
3	4.0	613.0	370.0
3	4.0	660.0	417.0
3	4.0	697.0	454.0
3	4.0	730.0	487.0
3	4.0	763.0	520.0
3	5.0	802.0	559.0
3	5.0	841.0	598.0
3	5.0	880.0	637.0
3	5.0	912.0	669.0

Table B 57 -- DCP test results for lift 5 test point 4 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	249.0	0.0
4	1.0	283.0	34.0
4	1.0	309.0	60.0
4	2.0	347.0	98.0
4	2.0	367.0	118.0
4	2.0	392.0	143.0
4	3.0	427.0	178.0
4	3.0	458.0	209.0
4	4.0	499.0	250.0
4	4.0	540.0	291.0
4	4.0	580.0	331.0
4	4.0	609.0	360.0
4	5.0	644.0	395.0
4	5.0	681.0	432.0
4	5.0	719.0	470.0
4	5.0	758.0	509.0
4	5.0	800.0	551.0
4	5.0	842.0	593.0
4	5.0	890.0	641.0
4	5.0	939.0	690.0

Table B 58 -- DCP test results for replaced lift 5 before it rained test point 1 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	83.0	0.0
1	2.0	162.0	79.0
1	2.0	209.0	126.0
1	3.0	330.0	247.0
1	2.0	456.0	373.0
1	5.0	543.0	460.0
1	5.0	597.0	514.0
1	5.0	638.0	555.0
1	10.0	721.0	638.0
1	10.0	819.0	736.0

Table B 59 -- DCP test results for lift 5 before it rained test point 2 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	85.0	0.0
2	1.0	147.0	62.0
2	2.0	227.0	142.0
2	2.0	291.0	206.0
2	3.0	389.0	304.0
2	5.0	469.0	384.0
2	5.0	533.0	448.0
2	8.0	603.0	518.0
2	10.0	670.0	585.0
2	10.0	753.0	668.0
2	10.0	850.0	765.0

Table A 1 -- DCP test results for lift 5 before it rained test point 3 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	94.0	0.0
3	1.0	127.0	33.0
3	5.0	138.0	44.0
3	5.0	228.0	134.0
3	3.0	285.0	191.0
3	3.0	386.0	292.0
3	3.0	474.0	380.0
3	2.0	559.0	465.0
3	3.0	620.0	526.0
3	5.0	682.0	588.0
3	5.0	724.0	630.0
3	5.0	758.0	664.0
3	5.0	782.0	688.0
3	5.0	808.0	714.0

Table B 60 -- DCP test results for lift 5 before it rained test point 4 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	84.0	0.0
4	1.0	146.0	62.0
4	1.0	188.0	104.0
4	2.0	238.0	154.0
4	3.0	331.0	247.0
4	3.0	412.0	328.0
4	3.0	514.0	430.0
4	3.0	572.0	488.0
4	5.0	612.0	528.0
4	8.0	665.0	581.0
4	10.0	750.0	666.0
4	10.0	847.0	763.0

Table B 61 -- DCP test results for lift 5 before it rained test point 5 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
5	0.0	78.0	0.0
5	2.0	233.0	155.0
5	2.0	320.0	242.0
5	3.0	425.0	347.0
5	3.0	527.0	449.0
5	2.0	660.0	582.0
5	2.0	821.0	743.0

Table B 62 -- DCP test results for lift 5 before it rained test point 6 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
6	0.0	76.0	0.0
6	1.0	150.0	74.0
6	1.0	196.0	120.0
6	2.0	340.0	264.0
6	2.0	507.0	431.0
6	2.0	554.0	478.0
6	3.0	605.0	529.0
6	4.0	757.0	681.0
6	1.0	824.0	748.0
6	0.0	76.0	0.0
6	1.0	150.0	74.0
6	1.0	196.0	120.0

Table B 63 -- DCP test results for lift 5 before it rained test point 7 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
7	0.0	97.0	0.0
7	2.0	192.0	95.0
7	3.0	293.0	196.0
7	2.0	386.0	289.0
7	2.0	518.0	421.0
7	2.0	645.0	548.0
7	2.0	776.0	679.0
7	2.0	953.0	856.0

Table B 64 -- DCP test results for lift 5 before it rained test point 8 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
8	0.0	55.0	0.0
8	1.0	129.0	74.0
8	2.0	220.0	165.0
8	2.0	334.0	279.0
8	2.0	449.0	394.0
8	2.0	555.0	500.0
8	2.0	711.0	656.0
8	2.0	870.0	815.0

Table B 65 -- DCP test results for replaced lift 5 after it rained test point 1 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	156.0	0.0
1	3.0	336.0	180.0
1	2.0	443.0	287.0
1	1.0	573.0	417.0
1	3.0	667.0	511.0
1	5.0	723.0	567.0
1	8.0	796.0	640.0
1	8.0	884.0	728.0

Table B 66 -- DCP test results for lift 5 after it rained test point 2 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	190.0	0.0
2	1.0	357.0	167.0
2	1.0	461.0	271.0
2	1.0	552.0	362.0
2	1.0	623.0	433.0
2	1.0	646.0	456.0
2	2.0	675.0	485.0
2	3.0	700.0	510.0
2	5.0	742.0	552.0
2	5.0	791.0	601.0
2	5.0	861.0	671.0
2	2.0	905.0	715.0
2	2.0	935.0	745.0

Table B 67 -- DCP test results for lift 5 after it rained test point 3 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	165.0	0.0
3	1.0	293.0	128.0
3	1.0	422.0	257.0
3	1.0	523.0	358.0
3	1.0	634.0	469.0
3	1.0	661.0	496.0
3	2.0	695.0	530.0
3	2.0	733.0	568.0
3	4.0	810.0	645.0
3	4.0	861.0	696.0
3	4.0	911.0	746.0

Table B 68 -- DCP test results for lift 5 after it rained test point 4 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	144.0	0.0
4	1.0	215.0	71.0
4	1.0	264.0	120.0
4	3.0	280.0	136.0
4	3.0	354.0	210.0
4	1.0	432.0	288.0
4	1.0	496.0	352.0
4	1.0	586.0	442.0
4	1.0	650.0	506.0
4	1.0	666.0	522.0
4	4.0	705.0	561.0
4	4.0	742.0	598.0
4	4.0	781.0	637.0
4	4.0	821.0	677.0
4	3.0	862.0	718.0
4	3.0	903.0	759.0
4	3.0	942.0	798.0
4	3.0	985.0	841.0

Table B 69 -- DCP test results for lift 5 after it rained test point 5 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
5	0.0	147.0	0.0
5	1.0	262.0	115.0
5	1.0	343.0	196.0
5	1.0	421.0	274.0
5	1.0	468.0	321.0
5	1.0	519.0	372.0
5	2.0	596.0	449.0
5	3.0	636.0	489.0
5	2.0	685.0	538.0
5	1.0	736.0	589.0
5	1.0	801.0	654.0
5	1.0	869.0	722.0
5	1.0	943.0	796.0
5	1.0	984.0	837.0

Table B 70 -- DCP test results for lift 5 after it rained test point 6 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
6	0.0	156.0	0.0
6	1.0	258.0	102.0
6	1.0	339.0	183.0
6	1.0	386.0	230.0
6	2.0	408.0	252.0
6	2.0	442.0	286.0
6	1.0	495.0	339.0
6	2.0	542.0	386.0
6	3.0	596.0	440.0
6	3.0	648.0	492.0
6	3.0	701.0	545.0
6	1.0	729.0	573.0
6	1.0	781.0	625.0
6	1.0	877.0	721.0
6	1.0	955.0	799.0
6	1.0	990.0	834.0

Table B 71 -- DCP test results for lift 5 after it rained test point 7 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
7	0.0	157.0	0.0
7	1.0	333.0	176.0
7	1.0	538.0	381.0
7	1.0	654.0	497.0
7	1.0	729.0	572.0
7	1.0	820.0	663.0
7	1.0	948.0	791.0
7	1.0	1030.0	873.0

Table B 72 -- DCP test results for lift 5 after it rained test point 8 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
8	0.0	179.0	0.0
8	1.0	311.0	132.0
8	1.0	398.0	219.0
8	1.0	540.0	361.0
8	1.0	653.0	474.0
8	1.0	746.0	567.0
8	1.0	838.0	659.0
8	1.0	936.0	757.0
8	1.0	1048.0	869.0

Table B 73 -- DCP test results for lift 5 after it rained test point 9 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
9	0.0	147.0	0.0
9	1.0	228.0	81.0
9	3.0	334.0	187.0
9	3.0	445.0	298.0
9	2.0	564.0	417.0
9	2.0	716.0	569.0
9	2.0	889.0	742.0
9	1.0	968.0	821.0

Table B 74 -- DCP test results for lift 5 after it rained test point 10 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
10	0.0	160.0	0.0
10	1.0	274.0	114.0
10	2.0	399.0	239.0
10	3.0	447.0	287.0
10	3.0	536.0	376.0
10	2.0	625.0	465.0
10	2.0	677.0	517.0
10	5.0	742.0	582.0
10	3.0	809.0	649.0
10	5.0	936.0	776.0

Table B 75 -- DCP test results for lift 5 after it rained test point 11 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
11	11.0	1.0	197.0
11	11.0	2.0	294.0
11	11.0	1.0	346.0
11	11.0	1.0	423.0
11	11.0	1.0	486.0
11	11.0	2.0	600.0
11	11.0	1.0	665.0
11	11.0	1.0	728.0
11	11.0	1.0	799.0
11	11.0	1.0	857.0
11	11.0	1.0	920.0
11	11.0	1.0	990.0

Table B 76 -- DCP test results for lift 5 after it rained test point 12 for Trench B

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
12	0.0	172.0	0.0
12	1.0	336.0	164.0
12	1.0	375.0	203.0
12	1.0	440.0	268.0
12	1.0	512.0	340.0
12	1.0	553.0	381.0
12	1.0	616.0	444.0
12	1.0	679.0	507.0
12	1.0	738.0	566.0
12	1.0	795.0	623.0
12	1.0	854.0	682.0
12	1.0	903.0	731.0
12	1.0	964.0	792.0
12	1.0	1023.0	851.0

Table B 77 – Summary of DCPI results from the DCP tests for Trench B

Location	Number of test points	Average depth of tests (inches)	Average DCPI	Standard deviation	Coefficient of variance (%)
Third lift	4	27.0	15.0	7.3	48.7
Fifth lift	4	26.7	16.6	9.0	54.2
Replaced fifth lift *before rain event* for tests within the trench	4	27.5	24.6	16.4	66.7
Replaced fifth lift *before rain event* for tests in the T-section	4	31.1	61.8	18.2	29.4
Replaced fifth lift *after rain event* for tests within the trench	4	27.1	56.2	49.3	87.7
Replaced fifth lift *after rain event* for tests in the T-section	4	33.6	48.0	53.6	111.7
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	32.3	63.2	34.7	54.9

Table B 78 – Summary of average CBR results from the DCP tests for Trench B

Location	Number of test points	Average depth of tests (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	27.0	16	7.4	46.3
Fifth lift	4	26.7	20	8.0	40.0
Replaced fifth lift *before rain event* for tests within the trench	4	27.5	15	11.9	79.3
Replaced fifth lift *before rain event* for tests in the T-section	4	31.1	4	1.7	42.5
Replaced fifth lift *after rain event* for tests within the trench	4	27.1	8	48.7	608.7
Replaced fifth lift *after rain event* for tests in the T-section	4	33.6	1	2.6	260.0
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	32.3	4	3.6	90.0

Clegg Hammer Test Results

Table B 79 -- Clegg Hammer test results for lift 3 for Trench B

Location #	IV Value	CBR (%)
1	16.6	24.8
2	7.9	8.4
3	10.6	12.6
4	9.7	11.1
Average	11.2	14.2
Standard Deviation	3.8	7.3
Coefficient of variance	33.7	51.3

Table B 80 -- Clegg Hammer test results for lift 5 for Trench B

Location #	IV Value	CBR (%)
1	13.6	18.2
2	12.0	15.1
3	22.9	42.2
4	22.9	42.2
Average	17.9	29.4
Standard Deviation	5.9	14.8
Coefficient of variance	32.9	50.4

Table B 81 -- Clegg Hammer test results for replaced lift 5 before it rained for test points within Trench B

Location #	IV Value	CBR (%)
1	6.4	6.4
2	3.9	3.7
3	3.0	3.0
4	5.8	5.7
Average	4.8	4.7
Standard Deviation	1.6	1.6
Coefficient of variance	33.3	34.6

Table B 82 -- Clegg Hammer test results for replaced lift 5 before it rained for test points in T-section for Trench B

Location #	IV Value	CBR (%)
5	3.4	3.3
6	3.8	3.7
7	4.4	4.2
8	5.1	4.9
Average	4.2	4.0
Standard Deviation	0.7	0.7
Coefficient of variance	17.7	17.9

Table B 83 -- Clegg Hammer test results for replaced lift 5 after it rained for test points within Trench B

Location #	IV Value	CBR (%)
1	7.5	7.8
2	15.1	21.4
3	6.5	6.6
4	5.9	5.8
Average	8.8	10.4
Standard Deviation	4.3	7.4
Coefficient of variance	49.0	70.8

Table B 84 -- Clegg Hammer test results for replaced lift 5 after it rained for test points in T-section for Trench B

Location #	IV Value	CBR (%)
5	6.5	6.6
6	5.2	5.1
7	7.3	7.6
8	7.3	7.6
Average	6.6	6.7
Standard Deviation	1.0	1.2
Coefficient of variance	15.1	17.8

Table B 85 -- Clegg Hammer test results for replaced lift 5 after it rained for test points in soil adjacent to Trench B

Location #	IV Value	CBR (%)
9	11.2	13.6
10	5.1	4.9
11	8.4	9.1
12	12.0	15.1
Average	9.2	10.7
Standard Deviation	3.1	4.6
Coefficient of variance	34.1	42.9

Table B 86 – Summary of impact value results from the Clegg Hammer tests for Trench B

Location	Number of test points	Average IV reading	Min/Max IV readings	Standard deviation	Coefficient of variance (%)
Third lift	4	14.2	7.9 / 16.6	3.8	33.6
Fifth lift	4	17.9	12.0 / 22.9	5.9	32.9
Replaced fifth lift *before rain event* for tests within the trench	4	4.8	3.9 / 6.4	1.6	33.3
Replaced fifth lift *before rain event* for tests in the T-section	4	4.2	3.4 / 5.1	0.7	16.7
Replaced fifth lift *after rain event* for tests within the trench	4	8.8	5.8 / 15.1	4.3	48.9
Replaced fifth lift *after rain event* for tests in the T-section	4	6.6	7.3 / 5.1	1.2	17.1
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	9.2	5.1 / 12.0	3.1	33.7

Table B 87 – Summary of CBR results from the Clegg Hammer tests for Trench B

Location	Number of test points	Average CBR (%)	Min/Max CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	14	8 / 25	7.3	51.3
Fifth lift	4	28	15 / 42	14.8	50.4
Replaced fifth lift *before rain event* for tests within the trench	4	5	3 / 6	1.6	34.6
Replaced fifth lift *before rain event* for tests in the T-section	4	4	3/ 5	0.7	17.5
Replaced fifth lift *after rain event* for tests within the trench	4	15	6 / 21	7.4	74.0
Replaced fifth lift *after rain event* for tests in the T-section	4	7	5 / 8	1.2	17.1
Replaced fifth lift *after rain event* for tests in the soil adjacent to the trench	4	11	5 / 15	4.5	40.9

B.1.3 - Trench C

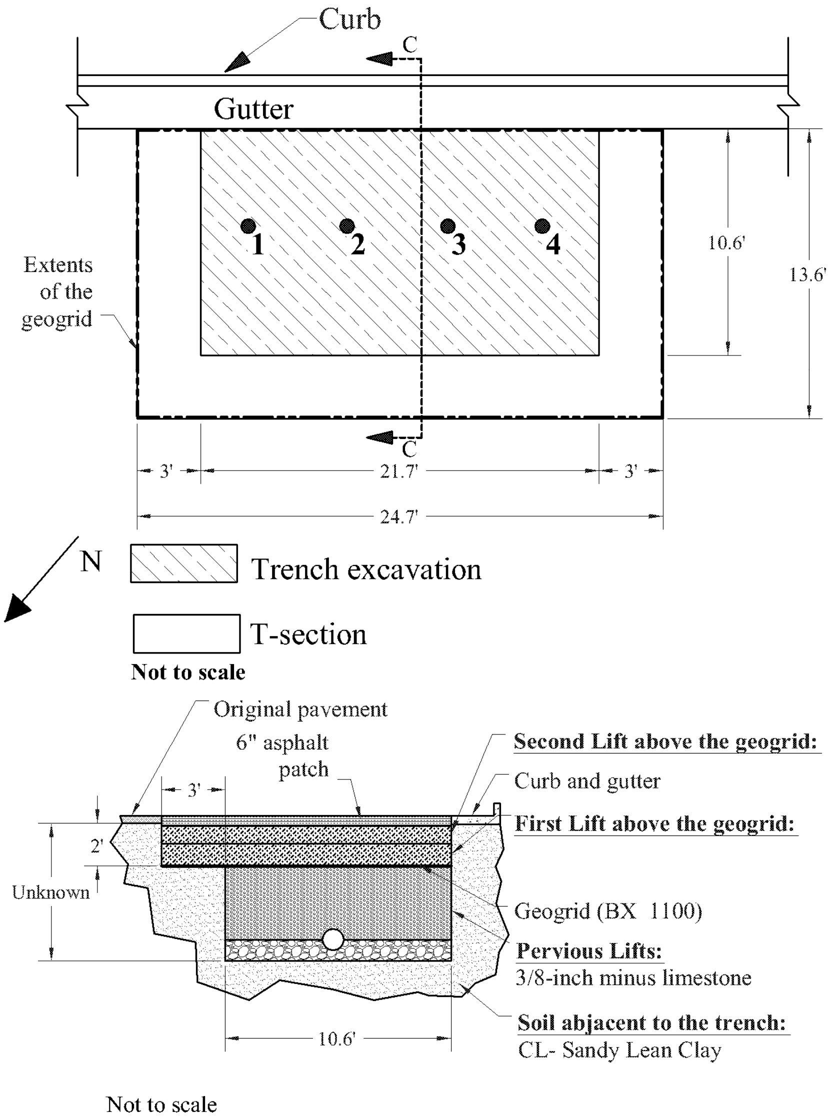


Figure B 3 -- Field-testing locations for Trench C

Nuclear Density Test Results

Table B 88 -- Moisture contents from the Nuclear Density testing results for first lift above geogrid for Trench C

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	10.6		10.6		
2	12.4		12.4		
3	12.5		12.5		
4	9.7		9.7		
Average			11.3		
Standard deviation			1.4		
Coefficient of variance			12.2		

Table B 89 -- Dry unit weight from the Nuclear Density testing results for first lift above geogrid for Trench C

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	114.9		111.5		
2	111.1		110.9		
3	101.2		116.0		
4	116.8		113.2		
Average			111.0		
Standard deviation			6.9		
Coefficient of variance			6.3		

Table B 90 -- Moisture contents from the Nuclear Density testing results for second lift above geogrid for Trench C

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	9.7		10.6		
2	10.7		12.4		
3	8.9		12.5		
4	11.0		9.7		
Average			10.1		
Standard deviation			1.0		
Coefficient of variance			9.5		

Table B 91 -- Dry unit weight from the Nuclear Density testing results for second lift above geogrid for Trench C

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	117.4		111.5		
2	119.6		110.9		
3	121.2		116.0		
4	113.1		113.2		
Average			117.8		
Standard deviation			3.5		
Coefficient of variance			3.0		

Table B 92 – Summary of moisture content results from the Nuclear Density tests for Trench C

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Standard deviation	Coefficient of variance (%)
First lift above the geogrid	4	11.3	9.7 / 12.5	1.4	12.4
Second lift above the geogrid	4	10.0	8.9 / 11.0	1.0	3.0

Table B 93—Summary of dry unit weight results from the Nuclear Density tests for Trench C

Location	Number of test points	Average dry unit weight (pcf)	Min/Max dry unit weight (pcf)	Standard deviation	Coefficient of variance (%)
First lift above the geogrid	4	111.0	101.2 / 116.8	6.9	6.2
Second lift above the geogrid	4	117.8	113.1 / 121.2	3.5	3.0

DCP Test Results

Table B 94 -- DCP test results for first lift above geogrid test point 1 for Trench C

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	190.0	0.0
1	1.0	241.0	51.0
1	2.0	271.0	81.0
1	2.0	342.0	152.0
1	1.0	432.0	242.0
1	1.0	500.0	310.0
1	2.0	544.0	354.0
1	2.0	632.0	442.0
1	2.0	713.0	523.0
1	2.0	812.0	622.0
1	2.0	923.0	733.0

Table B 95 -- DCP test results for first lift above geogrid test point 2 for Trench C

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	182.0	0.0
2	1.0	221.0	39.0
2	1.0	262.0	80.0
2	2.0	298.0	116.0
2	2.0	342.0	160.0
2	1.0	358.0	176.0
2	1.0	372.0	190.0
2	2.0	395.0	213.0
2	2.0	410.0	228.0
2	2.0	430.0	248.0
2	2.0	452.0	270.0
2	2.0	473.0	291.0
2	2.0	495.0	313.0
2	2.0	523.0	341.0
2	2.0	545.0	363.0
2	4.0	600.0	418.0
2	4.0	649.0	467.0
2	4.0	708.0	526.0
2	4.0	768.0	586.0
2	4.0	835.0	653.0
2	4.0	905.0	723.0

Table B 96 -- DCP test results for first lift above geogrid test point 3 for Trench C

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	198.0	0.0
3	1.0	223.0	25.0
3	1.0	262.0	64.0
3	2.0	312.0	114.0
3	2.0	358.0	160.0
3	1.0	384.0	186.0
3	1.0	440.0	242.0
3	1.0	522.0	324.0
3	1.0	571.0	373.0
3	1.0	632.0	434.0
3	1.0	691.0	493.0
3	1.0	746.0	548.0
3	1.0	813.0	615.0
3	1.0	914.0	716.0
3	1.0	1050.0	852.0

Table B 97 -- DCP test results for first lift above geogrid test point 4 for Trench C

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	195.0	0.0
4	1.0	242.0	47.0
4	1.0	269.0	74.0
4	2.0	336.0	141.0
4	2.0	470.0	275.0
4	1.0	622.0	427.0
4	1.0	702.0	507.0
4	1.0	705.0	510.0
4	1.0	782.0	587.0
4	2.0	813.0	618.0
4	2.0	883.0	688.0
4	2.0	995.0	800.0

Table B 98 -- DCP test results for second lift above the geogrid geogrid test point 1 for Trench C

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	196.0	0.0
1	1.0	228.0	32.0
1	1.0	248.0	52.0
1	2.0	293.0	97.0
1	2.0	326.0	130.0
1	2.0	362.0	166.0
1	2.0	418.0	222.0
1	2.0	459.0	263.0
1	2.0	495.0	299.0
1	2.0	523.0	327.0
1	2.0	573.0	377.0
1	2.0	645.0	449.0
1	2.0	711.0	515.0
1	2.0	786.0	590.0
1	2.0	870.0	674.0
1	2.0	951.0	755.0

Table B 99 -- DCP test results for second lift above the geogrid test point 2 for Trench C

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	198.0	0.0
2	1.0	230.0	32.0
2	1.0	256.0	58.0
2	2.0	299.0	101.0
2	2.0	339.0	141.0
2	2.0	367.0	169.0
2	2.0	396.0	198.0
2	2.0	422.0	224.0
2	2.0	459.0	261.0
2	2.0	508.0	310.0
2	2.0	545.0	347.0
2	2.0	576.0	378.0
2	2.0	637.0	439.0
2	2.0	680.0	482.0
2	2.0	699.0	501.0
2	2.0	712.0	514.0
2	4.0	746.0	548.0
2	4.0	784.0	586.0
2	4.0	821.0	623.0
2	4.0	863.0	665.0
2	4.0	908.0	710.0
2	4.0	949.0	751.0

Table B 100 -- DCP test results for second lift above the geogrid test point 3 for Trench C

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	184.0	0.0
3	1.0	242.0	58.0
3	1.0	269.0	85.0
3	2.0	313.0	129.0
3	2.0	352.0	168.0
3	2.0	397.0	213.0
3	2.0	444.0	260.0
3	2.0	508.0	324.0
3	2.0	558.0	374.0
3	2.0	586.0	402.0
3	2.0	614.0	430.0
3	2.0	664.0	480.0
3	1.0	742.0	558.0
3	2.0	849.0	665.0
3	1.0	903.0	719.0
3	2.0	985.0	801.0

Table B 101 -- DCP test results for second lift above the geogrid test point 4 for Trench C

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	167.0	0.0
4	1.0	222.0	55.0
4	1.0	255.0	88.0
4	2.0	300.0	133.0
4	2.0	368.0	201.0
4	2.0	422.0	255.0
4	2.0	476.0	309.0
4	2.0	523.0	356.0
4	2.0	569.0	402.0
4	2.0	631.0	464.0
4	1.0	806.0	639.0
4	1.0	887.0	720.0
4	1.0	951.0	784.0

Clegg Hammer Test *Results*

Table B 102 -- Clegg Hammer test results for the first lift above the geogrid for Trench C

Location #	IV Value	CBR (%)
1	6.7	6.8
2	8.5	9.2
3	11.5	14.1
4	5.4	5.3
Average	8.0	8.9
Standard Deviation	2.6	3.9
Coefficient of variance	32.9	43.8

Table B 103 -- Clegg Hammer test results for second lift above the geogrid for Trench C

Location #	IV Value	CBR (%)
1	7.6	8.0
2	9.0	10.0
3	9.7	11.1
4	8.3	9.0
Average	8.7	9.5
Standard Deviation	0.9	1.3
Coefficient of variance	10.4	14.1

Table B 104 – Summary of impact value results from the Clegg Hammer tests for Trench C

Location	Number of test points	Average IV reading	Min/Max IV readings	Standard deviation	Coefficient of variance (%)
First lift above the geogrid	4	8.0	5.4 / 11.5	2.6	32.5
Second lift above the geogrid	4	8.7	7.9 / 9.7	0.9	10.3

Table B 105 – summary of CBR results from the Clegg Hammer tests for Trench C

Location	Number of test points	Average CBR (%)	Min/Max CBR (%)	Standard deviation	Coefficient of variance (%)
First lift above the geogrid	4	9	7 / 14	3.9	43.3
Second lift above the geogrid	4	9	8 / 11	1.3	13.7

B.1.4 - Trench D

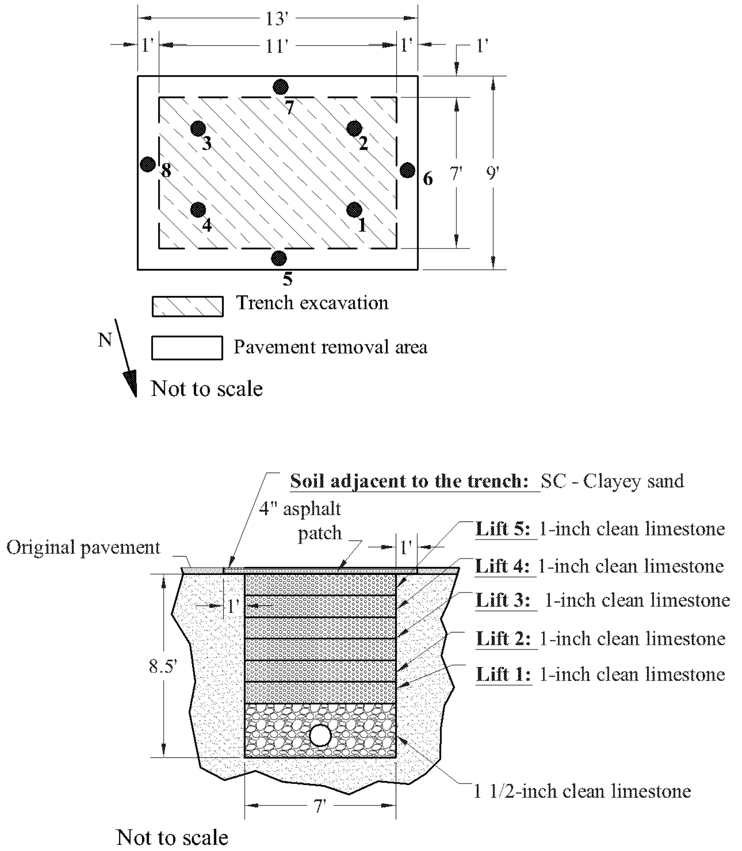


Figure B 4 -- Field-testing locations for Trench D

Nuclear Density Test Results

Table B 106 -- Moisture contents from the Nuclear Density testing results for lift 3 for Trench D

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	3.5	3.1	3.3	0.3	8.0
2	2.4	2.7	2.5	0.2	8.6
3	3.1	3.2	3.2	0.1	2.9
4	3.1	3.4	3.2	0.2	7.0
Average			3.0		
Standard deviation			0.3		
Coefficient of variance			11.3		

Table B 107 -- Dry unit weight from the Nuclear Density testing results for lift 3 for Trench D

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	105.0	103.5	104.3	1.1	1.0
2	108.4	106.0	107.2	1.7	1.6
3	108.4	106.6	107.5	1.3	1.2
4	108.7	108.5	108.6	0.1	0.1
Average			106.9		
Standard deviation			1.9		
Coefficient of variance			1.7		

Table B 108 -- Moisture contents from the Nuclear Density testing results for lift 5 within the trench for Trench D

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	2.2	1.5	1.9	0.5	29.5
2	2.1	2.2	2.1	0.1	5.4
3	2.3	2.2	2.2	0.0	2.1
4	1.4	2.3	1.8	0.6	32.6
Average			2.0		
Standard deviation			0.2		
Coefficient of variance			10.3		

Table B 109 -- Dry unit weight from the Nuclear Density testing results for lift 5 within the trench for Trench D

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	107.4	111.6	109.5	3.0	2.7
2	107.7	106.4	107.1	0.9	0.9
3	115.1	112.9	114.0	1.6	1.4
4	110.6	108.1	109.4	1.8	1.6
Average			110.0		
Standard deviation			2.9		
Coefficient of variance			2.6		

Table B 110 -- Moisture contents from the Nuclear Density testing results for lift 5 in soil adjacent to Trench D

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	5.7	8.9	7.3	2.2	30.3
2	1.7	3.3	2.5	1.1	45.4
3	4.2	5.0	4.6	0.6	13.3
4	5.9	5.9	5.9	0.0	0.2
Average			5.1		
Standard deviation			2.0		
Coefficient of variance			40.0		

Table B 111 -- Dry unit weight from the Nuclear Density testing results for lift 5 in soil adjacent to Trench D

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	122.2	122.8	122.5	0.4	0.3
2	107.7	106.5	107.1	0.8	0.8
3	120.9	123.8	122.4	2.1	1.7
4	119.0	125.4	122.2	4.5	3.7
Average			118.5		
Standard deviation			7.6		
Coefficient of variance			6.4		

Table B 112 – Summary of moisture content results from the Nuclear Density tests for Trench D

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	3.0	2.5 / 3.0	0.3	10
Fifth lift test points within the trench	4	2.0	1.8 / 2.8	0.2	10.2
Soil adjacent to the trench	4	5.1	2.5 / 7.3	2.0	39.2

Table B 113 – Summary of Dry unit weight results from the Nuclear Density tests for Trench D

Location	Number of test points	Average dry unit weight (pcf)	Min/Max dry unit weight from field-testing (pcf)	Relative density (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	106.9	104.3 / 108.6	57	19	1.8
Fifth lift test points within the trench	4	110.0	107.1 / 114.0	63	2.9	2.6
Soil adjacent to the trench	4	118.5	107.1 / 122.5	N/A	7.6	6.4

DCP Test Results

Table B 114 -- DCP test results for lift 3 test point 1 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	150.0	0.0
1	1.0	220.0	70.0
1	2.0	265.0	115.0
1	2.0	305.0	155.0
1	3.0	355.0	205.0
1	3.0	400.0	250.0
1	3.0	440.0	290.0
1	5.0	485.0	335.0
1	5.0	530.0	380.0
1	5.0	580.0	430.0
1	5.0	630.0	480.0
1	5.0	664.0	514.0
1	5.0	690.0	540.0
1	5.0	723.0	573.0
1	5.0	756.0	606.0

Table B 115 -- DCP test results for lift 3 test point 2 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	128.0	0.0
2	1.0	232.0	104.0
2	2.0	306.0	178.0
2	3.0	373.0	245.0
2	3.0	432.0	304.0
2	3.0	474.0	346.0
2	4.0	528.0	400.0
2	3.0	563.0	435.0
2	3.0	597.0	469.0
2	5.0	638.0	510.0
2	5.0	678.0	550.0
2	5.0	704.0	576.0
2	5.0	736.0	608.0
2	5.0	771.0	643.0
2	5.0	796.0	668.0

Table B 116 -- DCP test results for lift 3 test point 3 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	169.0	0.0
3	1.0	273.0	104.0
3	1.0	314.0	145.0
3	3.0	397.0	228.0
3	3.0	444.0	275.0
3	5.0	512.0	343.0
3	5.0	576.0	407.0
3	5.0	600.0	431.0
3	5.0	649.0	480.0
3	8.0	692.0	523.0
3	8.0	747.0	578.0

Table B 117 -- DCP test results for lift 3 test point 4 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	169.0	0.0
4	1.0	208.0	39.0
4	2.0	270.0	101.0
4	2.0	310.0	141.0
4	3.0	353.0	184.0
4	3.0	396.0	227.0
4	3.0	429.0	260.0
4	3.0	455.0	286.0
4	3.0	487.0	318.0
4	5.0	534.0	365.0
4	5.0	574.0	405.0
4	5.0	628.0	459.0
4	8.0	692.0	523.0
4	8.0	763.0	594.0

Table B 118 -- DCP test results for lift 5 test point 1 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	167.0	0.0
1	1.0	231.0	64.0
1	3.0	303.0	136.0
1	3.0	394.0	227.0
1	5.0	404.0	237.0
1	5.0	453.0	286.0
1	5.0	507.0	340.0
1	5.0	553.0	386.0
1	5.0	607.0	440.0
1	5.0	648.0	481.0
1	8.0	697.0	530.0
1	10.0	744.0	577.0
1	10.0	805.0	638.0
1	10.0	864.0	697.0
1	10.0	937.0	770.0

Table B 119 -- DCP test results for lift 5 test point 2 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	199.0	0.0
2	1.0	250.0	51.0
2	1.0	286.0	87.0
2	5.0	388.0	189.0
2	8.0	476.0	277.0
2	10.0	556.0	357.0
2	10.0	631.0	432.0
2	10.0	711.0	512.0
2	10.0	780.0	581.0
2	10.0	837.0	638.0
2	5.0	877.0	678.0
2	5.0	916.0	717.0

Table B 120 -- DCP test results for lift 5 test point 3 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	153.0	0.0
3	1.0	236.0	83.0
3	5.0	334.0	181.0
3	5.0	404.0	251.0
3	5.0	466.0	313.0
3	8.0	537.0	384.0
3	10.0	616.0	463.0
3	10.0	704.0	551.0
3	10.0	784.0	631.0
3	10.0	845.0	692.0
3	10.0	945.0	792.0

Table B 121 -- DCP test results for lift 5 test point 4 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	203.0	0.0
4	1.0	254.0	51.0
4	2.0	294.0	91.0
4	3.0	372.0	169.0
4	3.0	412.0	209.0
4	5.0	470.0	267.0
4	10.0	566.0	363.0
4	10.0	657.0	454.0
4	10.0	710.0	507.0
4	10.0	772.0	569.0
4	10.0	848.0	645.0
4	10.0	912.0	709.0

Table B 122 -- DCP test results for lift 5 test point 5 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
5	0.0	134.0	0.0
5	1.0	156.0	22.0
5	1.0	172.0	38.0
5	3.0	202.0	68.0
5	5.0	235.0	101.0
5	8.0	335.0	201.0
5	2.0	405.0	271.0
5	2.0	498.0	364.0
5	1.0	557.0	423.0
5	2.0	694.0	560.0
5	2.0	782.0	648.0
5	2.0	868.0	734.0
	2.0	924.0	790.0

Table B 123 -- DCP test results for lift 5 test point 6 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
6	0.0	162.0	0.0
6	1.0	253.0	91.0
6	1.0	302.0	140.0
6	3.0	354.0	192.0
6	5.0	437.0	275.0
6	5.0	506.0	344.0
6	8.0	596.0	434.0
6	8.0	687.0	525.0
6	10.0	764.0	602.0
6	10.0	845.0	683.0
6	5.0	899.0	737.0

Table B 124 -- DCP test results for lift 5 test point 7 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
7	0.0	150.0	0.0
7	1.0	178.0	28.0
7	5.0	225.0	75.0
7	5.0	262.0	112.0
7	7.0	371.0	221.0
7	2.0	470.0	320.0
7	2.0	628.0	478.0
7	2.0	805.0	655.0
7	1.0	913.0	763.0

Table B 125 -- DCP test results for lift 5 test point 8 for Trench D

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
8	0.0	153.0	0.0
8	3.0	198.0	45.0
8	10.0	265.0	112.0
8	6.0	376.0	223.0
8	2.0	487.0	334.0
8	1.0	575.0	422.0
8	2.0	710.0	557.0
8	2.0	826.0	673.0
8	2.0	944.0	791.0

Table B 126 -- DCPI results from the DCP tests for Trench D

Location	Number of test points	Average depth of tests (inches)	Average DCPI	Standard deviation	Coefficient of variance (%)
Third lift	4	27.3	33.2	34.6	103.0
Fifth lift test points within the trench	4	29.4	15.9	16.7	105.0
Soil adjacent to the trench	4	29.8	40.5	30.8	76.0

Table B 127 – Average CBR results from the DCP tests for Trench D

Location	Number of test points	Average depth of tests (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	27.3	26	26.8	64.6
Fifth lift test points within the trench	4	29.4	23	12.7	55.2
Soil adjacent to the trench	4	29.8	11	9.7	88.2

Clegg Hammer Test Results

Table B 128 -- Clegg Hammer test results for lift 3 for Trench D

Location #	IV Value	CBR (%)
1	14.0	19.0
2	13.4	17.8
3	20.6	35.3
4	13.0	17.0
Average	15.3	22.3
Standard Deviation	3.6	8.7
Coefficient of variance	23.5	39.3

Table B 129 -- Clegg Hammer test results for lift 5 within the trench for Trench D

Location #	IV Value	CBR (%)
1	24.5	47.3
2	10.9	13.1
3	29.7	66.1
4	21.5	37.9
Average	21.7	41.1
Standard Deviation	7.9	22.0
Coefficient of variance	36.6	53.6

Table B 130 -- Clegg Hammer test results for lift 5 for soil adjacent to the trench for Trench D

Location #	IV Value	CBR (%)
1	23.3	43.5
2	23.3	43.5
3	70.0	316.8
4	31.0	71.2
Average	36.9	118.7
Standard Deviation	22.4	132.7
Coefficient of variance	60.6	111.8

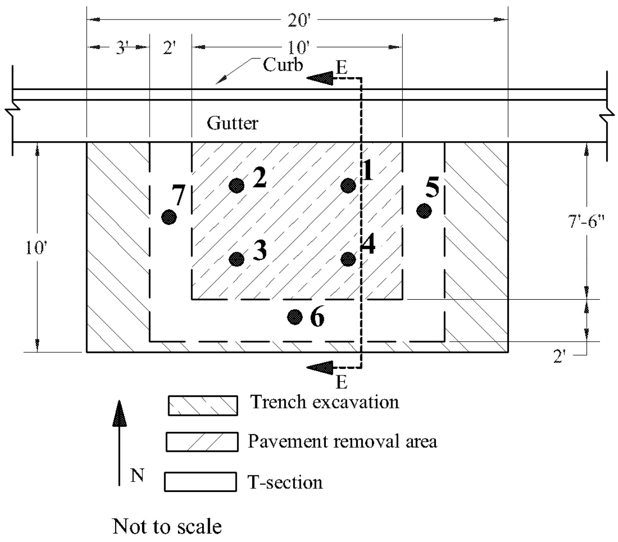
Table B 131 -- Impact value results from the Clegg Hammer tests for Trench D

Location	Number of test points	Average IV reading	Min/Max IV readings	Standard deviation	Coefficient of variance (%)
Third lift	4	15.5	13.0 / 20.6	3.4	21.9
Fifth lift test points within the trench	4	21.7	29.7 / 10.9	5.5	25.3
Soil adjacent to the trench	4	36.9	23.3 / 70.0	22.4	60.6

Table B 132 -- CBR results from the Clegg Hammer tests for Trench D

Location	Number of test points	Average CBR (%)	Min/Max CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	22	17 / 35	8.8	40.0
Fifth lift test points within the trench	4	41	13 / 66	25.6	62.4
Soil adjacent to the trench	4	37	43 / 316	132.7	115.5

B.1.5 - Trench E



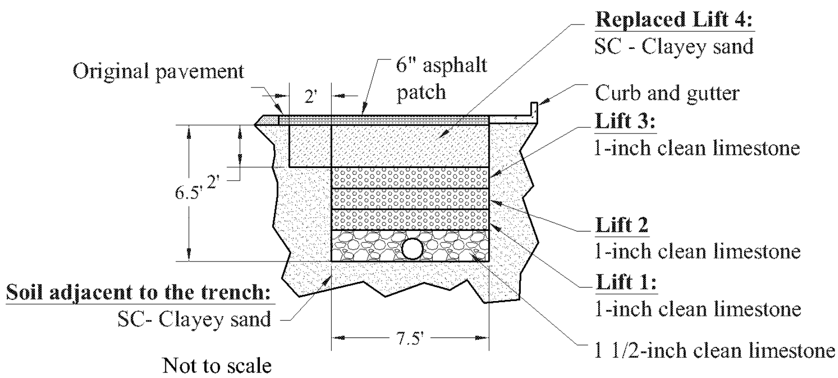


Figure B 5 -- Field-testing locations for Trench E

Nuclear Density Test Results

Table B 133 -- Moisture contents from the Nuclear Density testing results for lift 3 for Trench E

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	4.6	5.1	4.9	0.4	7.3
2	5.1	6.3	5.7	0.8	14.9
3	6.5	5.4	6.0	0.8	13.1
4	6.0	5.6	5.8	0.3	4.9
Average			5.6		
Standard deviation			0.5		
Coefficient of variance			8.9		

Table B 134 -- Dry unit weight from the Nuclear Density testing results for lift 3 for Trench E

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	112.4	110.2	111.3	1.6	1.4
2	108.4	100.0	104.2	5.9	5.7
3	101.8	105.5	103.7	2.6	2.5
4	101.9	104.7	103.3	2.0	1.9
Average			105.6		
Standard deviation			3.8		
Coefficient of variance			3.6		

Table B 135 -- Moisture contents from the Nuclear Density testing results for lift 5 for Trench E

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	2.6	3.7	3.2	0.8	24.7
2	3.2	3.7	3.5	0.4	10.2
3	3.0	4.0	3.5	0.7	20.2
4	2.7	3.9	3.3	0.8	25.7
Average			3.4		
Standard deviation			0.2		
Coefficient of variance			4.7		

Table B 136 -- Dry unit weight from the Nuclear Density testing results for lift 5 for Trench E

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	106.4	100.6	103.5	4.1	4.0
2	101.1	97.9	99.5	2.3	2.3
3	104.6	104.6	104.6	0.0	0.0
4	104.7	97.6	101.2	5.0	5.0
Average			102.2		
Standard deviation			2.3		
Coefficient of variance			2.2		

Table B 137 -- Moisture contents from the Nuclear Density testing results for replaced lift 5 for test points within the trench for Trench E

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	6.7	6.9	6.8	0.1	1.7
2	10.0	14.9	12.4	3.5	28.1
3	11.7	13.0	12.3	1.0	8.0
4	10.5	11.3	10.9	0.6	5.1
Average			10.6		
Standard deviation			2.7		
Coefficient of variance			25.1		

Table B 138 -- Dry unit weight from the Nuclear Density testing results for replaced lift 5 for test points within the trench

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	104.1	106.5	105.3	1.7	1.6
2	106.7	98.8	102.7	5.6	5.5
3	94.6	94.6	94.6	0.0	0.0
4	98.0	95.2	96.6	2.0	2.0
Average			99.8		
Standard deviation			5.0		
Coefficient of variance			5.1		

Table B 139 -- Moisture contents from the Nuclear Density testing results for replaced lift 5 for test points in the T-section for Trench E

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
5	8.7	8.9	8.8	0.1	1.1
6	12.9	16.4	14.7	2.5	16.8
7	12.0	14.5	13.2	1.8	13.5
Average			12.2		
Standard deviation			9.4		
Coefficient of variance			3.1		

Table B 140 -- Dry unit weight from the Nuclear Density testing results for replaced lift 5 for test points in the T-section for Trench E

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
5	105.0	103.9	104.5	0.8	0.7
6	98.7	93.4	96.1	3.8	3.9
7	99.1	91.8	95.5	5.2	5.4
Average			98.7		
Standard deviation			25.3		
Coefficient of variance			5.0		

Table B 141 -- Dry unit weight results from the Nuclear Density tests on Trench E

Location	Number of test points	Average dry unit weight (pcf)	Relative density (%)	Min/Max Dry unit weight (pcf)	Standard deviation	Coefficient of variance (%)
Third lift	4	105.6	54%	103.3 / 111.3	3.8	3.6
Fifth lift tested on July 12, 2007	4	102.2	47%	99.5 / 104.6	2.3	2.3
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	99.8	N/A	94.5 / 102.7	5.0	5.0
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	98.7	N/A	95.5 / 104.5	5.0	5.1

Table B 142 -- Moisture content results from the Nuclear Density tests for Trench E

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	3.0	4.9 / 6.0	0.5	16.6
Fifth lift tested on July 12, 2007	4	3.4	3.2 / 3.5	0.2	5.9
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	10.6	6.8 / 12.9	2.7	25.5
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	12.2	8.8 / 14.7	3.1	25.4

DCP Test Results

Table B 143 -- DCP test results for lift 3 test point 1 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	265.0	0.0
1	2.0	307.0	42.0
1	2.0	340.0	75.0
1	2.0	366.0	101.0
1	2.0	387.0	122.0
1	2.0	407.0	142.0
1	2.0	424.0	159.0
1	2.0	438.0	173.0
1	2.0	451.0	186.0
1	2.0	461.0	196.0
1	2.0	472.0	207.0
1	4.0	500.0	235.0
1	4.0	532.0	267.0
1	4.0	560.0	295.0
1	4.0	583.0	318.0
1	4.0	604.0	339.0
1	4.0	628.0	363.0
1	4.0	652.0	387.0
1	4.0	679.0	414.0
1	4.0	712.0	447.0
1	4.0	743.0	478.0
1	4.0	775.0	510.0
1	4.0	817.0	552.0
1	4.0	856.0	591.0
1	4.0	892.0	627.0
1	3.0	915.0	650.0
1	4.0	946.0	681.0

Table B 144 -- DCP test results for lift 3 test point 2 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	252.0	0.0
2	1.0	288.0	36.0
2	1.0	314.0	62.0
2	2.0	349.0	97.0
2	2.0	372.0	120.0
2	3.0	405.0	153.0
2	3.0	440.0	188.0
2	3.0	471.0	219.0
2	3.0	506.0	254.0
2	5.0	544.0	292.0
2	5.0	591.0	339.0
2	5.0	626.0	374.0
2	5.0	670.0	418.0
2	5.0	709.0	457.0
2	5.0	754.0	502.0
2	4.0	808.0	556.0
2	3.0	855.0	603.0
2	3.0	922.0	670.0
2	3.0	947.0	695.0

Table B 145 -- DCP test results for lift 3 test point 3 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	270.0	0.0
3	1.0	317.0	47.0
3	2.0	366.0	96.0
3	2.0	388.0	118.0
3	2.0	413.0	143.0
3	2.0	433.0	163.0
3	2.0	455.0	185.0
3	3.0	485.0	215.0
3	3.0	512.0	242.0
3	3.0	537.0	267.0
3	3.0	570.0	300.0
3	5.0	602.0	332.0
3	5.0	640.0	370.0
3	5.0	680.0	410.0
3	5.0	715.0	445.0
3	5.0	747.0	477.0
3	5.0	778.0	508.0
3	5.0	826.0	556.0
3	3.0	862.0	592.0
3	3.0	897.0	627.0
3	3.0	910.0	640.0

Table B 146 -- DCP test results for lift 3 test point 4 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	265.0	0.0
4	2.0	329.0	64.0
4	2.0	365.0	100.0
4	2.0	401.0	136.0
4	2.0	423.0	158.0
4	2.0	437.0	172.0
4	4.0	476.0	211.0
4	2.0	489.0	224.0
4	2.0	499.0	234.0
4	4.0	528.0	263.0
4	4.0	549.0	284.0
4	4.0	570.0	305.0
4	5.0	615.0	350.0
4	4.0	639.0	374.0
4	4.0	662.0	397.0
4	4.0	690.0	425.0
4	4.0	721.0	456.0
4	4.0	751.0	486.0
4	4.0	783.0	518.0
4	4.0	810.0	545.0
4	4.0	840.0	575.0
4	4.0	869.0	604.0
4	4.0	895.0	630.0
4	4.0	920.0	655.0

Table B 147 -- DCP test results for lift 5 test point 1 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	290.0	0.0
1	1.0	347.0	57.0
1	1.0	372.0	82.0
1	1.0	389.0	99.0
1	2.0	422.0	132.0
1	2.0	460.0	170.0
1	2.0	490.0	200.0
1	2.0	519.0	229.0
1	3.0	549.0	259.0
1	3.0	581.0	291.0
1	3.0	610.0	320.0
1	3.0	631.0	341.0
1	5.0	675.0	385.0
1	5.0	721.0	431.0
1	5.0	753.0	463.0
1	5.0	797.0	507.0
1	5.0	850.0	560.0
1	5.0	883.0	593.0
1	5.0	906.0	616.0

Table B 148 -- DCP test results for lift 5 test point 2 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	305.0	0.0
2	1.0	366.0	61.0
2	1.0	399.0	94.0
2	1.0	416.0	111.0
2	1.0	435.0	130.0
2	2.0	467.0	162.0
2	2.0	505.0	200.0
2	2.0	537.0	232.0
2	3.0	568.0	263.0
2	3.0	612.0	307.0
2	3.0	649.0	344.0
2	3.0	676.0	371.0
2	3.0	704.0	399.0
2	5.0	760.0	455.0
2	5.0	815.0	510.0
2	5.0	854.0	549.0
2	5.0	882.0	577.0
2	5.0	910.0	605.0

Table B 149 -- DCP test results for lift 5 test point 3 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	257.0	0.0
3	1.0	307.0	50.0
3	1.0	338.0	81.0
3	1.0	352.0	95.0
3	1.0	362.0	105.0
3	2.0	390.0	133.0
3	2.0	419.0	162.0
3	2.0	438.0	181.0
3	3.0	473.0	216.0
3	3.0	504.0	247.0
3	3.0	543.0	286.0
3	3.0	579.0	322.0
3	3.0	614.0	357.0
3	3.0	650.0	393.0
3	3.0	680.0	423.0
3	3.0	702.0	445.0
3	3.0	723.0	466.0
3	5.0	770.0	513.0
3	5.0	814.0	557.0
3	5.0	853.0	596.0
3	5.0	892.0	635.0

Table B 150 -- DCP test results for lift 5 test point 4 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	275.0	0.0
4	1.0	311.0	36.0
4	1.0	345.0	70.0
4	2.0	383.0	108.0
4	2.0	414.0	139.0
4	2.0	442.0	167.0
4	2.0	465.0	190.0
4	2.0	489.0	214.0
4	2.0	508.0	233.0
4	3.0	541.0	266.0
4	3.0	570.0	295.0
4	3.0	591.0	316.0
4	3.0	615.0	340.0
4	3.0	649.0	374.0
4	3.0	674.0	399.0
4	5.0	719.0	444.0
4	5.0	764.0	489.0
4	5.0	814.0	539.0
4	5.0	853.0	578.0
4	5.0	904.0	629.0

Table B 151 -- DCP test results for replaced lift 5 test point 1 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	88.0	0.0
1	1.0	141.0	53.0
1	1.0	191.0	103.0
1	1.0	246.0	158.0
1	1.0	307.0	219.0
1	1.0	341.0	253.0
1	1.0	381.0	293.0
1	1.0	421.0	333.0
1	1.0	454.0	366.0
1	2.0	505.0	417.0
1	2.0	533.0	445.0
1	5.0	564.0	476.0
1	8.0	600.0	512.0
1	8.0	628.0	540.0
1	10.0	662.0	574.0
1	10.0	700.0	612.0

Table B 152 -- DCP test results for replaced lift 5 test point 2 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	110.0	0.0
2	1.0	172.0	62.0
2	1.0	247.0	137.0
2	1.0	292.0	182.0
2	1.0	351.0	241.0
2	1.0	399.0	289.0
2	1.0	437.0	327.0
2	1.0	474.0	364.0
2	2.0	526.0	416.0
2	559.0	449.0	2.0
2	607.0	497.0	3.0
2	634.0	524.0	5.0
2	680.0	570.0	8.0
2	718.0	608.0	8.0
2	761.0	651.0	8.0
2	810.0	700.0	8.0

Table B 153 -- DCP test results for replaced lift 5 test point 3 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	115.0	0.0
3	1.0	202.0	87.0
3	1.0	259.0	144.0
3	1.0	310.0	195.0
3	1.0	373.0	258.0
3	1.0	450.0	335.0
3	1.0	491.0	376.0
3	1.0	521.0	406.0
3	1.0	576.0	461.0
3	3.0	626.0	511.0
3	5.0	662.0	547.0
3	8.0	721.0	606.0
3	8.0	772.0	657.0
3	8.0	836.0	721.0

Table B 154 -- DCP test results for replaced lift 5 test point 4 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	99.0	0.0
4	1.0	163.0	64.0
4	1.0	236.0	137.0
4	1.0	322.0	223.0
4	1.0	413.0	314.0
4	1.0	522.0	423.0
4	1.0	577.0	478.0
4	3.0	642.0	543.0
4	3.0	703.0	604.0
4	1.0	736.0	637.0
4	1.0	775.0	676.0
4	1.0	822.0	723.0

Table B 155 -- DCP test results for replaced lift 5 test point 5 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
5	0.0	114.0	0.0
5	1.0	215.0	101.0
5	1.0	305.0	191.0
5	1.0	366.0	252.0
5	1.0	399.0	285.0
5	1.0	464.0	350.0
5	1.0	537.0	423.0
5	1.0	605.0	491.0
5	1.0	676.0	562.0
5	1.0	746.0	632.0
5	1.0	820.0	706.0

Table B 156 -- DCP test results for replaced lift 5 test point 6 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
6	0.0	88.0	0.0
6	1.0	150.0	62.0
6	1.0	194.0	106.0
6	1.0	255.0	167.0
6	1.0	318.0	230.0
6	1.0	389.0	301.0
6	1.0	457.0	369.0
6	1.0	526.0	438.0
6	1.0	559.0	471.0
6	1.0	638.0	550.0
6	1.0	720.0	632.0
6	1.0	787.0	699.0
6	1.0	852.0	764.0
6	0.0	88.0	0.0

Table B 157 -- DCP test results for replaced lift 5 test point 7 for Trench E

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
7	0.0	145.0	0.0
7	1.0	200.0	55.0
7	1.0	295.0	150.0
7	1.0	389.0	244.0
7	1.0	474.0	329.0
7	1.0	556.0	411.0
7	1.0	662.0	517.0
7	1.0	731.0	586.0
7	1.0	793.0	648.0
7	1.0	850.0	705.0

Table B 158 -- DCPI results from the DCP tests for Trench E

Location	Number of test points	Average depth of tests (inches)	Average DCPI	Standard deviation	Coefficient of variance (%)
Third lift	4	22.7	14.3	9.2	
Fifth lift tested on July 12, 2007	4	24.5	19.8	9.3	47.0
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	27.1	44.5	29.7	66.7
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	28.5	74.2	16.1	21.7

Table B 159 – Average CBR results from the DCP tests for Trench E

Location	Number of test points	Average depth of tests (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	22.7	28	12	
Fifth lift tested on July 12, 2007	4	24.5	16	12.7	79.4
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	27.1	13	17.6	135.4
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	28.5	3	0.8	26.7

Clegg Hammer *Test Results*

Table B 160 -- Clegg Hammer test results for lift 3 for Trench E

Location #	IV Value	CBR (%)
1	13.6	18.2
2	17.3	26.5
3	14.2	19.4
4	15.8	23.0
Average	15.2	21.8
Standard Deviation	1.7	3.8
Coefficient of variance	10.9	17.3

Table B 161 -- Clegg Hammer test results for lift 5 for Trench E

Location #	IV Value	CBR (%)
1	12.3	15.6
2	9.9	11.4
3	11.0	13.2
4	11.4	14.0
Average	11.2	13.6
Standard Deviation	1.0	1.7
Coefficient of variance	8.9	12.9

Table B 162 -- Clegg Hammer test results for replaced lift 5 within the trench for Trench E

Location #	IV Value	CBR (%)
1	3.3	3.2
2	5.3	5.2
3	4.0	3.8
4	4.7	4.5
Average	4.3	4.2
Standard Deviation	0.9	0.8
Coefficient of variance	20.0	20.2

Table B 163 -- Clegg Hammer test results for replaced lift 5 for soil adjacent to the trench for Trench E

Location #	IV Value	CBR (%)
6	4.8	4.6
7	5.8	5.7
8	3.5	3.4
Average	4.7	4.6
Standard Deviation	1.2	1.2
Coefficient of variance	24.5	25.5

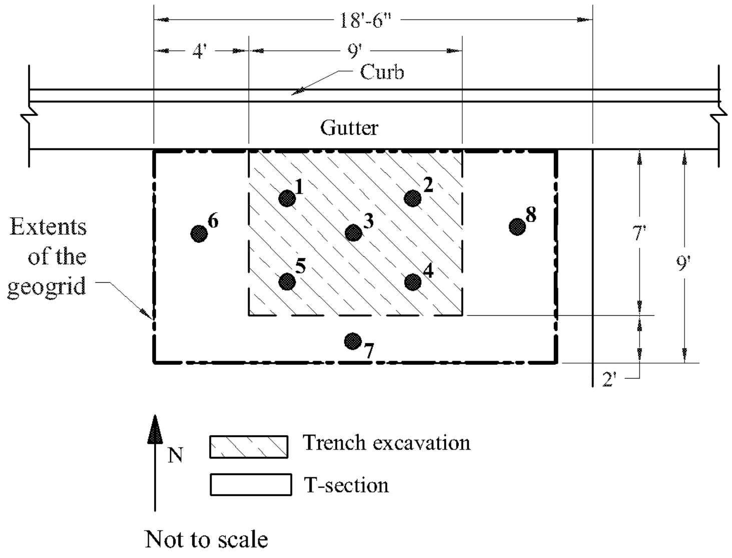
Table B 164 – Summary of impact value results from the Clegg Hammer tests for Trench E

Location	Number of test points	Average IV reading	Min/Max IV readings	Standard deviation	Coefficient of variance (%)
Third lift	4	15.2	13.6 / 17.3	1.7	11.2
Fifth lift tested on July 12, 2007	4	11.2	9.9 / 12.3	1.0	9.0
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	4.3	3.3 / 5.3	0.9	20.9
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	4.7	3.5 / 5.8	1.2	25.5

Table B 165—Summary of CBR results from the Clegg Hammer tests for Trench E

Location	Number of test points	Average CBR (%)	Min/Max CBR (%)	Standard deviation	Coefficient of variance (%)
Third lift	4	22	18 / 27	3.8	17.0
Fifth lift tested on July 12, 2007	4	14	11 / 16	1.8	13.2
Replaced fifth lift at test points within the trench tested on July 18, 2007	4	4	3 / 5	0.8	20.0
Replaced fifth lift at test points in the T-section tested on July 18, 2007	3	5	3 / 6	1.2	26.1

B.1.6 - Trench F



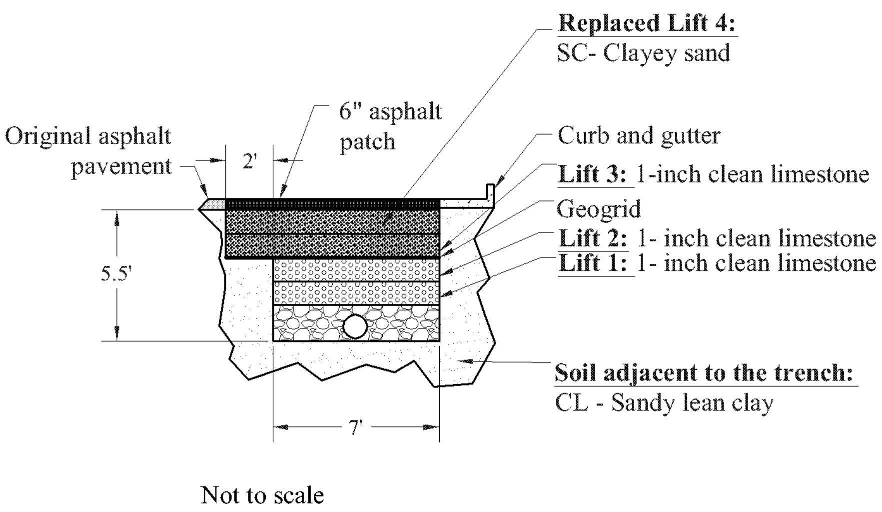


Figure B 6 -- Field-testing locations for Trench F

Nuclear Density Test Results

Table B 166 -- Moisture contents from the Nuclear Density testing results for lift 2 for Trench F

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	8.9	5.6	7.3	0.4	0.1
2	4.8	5.6	5.2	0.8	0.1
3	3.3	3.4	3.4	0.8	0.1
4	5.1	4.4	4.8	0.3	0.0
5	6.0	5.2	5.6		
Average			5.2		
Standard deviation			1.0		
Coefficient of variance			18.7		

Table B 167 -- Dry unit weight from the Nuclear Density testing results for lift 2 for Trench F

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	94.6	99.2	96.9	3.3	3.4
2	101.1	97.1	99.1	2.8	2.9
3	97.7	97.4	97.6	0.2	0.2
4	93.2	88.2	90.7	3.5	3.9
5	90.6	93.0	91.8	1.7	1.8
Average			95.2		
Standard deviation			4.2		
Coefficient of variance			4.4		

Table B 168 -- Moisture contents from the Nuclear Density testing results for lift 4 for Trench F

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	4.0	4.1	4.1	0.1	1.7
2	3.5	4.1	3.8	0.4	11.2
3	3.3	3.8	3.6	0.4	10.0
4	3.9	3.2	3.6	0.5	13.9
5	3.3	3.6	3.5	0.2	6.1
Average			3.7		
Standard deviation			0.2		
Coefficient of variance			6.6		

Table B 169 -- Dry unit weight from the Nuclear Density testing results for lift 4 for Trench F

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	100.0	99.1	99.6	0.6	0.6
2	93.9	97.4	95.7	2.5	2.6
3	104.0	104.1	104.1	0.1	0.1
4	98.7	92.9	95.8	4.1	4.3
5	100.9	99.0	100.0	1.3	1.3
Average			99.0		
Standard deviation			3.5		
Coefficient of variance			3.5		

Table B 170 -- Moisture contents from the Nuclear Density testing results for replaced lift 4 within the trench for Trench F

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	8.9	9.7	9.3	0.6	6.2
2	12.1	13.3	12.7	0.9	6.7
3	14.6	13.7	14.1	0.7	4.9
4	13.4	13.0	13.2	0.3	2.4
5	12.0	13.2	12.6	0.8	6.5
Average			12.4		
Standard deviation			1.8		
Coefficient of variance			14.9		

Table B 171 -- Dry unit weight from the Nuclear Density testing results for replaced lift 4 within the trench for Trench F

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	109.6	112.4	111.0	2.0	1.8
2	105.5	93.8	99.7	8.3	8.3
3	101.9	112.2	107.1	7.3	6.8
4	113.8	114.7	114.3	0.6	0.6
5	114.0	110.0	112.0	2.8	2.5
Average			108.8		
Standard deviation			5.7		
Coefficient of variance			5.3		

Table B 172 -- Moisture contents from the Nuclear Density testing results for replaced lift 4 in T-section for Trench F

Location #	Moisture contents No 1 (%)	Moisture contents No 2(%)	Average moisture content (%)	Standard deviation	Coefficient of variance
1	8.9	9.7	9.3	0.6	6.6
2	15.4	15.1	15.3	0.2	1.4
3	14.1	12.7	13.4	0.9	7.0
Average			12.7		
Standard deviation			3.0		
Coefficient of variance			24.1		

Table B 173 -- Dry unit weight from the Nuclear Density testing results for replaced lift 4 in T-section for Trench F

Location #	Dry unit weight No 1 (pcf)	Dry unit weight No 1 (pcf)	Average dry unit weight (pcf)	Standard deviation	Coefficient of variance
1	112.9	110.2	111.6	1.9	1.7
2	108.2	107.9	108.1	0.2	0.2
3	112.7	111.9	112.3	0.6	0.5
Average			110.6		
Standard deviation			2.3		
Coefficient of variance			2.1		

Table B 174 – Summary of dry unit weight results from the Nuclear Density tests on Trench F

Location	Number of test points	Average dry unit weight (pcf)	Relative density (%)	Min/Max dry unit weight (pcf)	Standard deviation	Coefficient of variance (%)
Second Lift	5	95.2	29	90.7 / 99.1	4.2	4.4
Fourth Lift tested on July 12, 2007	5	99.0	39	85.7 / 104.1	3.5	12.1
Replaced Fourth Lift for test points within the trench tested on July 18, 2007	5	108.8	N/A	99.7 / 114.3	5.7	5.2
Replaced Fourth Lift for test points in the T-section tested on July 18, 2007	3	110.6	N/A	108.1 / 112.3	5.1	2.1

Table B 175—Summary of moisture content results from the Nuclear Density tests for Trench F

Location	Number of test points	Average moisture content (%)	Min/Max moisture content (%)	Standard deviation	Coefficient of variance (%)
Second Lift	5	5.6	3.4 / 7/3	1.0	18.8
Fourth Lift tested on July 12, 2007	5	3.6	3.5 / 4.0	0.2	5.4
Replaced Fourth Lift for test points within the trench tested on July 18, 2007	5	12.3	9.3 / 14.5	1.8	14.5
Replaced Fourth Lift for test points in the T-section tested on July 18, 2007	3	12.6	9.3 / 12.3	3.0	23.8

DCP Test Results

Table B 176 -- DCP test results for lift 2 test point 1 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	278.0	0.0
1	1.0	331.0	53.0
1	1.0	365.0	87.0
1	1.0	401.0	123.0
1	1.0	424.0	146.0
1	1.0	451.0	173.0
1	1.0	472.0	194.0
1	1.0	493.0	215.0
1	2.0	523.0	245.0
1	2.0	549.0	271.0
1	2.0	577.0	299.0
1	2.0	605.0	327.0
1	3.0	638.0	360.0
1	3.0	668.0	390.0
1	3.0	699.0	421.0
1	2.0	723.0	445.0
1	2.0	750.0	472.0
1	2.0	772.0	494.0
1	2.0	795.0	517.0
1	2.0	815.0	537.0
1	2.0	834.0	556.0
1	2.0	854.0	576.0
1	1.0	868.0	590.0
1	2.0	885.0	607.0
1	2.0	908.0	630.0

Table B 177 -- DCP test results for lift 2 test point 2 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	271.0	0.0
2	1.0	332.0	61.0
2	1.0	358.0	87.0
2	1.0	381.0	110.0
2	4.0	439.0	168.0
2	4.0	508.0	237.0
2	4.0	565.0	294.0
2	2.0	598.0	327.0
2	3.0	633.0	362.0
2	3.0	677.0	406.0
2	3.0	716.0	445.0
2	3.0	753.0	482.0
2	3.0	794.0	523.0
2	3.0	832.0	561.0
2	3.0	874.0	603.0
2	1.0	896.0	625.0
2	3.0	933.0	662.0

Table B 178 -- DCP test results for lift 2 test point 3 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	290.0	0.0
3	1.0	369.0	79.0
3	1.0	408.0	118.0
3	1.0	442.0	152.0
3	1.0	459.0	169.0
3	1.0	478.0	188.0
3	2.0	507.0	217.0
3	3.0	558.0	268.0
3	3.0	606.0	316.0
3	3.0	644.0	354.0
3	3.0	685.0	395.0
3	3.0	710.0	420.0
3	3.0	743.0	453.0
3	3.0	782.0	492.0
3	3.0	814.0	524.0
3	3.0	842.0	552.0
3	3.0	872.0	582.0
3	3.0	894.0	604.0

Table B 179 -- DCP test results for lift 2 test point 4 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	280.0	0.0
4	1.0	364.0	84.0
4	1.0	405.0	125.0
4	2.0	447.0	167.0
4	2.0	489.0	209.0
4	2.0	541.0	261.0
4	2.0	644.0	364.0
4	1.0	704.0	424.0
4	1.0	735.0	455.0
4	1.0	765.0	485.0
4	1.0	844.0	564.0
4	1.0	917.0	637.0

Table B 180 -- DCP test results for lift 2 test point 5 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
5	0.0	268.0	0.0
5	1.0	343.0	75.0
5	1.0	372.0	104.0
5	1.0	404.0	136.0
5	1.0	433.0	165.0
5	1.0	459.0	191.0
5	1.0	475.0	207.0
5	1.0	497.0	229.0
5	1.0	513.0	245.0
5	1.0	528.0	260.0
5	1.0	555.0	287.0
5	1.0	586.0	318.0
5	1.0	617.0	349.0
5	2.0	642.0	374.0
5	2.0	663.0	395.0
5	2.0	697.0	429.0
5	2.0	712.0	444.0
5	2.0	734.0	466.0
5	2.0	820.0	552.0
5	1.0	873.0	605.0
5	1.0	924.0	656.0

Table B 181 -- DCP test results for lift 4 test point 1 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	272.0	0.0
1	1.0	341.0	69.0
1	1.0	364.0	92.0
1	1.0	402.0	130.0
1	1.0	427.0	155.0
1	1.0	449.0	177.0
1	2.0	491.0	219.0
1	3.0	530.0	258.0
1	3.0	569.0	297.0
1	3.0	600.0	328.0
1	3.0	631.0	359.0
1	3.0	664.0	392.0
1	3.0	695.0	423.0
1	3.0	719.0	447.0
1	3.0	743.0	471.0
1	3.0	769.0	497.0
1	3.0	798.0	526.0
1	5.0	846.0	574.0
1	5.0	911.0	639.0

Table B 182 -- DCP test results for lift 4 test point 2 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	313.0	0.0
2	1.0	395.0	82.0
2	1.0	439.0	126.0
2	1.0	462.0	149.0
2	1.0	479.0	166.0
2	1.0	494.0	181.0
2	2.0	530.0	217.0
2	3.0	589.0	276.0
2	3.0	628.0	315.0
2	5.0	689.0	376.0
2	5.0	740.0	427.0
2	5.0	789.0	476.0
2	5.0	830.0	517.0
2	5.0	878.0	565.0
2	5.0	932.0	619.0

Table B 183 -- DCP test results for lift 4 test point 3 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	278.0	0.0
3	1.0	342.0	64.0
3	1.0	372.0	94.0
3	1.0	406.0	128.0
3	1.0	427.0	149.0
3	1.0	443.0	165.0
3	2.0	480.0	202.0
3	3.0	538.0	260.0
3	3.0	584.0	306.0
3	3.0	628.0	350.0
3	5.0	687.0	409.0
3	5.0	738.0	460.0
3	5.0	798.0	520.0
3	5.0	852.0	574.0
3	5.0	906.0	628.0

Table B 184 -- DCP test results for lift 4 test point 4 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	285.0	0.0
4	1.0	339.0	54.0
4	1.0	381.0	96.0
4	1.0	411.0	126.0
4	1.0	432.0	147.0
4	2.0	473.0	188.0
4	2.0	511.0	226.0
4	3.0	563.0	278.0
4	3.0	606.0	321.0
4	3.0	657.0	372.0
4	3.0	683.0	398.0
4	5.0	744.0	459.0
4	5.0	800.0	515.0
4	5.0	853.0	568.0
4	5.0	898.0	613.0

Table B 185 -- DCP test results for lift 4 test point 5 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
5	0.0	281.0	0.0
5	1.0	369.0	88.0
5	1.0	394.0	113.0
5	1.0	415.0	134.0
5	1.0	432.0	151.0
5	2.0	474.0	193.0
5	2.0	502.0	221.0
5	2.0	529.0	248.0
5	3.0	564.0	283.0
5	3.0	599.0	318.0
5	3.0	629.0	348.0
5	3.0	660.0	379.0
5	5.0	702.0	421.0
5	5.0	764.0	483.0
5	5.0	828.0	547.0
5	5.0	889.0	608.0

Table B 186 -- DCP test results for replaced lift 4 test point 1 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0.0	57.0	0.0
1	2.0	128.0	71.0
1	2.0	170.0	113.0
1	2.0	241.0	184.0
1	2.0	281.0	224.0
1	2.0	317.0	260.0
1	3.0	360.0	303.0
1	5.0	404.0	347.0
1	5.0	456.0	399.0
1	5.0	497.0	440.0
1	5.0	528.0	471.0
1	5.0	556.0	499.0
1	5.0	591.0	534.0
1	8.0	647.0	590.0
1	8.0	697.0	640.0
1	8.0	748.0	691.0
1	8.0	803.0	746.0

Table B 187 -- DCP test results for replaced lift 4 test point 2 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0.0	41.0	0.0
2	1.0	126.0	85.0
2	1.0	191.0	150.0
2	1.0	260.0	219.0
2	1.0	310.0	269.0
2	2.0	388.0	347.0
2	2.0	443.0	402.0
2	5.0	501.0	460.0
2	5.0	555.0	514.0
2	5.0	610.0	569.0
2	5.0	669.0	628.0
2	5.0	711.0	670.0
2	5.0	752.0	711.0
2	6.0	797.0	756.0

Table B 188 -- DCP test results for replaced lift 4 test point 3 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0.0	43.0	0.0
3	1.0	131.0	88.0
3	1.0	222.0	179.0
3	1.0	296.0	253.0
3	1.0	366.0	323.0
3	1.0	431.0	388.0
3	2.0	476.0	433.0
3	3.0	522.0	479.0
3	3.0	556.0	513.0
3	5.0	619.0	576.0
3	5.0	660.0	617.0
3	5.0	696.0	653.0
3	5.0	725.0	682.0
3	5.0	761.0	718.0
3	5.0	800.0	757.0

Table B 189 -- DCP test results for replaced lift 4 test point 4 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0.0	44.0	0.0
4	1.0	121.0	77.0
4	1.0	188.0	144.0
4	1.0	241.0	197.0
4	1.0	316.0	272.0
4	1.0	349.0	305.0
4	1.0	390.0	346.0
4	1.0	472.0	428.0
4	1.0	527.0	483.0
4	2.0	585.0	541.0
4	2.0	648.0	604.0
4	2.0	701.0	657.0
4	3.0	772.0	728.0
4	3.0	853.0	809.0

Table B 190 -- DCP test results for replaced lift 4 test point 5 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
5	0.0	53.0	0.0
5	1.0	111.0	58.0
5	5.0	158.0	105.0
5	3.0	218.0	165.0
5	3.0	315.0	262.0
5	3.0	415.0	362.0
5	5.0	495.0	442.0
5	5.0	552.0	499.0
5	8.0	610.0	557.0
5	8.0	665.0	612.0
5	8.0	762.0	709.0
5	8.0	841.0	788.0

Table B 191 -- DCP test results for replaced lift 4 test point 6 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
6	0.0	40.0	0.0
6	1.0	85.0	45.0
6	2.0	140.0	100.0
6	3.0	220.0	180.0
6	3.0	313.0	273.0
6	2.0	376.0	336.0
6	2.0	455.0	415.0
6	2.0	538.0	498.0
6	2.0	620.0	580.0
6	2.0	734.0	694.0
6	1.0	842.0	802.0

Table B 192 -- DCP test results for replaced lift 4 test point 7 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
7	0.0	53.0	0.0
7	1.0	145.0	92.0
7	1.0	226.0	173.0
7	1.0	290.0	237.0
7	1.0	344.0	291.0
7	1.0	430.0	377.0
7	2.0	489.0	436.0
7	2.0	545.0	492.0
7	2.0	635.0	582.0
7	2.0	759.0	706.0
7	1.0	838.0	785.0

Table B 193 -- DCP test results for replaced lift 4 test point 8 for Trench F

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
8	0.0	59.0	0.0
8	1.0	151.0	92.0
8	1.0	202.0	143.0
8	2.0	325.0	266.0
8	1.0	415.0	356.0
8	1.0	473.0	414.0
8	1.0	546.0	487.0
8	1.0	594.0	535.0
8	1.0	640.0	581.0
8	1.0	674.0	615.0
8	1.0	726.0	667.0
8	1.0	791.0	732.0
8	1.0	833.0	774.0
8	1.0	862.0	803.0
8	1.0	912.0	853.0

Table B 194 – Summary DCPI results from the DCP tests for Trench F

Location	Number of test points	Depth of test (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Second Lift	5	24.6	30.6	22.7	74.9
Fourth Lift tested on July 12, 2007	5	24.5	22.1	9.6	43.2
Replaced Fourth Lift for test points within the trench tested on July 18, 2007	5	30.5	2.4	11.6	493.6
Replaced Fourth Lift for test points tested in the T-section on July 18, 2007	3	30.2	58.4	21.7	37.2

Table B 195 –Summary of CBR results from the DCP tests for Trench F

Location	Number of test points	Depth of test (inches)	Average CBR (%)	Standard deviation	Coefficient of variance (%)
Second Lift	5	24.6	11	7.0	63.6
Fourth Lift tested on July 12, 2007	5	24.5	15	7.1	47.3
Replaced Fourth Lift for test points within the trench tested on July 18, 2007	5	30.5	13	0.4	3.1
Replaced Fourth Lift for test points in the T-section tested on July 18, 2007	3	30.2	3	1.7	45.8

Clegg Hammer Test Results

Table B 196 -- Clegg Hammer test results for lift 2 for Trench F

Location #	IV Value	CBR (%)
1	14.4	19.9
2	11.1	13.4
3	9.2	10.3
4	18.2	28.8
5	14.2	19.4
Average	14.2	19.4
Standard Deviation	13.4	18.4
Coefficient of variance	3.4	7.1

Table B 197 -- Clegg Hammer test results for lift 4 for Trench F

Location #	IV Value	CBR (%)
1	11.2	13.6
2	12.1	15.2
3	9.2	10.3
4	17.5	27.0
5	10.8	12.9
Average	10.8	12.9
Standard Deviation	12.2	15.8
Coefficient of variance	3.2	6.5

Table B 198 -- Clegg Hammer test results for replaced lift 4 within the trench for Trench F

Location #	IV Value	CBR (%)
1	6.8	6.9
2	9.9	11.4
3	10.3	12.1
4	7.3	7.6
5	6.4	6.4
Average	8.1	8.9
Standard Deviation	1.8	2.6
Coefficient of variance	22.4	29.8

Table B 199 -- Clegg Hammer test results for replaced lift 4 in T-section for Trench F

Location #	IV Value	CBR (%)
6	19.0	30.9
7	13.8	18.6
8	4.9	4.7
Average	12.6	18.1
Standard Deviation	7.1	13.1
Coefficient of variance	56.7	72.4

Table B 200 – Summary of impact value results from the Clegg Hammer tests for Trench F

Location	Number of Test Points	Average IV reading	Min/Max IV readings	Standard Deviation	Coefficient of Variance (%)
Second Lift	5	13.4	9.2 / 18.2	3.5	26.1
Fourth Lift tested on July 12, 2007	5	11.2	9.9 / 12.3	1.0	9.0
Replaced Fourth Lift for test points within the trench tested on July 18, 2007	5	12.2	6.4 / 10.3	1.8	22.2
Replaced Fourth Lift for test points in the T-section tested on July 18, 2007	3	12.6	4.9 / 13.8	7.1	56.3

Table B 201 – Summary of CBR results from the Clegg Hammer tests for Trench F

Location	Number of Test Points	Average CBR (%)	Min/Max CBR (%)	Standard Deviation	Coefficient of Variance (%)
Second lift	5	18	1 / 29	7.1	38.6
Fourth lift tested on July 12, 2007	5	16	27 / 10	6.5	40.6
Replaced fourth lift for test points within the trench tested on July 18, 2007	5	9	6 / 12	2.6	29.2
Replaced fourth lift for test points in the T-section tested on July 18, 2007	3	18	5 / 31	13.1	72.4

B.2 – Instrumented Trenches

B.2.1 – Instrumented Trench 1

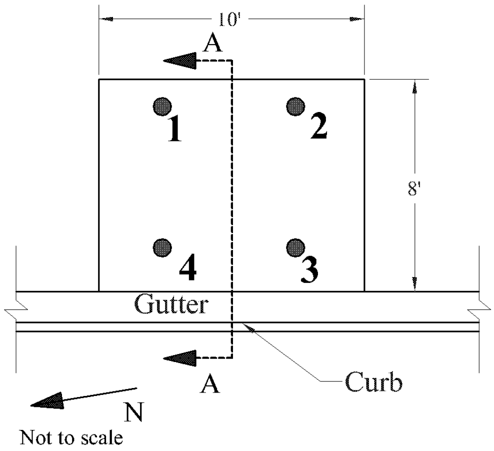


Figure B 7 -- Field-testing locations for Instrumented Trench 1

Nuclear Density Test Results

Table B 202– Moisture contents from the Nuclear Density testing for Trench 1

Lift	Location				Average	Standard Deviation	Coefficient of Variance
	1	2	3	4			
lift 2	121.50	123.40	115.10	119.90	119.98	3.55	12.61
lift 3	118.10	121.20	121.40	113.20	118.48	3.83	14.65
lift 4	123.10	123.50	124.40	120.00	122.75	1.91	3.66
lift 5	125.20	111.40	123.70	121.10	120.35	6.20	38.47
lift 6	124.80	122.60	122.20	121.20	122.70	1.52	2.31
lift 7	125.80	122.30	121.40	125.70	123.80	2.28	5.21
lift 8	106.40	109.40	110.90	111.00	109.43	2.15	4.60
Trench Average					119.64		

DCP Test Results

Table B 203 -- DCP test results for lift 2 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	364	0
1	2	412	48
1	3	480	116
1	3	551	187
1	2	598	234
1	3	690	326
1	2	813	449
1	3	904	540
1	5	954	590
1	5	1010	646

Table B 204 -- DCP test results for lift 2 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	384	0
2	2	439	55
2	3	496	112
2	2	547	163
2	3	580	196
2	3	619	235
2	3	691	307
2	2	748	364
2	1	810	426
2	3	889	505
2	3	949	565
2	3	998	614
2	3	1027	643

Table B 205 -- DCP test results for lift 2 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	371	0
3	2	442	71
3	3	517	146
3	3	590	219
3	3	672	301
3	1	723	352
3	1	919	548
3	3	991	620
3	3	1047	676

Table B 206 -- DCP test results for lift 2 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	376	0
4	2	457	81
4	3	549	173
4	3	640	264
4	3	805	429
4	3	882	506
4	3	935	559
4	5	1000	624

Table B 207 -- DCP test results for lift 4 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	365	0
1	2	437	72
1	2	510	145
1	3	566	201
1	3	611	246
1	5	653	288
1	5	699	334
1	5	760	395
1	5	811	446
1	10	861	496

Table B 208 -- DCP test results for lift 4 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	355	0
2	2	394	39
2	2	435	80
2	3	485	130
2	4	549	194
2	4	609	254
2	5	637	282
2	10	703	348
2	10	803	448
2	5	863	508

Table B 209 -- DCP test results for lift 4 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	354	0
3	2	395	41
3	3	450	96
3	5	534	180
3	5	600	246
3	5	644	290
3	10	765	411
3	10	860	506

Table B 210 -- DCP test results for lift 4 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	360	0
4	2	430	70
4	3	508	148
4	3	577	217
4	5	653	293
4	5	709	349
4	5	771	411
4	5	829	469

Table B 211 -- DCP test results for lift 6 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	364	0
1	2	425	61
1	3	493	129
1	4	574	210
1	5	634	270
1	5	655	291
1	5	700	336
1	10	838	474

Table B 212 -- DCP test results for lift 6 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	376	0
2	2	423	47
2	3	468	92
2	5	527	151
2	5	605	229
2	5	647	271
2	5	677	301
2	5	715	339
2	10	804	428
2	10	885	509

Table B 213 -- DCP test results for lift 6 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	367	0
3	2	414	47
3	2	463	96
3	3	519	152
3	3	581	214
3	4	615	248
3	8	666	299
3	8	732	365
3	8	809	442
3	8	885	518

Table B 214 -- DCP test results for lift 6 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	360	0
4	2	398	38
4	3	458	98
4	4	531	171
4	5	595	235
4	6	641	281
4	6	702	342

Table B 215 -- DCP test results for lift 7 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	352	0
1	2	395	43
1	2	438	86
1	2	480	128
1	4	551	199
1	4	616	264
1	4	675	323
1	6	726	374
1	6	772	420
1	8	850	498

Table B 216 -- DCP test results for lift 7 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	371	0
2	2	426	55
2	2	466	95
2	4	544	173
2	4	620	249
2	4	675	304
2	6	711	340
2	6	756	385
2	8	848	477

Table B 217 -- DCP test results for lift 7 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	361	0
3	2	404	43
3	2	431	70
3	4	487	126
3	4	538	177
3	6	619	258
3	6	655	294
3	8	711	350
3	8	775	414
3	8	848	487

Table B 218 -- DCP test results for lift 7 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	352	0
4	2	388	36
4	2	417	65
4	4	467	115
4	4	518	166
4	4	565	213
4	4	615	263
4	6	679	327
4	6	713	361
4	8	764	412
4	8	833	481

Table B 219 -- DCP test results for lift 8 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	380	0
1	1	445	65
1	1	498	118
1	1	540	160
1	3	555	175
1	3	600	220
1	5	681	301
1	5	773	393
1	5	861	481
1	5	892	512

Table B 220 -- DCP test results for lift 8 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	384	0
2	1	445	61
2	1	481	97
2	1	515	131
2	2	551	167
2	4	592	208
2	4	637	253
2	5	701	317
2	5	770	386
2	5	843	459

Table B 221 -- DCP test results for lift 8 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	394	0
3	1	450	56
3	1	480	86
3	4	530	136
3	4	585	191
3	4	642	248
3	5	707	313
3	5	778	384
3	5	852	458
3	5	880	486

Table B 222 -- DCP test results for lift 8 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	376	0
4	1	440	64
4	1	475	99
4	2	500	124
4	2	532	156
4	4	599	223
4	4	661	285
4	4	726	350
4	5	831	455
4	5	877	501

B.2.2 – Instrumented Trench 2

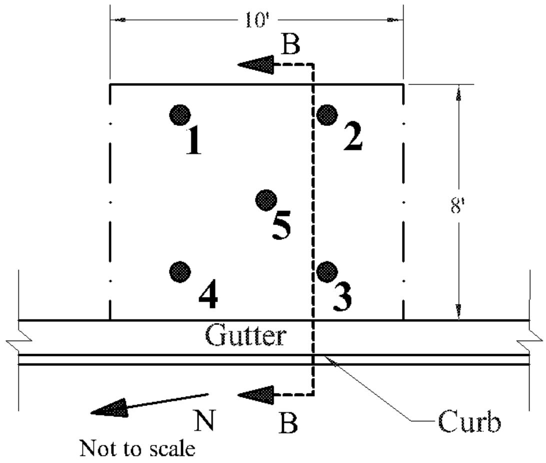


Figure B 8 -- Field-testing locations for Instrumented Trench 2

Nuclear Density Test Results

Table B 223– Moisture contents from the Nuclear Density testing for Trench 1

Lift	Location					Average	Standard Deviation	Coefficient of Variance
	1	2	3	4	5			
Lift 1		92.3	98.4		104.1	98.27	5.90	6.01
Lift 2	105.1	98.3	101.0	97.4		100.45	3.46	3.44
Lift 3	102.6	96.7	99.1	104.5	106.8	101.94	4.07	3.99
Lift 4	104.3	102.4	97.6	107.3		102.90	4.07	3.95
Lift 5		102.6	97.1	101.6		100.43	2.93	2.92
Average for Trench						100.8		

DCP Test Results

Table B 224 -- DCP test results for lift 1 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	380	0
2	1	455	75
2	2	524	144
2	3	531	151
2	4	574	194
2	5	634	254
2	6	912	532
2	0	380	0
2	1	455	75
2	2	524	144
2	3	531	151
2	4	574	194
2	5	634	254

Table B 225 -- DCP test results for lift 1 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	380	0
3	1	480	100
3	2	515	135
3	3	548	168
3	4	583	203
3	5	621	241
3	6	659	279
3	7	700	320
3	8	775	395
3	9	837	457

Table B 226 -- DCP test results for lift 1 test point 5

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)

5	0	395	0
5	1	458	63
5	2	492	97
5	3	519	124
5	4	540	145
5	5	563	168
5	6	586	191
5	7	609	214
5	8	634	239
5	9	664	269
5	10	700	305
5	11	820	425

Table B 227 -- DCP test results for lift 2 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	400	0
1	1	446	46
1	2	509	109
1	2	555	155
1	2	600	200
1	2	634	234
1	2	686	286
1	4	731	331
1	4	780	380
1	4	832	432
1	4	906	506
1	4	1038	638

Table B 228 -- DCP test results for lift 2 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	400	0
2	2	500	100
2	2	568	168
2	2	619	219
2	2	664	264
2	2	707	307

Table B 229 -- DCP test results for lift 2 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	418	0
3	1	531	113
3	1	590	172
3	1	640	222
3	1	680	262
3	1	713	295
3	1	742	324
3	2	805	387
3	2	921	503

Table B 230 -- DCP test results for lift 2 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	402	0
4	1	471	69
4	1	509	107
4	2	558	156
4	2	604	202
4	2	638	236
4	3	679	277
4	4	716	314
4	3	740	338
4	4	786	384
4	4	835	433
4	4	886	484
4	4	946	544

Table B 231 -- DCP test results for lift 3 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	378	0
1	1	434	56
1	3	520	142
1	3	595	217
1	4	684	306
1	4	747	369
1	4	829	451
1	4	925	547
1	4	979	601
1	4	1036	658

Table B 232 -- DCP test results for lift 3 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	390	0
2	1	471	81
2	2	546	156
2	3	648	258
2	4	775	385
2	4	865	475
2	4	921	531
2	4	970	580
2	4	1020	630
2	3	1058	668

Table B 233 -- DCP test results for lift 3 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	395	0
3	1	504	109
3	2	605	210
3	3	695	300
3	4	778	383
3	4	862	467
3	4	937	542
3	4	987	592
3	3	1054	659

Table B 234 -- DCP test results for lift 3 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	406	0
4	1	467	61
4	2	533	127
4	3	613	207
4	4	713	307
4	4	796	390
4	4	886	480
4	4	962	556
4	4	1114	708

Table B 235 -- DCP test results for lift 4 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	377	0
1	1	416	39
1	3	482	105
1	3	529	152
1	4	583	206
1	4	628	251
1	4	671	294
1	5	717	340
1	5	751	374
1	5	790	413
1	5	835	458
1	5	882	505
1	5	935	558
1	5	987	610
1	5	1037	660

Table B 236 -- DCP test results for lift 4 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	402	0
2	1	452	50
2	2	564	162
2	2	614	212
2	2	678	276
2	4	735	333
2	4	787	385
2	4	829	427
2	4	886	484
2	4	906	504
2	4	950	548
2	4	996	594
2	4	1046	644

Table B 237 -- DCP test results for lift 4 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	403	0
3	1	462	59
3	1	490	87
3	2	539	136
3	3	602	199
3	3	659	256
3	3	711	308
3	3	752	349
3	4	806	403
3	4	864	461
3	4	931	528
3	4	998	595
3	4	1080	677

Table B 238 -- DCP test results for lift 4 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	386	0
4	1	439	53
4	1	468	82
4	2	514	128
4	3	563	177
4	3	613	227
4	3	658	272
4	4	699	313
4	4	746	360
4	4	791	405
4	4	837	451
4	4	886	500
4	4	935	549
4	4	995	609
4	4	1060	674

B.2.3 – Instrumented Trench 3

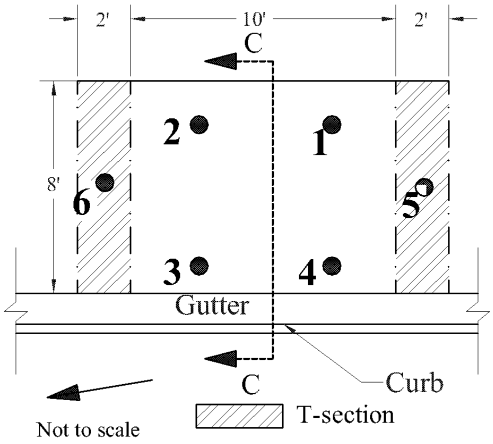


Figure B 9 -- Field-testing locations for Instrumented Trench 3

Nuclear Density Test Results

Lift	Location						Average	Standard Deviation	Coefficient of Variance
	1	2	3	4	5	6			
Lift 2	104.6	113.6	127.6	114.6			115.1	9.5	8.2
Lift 3	111.0	119.7	107.4	112.2			112.6	5.2	4.6
Lift 4	107.4	119.4	111.2	114.6			113.2	5.1	4.5
Lift 5	109.4	105.9	114.9	113.8			111.0	4.1	3.7
Lift 6	110.2	115.8	116.0	119.0			115.3	3.7	3.2
Lift 7	119.0	114.3	117.5	115.2			116.5	2.1	1.8
Lift 8	112.8	111.3	108.6	107.8			110.1	2.3	2.1
Lift 9	113.6	117.1	113.3	113.5			114.4	1.8	1.6
Lift 8					107.5	112.7	110.1	3.7	3.3
Lift 9					119.9	119.2	119.6	0.5	0.4
Average for Trench							113.8		

DCP Test Results

Table B 239 -- DCP test results for lift 1 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	372	0
1	2	427	55
1	2	504	132
1	3	565	193
1	1	653	281
1	1	708	336
1	1	732	360
1	1	762	390
1	1	824	452
1	1	878	506
1	1	910	538

Table B 240 -- DCP test results for lift 1 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	402	0
2	1	450	48
2	2	523	121
2	3	636	234
2	1	749	347
2	1	930	528

Table B 241 -- DCP test results for lift 1 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	374	0
3	1	414	40
3	2	469	95
3	3	532	158
3	4	645	271
3	4	758	384
3	1	1005	631

Table B 242 -- DCP test results for lift 1 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	378	0
4	2	469	91
4	2	540	162
4	2	612	234
4	1	642	264
4	1	711	333
4	1	741	363
4	1	771	393
4	2	831	453
4	2	903	525
4	1	978	600

Table B 243 -- DCP test results for lift 3 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	377	0
1	2	428	51
1	3	499	122
1	4	596	219
1	5	711	334
1	5	772	395
1	5	865	488
1	5	942	565

Table B 244 -- DCP test results for lift 3 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	404	0
2	1	473	69
2	2	511	107
2	2	609	205
2	2	650	246
2	3	940	536

Table B 245 -- DCP test results for lift 3 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	410	0
3	1	458	48
3	2	524	114
3	2	608	198
3	1	692	282
3	1	1028	618

Table B 246 -- DCP test results for lift 3 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	389	0
4	1	458	69
4	1	513	124
4	1	570	181
4	1	625	236
4	1	675	286
4	2	706	317
4	4	740	351
4	5	795	406
4	5	861	472
4	5	933	544

Table B 247 -- DCP test results for lift 4 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	374	0
1	1	413	39
1	2	481	107
1	4	600	226
1	4	638	264
1	8	702	328
1	8	838	464
1	4	931	557
1	4	964	590

Table B 248 -- DCP test results for lift 4 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	377	0
2	1	428	51
2	2	482	105
2	4	552	175
2	4	613	236
2	4	667	290
2	8	742	365
2	8	817	440
2	8	890	513
2	8	948	571

Table B 249 -- DCP test results for lift 4 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	395	0
3	1	449	54
3	1	475	80
3	4	552	157
3	4	609	214
3	4	645	250
3	4	674	279
3	8	735	340
3	8	798	403
3	8	856	461
3	8	911	516
3	8	957	562

Table B 250 -- DCP test results for lift 4 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	378	0
4	1	404	26
4	2	465	87
4	4	558	180
4	4	621	243
4	4	651	273
4	8	741	363
4	8	880	502
4	8	1040	662

Table B 251 -- DCP test results for lift 5 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	425	0
1	1	473	48
1	1	511	86
1	1	555	130
1	2	635	210
1	3	688	263
1	4	740	315
1	4	801	376
1	4	876	451
1	8	984	559

Table B 252 -- DCP test results for lift 5 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	361	0
2	1	392	31
2	1	426	65
2	2	481	120
2	3	557	196
2	3	639	278
2	4	680	319
2	8	767	406
2	8	912	551

Table B 253 -- DCP test results for lift 5 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	393	0
3	1	460	67
3	1	500	107
3	2	560	167
3	2	606	213
3	4	647	254
3	8	732	339
3	8	863	470
3	4	929	536

Table B 254 -- DCP test results for lift 5 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	370	0
4	1	416	46
4	1	450	80
4	2	509	139
4	2	562	192
4	4	635	265
4	4	671	301
4	6	737	367
4	8	851	481
4	8	916	546

Table B 255 -- DCP test results for lift 7 test point 1

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
1	0	381	0
1	1	433	52
1	3	519	138
1	5	622	241
1	8	718	337
1	8	861	480
1	8	920	539
1	8	1000	619

Table B 256 -- DCP test results for lift 7 test point 2

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
2	0	368	0
2	1	407	39
2	2	501	133
2	3	605	237
2	8	698	330
2	8	837	469
2	8	963	595
2	6	1090	722

Table B 257 -- DCP test results for lift 7 test point 3

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
3	0	384	0
3	1	431	47
3	3	515	131
3	5	620	236
3	5	680	296
3	5	745	361
3	5	826	442
3	5	897	513
3	5	942	558
3	5	1005	621

Table B 258 -- DCP test results for lift 7 test point 4

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	0	378	0
4	1	411	33
4	3	490	112
4	5	608	230
4	5	672	294
4	5	738	360
4	5	833	455
4	5	905	527
4	5	946	568
4	5	1006	628

Table B 259 -- DCP test results for lift 7 test point 5

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
5	0	382	0
5	1	420	38
5	3	510	128
5	5	632	250
5	5	720	338
5	2	790	408
5	1	862	480

Table B 260 -- DCP test results for lift 7 test point 6

Location #	# of Blows	Cumulative Penetration (mm)	Total Penetration (mm)
4	1	382	0
4	1	422	40
4	3	511	129
4	3	590	208
4	2	632	250
4	1	649	267
4	2	666	284
4	1	677	295
4	1	734	352
4	1	766	384
4	1	797	415
4	1	834	452

APPENDIX C.0 FWD TESTING RESULTS

APPENDIX C.0 – FWD TESTING RESULTS

C.1 – Phase I Local Agency Utility Cut Restorations

C.1.1 - Phase I: Ames (20th Street and Hayes Avenue)

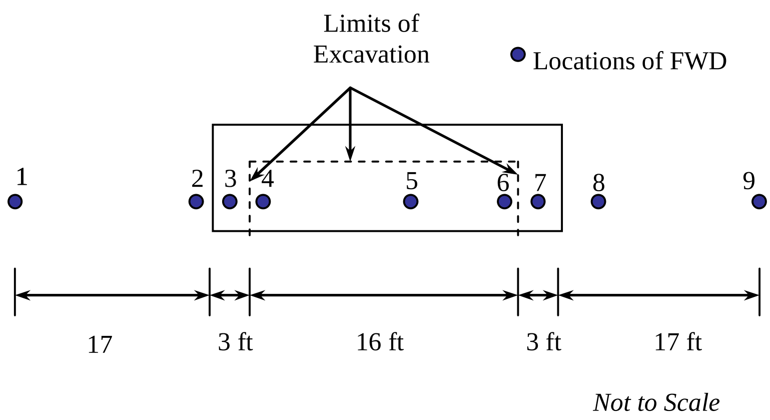


Figure C 1 -- FWD testing locations for Ames (from Schaefer et al.. 2005)

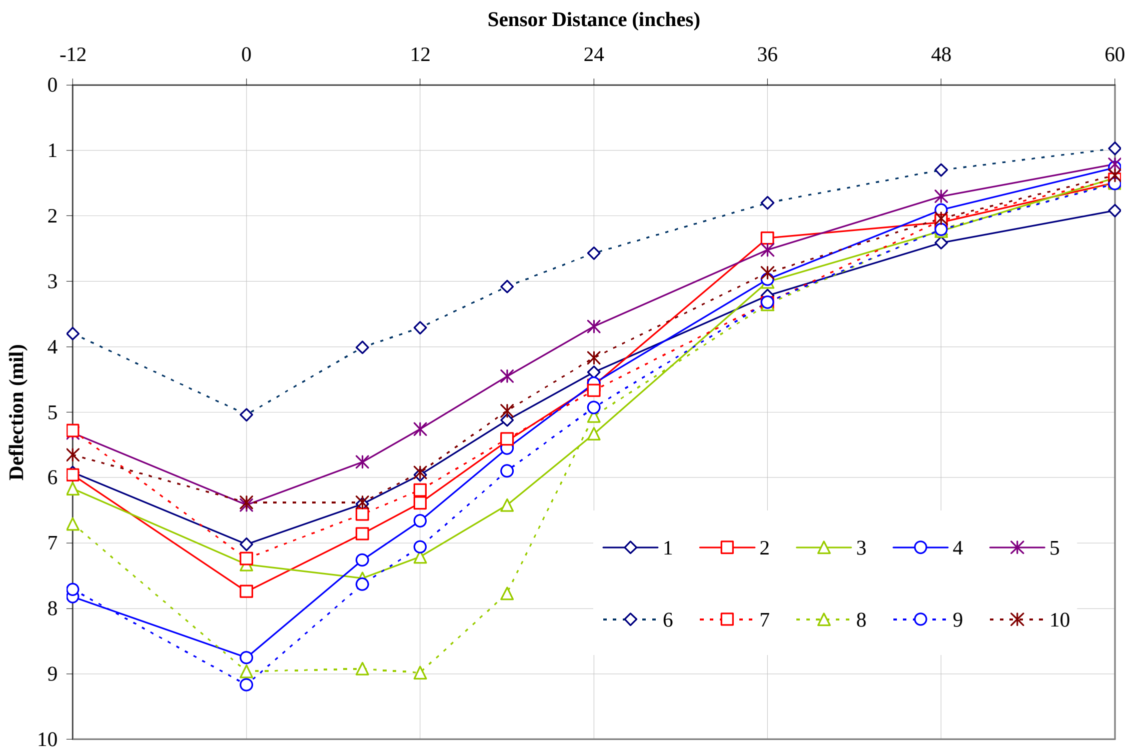


Figure C 2 -- Phase I: Ames - 6 kip test in June 2007

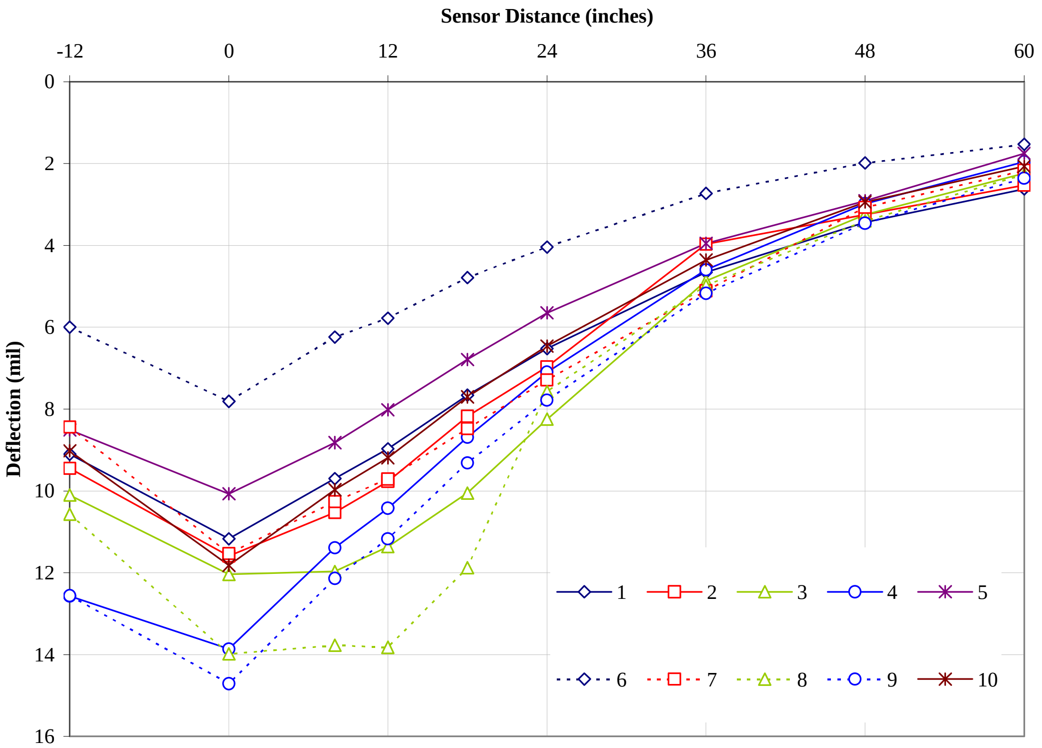


Figure C 3 -- Phase I: Ames - 9 kip test in June 2007

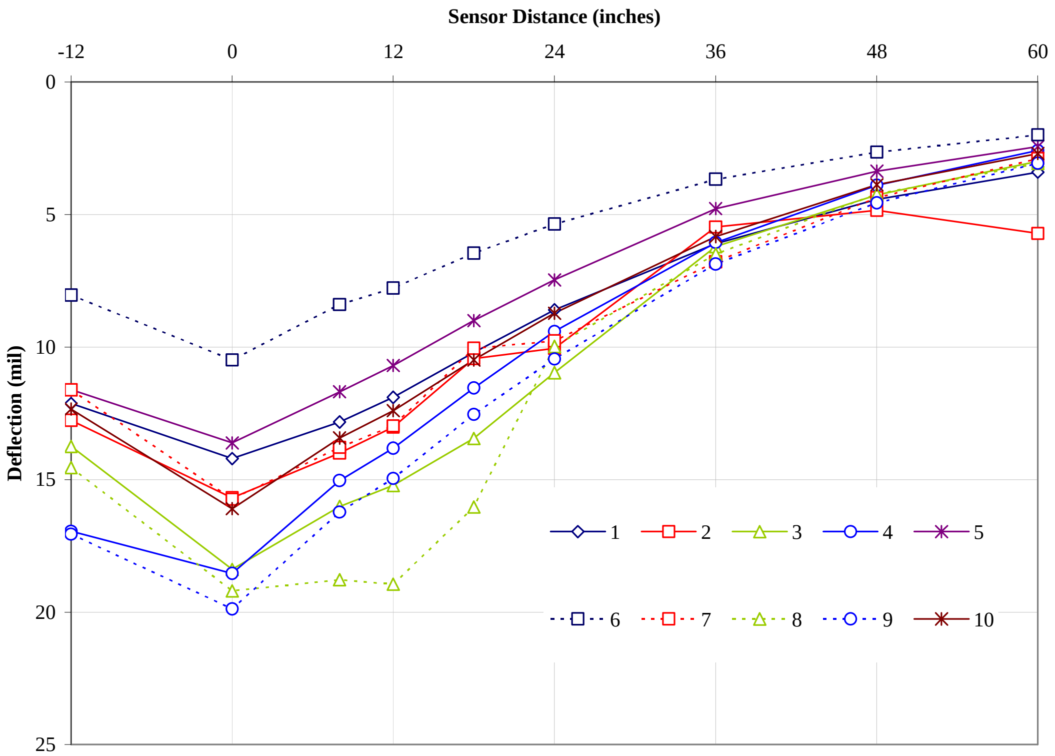


Figure C 4 -- Phase I: Ames - 12 kip test in June 2007

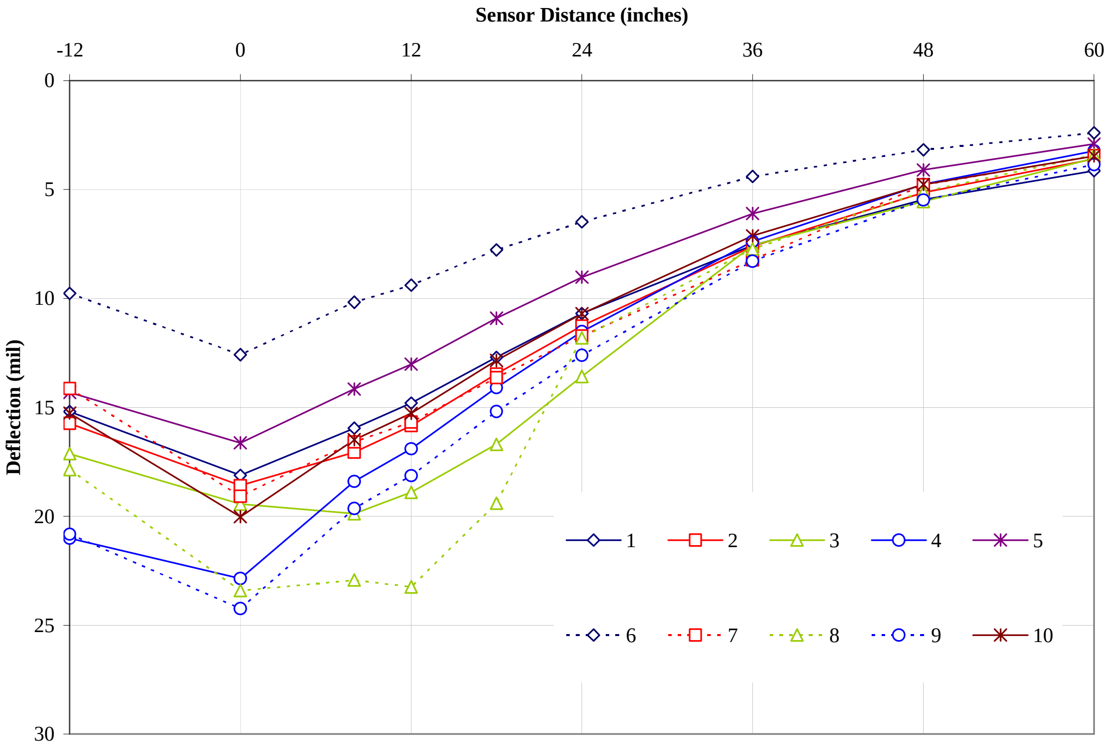


Figure C 5 -- Phase I: Ames - 15 kip test in June 2007

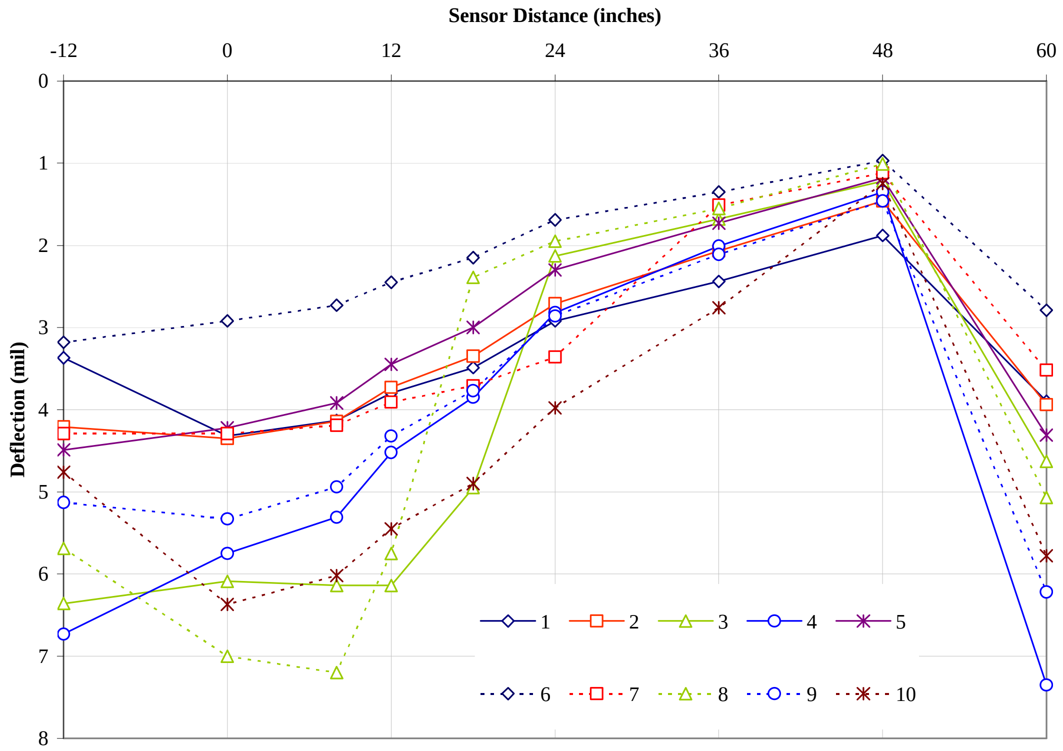


Figure C 6 -- Phase I: Ames - 6 kip test in November 2007

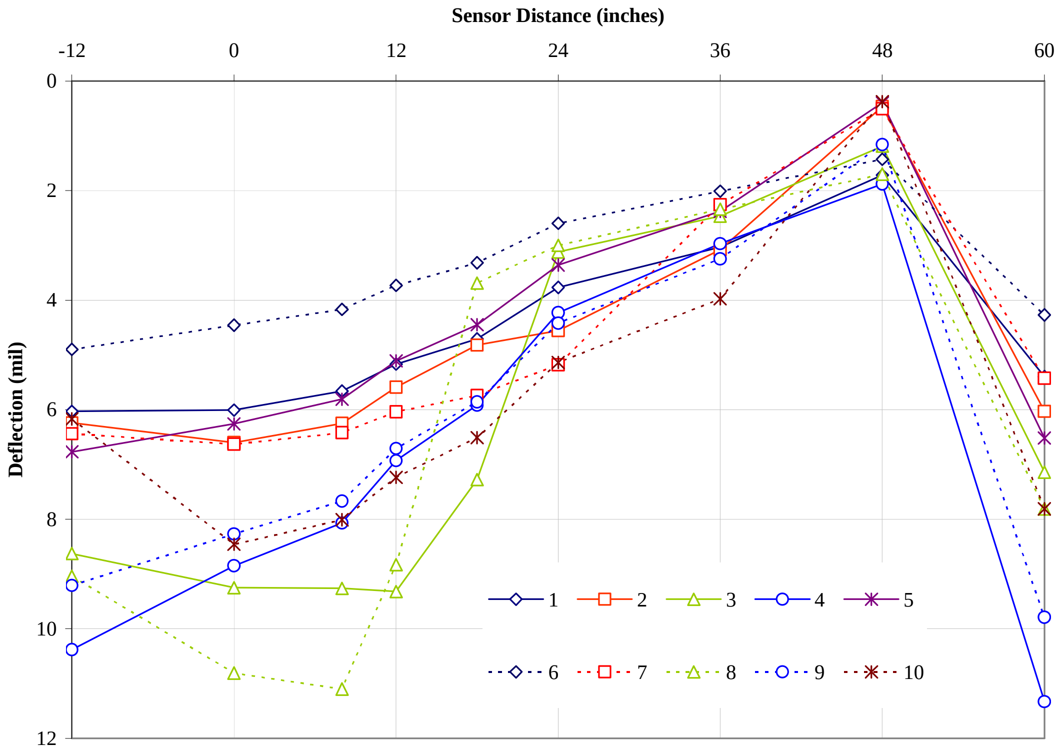


Figure C 7 -- Phase I: Ames - 9 kip test in November 2007

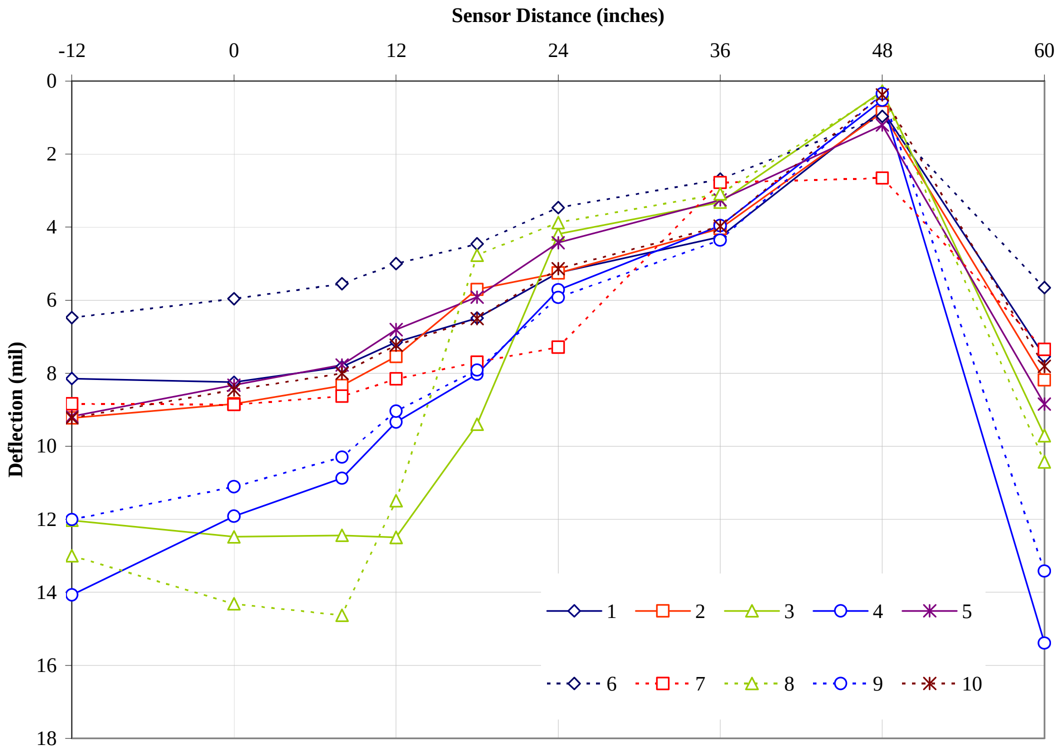


Figure C 8 -- Phase I: Ames - 12 kip test in November 2007

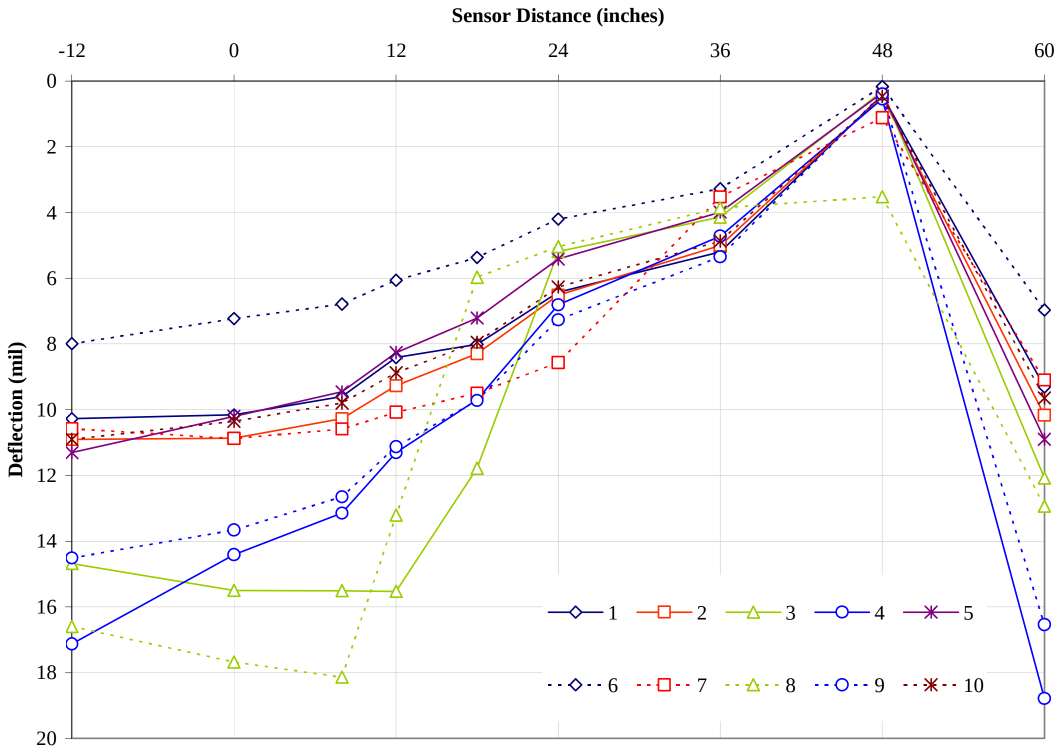


Figure C 9 -- Phase I: Ames - 15 kip test in November 2007

C.1.2 - Phase I: Cedar Rapids (Miami Drive and Sherman Avenue)

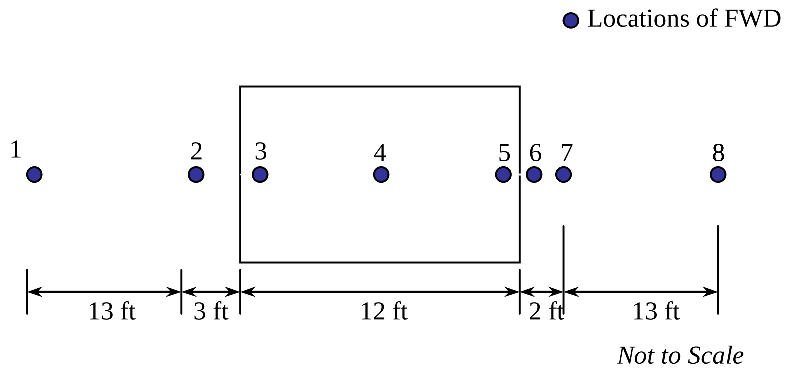


Figure C 10 -- Locations of FWD testing points for Cedar Rapids trench (from Schaefer et al. (2005))

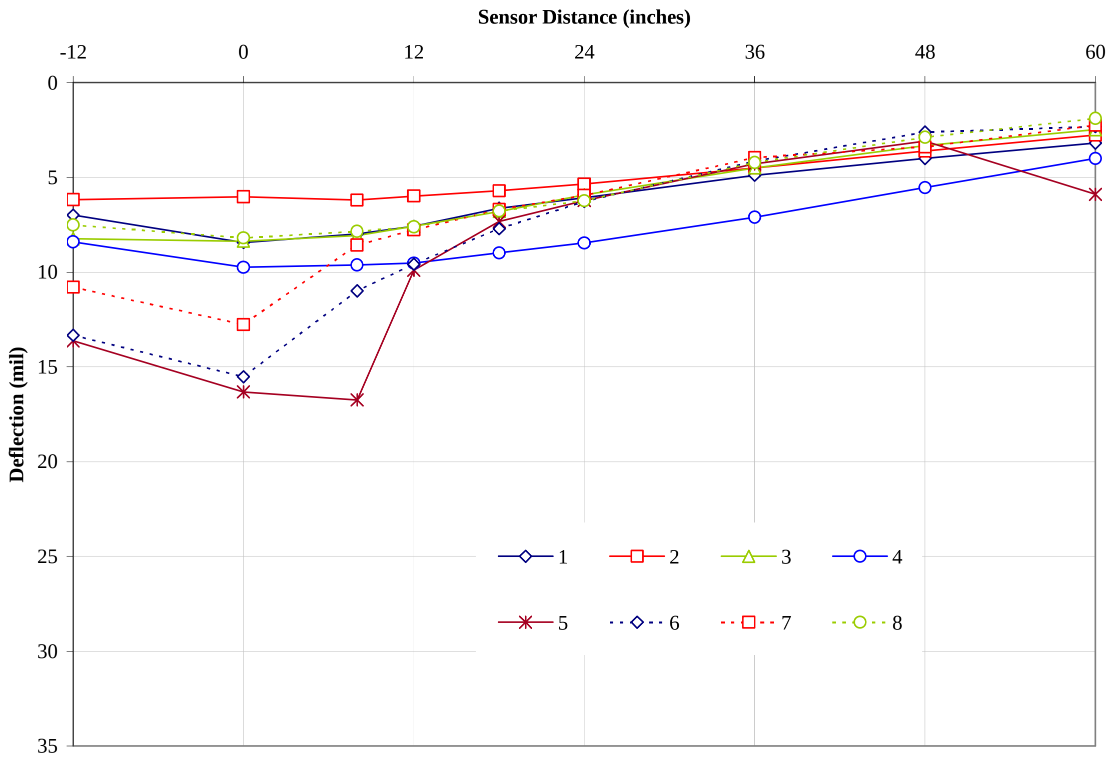


Figure C 11 -- Phase I: Cedar Rapids - 6 kip test in June 2007

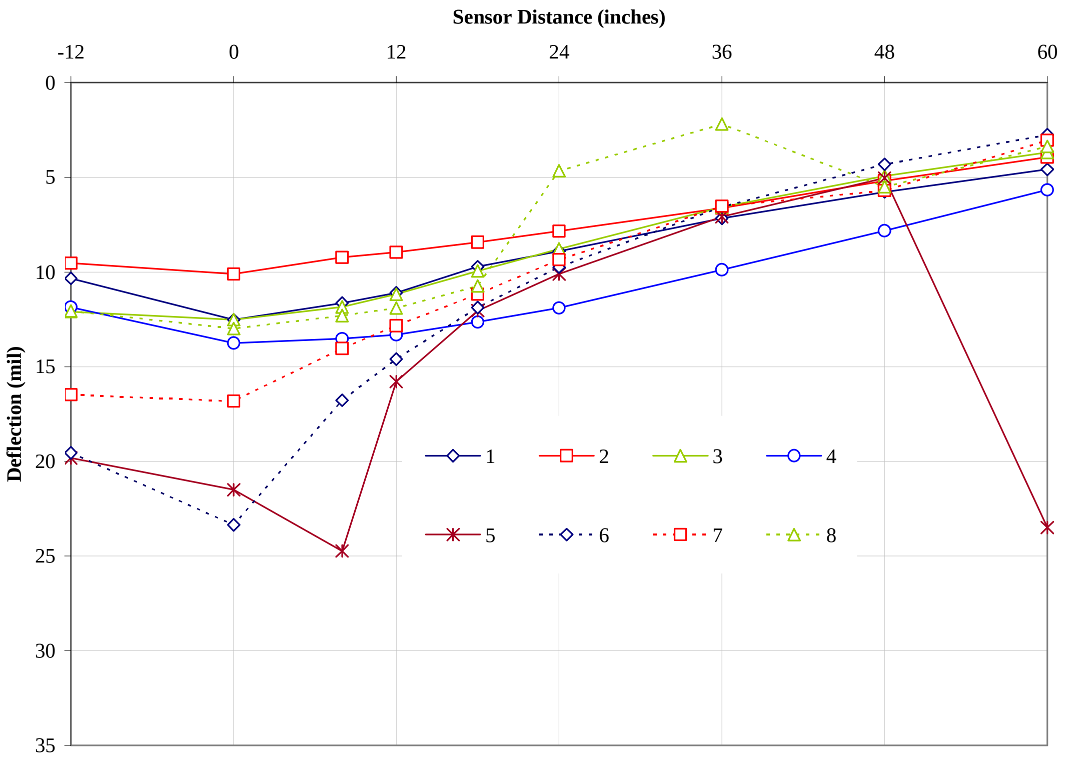


Figure C 12 -- Phase I: Cedar Rapids - 9 kip test in June 2007

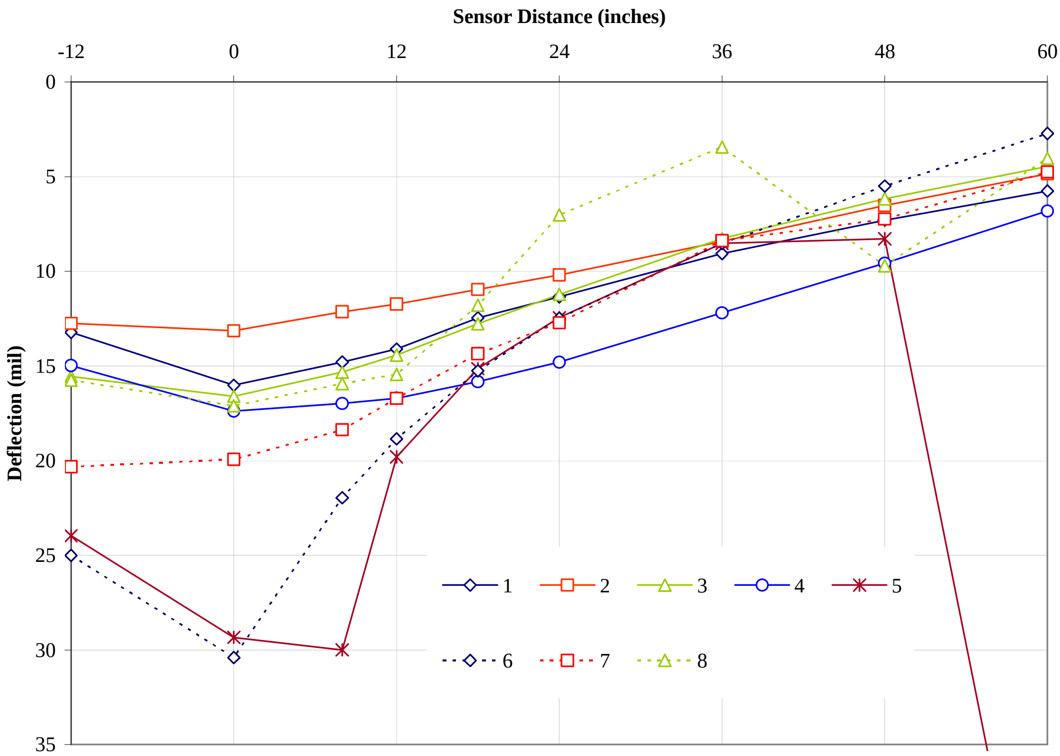


Figure C 13 -- Phase I: Cedar Rapids - 12 kip test in June 2007

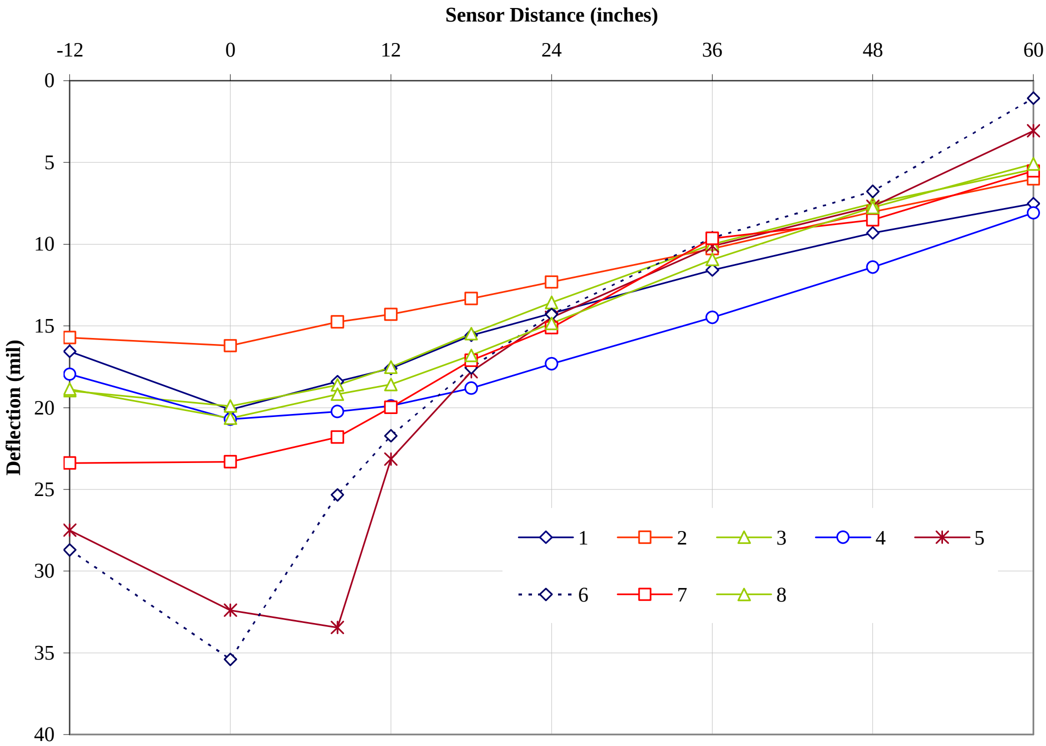


Figure C 14 -- Phase I: Cedar Rapids - 15 kip test in June 2007

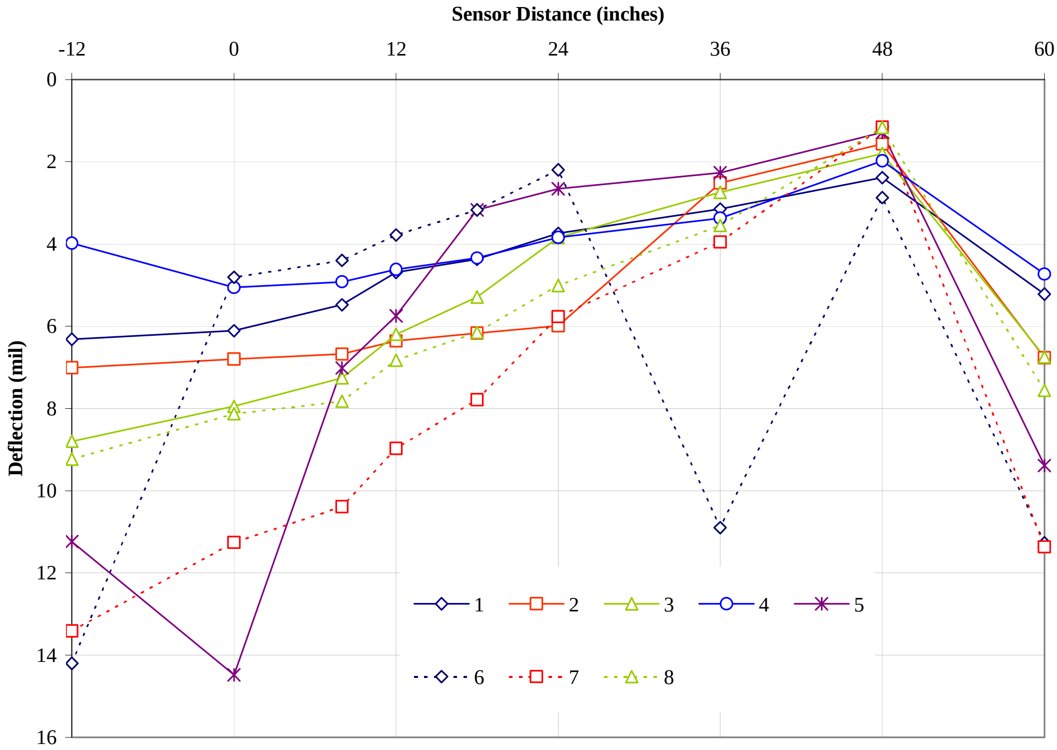


Figure C 15 -- Phase I: Cedar Rapids - 6 kip test in November 2007

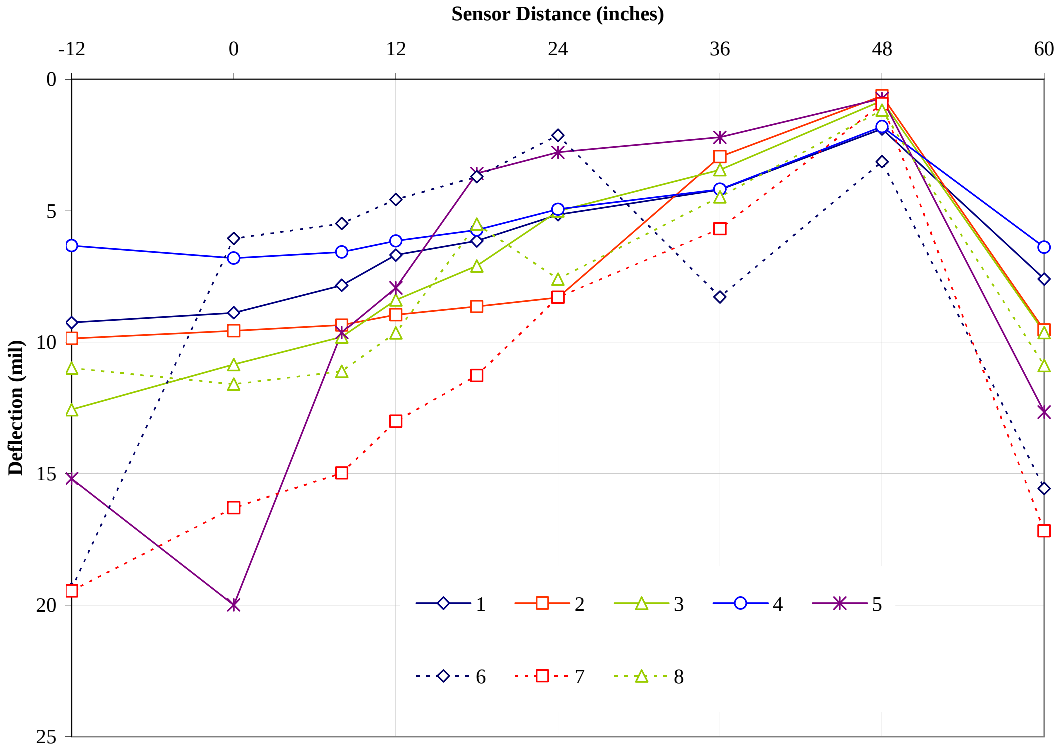


Figure C 16 -- Phase I: Cedar Rapids 9 kip test in November 2007

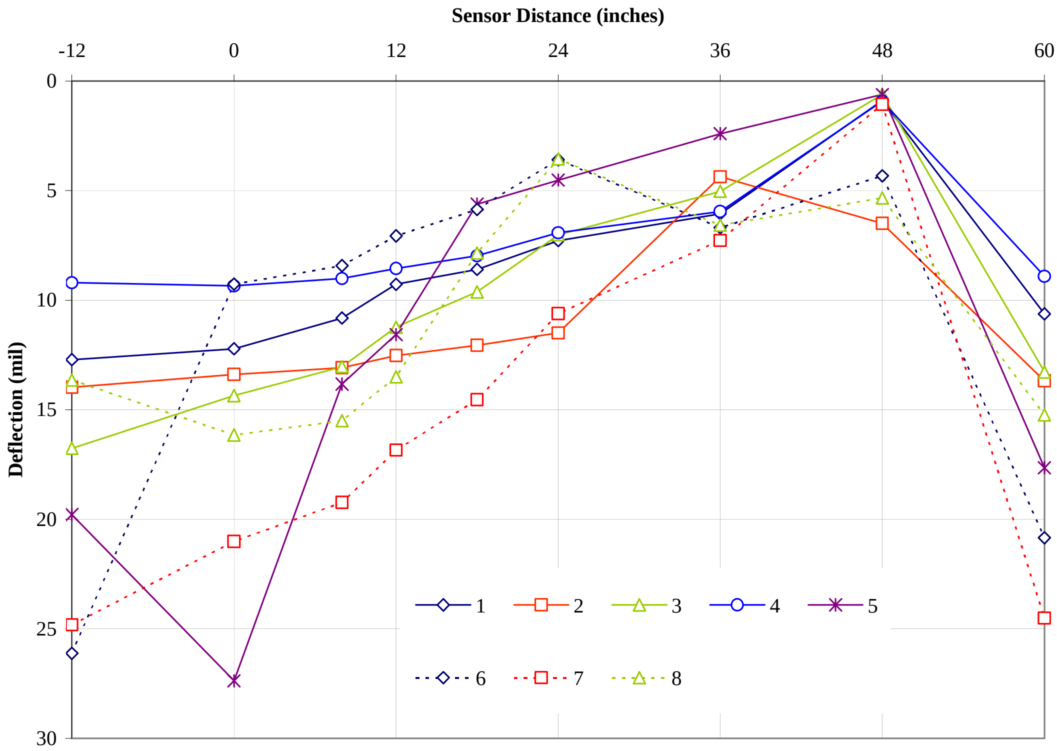


Figure C 17 -- Phase I: Cedar Rapids 12 kip test in November 2007

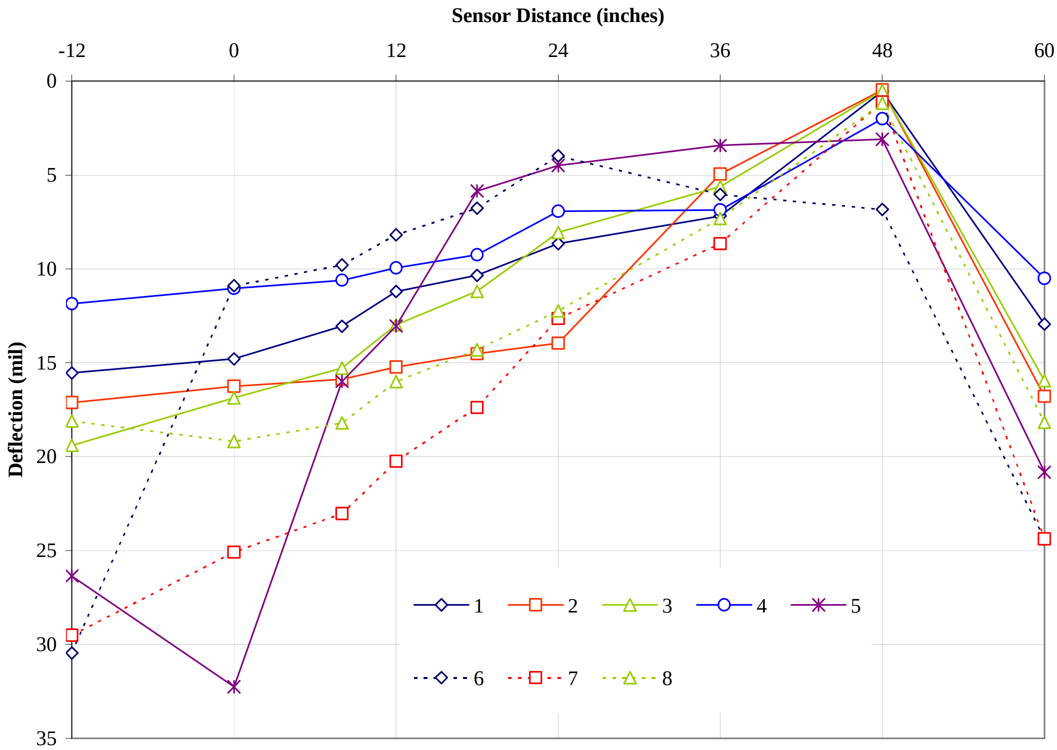


Figure C 18 -- Phase I: Cedar Rapids 15 kip test in November 2007

C.1.3 - Phase I: Des Moines (East 28th Street and Grand Avenue)

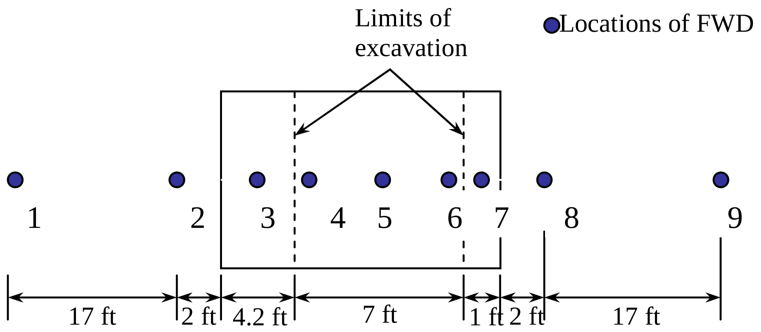


Figure C 19 – Locations of FWD testing locations for Des Moines (from Schaefer et al. (2005))

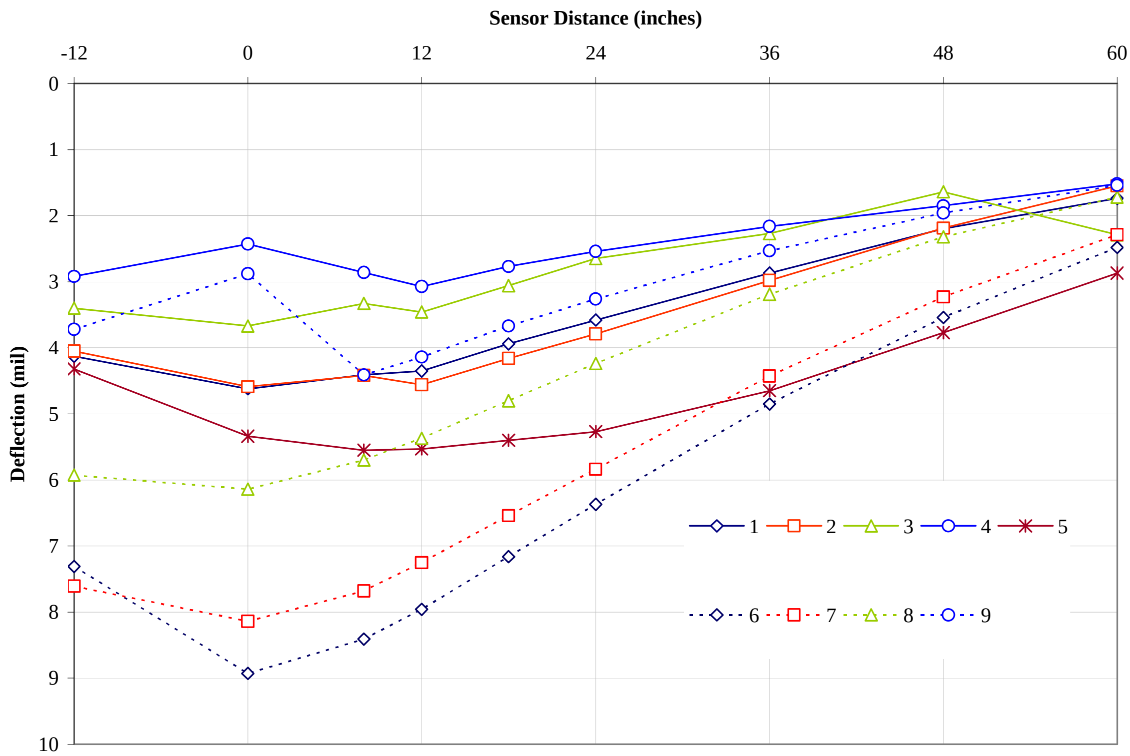


Figure C 20 -- Phase I: Des Moines - 6 kip test in June 2007

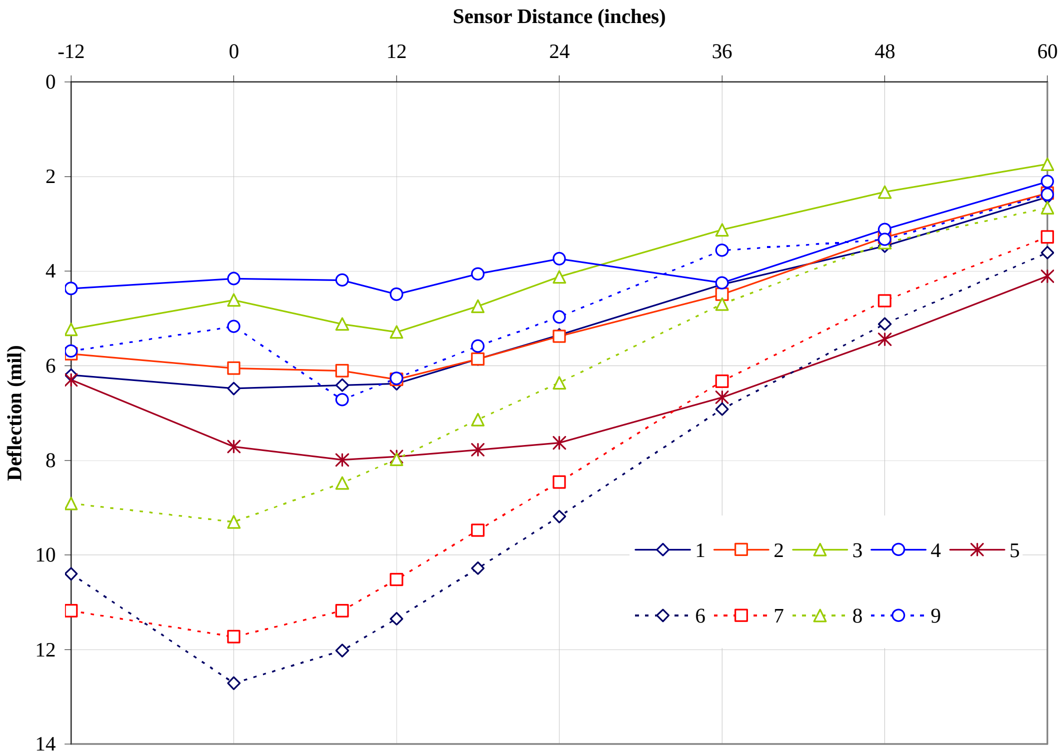


Figure C 21 -- Phase I: Des Moines - 9 kip test in June 2007

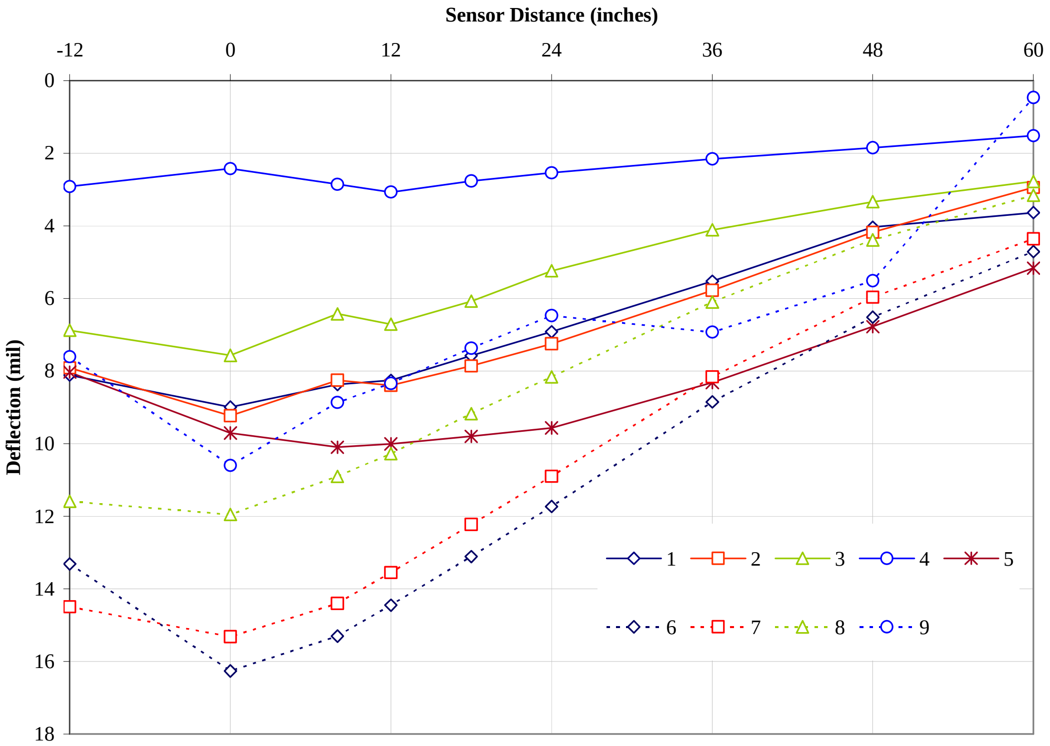


Figure C 22 -- Phase I: Des Moines - 12 kip test in June 2007

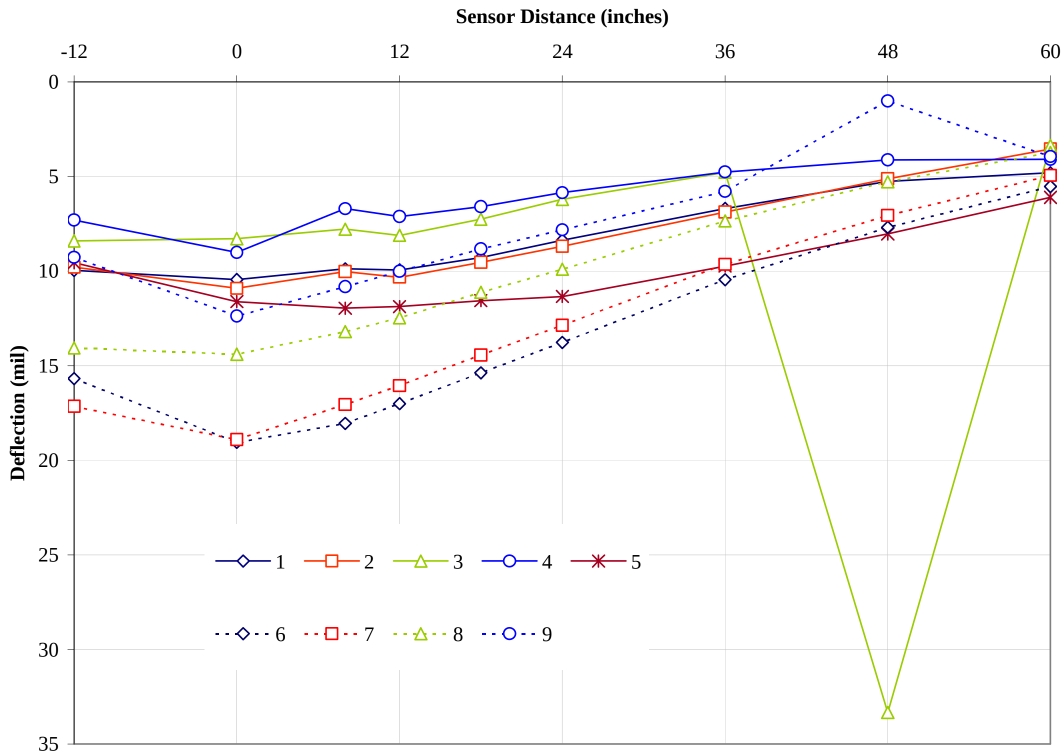


Figure C 23 -- Phase I: Des Moines - 15 kip test in June 2007

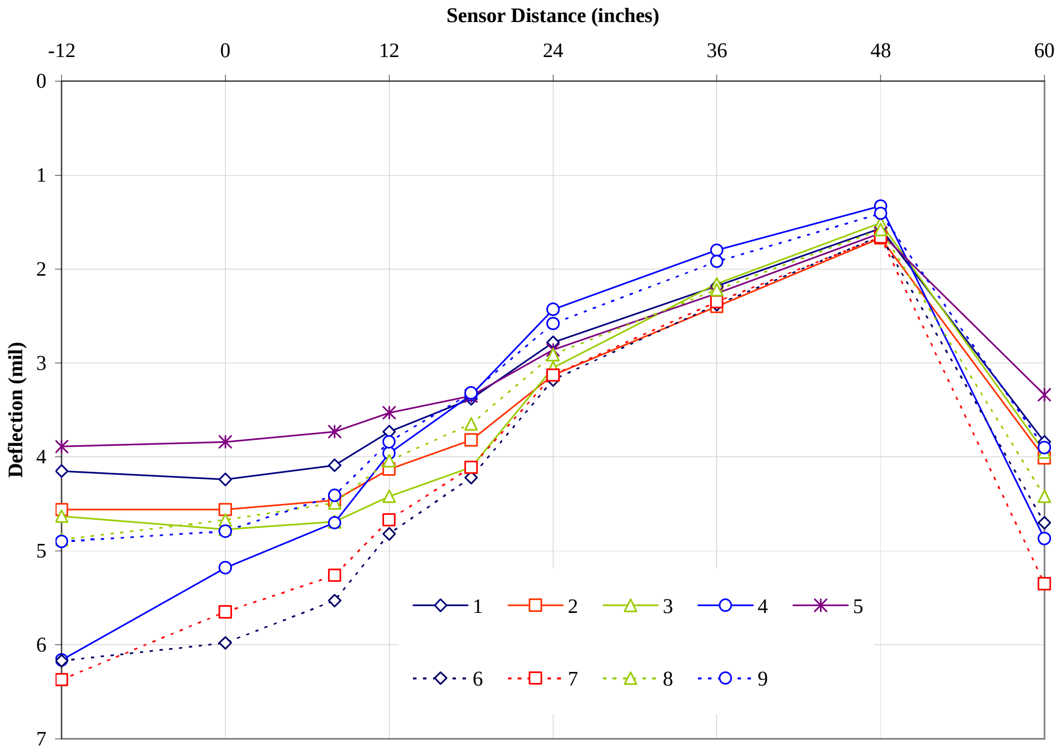


Figure C 24 -- Phase I: Des Moines - 6 kip test in November 2007

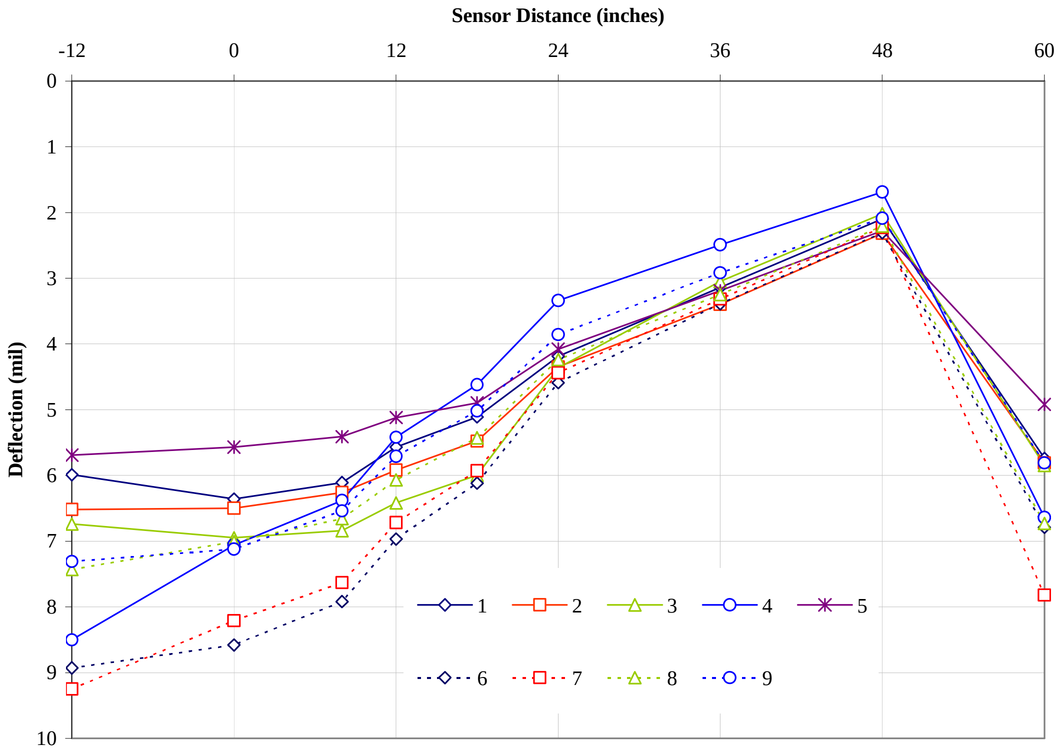


Figure C 25 -- Phase I: Des Moines - 9 kip test in November 2007

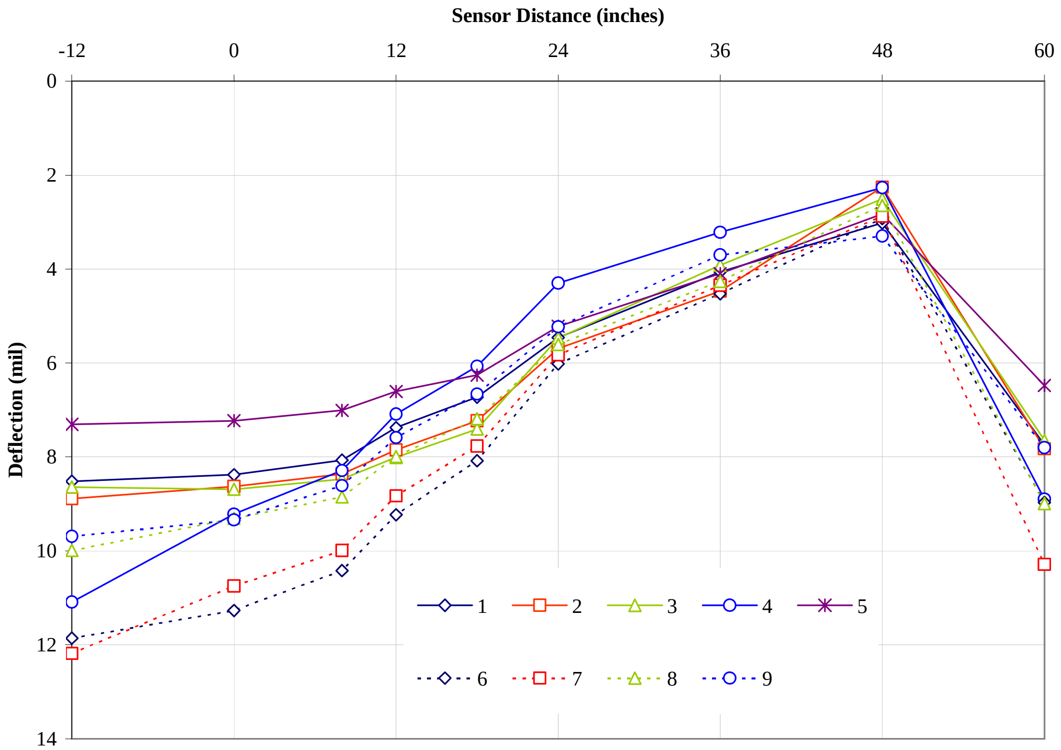


Figure C 26 -- Phase I: Des Moines -12 kip test in November 2007

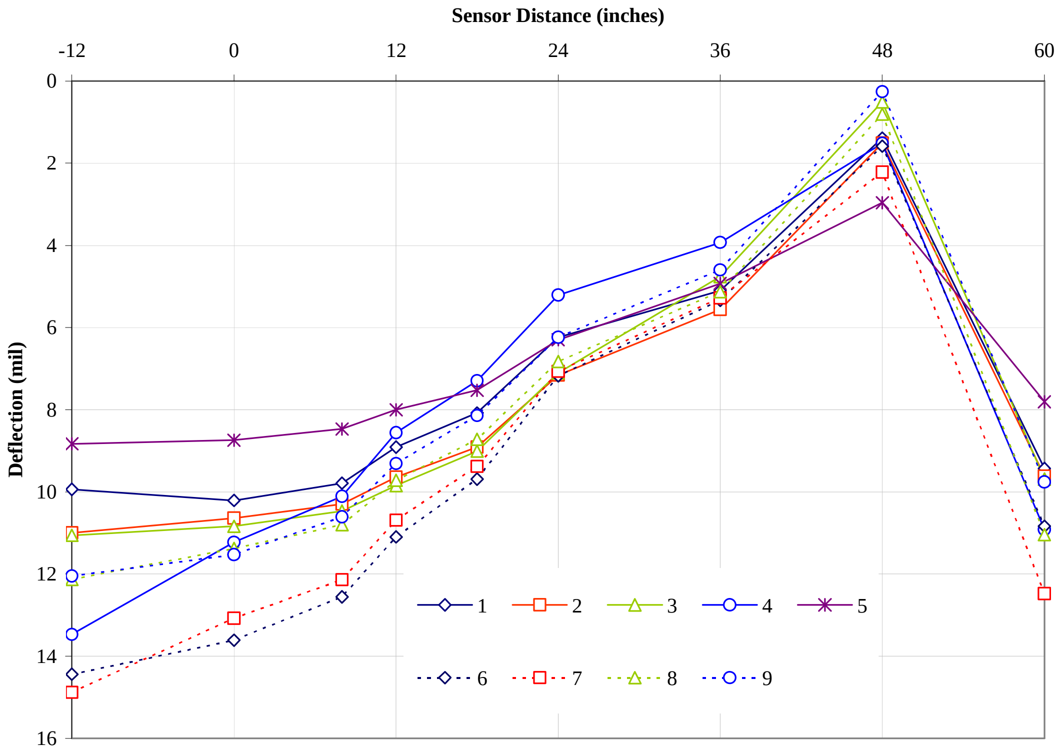


Figure C 27 -- Phase I: Des Moines - 15 kip test in November 2007

C.2 – Recommended Trenches

C.2.1 - Trench A

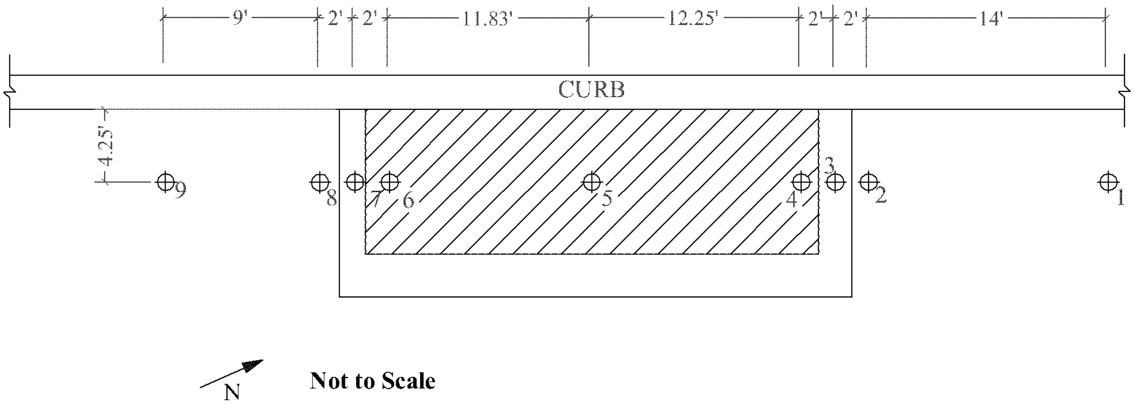


Figure C 28 -- FWD testing locations for Trench A

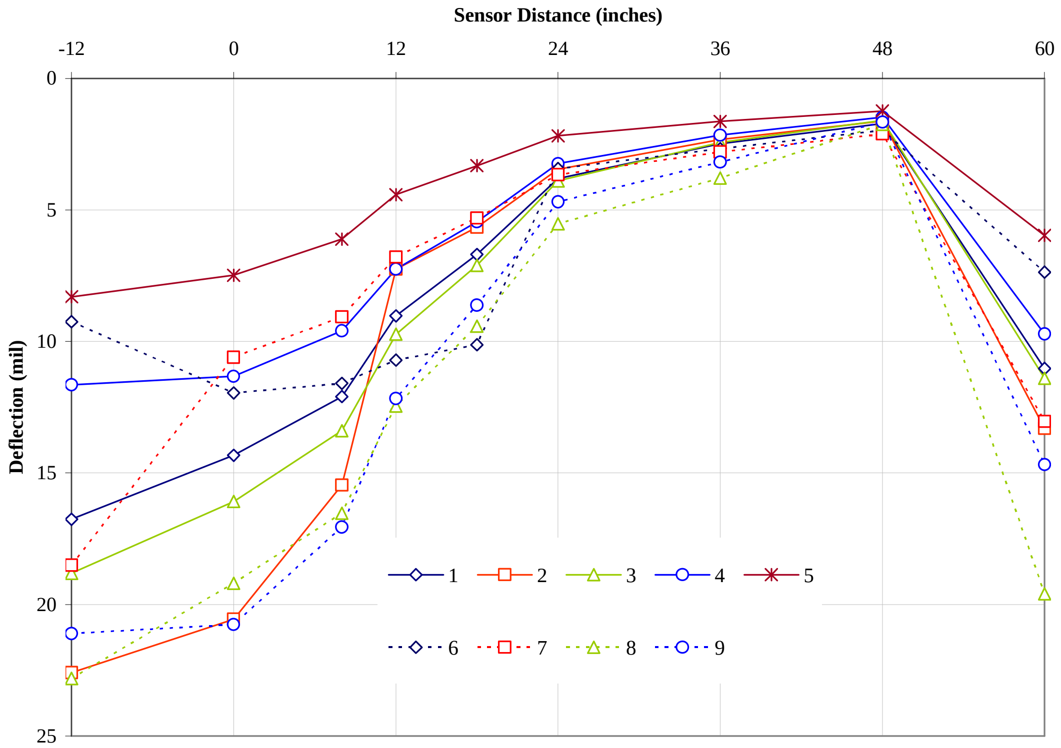


Figure C 29 -- Trench A – 6 kip test in November 2007

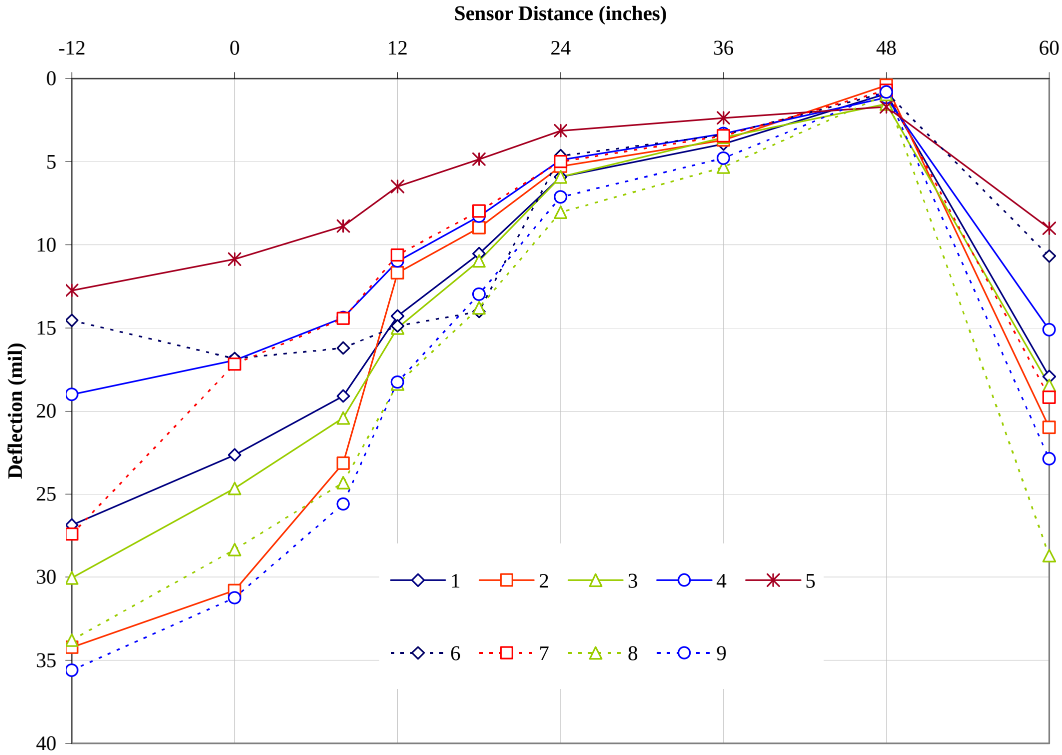


Figure C 30 -- Trench A – 9 kip test in November 2007

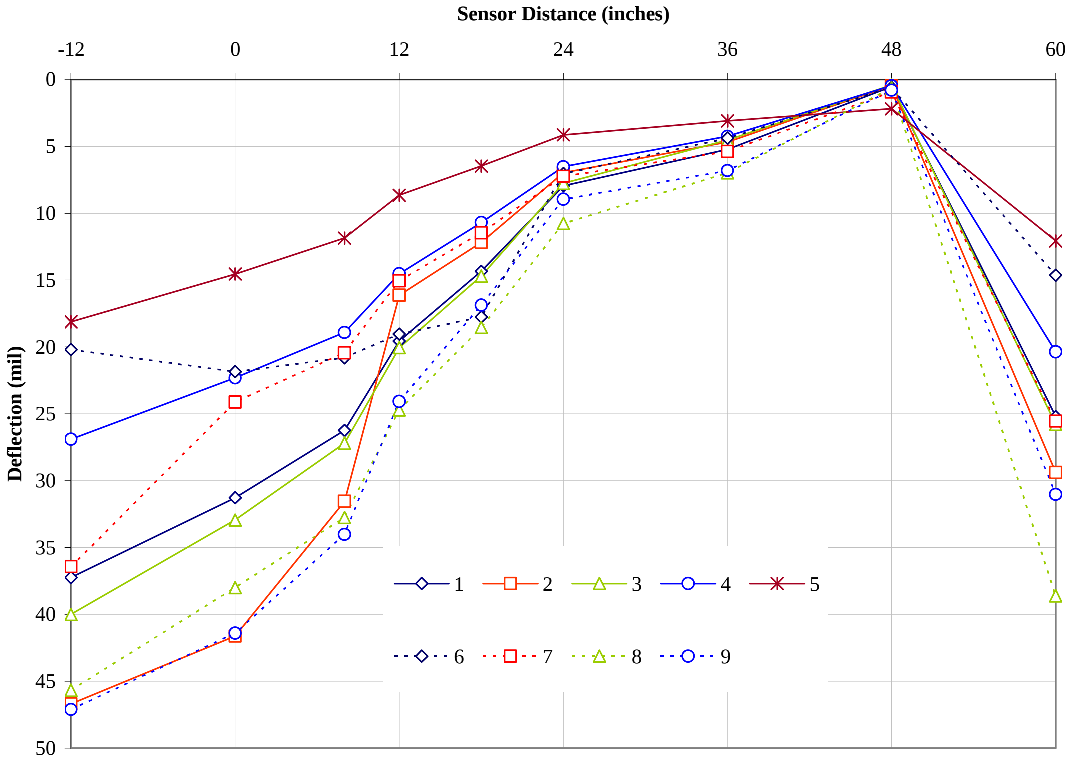


Figure C 31 -- Trench A –12 kip test in November 2007

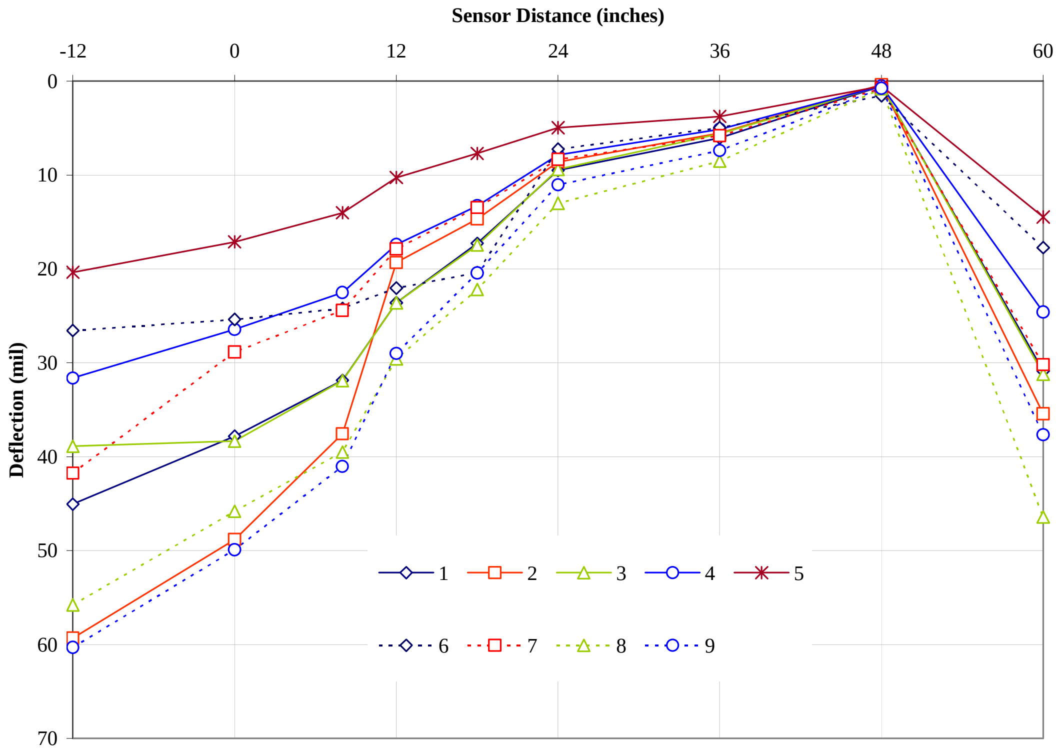


Figure C 32 -- Trench A – 15 kip test in November 2007

C.2.2 - Trench C

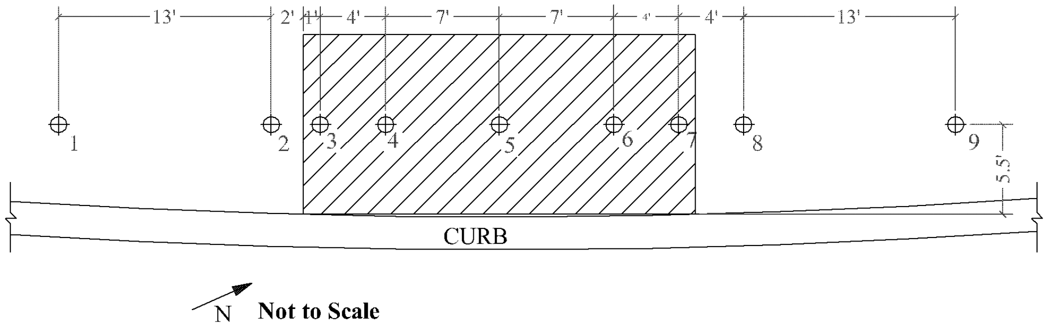


Figure C 33 -- FWD testing locations for Trench C

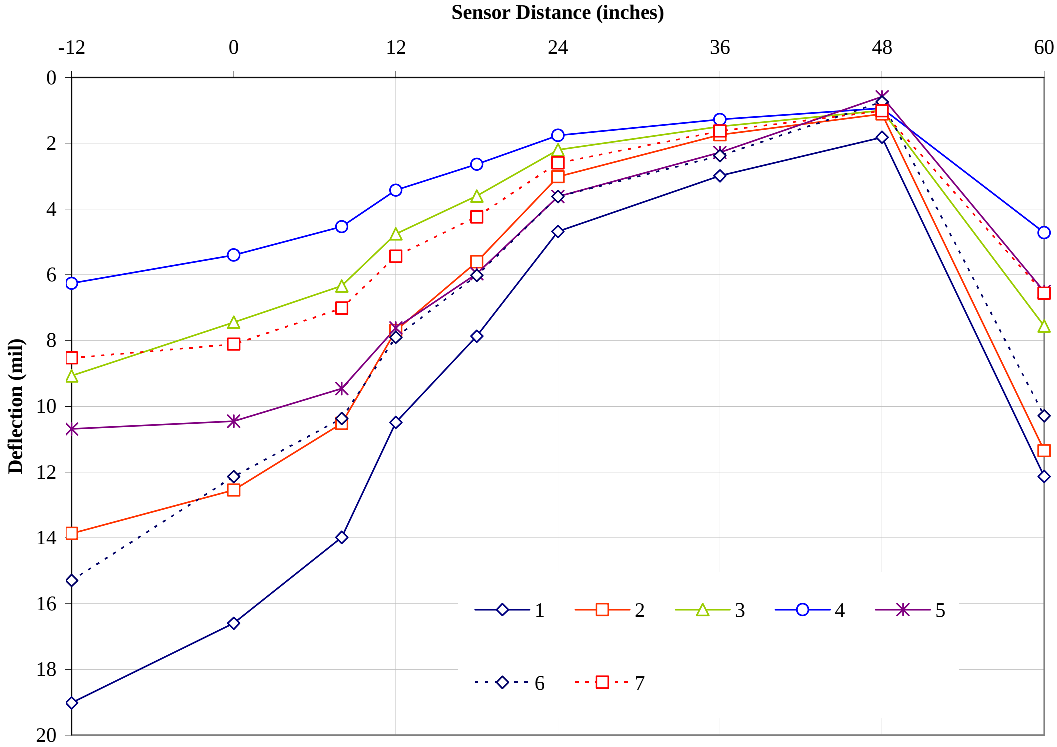


Figure C 34 -- Trench C – 6 kip test in June 2007

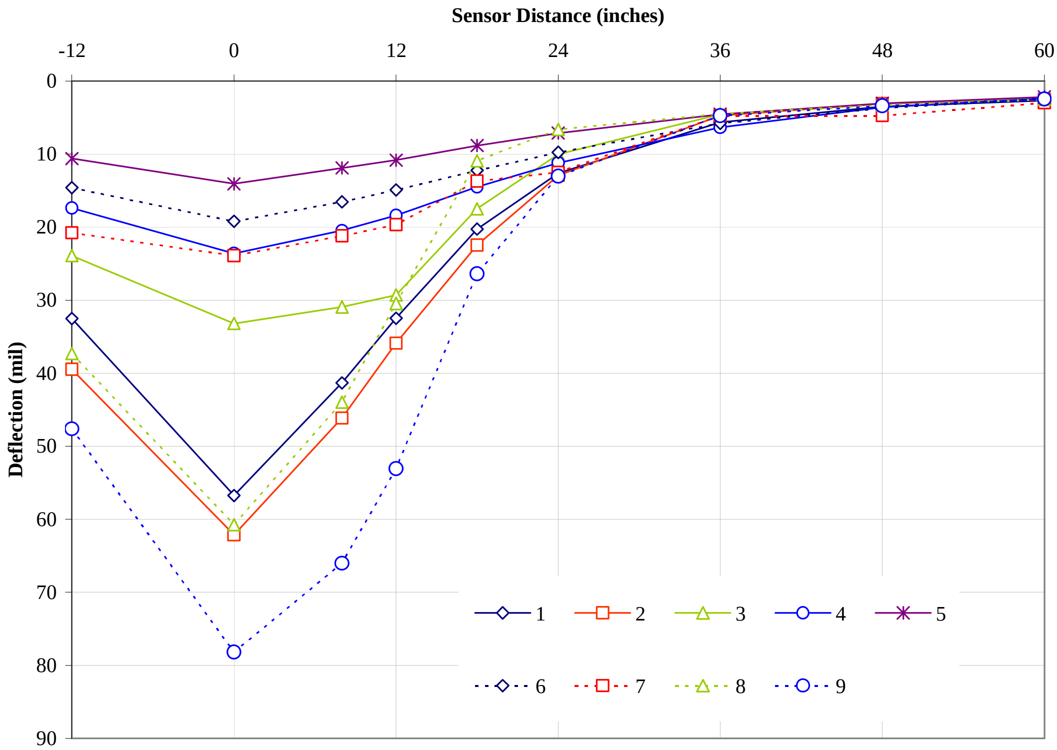


Figure C 35 -- Trench C – 9 kip test in June 2007

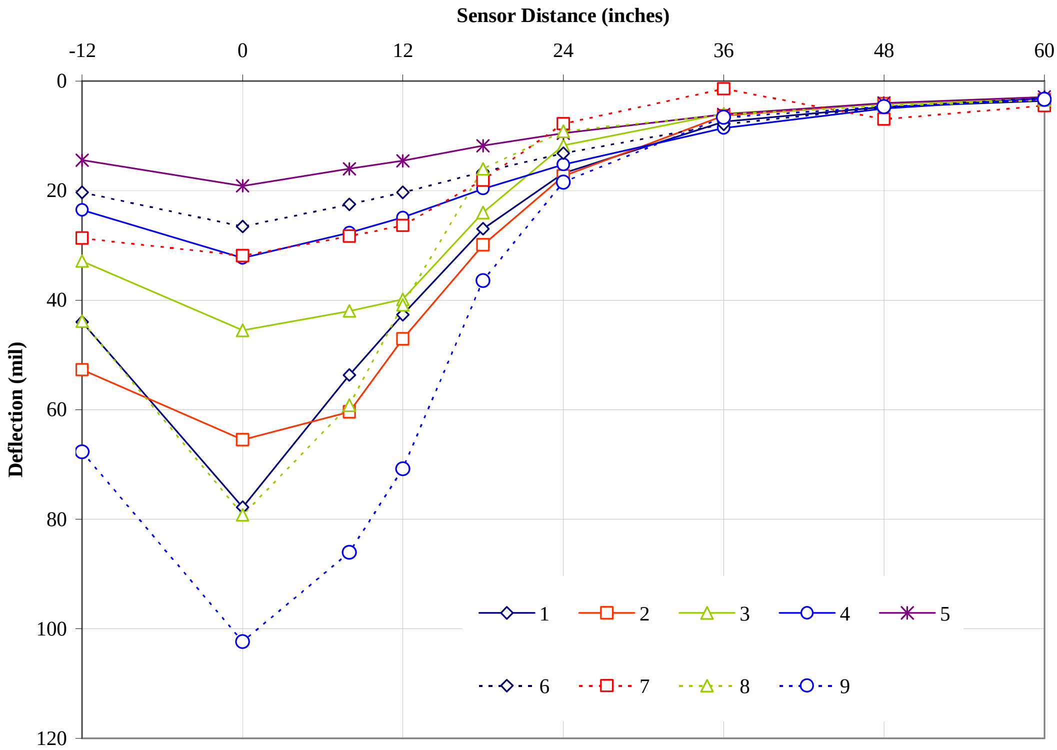


Figure C 36 -- Trench C – 12 kip test in June 2007

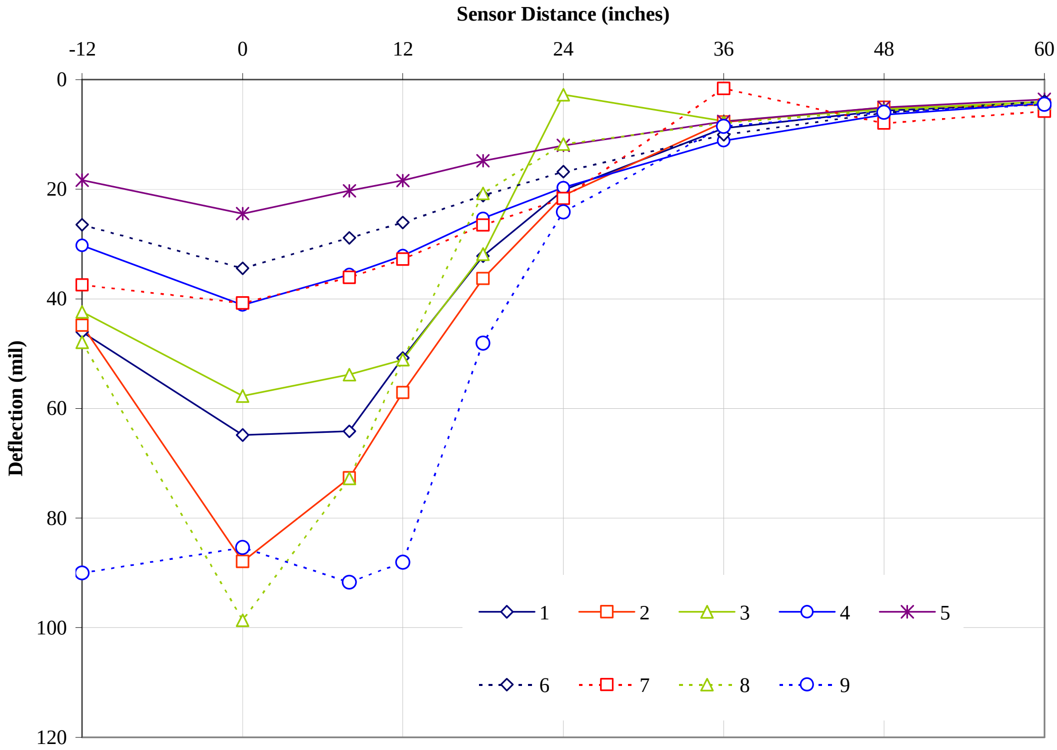


Figure C 37 -- Trench C – 15 kip test in June 2007

C.2.3 - Trench D

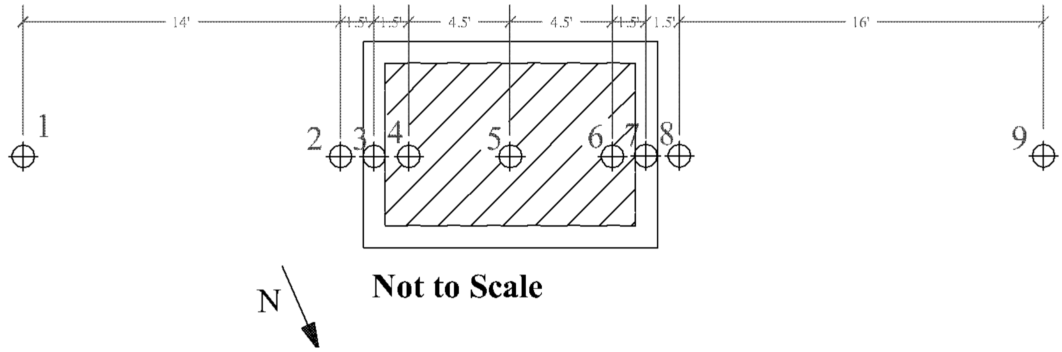


Figure C 38 -- FWD test locations from Trench D

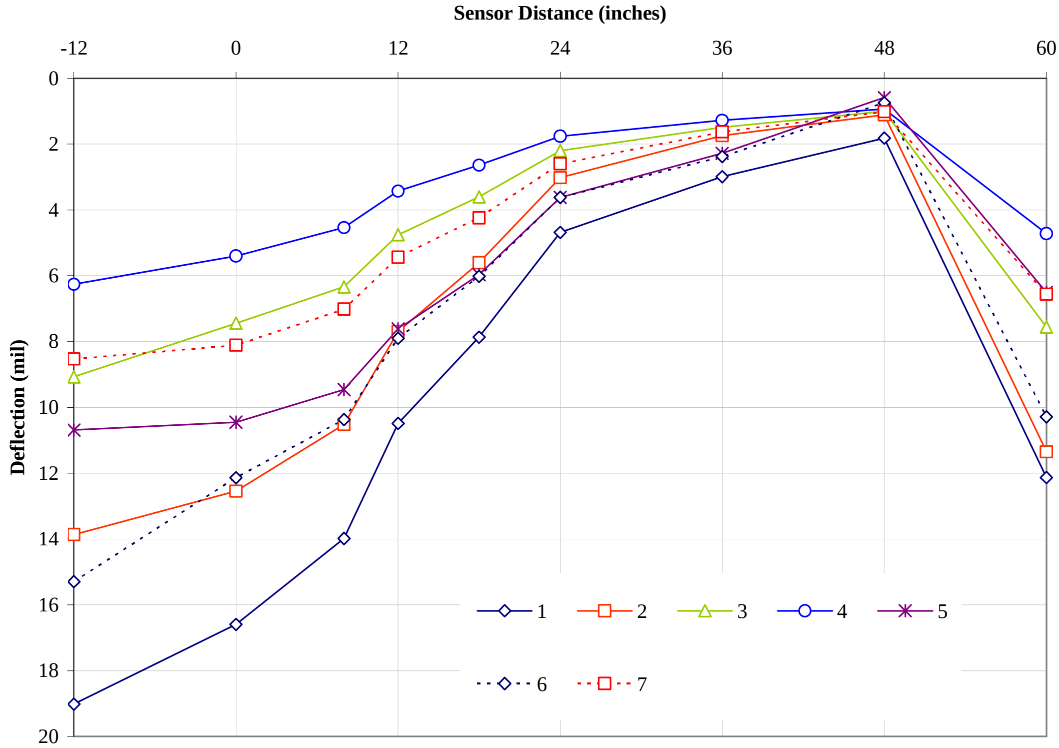


Figure C 39 -- Trench D – 6 kip test in November 2007

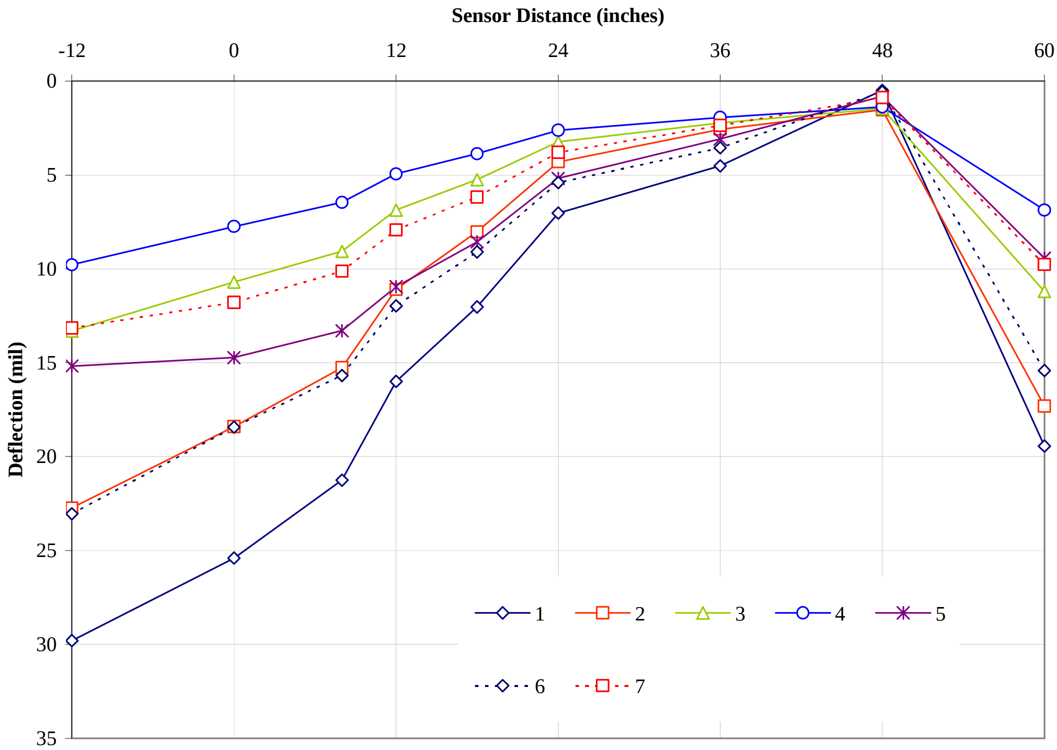


Figure C 40 -- Trench D – 9 kip test in November 2007

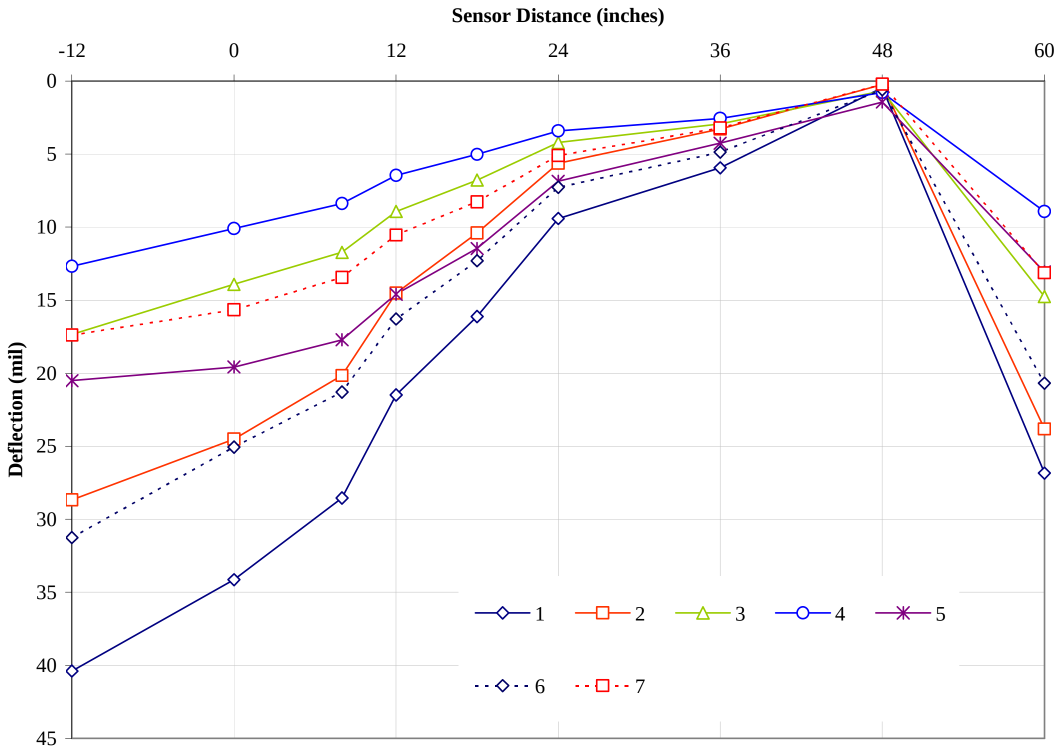


Figure C 41 -- Trench D – 12 kip test in November 2007

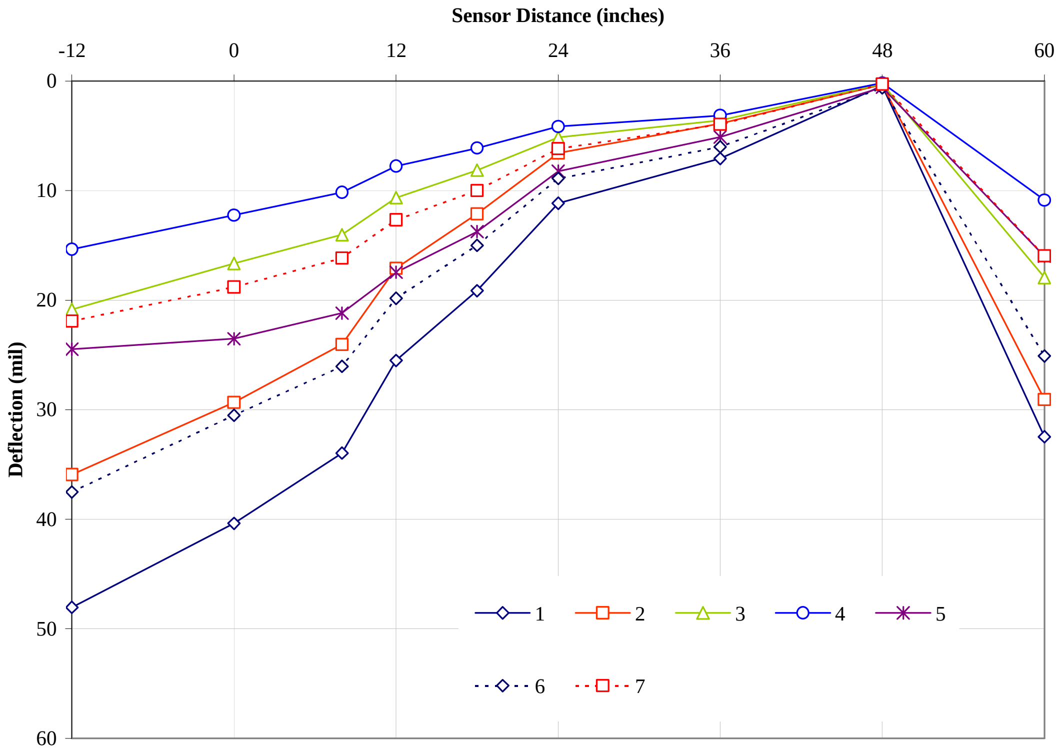


Figure C 42 -- Trench D – 15 kip test in November 2007

C.2.4 - Trench E

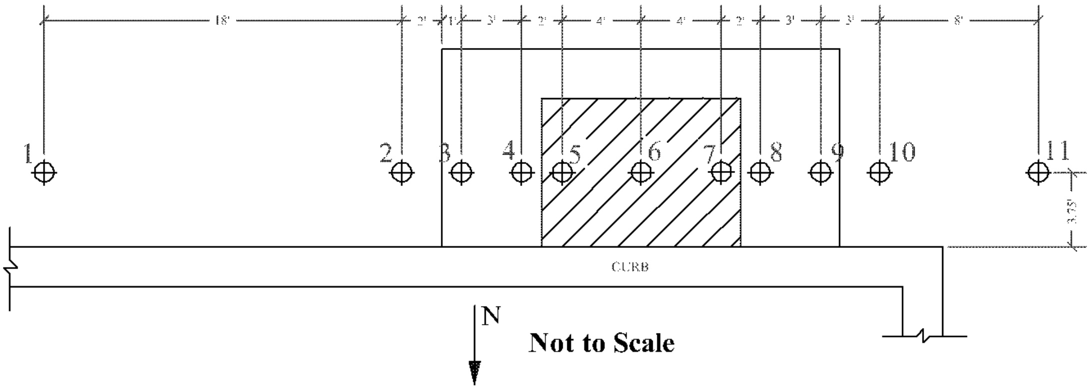


Figure C 43 -- FWD test locations for Trench E

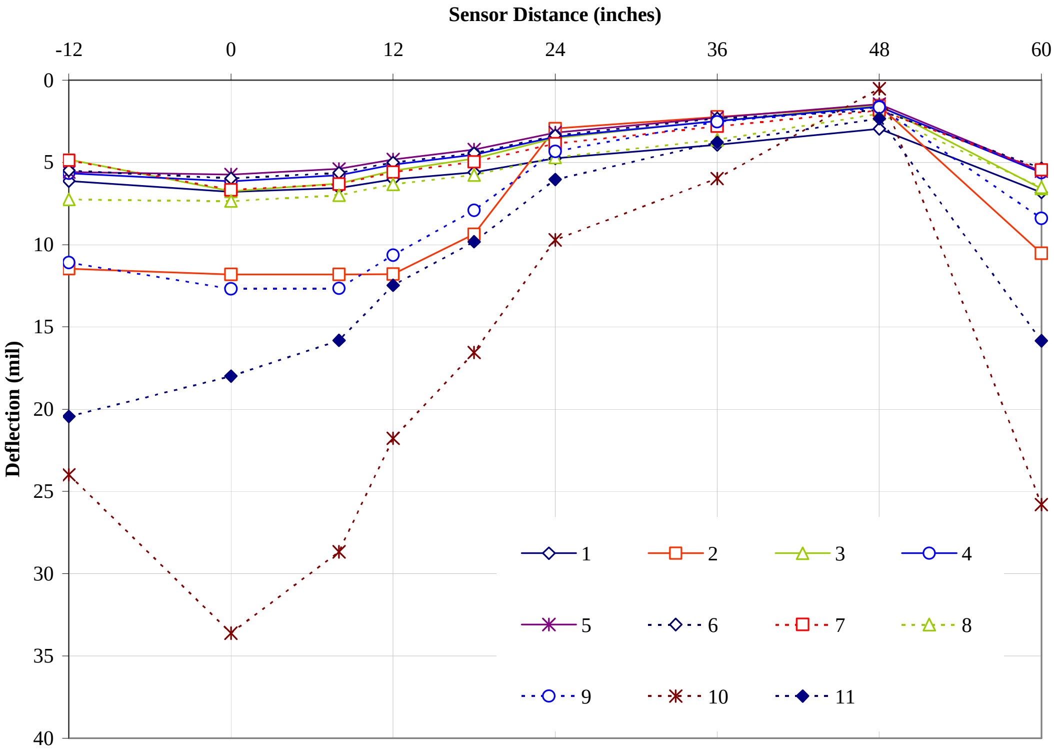


Figure C 44 -- Trench E – 6 kip test in November 2007

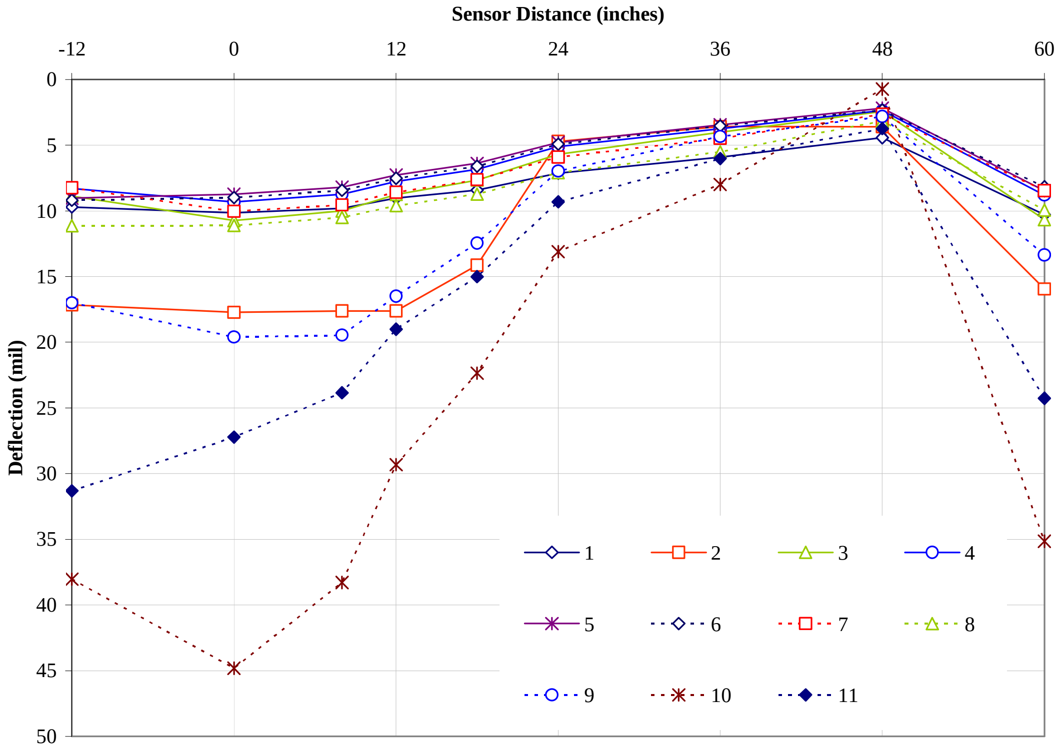


Figure C 45 -- Trench E – 9 kip test in November 2007

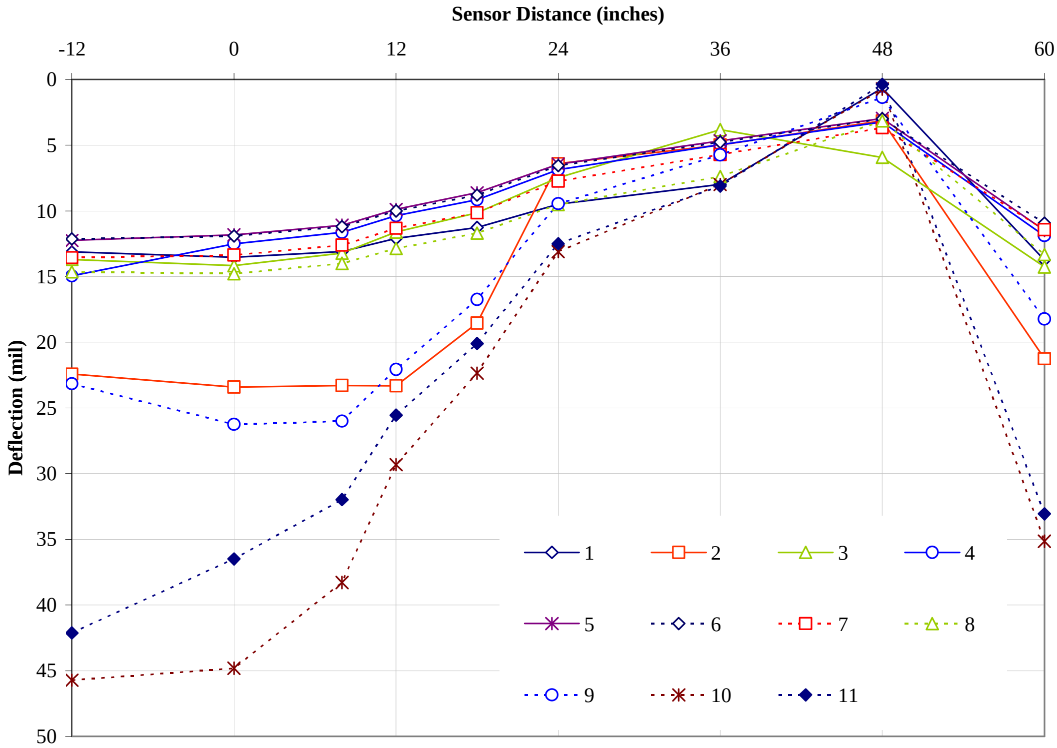


Figure C 46 -- Trench E – 12 kip test in November 2007

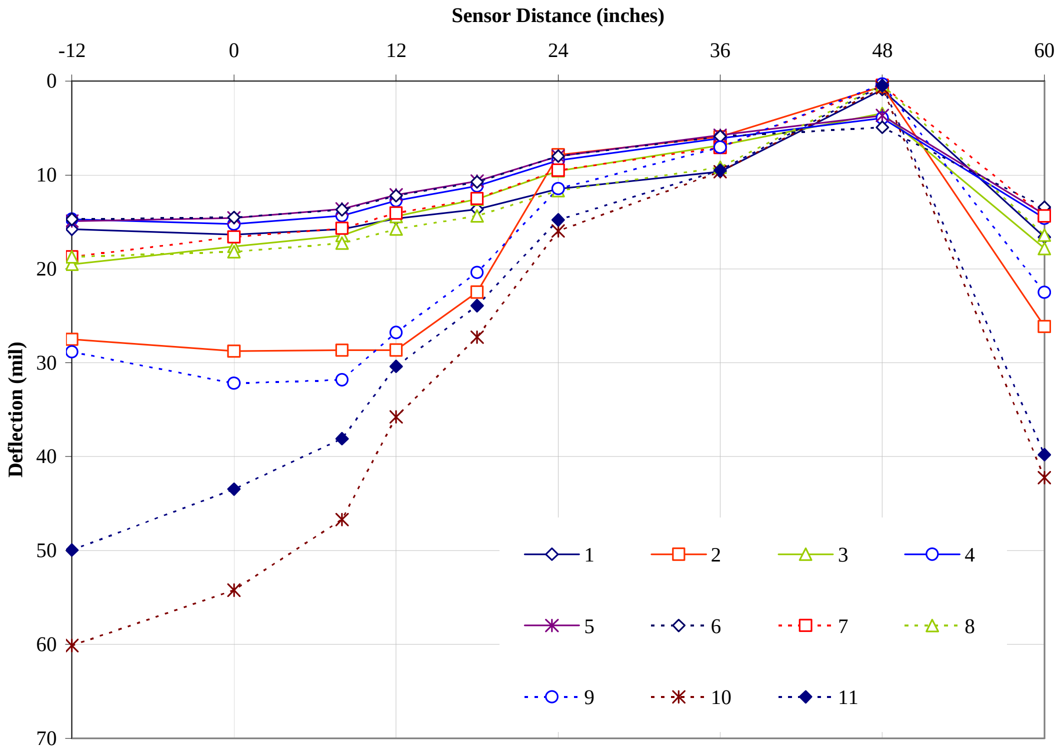


Figure C 47 -- Trench E –15 kip test in November 2007

C.2.5 - Trench F

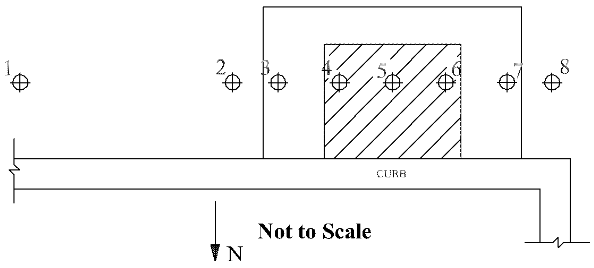


Figure C 48 -- FWD test locations for Trench F

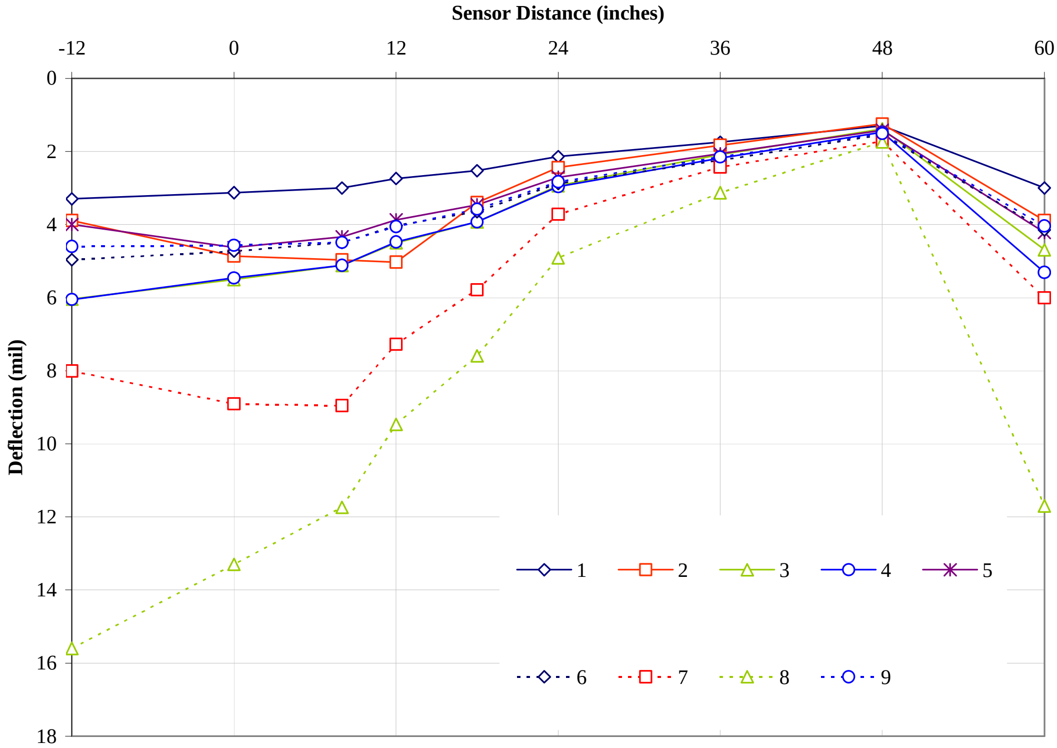


Figure C 49 -- Trench F – 6 kip test in November 2007

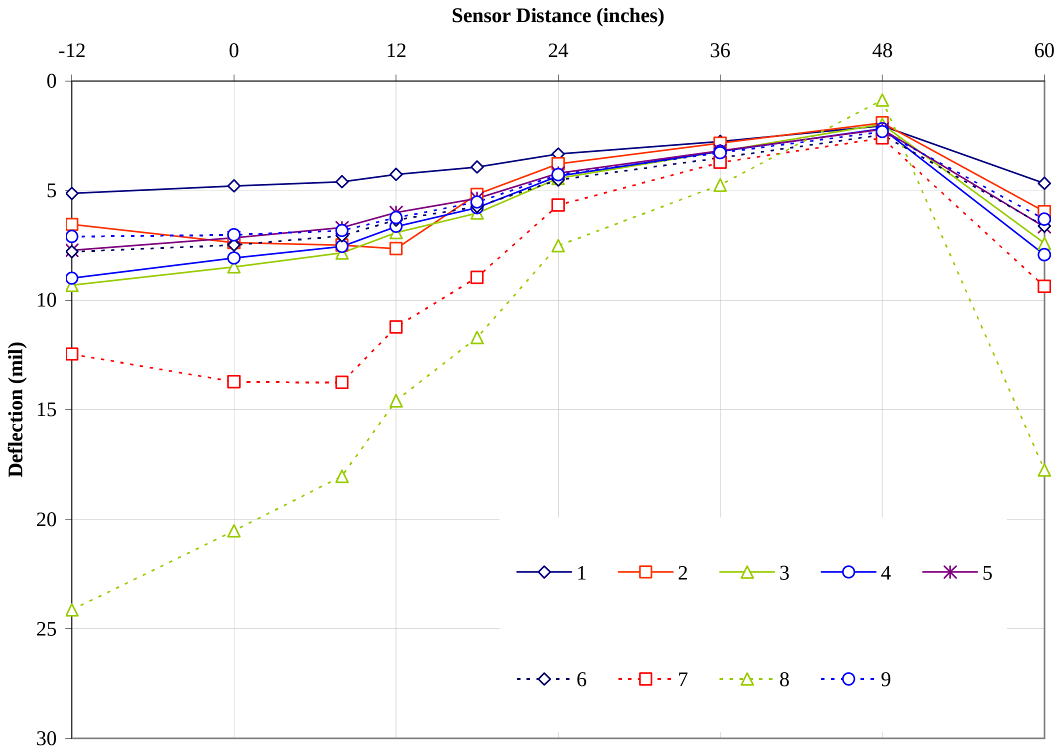


Figure C 50 -- Trench F – 9 kip test in November 2007

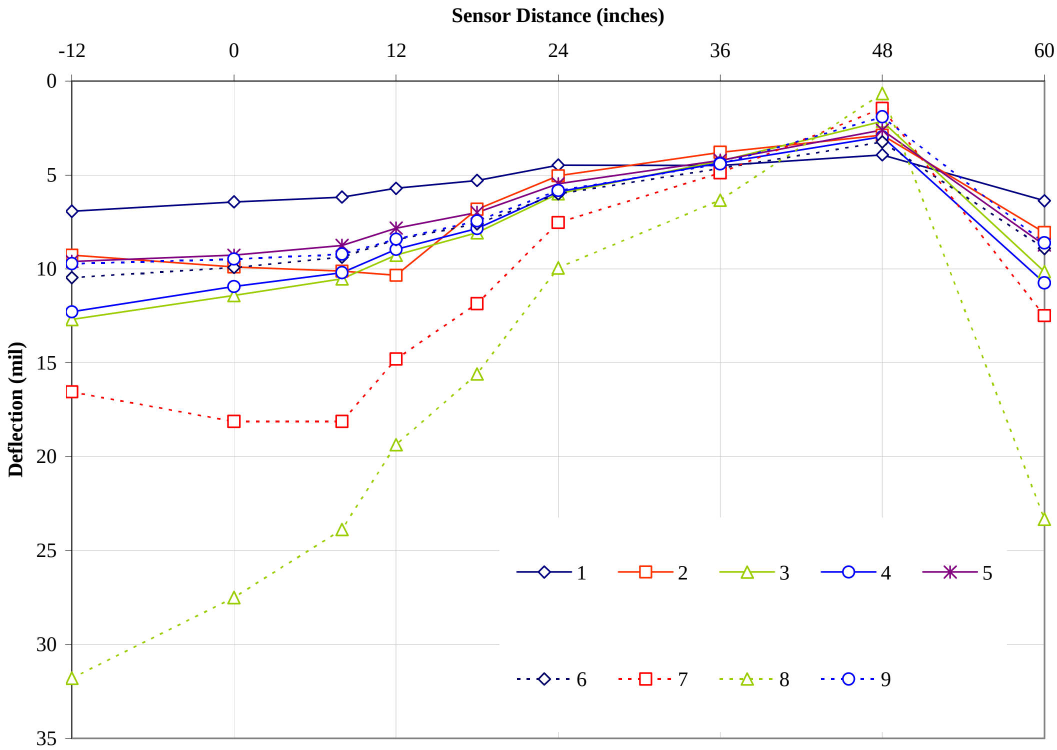


Figure C 51 -- Trench F – 12 kip test in November 2007

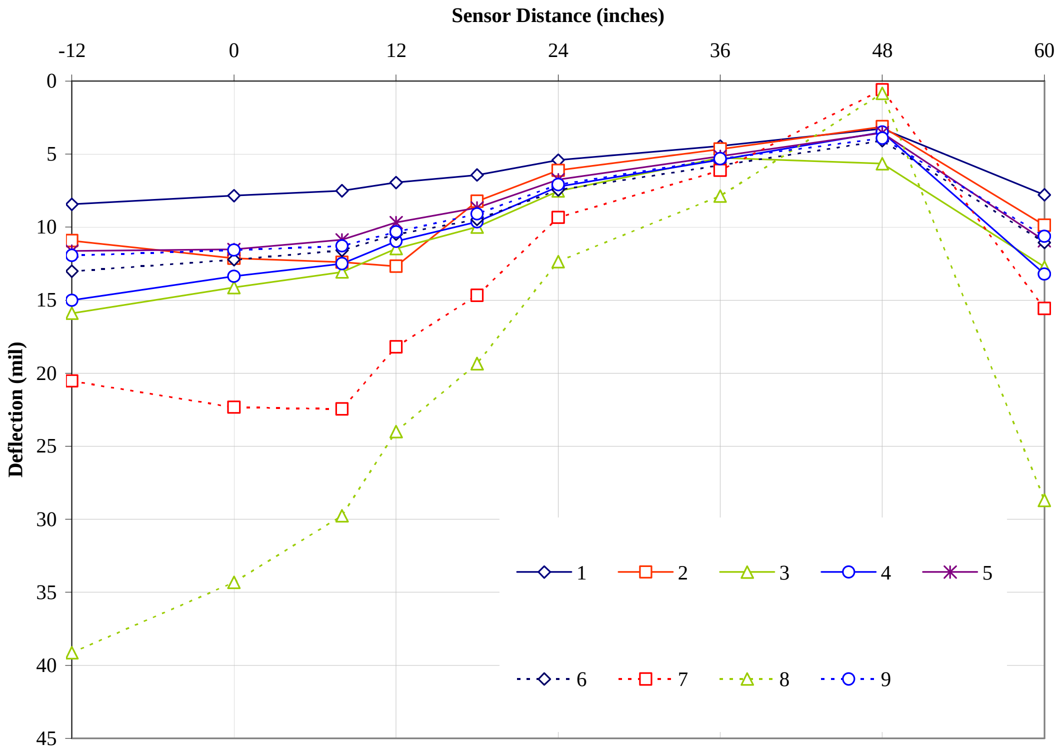


Figure C 52 -- Trench F – 15 kip test in November 2007

C.3 – Instrumented Trenches

C.3.1 – Instrumented Trench 1

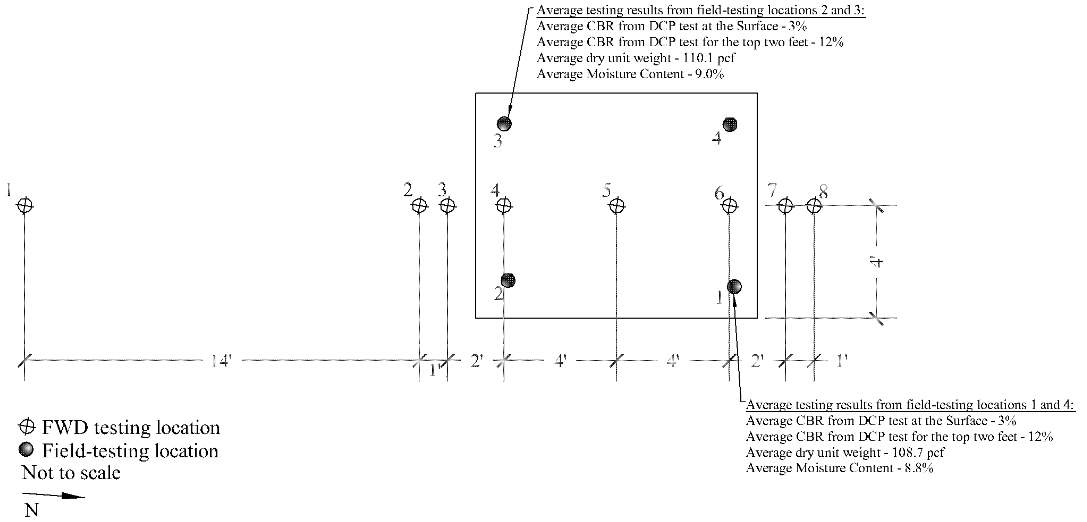


Figure C 53 -- FWD testing locations for Trench 1 and average field-testing results for the upper most lift for the north and south edges of the trench

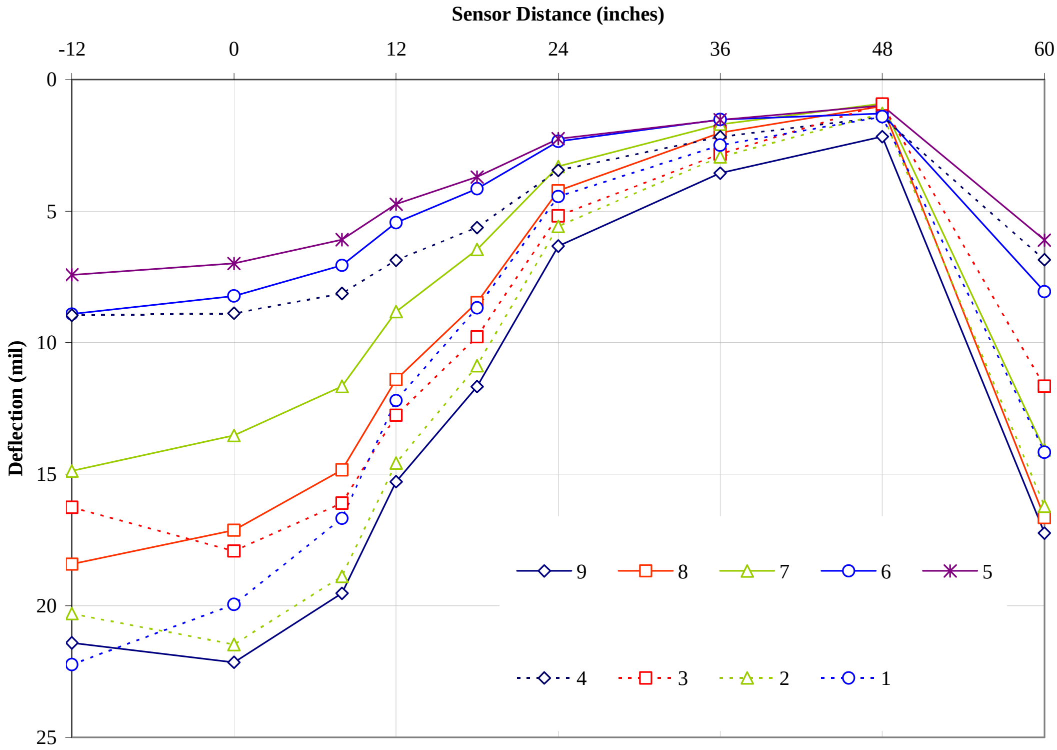


Figure C 54 -- Trench 1 – 6 kip test in November 2007

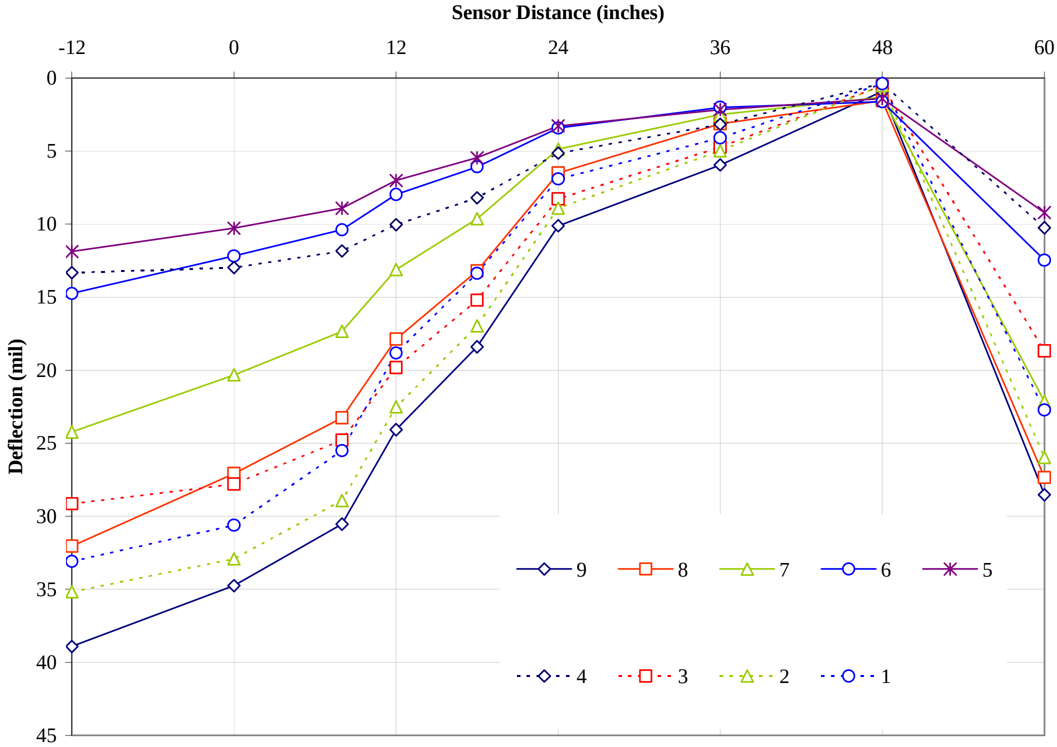


Figure C 55 -- Trench 1 – 9 kip test in November 2007

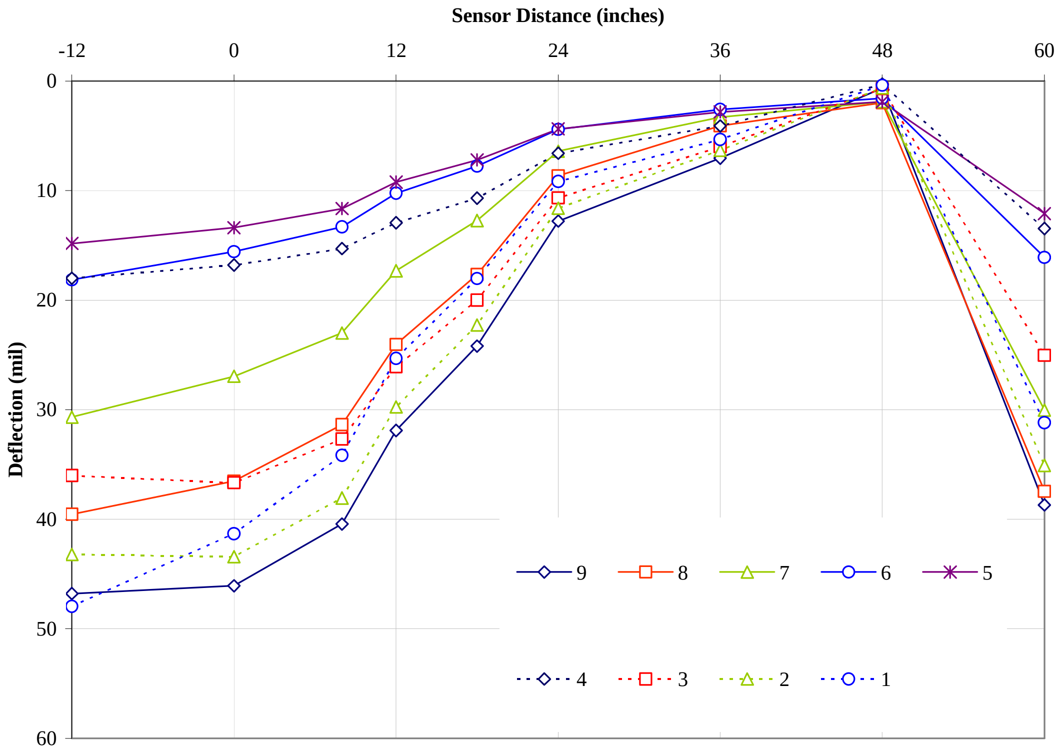


Figure C 56 -- Trench 1 – 12 kip test in November 2007

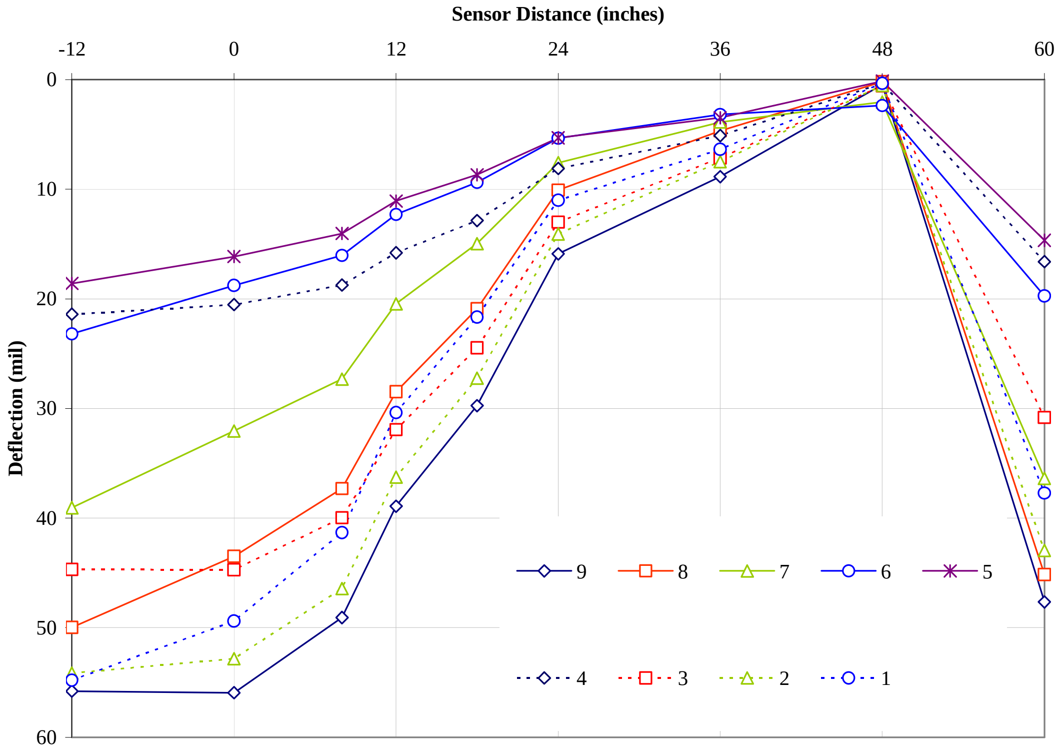


Figure C 57 -- Trench 1 – 15 kip test in November 2007

C.3.2 – Instrumented Trench 2

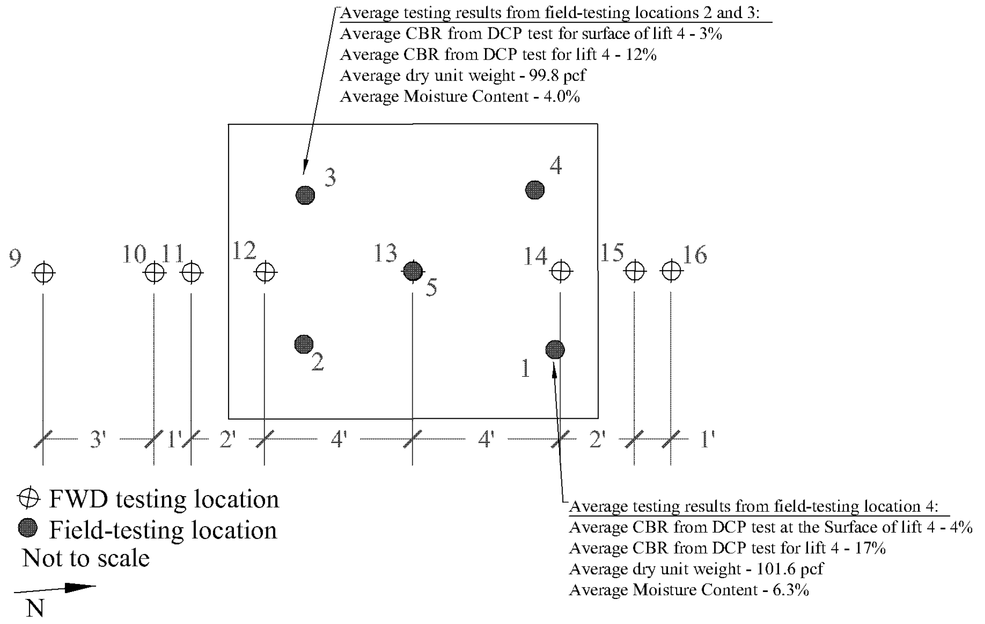


Figure C 58 -- Location of FWD testing for Trench 2 with the field-testing locations and average field-testing results

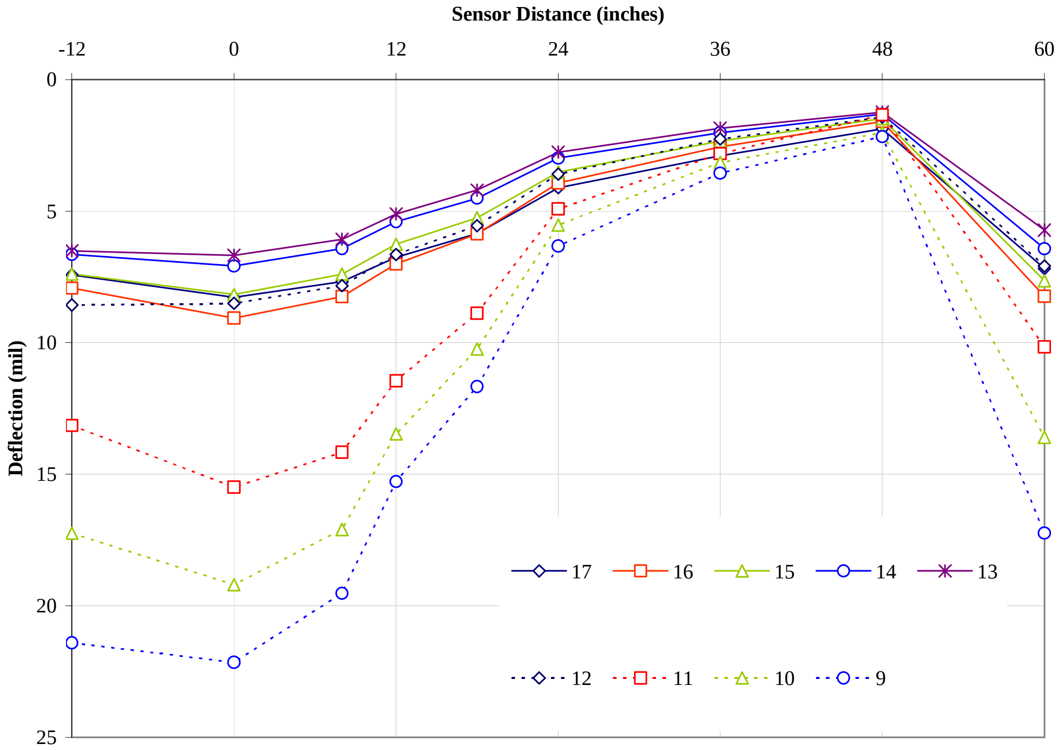


Figure C 59 -- Trench 2 – 6 kip test in November 2007

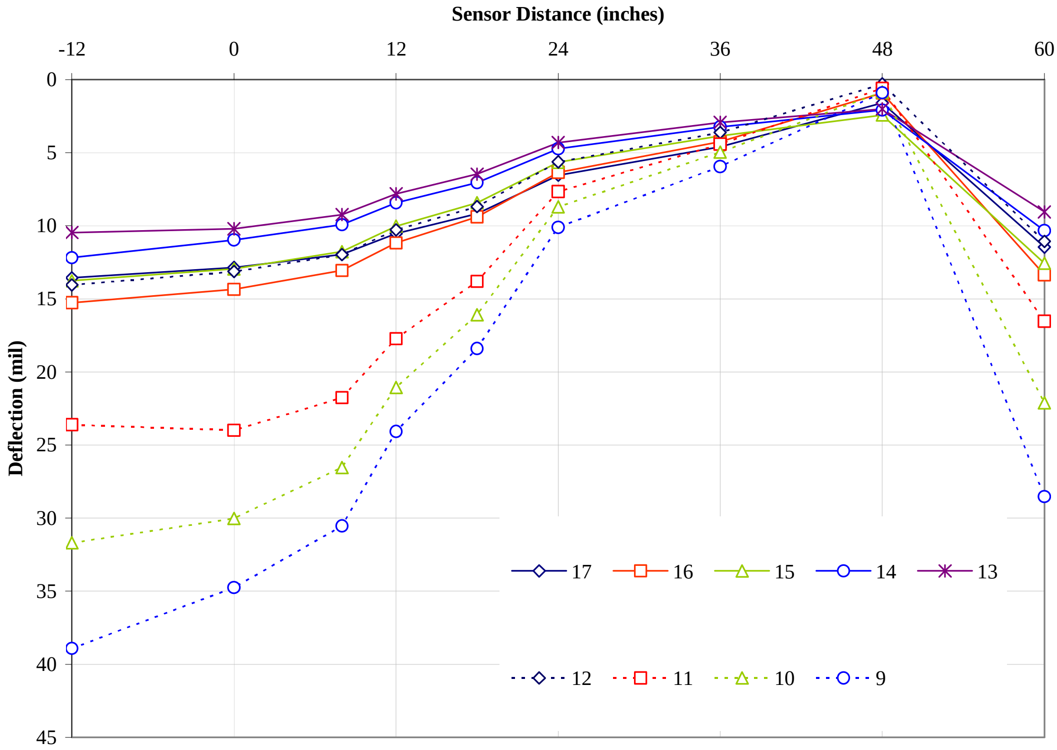


Figure C 60 -- Trench 2 – 9 kip test in November 2007

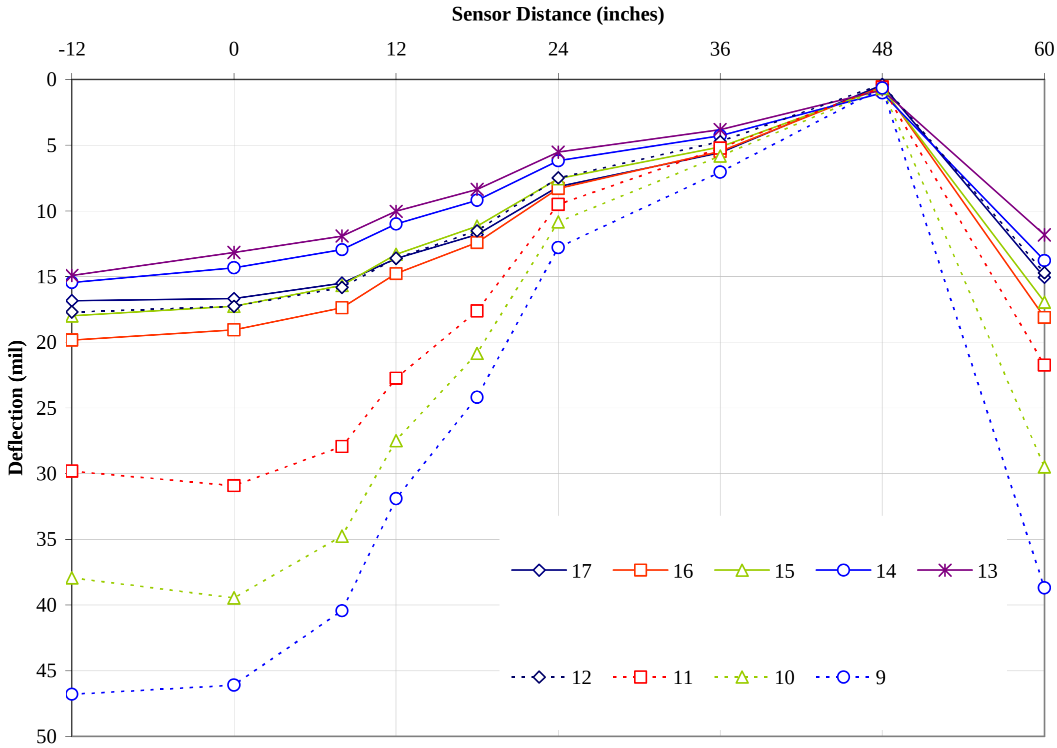


Figure C 61 -- Trench 2 – 12 kip test in November 2007

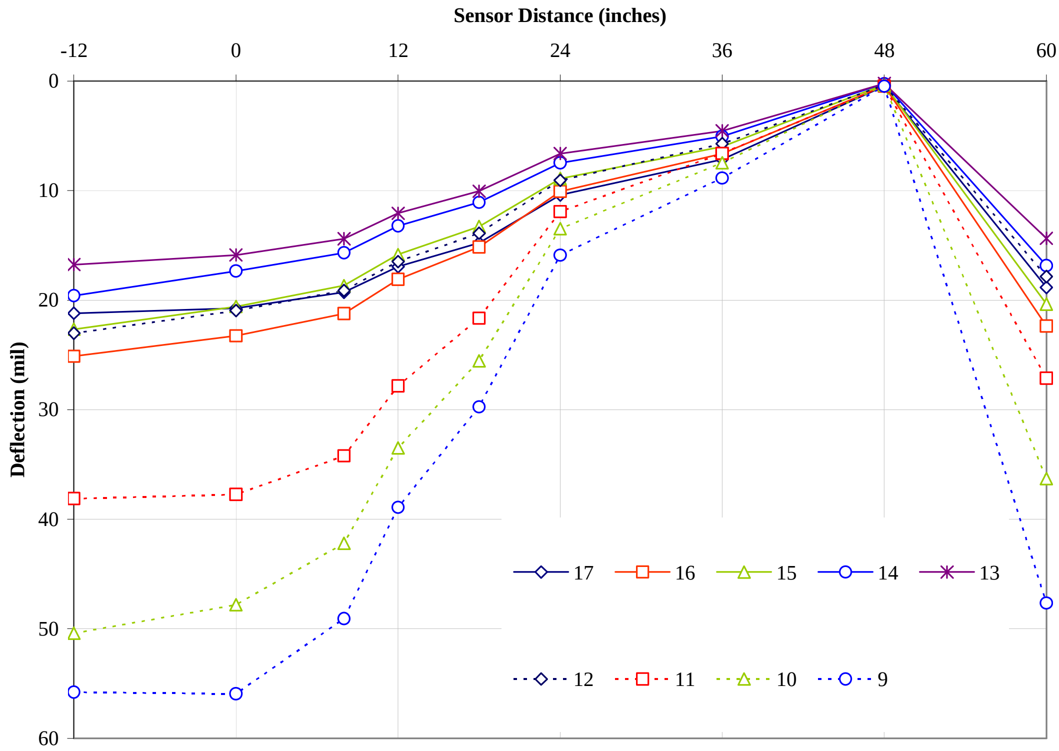


Figure C 62 -- Trench 2 – 15 kip test in November 2007

C.3.3 – Instrumented Trench 3

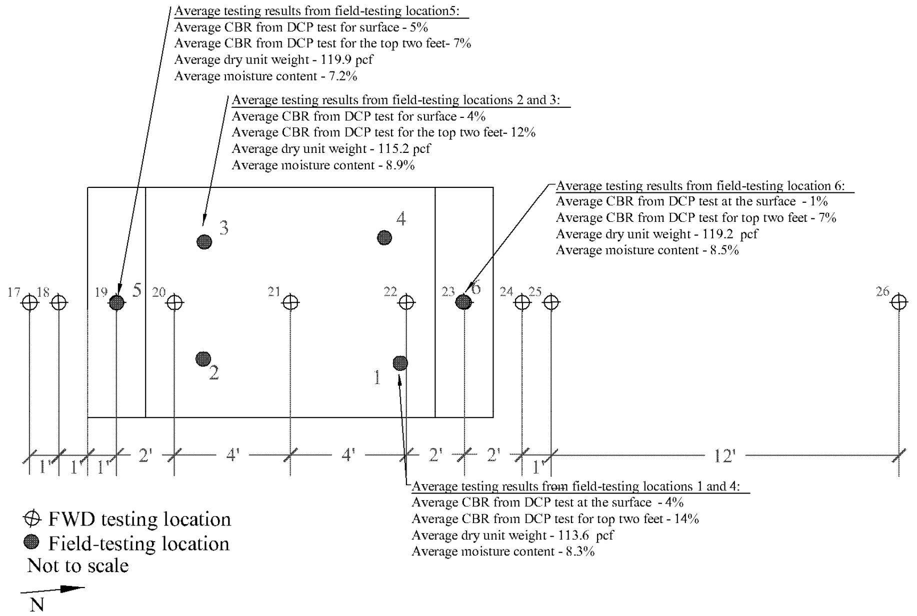


Figure C 63 -- Location of FWD testing locations for Trench 3

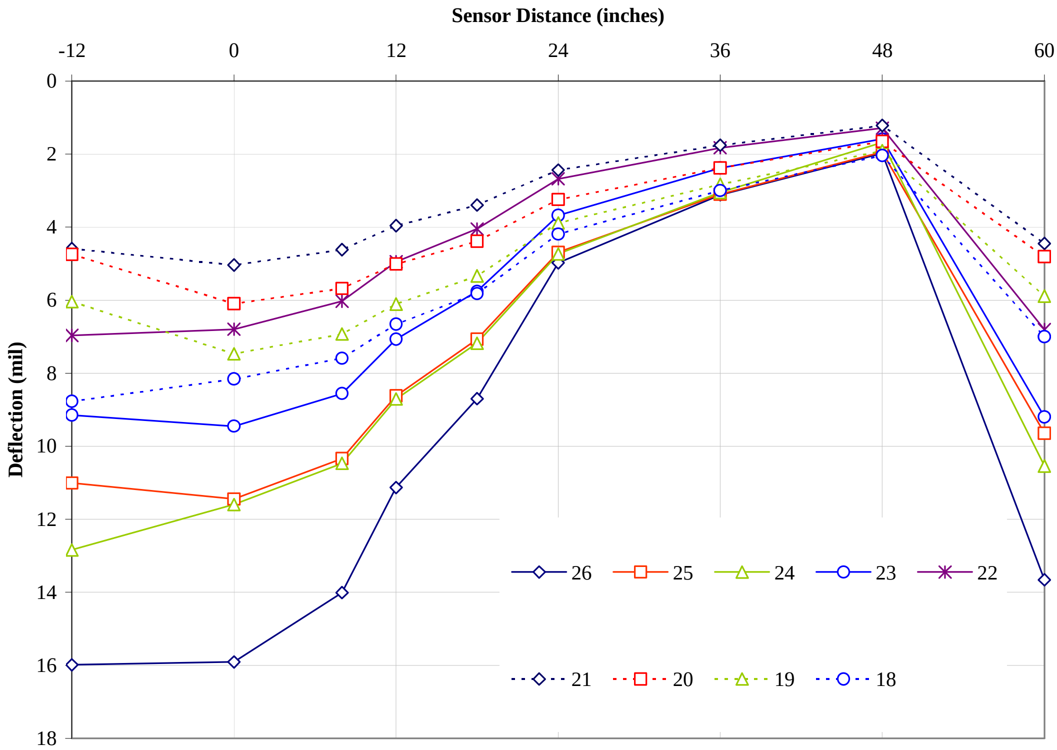


Figure C 64 -- Trench 3 – 6 kip test in November 2007

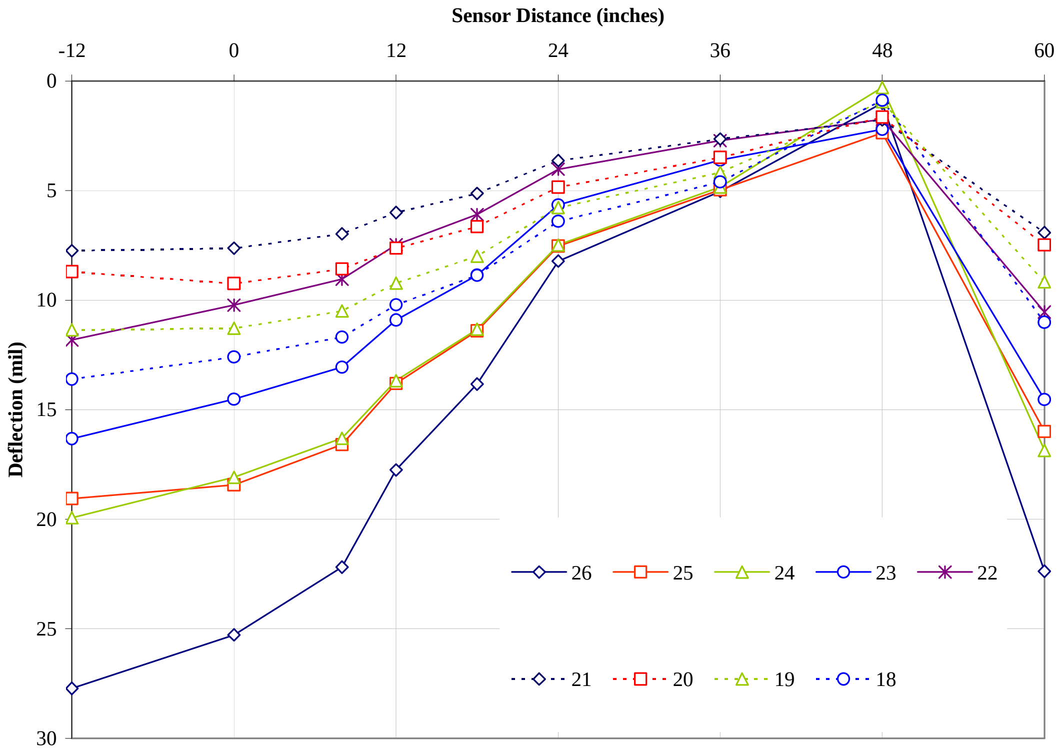


Figure C 65 -- Trench 3 – 9 kip test in November 2007

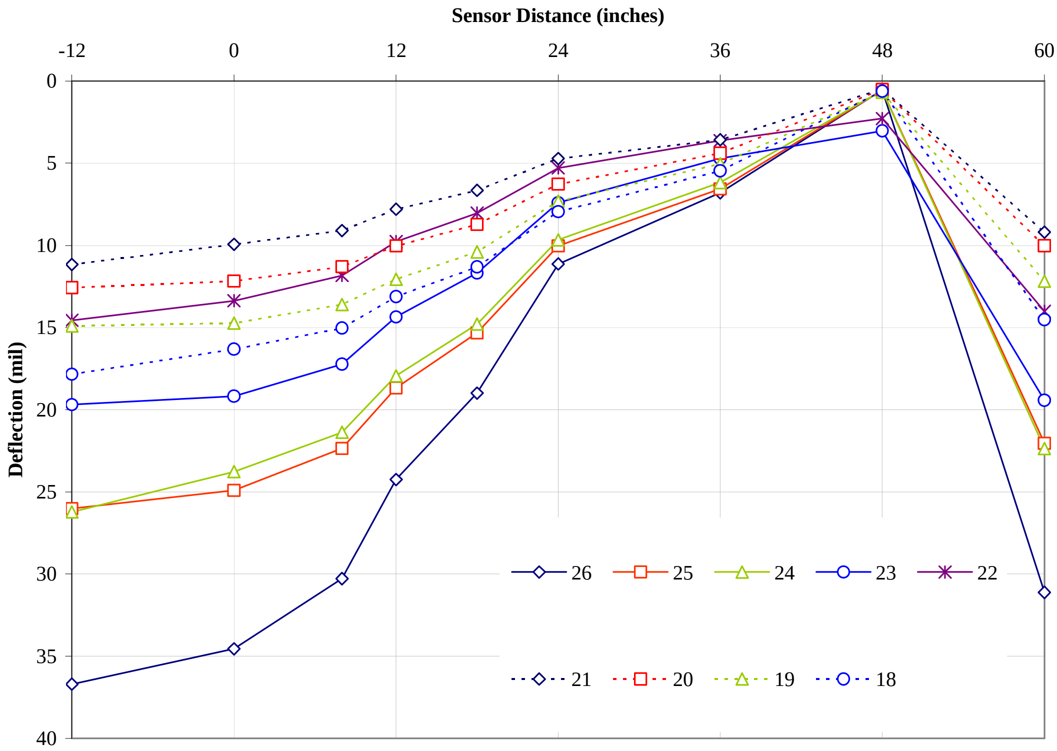


Figure C 66 -- Trench 3 – 12 kip test in November 2007

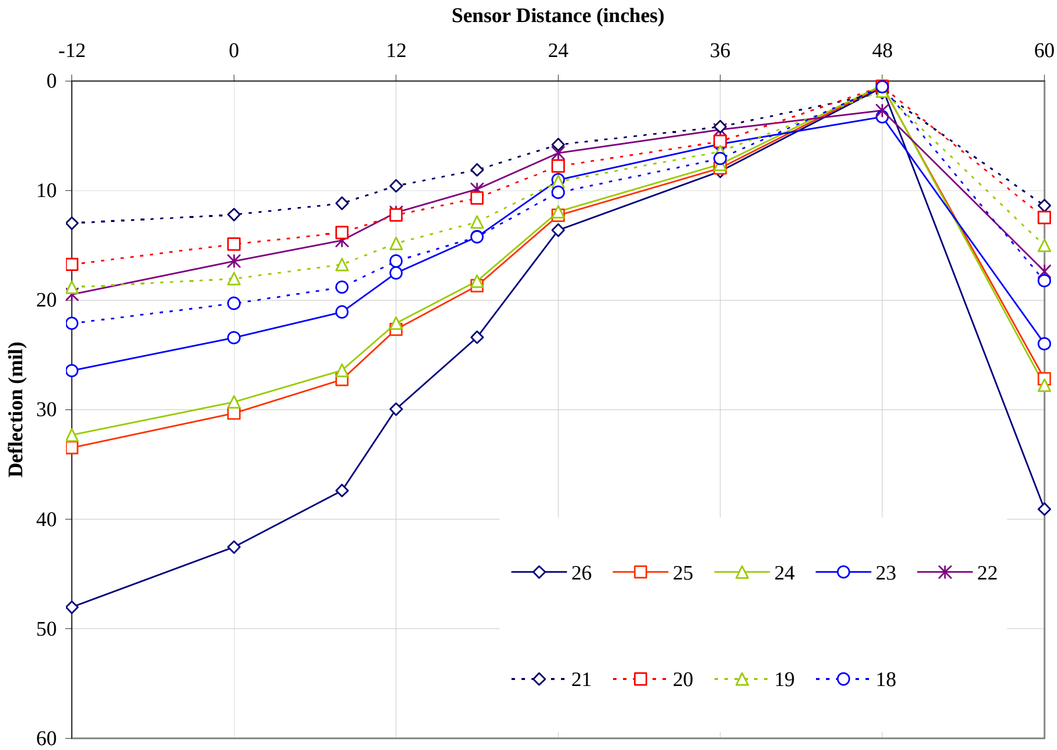


Figure C 67 -- Trench 3 – 15 kip test in November 2007

APPENDIX D.0 SURVEY RESULTS

APPENDIX D.0 – SURVEY RESULTS

D.1 – Phase I Local Agency Utility Cut Restorations

D.1.1 - Phase I: Ames (20th Street and Hayes Avenue)

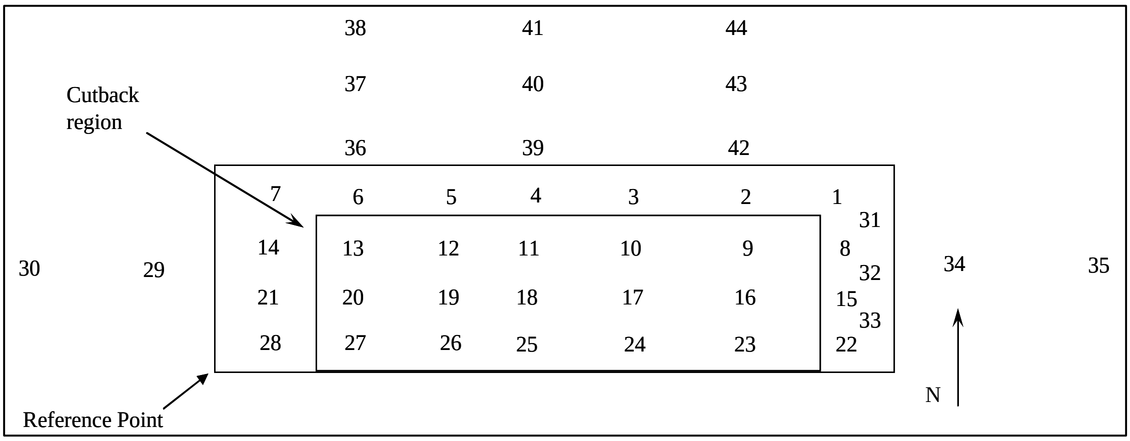


Figure D 1 -- Survey locations for Ames Trench

Table D 1 –Coordinates of survey points

Benchmark: West Hydrant (top nut)					
Point	**X (ft)**	**Y (ft)**	**Point**	**X (ft)**	**Y (ft)**
Reference point southwest corner of the patch	0	0	**23**	15.8	0.9
1	18.75	7.9	**24**	12.85	0.9
2	15.8	7.9	**25**	9.9	0.9
3	12.85	7.9	**26**	6.95	0.9
4	9.9	7.9	**27**	4	0.9
5	6.95	7.9	**28**	1.05	0.9
6	4	7.9	**29**	-2	5.9
7	1.05	7.9	**30**	-9	5.9
8	18.75	6.9	**31**	221.7	6.9
9	15.8	6.9	**32**	21.7	3.9
10	12.85	6.9	**33**	21.7	0.9
11	9.9	6.9	**34**	24.7	6.9
12	6.95	6.9	**35**	31.7	6.9
13	4	6.9	**36**	5	10
14	1.05	6.9	**37**	5	13
15	18.75	3.9	**38**	5	18
16	15.8	3.9	**39**	10	10
17	12.85	3.9	**40**	10	13
18	9.9	3.9	**41**	10	18
19	6.95	3.9	**42**	15	10
20	4	3.9	**43**	15	13
21	1.05	3.9	**44**	15	18
22	18.75	0.9			

Table D 2 -- Elevation surveys

Point	12/17/2004		5/10/2005		5/11/2007	
	Survey reading (ft)	Elevation (ft)	Survey reading (ft)	Elevation (ft)	Survey reading (ft)	Elevation (ft)
West Hydrant (top nut)	1.28	100	0.93	100	0.22	100
1	5.23	96.05	4.93	96	5.42	95.98
2	5.22	96.06	4.93	96	5.41	95.99
3	5.25	96.03	4.96	95.97	5.45	95.95
4	5.28	96	4.99	95.94	5.48	95.92
5	5.3	95.98	5.01	95.92	5.5	95.9
6	5.32	95.96	5.03	95.9	5.52	95.88
7	5.34	95.94	5.05	95.88	5.53	95.87
8	5.25	96.03	4.96	95.97	5.44	95.96
9	5.25	96.03	4.96	95.97	5.44	95.96
10	5.29	95.99	4.99	95.94	5.47	95.93
11	5.32	95.96	5.03	95.9	5.5	95.9
12	5.34	95.94	5.04	95.89	5.52	95.88
13	5.36	95.92	5.065	95.865	5.53	95.87
14	5.37	95.91	5.08	95.85	5.54	95.86
15	5.34	95.94	5.035	95.895	5.51	95.89
16	5.33	95.95	5.035	95.895	5.52	95.88
17	5.38	95.9	5.085	95.845	5.58	95.82
18	5.43	95.85	5.145	95.785	5.61	95.79
19	5.42	95.86	5.135	95.795	5.6	95.8
20	5.42	95.86	5.12	95.81	5.59	95.81
21	5.43	95.85	5.125	95.805	5.6	95.8
22	5.48	95.8	5.185	95.745	5.67	95.73
23	5.47	95.81	5.18	95.75	5.69	95.71
24	5.5	95.78	5.2	95.73	5.7	95.7
25	5.51	95.77	5.225	95.705	5.72	95.68
26	5.52	95.76	5.24	95.69	5.74	95.66
27	5.52	95.76	5.23	95.7	5.73	95.67
28	5.51	95.77	5.21	95.72	5.71	95.69
29	5.41	95.87	5.14	95.79	5.57	95.83
30	5.45	95.83	5.17	95.76	5.61	95.79
31	5.25	96.03	4.96	95.97	5.44	95.96
32	5.33	95.95	5.02	95.91	5.48	95.92
33	5.47	95.81	5.18	95.75	5.65	95.75
34	5.29	95.99	5	95.93	5.43	95.97
35	5.25	96.03	4.95	95.98	5.36	96.04
36					5.49	95.91

37					5.44	95.96
38					5.38	96.02
39					5.44	95.96
40					5.39	96.01
41					5.34	96.06
42					5.4	96
43					5.36	96.04
44					5.31	96.09

D.1.2 -Phase I: Cedar Rapids (Miami Drive and Sherman Avenue)

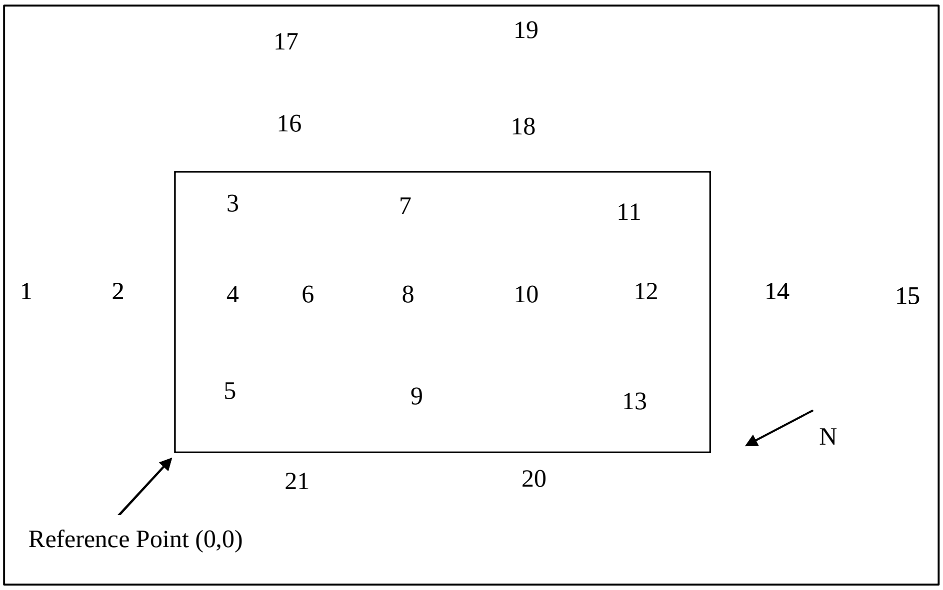


Figure D 2 -- Survey locations for Cedar Rapids Trench

Table D 3 –Coordinates of survey points Cedar Rapids Trench

BM: Hydrant NE top nut		
Point	**X (ft)**	**Y (ft)**
North corner of patch	0	0
1	-6	4
2	-1.8	4.1
3	1.15	7
4	1.15	4.3
5	1.15	1
6	3.35	4.2
7	5.85	6.8
8	5.85	4.3
9	5.85	1.3
10	7.95	4.3
11	10.55	7.35
12	10.55	4.25
13	10.55	1.5
14	13.65	4.25
15	17.75	5.5
16	3.35	9
17	3.35	14
18	7.95	9

19	7.95	14
20	7.95	-1
21	3.35	-1

Table D 4 -- Elevation surveys Cedar Rapids Trench

Point	**7/21/2004**		**10/29/2004**		**4/20/2005**		**5/22/2007**	
	Survey reading (ft)	**Elevation (ft)**	**Survey reading (ft)**	**Elevation (ft)**	**Survey reading (ft)**	**Elevation (ft)**	**Survey reading (ft)**	**Elevation (ft)**
BM: Hydrant NE top nut	2.88	100	2.8	100	2.6	100	1.32	100
1	5.63	97.25	5.55	97.25	5.35	97.25	4.08	97.24
2	5.67	97.21	5.59	97.21	5.4	97.2	4.09	97.23
3	5.62	97.26	5.55	97.25	5.35	97.25	4.08	97.24
4	5.71	97.17	5.64	97.16	5.45	97.15	4.19	97.13
5	5.83	97.05	5.75	97.05	5.56	97.04	4.3	97.02
6	5.76	97.12	5.69	97.11	5.495	97.105	4.24	97.08
7	5.66	97.22	5.58	97.22	5.39	97.21	4.13	97.19
8	5.78	97.1	5.7	97.1	5.505	97.095	4.24	97.08
9	5.91	96.97	5.83	96.97	5.65	96.95	4.4	96.92
10	5.78	97.1	5.71	97.09	5.53	97.07	4.26	97.06
11	5.66	97.22	5.59	97.21	5.4	97.2	4.11	97.21
12	5.79	97.09	5.72	97.08	5.545	97.055	4.26	97.06
13	5.93	96.95	5.86	96.94	5.67	96.93	4.39	96.93
14	5.87	97.01	5.801	96.999	5.62	96.98	4.35	96.97
15	5.86	97.02	5.78	97.02	5.58	97.02	4.3	97.02
16							3.99	-2.67
17							3.83	-2.51
18							4.02	-2.7
19							3.86	-2.54
20							4.34	-3.02
21							4.32	-3

D.1.3 - Phase I: Des Moines (East 28th Street and East Grand Avenue)

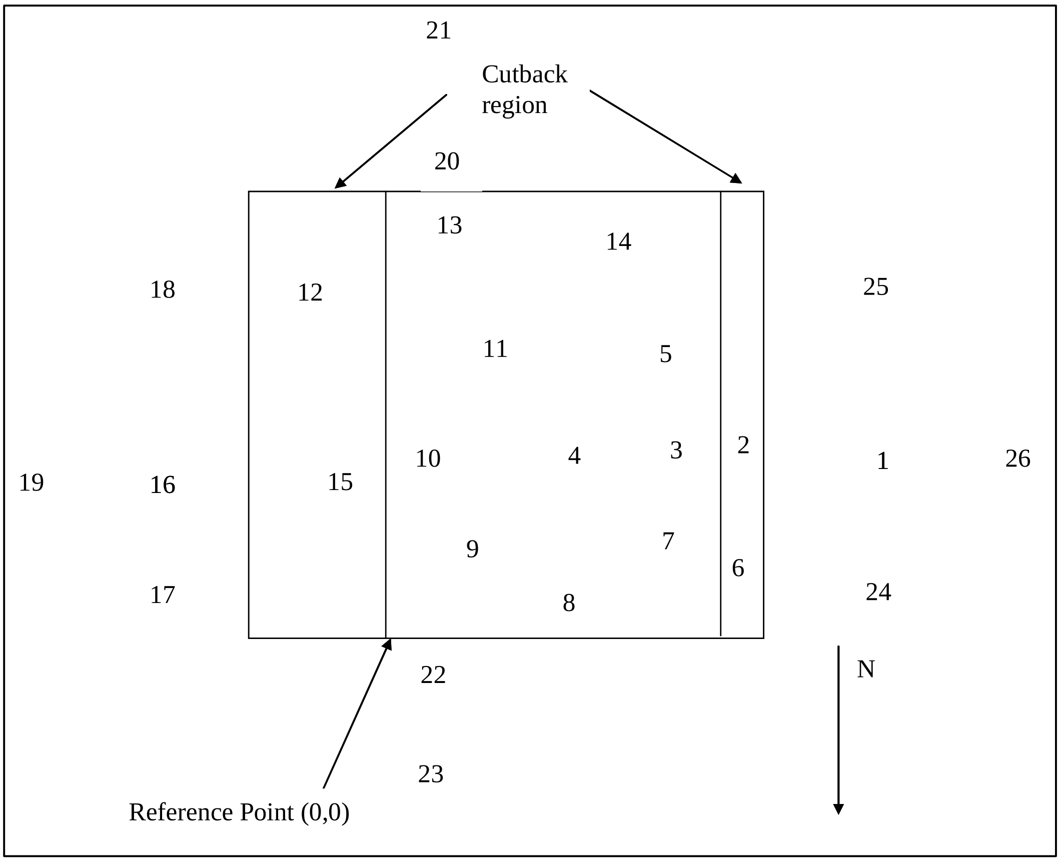


Figure D 3 -- Survey locations for Des Moines Trench

Table D 5 -- Elevation surveys for Des Moines Trench

BM: Top Hydrant NE		
Point	**X (ft)**	**Y (ft)**
Reference point: Northeast corner of Trench	0	0
1	8.7	4.7
2	6.35	5.2
3	4.65	5.05
4	3.25	5.1
5	5	7.7
6	6.15	1.3
7	4.7	2.7
8	3.05	0.75
9	1.7	2.45
10	0.5	5.65
11	7.4	1.6
12	-1.85	7.75
13	1	9.6
14	3.15	9.55
15	-1.9	2.7
16	-5	5.65
17	-5	2.7
18	-5	7.75
19	-10	5.65
20	1	13
21	1	18
22	1	-2
23	1	-6
24	7.4	2.7
25	7.4	7.75
26	12	4.7

Table D 6 -- Elevation surveys for Des Moines Trench

Point	7/17/2004		10/29/2004		4/16/2005		5/14/2007	
	Survey reading (ft)	Elevation (ft)	Survey reading (ft)	Elevation (ft)	Survey reading (ft)	Elevation (ft)	Survey reading (ft)	Elevation (ft)
BM: Top Hydrant NE	2.7	100	2.6	100	2.29	100	2.85	100
1	5.17	97.53	5.07	97.53	4.76	97.53	5.47	97.53
2	5.16	97.54	5.06	97.54	4.76	97.53	5.47	97.53
3	5.18	97.52	5.08	97.52	4.77	97.52	5.48	97.52
4	5.17	97.53	5.07	97.53	4.77	97.52	5.48	97.52
5	5.12	97.58	5.02	97.58	4.72	97.57	5.42	97.58
6	5.23	97.47	5.13	97.47	4.825	97.465	5.56	97.44
7	5.26	97.44	5.16	97.44	4.86	97.43	5.53	97.47
8	5.27	97.43	5.17	97.43	4.86	97.43	5.57	97.43
9	5.23	97.47	5.13	97.47	4.83	97.46	5.54	97.46
10	5.16	97.54	5.07	97.53	4.76	97.53	5.47	97.53
11	5.12	97.58	5.02	97.58	4.72	97.57	5.45	97.55
12	5.13	97.57	5.03	97.57	4.725	97.565	5.43	97.57
13	5.09	97.61	4.99	97.61	4.685	97.605	5.4	97.6
14	5.09	97.61	4.99	97.61	4.685	97.605	5.39	97.61
15	5.24	97.46	5.14	97.46	4.84	97.45	5.54	97.46
16	5.21	97.49	5.12	97.48	4.81	97.48	5.51	97.49
17							5.56	97.44
18							5.46	97.54
19							5.53	97.47
20							5.39	97.61
21							5.45	97.55
22							5.69	97.31
23							5.82	97.18
24							5.52	97.48
25							5.42	97.58
26							5.47	97.53

D.2 – Recommended Trenches

D.2.1 – Trench A

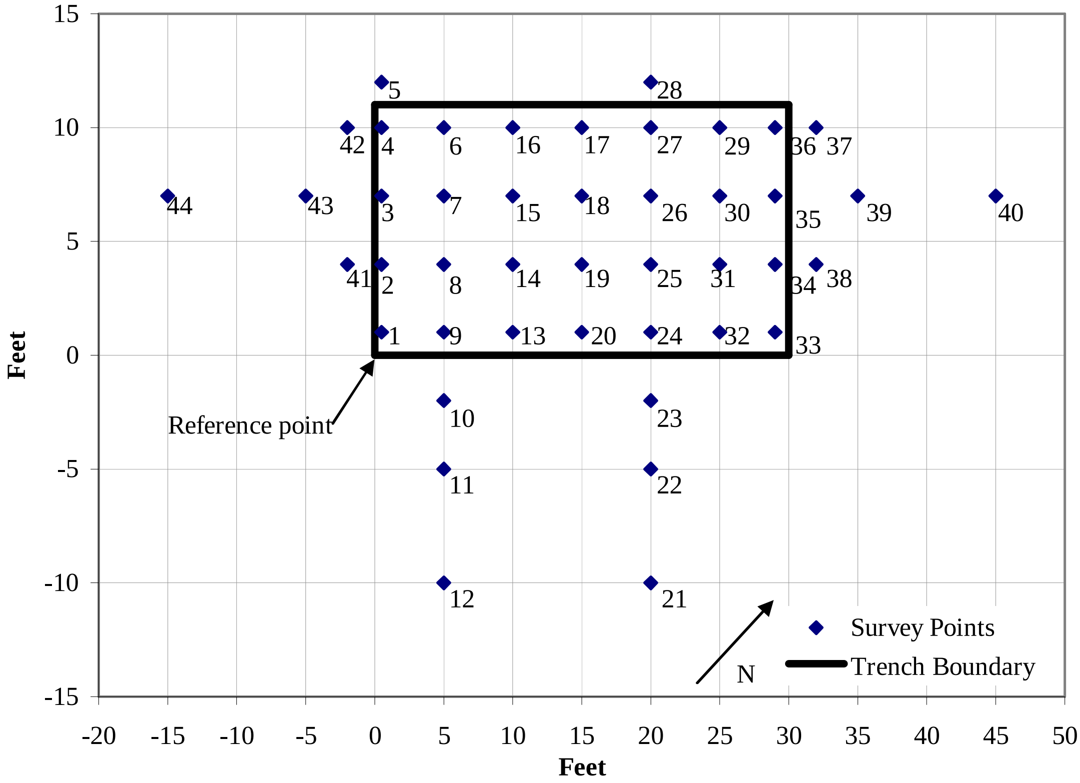


Figure D 4 -- Survey locations for Trench A

Table D 7 – Survey point locations and elevation surveys for Trench A

Point	Location		5/11/2007		3/20/2008	
	x	y	Elevation Reading (ft)	Actual Elevation (ft)	Elevation Reading (ft)	Actual Elevation (ft)
Bench Mark: Hydrant at McKinley and Fillmore			1.15	100	0.21	100
Reference point: South corner of the patch	0	0				
1	0.5	1	6.54	94.61	5.56	94.65
2	0.5	4	6.67	94.48	5.67	94.54
3	0.5	7	6.77	94.38	5.79	94.42
4	0.5	10	6.94	94.21	5.96	94.25
5	0.5	12	7.06	94.09	6.14	94.07
6	5	10	6.95	94.2	5.98	94.23
7	5	7	6.77	94.38	5.79	94.42
8	5	4	6.61	94.54	5.64	94.57
9	5	1	6.52	94.63	5.54	94.67
10	5	-2	6.43	94.72	5.45	94.76
11	5	-5	6.58	94.57	5.59	94.62
12	5	-10	6.84	94.31	5.86	94.35
13	10	1	6.43	94.72	5.43	94.78
14	10	4	6.56	94.59	5.57	94.64
15	10	7	6.73	94.42	5.74	94.47
16	10	10	6.9	94.25	5.94	94.27
17	15	10	6.81	94.34	5.85	94.36
18	15	7	6.58	94.57	5.62	94.59
19	15	4	6.45	94.7	5.46	94.75
20	15	1	6.39	94.76	5.39	94.82
21	20	-10	6.77	94.38	5.76	94.45
22	20	-5	6.49	94.66	5.5	94.71
23	20	-2	6.33	94.82	5.32	94.89
24	20	1	6.33	94.82	5.34	94.87
25	20	4	6.41	94.74	5.44	94.77
26	20	7	6.55	94.6	5.6	94.61
27	20	10	6.75	94.4	5.78	94.43
28	20	12	6.88	94.27	5.92	94.29
29	25	10	6.67	94.48	5.7	94.51
30	25	7	6.51	94.64	5.56	94.65
31	25	4	6.37	94.78	5.4	94.81
32	25	1	6.29	94.86	5.31	94.9
33	29	1	6.25	94.9	5.27	94.94
34	29	4	6.36	94.79	5.38	94.83
35	29	7	6.46	94.69	5.51	94.7

36	29	10	6.62	94.53	5.65	94.56
37	32	10	6.56	94.59	5.6	94.61
38	32	4	6.33	94.82	5.35	94.86
39	35	7	6.41	94.74	5.46	94.75
40	45	7	6.3	94.85	5.35	94.86
41	-2	4	6.66	94.49	5.68	94.53
42	-2	10	6.93	94.22	5.98	94.23
43	-5	7	6.81	94.34	5.83	94.38
44	-15	7	6.87	94.28	5.91	94.3

D.2.2 – Trench B

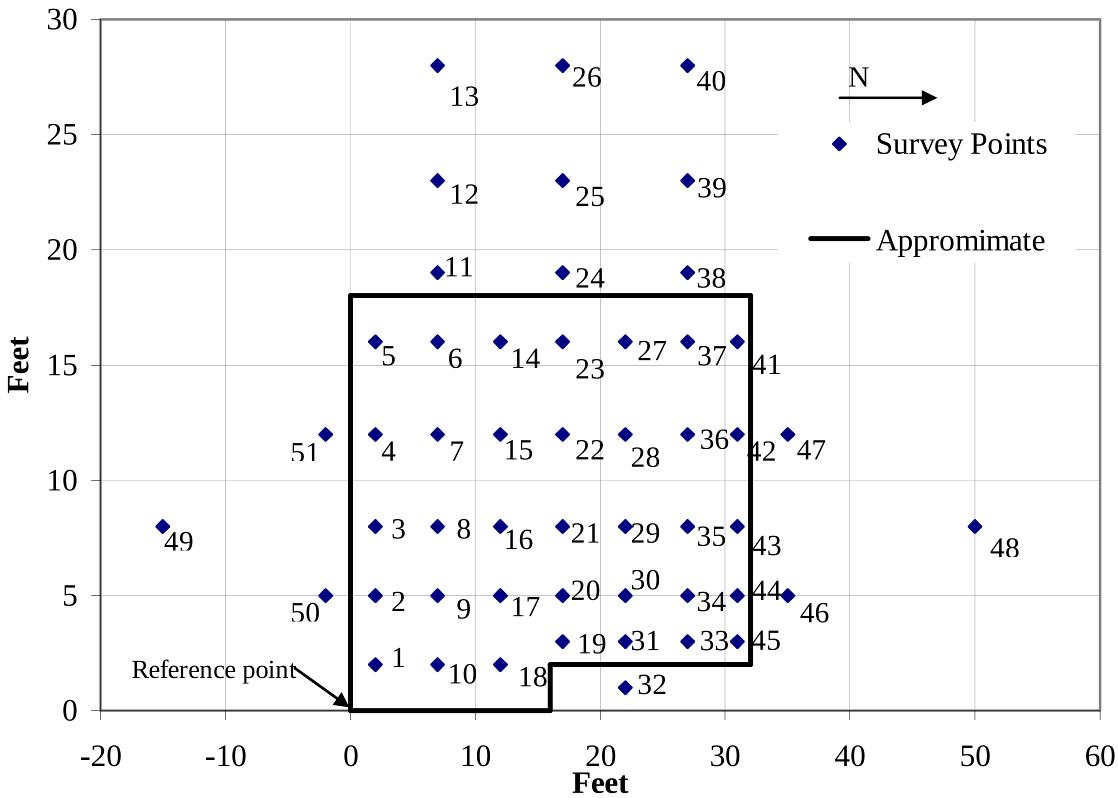


Figure D 5 -- Survey locations for Trench B

Table D 8 – Survey point locations and elevation surveys for Trench B

Point	Location		5/11/2007		3/19/2008	
	x	y	Elevation Reading (ft)	Actual Elevation (ft)	Elevation Reading (ft)	Actual Elevation (ft)
Bench Mark: Hydrant on 9th and Carroll			3.44	100	2.66	100
Reference Point: Southeast corner of patch	0	0				
1	2	2	6.32	97.12	5.5	97.16
2	2	5	6.27	97.17	5.45	97.21
3	2	8	6.16	97.28	5.35	97.31
4	2	12	6.14	97.3	5.34	97.32
5	2	16	6.12	97.32	5.31	97.35
6	7	16	6.14	97.3	5.34	97.32
7	7	12	6.17	97.27	5.36	97.3
8	7	8	6.21	97.23	5.41	97.25
9	7	5	6.29	97.15	5.47	97.19
10	7	2	6.33	97.11	5.51	97.15
11	7	19	6.16	97.28	5.35	97.31
12	7	23	6.27	97.17	5.47	97.19
13	7	28	6.46	96.98	5.64	97.02
14	12	16	6.1	97.34	5.29	97.37
15	12	12	6.14	97.3	5.33	97.33
16	12	8	6.22	97.22	5.41	97.25
17	12	5	6.31	97.13	5.5	97.16
18	12	2	6.32	97.12	5.52	97.14
19	17	3	6.28	97.16	5.46	97.2
20	17	5	6.22	97.22	5.41	97.25
21	17	8	6.1	97.34	5.28	97.38
22	17	12	6.06	97.38	5.27	97.39
23	17	16	6.04	97.4	5.22	97.44
24	17	19	6.08	97.36	5.23	97.43
25	17	23	6.24	97.2	5.39	97.27
26	17	28	6.46	96.98	5.63	97.03
27	22	16	6.02	97.42	5.2	97.46
28	22	12	6.01	97.43	5.22	97.44
29	22	8	6.02	97.42	5.23	97.43
30	22	5	6.14	97.3	5.35	97.31
31	22	3	6.21	97.23	5.39	97.27

32	22	1	6.31	97.13	5.35	97.31
33	27	3	6.05	97.39	5.23	97.43
34	27	5	6	97.44	5.2	97.46
35	27	8	5.93	97.51	5.14	97.52
36	27	12	5.94	97.5	5.14	97.52
37	27	16	5.93	97.51	5.12	97.54
38	27	19	5.96	97.48	5.12	97.54
39	27	23	6.06	97.38	5.2	97.46
40	27	28	6.33	97.11	5.48	97.18
41	31	16	5.82	97.62	5.01	97.65
42	31	12	5.85	97.59	5.04	97.62
43	31	8	5.86	97.58	5.55	97.11
44	31	5	5.88	97.56	5.57	97.09
45	31	3	5.92	97.52	5.1	97.56
46	35	5	5.74	97.7	4.94	97.72
47	35	12	5.7	97.74	4.9	97.76
48	50	8	5.57	97.87	4.78	97.88
49	-15	8	6.15	97.29	5.36	97.3
50	-2	5	6.21	97.23	5.29	97.37
51	-2	12	6.12	97.32	5.34	97.32

D.2.3 – Trench C

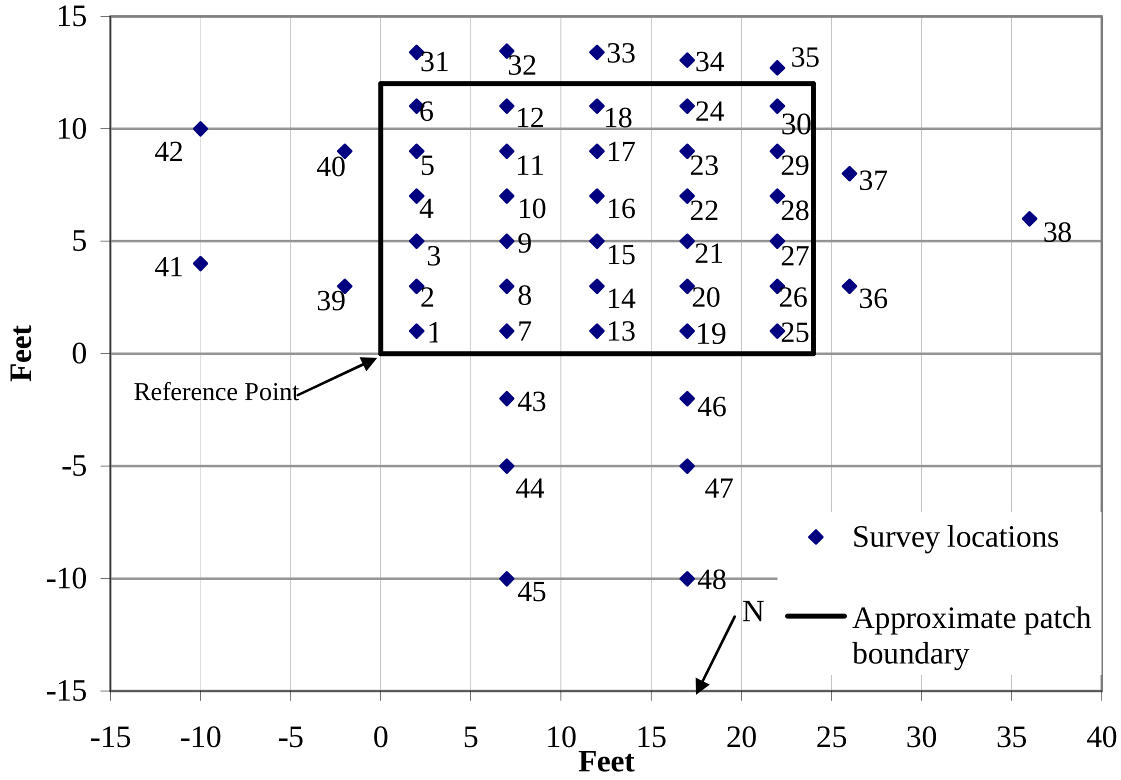


Figure D 6 -- Survey locations for Trench C

Table D 9 – Survey point locations and elevation surveys for Trench C

Point	Location		5/11/2007		3/20/2008	
	x	y	Elevation Reading (ft)	Actual Elevation (ft)	Elevation Reading (ft)	Actual Elevation (ft)
Benchmark: Hydrant McKinley and Fillmore			0.35	100	0.21	100
Reference Point: Northeast corner	0	0				
1	2	1	5.38	94.97	5.13	95.08
2	2	3	5.43	94.92	5.18	95.03
3	2	5	5.48	94.87	5.22	94.99
4	2	7	5.53	94.82	5.27	94.94
5	2	9	5.6	94.75	5.34	94.87
6	2	11	5.66	94.69	5.4	94.81
7	7	1	5.4	94.95	5.4	94.81
8	7	3	5.42	94.93	5.33	94.88
9	7	5	5.48	94.87	5.27	94.94
10	7	7	5.52	94.83	5.23	94.98
11	7	9	5.58	94.77	5.17	95.04
12	7	11	5.66	94.69	5.15	95.06
13	12	1	5.44	94.91	5.18	95.03
14	12	3	5.45	94.9	5.21	95
15	12	5	5.49	94.86	5.24	94.97
16	12	7	5.54	94.81	5.29	94.92
17	12	9	5.62	94.73	5.35	94.86
18	12	11	5.7	94.65	5.42	94.79
19	17	1	5.44	94.91	5.5	94.71
20	17	3	5.44	94.91	5.41	94.8
21	17	5	5.49	94.86	5.33	94.88
22	17	7	5.58	94.77	5.25	94.96
23	17	9	5.55	94.8	5.19	95.02
24	17	11	5.58	94.77	5.18	95.03
25	22	1	5.67	94.68	5.24	94.97
26	22	3	5.55	94.8	5.28	94.93
27	22	5	5.58	94.77	5.32	94.89
28	22	7	5.67	94.68	5.39	94.82

29	22	9	5.77	94.58	5.49	94.72
30	22	11	5.85	94.5	5.58	94.63
31	2	13.4	5.73	94.62	5.53	94.68
32	7	13.45	5.73	94.62	5.49	94.72
33	12	13.4	5.73	94.62	5.51	94.7
34	17	13.05	5.85	94.5	5.61	94.6
35	22	12.7	5.96	94.39	5.71	94.5
36	26	3	5.62	94.73	5.36	94.85
37	26	8	5.82	94.53	5.55	94.66
38	36	6	5.89	94.46	5.54	94.67
39	-2	3	5.38	94.97	5.11	95.1
40	-2	9	5.58	94.77	5.3	94.91
41	-10	4	5.34	95.01	5.04	95.17
42	-10	10	5.5	94.85	5.22	94.99
43	7	-2	5.42	94.93	5.2	95.01
44	7	-5	5.49	94.86	5.28	94.93
45	7	-10	5.65	94.7	5.45	94.76
46	17	-2	5.46	94.89	5.16	95.05
47	17	-5	5.54	94.81	5.24	94.97
48	17	-10	5.71	94.64	5.4	94.81

D.2.4 – Trench D

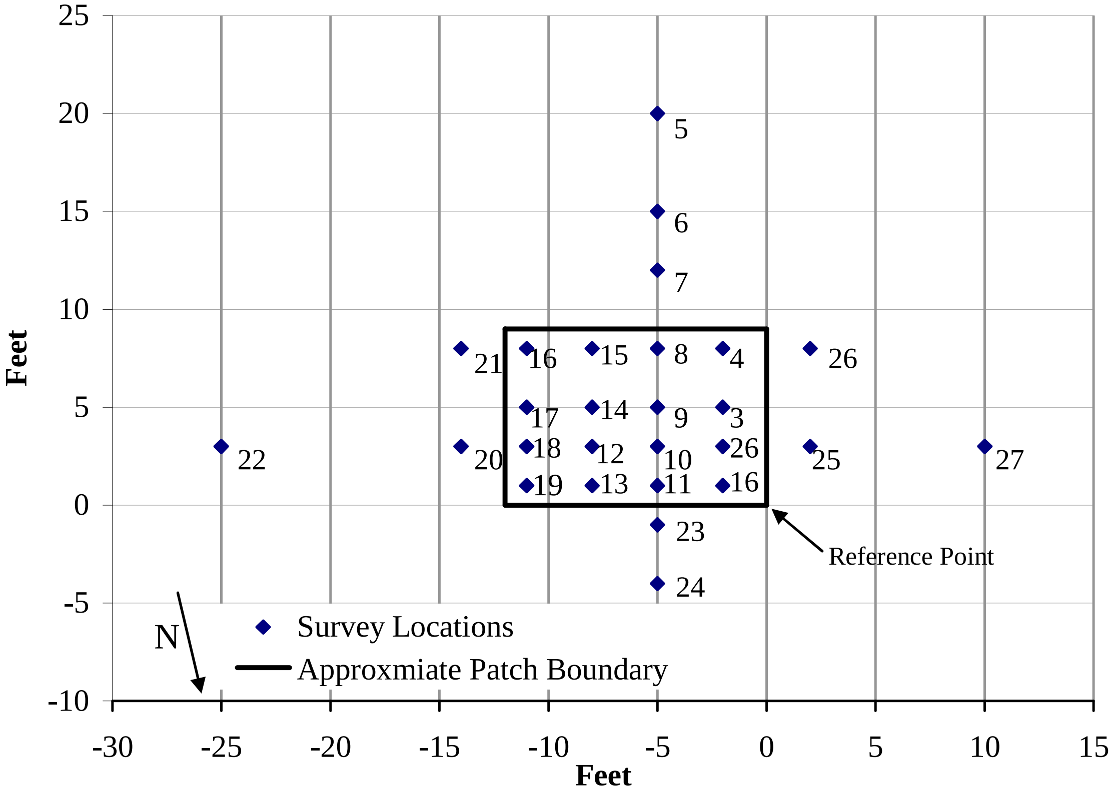


Figure D 7 -- Survey locations for Trench D

Table D 10 – Survey point locations and elevation surveys for Trench D

Point	Location		5/11/2007		3/20/2008	
	x	y	Elevation Reading (ft)	Actual Elevation (ft)	Elevation Reading (ft)	Actual Elevation (ft)
Benchmark: Hydrant north of patch			2.77	100	2.11	100
Reference Point: Northwest corner of patch	0	0				
1	-2	1	5.52	97.25	4.81	97.3
2	-2	3	5.48	97.29	4.8	97.31
3	-2	5	5.43	97.34	4.77	97.34
4	-2	8	5.39	97.38	4.7	97.41
5	-5	20	5.99	96.78	4.51	97.6
6	-5	15	5.63	97.14	4.87	97.24
7	-5	12	5.47	97.3	4.7	97.41
8	-5	8	5.39	97.38	4.7	97.41
9	-5	5	5.42	97.35	4.7	97.41
10	-5	3	5.45	97.32	4.78	97.33
11	-5	1	5.5	97.27	4.79	97.32
12	-8	1	5.49	97.28	4.76	97.35
13	-8	3	5.45	97.32	4.77	97.34
14	-8	5	5.4	97.37	4.75	97.36
15	-8	8	5.39	97.38	4.75	97.36
16	-11	8	5.39	97.38	4.69	97.42
17	-11	5	5.41	97.36	4.72	97.39
18	-11	3	5.45	97.32	4.75	97.36
19	-11	1	5.49	97.28	4.76	97.35
20	-14	3	5.46	97.31	4.75	97.36
21	-14	8	5.36	97.41	4.66	97.45
22	-25	3	5.47	97.3	4.6	97.51
23	-5	-1	5.61	97.16	4.86	97.25
24	-5	-4	5.82	96.95	5.12	96.99
25	2	3	5.48	97.29	4.76	97.35
26	2	8	5.37	97.4	4.62	97.49
27	10	3	5.47	97.3	4.8	97.31

D.2.5 – Trench E

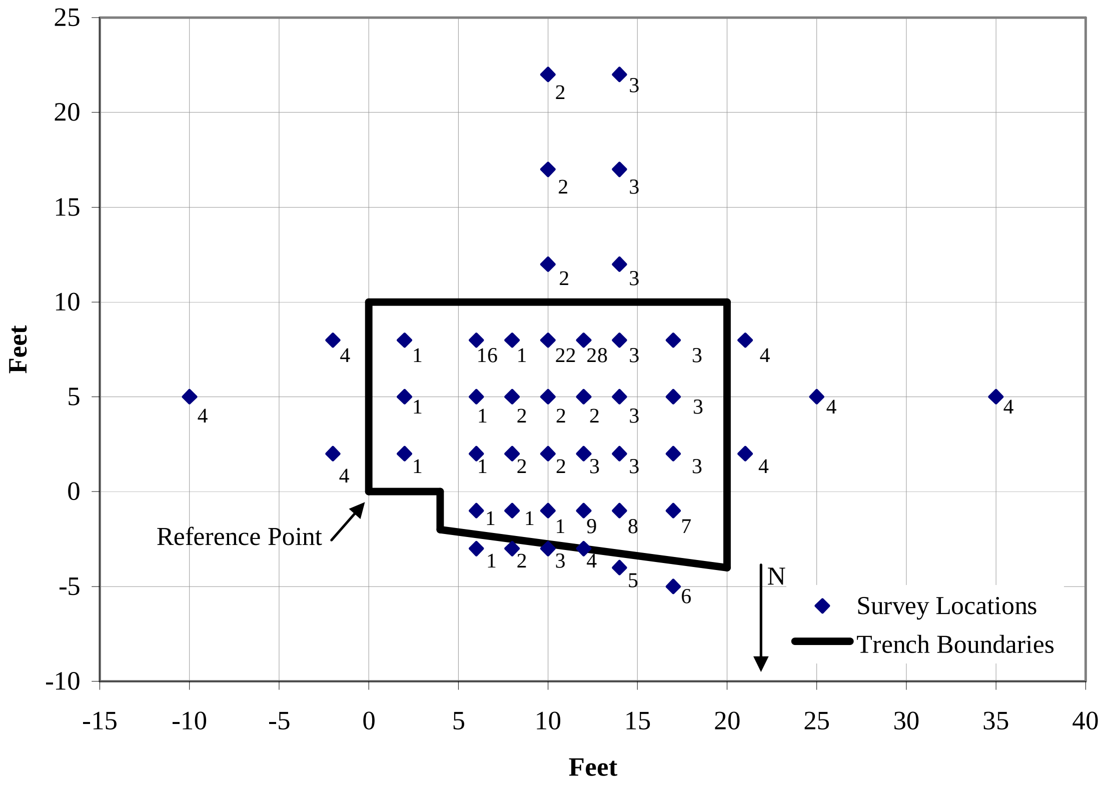


Figure D 8 -- Survey locations for Trench E

Table D 11 – Survey point locations and elevation surveys for Trench E

Point	Location		5/11/2007		3/19/2008	
	x	y	Elevation Reading (ft)	Actual Elevation (ft)	Elevation Reading (ft)	Actual Elevation (ft)
Benchmark: 7th Street and Carroll Avenue			2.98	100	2.09	100
Reference Point: Northeast corner	0	0				
1	6	-3	5.96	97.02	5.09	97
2	8	-3	5.92	97.06	5.02	97.07
3	10	-3	5.82	97.16	4.97	97.12
4	12	-3	5.87	97.11	4.98	97.11
5	14	-4	5.82	97.16	4.09	98
6	17	-5	5.85	97.13	5	97.09
7	17	-1	5.58	97.4	4.7	97.39
8	14	-1	5.61	97.37	4.74	97.35
9	12	-1	5.62	97.36	4.75	97.34
10	10	-1	5.65	97.33	4.78	97.31
11	8	-1	5.7	97.28	4.82	97.27
12	6	-1	5.74	97.24	4.86	97.23
13	2	2	5.57	97.41	4.7	97.39
14	2	5	5.39	97.59	4.54	97.55
15	2	8	5.28	97.7	4.43	97.66
16	6	8	5.26	97.72	4.42	97.67
17	6	5	5.39	97.59	4.54	97.55
18	6	2	5.55	97.43	4.69	97.4
19	8	2	5.53	97.45	4.66	97.43
20	8	5	5.38	97.6	4.53	97.56
21	8	8	5.27	97.71	4.43	97.66
22	10	8	5.27	97.71	4.44	97.65
23	10	5	5.37	97.61	4.52	97.57
24	10	2	5.49	97.49	4.63	97.46
25	10	12	5.22	97.76	4.37	97.72
26	10	17	5.22	97.76	4.34	97.75
27	10	22	5.37	97.61	4.42	97.67
28	12	8	5.27	97.71	4.44	97.65
29	12	5	5.38	97.6	4.53	97.56
30	12	2	5.5	97.48	4.63	97.46
31	14	2	5.5	97.48	4.63	97.46
32	14	5	5.36	97.62	4.51	97.58

33	14	8	5.27	97.71	4.42	97.67
34	14	12	5.36	97.62	4.34	97.75
35	14	17	5.48	97.5	4.31	97.78
36	14	22	5.42	97.56	4.33	97.76
37	17	8	5.27	97.71	4.41	97.68
38	17	5	5.37	97.61	4.51	97.58
39	17	2	5.48	97.5	4.61	97.48
40	21	2	5.42	97.56	4.54	97.55
41	21	8	5.27	97.71	4.4	97.69
42	25	5	5.35	97.63	4.4	97.69
43	35	5	5.36	97.62	4.48	97.61
44	-2	2	5.59	97.39	4.72	97.37
45	-2	8	5.34	97.64	4.49	97.6
46	-10	5	5.44	97.54	4.56	97.53

D.26 – Trench F

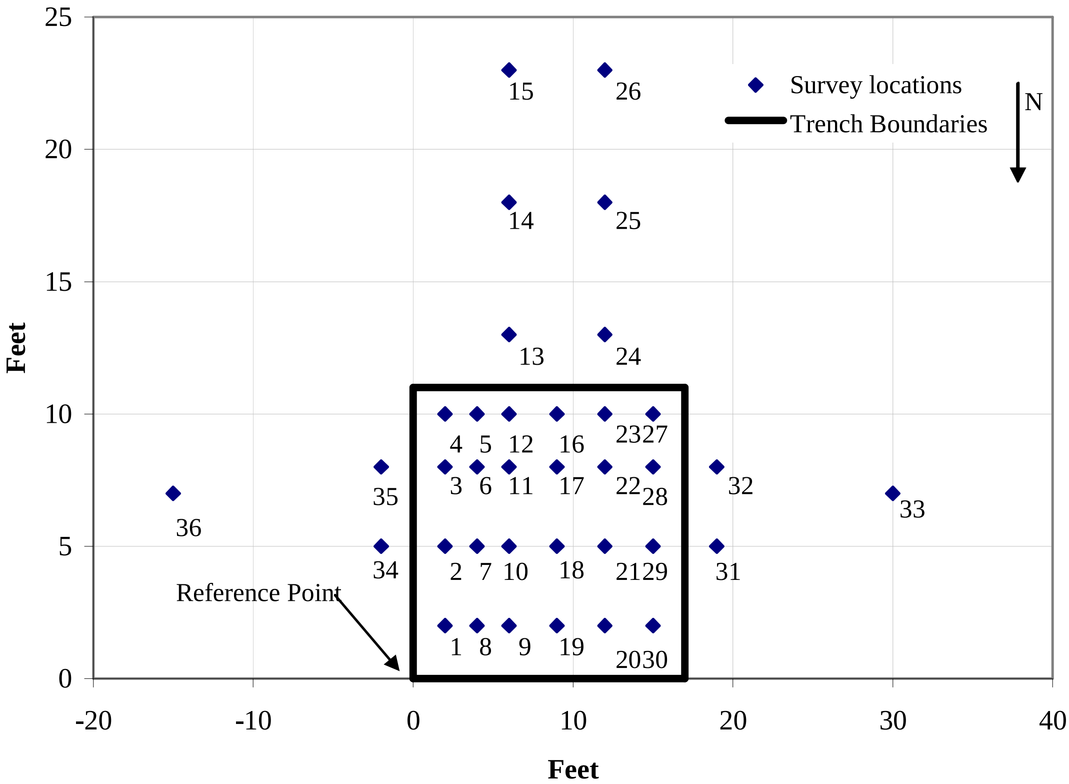


Figure D 9 -- Survey locations for Trench F

Table D 12 – Survey point locations and elevation surveys for Trench F

Point	Location		5/11/2007		3/19/2008	
	x	y	Elevation Reading (ft)	Acutal Elevation (ft)	Elevation Reading (ft)	Acutal Elevation (ft)
Benchmark: Hydrant on 6th Street and Carroll Avenue			2.78	100	2.02	100
Reference Point: Northeast corner of patch						
1	2	2	5.76	97.02	5	97.02
2	2	5	5.58	97.2	4.83	97.19
3	2	8	5.47	97.31	4.73	97.29
4	2	10	5.42	97.36	4.67	97.35
5	4	10	5.44	97.34	4.68	97.34
6	4	8	5.5	97.28	4.74	97.28
7	4	5	5.6	97.18	4.85	97.17
8	4	2	5.76	97.02	5	97.02
9	6	2	5.79	96.99	5.02	97
10	6	5	5.61	97.17	4.86	97.16
11	6	8	5.5	97.28	4.76	97.26
12	6	10	5.45	97.33	4.69	97.33
13	6	13	5.42	97.36	4.65	97.37
14	6	18	5.3	97.48	4.62	97.4
15	6	23	5.41	97.37	4.64	97.38
16	9	10	5.46	97.32	4.71	97.31
17	9	8	5.52	97.26	4.77	97.25
18	9	5	5.5	97.28	4.84	97.18
19	9	2	5.84	96.94	5.01	97.01
20	12	2	5.83	96.95	5.07	96.95
21	12	5	5.65	97.13	4.89	97.13
22	12	8	5.52	97.26	4.77	97.25
23	12	10	5.44	97.34	4.7	97.32
24	12	13	5.41	97.37	4.62	97.4
25	12	18	5.3	97.48	4.61	97.41
26	12	23	5.45	97.33	4.67	97.35

27	15	10	5.45	97.33	4.71	97.31
28	15	8	5.52	97.26	4.77	97.25
29	15	5	5.64	97.14	5.09	96.93
30	15	2	5.8	96.98	5.04	96.98
31	19	5	5.65	97.13	4.87	97.15
32	19	8	5.54	97.24	4.78	97.24
33	30	7	5.6	97.18	4.82	97.2
34	-2	5	5.6	97.18	4.84	97.18
35	-2	8	5.48	97.3	4.72	97.3
36	-15	7	5.47	97.31	4.78	97.24

D.3 – Instrumented Trenches

D.3.1 – Instrumented Trench 1

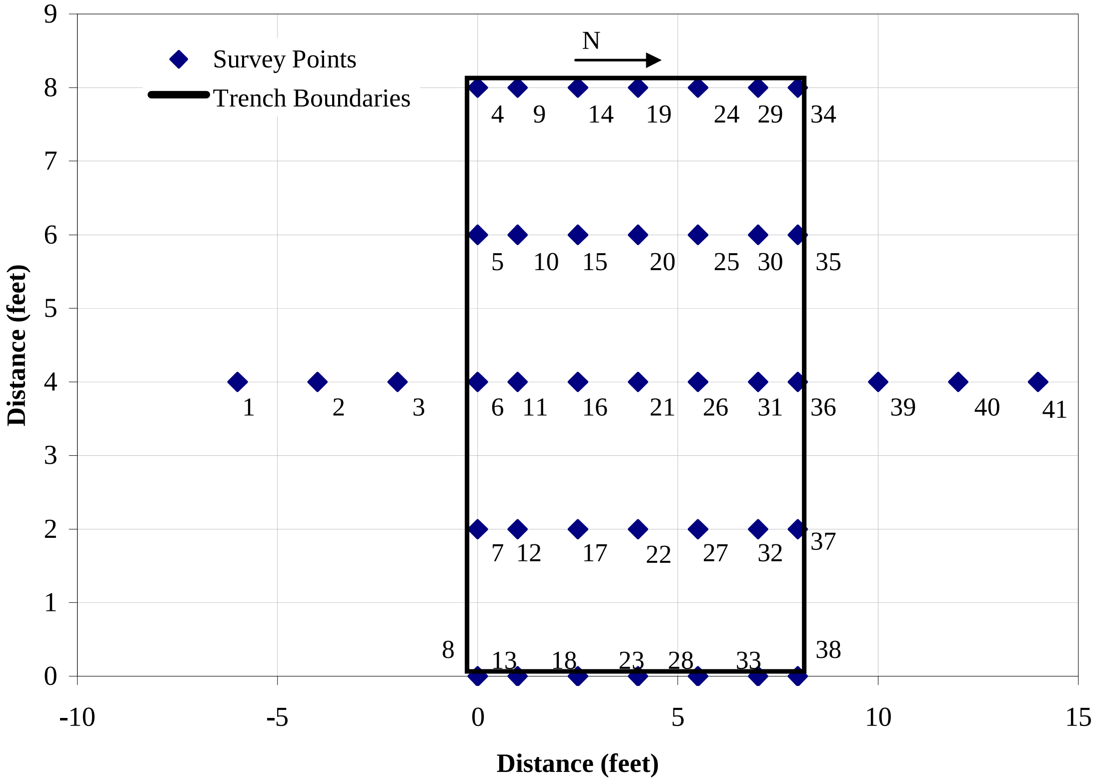


Figure D 10 -- Survey locations for Instrumented Trench 1

Table D 13 – Survey point locations and elevation surveys for Instrumented Trench 1

Point	Location		5/11/2007		5/11/2007	
	x	y	Elevation Reading (ft)	Actual Elevation (ft)	Elevation Reading (ft)	Actual Elevation (ft)
Benchmark: Hydrant southeast of site	0	0	2.18	100	2.99	100
1	-6	4	4.7	97.48	5.49	97.5
2	-4	4	4.68	97.5	5.46	97.53
3	-2	4	4.66	97.52	5.45	97.54
4	0	8	4.83	97.35	5.61	97.38
5	0	6	4.72	97.46	5.5	97.49
6	0	4	4.64	97.54	5.43	97.56
7	0	2	4.57	97.61	5.36	97.63
8	0	0	4.51	97.67	5.31	97.68
9	1	8	4.8	97.38	5.58	97.41
10	1	6	4.71	97.47	5.49	97.5
11	1	4	4.63	97.55	5.41	97.58
12	1	2	4.56	97.62	5.34	97.65
13	1	0	4.5	97.68	5.29	97.7
14	2.5	8	4.79	97.39	5.58	97.41
15	2.5	6	4.7	97.48	5.47	97.52
16	2.5	4	4.61	97.57	5.39	97.6
17	2.5	2	4.54	97.64	5.32	97.67
18	2.5	0	4.49	97.69	5.27	97.72
19	4	8	4.76	97.42	5.56	97.43
20	4	6	4.67	97.51	5.45	97.54
21	4	4	4.58	97.6	5.36	97.63
22	4	2	4.51	97.67	5.29	97.7
23	4	0	4.45	97.73	5.24	97.75
24	5.5	8	4.74	97.44	5.53	97.46
25	5.5	6	4.65	97.53	5.42	97.57
26	5.5	4	4.56	97.62	5.34	97.65
27	5.5	2	4.49	97.69	5.27	97.72
28	5.5	0	4.43	97.75	5.21	97.78
29	7	8	4.71	97.47	5.51	97.48
30	7	6	4.62	97.56	5.4	97.59
31	7	4	4.53	97.65	5.31	97.68
32	7	2	4.46	97.72	5.24	97.75

33	7	0	4.4	97.78	5.18	97.81
34	8	8	4.7	97.48	5.49	97.5
35	8	6	4.6	97.58	5.39	97.6
36	8	4	4.51	97.67	5.3	97.69
37	8	2	4.45	97.73	5.23	97.76
38	8	0	4.39	97.79	5.17	97.82
39	10	4	4.49	97.69	5.26	97.73
40	12	4	4.43	97.75	5.22	97.77
41	14	4	4.4	97.78	5.18	97.81

D.3.2 – Instrumented Trench 2

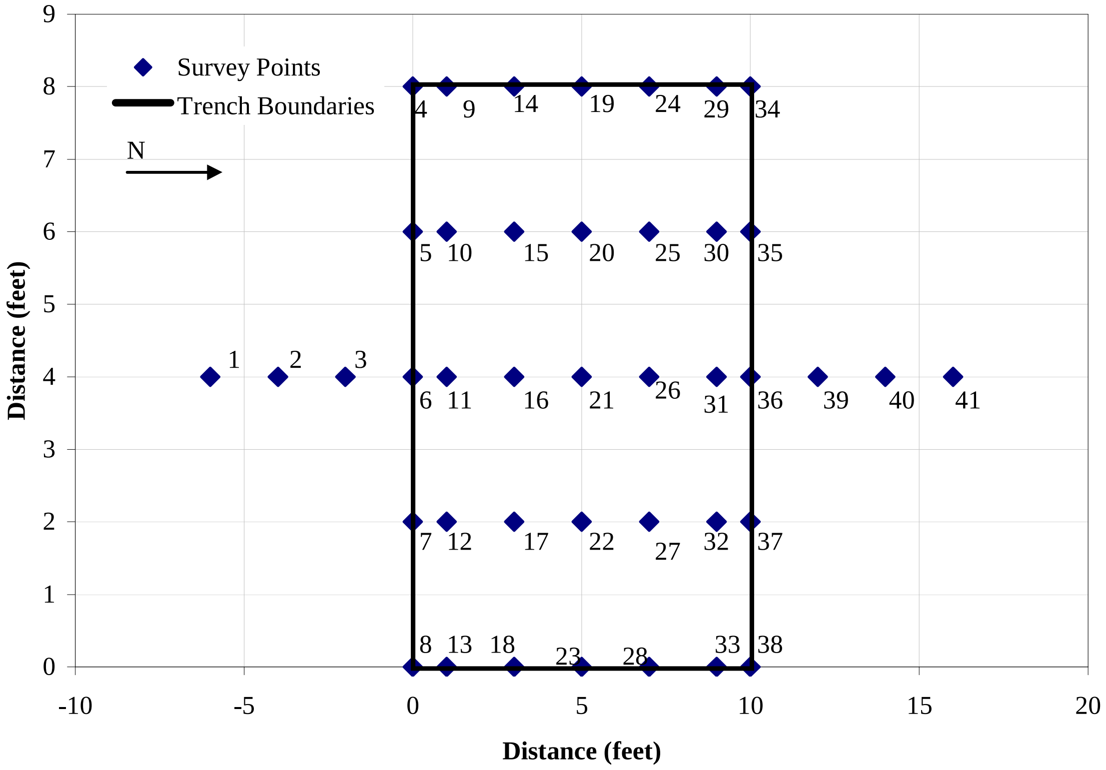


Figure D 11 -- Survey locations for Instrumented Trench 2

Table D 14 – Survey point locations and elevation surveys for Instrumented Trench 2

Point	Location		5/11/2007		5/11/2007	
	x	y	Elevation Reading (ft)	Actual Elevation (ft)	Elevation Reading (ft)	Actual Elevation (ft)
Benchmark: Hydrant southeast of site	0	0	2.18	100	2.99	100
1	-6	4	4.35	97.83	5.13	97.86
2	-4	4	4.33	97.85	5.1	97.89
3	-2	4	4.29	97.89	5.08	97.91
4	0	8	4.45	97.73	5.23	97.76
5	0	6	4.37	97.81	5.15	97.84
6	0	4	4.29	97.89	5.06	97.93
7	0	2	4.21	97.97	4.99	98
8	0	0	4.14	98.04	4.92	98.07
9	1	8	4.42	97.76	5.2	97.79
10	1	6	4.35	97.83	5.13	97.86
11	1	4	4.26	97.92	5.05	97.94
12	1	2	4.19	97.99	4.97	98.02
13	1	0	4.13	98.05	4.91	98.08
14	3	8	4.4	97.78	5.17	97.82
15	3	6	4.32	97.86	5.1	97.89
16	3	4	4.23	97.95	5.02	97.97
17	3	2	4.16	98.02	4.94	98.05
18	3	0	4.1	98.08	4.88	98.11
19	5	8	4.36	97.82	5.14	97.85
20	5	6	4.29	97.89	5.07	97.92
21	5	4	4.2	97.98	4.99	98
22	5	2	4.13	98.05	4.92	98.07
23	5	0	4.06	98.12	4.85	98.14
24	7	8	4.33	97.85	5.11	97.88
25	7	6	4.25	97.93	5.03	97.96
26	7	4	4.17	98.01	4.96	98.03
27	7	2	4.1	98.08	4.9	98.09
28	7	0	4.04	98.14	4.83	98.16
29	9	8	4.31	97.87	5.1	97.89
30	9	6	4.23	97.95	5.01	97.98
31	9	4	4.15	98.03	4.94	98.05
32	9	2	4.08	98.1	4.88	98.11

33	9	0	4.01	98.17	4.81	98.18
34	10	8	4.3	97.88	5.08	97.91
35	10	6	4.22	97.96	5	97.99
36	10	4	4.14	98.04	4.93	98.06
37	10	2	4.07	98.11	4.86	98.13
38	10	0	4	98.18	4.79	98.2
39	12	4	4.12	98.06	4.9	98.09
40	14	4	4.11	98.07	4.9	98.09
41	16	4	4.07	98.11	4.86	98.13

D.3.3 – Instrumented Trench 3

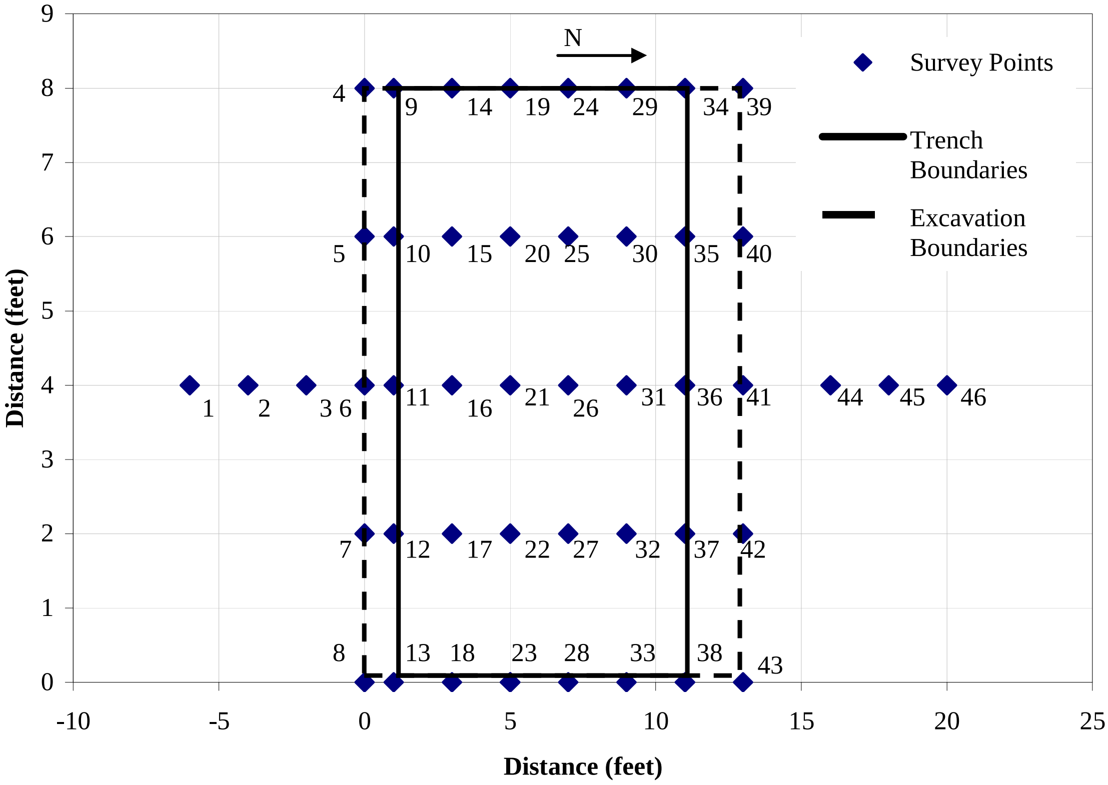


Figure D 12 -- Survey locations for Instrumented Trench 3

Table D 15 – Survey point locations and elevation surveys for Instrumented Trench 3

Point	Location		5/11/2007		5/11/2007	
	x	y	Elevation Reading (ft)	Actual Elevation (ft)	Elevation Reading (ft)	Actual Elevation (ft)
Benchmark: Hydrant southeast of site	0	0	2.18	100	2.99	100
1	-6	4	3.92	98.26	4.7	98.29
2	-4	4	3.9	98.28	4.67	98.32
3	-2	4	3.86	98.32	4.64	98.35
4	0	8	3.99	98.19	4.76	98.23
5	0	6	3.9	98.28	4.67	98.32
6	0	4	3.83	98.35	4.61	98.38
7	0	2	3.76	98.42	4.55	98.44
8	0	0				
9	1	0	3.72	98.46	4.49	98.5
10	1	8	3.97	98.21	4.73	98.26
11	1	6	3.88	98.3	4.66	98.33
12	1	4	3.82	98.36	4.6	98.39
13	1	2	3.74	98.44	4.54	98.45
14	3	0	3.7	98.48	4.48	98.51
15	3	8	3.93	98.25	4.71	98.28
16	3	6	3.86	98.32	4.64	98.35
17	3	4	3.79	98.39	4.57	98.42
18	3	2	3.73	98.45	4.51	98.48
19	5	0	3.67	98.51	4.45	98.54
20	5	8	3.91	98.27	4.69	98.3
21	5	6	3.84	98.34	4.61	98.38
22	5	4	3.77	98.41	4.55	98.44
23	5	2	3.7	98.48	4.5	98.49
24	5	0	3.65	98.53	4.43	98.56
25	7	8	3.89	98.29	4.67	98.32
26	7	6	3.81	98.37	4.59	98.4
27	7	4	3.75	98.43	4.53	98.46
28	7	2	3.68	98.5	4.47	98.52
29	7	0	3.63	98.55	4.41	98.58
30	9	8	3.89	98.29	4.67	98.32
31	9	6	3.8	98.38	4.57	98.42
32	9	4	3.72	98.46	4.51	98.48

33	9	2	3.66	98.52	4.45	98.54
34	9	0	3.6	98.58	4.4	98.59
35	11	8	3.87	98.31	4.65	98.34
36	11	6	3.78	98.4	4.55	98.44
37	11	4	3.7	98.48	4.48	98.51
38	11	2	3.63	98.55	4.42	98.57
39	11	0	3.58	98.6	4.37	98.62
40	13	8	3.85	98.33	4.63	98.36
41	13	6	3.75	98.43	4.54	98.45
42	13	4	3.68	98.5	4.47	98.52
43	13	2	3.61	98.57	4.4	98.59
45	13	0	3.56	98.62	4.35	98.64
46	16	4	3.66	98.52	4.44	98.55

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