R-89-07

FULLERTON PVC PIPE TEST SECTION

August 1989

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
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16. ABSTRACT

A special test section of 27-inch-diameter PVC (polyvinyl chloride) pipe was constructed in November 1987 near Elba, Nebraska. Measurements were made of pipe deflections, pipe invert elevations, and soil properties and in-place unit weights. Pipe deflections will continue to be monitored for several years. This report describes the installation, pipe properties, soil properties, and pipe deflection measurements taken through the 1-year reading period.

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Denver, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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Funds for purchase of the pipe, some travel, and for preparation of reports was provided by the OCCS (Open and Closed Conduit Systems) Committee.

The Twin Loups Irrigation District provided earth-moving equipment and operators for the test section construction.

During installation, diameter measurements were taken by Dan Boersen and recorded by Gordon Jensen. Other Reclamation personnel who assisted with the installation were Ray Kehler, Mike Kube, Larry Cast, and Amster Howard.

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INTRODUCTION

This report contains results of a test section of buried PVC (polyvinyl chloride) pipe installed near Elba, Nebraska, during November 1987. The test section was constructed at a special site to evaluate the short- and long-term behavior of PVC pipe installed with three different bedding conditions. This report discusses installation of the test section and measurements made during installation. Measurements made up through 1 year following installation are also included. Various nonstandard pipe bedding conditions were used to investigate the possibility of reducing construction costs associated with the standard installation requirements.

The test section was not made part of a functioning distribution system in order to gain access to take pipe diameter measurements whenever required. Results include measurements of pipe diameters as the pipe deflects, pipe invert elevations, and unit weights and physical properties of the soils used in construction.

There has been a lack of information concerning the long-term deflection of flexible pipe. This report and a future report, approximately 5 years after installation, will provide useful long-term data.

BEHAVIOR OF FLEXIBLE PIPE

Load on a buried pipe is created by the backfill soil placed over the top of the pipe and any surcharge and/or live load on the backfill surface over the pipe. Flexible pipe is designed to transmit the load on the pipe to the soil at the sides of the pipe. As the load on the pipe increases, the vertical diameter of the pipe decreases and the horizontal diameter increases. The increase in horizontal diameter is resisted by the stiffness of the soil at the sides of the pipe.

In the design of structural members, the strain (or deformation) of an element of the material can be determined from the ratio of the load (or stress) on the member to its modulus of elasticity (strain = stress/modulus of elasticity). The deflection of a buried pipe can be predicted in a similar fashion. The cross-sectional ring deflects (deforms) according to the ratio of the load on the ring to the modulus of elasticity of the "material." However, the material modulus is more complicated because a soil-structure interaction takes place. The material modulus becomes a combination of the structural modulus (stiffness) of the pipe and the modulus (stiffness) of the soil beside the pipe, so that:

$$\text{pipe deflection} = \frac{\text{load on the pipe}}{\text{pipe stiffness} + \text{soil stiffness}}$$

There are several variations of this relationship used to predict the deflection of a buried flexible pipe. The most common is the Iowa Formula (Spangler, 1941; Watkins and Spangler, 1958), developed by Professor M. G. Spangler of Iowa State University. The modified Iowa Formula is given as:

$$\Delta X = D_l \frac{KWr^3}{EI + 0.061 E' r^3}$$

where:

ΔX = horizontal deflection of the pipe, inches
D_l = deflection lag factor
K = bedding constant
W = load per unit length of pipe, lb/lin in (calculated from Marston Theory)
r = pipe nominal radius, inches
E = tensile modulus of elasticity of the pipe material, lb/in^2
I = moment of inertia per unit length, in^4/lin in
E' = modulus of soil reaction, lb/in^2

DEFINITIONS

"Bedding" refers to placement of soil beneath and beside the pipe up to a height of 0.7 of the outside diameter of the pipe or up to the top of the pipe. "Backfill" refers to placement of soil over the pipe, and "cover" is the vertical distance from the top of the pipe to the top of the backfill.

BEDDING CONDITIONS

The three pipe bedding conditions examined for this study are illustrated on figure 1. The three conditions will be referred to as "dumped," "95 percent," and "85 percent" sections, and are described as follows:

- **Dumped section.** - Native soil from the trench excavation was dumped into the trench around and over the pipe without any compaction.

- **95 percent section.** - Native soil from the trench excavation was placed in 8- to 9-inch loose lifts beside the pipe and compacted to at least 95 percent compaction. These lifts were placed until the compacted bedding was up to at least 0.7 of the outside diameter of the pipe.

- **85 percent section.** - Native soil from the trench excavation was placed in loose lifts and compacted to about 85 percent compaction for the whole trench section, that is, from the trench bottom to the ground surface.

These particular bedding conditions were selected to be different from Reclamation "standard installation" and the "alternate installation" for PVC pipe. These are potentially the most practical variations.

The "standard installation" is illustrated on figure 2. Deflection of a flexible pipe due to earth load depends on a combination of pipe stiffness and soil stiffness. In the "standard installation," a low-stiffness pipe is used with a high-stiffness soil. The soil is specified to be a clean, cohesionless, free-draining "select material" compacted to 70 percent relative density. For the "alternate

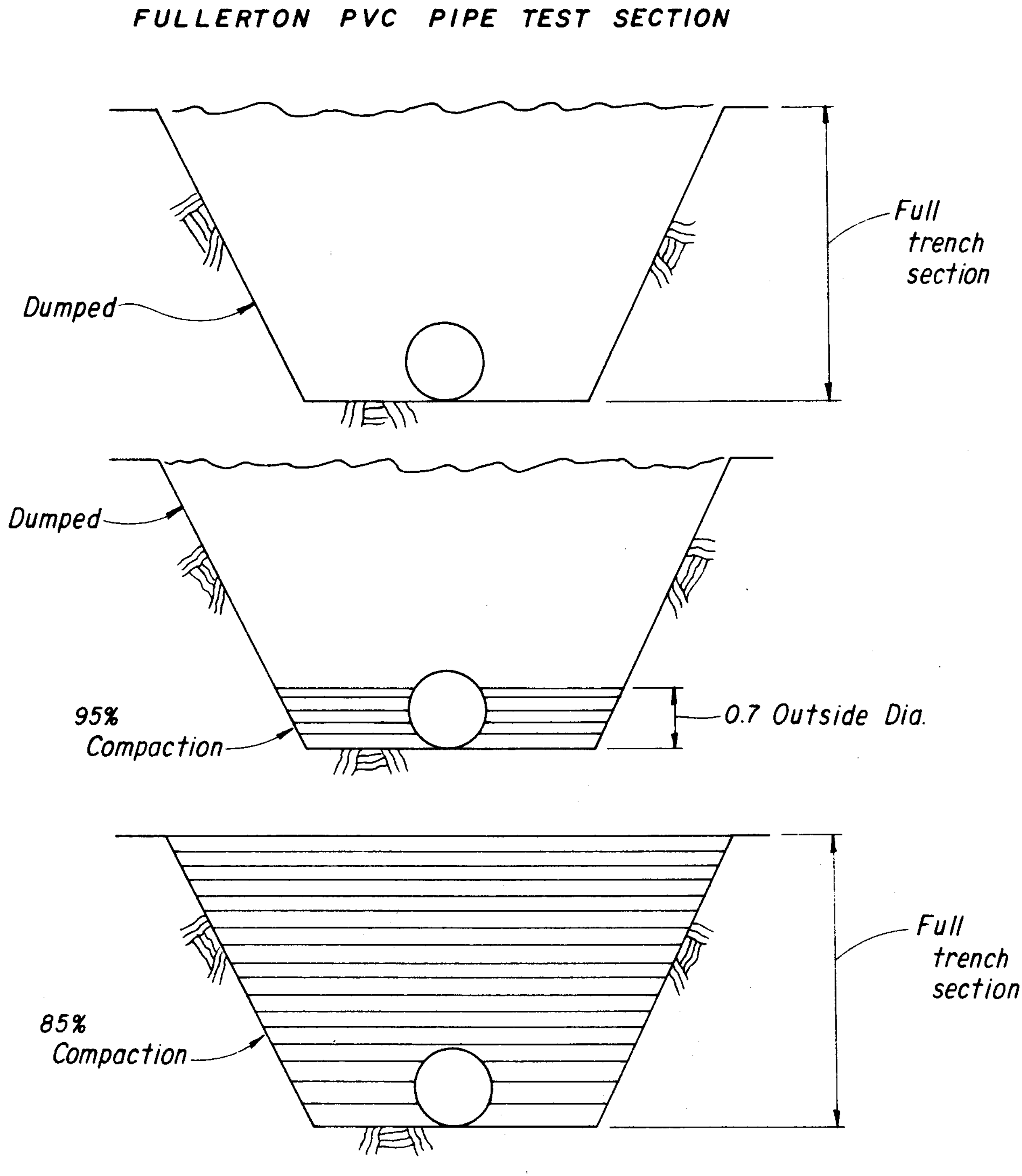
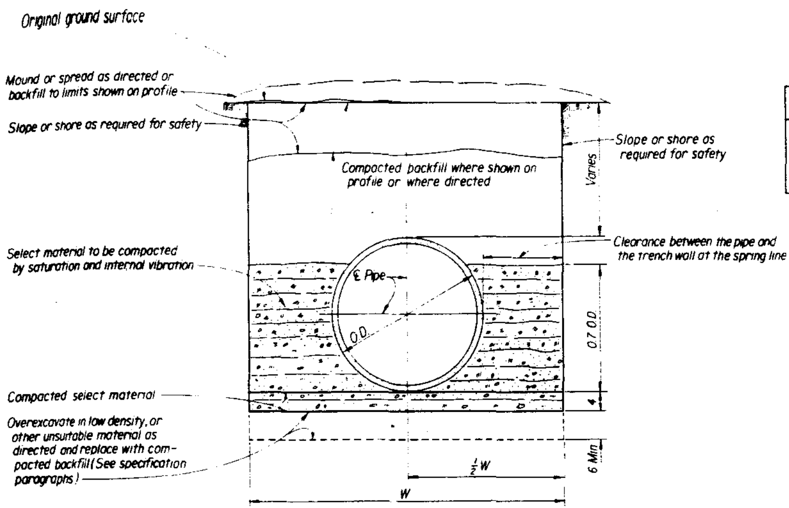


Figure 1. - Bedding and backfill conditions



FLEXIBLE PIPE - TYPES 1, 2, AND 3
TYPICAL EARTHWORK FOR
STEEL PIPE..........(12"-54")
REINFORCED PLASTIC MORTAR PIPE..........(12"-54")
PRETENSIONED CONCRETE CYLINDER PIPE..........(21"-54")
DUCTILE IRON PIPE..........(42"-54")
REINFORCED THERMOSETTING RESIN PIPE..........(12"-54")
PVC PIPE..........(12"-27")

GRADATION FOR SELECT MATERIAL

SIZE	PERCENT BY WEIGHT
Passing No. 200 sieve	5 or less
Maximum size shall not exceed ¾ inch	

MINIMUM INSTALLATION WIDTH

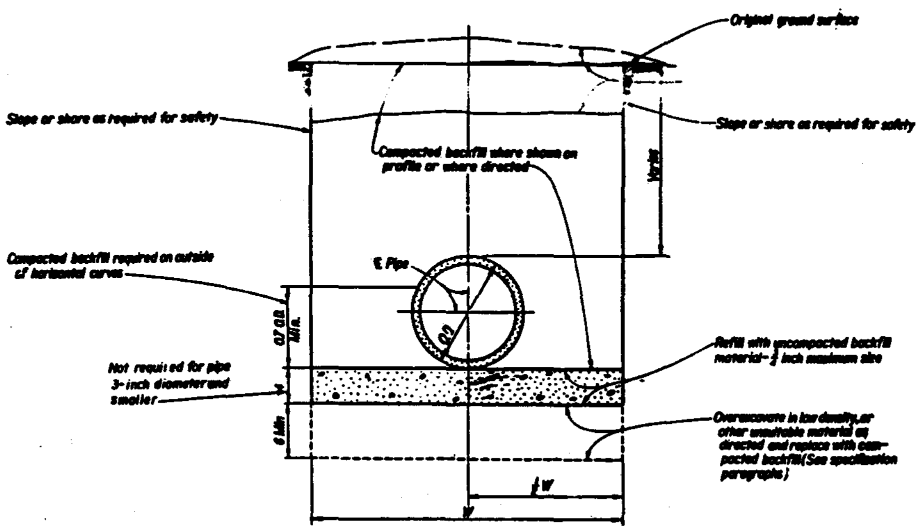
PIPE I.D. INCHES	W FEET
6 and less	2.0
Over 6 thru 18	0.083 (O.D. + 20)
Over 18	0.083 (O.D. + 36)

NOTE: .083 = Conversion factor inches to feet

FLEXIBLE PIPE CLEARANCE

TRENCH TYPE *	MINIMUM CLEARANCE
1	0.5 (12 W - O.D.)
2	1.0 (O.D.)
3	2.0 (O.D.)

* Trench type is determined by comparing the strength of the trench wall against that of compacted soil in resisting lateral pipe deflections.
Type 1 - Trench wall strength > Compacted soil.
Type 2 - Trench wall strength = Compacted soil.
Type 3 - Trench wall strength < Compacted soil.



TYPICAL EARTHWORK FOR
STEEL PIPE..........(2"-10")
ASBESTOS-CEMENT PRESSURE PIPE..........(4"-10")
REINFORCED PLASTIC MORTAR PIPE..........(8"-10")
PRETENSIONED CONCRETE CYLINDER PIPE..........(10")
DUCTILE IRON PIPE..........(4"-20")
REINFORCED THERMOSETTING RESIN PIPE..........(8"-10")
PVC PIPE (ALL HEAD CLASSES)..........(2"-10")
PVC PIPE (H ≥ 475)..........(12"-27")

Figure 2. - Standard and alternate pipe installations.

installation," shown on figure 2, a high stiffness pipe is used with a low-stiffness soil which can be native soil excavated from the trench. These two options provide the contractor a choice that depends on relative costs of two different stiffnesses of pipe and on labor-intensive soil compaction for a particular pipeline.

TEST SITE

The test section site is located about 1 mile north of Elba, Nebraska, along the west side of Nebraska Highway No. 11, as shown on figure 3. A plan view of the test section is shown on figure 4 and the profile on figure 5.

The typical trench section is shown on figure 6 and pipe diameter measurement locations are shown on figure 7. The Government purchased a permanent easement for the test section to facilitate access to the pipe for future readings.

The original trench section was to have about 18 inches of clearance on each side of the pipe, or a total bottom width of 5 feet 4 inches. The total depth was to be 18 feet so there would be 15 feet of cover over the pipe. At a depth of about 13 feet, a layer of clean, fine sand was encountered. As the sand dried, it began to slough creating vertical walls in the sand. Since the sloughing would undercut the overlying clay material, the excavation was terminated at a depth of about 15 feet 6 inches. The result was that the trench width at spring line of the pipe was 11 to 13 feet. This trench width is about 5 pipe diameters, which means the pipe was installed in a nontypical condition.

In order to obtain as much cover (load) as possible over this pipe, the soil was mounded over the trench to create a final cover over the pipe of 15 feet.

PIPE

The PVC pipe was 27-inch nominal inside diameter, SDR-51, rated to 80 lb/in^2, and the sections were 20 feet long. The pipe was purchased from Diamond Plastics Corporation of Grand Island, Nebraska, and is made with an integral bell to utilize a gasket for sealing, meeting the specifications defined in ASTM F 477. The bell-and-spigot joint is illustrated on figures 8 and 9.

The pipe was marked "Diamond 27 PIP SDR51 80PSI PVC 12454-B 6XBZF15D." The pipe is described in a catalog as "Agricultural PVC Pipe" having the following properties:

Outside diameter	= 27.953 inches
Inside diameter	= 26.857 inches
Wall thickness	= 0.548 inch
Modulus of elasticity	= 400,000 lb/in^2

Several measurements of the pipe wall thickness were made at the cut end of the outlet pipe using a vernier caliper. As shown in table 1, the measurements ranged from 0.595 to 0.629 inch with an average of 0.617.

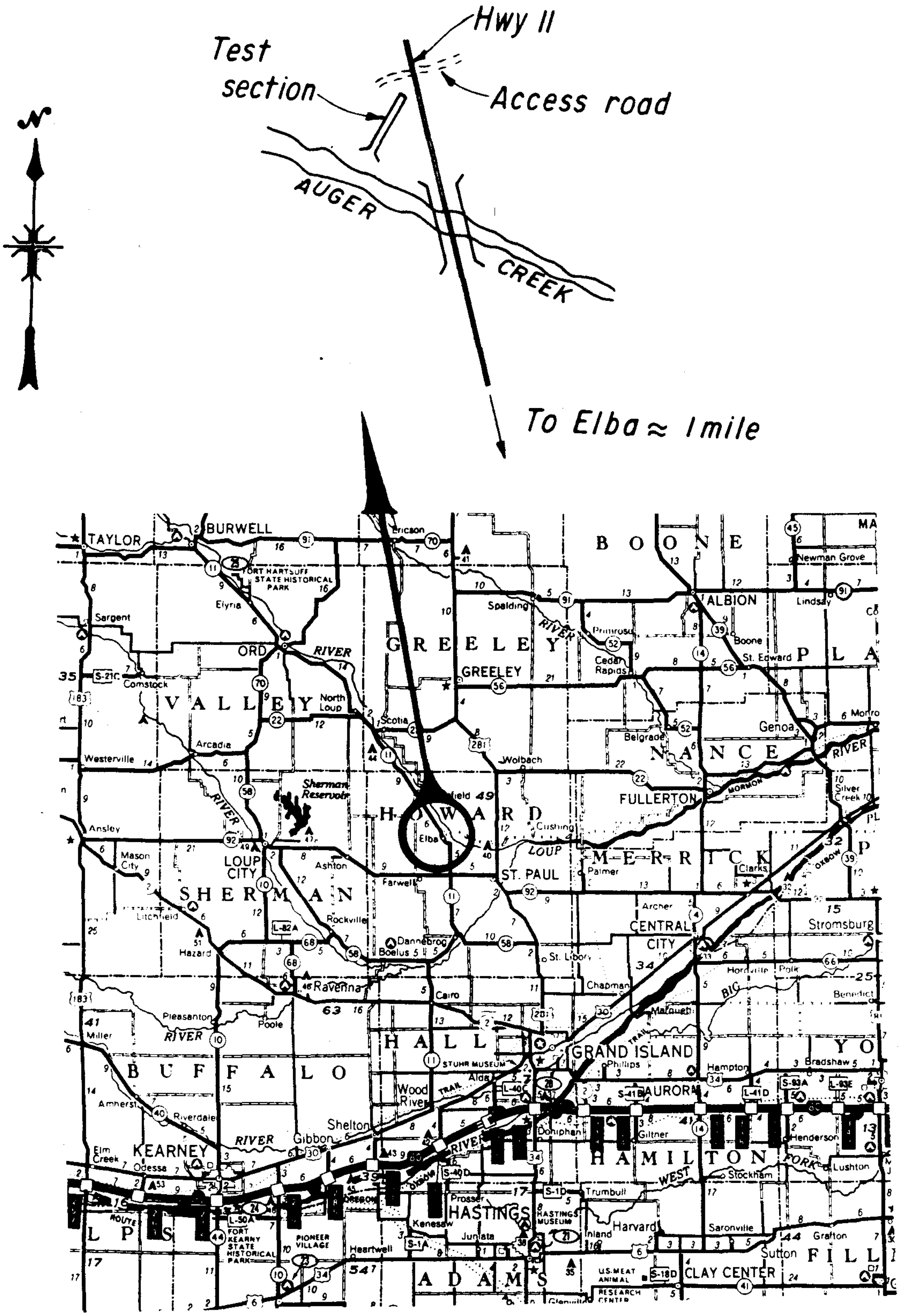


Figure 3. - Test section location map.

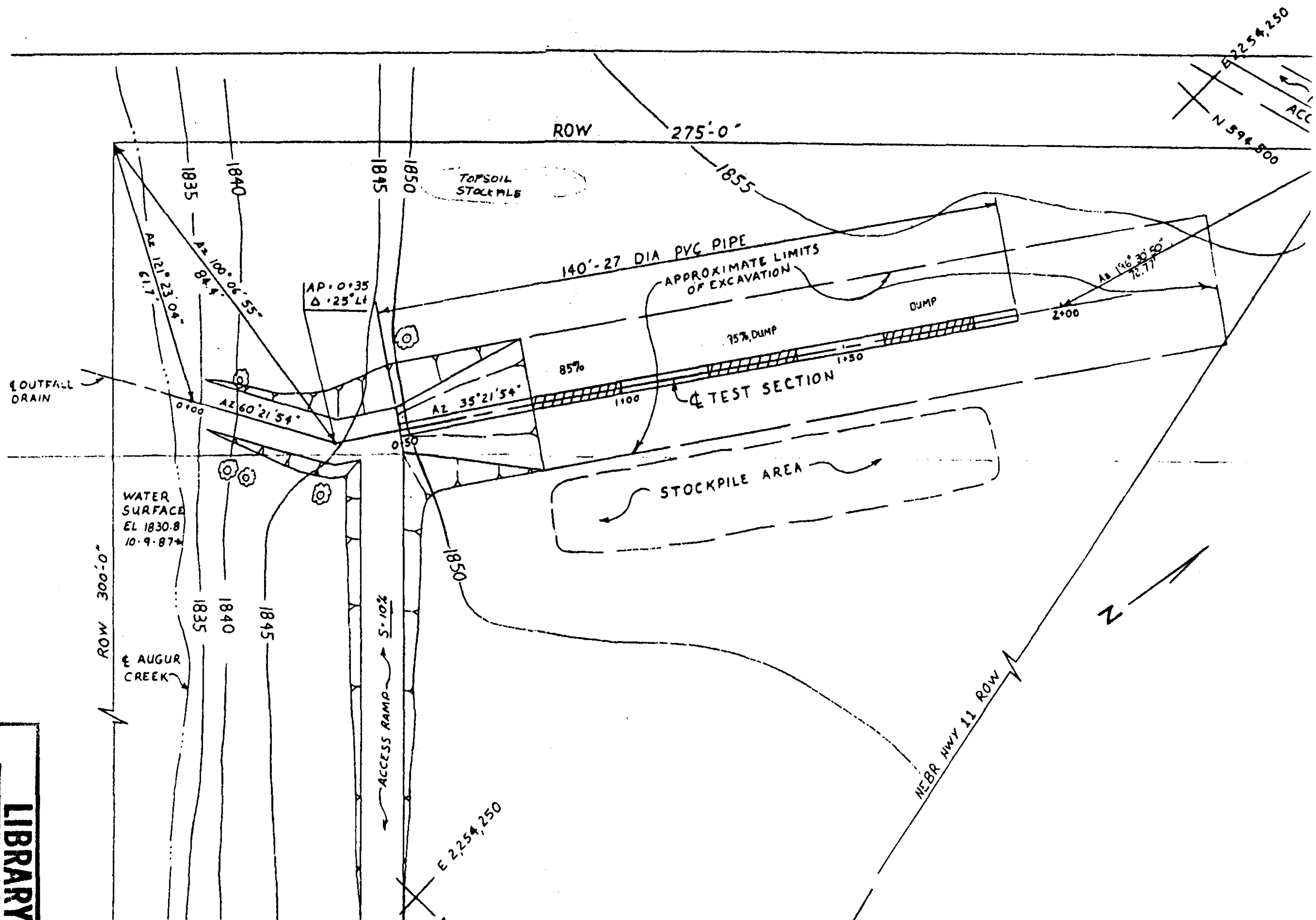


Figure 4. - Plan view of test section site.

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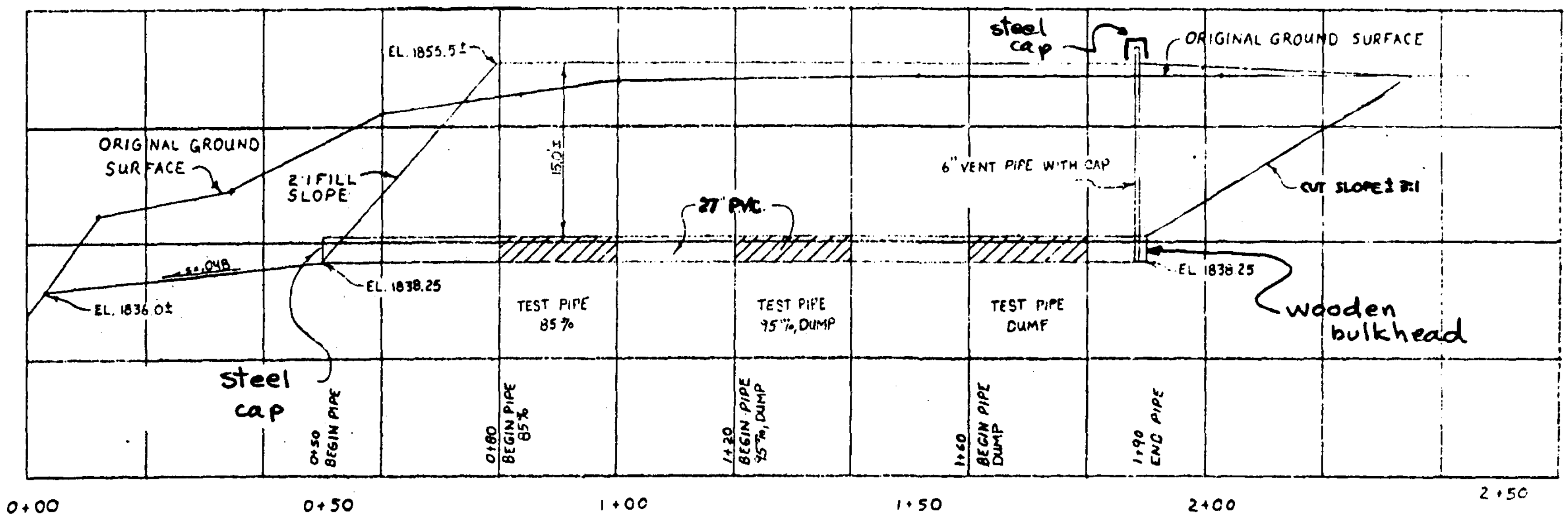

Figure 5. - Profile of test section site.

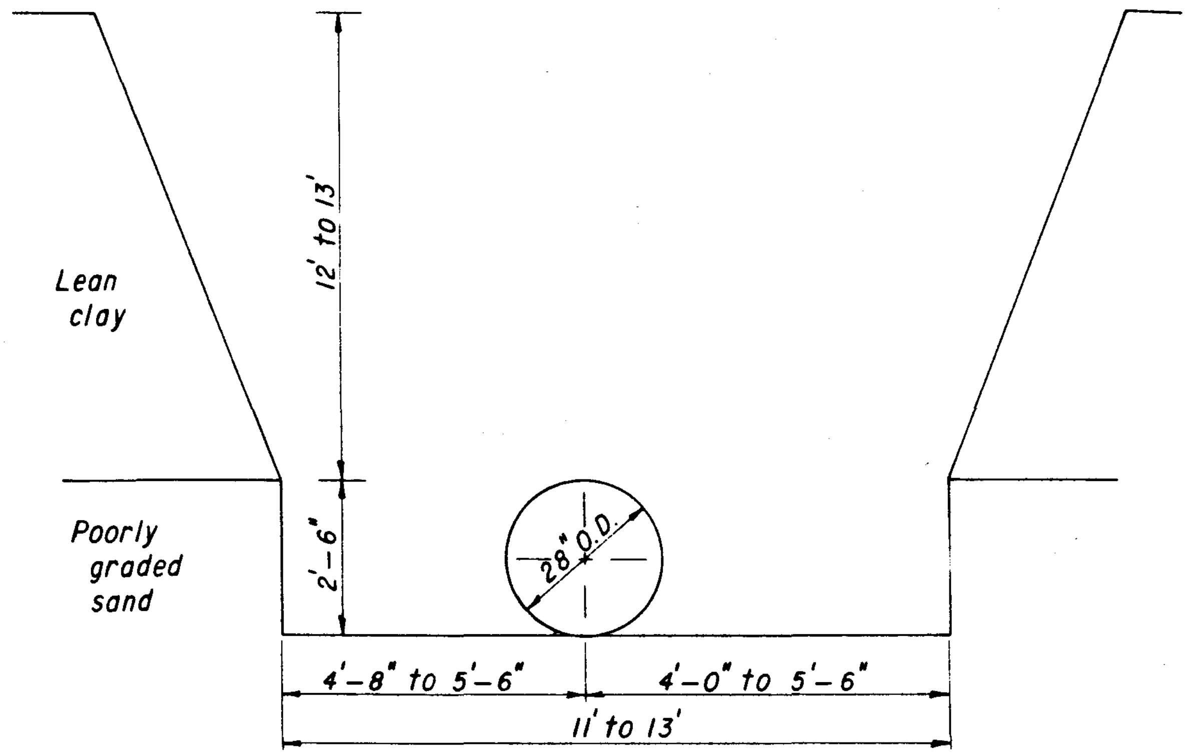

Figure 6. - Typical trench section for test section.

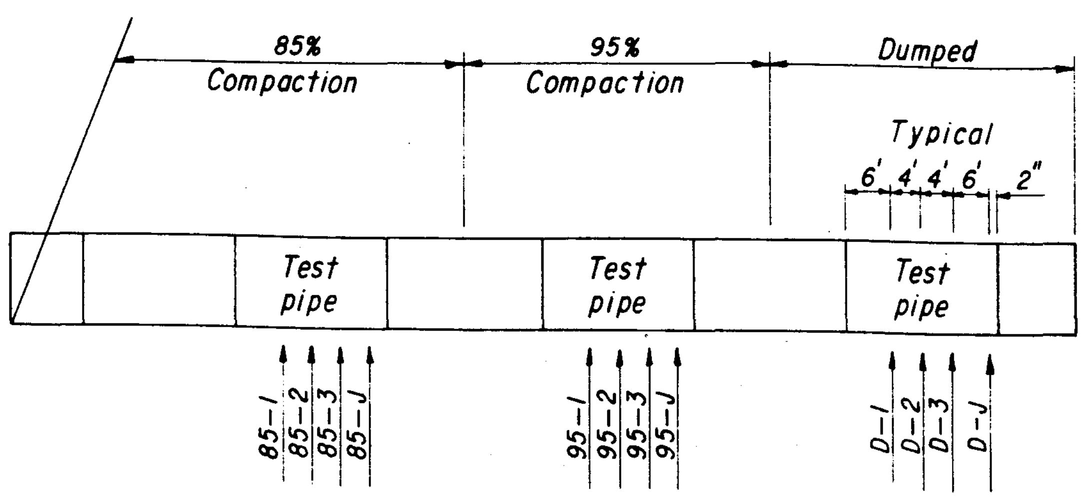

Figure 7. - Pipe diameter measurement locations.

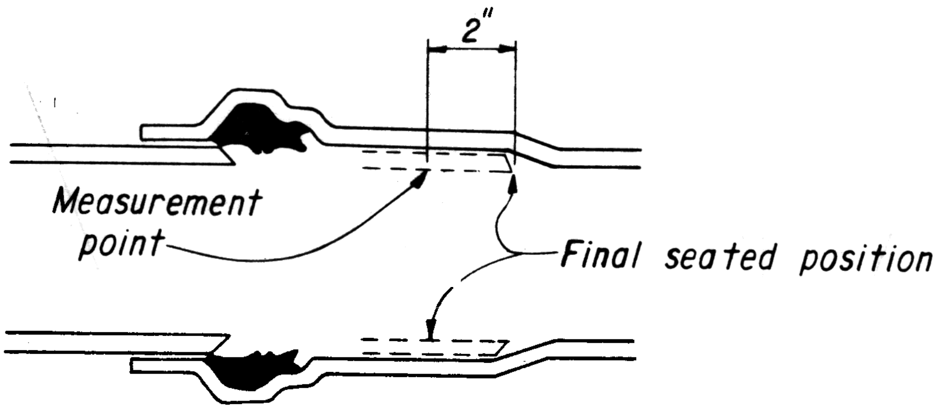

Figure 8. - Schematic of bell-and-spigot joint.

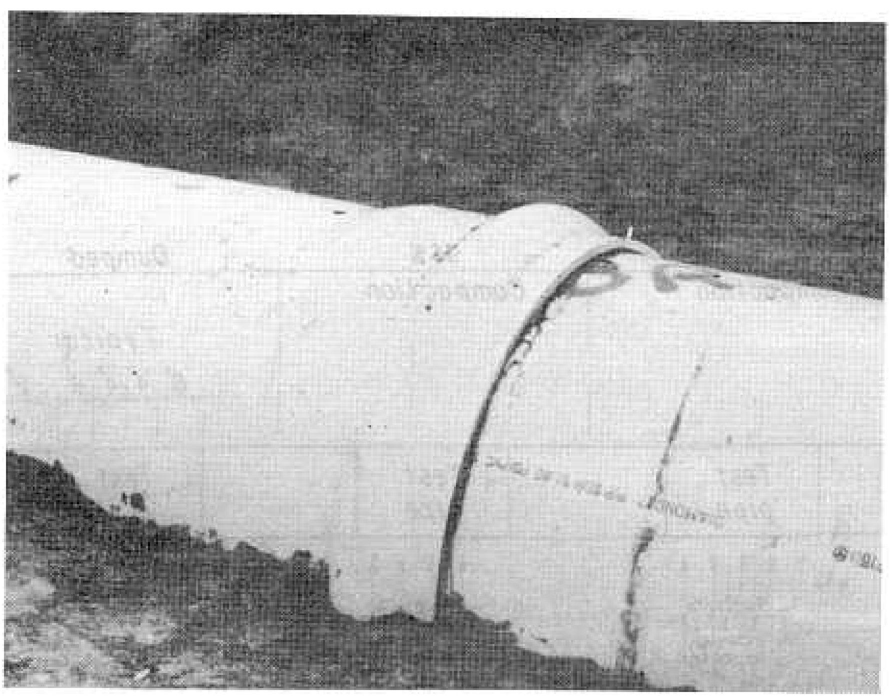

Figure 9. - Bell-and-spigot joint.

The pipe stiffness for use in the equation for predicting the pipe deflection under load is expressed as:

$$\text{pipe stiffness, lb/in}^2 = \frac{EI}{r^3}$$

where:

E = modulus of elasticity, lb/in^2
I = moment of inertia of section of pipewall, in^4/in
r = pipe radius, inches

The moment of inertia for a straight wall pipe is equal to $t^3/12$ where "t" is the pipe wall thickness. Using the following nominal values, the pipe stiffness, EI/r^3, was calculated to be 2.2 lb/in^2:

E = 400,000 lb/in^2
t = 0.55 inch
D = 27.0 inches

If the measured wall thickness of 0.62 inch was used, the pipe stiffness would be 3.2 lb/in^2, or about 50 percent higher. However, measurements were made on only one pipe at one section and may or may not be representative of the entire test section. In addition, because predictions of pipe deflection are generally based on nominal values, the nominal pipe stiffness is used in this study for comparison purposes.

SOIL PROPERTIES

Results of in-place density tests and physical properties tests of the soils are presented in appendix A along with exploration logs of the test site.

Foundation and Trench Walls

The soil in the foundation and in the trench walls from the trench bottom up to about the top of the pipe was classified as a POORLY GRADED SAND. Four in-place densities were measured in this material. Relative densities ranged from 61 to 88 percent with an average of 72 percent. Trench wall conditions would be considered trench type I as used in Reclamation (Bureau of Reclamation, 1981).

Native Soil

The native soil excavated from the trench was classified as LEAN CLAY.

CONSTRUCTION SEQUENCE OF TEST SECTION

Excavation of the trench section was performed under contract and was accomplished using a scraper on October 27 and 28 with final shaping done with a hydraulic excavator on October 29, 1987.

The pipe was laid in the trench bottom and joined on November 2, 1987. The grade of the pipe was adjusted by tamping under the pipe with a 2 by 4 board.

Initial pipe diameter and pipe invert measurements were made on the morning of November 3. A photograph of the pipe in the trench before any backfilling is shown on figure 10.

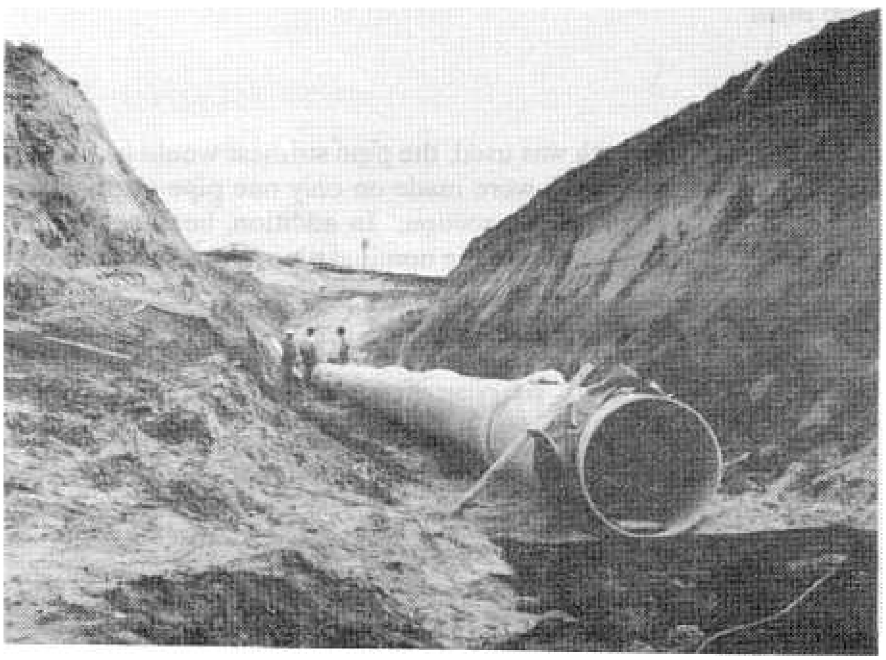

Figure 10. - Pipe in trench before backfilling.

The sequence of placing the bedding and backfill soil and measuring soil densities is illustrated for each test reach on figures 11 through 14.

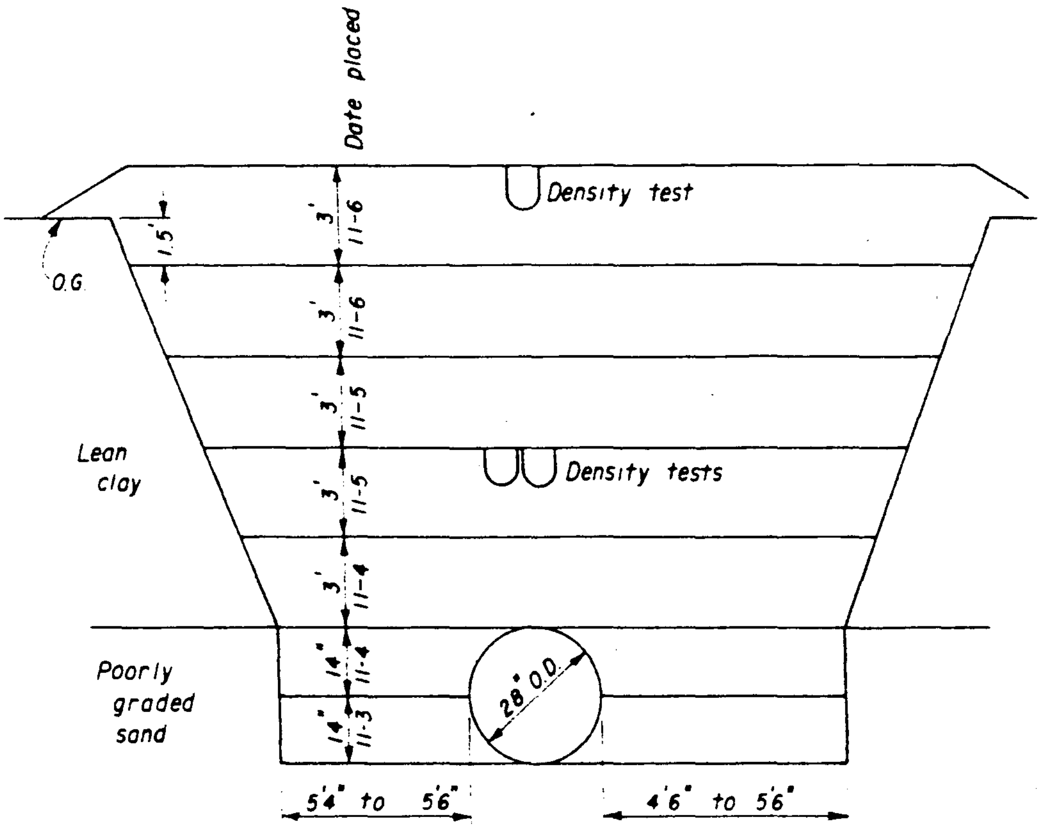

Figure 11. - Dumped section - backfilling sequence.

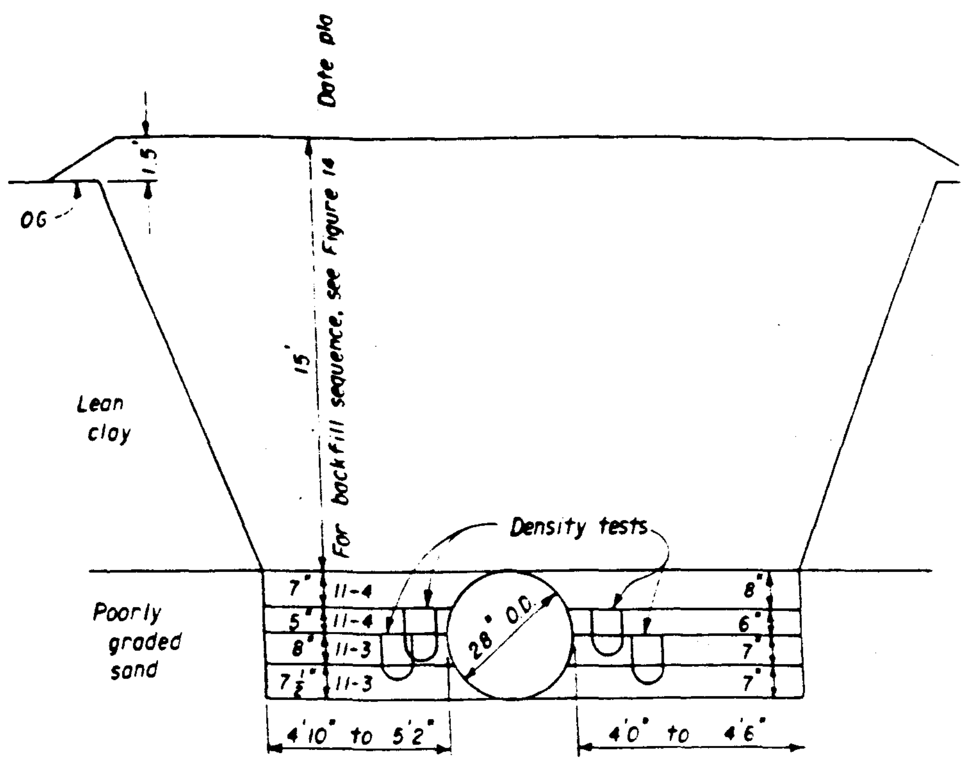

Figure 12. - 85 percent section - backfilling sequence.

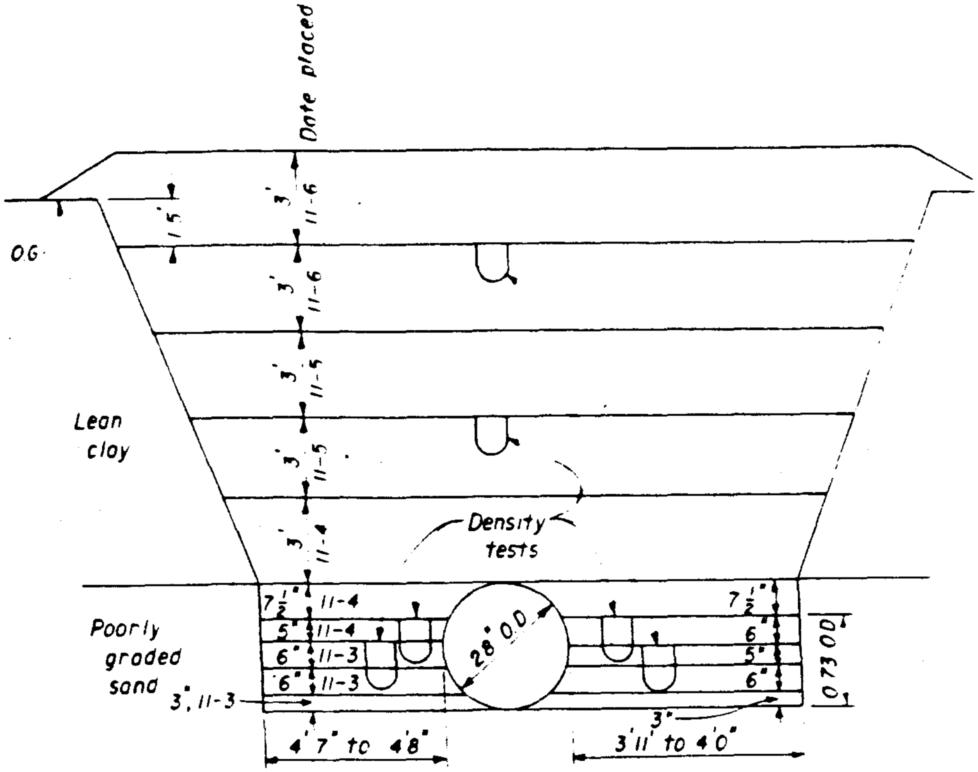

Figure 13. - 95 percent section - backfilling sequence.

date placed	lift thickness	height of cover	method of compaction	density tests	measurements made
11-6	two 18" lifts	15'	wheel rolled		diameters
11-6	two 18" lifts	12'	wheel rolled		density diameters
11-6	two 12" lifts	9'	wheel rolled		diameters
11-6	three 8" lifts	7'	wheel rolled		density diameters
11-5	6"		wheel rolled		diameters
11-5	two 9" lifts	4.5'	wheel rolled		density diameters
11-5	8"		wheel rolled		cover, diameters, invert elevations
11-5	8"		wheel rolled		density
11-5	6"		wackers		
11-4	6"		wackers		density, diameters
11-4	6"		wackers		

Figure 14. - Detailed backfilling sequence of 85 percent section.

The soil was dumped in beside the pipe using a hydraulic excavator as illustrated on figure 15.

Figure 15. - Soil being dumped into trench.

Dumped section. - The soil was placed in two loose lifts beside the pipe, one lift from trench bottom to pipe spring line and the other from spring line to the top of the pipe. For each lift loose soil was leveled using garden rakes and shovels.

The backfill over the pipe was placed in 3-foot-thick loose lifts up to a final cover height of 15 feet. These lifts were leveled using the hydraulic excavator bucket.

85 percent section. - From the trench bottom to the top of the pipe, the soil was placed in 8-inch loose lifts and compacted with one pass of a wacker (see fig. 16) to about 6 inches. This was continued over the pipe up to a cover height of 3 feet. Then progressively thicker lifts were used and these were compacted using wheel traffic from a front-end loader as shown on figure 17.

Figure 16. - Compaction using a wacker.

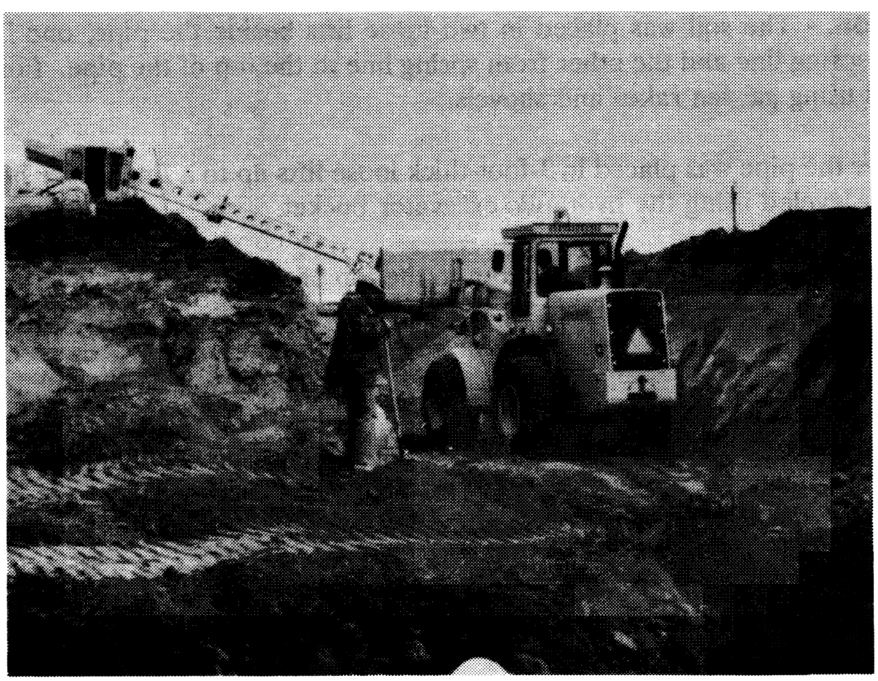

Figure 17. - Compaction using wheel rolling.

95 percent section. - From trench bottom up to 0.7 of the outside pipe diameter, the soil was placed in about 8-inch loose lifts and compacted with several passes of a wacker to a compacted height of about 6 inches. The required number of passes was monitored by measuring the in-place density using a sand cone device, as shown on figure 18. After having placed compacted soil to a height of 0.7 of the outside diameter of the pipe, loose soil was placed and leveled up to the top of the pipe. The backfill sequence of placing soil over the pipe was the same as described for the dumped section.

Figure 18. - Measuring in-place density using a sand cone device.

Completion

Backfill placement was completed Friday, November 6, 1987, the zero day for calculating time lag. Final dressup and cleanup of the area were performed on November 9 and 10.

UNIT WEIGHT OF BACKFILL OVER PIPE

Dumped and 95 Percent Sections

Five in-place unit weight tests were performed in the uncompacted backfill soil over the dumped section and the 95 percent section. Test results are summarized in table 1. Two of the tests were performed in the backfill over the 95 percent section and three were performed in the backfill over the dumped section. However, test results were so similar that unit weight of the uncompacted backfill will be discussed without regard to location.

The wet unit weight of the uncompacted backfill ranged from 78.7 to 84.2 lbf/ft^3 with an average of 81.3 lbf/ft^3. For calculation of the predicted pipe deflection, a unit weight of 81 lbf/ft^3 was used.

Percent compaction of the uncompacted backfill ranged from 66.8 to 74.3 percent with an average of 70.7 percent.

85 Percent Section

Five in-place unit weight tests were performed in the compacted backfill soil over the 85 percent section. Test results are summarized in table 2.

Wet unit weights of soil compacted over the top of the pipe ranged from 90.0 to 100.6 lbf/ft^3 with an average of 96.6 lbf/ft^3. For calculation of the predicted pipe deflection, a unit weight of 97 lbf/ft^3 was used.

Percent compaction of the compacted backfill ranged from 81.0 to 89.8 percent with an average of 86.4 percent.

DEGREE OF COMPACTION OF BEDDING SOIL

To determine the degree of compaction of the bedding soil (soil placed beside the pipe), percent compaction was determined for each test reach. The degree of compaction is required in order to determine E′, Modulus of Soil Reaction, used in calculating predicted pipe deflection (Howard, 1977). The degrees of compaction used are *dumped, slight, moderate,* and *high.*

Dumped Section

The dumped section had no compaction except for occasional foot traffic associated with spreading the soil in level increments at spring line and at the top of the pipe. The unit weight and percent compaction of the bedding was assumed to be the same as those discussed under "Unit Weight of Backfill over Pipe" section. The degree of compaction would be *dumped.*

85 Percent Section

In-place unit weight test results are summarized in table 2. Two tests were performed when the bedding soil was at spring line and two tests when the bedding was at 0.7 o.d. (outside diameter).

Percent compaction ranged from 85.3 to 91.0 percent with an average of 88.5 percent. The degree of compaction would be *moderate.*

95 Percent Section

In-place unit weight test results are summarized in table 3. Two tests were performed with the bedding at spring line and two tests when the bedding was at 0.7 o.d.. Percent compaction ranged from 94.3 to 96.7 percent with an average of 95.7 percent. The degree of compaction would be *high.*

PIPE DIAMETER MEASUREMENTS

Measurement points for vertical diameters were established by locating and marking the invert of the pipe using steel balls and then marking the top of the pipe using a plumb bob. As shown on figure 19, a special device was then used to locate horizontal diameters. As the device was placed on the vertical diameter marks, the ends were used to locate the horizontal diameter. Care was taken that the device was perpendicular to the axis of the pipe. A screw was inserted into the pipe wall at the marked locations of the vertical and horizontal diameters.

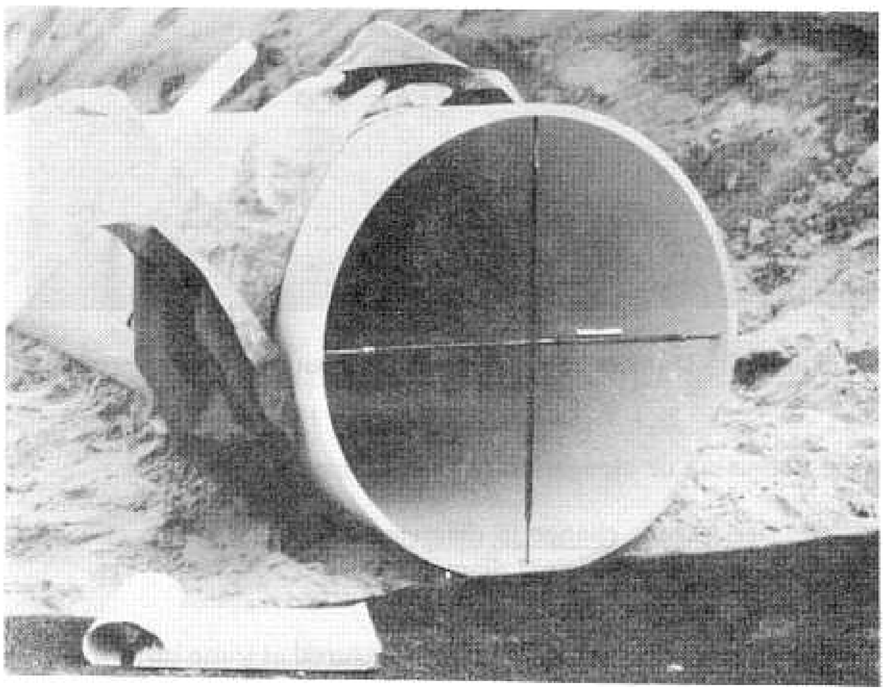

Figure 19. - Device used to mark vertical and horizontal diameter measurement points.

As illustrated on figure 20, the diameters were measured with an inside micrometer that could be read to 0.001 inch. These measurements were made with the ends of the inside micrometer on the screw heads.

Diameter measurements are tabulated in table 4. The readings are accurate to about plus or minus 0.010 inch because of the variation in the pressure used to tighten the micrometer in the final reading position. The readings through final backfilling were all made by the same person.

All elongations and deflections discussed are the *vertical* elongations and deflections of the pipe unless otherwise described. Elongation is defined as an increase in the vertical diameter of the pipe due to bedding soil being placed beside the pipe and compacted. Deflection is defined as a decrease in the vertical diameter of the pipe due to backfill soil being placed above the top of the pipe.

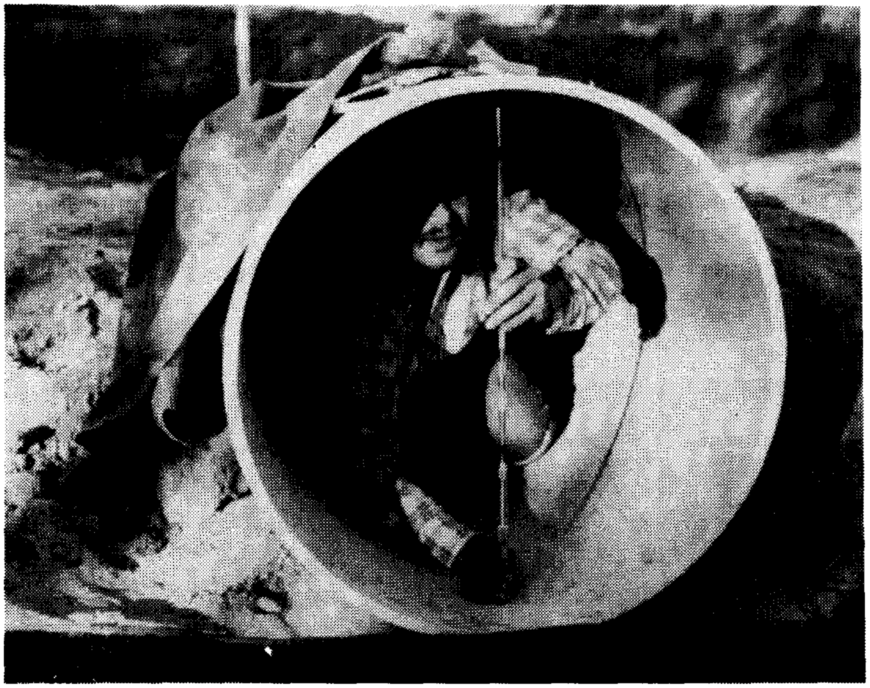

Figure 20. - Diameter measurements using an inside micrometer.

The percent vertical deflection or elongation (ΔY) is defined as:

$$\Delta Y\ (\%) = \frac{\text{change in diameter}}{\text{original diameter}} \times 100$$

For elongation, "change in diameter" is the diameter measured at some stage in the bedding process minus the diameter of the pipe when the pipe was in place on the trench bottom before any bedding operation was begun. For deflection, "change in diameter" is the diameter measured when bedding was completed up to the top of the pipe minus the diameter measured during or after the backfilling process. The "original diameter" used for both elongation and deflection calculations was the nominal inside diameter of the pipe, 27 inches.

Elongation is shown as a negative value and deflection is given as a positive value.

PIPE ELONGATION DURING BEDDING

Flexible pipe can elongate (increase in vertical diameter and decrease in horizontal diameter) due to compaction of the bedding soil alongside the pipe. The diameters (horizontal and vertical) of the pipe were measured with the pipe resting in place on the trench bottom before any bedding soil was placed. Diameter measurements were again made after each lift of soil was placed and compacted. The dumped bedding was placed in two lifts and diameter measurements were made after each placement.

Pipe diameter elongation at each measurement station is shown on table 5. Both vertical and horizontal diameter changes are shown. Horizontal diameter change was larger than vertical diameter change as summarized in the following table:

Test reach	Percent average elongation with soil at top of pipe	
	Vertical	Horizontal
Dumped	-0.2	-0.3
85 percent compaction	-1.6	-1.6
95 percent compaction	-3.0	-3.1

The amount of elongation was directly related to the compactive effort applied to the bedding soil. The measurements show that just dumping soil beside a pipe can result in elongation. Compacting the bedding soil to over 95 percent compaction can elongate the pipe about 3 percent.

Maximum and minimum vertical elongations are shown in the following table along with average vertical elongation for all readings in the pipe barrel:

Test reach	Percent vertical elongation		
	Minimum	Maximum	Average
Dumped	-0.2	-0.3	-0.2
85 percent compaction	-1.5	-1.6	-1.6
95 percent compaction	-2.9	-3.1	-3.0

The percent vertical elongation values appear to be typical based on other reported measured values (Howard, 1981a).

PIPE DEFLECTION DURING BACKFILLING

Flexible pipe deflects (decreases in vertical diameter and increases in horizontal diameter) due to backfill load on the pipe. The initial diameter (or zero) reading for calculating deflection was the pipe diameter measured when bedding soil was at the top of the pipe. From this zero point, any changes in pipe diameters are due to backfill placed over the pipe. The deflections are shown in table 5.

The following table summarizes maximum and minimum vertical deflections at 15 feet of cover along with the average deflection:

Test reach	Percent vertical deflection at 15 feet of cover		
	Minimum	Maximum	Average
Dumped	9.2	9.6	9.4
85 percent compaction	0.9	1.2	1.0
95 percent compaction	0.8	1.0	0.9

Percent vertical deflection versus cover height is plotted for each test reach as shown on figure 21.

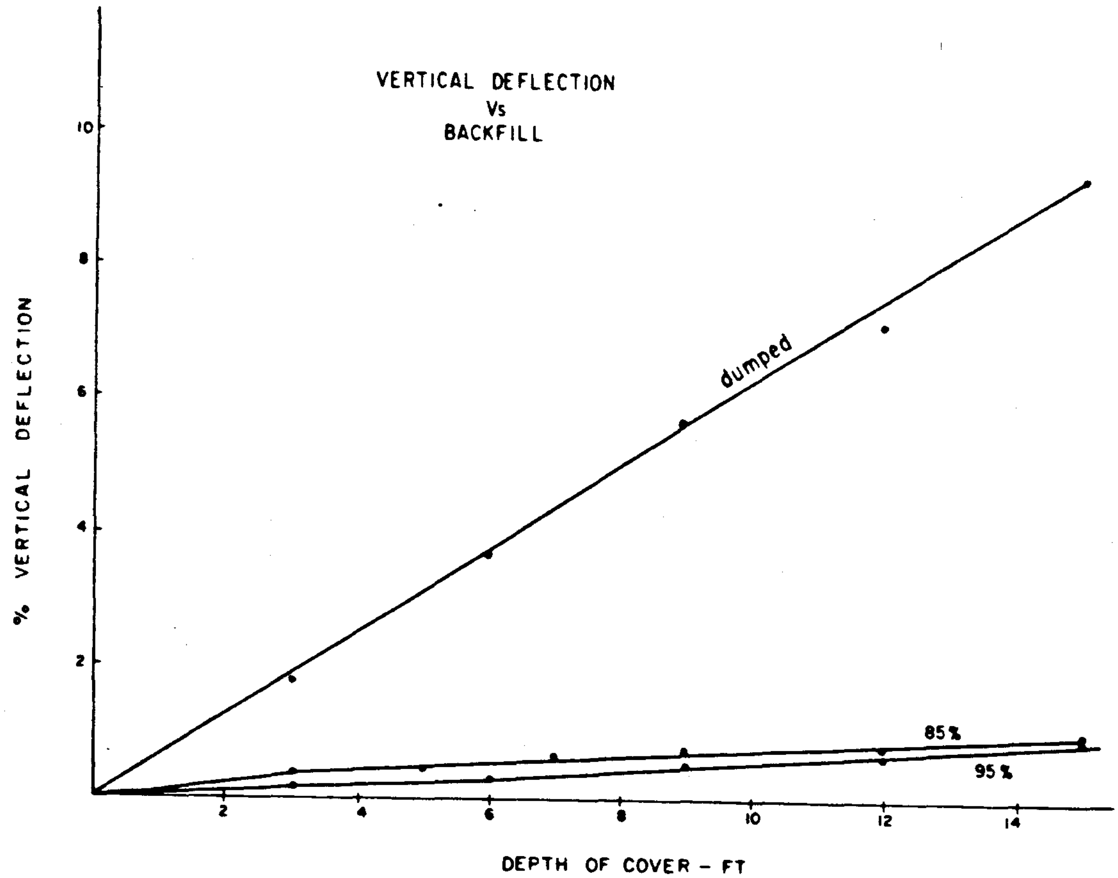

Figure 21. - Pipe deflection versus cover height.

Vertical Versus Horizontal Diameter Changes

Both vertical and horizontal deflections are shown in table 5. Horizontal deflections were smaller than vertical deflections as summarized in the following table:

	Average percent deflection at 15 feet of cover		
Test reach	Vertical ΔY	Horizontal ΔX	Ratio ΔX/ΔY
Dumped	9.4	8.4	0.89
85 percent compaction	1.0	0.8	0.80
95 percent compaction	0.9	0.5	0.56

For pipe that deflects elliptically, the ratio of the horizontal to vertical deflections should be about 0.91 (Howard, 1981b).

Net Change in Pipe Diameter

The net change in pipe diameter from measurements made when the pipe was in place on the trench bottom and after backfilling was completed is shown on the following table:

Test reach	Elongation (percent)	Vertical Deflection (percent)	Net change (percent)
Dumped	-0.2	9.4	9.2
85 percent compaction	-1.6	1.0	-0.6
95 percent compaction	-3.0	0.9	-2.1

On the day the 15 feet of cover was completed, the pipes with compacted beddings had not returned to their original diameter.

Theoretical Versus Actual Deflections

Theoretical deflections at 15 feet of cover for each bedding condition were calculated using the following equation (Howard, 1977):

$$\Delta Y\ (\%) = T_f \frac{0.0694\gamma\ h}{EI/r^3 + 0.061\ E'}$$

where:

$\Delta Y(\%)$ = theoretical vertical deflection in percent
T_f = time lag factor, 1.0
γ = backfill soil unit weight in lbf/ft^3 = 81 lbf/ft^3 for dumped and 95 percent sections, or 97 lbf/ft^3 for 85 percent section
h = cover height in feet over pipe = 15 feet
EI/r^3 = pipe stiffness in lb/in^2 = 2.2 lb/in^2
E' = modulus of soil reaction in lb/in^2, varies with compaction and soil type (Howard, 1977)

This equation is a commonly used variation of the Iowa Formula. A time lag factor of 1.0 was used to calculate the initial (day backfilling completed) deflections.

The soil type used would be "fine-grained soil with less than 25 percent coarse-grained particles." For the six bedding conditions, E′ values were selected as follows (Howard, 1977):

Test reach	Degree of compaction	Modulus of soil reaction E' in lb/in^2
Dumped	Dump	50
85 percent compaction	Moderate	400
95 percent compaction	High	1,000

The actual average deflection is compared with theoretical predicted deflections on figures 22 through 24. The actual average deflection can vary from the predicted deflection within a percentage that is based on the degree of compaction as follows:

High degree of compaction	±1/2 percent
Moderate degree of compaction	±1 percent
Dumped and slight degree of compaction	±2 percent

The range of deflections, within which each bedding condition deflection should fall, is also shown on figures 22 through 24.

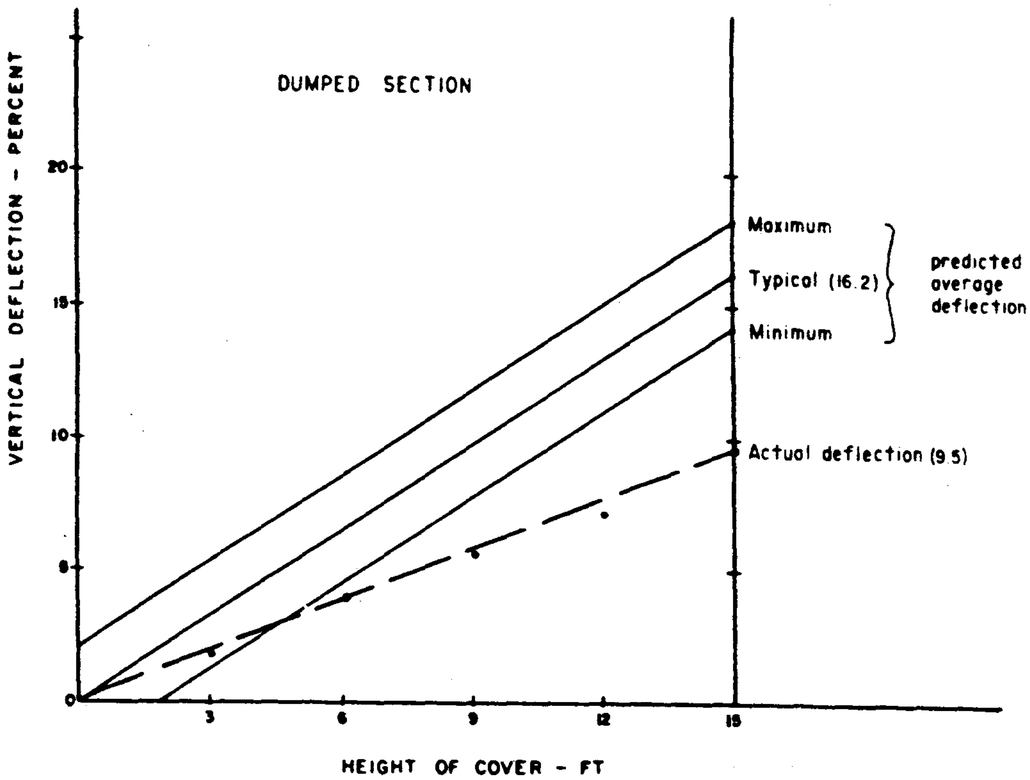

Figure 22. - Pipe deflection in dumped section.

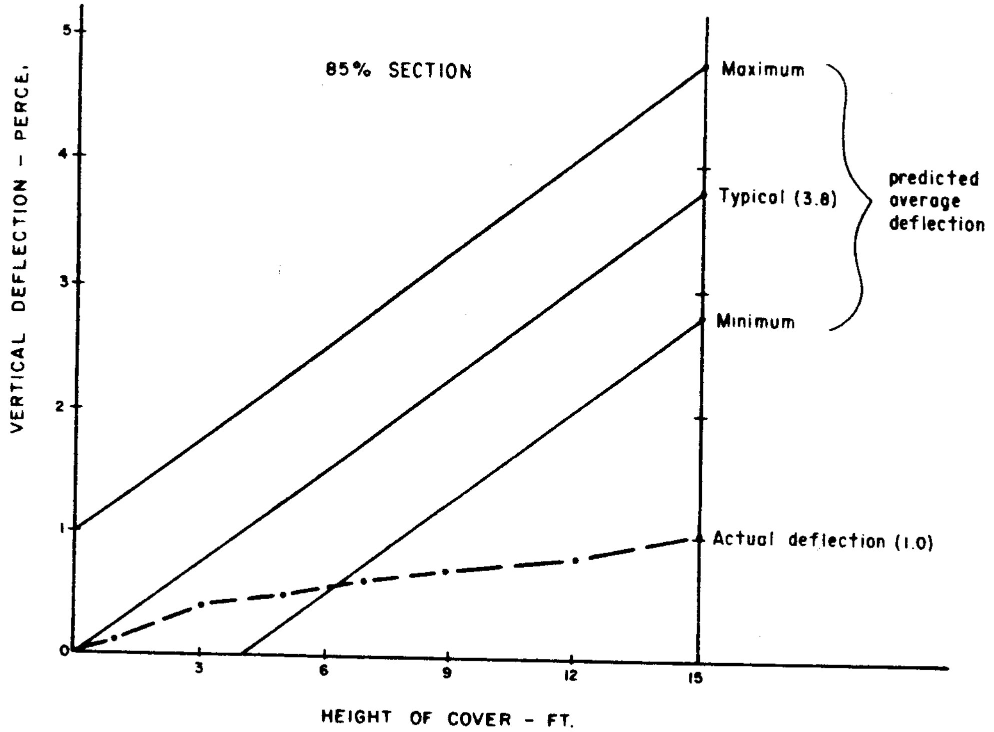

Figure 23. - Pipe deflection in 85 percent section.

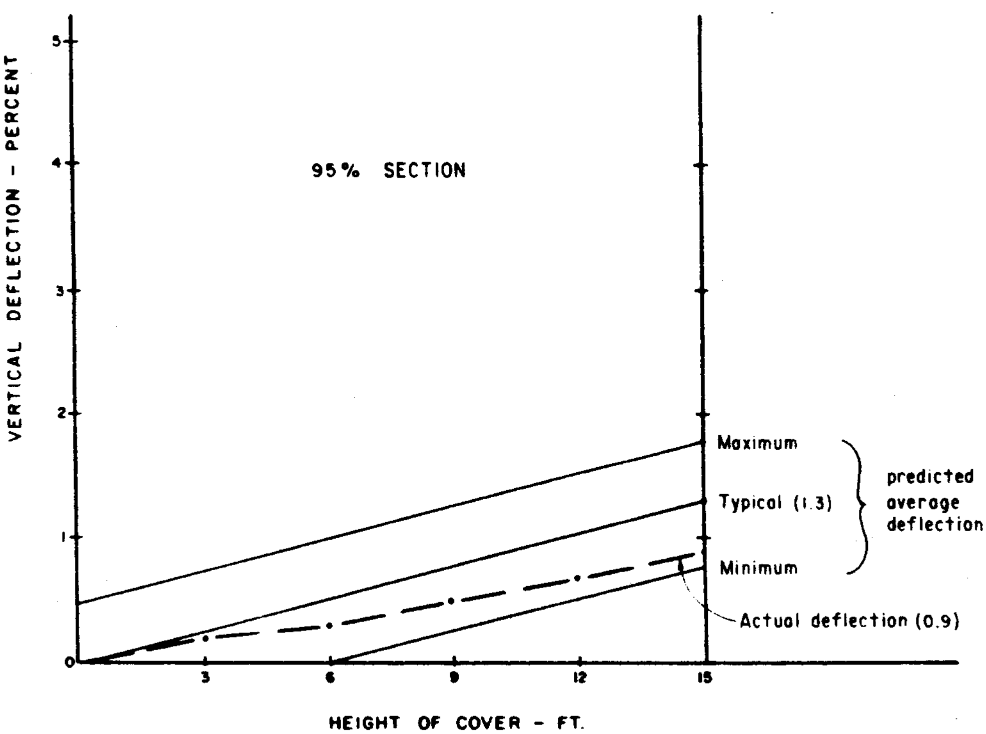

Figure 24. - Pipe deflection in 95 percent section.

Pipe in the dumped section deflected about half the predicted value. The E′ value was backcalculated to be 111 as compared to the recommended value of 50.

Pipe in the 85 percent section deflected about one-fourth the predicted value. The E′ value was backcalculated to be 1,634 as compared to the recommended value of 400.

Pipe in the 95 percent section deflected within the anticipated deflection range. The E′ value was backcalculated to be 1,513 as compared to the recommended value of 1,000.

TIME LAG OF PIPE DEFLECTIONS

A flexible pipe continues to deflect over time for two reasons (Howard, 1981b):

1. Increase in the soil load on the pipe.

2. Compression and consolidation of the soil at the sides of the pipe.

Diameter measurements were made at the following time periods following completion of backfilling: 1, 3, 7, and 14 days, 1, 2, 3, and 6 months, and 1 year. These readings are tabulated in table 4 and the deflections are shown in table 5. Future readings will be made at 2, 3, 4, and 5 years.

Time lag is defined as the ratio of the deflection measured at some time period following completion of backfill to the deflection measured at completion of backfill.

The following table gives time lag factors for vertical deflections measured at 1 and 6 months and 1 year:

	Percent vertical deflection				Time lag factor		
Test reach	**0 day**	**1 mo**	**6 mo**	**1 yr**	**1 mo**	**6 mo**	**1 yr**
Dumped	9.5	10.8	11.9	12.6	1.1	1.3	1.3
85 percent compaction	1.0	1.5	1.8	2.0	1.5	1.8	2.0
95 percent compaction	0.9	1.3	1.6	1.7	1.4	1.8	1.8

Based on other studies and recommended values, the anticipated time lag factors, over several years, are 1.5 for the dumped section and 2.5 for the 85 percent and 95 percent sections. About 75 percent of the time lag factor should be reached in 3 to 6 months. Figures 25 through 27 show the percent vertical deflection versus time for the three test reaches. As shown in these figures, most of the increase in deflection with time has occurred within the 3- to 6-month period. Future reports will document subsequent time lag behavior.

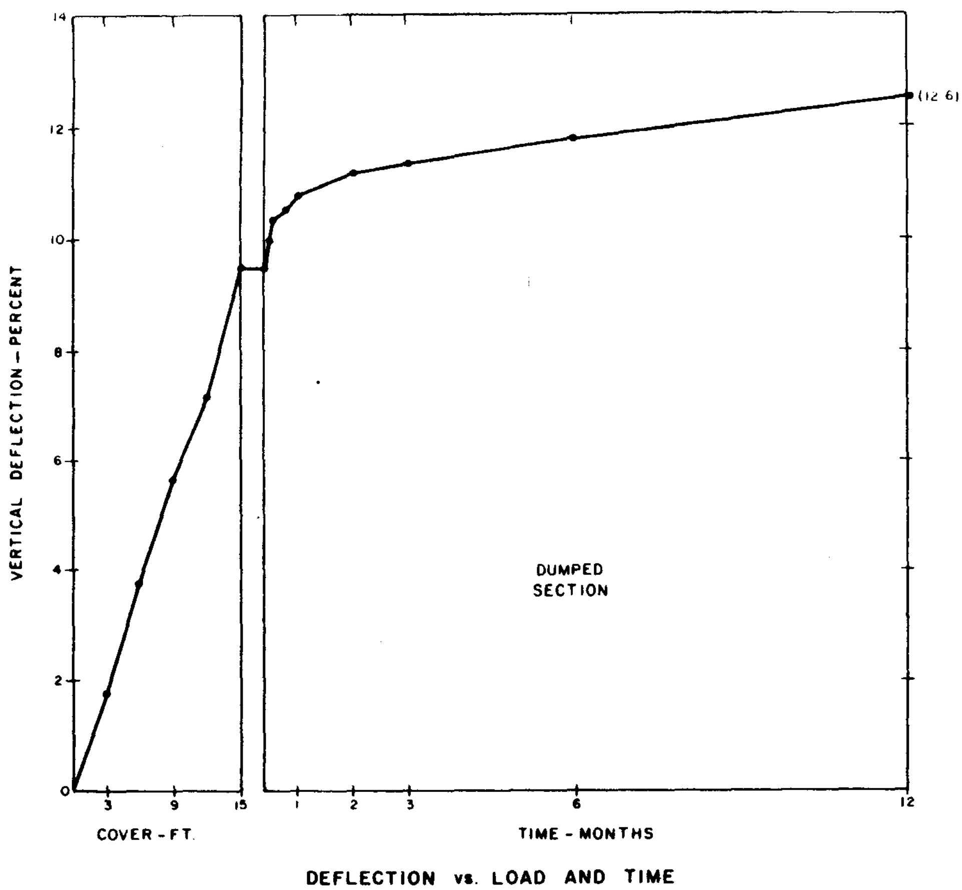

Figure 25. - Time-deflection plot for dumped section.

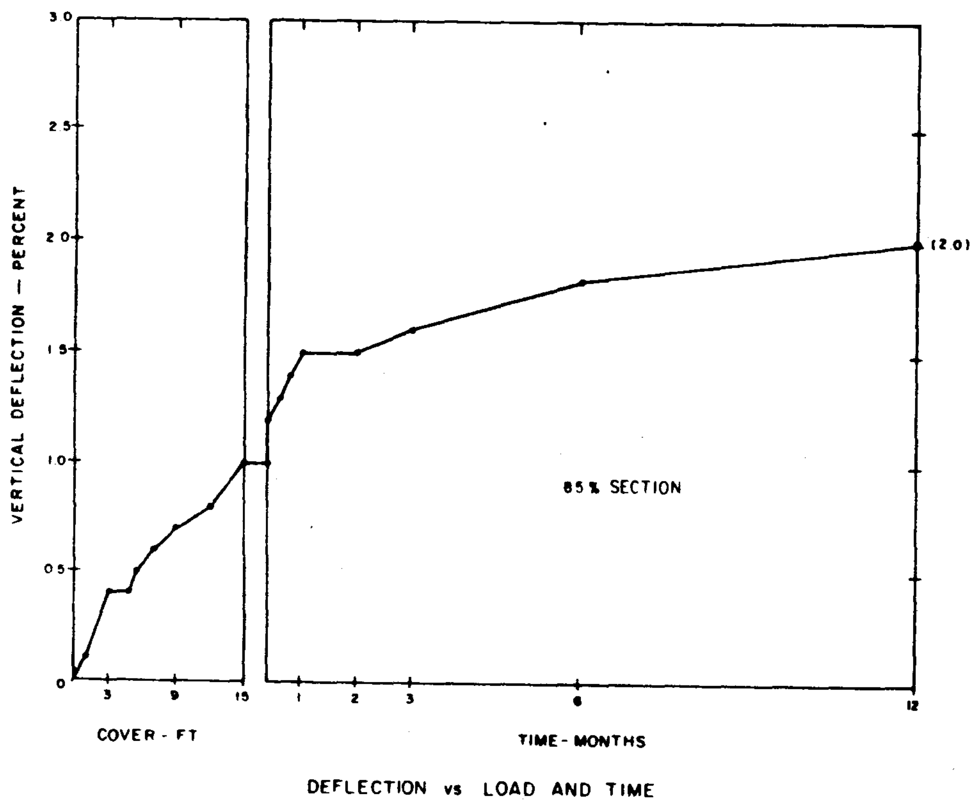

Figure 26. - Time-deflection plot for 85 percent section.

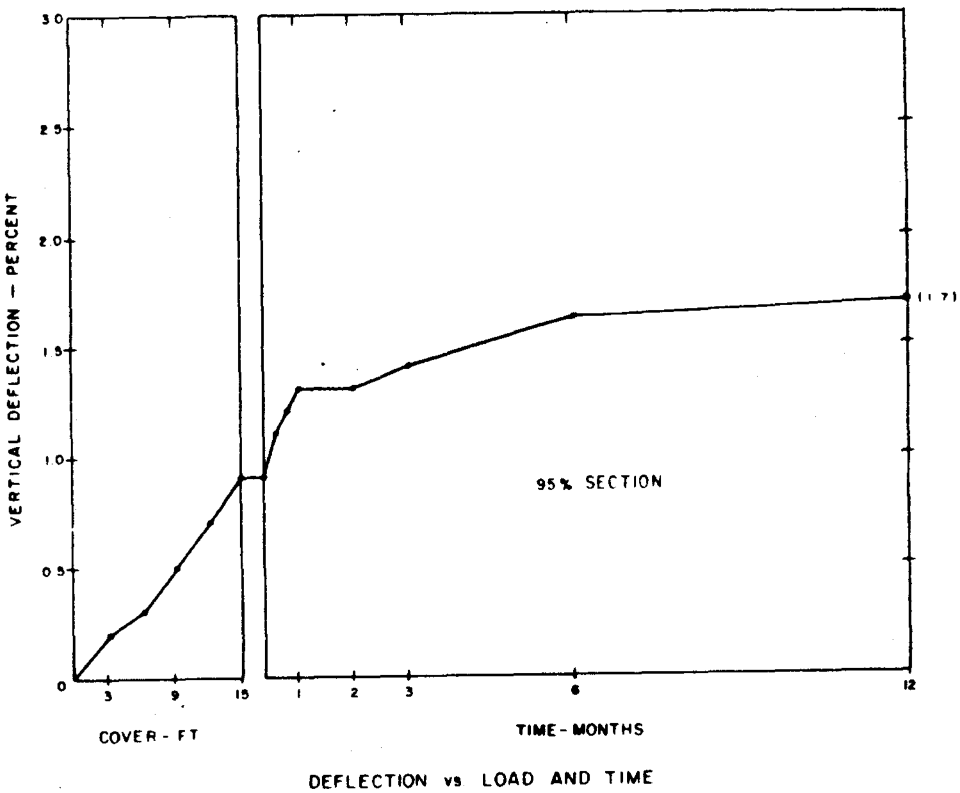

Figure 27. - Time-deflection plot for 95 percent section.

ELONGATION AND DEFLECTIONS OF PIPE JOINTS

Diameter measurements of pipe joints were made at the spigot side of the joint at the upstream end of each test pipe. These measurements were made about 2 inches from the end of the pipe.

The joint is stiffer than the barrel of the pipe and smaller elongation and deflection values were recorded at the joints.

Elongation

Horizontal diameter change was larger than vertical diameter change as summarized in the following table:

Test reach	Percent elongation with soil at top of pipe	
	Vertical	Horizontal
Dumped	-0.1	-0.1
85 percent compaction	-0.8	-0.9
95 percent compaction	-1.9	-2.0

The amount of elongation was directly related to the compactive effort applied to the bedding soil. The measurements show that just dumping soil beside the pipe can result in joint elongation. Compacting the bedding soil to over 95 percent compaction can elongate the joint about 2 percent.

Deflection

Deflection of joints due to backfilling over the pipe are shown on the following table along with the ratio of horizontal to vertical diameter:

Test reach	Percent deflection at 15 feet of cover: Vertical ΔY	Horizontal ΔX	Ratio $\Delta X/\Delta Y$
Dumped	8.0	7.2	0.90
85 percent compaction	0.7	0.7	1.00
95 percent compaction	0.5	0.5	1.00

The ratio of horizontal to vertical deflection of the joints is 0.9 or more.

Net Change in Pipe Diameter

The net change in pipe diameter at the joints from measurements made when the pipe was in place on the trench bottom and after backfilling was completed is shown on the following table:

Test reach	Percent vertical change: Elongation	Deflection	Net Change
Dumped	-0.1	8.0	7.9
85 percent compaction	-0.8	0.7	-0.1
95 percent compaction	-1.9	0.5	-1.4

As with net change in the barrel of the pipe, on the day the 15 feet of cover was completed, the pipe with compacted beddings had not returned to its original diameter.

Time Lag

The following table gives time lag factors for the vertical deflections measured:

Test reach	Percent vertical deflection				Time lag factor		
	0 day	1 mo	6 mo	1 yr	1 mo	6 mo	1 yr
Dumped	8.0	9.4	10.5	11.4	1.2	1.3	1.4
85 percent compaction	0.7	1.0	1.4	1.5	1.5	2.0	2.1
95 percent compaction	0.5	0.7	1.1	1.2	1.5	2.3	2.4

Comparison of Joint and Barrel of Pipe

Relative stiffness of the joint is illustrated in the following table comparing elongation and deflection of this joint with average values for the barrel of the pipe:

	Percent vertical change			
	Elongation		Deflection	
Test reach	Barrel	Joint	Barrel	Joint
Dumped	-0.2	-0.1	9.4	8.0
85 percent compaction	-1.6	-0.8	1.0	0.7
95 percent compaction	-3.0	-1.9	0.9	0.5

Change in the joint compared to change in the barrel of the pipe ranges from about 50 to 85 percent.

PIPE INVERT ELEVATIONS

The elevation of the pipe invert was monitored during installation using surveying equipment to measure the elevation of the top of the screw heads in the pipe invert. A summary of the elevation readings is shown in table 6. Changes in elevation as construction progressed are summarized in table 7.

Of particular interest was any raising of the pipe due to compaction of bedding below the spring line of the pipe. For lightweight pipe, compactive effort in the haunch area of the pipe can raise the pipe. To prevent any significant raising, sandbags were placed on top of the pipe in the 95-percent section.

Placement and compaction of soil in the 95-percent section up to the spring line of the pipe raised the pipe about 0.04 foot. Continuation of compacted bedding up to 0.7 o.d. raised the pipe another 0.01 foot. The 85-percent section did not have sandbags on top of the pipe, and placement and compaction of soil up to spring line and then to 0.07 o.d. did not affect invert elevation significantly.

In all three sections, loading the pipe by placement of the backfill over the pipe showed a general trend of the pipe settling only about 0.01 to 0.02 foot.

Elevation readings made 2 weeks following completion of backfilling indicated further settlement of about 0.01 foot. The 1-year readings show that the pipe has settled about 0.1 foot.

Compared to the amount of elongation and deflection that occurred, movement of the pipe invert was relatively small.

SUMMARY AND CONCLUSIONS

A special test section of 27-inch-diameter PVC pipe was constructed in November 1987 near Elba, Nebraska. Pipe deflections, pipe invert elevations, and soil physical properties and in-place unit weights were measured. Pipe deflections are to be monitored periodically to evaluate time-deflection behavior of the pipe. Measurements from the test section through the 1-year readings gave the following results:

1. Pipe deflections in the dumped and 85 percent sections are much less than predicted.

2. Pipe deflection in the 95 percent section is within the range of predicted values.

3. Pipe elongation (increase in vertical diameter) created during placement of bedding soil beside the pipe was typical based on other reported values.

4. Pipe joints deflections ranged from about 50 to 85 percent of the deflection measured in the pipe barrel.

Impact on Current Reclamation Pipe Installation Requirements

The Bureau of Reclamation currently allows two methods of installing PVC pipe. One is to use low-stiffness pipe with high-stiffness bedding soil and the other is to use high-stiffness pipe with low-stiffness bedding soil. The high-stiffness soil is required to be clean, cohesionless, free-draining soil compacted to 70 percent relative density. For most projects, this type of material must be manufactured and imported. Reclamation is considering allowing native soil excavated from the trench to be compacted beside the pipe, as in the case of this study, in place of the cohesionless select material now specified. As illustrated from the results of this study, a successful pipeline can be constructed in this manner. While potentially lowering construction costs, the disadvantages would be site-specific designs to allow use of native soil, reduced bedding stiffnesses that may limit the allowable cover over the pipe, and a more extensive investigations program to ascertain the properties of the local soils.

This study indicated that compacting the backfill over the pipe may assist in creating soil arching that reduces the load on the pipe. Future measurements will determine if the arching is permanent. Further evaluation is warranted.

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Table 1. - Pipe wall thickness measurements

0.629
0.595
0.609
0.627
0.602
0.622
0.626
0.624
0.622

Table 2. - Summary of unit weight tests - dumped backfill over pipe

				In-place			Compaction test			
Test date 1987	Station (ft)	Offset L = left R = Right (ft)	Depth of cover (ft)	Wet unit weight (lbf/ft^3)	Dry unit weight (lbf/ft^3)	Moisture content (%)	Maximum unit weight (lbf/ft^3)	Optimum moisture content (%)	Percent compaction	Moisture difference (%)
					Over 95 percent section					
11-5	1+35	2R	6	82.2	70.9	16.0	95.4	21.4	74.3	5.4 dry
11-6	1+40	0	12	78.7	69.0	14.1	103.3	21.3	66.8	7.2 dry
			Average	80.5					70.6	
					Over dumped section					
11-5	1+71	0	6	84.2	74.8	12.5	104.4	18.4	71.7	5.9 dry
11-5	1+50	5L	6	79.9	68.6	16.4	97.1	23.0	70.7	6.6 dry
11-6	1+60	4R	15	81.6	70.6	15.5	101.3	20.4	69.7	4.9 dry
			Average	81.9					70.7	
Average of all dumped backfill over pipe				81.3					70.6	

Table 3. - Summary of unit weight tests - 85 percent section

Test date 1987	Station (ft)	Offset L = left R = right (ft)	Location description	In-place: Dry unit weight (lbf/ft^3)	In-place: Moisture content (%)	Compaction test: Maximum unit weight (lbf/ft^3)	Compaction test: Optimum moisture content (%)	Percent compaction	Moisture difference (%)	Wet unit weight of cover soil (lbf/ft^3)
					Pipe zone					
11-3	0+85	2R	Spring line	85.5	20.8	95.3	22.9	89.7	2.1 dry	
11-3	0+91	2L	Spring line	82.9	20.7	97.2	23.0	85.3	2.3 dry	
11-4	0+92	2R	0.7 o.d.	89.2	23.9	98.0	20.9	91.0	3.0 wet	
11-4	0+88	2L	0.7 o.d.	86.1	22.7	98.4	22.3	87.5	0.4 wet	
							Average	88.5		
					Pipe cover					
11-4	≈0+90	0	1-foot cover	77.8	15.8	95.9	23.5	81.0	7.7 dry	90.0
11-5	0+85		2.5-foot cover	83.1	16.7	95.4	22.9	87.2	6.2 dry	97.0
11-5	0+95	0	4.5-foot cover	86.7	16.0	96.6	22.1	89.8	6.1 dry	100.6
11-6	1+00	6L	7-foot cover	83.9	16.3	96.9	21.4	86.6	5.1 dry	97.6
11-6	0+96	4L	12-foot cover	84.5	16.7	96.8	22.4	87.3	5.7 dry	98.6
							Average	86.4		96.6

Table 4. - Summary of unit weight tests - 95 percent section

Test date 1987	Station (ft)	Offset L = left R = right (ft)	Location description	In-place Dry unit weight (lbf/ft³)	In-place Moisture content (%)	Compaction test Maximum unit weight (lbf/ft³)	Compaction test Optimum moisture content (%)	Percent compaction	Moisture difference (%)
11-3	1+32	2L	Spring line	93.9	21.5	97.4	23.1	96.4	1.6 dry
11-3	1+25	2R	Spring line	92.9	21.4	96.1	23.8	96.7	2.4 dry
11-4	1+28	2L	0.7 o.d.	91.0	25.6	95.5	23.5	95.3	2.1 wet
11-4	1+32	2R	0.7 o.d.	93.1	22.6	98.7	20.1	94.3	2.5 wet
						Average		95.7	

Table 5. - Summary of pipe diameter measurements

Dumped section

Date	Condition	Sta. D-1		Sta. D-2		Sta. D-3		Sta. D-J	
		Y-in	X-in	Y-in	X-in	Y-in	X-in	Y-in	X-in
11-3-87	Initial	26.346	26.671	26.297	26.726	26.356	26.757	26.409	26.611
	Bedding								
11-4-87	Spring line	26.375	26.621	26.319	26.685	26.389	26.706	26.459	26.555
11-4-87	Top of pipe	26.398	26.600	26.364	26.642	26.429	26.673	26.445	26.574
	Backfill								
11-4-87	3-ft cover	25.923	27.022	25.874	27.116	25.938	27.155	26.021	26.984
11-5-87	3-ft cover	25.869	27.098	25.822	27.168	25.884	27.206	25.973	27.025
11-5-87	6-ft cover	25.384	27.540	25.330	27.615	25.439	27.619	25.602	27.375
11-5-87	9-ft cover	24.909	27.966	24.805	28.091	24.883	28.113	25.167	27.770
11-6-87	9-ft cover	24.806	28.051	24.695	28.186	24.783	28.207	25.061	27.861
11-6-87	12-ft cover	24.504	28.312	24.377	28.456	24.462	28.477	24.794	28.090
11-6-87	15-ft cover	23.905	28.813	23.768	28.971	23.867	28.969	24.292	28.526
	Time lag								
11-7-87	1 day	23.772	28.916	23.613	29.092	23.707	29.102	24.142	28.655
11-9-87	3 days	23.719	28.962	23.557	29.142	23.647	29.154	24.088	28.75
11-13-87	1 week	23.666	29.003	23.501	29.190	23.586	29.203	24.030	28.762
11-20-87	2 weeks	23.617	29.042	23.444	29.231	23.533	29.251	23.975	28.806
12-4-87	1 month	23.561	29.081	23.387	29.278	23.473	29.302	23.920	28.855
1-8-88	2 months	23.479	29.141	23.300	29.347	23.384	29.367	23.828	28.930
2-8-88	3 months	23.423	29.185	23.238	29.391	23.326	29.410	23.767	28.985
5-6-88	6 months	23.294	29.215	23.111	29.426	23.191	29.456	23.617	29.029
11-4-88	1 year	23.099	29.387	22.931	29.599	22.993	29.633	23.379	29.249

Table 5. - Summary of pipe diameter measurements - Continued

85 percent section

Date	Condition	Sta. 85-1		Sta. 85-2		Sta. 85-3		Sta. 85-J	
		Y-in	X-in	Y-in	X-in	Y-in	X-in	Y-in	X-in
11-3-87	Initial	26.406	26.557	26.509	26.502	26.638	26.489	26.492	26.557
				Bedding					
11-4-87	Spring line	26.683	26.247	26.757	26.220	26.876	26.213	26.573	26.452
11-4-87	0.7 o.d.	26.831	26.111	26.895	26.090	27.024	26.081	26.665	26.344
11-4-87	Top of pipe	26.842	26.104	26.928	26.067	27.049	26.058	26.720	26.324
				Backfill					
11-4-87	1-ft cover	26.810	26.120	26.902	26.082	27.021	26.071	26.706	26.327
11-5-87	1-ft cover	26.798	26.130	26.897	26.097	27.008	26.083	26.700	26.327
11-5-87	3-ft cover	26.745	26.166	26.829	26.142	26.939	26.122	26.669	26.365
11-5-87	4.5-ft cover	26.732	26.180	26.817	26.154	26.926	26.135	26.663	26.376
11-5-87	5.0-ft cover	26.721	26.186	26.810	26.159	26.916	26.141	26.656	26.379
11-6-87	5.0-ft cover	26.706	26.200	26.793	26.176	26.900	26.158	26.647	26.388
11-6-87	7-ft cover	26.676	26.220	26.767	26.193	26.868	26.178	26.626	26.408
11-6-87	9-ft cover	26.653	26.242	26.742	26.218	26.840	26.201	26.605	26.432
11-6-87	12-ft cover	26.622	26.265	26.712	26.240	26.805	26.222	26.583	26.452
11-6-87	15-ft cover	26.583	26.302	26.673	26.279	26.748	26.263	26.538	26.500
				Time lag					
11-7-87	1 day	26.537	26.343	26.628	26.322	26.702	26.309	26.504	26.545
11-9-87	3 days	26.514	26.368	26.606	26.351	26.677	26.337	26.485	26.569
11-13-87	1 week	26.496	26.386	26.586	26.370	26.654	26.357	26.465	26.582
11-20-87	2 weeks	26.480	26.405	26.570	26.385	26.636	26.376	26.455	26.605
12-4-87	1 month	26.463	26.420	26.555	26.402	26.619	26.385	26.438	26.620
1-8-88	2 months	26.438	26.446	26.532	26.424	26.601	26.410	26.424	26.632
2-8-88	3 months	26.421	26.461	26.515	26.441	26.579	26.422	26.410	26.654
5-6-88	6 months	26.360	26.444	26.456	26.426	26.523	26.392	26.340	26.623
11-4-88	1 year	26.318	26.484	26.420	26.469	26.490	26.428	26.310	26.631

Table 5. - Summary of pipe diameter measurements - Continued

95 percent section

Date	Condition	Sta. 95-1		Sta. 95-2		Sta. 95-3		Sta. 95-J	
		Y-in	X-in	Y-in	X-in	Y-in	X-in	Y-in	X-in
11-3-87	Initial	26.613	26.485	26.619	26.515	26.611	26.469	26.490	26.558
	Bedding								
11-3-87	Sand bags on top	26.558	26.560	26.593	26.563	26.554	26.556	26.464	26.616
11-4-87	0.5 o.d.	27.194	25.828	27.185	25.873	27.135	25.872	26.821	26.198
11-4-87	0.7 o.d.	27.449	25.621	27.444	25.663	27.405	25.659	26.993	26.024
11-4-87	Top of pipe	27.446	25.617	27.440	25.660	27.397	25.660	27.012	26.015
	Backfill								
11-4-87	3-ft cover	27.402	25.626	27.392	25.679	27.355	25.673	27.007	26.015
11-5-87	3-ft cover	27.382	25.639	27.372	25.693	27.335	25.686	27.001	26.021
11-5-87	6-ft cover	27.358	25.651	27.344	25.711	27.305	25.702	26.980	26.035
11-5-87	9-ft cover	27.325	25.672	27.306	25.735	27.264	25.727	26.960	26.059
11-6-87	9-ft cover	27.298	25.692	27.280	25.754	27.241	25.750	26.945	26.079
11-6-87	12-ft cover	27.280	25.703	27.252	25.770	27.207	25.767	26.926	26.096
11-6-87	15-ft cover	27.221	25.730	27.183	25.806	27.139	25.818	26.882	26.145
	Time Lag								
11-7-87	1 day	27.191	25.765	27.154	25.841	27.106	25.845	26.859	26.170
11-9-87	3 days	27.173	25.785	27.133	25.861	27.084	25.864	26.848	26.195
11-13-87	1 week	27.160	25.801	27.118	25.876	27.071	25.877	26.837	26.209
11-20-87	2 weeks	27.149	25.811	27.104	25.884	27.055	25.890	26.824	26.220
12-4-87	1 month	27.139	25.826	27.089	25.903	27.041	25.903	26.816	26.236
1-8-88	2 months	27.120	25.842	27.067	25.921	27.022	25.924	26.801	26.260
2-8-88	3 months	27.102	25.857	27.051	25.933	27.005	25.938	26.786	26.270
5-6-88	6 months	27.042	25.838	26.984	25.916	26.943	25.924	26.714	26.234
11-4-88	1 year	27.034	25.856	26.968	25.931	26.934	25.930	26.698	26.234

Y = Vertical diameter reading.
X = Horizontal diameter reading

Table 6. - Summary of pipe elongation and deflection

Dumped section

Date	Condition	Sta. D-1			Sta. D-2			Sta. D-3			Average			Joint		
		ΔY-%	ΔX-%	$\frac{\Delta Y}{T_f}$	ΔY-%	ΔX-%	$\frac{\Delta Y}{T_f}$	ΔY-%	ΔX-%	$\frac{\Delta Y}{T_f}$	ΔY-%	ΔX-%	$\frac{\Delta Y}{T_f}$	ΔY-%	ΔX-%	$\frac{\Delta Y}{T_f}$
11-4-87	Spring line	-0.1	-0.2		-0.1	-0.2		-0.1	-0.2		-0.1	-0.2		-0.2	-0.2	
11-4-87	Top of pipe	-0.2	-0.3		-0.3	-0.3		-0.3	-0.3		-0.2	-0.3		-0.1	-0.1	
	Backfill															
11-4-87	3-ft cover	1.8	1.6		1.8	1.8		1.9	1.9		1.8	1.7		1.6	1.5	
11-5-87	3-ft cover	2.0	1.8		2.0	2.0		2.0	2.0		2.0	1.9		1.8	1.7	
11-5-87	6-ft cover	3.8	3.5		3.8	3.6		3.7	3.5		3.8	3.5		3.1	3.0	
11-5-87	9-ft cover	5.5	5.1		5.8	5.4		5.7	5.3		5.7	5.3		4.7	4.4	
11-6-87	9-ft cover	5.9	5.4		6.2	5.7		6.1	5.7		6.1	5.6		5.1	4.8	
11-6-87	12-ft cover	7.0	6.3		7.4	6.7		7.3	6.7		7.2	6.6		6.1	5.6	
11-6-87	15-ft cover	9.2	8.2		9.6	8.6		9.5	8.4		9.5	8.5		8.0	7.2	
	Time lag															
11-7-87	1 day	9.7	8.6	1.1	10.2	9.1	1.1	10.1	9.0	1.1	10.0	8.9	1.1	8.5	7.7	1.1
11-9-87	3 days	9.9	8.8	1.1	10.4	9.3	1.1	10.3	9.2	1.1	10.2	9.1	1.1	8.7	7.9	1.1
11-13-87	1 week	10.1	8.9	1.1	10.6	9.4	1.1	10.5	9.4	1.1	10.4	9.2	1.1	8.9	8.1	1.1
11-20-87	2 weeks	10.3	9.0	1.1	10.8	9.6	1.1	10.7	9.6	1.1	10.6	9.4	1.1	9.2	8.3	1.1
12-4-87	1 month	10.5	9.2	1.1	11.0	9.8	1.1	11.0	9.7	1.2	10.8	9.6	1.1	9.4	8.5	1.2
1-8-88	2 months	10.8	9.4	1.2	11.4	10.0	1.2	11.3	10.0	1.2	11.2	9.8	1.2	9.7	8.7	1.2
2-8-88	3 months	11.0	9.6	1.2	11.6	10.2	1.2	11.5	10.1	1.2	11.4	10.0	1.2	9.9	8.9	1.2
5-6-88	6 months	11.5	9.7	1.2	12.0	10.3	1.3	12.0	10.3	1.3	11.9	10.1	1.3	10.5	9.1	1.3
11-4-88	1 year	12.2	10.3	1.3	12.7	11.0	1.3	12.7	11.0	1.3	12.6	10.8	1.3	11.4	9.9	1.4

Table 6. - Summary of pipe elongation and deflection - Continued

95 percent section

Date	Condition	Sta. 95-1			Sta. 95-2			Sta. 95-3			Average			Joint		
		ΔY-%	ΔX-%	ΔY T_f	ΔY-%	ΔX-%	ΔY T_f	ΔY-%	ΔX-%	ΔY T_f	ΔY-%	ΔX-%	ΔY T_f	ΔY-%	ΔX-%	ΔY T_f
11-3-87	Sandbags on top	0.2	0.3		0.1	0.2		0.2	0.3		0.2	0.3		0.1	0.2	
11-4-87	0.5 o.d.	-2.2	-2.4		-2.1	-2.4		-2.1	-2.5		-2.1	-2.5		-1.3	-1.6	
11-4-87	0.7 o.d.	-3.1	-3.2		-3.1	-3.2		-2.9	-3.0		-3.0	-3.1		-1.9	-2.0	
11-4-87	Top of pipe	-3.1	-3.2		-3.0	-3.2		-2.9	-3.0		-3.0	-3.1		-1.9	-2.0	
	Backfill															
11-4-87	3-ft cover	0.2	0.0		0.2	0.1		0.2	0.1		0.2	0.1		0.0	0.0	
11-5-87	3-ft cover	0.2	0.1		0.3	0.1		0.2	0.1		0.2	0.1		0.0	0.0	
11-5-87	6-ft cover	0.3	0.1		0.4	0.2		0.3	0.2		0.3	0.2		0.1	0.1	
11-5-87	9-ft cover	0.4	0.2		0.5	0.3		0.5	0.3		0.5	0.2		0.2	0.2	
11-6-87	9-ft cover	0.6	0.3		0.6	0.4		0.6	0.3		0.6	0.3		0.2	0.2	
11-6-87	12-ft cover	0.6	0.3		0.7	0.4		0.7	0.4		0.7	0.4		0.3	0.3	
11-6-87	15-ft cover	0.8	0.4		1.0	0.5		1.0	0.6		0.9	0.5		0.5	0.5	
	Time lag															
11-7-87	1 day	0.9	0.5	1.1	1.1	0.7	1.1	1.1	0.7	1.1	1.0	0.6	1.1	0.6	0.6	1.2
11-9-87	3 days	1.0	0.6	1.2	1.1	0.7	1.2	1.2	0.8	1.2	1.1	0.7	1.2	0.6	0.7	1.3
11-13-87	1 week	1.1	0.7	1.3	1.2	0.8	1.3	1.2	0.8	1.3	1.2	0.8	1.3	0.6	0.7	1.3
11-20-87	2 weeks	1.1	0.7	1.3	1.2	0.8	1.3	1.3	0.9	1.3	1.2	0.8	1.3	0.7	0.8	1.4
12-4-87	1 month	1.1	0.8	1.4	1.3	0.9	1.4	1.3	0.9	1.4	1.3	0.9	1.4	0.7	0.8	1.5
1-8-88	2 months	1.2	0.8	1.5	1.4	1.0	1.5	1.4	1.0	1.5	1.3	0.9	1.5	0.8	0.9	1.6
2-8-88	3 months	1.3	0.9	1.5	1.4	1.0	1.5	1.5	1.0	1.5	1.4	1.0	1.5	0.8	0.9	1.7
5-6-88	6 months	1.5	0.8	1.8	1.7	0.9	1.8	1.7	1.0	1.8	1.6	0.9	1.8	1.1	0.8	2.3
11-4-88	1 year	1.5	0.9	1.8	1.7	1.0	1.8	1.7	1.0	1.8	1.7	1.0	1.8	1.2	0.8	2.4

Table 6. - Summary of pipe elongation and deflection - Continued

85 percent section

Date	Condition	Sta. 85-1			Sta. 85-2			Sta. 85-3			Average			Joint		
		ΔY-%	ΔX-%	ΔY T_f	ΔY-%	ΔX-%	ΔY T_f	ΔY-%	ΔX-%	ΔY T_f	ΔY-%	ΔX-%	ΔY T_f	ΔY-%	ΔX-%	ΔY T_f
11-4-87	Spring line	-1.0	-1.2		-0.9	-1.1		-0.9	-1.0		-0.9	-1.1		-0.3	-0.4	
11-4-87	0.7 o.d.	-1.6	-1.7		-1.4	-1.5		-1.4	-1.5		-1.5	-1.6		-0.6	-0.8	
11-4-87	Top of pipe	-1.6	-1.7		-1.6	-1.6		-1.5	-1.6		-1.6	-1.6		-0.8	-0.9	
	Backfill															
11-4-87	1-ft cover	0.1	0.1		0.1	0.1		0.1	0.1		0.1	0.1		0.1	0.0	
11-5-87	1-ft cover	0.2	0.1		0.1	0.1		0.2	0.1		0.1	0.1		0.1	0.0	
11-5-87	3-ft cover	0.4	0.2		0.4	0.3		0.4	0.2		0.4	0.3		0.2	0.2	
11-5-87	4.5-ft cover	0.4	0.3		0.4	0.3		0.5	0.3		0.4	0.3		0.2	0.2	
11-5-87	5.0-ft cover	0.5	0.3		0.4	0.3		0.5	0.3		0.5	0.3		0.2	0.2	
11-6-87	5.0-ft cover	0.5	0.4		0.5	0.4		0.6	0.4		0.5	0.4		0.3	0.2	
11-6-87	7-ft cover	0.6	0.4		0.6	0.5		0.7	0.4		0.6	0.5		0.4	0.3	
11-6-87	9-ft cover	0.7	0.5		0.7	0.6		0.8	0.5		0.7	0.5		0.4	0.4	
11-6-87	12-ft cover	0.8	0.6		0.8	0.6		0.9	0.6		0.8	0.6		0.5	0.5	
11-6-87	15-ft cover	1.0	0.7		0.9	0.8		1.2	0.8		1.0	0.8		0.7	0.7	
	Time lag															
11-7-87	1 day	1.1	0.9	1.2	1.1	0.9	1.2	1.3	0.9	1.2	1.2	0.9	1.2	0.8	0.8	1.2
11-9-87	3 days	1.2	1.0	1.3	1.2	1.1	1.3	1.4	1.0	1.2	1.3	1.0	1.2	0.9	0.9	1.3
11-13-87	1 week	1.3	1.0	1.3	1.3	1.1	1.3	1.5	1.1	1.3	1.3	1.1	1.3	0.9	1.0	1.4
11-20-87	2 weeks	1.3	1.1	1.4	1.3	1.2	1.4	1.5	1.2	1.4	1.4	1.2	1.4	1.0	1.0	1.5
12-4-87	1 month	1.4	1.2	1.5	1.4	1.2	1.5	1.6	1.2	1.4	1.5	1.2	1.4	1.0	1.1	1.5
1-8-88	2 months	1.5	1.3	1.6	1.5	1.3	1.6	1.7	1.3	1.5	1.5	1.3	1.5	1.1	1.1	1.6
2-8-88	3 months	1.6	1.3	1.6	1.5	1.4	1.6	1.7	1.4	1.6	1.6	1.4	1.6	1.2	1.2	1.7
5-6-88	6 months	1.8	1.3	1.9	1.7	1.3	1.9	1.9	1.2	1.7	1.8	1.3	1.8	1.4	1.1	2.0
11-4-88	1 year	1.9	1.4	1.9	1.9	1.5	2.1	2.1	1.4	1.8	2.0	1.4	2.0	1.5	1.1	2.1

ΔY = Percent vertical deflection.
ΔX = Percent horizontal deflection.
T_f = Time lag factor.

Table 7. - Summary of pipe invert elevation readings

Station	Date of elevation reading (1987)*						
	11-3 initial	11-4(A)	11-4(B)	11-5	11-6	11-20	11-7-88
DJ	8.28	8.23	8.33	8.26	8.26	8.26	8.16
D-3	8.24	8.23	8.31	8.26	8.26	8.25	8.14
D-2	8.24	8.23	8.27	8.22	8.21	8.23	8.12
D-1	8.24	8.23	8.25	8.22	8.21	8.21	8.10
95J	8.23	8.27	8.25	8.24	8.24	8.24	8.14
95-3	8.22	8.24	8.25	8.24	8.24	8.23	8.13
95-2	8.20	8.24	8.25	8.24	8.24	8.22	8.12
95-1	8.20	8.24	8.25	8.24	8.24	8.22	8.12
85J	8.26	8.28	8.25	8.26	8.24	8.25	8.14
85-3	8.24	8.24	8.25	8.26	8.24	8.23	8.13
85-2	8.24	8.24	8.25	8.25	8.24	8.23	8.13
85-1	8.23	8.24	8.25	8.25	8.24	8.24	8.13

* All readings are elevation 1838.

Key to readings

11-3 Pipe trench bottom, no bedding or backfill.

11-4(A) Bedding soil to spring line for all pipe.

11-4(B) Bedding soil to 0.7 o.d. for 85 and 95 percent sections, soil to top of pipe on *dumped* section.

11-5 5.5-foot backfill over pipe in 85 and 95 percent sections, 3-foot backfill over pipe in *dumped* section.

11-6 15-foot backfill over all pipe (day backfilling completed).

11-20 2 weeks after backfilling completed.

11-7-88 1-year readings.

Table 8. - Summary of pipe invert elevation changes

Station	Date of elevation reading (1987) 11-4(A) spring line	11-4(B) 0.7 o.d. or top of pipe	11-5 3 to 5.5 ft backfill	11-6 15 ft of backfill	11-20 2-week reading
DJ - Change from initial	Down 0.05	Up 0.05	Down 0.02	Down 0.02	Down 0.02
- Change from previous reading	-	Up 0.10	Down 0.07	0	0
D-3 - Change from initial	Down 0.01	Up 0.07	Up 0.02	Up 0.02	Up 0.01
- Change from previous reading	-	Up 0.07	Down 0.05	0	Down 0.01
D-2 - Change from initial	Down 0.01	Up 0.03	Down 0.02	Down 0.03	Down 0.01
- Change from previous reading	-	Up 0.04	Down 0.05	Down 0.01	Up 0.02
D-1 - Change from initial	Down 0.01	Up 0.01	Down 0.02	Down 0.03	Down 0.03
- Change from previous reading	-	Up 0.02	Down 0.03	Down 0.01	0
95J - Change from initial	Up 0.04	Up 0.02	Up 0.01	Up 0.01	Up 0.01
- Change from previous reading	-	Down 0.02	Down 0.01	0	0
95-3 - Change from initial	Up 0.02	Up 0.03	Up 0.02	Up 0.02	Up 0.01
- Change from previous reading	-	Up 0.01	Down 0.01	0	Down 0.01
95-2 - Change from initial	Up 0.04	Up 0.05	Up 0.04	Up 0.04	Up 0.02
- Change from previous reading	-	Up 0.01	Down 0.01	0	Down 0.02
95-1 - Change from initial	Up 0.04	Up 0.05	Up 0.04	Up 0.04	Up 0.02
- Change from previous reading	-	Up 0.01	Down 0.01	0	Down 0.02
85J - Change from initial	Up 0.02	Down 0.01	0	Down 0.02	Down 0.01
- Change from previous reading	-	Down 0.03	Up 0.01	Down 0.02	Up 0.01
85-3 - Change from initial	0	Up 0.01	Up 0.02	0	Down 0.01
- Change from previous reading	-	Up 0.01	Up 0.01	Down 0.02	Down 0.01

Table 8. - Summary of pipe invert elevation changes - Continued

Station	Date of elevation reading (1987)				
	11-4(A) spring line	11-4(B) 0.7 o.d. or top of pipe	11-5 3 to 5.5 ft backfill	11-6 15 ft of backfill	11-20 2-week reading
85-2 - Change from initial	0	Up 0.01	0	Down 0.01	Down 0.01
- Change from previous reading	-	Up 0.01	0	Down 0.01	Down 0.01
85-1 - Change from initial	Up 0.01	Up 0.02	Up 0.02	Up 0.01	Up 0.01
- Change from previous reading	-	Up 0.01	0	Down 0.01	0

APPENDIX A

Soil Physical Properties

Preliminary Investigations

During investigations for a site for the test section, several drill holes were made in the area of the final location. The location of DH-1 DF, closest to the final site, is shown on figure 4. The geological log of the drill hole is shown on figure A-1. Results of laboratory tests on the recovered soil are given in table A-2.

Trench Bottom, Bedding, and Backfill Soils

Tests to determine the relative density of the sand in the trench walls beside the pipe were performed on material in the trench bottom. A summary of laboratory and field densities is shown in table A-1. Physical properties testing was performed on some of these soils and results are summarized in table A-2. A summary plot of gradation test results is shown on figure A-2.

Physical properties testing was also performed on the soil used for pipe bedding and backfill by testing the material excavated during some of the in-place density tests. Test results are shown in table A-2.

A laboratory compaction test was performed on a sample of soil used for bedding and backfill, and test results are shown on figure A-3. The material was obtained from several locations in the spoil pile on the east side of the trench.

All tests were performed in accordance with the *Earth Manual*, 2nd Edition, Bureau of Reclamation, 1974.

Table A-1. - Summary of relative density tests

Test identification				Minimum index unit weight (lbf/ft³)	Maximum index unit weight (lbf/ft³)	In-place dry unit weight (lbf/ft³)	In-place moisture content (%)	Percent relative density (%)
Date 1987	Station (ft)	Offset (ft)	Elevation					
10-30	0+90	C.L.	Trench bottom	92.9	114.7	105.1	4.6	61
10-30	1+30	C.L.	Trench bottom	93.6	109.3	102.7	5.2	62
10-30	1+70	C.L.	Trench bottom	90.8	115.5	108.9	3.2	78
11-3	1+15	5 left	0.5 ft below pipe invert	94.4	110.0	108.1	2.1	88
11-3	1+35	5 right	1 ft below pipe invert	94.1	112.4	109.0	1.6	84
						Average	3.3	75

Table A-2. - Summary of physical properties test results

Test identification				Soil classification	Gradation		Atterberg limits	
Date 1987	Station (ft)	Offset (ft)	Elevation	symbol	% fines	% sand	LL	PI
				Trench bottom				
10-30	0+90	C.L.	Trench bottom	SP-SM	6	94		N.P.*
10-30	1+30	C.L.	Trench bottom	SP	2	98		
10-30	1+70	C.L.	Trench bottom	SP-SM	6	94		N.P.*
				Bedding and backfill				
11-4	1+28	2 ft left	0.7 o.d.	CL	96	4	44	21
11-5	1+50	5 ft left	6-ft cover	CL	97	3	36	16
11-3	1+25	2 ft right	Spring line	CL	96	4	39	15
11-6	0+96	4 ft left	12-ft cover	CL	98	2	38	20
11-6	1+60	4 ft right	15-ft cover	CL	91	9	32	16
				Drill hole during investigation				
4-23	DH-IDF		4-ft depth	CL	97	3	44	20
			9-ft depth	CH-CL	96	4	53	27
			14-ft depth	CL	98	2	38	16
			19-ft depth	CL-ML (visual)	51	49		

* Assumed

7-1887 (8-74)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 1

FEATURE Fullerton-Elba Pipe Laterals PROJECT North Loup Division STATE NE

HOLE NO. DH-1DF LOCATION COORDS. N. 594,473.1 E. 2,254,129.2 GROUND ELEV. 1857.3 DIP (ANGLE FROM HORIZ.) 90°

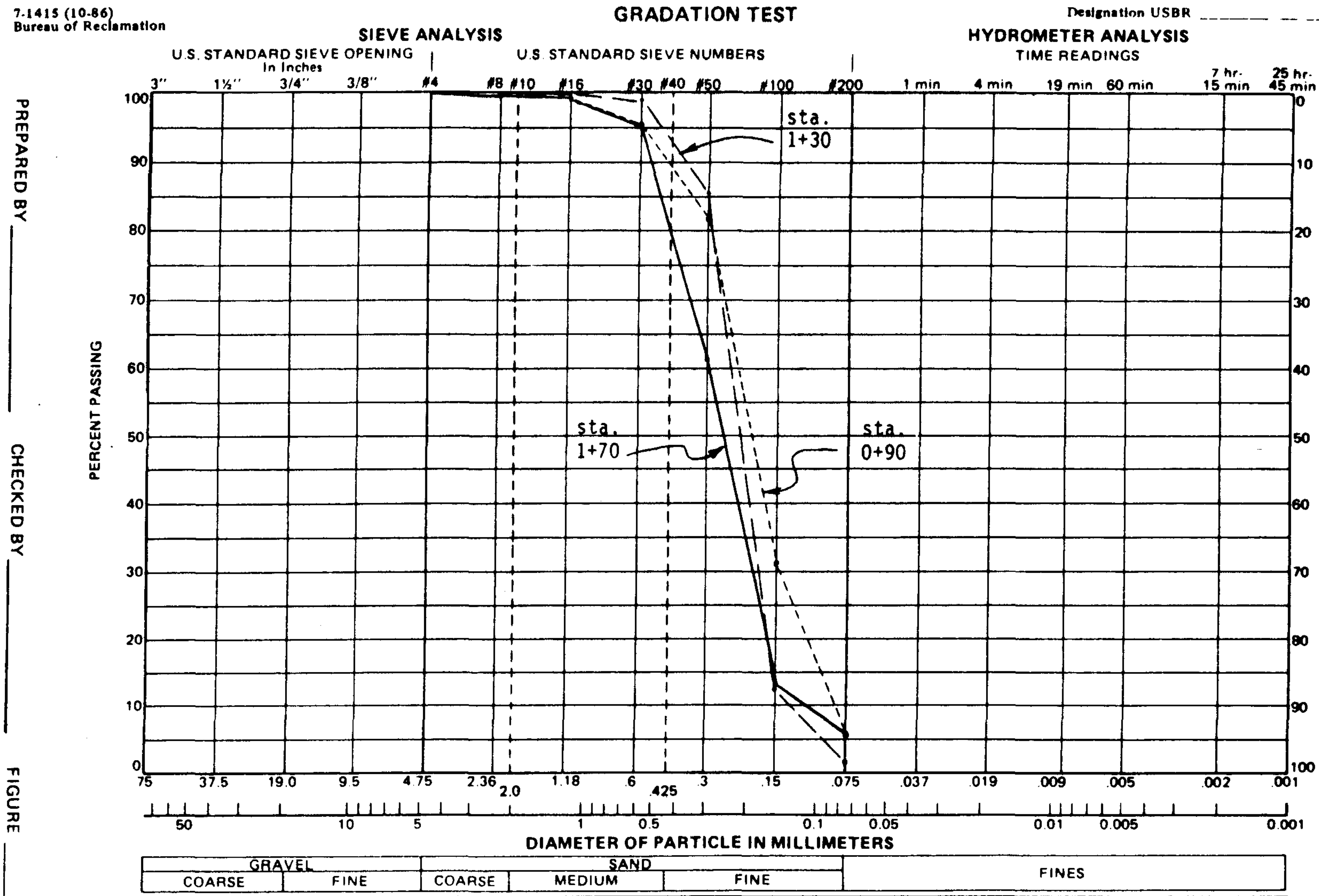
BEGUN 4-23-87 FINISHED 4-23-87 DEPTH OF OVERBURDEN Unknown TOTAL DEPTH 24.5' BEARING - - -

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED 4-23-87 Hole caved, wet at 22.8' LOGGED BY Cast LOG REVIEWED BY

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Ce, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Purpose: Locate site for deflection test of PVC pipe Drill Rig: CME-45 Driller: Prince Drill Method: 6½" O.D. hollow stem augers with 2" I.D. inner barrel Completion: Backfilled Note: DH-1ADF located 75' east, drilled to confirm site conditions. 0-15' lean clay. No log prepared.	2" CORE (0-24.5) 2"	100 100 100 100 60						1840.0 1837.8 1832.8	17.3 19.5 24.5			0-17.3 LEAN CLAY, approx. 95% fines with medium to high plasticity and 5% fine sand; maximum size fine sand; moist; black grading to gray-brown at 7 feet, lime streaks at 9', and grades to brown at 13.8'; bottom 1' grades siltier. (CL) 17.3-19.5 ALTERNATING BEDS OF POORLY GRADED and SILTY SAND, bed thickness ranges from 0.2-0.4'; approx. 80-100% fine sand with 0-20% nonplastic fines; maximum size fine sand; moist; tan. (SP and SM) 19.5-24.5 POORLY GRADED SAND, approx. 100% fine sand, trace of medium; maximum size medium sand; moist, becomes wet at 22.3; light gray-white. (SP)

FEATURE Fullerton-Elba Pipe Laterals PROJECT North Loup STATE NE SHEET 1 OF 1 HOLE NO. DH-1DF

Figure A-1. - Geologic log of drill hole.



SAMPLE NO.	HOLE NO.	ELEV. OR DEPTH ☐ft ☐m	UNIFIED SOIL CLASSIFICATION				ATTERBERG LIMITS			SPECIFIC GRAVITY		NOTES
			GROUP SYMBOL	% GRAVEL	% SAND	% FINES	LL (%)	PI (%)	SL (%)	MINUS NO. 4	OTHER	
Gradation analysis of sand in trench bottom												
FULLERTON PVC PIPE TEST SECTION												

GPO 852-232

PREPARED BY ______ CHECKED BY ______ FIGURE ______

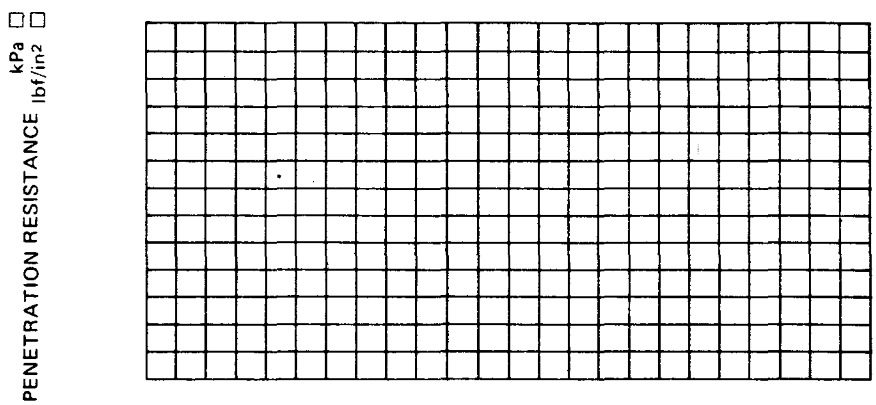
Figure A-2. - Summary plot of gradation results.

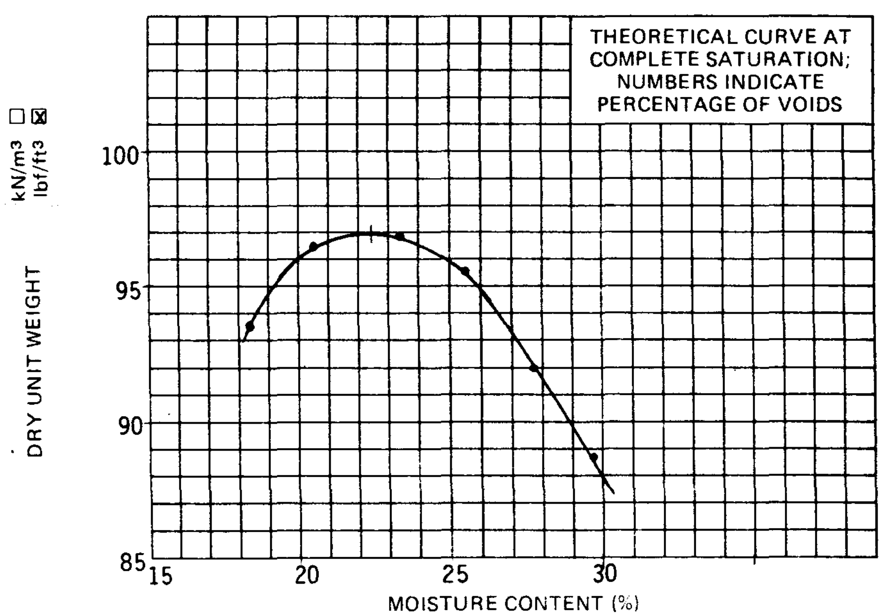
7-1414 (9-85) Bureau of Reclamation	COMPACTION - PENETRATION RESISTANCE CURVES	Designation USBR ______ __ __

SAMPLE NO.	FEATURE FULLERTON PVC PIPE TEST SECTION	PROJECT

Hole No. ______ Plotted by ______ Date ______

Depth ______ ft ☐ m ☐ Checked by ______ Date ______





CLASSIFICATION ______

Gravel ______ %

Sand ______ %

Fines ______ %

SPECIFIC GRAVITY

Minus No. 4 ______

Plus No. 4 ______

Bulk ______

Apparent ______

Absorption ______ %

COMPACTION

Method USBR E-11

Percent larger than tested 0

Maximum dry unit weight 97.0 ☐ kN/m3 ☒ lbf/ft3

Optimum moisture content 22.5 %

Degree of saturation @ opt ______ %

Penetration resistance @ opt ______ ☐ kPa ☐ lbf/in2

ATTERBERG LIMITS

Liquid Limit ______ %

Plasticity Index ______ %

Shrinkage Limit ______ %

Remarks ______

Tested 11-3-87

GPO 848-759

Figure A-3. - Test results of laboratory compaction test on soil sample used for bedding and backfill.

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-7923A, PO Box 25007, Denver Federal Center, Denver CO 80225-0007.