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LABORATORY LOAD TESTS ON BURIED FLEXIBLE PIPE PROGRESS REPORT NO. 5

Fiberglass Reinforced Plastic (FRP), Polyethylene (PE) and Polyvinyl Chloride (PVC) Pipe

Engineering and Research Center
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16. ABSTRACT

Laboratory tests were conducted to investigate the behavior of buried flexible pipes. Kinds of pipe tested were figerglass reinforced plastic (FRP), polyvinyl chloride (PVC), and polyethylene (PE). The pipes were buried in a large, steel, soil container in a lean clay backfill. A large universal testing machine was used to apply surcharge loads to the soil surface over the pipe. Measurements of the changing dimensions of the pipe, strain on the inner surface of the pipe, soil movement around the pipe, and soil pressures were made during a 1-day loading sequence. Test results are presented and deflections under load are compared to tests of steel pipe and of reinforced plastic mortar (RPM) pipe. The FRP pipe deflected similar to the RPM pipe, while PVC pipe and PE pipe showed a similarity to steel pipe. Three-edge bearing tests used to determine pipe strength did not provide a reliable basis for predicting the deflection of different kinds of pipe. Deflection values varied as much as 300 percent for different kinds of pipe even though their three-edge bearing load-deflection curves were identical. The study showed that FRP pipe deflects differently than steel, PVC, or PE pipe, and that care must be taken to assure proper bedding of the FRP pipe. (8 ref)

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by
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July 1973

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INTRODUCTION

The U.S. Bureau of Reclamation (USBR) has been load testing various types of pipe buried in lean clay in a large laboratory soil container to evaluate present design methods for flexible pipe and to evaluate some of the new types of pipe now available on the market. Surcharge loads were applied to the soil surface over the pipe with a large universal testing machine. Measurements of soil pressures, pipe deflection, soil movement, and strain on the inner surface of each pipe were made during a 1-day test. Although the soil movement, soil pressures, and strain readings have provided useful information, the most important findings in the study concern the load-deflection characteristics of the pipe.

Previous reports in this series have presented the results of steel pipe[1,2,3*] and of reinforced plastic mortar (RPM) pipe.[4] The steel pipe results have also been summarized in a paper.[5] The results of similar tests on fiberglass reinforced plastic pipe and on thermoplastic pipe (polyethylene and polyvinyl chloride) are presented in this report and their deflections under load compared to steel and to RPM pipe.

TYPES OF PIPE TESTED

The initial work in this program was done on three sizes of steel pipe of three different gages. Sections of 18-, 24-, and 30-inch (46-, 61-, and 76-cm) diameter pipe in 7-, 10-, and 14-gage thicknesses comprised this group of samples. The steel pipes were bare, unlined, and had plain ends.

Reinforced plastic mortar (RPM) pipe is a composite built from a thermosetting polyester resin, silicate sand, and glass filament reinforcing. The resin used is a basic isophthalic polyester resin, and the sand is a clean, well-graded, high-silica-content sand. One size of sand is used in the liner to achieve erosion resistance while a larger size is used in the pipe wall as a filler to replace the more costly resin with the lower-cost sand. The reinforcing filament is a particular type of borosilicate glass with a special surface treatment to enhance the adhesion of resin to glass. The pipe is built up in layers on a mandrel on a machine which is essentially a filament-winding process modified to incorporate the sand into the process. RPM pipe is commercially available in sizes from 8 inches (20 cm) to 54 inches (137 cm) in diameter. One 24-inch (61-cm) diameter RPM was tested, and the rest were 18 inches (46 cm) in diameter. Some of these pipes were standard products, and some were especially fabricated to provide specimens with a wide range of stiffnesses.

Fiberglass reinforced plastic (FRP) pipe is similar to the RPM pipe except that sand is not used in the process. Filament-wound pipe, such as RPM and FRP, is made by first placing a chemical-resistant liner (resin rich with either chopped glass fibers for FRP or sand for RPM) over a polished steel mandrel. Next, multiple, continuous strands of glass fibers saturated with vinyl ester or polyester resin are wound over the liner. The filament-winding process allows each manufacturer to change the angle of wrap of the filament reinforcing for specific design purposes. The length of the pipe is limited only by the length of the mandrel or shipping requirements. FRP pipe has been made in lengths up to 60 feet (18 meters). The wall thickness can also be easily varied in the filament-winding process to meet specific internal pressure requirements. FRP pipe is available commercially from 2 inches (5 cm) to 14 feet (4.3 meters) in diameter. The test pipes were 18-inch (46-cm) diameter specimens especially fabricated to provide test samples with specific stiffnesses.

Polyethylene (PE) pipe is made by extruding a homogeneous, thermoplastic, high-density polyethylene resin. It is available in sizes from 1/2 inch (1.27 cm) to 48 inches (122 cm) in diameter and in any length desired. It is also available in many different wall thicknesses. High-density polyethylene is inert to most chemicals and allows considerable flexibility along the length of the pipe which can eliminate the need for many elbows. The test pipe was a standard production pipe with an inside diameter of 18 inches (46 cm) and a wall thickness of 1 inch (2.5 cm).

Polyvinyl chloride (PVC) pipe is also made from a thermoplastic resin. Thermoplastics can be softened with heat with the original strength returning when the resin is cooled. Thermosetting plastics are different because once they are cured they are in their permanent form and cannot be reshaped or softened with heat. PVC pipe is made by continuously extruding unplasticized polyvinyl chloride. It is highly resistant to many chemicals and is more rigid than polyethylene pipe. PVC pipe is available in diameters only up to 15 inches (38 cm). The test pipe was a 15-inch (38-cm), outside diameter, low-head irrigation pipe.

The plastic-base pipe specimens were furnished without cost to the Bureau by a number of manufacturers. Their cooperation is acknowledged and appreciated.

*Numbers designate references at end of text.

DEFLECTION OF BURIED FLEXIBLE PIPE

In the design of structural members, the strain or deformation of an element of the material being used 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 modulus is either known for the material or it can be determined from laboratory tests.

The deflection of a buried circular conduit is found 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 becomes more complicated because a soil-structure interaction takes place. The soil load on a flexible pipe causes a decrease in the vertical diameter (ΔY) and an increase in the horizontal diameter (ΔX). The horizontal movement of the pipe into the soil develops a passive resistance that acts to help support the pipe. The modulus of the pipe acting as a ring and the modulus of the soil must be combined to provide a modulus value. The pipe-ring modulus is determined from a parallel plate test or a three-edge bearing test. The Ring Stiffness Factor, EI/r^3 (or pipe-ring modulus), is the ratio of the load on the ring to its deflection and applies to flexible pipe regardless of the pipe material. It can be found from either:

$$EI/r^3 = 0.149\ P/\Delta Y \text{ or}$$
$$EI/r^3 = 0.136\ P/\Delta X$$

where P is the line load per linear inch, ΔY is the vertical deflection in inches, and ΔX is the horizontal deflection in inches. EI/r^3 includes the modulus of elasticity (E) of the pipe wall material, the moment of inertia (I) of a section of the pipe wall, and the pipe radius (r).

Since the pipe is buried in soil, the time-compression rate of the soil must be considered since the pipe will continue to deflect as the supporting soil at the sides of the pipe compresses with time. The relationship then becomes:

$$\text{deflection} = (\text{time-lag}) \frac{\text{load}}{\text{material modulus}}$$

The most widely used equation for predicting pipe deflection is the Iowa Formula developed by Professor M. G. Spangler of Iowa State University.[6,7] The equation is given as:

$$\Delta X = D_l \frac{K W r^3}{EI + 0.061\, e' r^3}$$

where:

- ΔX = horizontal deflection of the pipe, inches
- D_l = deflection lag factor to compensate for the time-compression rate of the soil, dimensionless
- K = bedding constant which varies with the angle of the bedding, dimensionless
- W = load on the pipe per unit length, pounds per linear inch
- r = pipe radius, inches
- EI = pipe wall stiffness per unit length, in inch-pounds
- e' = modulus of soil reaction, pounds per square inch

The equation can be rearranged to give:

$$\Delta X/D = D_l \frac{KW/D}{EI/r^3 + 0.061\, e'}$$

where D = pipe diameter, inches

so that

$$\text{Pipe deflection} = (\text{time-lag}) \frac{\text{Load on the pipe}}{\text{Pipe modulus} + \text{Soil modulus}}$$

The load on the pipe depends on the weight of the soil over the pipe and a bedding constant that depends on the amount of bedding support for the pipe.

The pipe modulus is the Ring Stiffness Factor (EI/r^3) of the pipe determined from a parallel plate test or three-edge bearing test.

The soil modulus depends on the amount of support or passive resistance that the soil gives the pipe. The e' value is a modification[7] of the e value originally proposed by Spangler so that e' is a pipe-soil interaction modulus rather than a true soil modulus. The result is that a particular soil at a given density gives a unique e' value for that soil regardless of the pipe diameter. The soil modulus, e', has not yet been related to a laboratory test and must be considered a semi-empirical factor that is based on experience and judgment.

The series of laboratory load tests on buried flexible pipe was begun to evaluate the Iowa Formula and the soil parameters involved. Because not all surcharge loads on the soil surface over the pipe were held for an hour, the 1-minute deflection readings are used here for analysis, giving a deflection-lag factor of 1.0.

Deflections over the 1-hour load interval are related to the time-lag properties of the various backfill soils. The deflection-load curves then depend on the pipe modulus (Ring Stiffness Factor) and the soil modulus values (modulus of soil reaction). The relationship between the pipe modulus and the soil modulus was examined by varying the soil type and density, and pipe diameter, pipe wall thickness, and pipe material. The analysis of the results took two approaches:

1. Comparing pipe of various ring stiffnesses for a constant soil modulus value
2. Comparing pipe of equal ring stiffnesses for various soil modulus values

SCOPE OF REPORT

The first two progress reports[1,2] in this series discussed the results of steel pipe buried in a low-density, lean clay. Steel pipe with equal Ring Stiffness Factors deflected equally when the backfill soil was at a constant density and moisture content regardless of the pipe diameter and wall thickness. The modulus of the soil was low enough that the effect of the various Ring Stiffness Factors of the pipe could be seen in the pipe deflection as predicted by the Iowa Formula. The pipe deflected inversely proportional to their Ring Stiffness Factors. Progress Report No. 3[3] discussed the tests of steel pipe buried in high-density, lean clay. Steel pipe with low stiffnesses buckled elastically at low deflections. With stiffer pipe, the modulus of the backfill soil was high enough that the effect of the Ring Stiffness Factors of the pipe was becoming negligible. Steel pipe of various stiffnesses deflected similarly. The results of the steel pipe tests have also been summarized in a technical paper.[5]

Progress Report No. 4[4] covered the results of reinforced plastic mortar (RPM) pipe tested in both the low- and high-density, lean clay. In the high-density clay, the RPM pipe deflected about the same as the steel pipe even though the Ring Stiffness Factors were quite different. In the low-density clay, the deflections of the RPM pipe varied widely but were roughly inversely proportional to the Ring Stiffness Factors of the pipe. However, the RPM pipe deflected from two to three times as much as steel pipe with the same Ring Stiffness Factors.

When the soil is placed at a high density beside the pipe, it has high strength properties. As predicted by the Iowa Formula, the tests showed that with bedding soil of high strength, the pipe strength has little effect on the deflection of the pipe.

When the soil is placed at a low density, the pipe deflects inversely proportional to the pipe strength. According to the Iowa Formula, pipe of equal strength (Ring Stiffness Factor) should deflect equally regardless of the pipe material, pipe diameter, or wall thickness, but this was not the case in the tests on RPM pipe.

The research program was then extended to examine other types of plastic-base pipe. This report discusses the results of tests on fiberglass reinforced plastic (FRP), polyethylene (PE), and polyvinyl chloride (PVC) pipe in the low-density clay and compares the results to those of steel and RPM pipe. These results have also been included in a recent paper.[8]

DESCRIPTION OF TEST

Each test pipe was buried in a large, steel, soil container and surcharge loads applied by a large universal testing machine. A sectional drawing of a pipe in place in the container is shown in Figure 1. Measurements of the changing dimensions of the pipe, soil pressures on the soil container walls, the soil movement around the pipe, and the strain on the inner surface of the pipe were measured during the 1-day test period. Before each pipe was buried in the soil container, a three-edge bearing test was run on the pipe to determine the pipe modulus or stiffness.

To reduce the friction between the soil and the container wall, a coating of petrolatum was applied to the walls and covered with 2-mil (.051 mm) polyethylene film. The soil was placed in loose lifts and compacted to the required density. When soil reached the desired elevation of the bottom of the pipe, the pipe was placed on the soil surface. Circular stiffeners were placed in the pipe to prevent the relatively flexible pipe from becoming deformed during the soil compaction around the pipe. The pipe was also braced into place to prevent it from rising during soil compaction under the sides of the pipe. The soil was then compacted beside the pipe and on up to the top of the container. Density and moisture determinations of the soil were made as the material was placed in the container. Then a wooded load plate was placed on the soil surface to distribute the surcharge load from the testing machine.

Just before the load was applied, the stiffeners and braces were removed from the pipe. Installation of all instrumentation was completed and initial readings taken. Most load increments were applied at 1-hour intervals with a uniform loading rate. Most of the instruments were read at 1 and 60 minutes after each

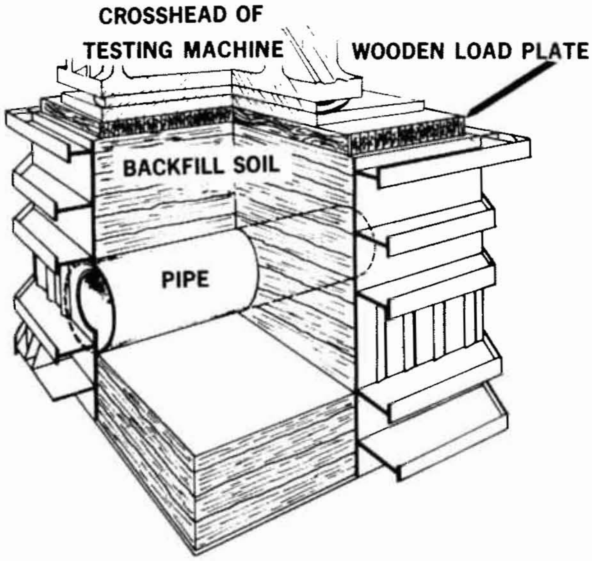

Figure 1. Soil container for buried pipe load tests.

load was applied. Reading intervals between these times varied with the type of data required. Figure 2 shows the container under the testing machine with the data readout equipment connected.

The steel pipe had four pressure cells mounted midway in the pipe, flush with the outside surface, with one each at the ends of the horizontal and vertical diameters to measure the soil pressures at these locations. Pressure cells were also mounted in the walls of the soil container to measure the lateral soil pressure. The pipe deflections were measured on one end of the pipe with inside micrometers and on the other end with a revolving dial gage. A circumferential ring of SR-4-type strain gages was located at a point about one-third the length of the pipe to measure the inner circumferential strains. Telescoping tubes with small plates at the ends were buried in the soil in line with the horizontal diameter of the pipe. The ends of the tubes extended through the soil container walls so that the horizontal soil movements during the loading could be measured.

RESULTS OF STEEL PIPE TESTS

Nine sections of steel pipe were tested in the low-density, lean clay at 90 percent of Proctor maximum dry density. The sections of pipe were divided into four groups according to their Ring Stiffness Factors. The horizontal deflections of the pipe in each group were plotted versus the surcharge load. The plots for two of the groups are shown as Figures 3 and 4. Regardless of the pipe diameter or wall thickness, steel pipe with similar Ring Stiffness Factors deflected similarly.

The average horizontal deflection-load curves for each Ring Stiffness group are shown in Figure 5. In the low-density, lean clay, the pipe deflected inversely proportional to the Ring Stiffness Factors of the pipe.

The horizontal deflection was selected for comparison because the vertical deflections did not show a good correlation due to the various patterns of deformation of the pipe. The pipe with low stiffnesses deflected rectangularly with $\Delta X/\Delta Y$ ratios of 0.6 to 0.8. The stiffest pipe deflected elliptically with $\Delta X/\Delta Y$ ratios of 0.8 to 0.9.

RESULTS OF RPM TESTS

Five 18-inch (46-cm) and one 24-inch (61-cm) diameter RPM pipes were tested in the low-density, lean clay at 90 percent of Proctor maximum dry density. The RPM pipe deflections were compared to those of steel pipe of similar stiffness. The three-edge bearing deflection-load curves for a steel pipe and an RPM pipe

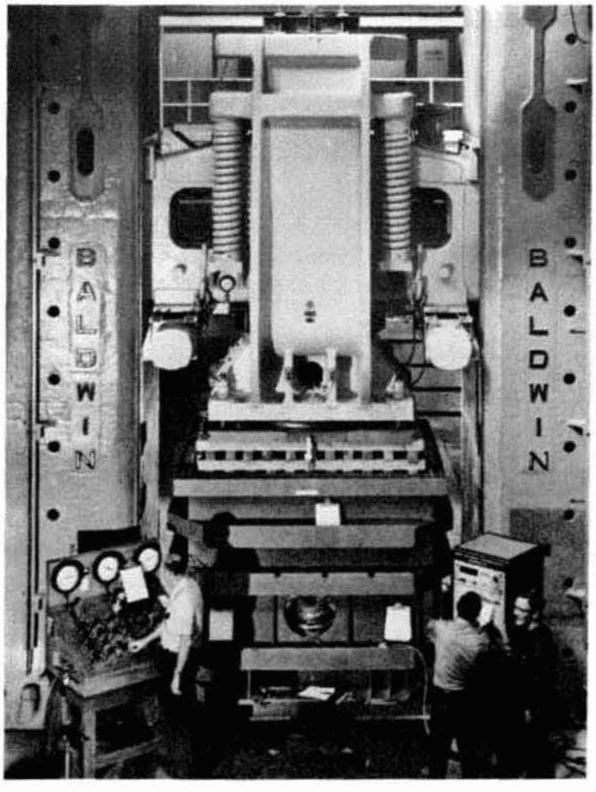

Figure 2. Soil container in place under the large universal testing machine with all instrumentation connected. Photo P801-D-73860

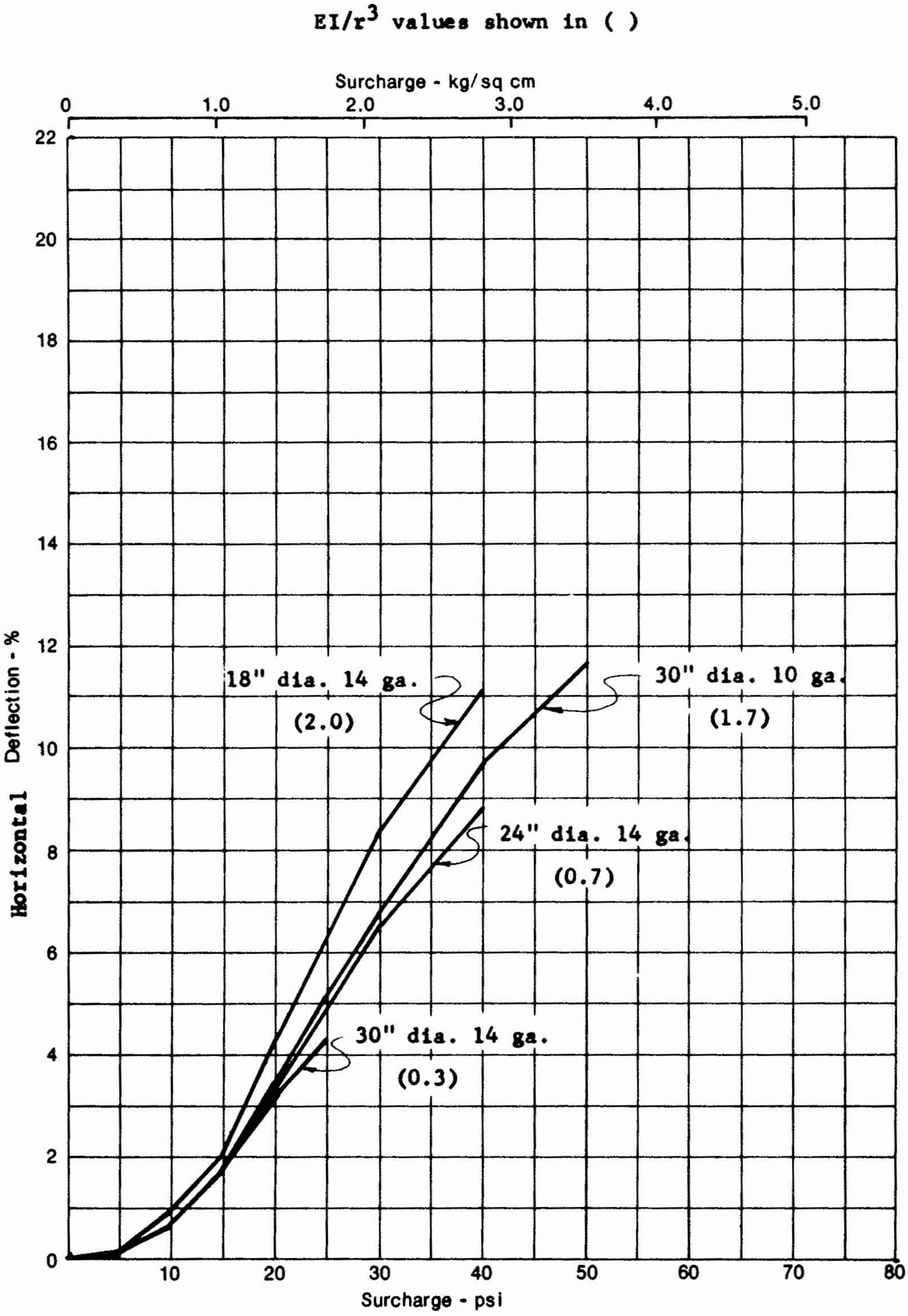

Figure 3. Steel pipe deflection (EI/r^3 = 0-2psi) in low-density clay.

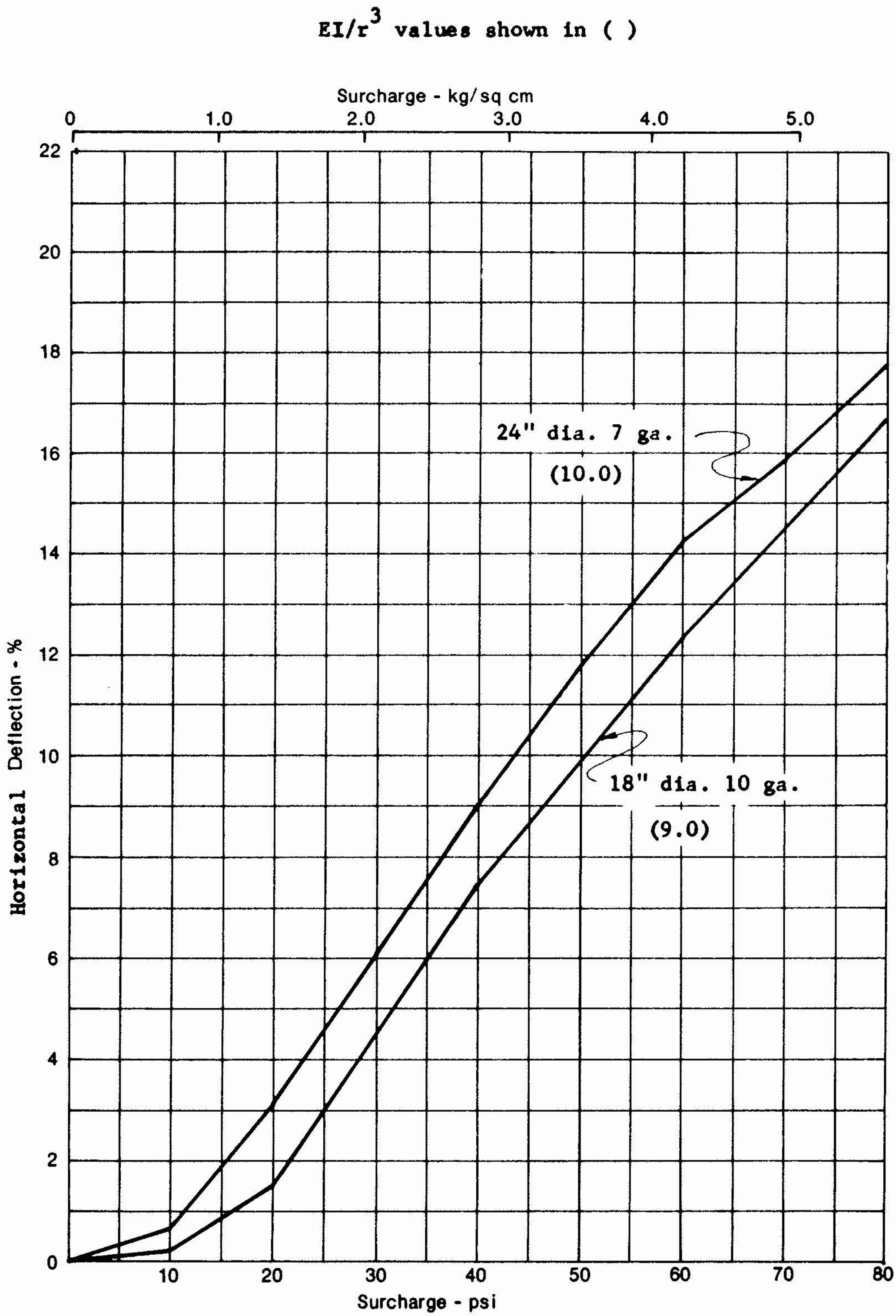

Figure 4. Steel pipe deflection (EI/r^3 = 9-10 psi) in low-density clay.

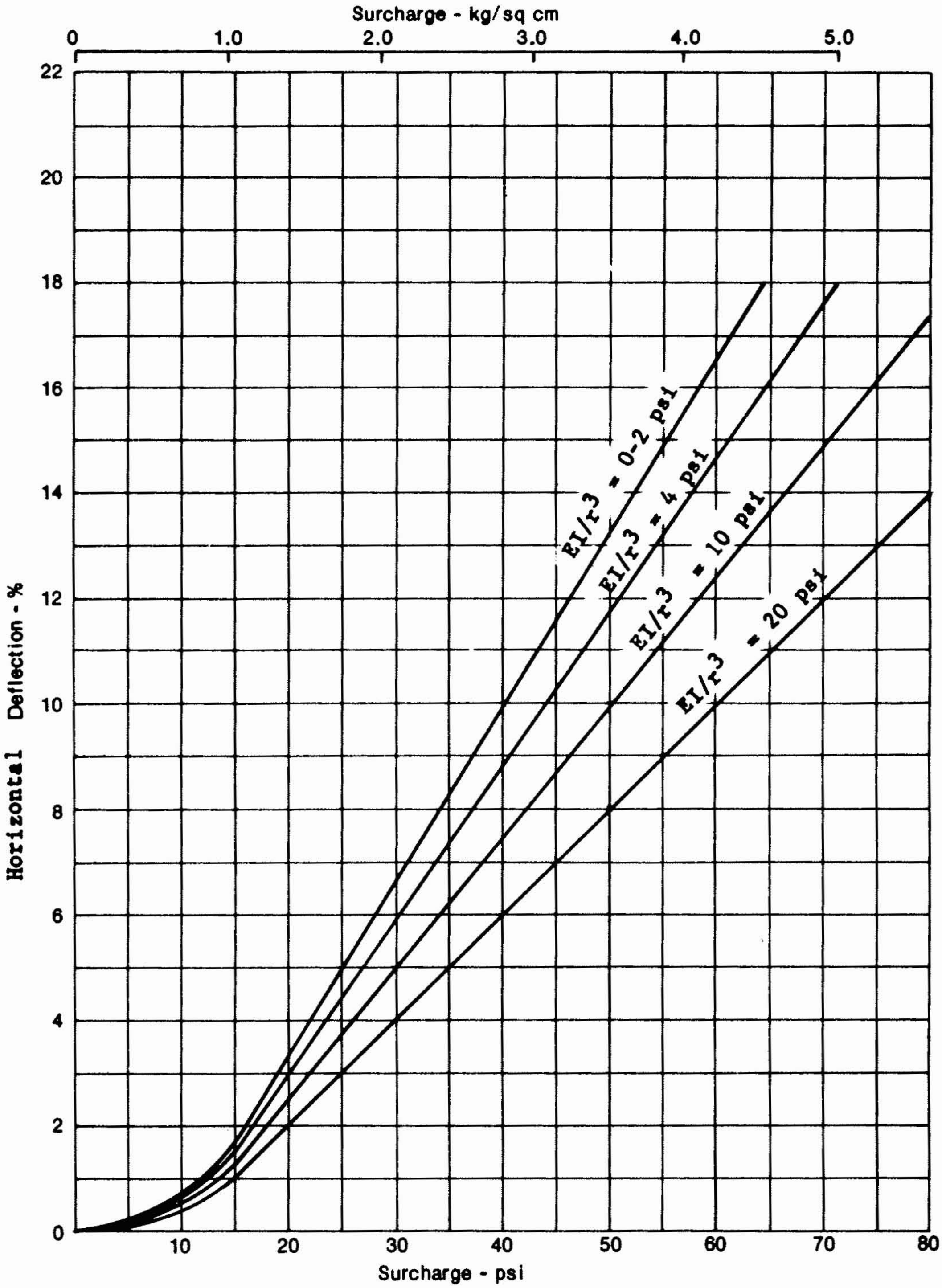

Figure 5. Steel pipe deflections (various EI/r^3 values) in low-density clay.

are shown in Figure 6. Their three-edge bearing test deflection curves are almost identical and give the same Ring Stiffness Factor for each pipe, 2.0 psi (0.14 kg/cm^2). The horizontal deflection-load curves for the same two pipes in the soil container load test are shown in Figure 7, with the RPM pipe deflecting about two to three times more than the steel pipe.

The three-edge bearing deflection load curve for the 24-inch (61-cm) diameter RPM pipe is shown in Figure 8 along with the curve for a 24-inch (61-cm) diameter steel pipe. Their three-edge bearing test results were identical and gave a Ring Stiffness Factor of 4.0 psi (0.28 kg/cm^2) for each pipe. The results from the soil container load tests are shown in Figure 9. The RPM pipe deflected about twice as much as the steel pipe of equal stiffness.

Similar comparisons of other RPM pipe with steel pipe gave similar results.

RESULTS OF FRP TESTS

Three sections of FRP pipe were tested in the low-density, lean clay at 90 percent of Proctor maximum dry density. Based on the conclusion from the steel pipe tests that pipe of equal Ring Stiffness Factors deflect equally for a constant soil type and density, the sections of pipe were grouped according to Ring Stiffness Factors and compared to steel pipe and RPM pipe of similar stiffnesses. The physical properties of all of the pipe are listed in Table 1. The backfill soil densities and moisture contents are shown in Table 2.

Figure 10 compares the deflections of the FRP pipe, EI/r^3 = 3.0 psi (0.21 kg/cm^2), with an RPM pipe and a steel pipe with EI/r^3 = 2.0 psi (0.14 kg/cm^2). The FRP pipe was 50 percent stiffer than the steel pipe but deflected about 60 percent more. If the RPM pipe and the FRP pipe had had the same stiffness, they probably would have similar deflection curves.

Figure 11 shows the deflections of the pipe with Ring Stiffness Factors from 3.5 psi (0.25 kg/cm^2) to 4.5 psi (0.32 kg/cm^2). These sections of pipe include three RPM, one FRP, and two steel. The RPM pipe deflected from two to three times more than the steel pipe. The FRP pipe deflection is about 60 to 100 percent higher than the steel pipe and slightly less than the RPM pipe.

In Figure 12, an RPM pipe, EI/r^3 = 14.5 to 17.5 psi (1.02 to 1.23 kg/cm^2); an FRP pipe, EI/r^3 = 19.0 psi (1.34 kg/cm^2); and a steel pipe, EI/r^3 = 20.5 to 22.5 psi (1.44 to 1.58 kg/cm^2), are compared. The RPM pipe deflected about twice as much as the steel pipe, and the FRP pipe deflected about 50 to 60 percent more (at the lower surcharges) than the steel pipe.

FRP pipe deflects slightly less than RPM pipe with the same Ring Stiffness and about 50 to 100 percent more than steel pipe of the same stiffness.

RESULTS OF THERMOPLASTIC PIPE TESTS

A 15-inch (38-cm) outside diameter PVC pipe and a 20-inch (51-cm) outside diameter PE pipe were tested in the low-density, lean clay at 90 percent of Proctor maximum dry density. Each pipe was compared with a group of steel and RPM pipe of similar stiffness. The physical properties of the pipe are listed in Table 3 and the backfill soil densities and moisture contents in Table 4.

The deflections of the PVC pipe, EI/r^3 = 7.0 psi (0.49 kg/cm^2), are plotted on Figure 13 along with those of an RPM pipe, EI/r^3 = 6.0 psi (0.42 kg/cm^2), and a steel pipe, EI/r^3 = 9.5 psi (0.67 kg/cm^2). The PVC pipe deflection and the steel pipe deflections are similar enough that if a steel pipe of equal Ring Stiffness had been tested, the PVC pipe and the steel pipe would have deflected equally. The deflections of the PVC pipe and the steel pipe are particularly close at the low surcharge; whereas the greatest difference between the RPM pipe and the steel pipe was at the low surcharge.

The PE pipe EI/r^3 = 8-10 psi (0.56-0.70 kg/cm^2) deflection is plotted in Figure 14 with two steel pipes of similar stiffness. The PE pipe deflected similarly to the steel pipe at the lower surcharges, and then the difference became greater at higher loads. It was difficult to select a Ring Stiffness Factor for the polyethylene pipe because of creep of the pipe under constant load in the three-edge bearing test and the fact that the Ring Stiffness Factor decreased significantly with increasing load. This may be why the deflections were similar at low loads, and the PE pipe deflected more than the steel pipe at higher loads. Since pipe loading in the field would occur in the lower part of the surcharge range used in these tests, the similarity of the deflections at the lower loads was felt to be the more significant comparison.

In these two tests, the thermoplastic pipe deflected similarly to steel pipe of the same stiffness.

Table 1

RING STIFFNESS FACTORS
Steel, RPM, and FRP Pipe

Pipe description	Empirical EI/r^3 †				EI/r^3 value used	
	Low		High			
	psi	kg/cm^2	psi	kg/cm^2	psi	kg/cm^2
EI/r^3 = 0-2 psi						
18-inch-diameter RPM	1.83	0.13	2.00	0.14	2.0	0.14
18-inch-diameter 14-gage steel	1.81	0.13	2.02	0.14	2.0	0.14
24-inch-diameter 14-gage steel	0.65	0.05	0.66	0.05	0.7	0.05
30-inch-diameter 14-gage steel	0.30	0.02	0.34	0.02	0.3	0.02
30-inch-diameter 10-gage steel	1.61	0.11	1.69	0.12	1.7	0.12
EI/r^3 = 3 psi						
18-inch-diameter FRP	3.01	0.21	3.05	0.21	3.0	0.21
EI/r^3 = 4 psi						
18-inch-diameter RPM	3.07	0.22	3.62	0.25	3.5	0.25
18-inch-diameter RPM	3.96	0.28	4.98	0.35	4.5	0.32
24-inch-diameter RPM	3.68	0.26	4.05	0.28	4.0	0.28
18-inch-diameter FRP	4.48	0.31	4.56	0.32	4.5	0.32
24-inch-diameter 10-gage steel	3.86	0.27	3.99	0.28	4.0	0.28
30-inch-diameter 7-gage steel	3.84	0.27	4.25	0.30	4.0	0.28
EI/r^3 = 15-20 psi						
18-inch-diameter RPM	14.38	1.01	17.49	1.23	14.5–17.5	1.02–1.23
18-inch-diameter FRP	18.20	1.28	19.54	1.37	19.0	1.34
18-inch-diameter 7-gage steel	20.55	1.44	22.62	1.59	20.5–22.5	1.44–1.58

†Based on horizontal deflections on south end of pipe from three-edge bearing test. $EI/r^3 = 0.136\ P/\Delta X$; P = lbs/linear inch; ΔX = horizontal deflection in inches.

SUMMARY AND CONCLUSIONS

The USBR has been conducting special laboratory tests on buried sections of flexible pipe to investigate their behavior. The test pipe sections were buried in a large, steel, soil container in a lean clay backfill. Surcharge loads were applied to the soil surface over the pipe with a large universal testing machine. Measurements of the changing dimensions of the pipe, strain on the inner surface of the pipe, soil movement around the pipe, and soil pressures were made during a 1-day loading sequence.

Previous work on steel pipe showed a good correlation between the empirical data and the Iowa Formula for flexible pipe design. The Iowa Formula predicts the percent deflection of flexible pipe based on a ratio of the external load on the pipe to the combination of the pipe strength and the soil strength. These tests showed that with bedding soil of high strength (good backfill material adequately compacted) the pipe strength has little or no effect on the deflection of the pipe. When the soil is an inferior material or is poorly compacted, the pipe strength has a larger effect on the pipe deflection.

The testing program on RPM pipe showed that the type of pipe material did not affect the pipe deflection in high-strength bedding conditions. When the backfill was a low-density material, the RPM pipe deflected two to three times more than steel pipe of equivalent stiffness. The pipe strength as determined from three-edge bearing tests did not provide a reliable basis for determining the percent deflection of the pipe of two different materials (steel and RPM) buried in the low-density backfill.

The comparison of pipe of different materials was continued in the testing of fiberglass reinforced plastic (FRP), polyvinyl chloride (PVC), and polyethylene

Table 2

BACKFILL SOIL DENSITY AND MOISTURE
Steel, RPM, and FRP Pipe

Pipe description	Number of density tests	Backfill density in percent of Proctor maximum dry density			Soil moisture		
		Range percent	Mean percent	Standard deviation percent	Range percent	Mean percent	Standard deviation percent
EI/r^3 = 0-2 psi							
18-inch-diameter RPM	14	88.2–91.1	89.9	0.94	11.1–13.0	11.9	0.50
18-inch-diameter 14-gage steel	6	88.4–92.9	90.1	1.78	11.3–12.4	11.7	0.37
24-inch-diameter 14-gage steel	8	85.1–92.9	90.8	2.63	11.2–13.1	11.6	0.62
30-inch-diameter 14-gage steel	8	87.5–92.2	90.5	1.54	11.2–11.8	11.5	0.17
30-inch-diameter 10-gage steel	8	88.5–92.0	90.6	1.07	11.5–12.1	11.8	0.24
EI/r^3 = 3 psi							
18-inch-diameter FRP	12	88.1–91.4	89.4	0.98	11.3–13.7	12.2	0.66
EI/r^3 = 4 psi							
18-inch-diameter RPM	9	87.6–93.0	89.7	1.89	11.0–12.1	11.6	0.29
18-inch-diameter RPM	16	85.1–92.0	89.4	1.95	11.4–12.4	11.8	0.25
24-inch-diameter RPM	12	86.3–91.4	89.6	1.48	11.4–12.3	11.8	0.27
18-inch-diameter FRP	14	87.8–92.6	89.8	1.63	10.6–12.1	11.3	0.44
24-inch-diameter 10-gage steel	6	86.4–92.3	88.5	2.40	11.2–12.5	11.7	0.40
30-inch-diameter 7-gage steel	7	86.7–93.7	90.2	2.61	10.8–11.6	11.3	0.22
EI/r^3 = 15-20 psi							
18-inch-diameter RPM	14	87.7–92.8	90.6	1.37	11.3–12.4	11.7	0.32
18-inch-diameter FRP	12	88.1–92.4	90.6	1.62	9.3–11.9	10.9	0.70
18-inch-diameter 7-gage steel	6	86.5–94.1	90.2	2.51	10.7–12.1	11.6	0.53

(PE) pipe. The test results, as discussed in this report, gave the following conclusions:

1. The FRP pipe deflected slightly less than RPM pipe with the same Ring Stiffness and about 50 to 100 percent more than steel pipe of the same stiffness.

2. The thermoplastic pipe, PVC and PE, deflected similarly to steel pipe of the same stiffness.

The following conclusions are based on the data presented in the appendices of this report:

3. The soil pressures on the container walls opposite the horizontal diameter of the pipe were about the same as the soil pressures on the walls above the influence of the deflecting pipe. The average of the pressures on the walls was about 50 to 60 percent of the vertically applied surcharge pressure.

4. About 50 percent of the soil compression between the pipe and the container walls occurred in the 9 inches (23 cm) of soil adjacent to the pipe.

5. The horizontal movement of the pipe into the soil was equal on both sides of the pipe.

6. The polyethylene pipe deformed rectangularly as it was loaded, while the FRP and PVC deformed elliptically or semielliptically.

7. The PVC pipe deflected 29 percent vertically without any signs of structural distress. It returned to 97 percent of its original diameter 2 months after it was removed from the test container.

8. The PE pipe deflected 42 percent vertically without any signs of structural distress. It returned to 94 percent of its original diameter 2 months after it was removed from the test container.

9. Crazing (fine, hairlike cracks) of the inner surface of two of the three FRP pipe sections occurred between 10 and 20 percent vertical deflection.

Table 3

RING STIFFNESS FACTORS
Thermoplastic Pipe Compared to Steel and RPM Pipe

Pipe description	Empirical EI/r^3 †				EI/r^3 value used	
	Low		High			
	psi	kg/cm²	psi	kg/cm²	psi	kg/cm²
EI/r^3 = 6-7 psi						
18-inch-diameter RPM	5.94	0.42	6.61	0.46	6.0	0.42
15-inch-diameter PVC	6.88	0.48	7.31	0.51	7.0	0.49
EI/r^3 = 9-10 psi						
18-inch-diameter PE	8.16	0.57	10.18	0.72	8–10	0.56–0.70
18-inch-diameter 10-gage steel	8.97	0.63	9.75	0.69	9.5	0.67
24-inch-diameter 7-gage steel	9.81	0.69	10.58	0.74	10.0	0.70

†Based on horizontal deflections on south end of pipe from three-edge bearing test. $EI/r^3 = 0.136\ P/\Delta X$; P= lbs/linear inch; ΔX = horizontal deflection in inches.

Table 4

BACKFILL SOIL DENSITY AND MOISTURE
Thermoplastic Pipe Compared to Steel and RPM Pipe

Pipe description	Number of density tests	Backfill density in percent of Proctor maximum dry density			Soil moisture		
		Range percent	Mean percent	Standard deviation percent	Range percent	Mean percent	Standard deviation percent
EI/r^3 = 6-7 psi							
18-inch-diameter RPM	10	87.7–92.9	90.0	1.72	10.9–12.6	11.9	0.52
15-inch-diameter PVC	14	88.4–92.9	91.2	1.18	10.6–12.4	11.1	0.54
EI/r^3 = 9-10 psi							
18-inch-diameter PE	12	88.5–91.5	89.6	0.97	10.4–11.6	11.0	0.38
18-inch-diameter 10-gage steel	13	87.9–91.9	89.6	1.17	11.0–11.8	11.4	0.23
24-inch-diameter 7-gage steel	12	88.6–94.7	91.4	2.02	11.3–12.5	12.0	0.39

Under succeeding loads, the crazing slowly developed into definite longitudinal cracks where the inner surface of the pipe was under tension. The other FRP pipe sections longitudinally cracked suddenly at about 40 percent vertical deflection.

APPLICATIONS

Previous tests compared the deflection behavior of steel and RPM pipe in a buried condition. The phase of the testing covered in this report extended the comparison to three other types of pipe with one type represented by two different manufacturers. The study has shown that glass reinforced thermosetting plastic pipe behaves differently than steel or thermoplastic pipe and that care in assuring proper bedding for the glass reinforced thermosetting pipe is essential.

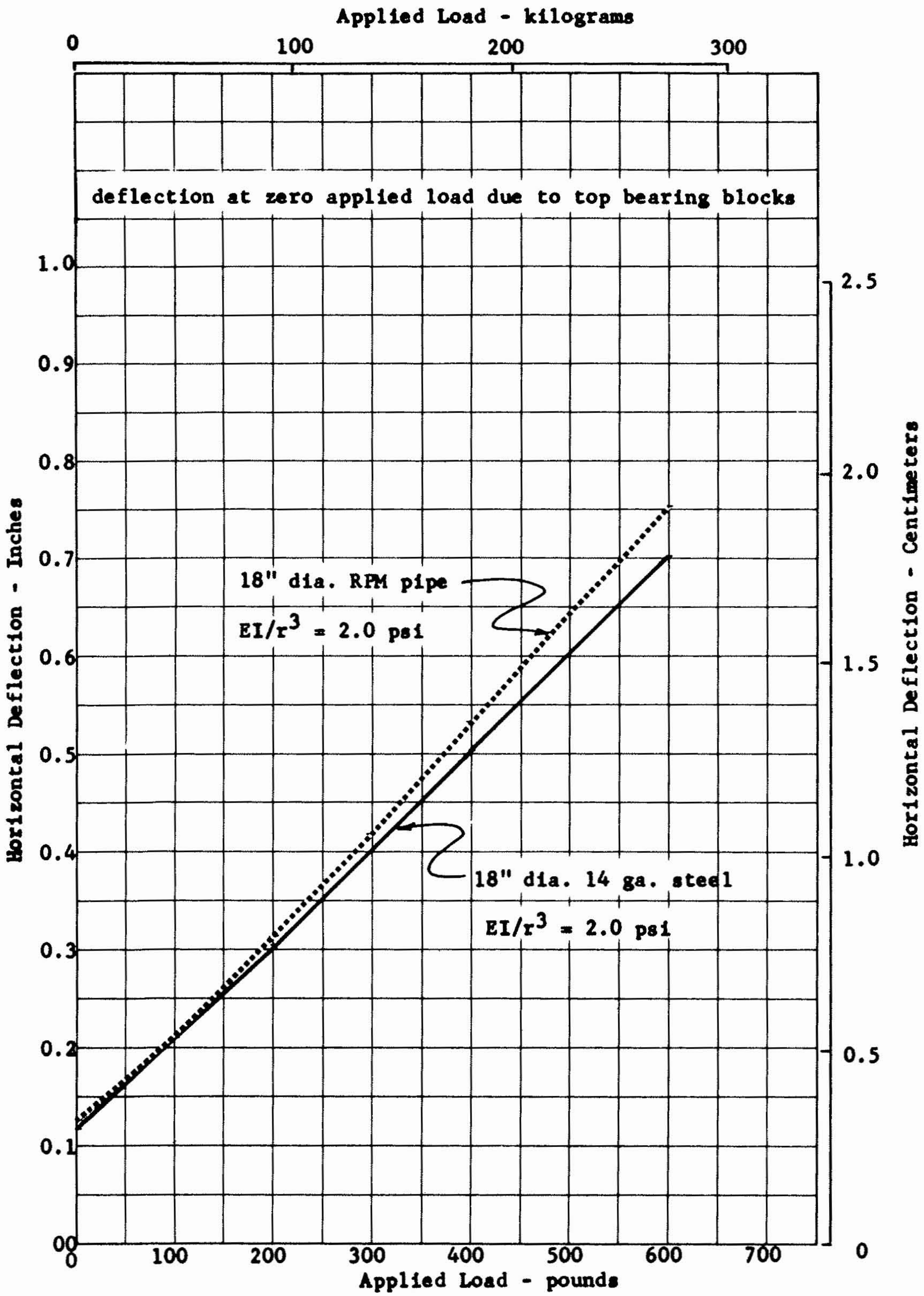

Figure 6. Three-edge bearing test deflections of pipe with $EI/r^3 = 2.0$ psi.

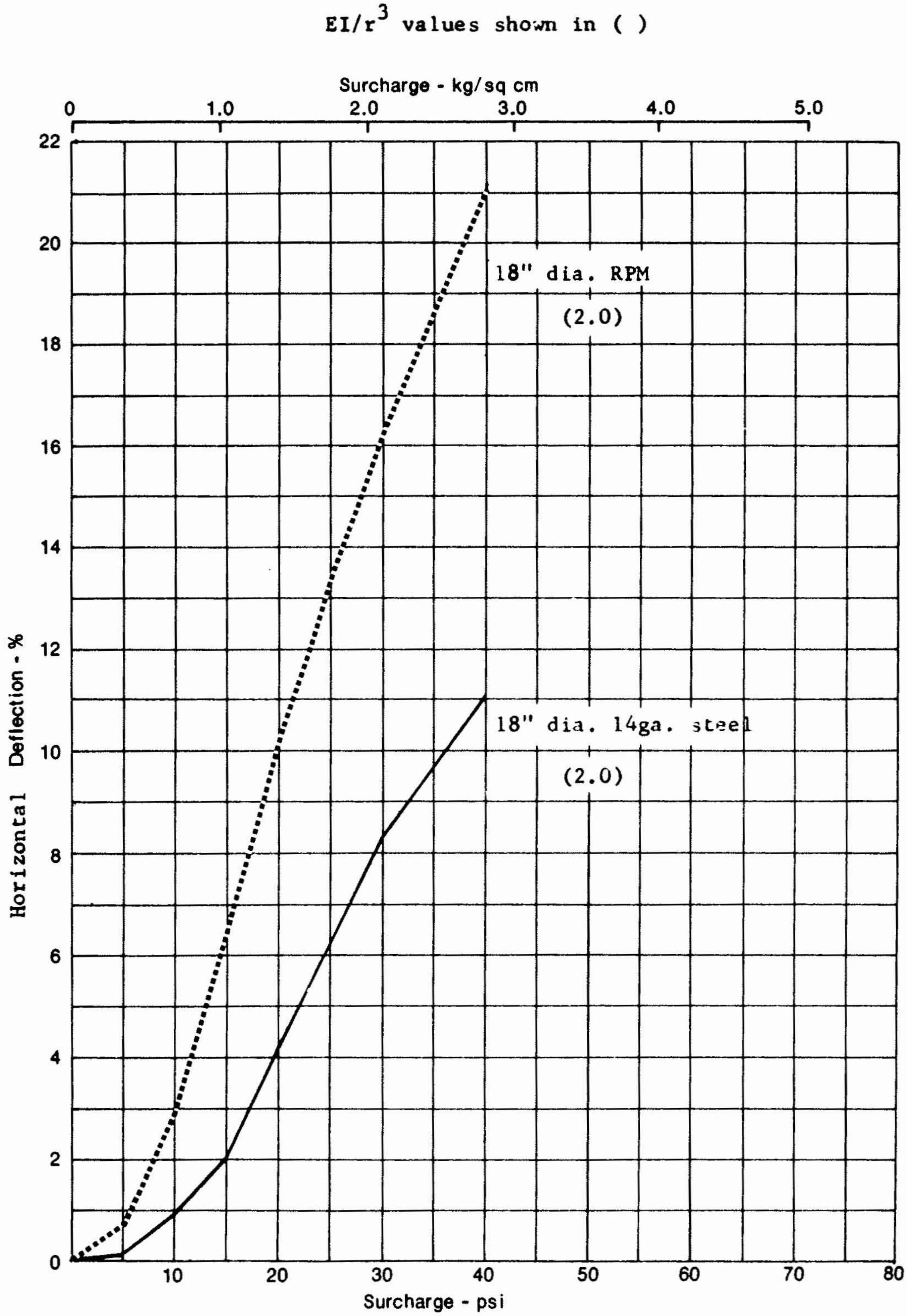

Figure 7. Soil container load test deflections of pipe with EI/r^3 = 2.0 psi.

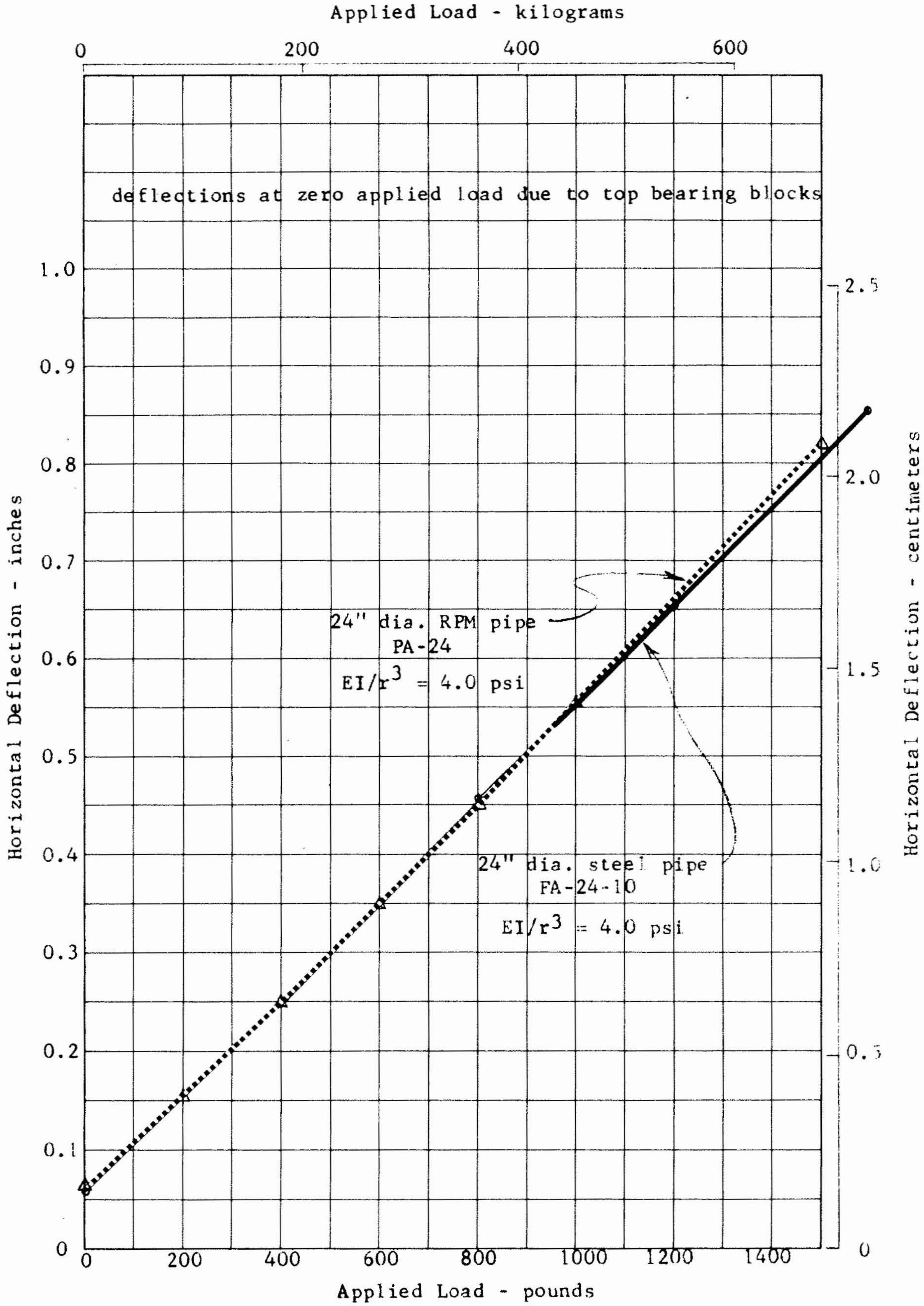

Figure 8. Three-edge bearing test deflections of pipe with $EI/r^3 = 4.0$ psi.

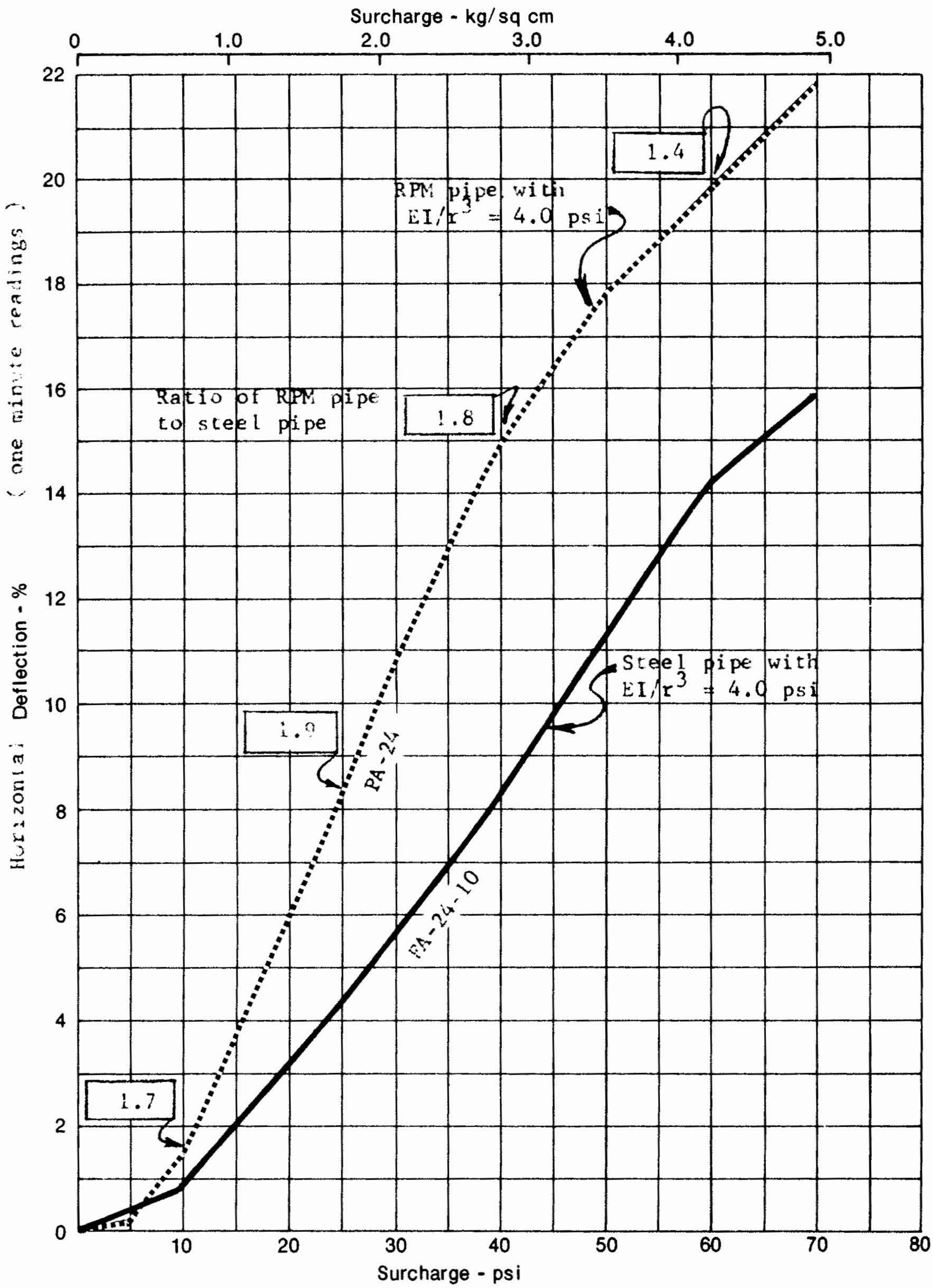

Figure 9. Soil container load test deflections of pipe with EI/r^3 = 4.0 psi.

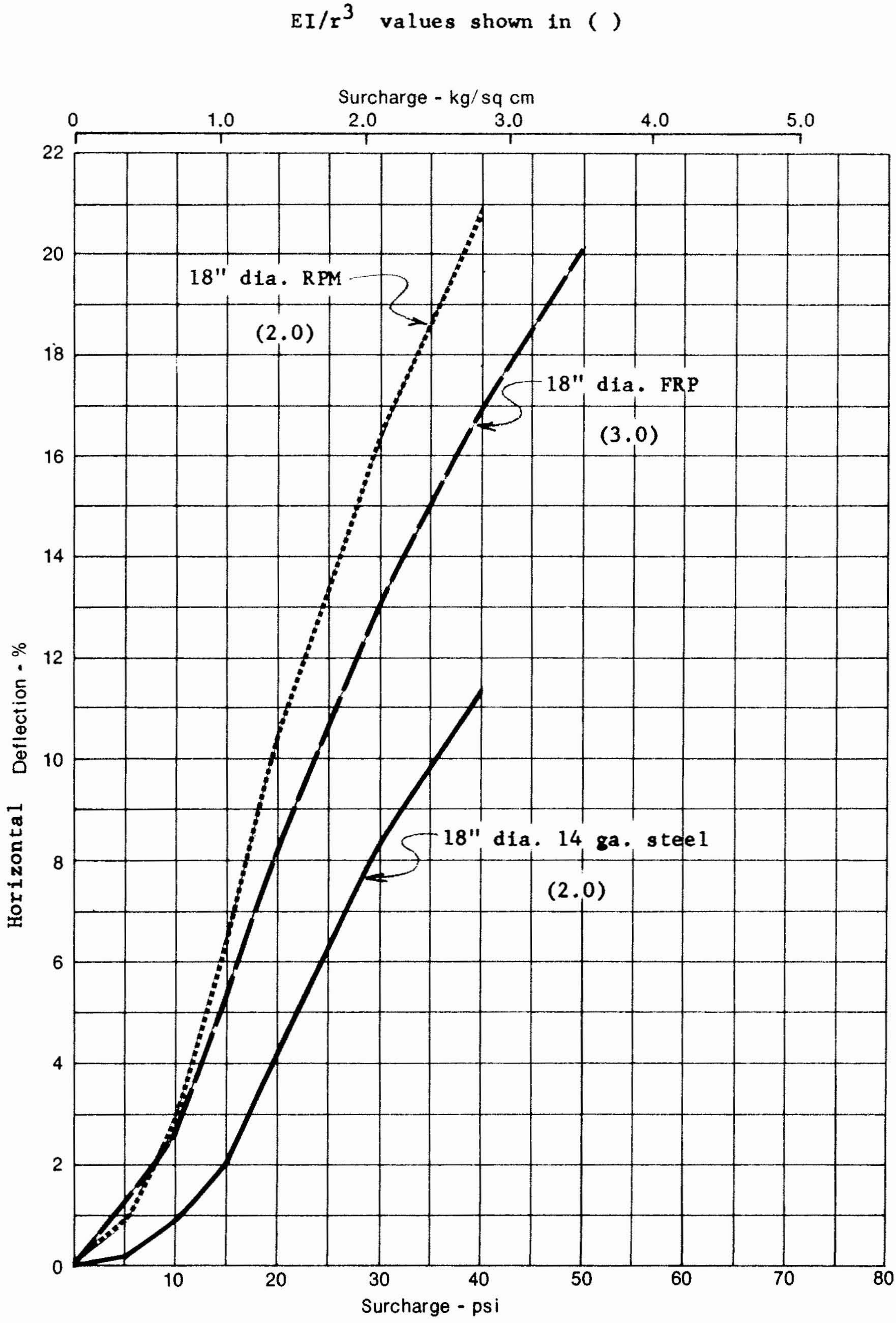

Figure 10. Deflection comparison of FRP, RPM and steel pipe with EI/r^3 = 2-3 psi.

EI/r³ values shown in ( )

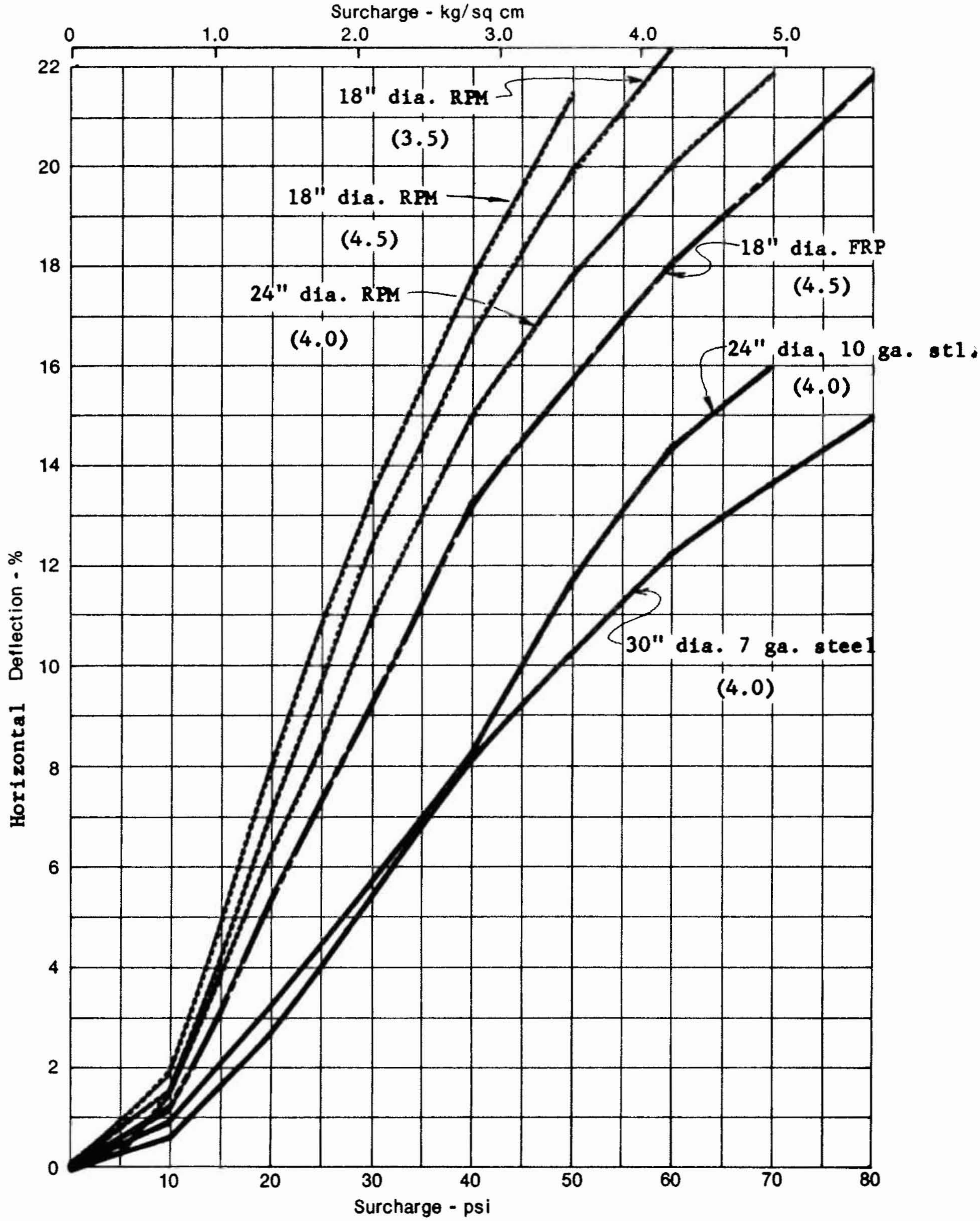

Figure 11. Deflection comparison of FRP, RPM, and steel pipe with EI/r^3 = 3.5-4.5 psi.

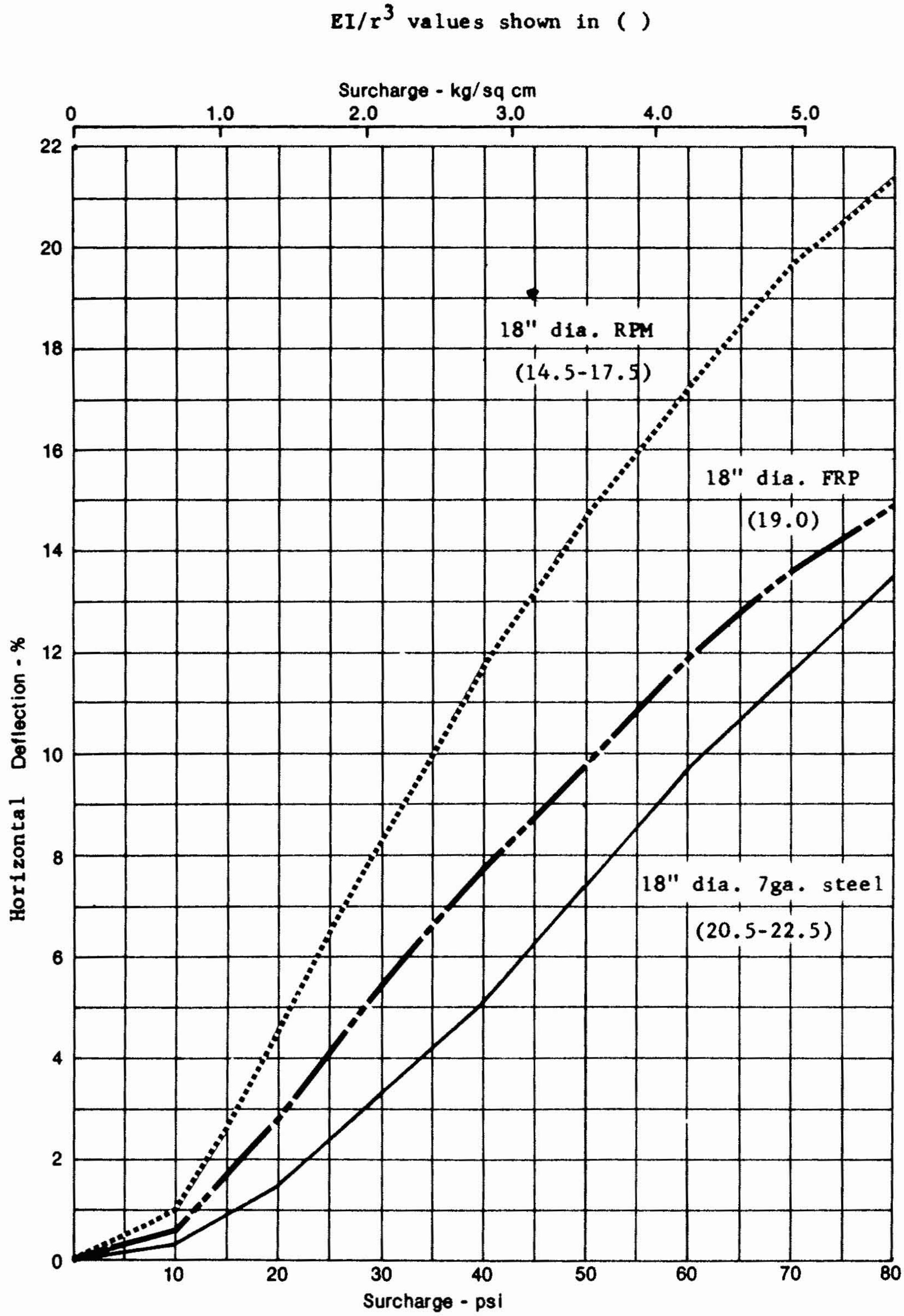

Figure 12. Deflection comparison of FRP, RPM, and steel pipe with EI/r^3 = 15-23 psi.

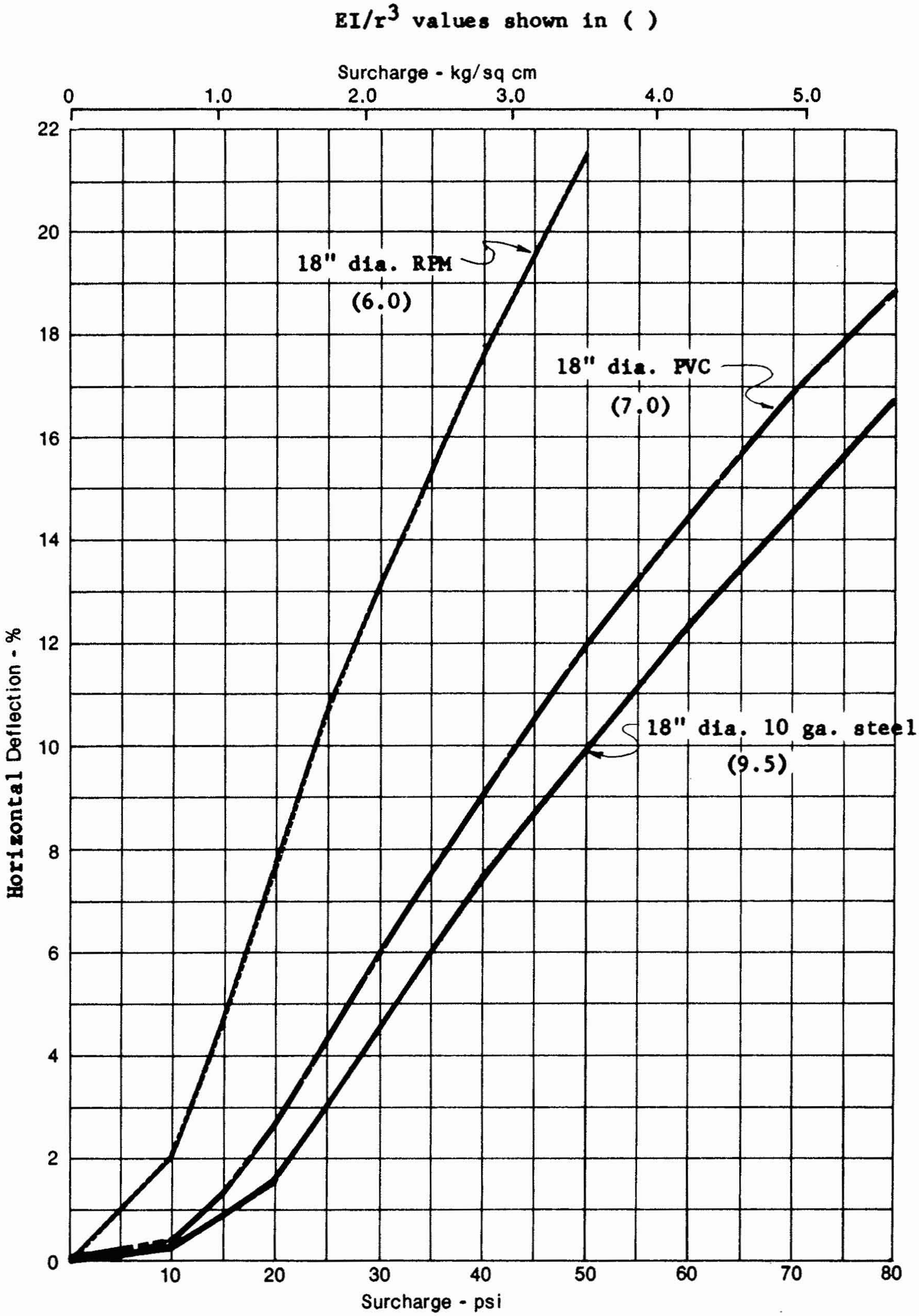

Figure 13. Deflection comparison of PVC pipe with an RPM pipe and a steel pipe.

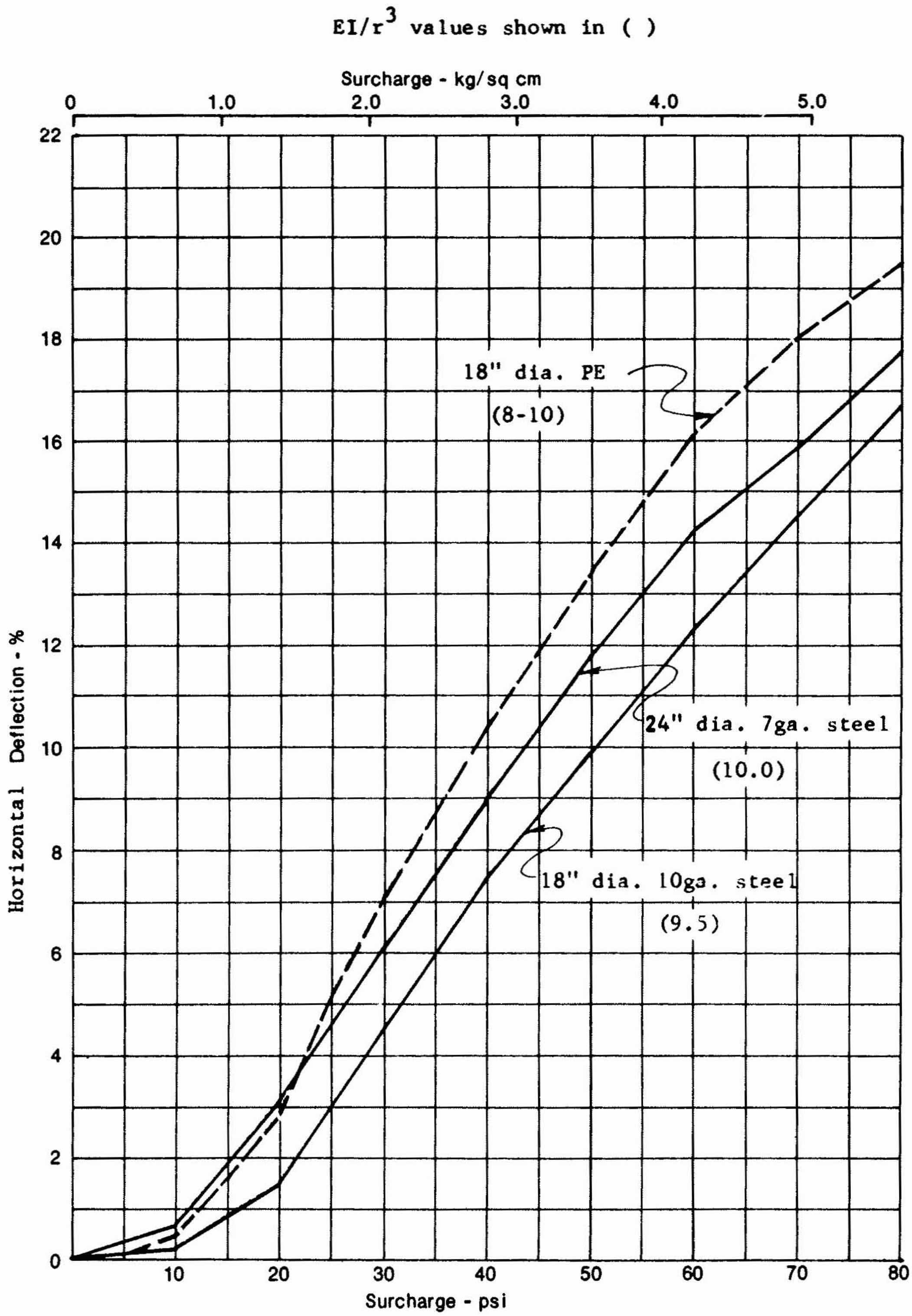

Figure 14. Deflection comparison of PE and steel pipe with EI/r^3 = 9-10 psi.

PERSONNEL PERFORMING TESTS

The assistance of the following people in conducting the tests is greatly appreciated:

J. H. Aikele	B. A. Callow	R. I. Kingery
A. A. Benavidez	C. T. Coffey	F. B. Larcom
M. L. Berry	L. J. Cox	D. E. Pritchard

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8. Howard, A. K., and Selander, C. E., "Laboratory Load Tests on Buried Reinforced Thermosetting, Thermoplastic, and Steel Pipe," paper at 28th Reinforced Plastics Technical and Management Conference, Society of Plastics Industry, February 7, 1973, Washington, D.C.

APPENDIX A

INDIVIDUAL TEST RESULTS

INTRODUCTION

Results of the individual tests are shown graphically in Figures A-1 through A-27 in the following order:

Load-Deflection Curves	A-1 through A-5
Soil Pressures on Container Walls	A-6 through A-10
Strain Gage Readings Around Pipe Circumference	A-11 through A-14
Soil Movement Between Pipe and Soil Container Wall	A-15 through A-22
Cross Sections of Pipe Under Load	A-23 through A-27

Unless otherwise noted the data shown are the 1-minute readings.

LOAD DEFLECTION CURVES

The 1-minute horizontal and vertical deflection curves are shown for each individual test in Figures A-1 through A-5.

The following table shows the percent increase in the pipe vertical deflection from 1 to 60 minutes:

Load	FRP and PVC pipe	Polyethylene pipe
10 psi (0.70 kg/cm^2)	50 percent	66 percent
20 psi (1.41 kg/cm^2)	20 percent	45 percent
30 psi (2.11 kg/cm^2)	11-15 percent	17 percent
40 psi (2.81 kg/cm^2)	6-13 percent	14 percent

At the lower loads, the polyethylene pipe showed higher changes in deflection with time than the others, but the deflection changes due to time were about the same at higher loads.

The $\Delta X/\Delta Y$ ratios are shown on each graph for selected load values. There is very little difference between the $\Delta X/\Delta Y$ ratio for the 1- and 60-minute readings. The range of $\Delta X/\Delta Y$ ratios for each test is:

Test	$\Delta X/\Delta Y$ ratio
FRP, EI/r^3 = 19.0 psi (1.34 kg/cm^2)	0.77–0.91
FRP, EI/r^3 = 4.5 psi (0.32 kg/cm^2)	0.69–0.88
FRP, EI/r^3 = 3.0 psi (0.21 kg/cm^2)	0.70–0.84
PVC, EI/r^3 = 7.0 psi (0.49 kg/cm^2)	0.69–0.83
PE, EI/r^3 = 8-10 psi (0.56-0.70 kg/cm^2)	0.54–0.66

The polyethylene pipe deflected rectangularly, as shown by the low $\Delta X/\Delta Y$ ratio of about 0.5–0.6. The other pipe deflected more elliptically. The lower the stiffness of the FRP, the lower the $\Delta X/\Delta Y$ ratio, as was the case for the steel pipe tested.

Photographs showing the deformed shape of the pipe are included in Appendix C of this report.

The diameters and wall thicknesses of the test pipe were measured before each test. Table A-1 shows the averages of 8 diameter measurements and 16 thickness measurements.

The data show that one end of the first FRP pipe listed was about 40 percent thicker than the other end. After the test, this pipe was cut into several sections and the wall thickness measured. About three-fourths of the pipe was the same thickness as the south end, and for the remainder of the pipe the thickness gradually increased. Apparently the test piece was cut out of the original standard pipe section close to the bell end of the pipe. The values for stiffness and deflections calculated from the south end measurement were used for comparison with the other pipe, since they should be more representative of the entire pipe length. The deflections of the south end (thinner section) were about 25 percent higher than those on the other end.

SOIL PRESSURES ON CONTAINER WALLS

Pressure cells mounted in the soil container walls measured the horizontal soil pressures on the wall. Four cells (two on each side wall) were mounted 4 feet (1.2 meters) from the top of the container opposite the horizontal diameter of the pipe. These cells should measure pressures due to the deflecting pipe in addition to the lateral pressures. Another four cells were 2 feet (0.6 meter) from the top of the container

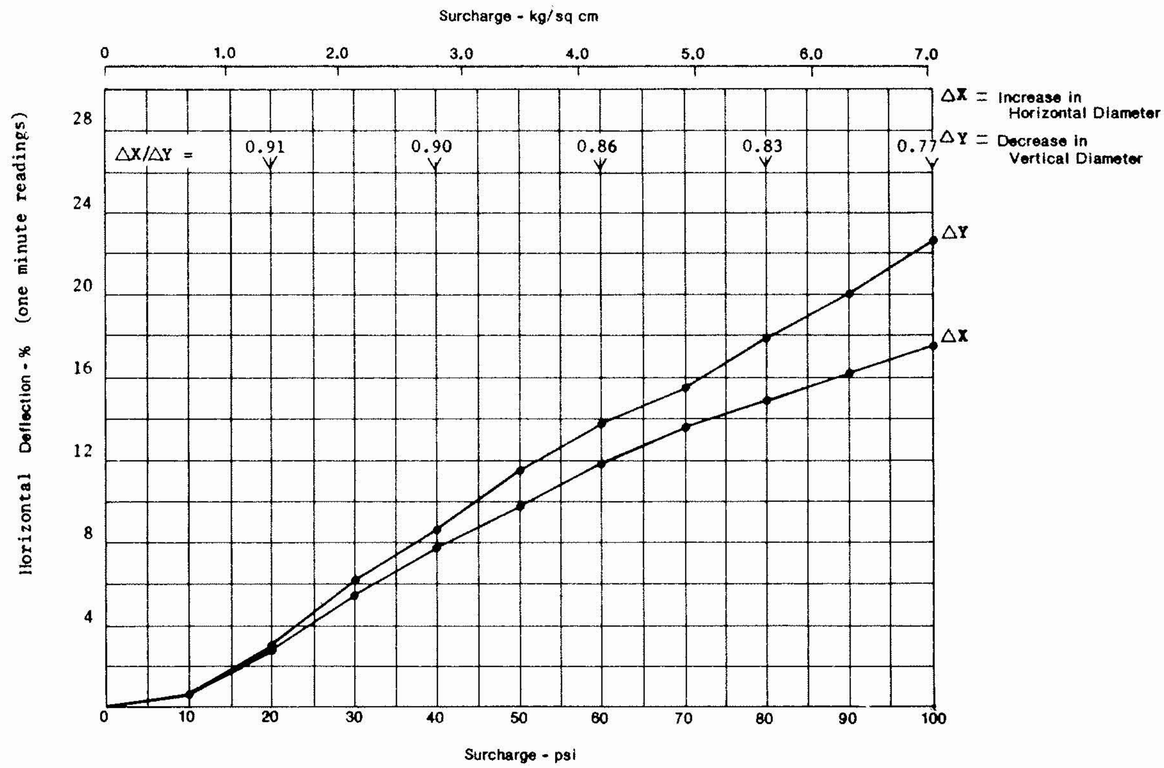

Figure A-1. Percent deflection of 18-inch-diameter FRP pipe with EI/r^3 = 19.0 psi (1.34 kg/cm^2).

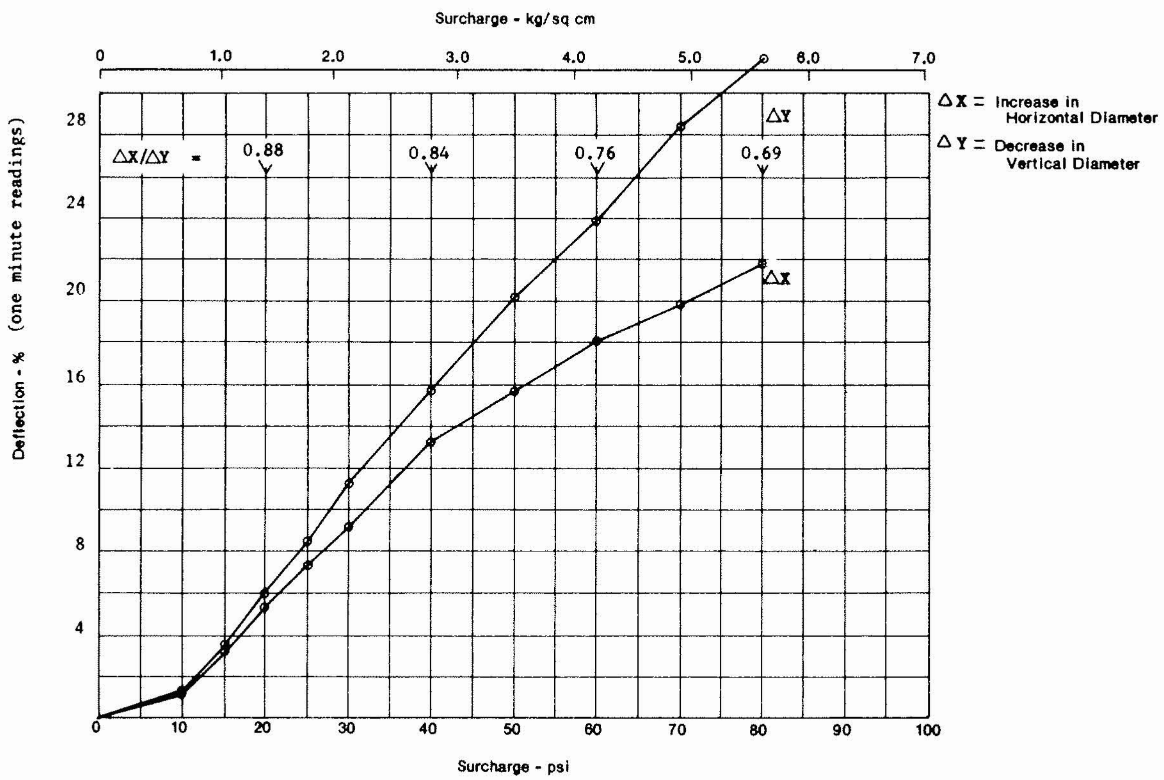

Figure A-2. Percent deflection of 18-inch-diameter FRP pipe with EI/r^3 = 4.5 psi (0.32 kg/cm^2).

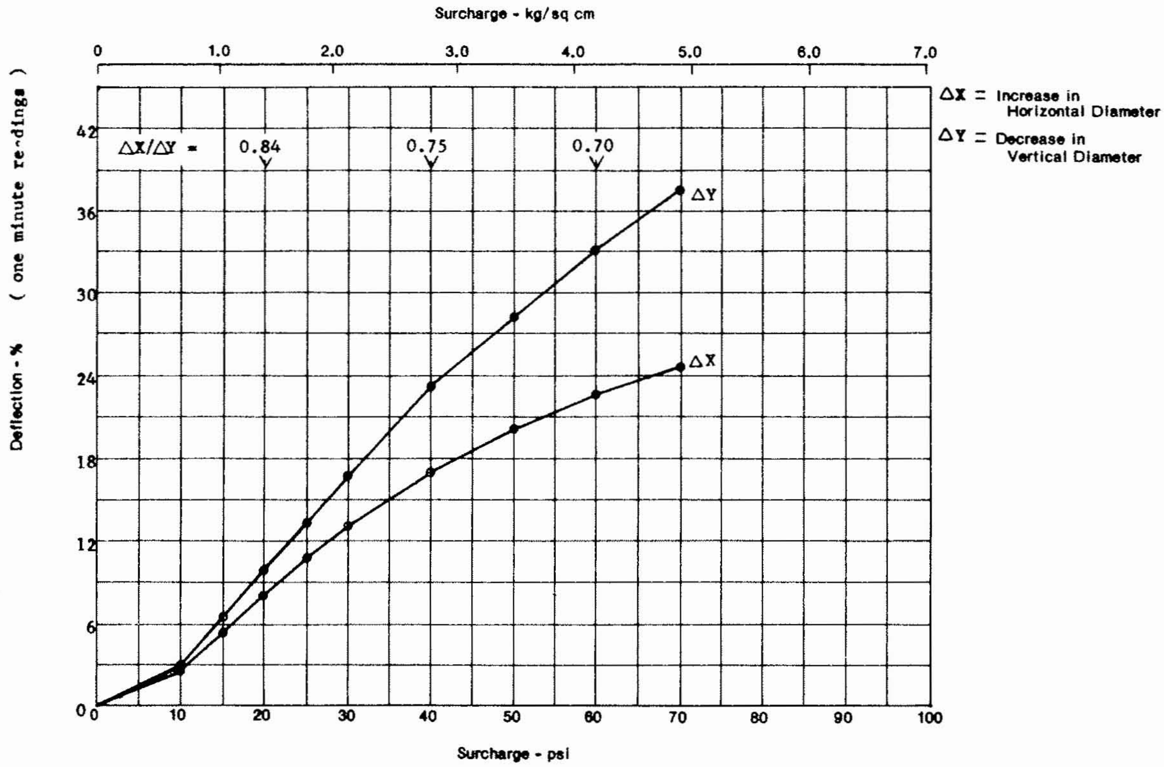

Figure A-3. Percent deflection of 18-inch-diameter FRP pipe with EI/r^3 = 3.0 psi (0.21 kg/cm^2).

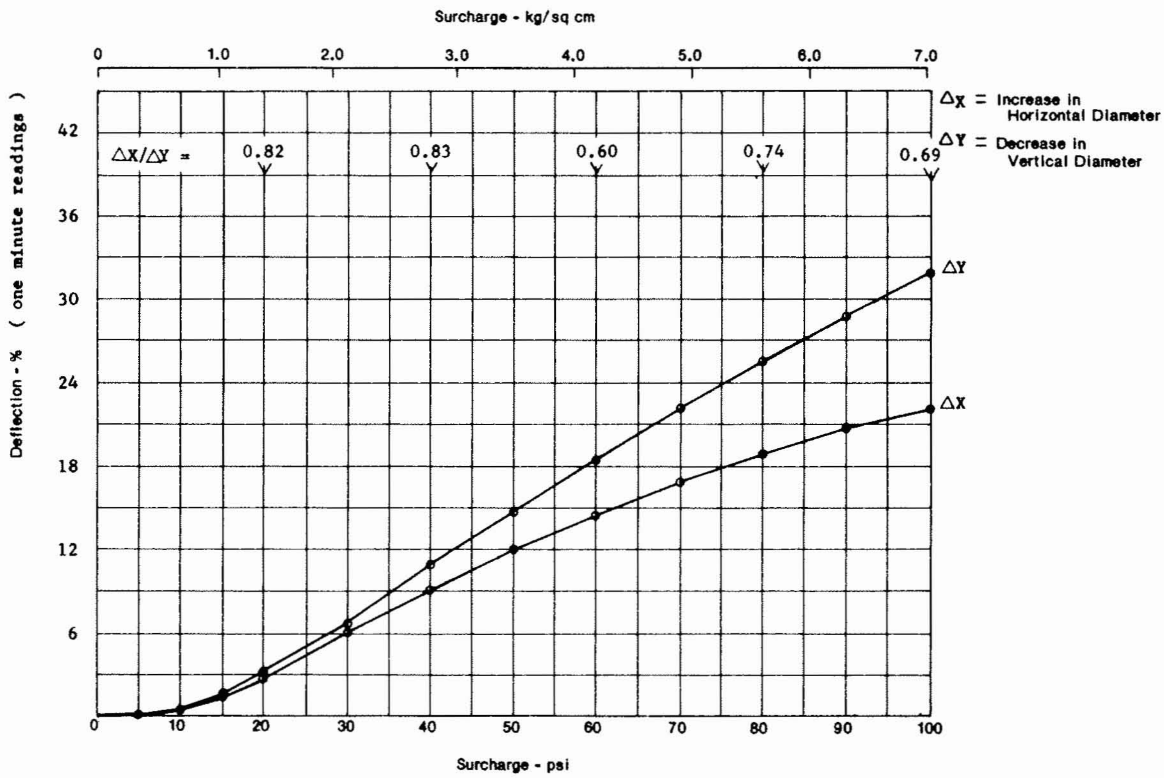

Figure A-4. Percent deflection of 15-inch-diameter PVC pipe with EI/r^3 = 7.0 psi (0.49 kg/cm^2).

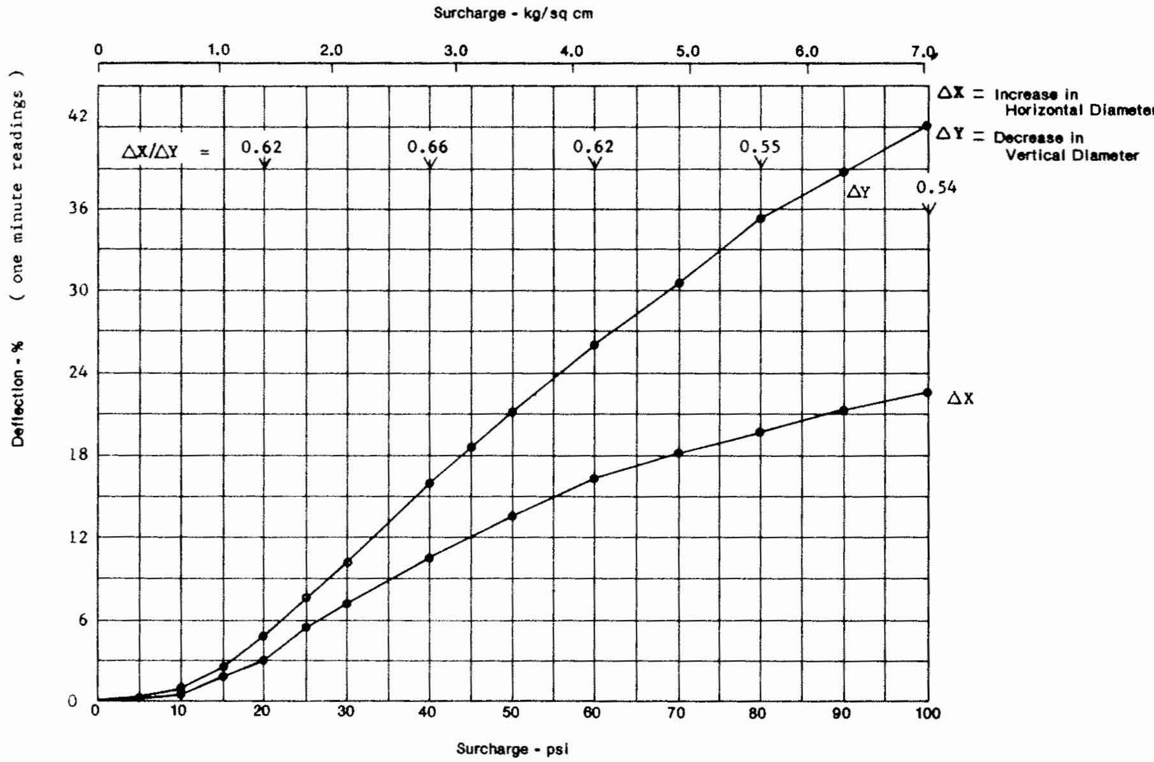

Figure A-5. Percent deflection of 18-inch-diameter PE pipe with EI/r^3 = 8-10 psi (0.56-0.70 kg/cm^2).

TABLE A–1.

PIPE DIMENSIONS

Test description	Wall thickness		Pipe diameter	
	North end inches (cm)	South end inches (cm)	North end inches (cm)	South end inches (cm)
18-inch FRP pipe EI/r^3 = 19.0 psi (1.34 kg/cm^2)	0.628 (1.60)	0.459 (1.17)	17.866 (45.38)	17.885 (45.43)
18-inch FRP pipe EI/r^3 = 4.5 psi (0.32 kg/cm^2)	0.271 (0.69)	0.273 (0.69)	17.889 (45.44)	17.889 (45.44)
18-inch FRP pipe EI/r^3 = 3.0 psi (0.21 kg/cm^2)	0.255 (0.65)	0.317 (0.81)	18.295 (46.47)	18.289 (46.45)
15-inch PVC pipe EI/r^3 = 7.0 psi (0.49 kg/cm^2)	0.419 (1.06)	0.419 (1.06)	14.453 (36.71)	14.466 (36.74)
18-inch PE pipe EI/r^3 = 8-10 psi (0.56-0.70 kg/cm^2)	0.908 (2.31)	0.908 (2.31)	17.973 (45.65)	17.975 (45.66)

and measured the lateral pressures without any significant interference from the pipe. Because of the small difference in elevation and the large surcharge applied, the lateral pressures are assumed to be the same at each cell location.

In the tests on the steel pipe and the RPM pipe, the cells opposite the pipe showed about the same pressures as the cells above the influence of the pipe for the pipes that were 18 inches (46-cm) in diameter. For the 24-inch (61-cm) and 30-inch (76-cm) pipe, the cells opposite the pipe showed definitely higher pressures than the upper cells.

Graphs showing the soil pressure on the container walls for each of the tests on the FRP, PVC, and PE pipe are shown in Figures A-6 through A-10. These pipe sections were all 18 inches (46-cm) or below in diameter, and the pressures were all about the same. The average pressure on the container walls for these tests was about 50 to 60 percent of the applied surcharge, slightly higher than the pressures on the container walls for the steel pipe tests.

STRAIN GAGE READINGS AROUND PIPE CIRCUMFERENCE

Because of the nature of polyethylene, no strain gages could be applied to this pipe. Graphs showing the strain gage readings for the other tests are shown in Figures A-11 through A-14. The strain gage patterns are those associated with pipes that deflect elliptically. The FRP pipe with a stiffness of 3.0 psi (0.21 kg/cm^2) was expected to have deflected more rectangularly, since the steel pipe with EI/r^3 values of 4.0 psi (0.28 kg/cm^2) or less all deflected in definitely rectangular patterns.

SOIL MOVEMENT BETWEEN PIPE AND SOIL CONTAINER WALLS

Telescoping tubes with small plates on the ends were buried in the soil in line with the horizontal diameter of the pipe. The ends of the tubes extended through the soil container wall so horizontal soil movements during the loading could be measured. Previously the tubes were only installed on one side of the pipe. In these tests on the FRP, PVC, and polyethylene pipe, the tubes were installed on both sides of the pipe to see if the pipe deflected equally in both directions. The telescoping tubes for the test on the PVC pipe malfunctioned, but the data is shown as Figures A-15 through A-22 for the other tests.

The data show that 50 percent of the soil compression between the pipe and the container wall occurred in the 9 inches (23-cm) of soil adjacent to the pipe, similar to results from the steel pipe and the RPM pipe tests. The movements measured by the tubes that rested against the wall of the pipe on both sides for each test agreed within 10 percent of each other, indicating that the pipe was moving equally toward the container walls. This indicates the uniformity of the soil compaction on either side of the pipe.

SHAPE OF THE PIPE CROSS SECTION UNDER LOAD

For measuring the shape of the pipe cross section, a dial gage is attached perpendicularly to a shaft mounted to the soil container extending into the pipe. The shaft is located parallel to the longitudinal axis of the pipe and is turned from outside the soil container. The axis of the shaft is offset from the longitudinal axis of the pipe so that at 0° (top of the pipe) the dial gage is almost fully extended, and at 180° the dial gage is almost fully retracted. This allows nearly the full range of the dial gage, 4 inches (10 cm), available to measure the settlement of the top of the pipe. Measurements inside the pipe are made at 15° intervals. The only comparable points between the dial gage angles and the angle markings on the pipe are at 0° and 180°.

The shapes of pipe after 1 minute of each load increment are shown in Figures A-23 through A-27. The readings start at 0°, and the 0° reading is repeated at the end. The difference in the 0° readings for each load on the graphs illustrates the amount of deflection that occurred during the 4 to 5 minutes which elapsed while making a round of readings.

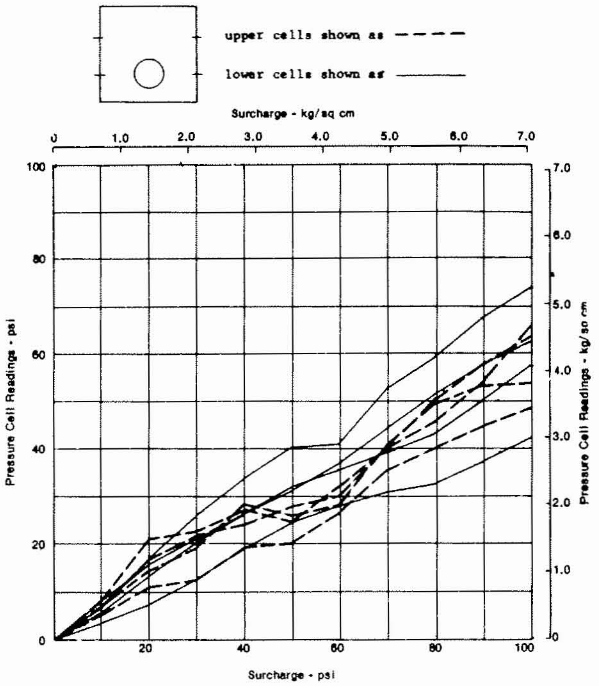

Figure A-6. Soil pressures on container walls, 18-inch-diameter FRP pipe, EI/r^3 = 19.0 psi (1.34 kg/cm^2)

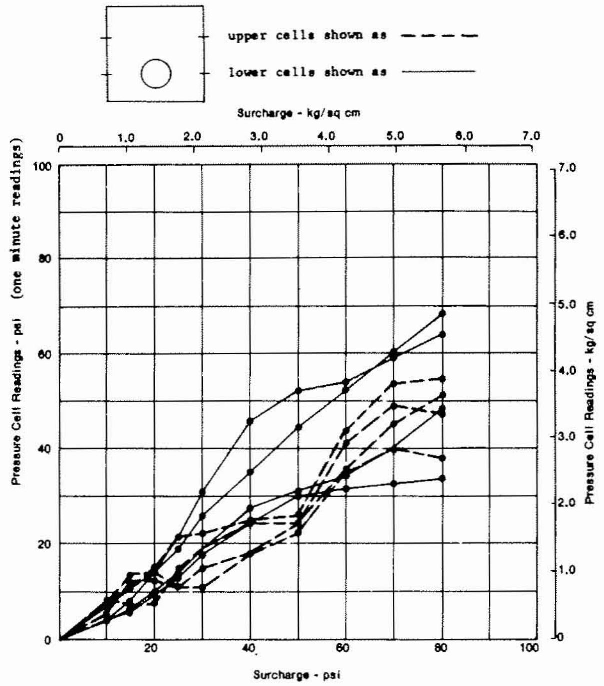

Figure A-7. Soil pressures on container walls, 18-inch-diameter FRP pipe, EI/r^3 = 4.5 psi (0.32 kg/cm^2).

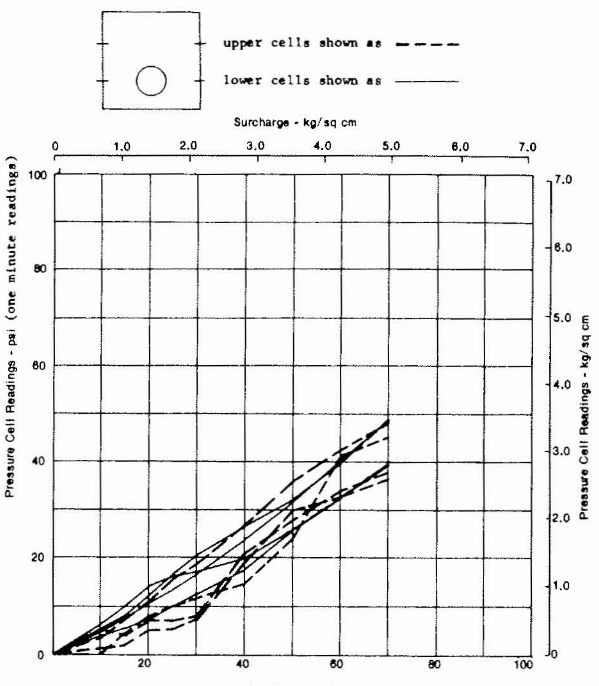

Figure A-8. Soil pressures on container walls, 18-inch-diameter FRP pipe, EI/r^3 = 3.0 psi (0.21 kg/cm^2).

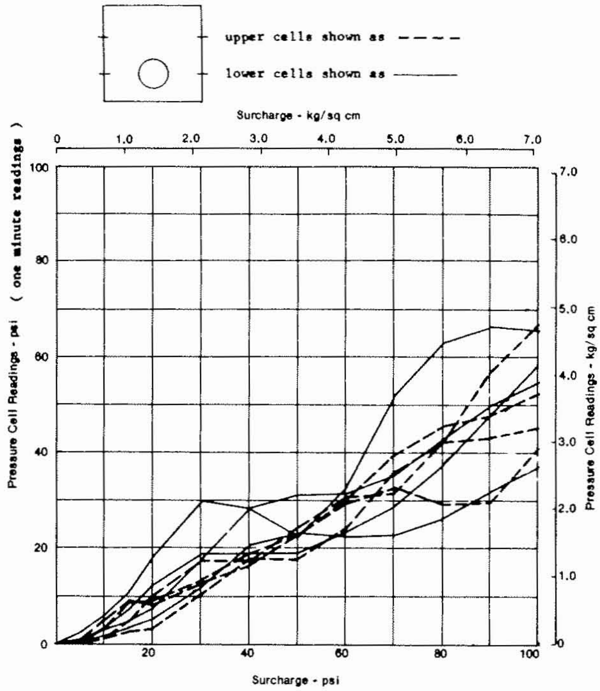

Figure A-9. Soil pressures on container walls, 15-inch-diameter PVC pipe, EI/r^3 = 7.0 psi (0.49 kg/cm²).

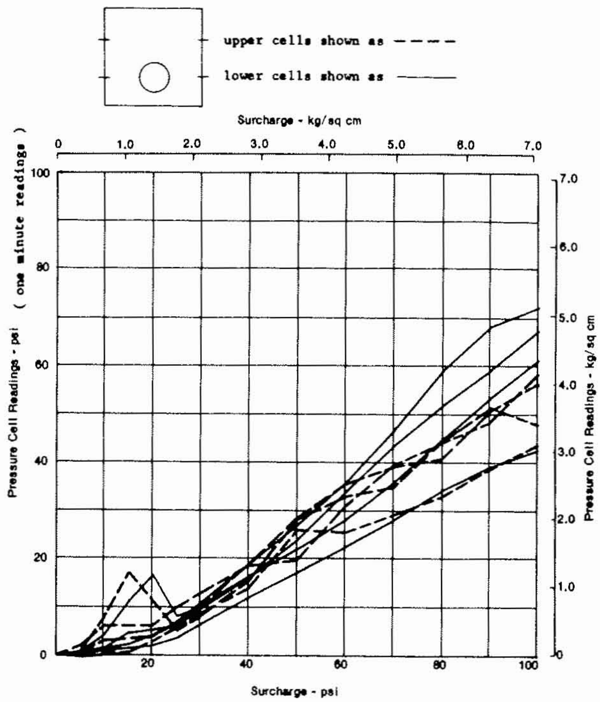

Figure A-10. Soil pressures on container walls, 18-inch-diameter PE pipe, EI/r^3 = 8-10 psi (0.56-0.70 kg/cm²).

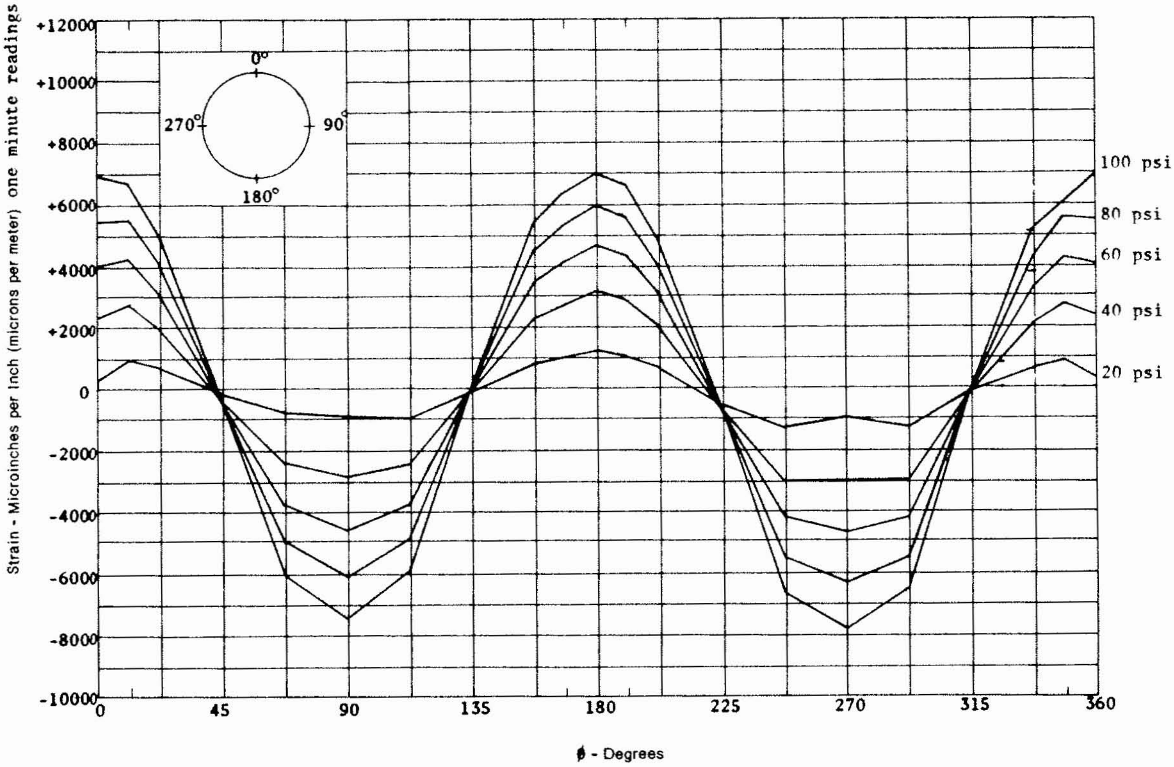

Figure A-11. Strain gage readings around inside pipe circumference, 18-inch-diameter FRP pipe with EI/r^3 = 19.0 psi (1.34 kg/cm^2).

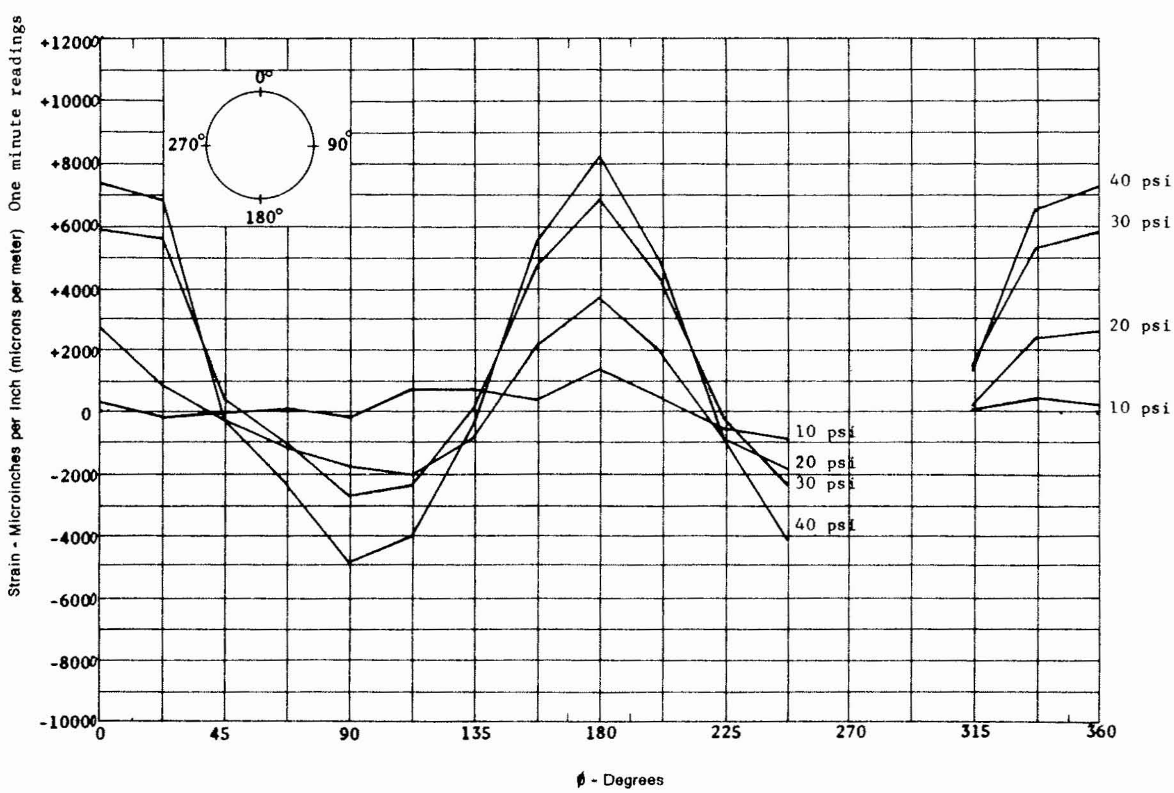

Figure A-12. Strain gage readings around inside pipe circumference, 18-inch-diameter FRP pipe with EI/r^3 = 4.5 psi (0.32 kg/cm^2).

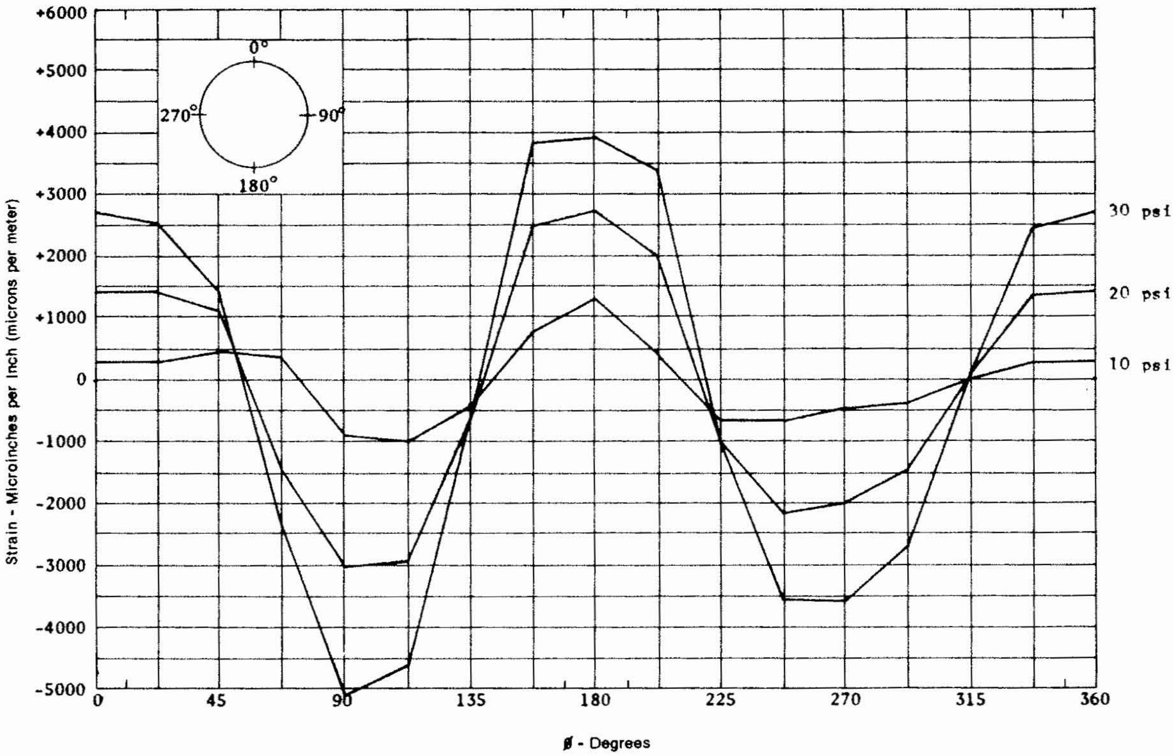

Figure A-13. Strain gage readings around inside pipe circumference, 18-inch-diameter FRP pipe with EI/r^3 = 3.0 psi (0.21 kg/cm^2).

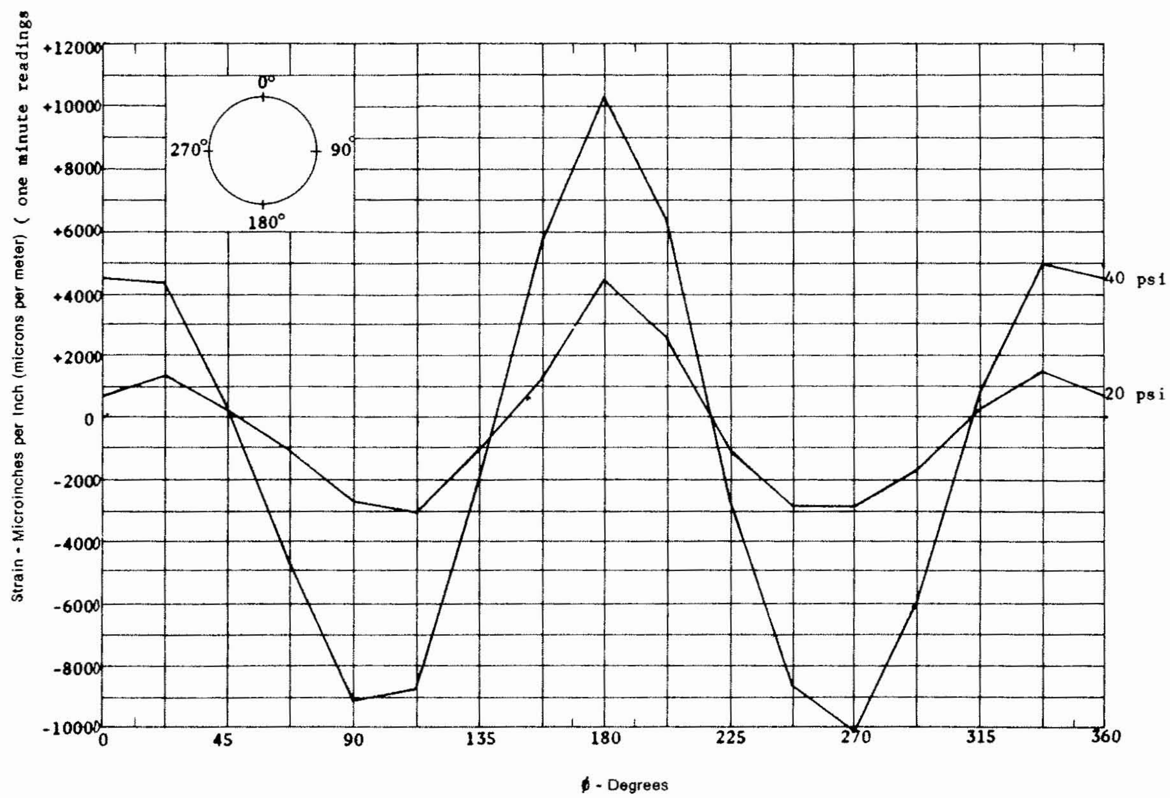

Figure A-14. Strain gage readings around inside pipe circumference, 15-inch-diameter PVC pipe with EI/r^3 = 7.0 psi (0.49 kg/cm^2).

*Original Distance to Side of Pipe

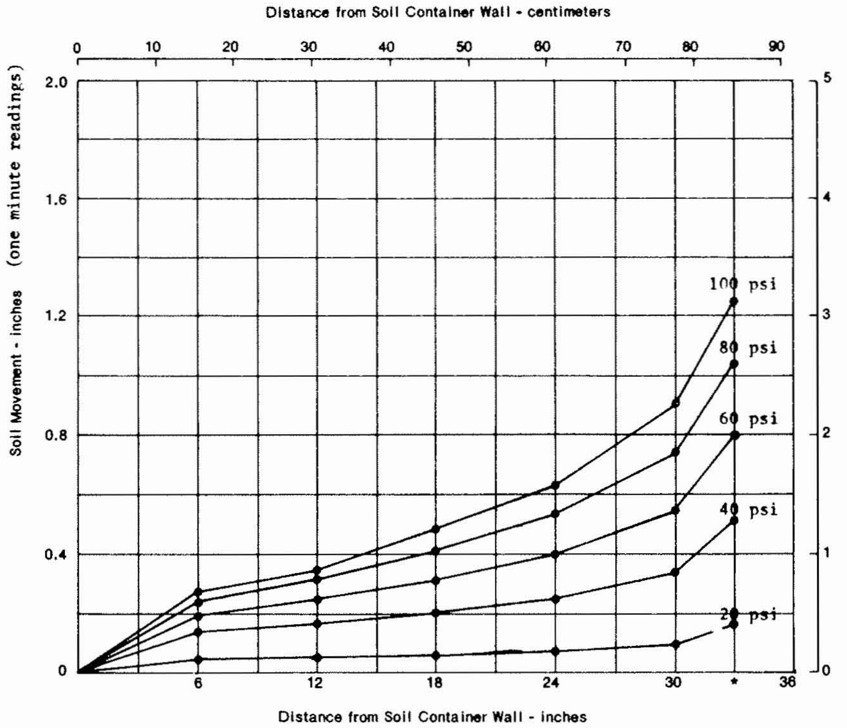

Figure A-15. Soil movement between pipe and soil container wall – east side of 18-inch-diameter FRP pipe with EI/r^3 = 19.0 psi (1.34 kg/cm^2).

*Original Distance to Side of Pipe

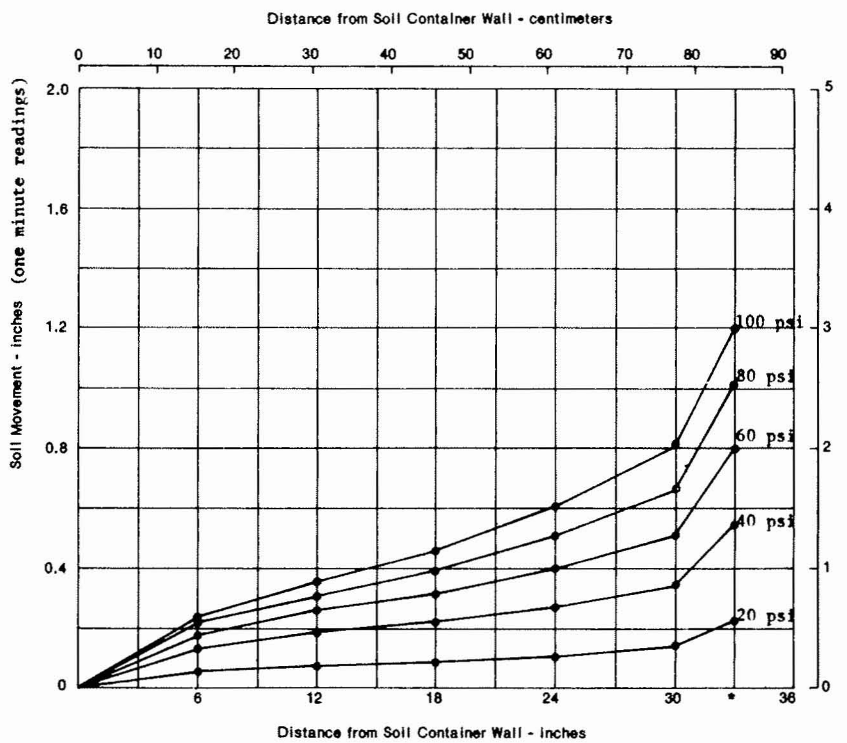

Figure A-16. Soil movement between pipe and soil container wall – west side of 18-inch-diameter FRP pipe with EI/r^3 = 19.0 psi (1.34 kg/cm^2).

*Original Distance to Side of Pipe

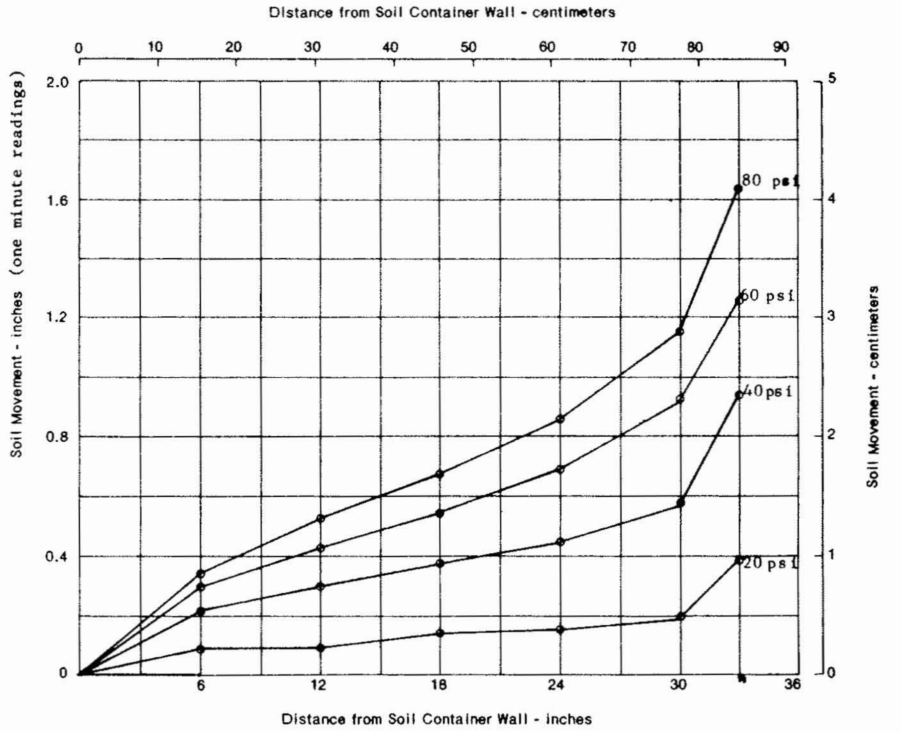

Figure A-17. Soil movement between pipe and soil container wall — east side of 18-inch-diameter FRP pipe with $EI/r^3 = 4.5$ psi (0.32 kg/cm^2).

*Original Distance to Side of Pipe

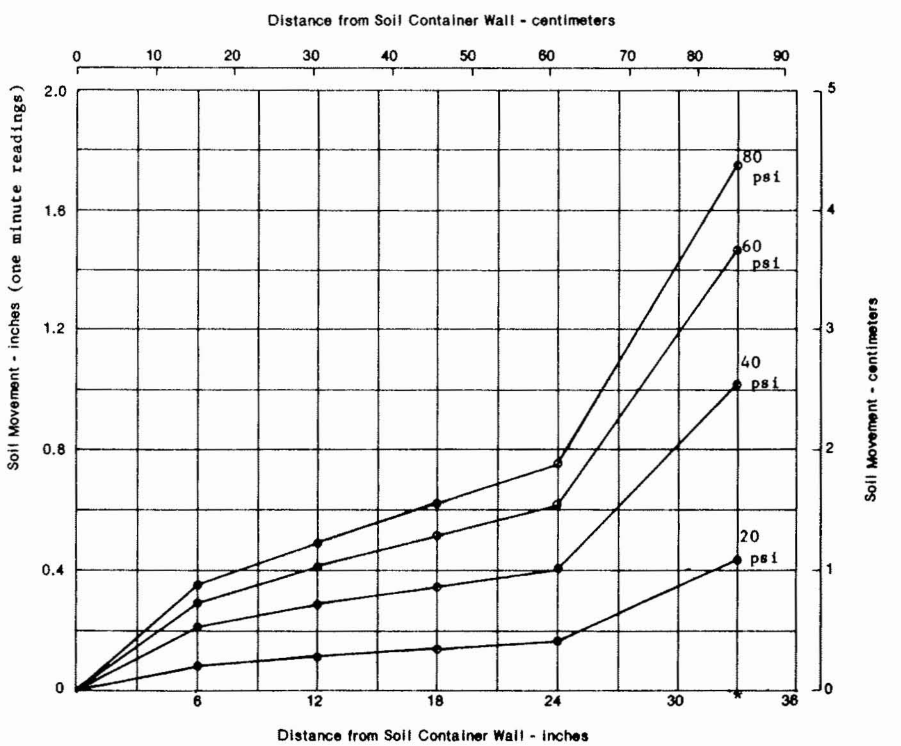

Figure A-18. Soil movement between pipe and soil container wall — west side of 18-inch-diameter FRP pipe with $EI/r^3 = 4.5$ psi (0.32 kg/cm^2).

*Original Distance to Side of Pipe

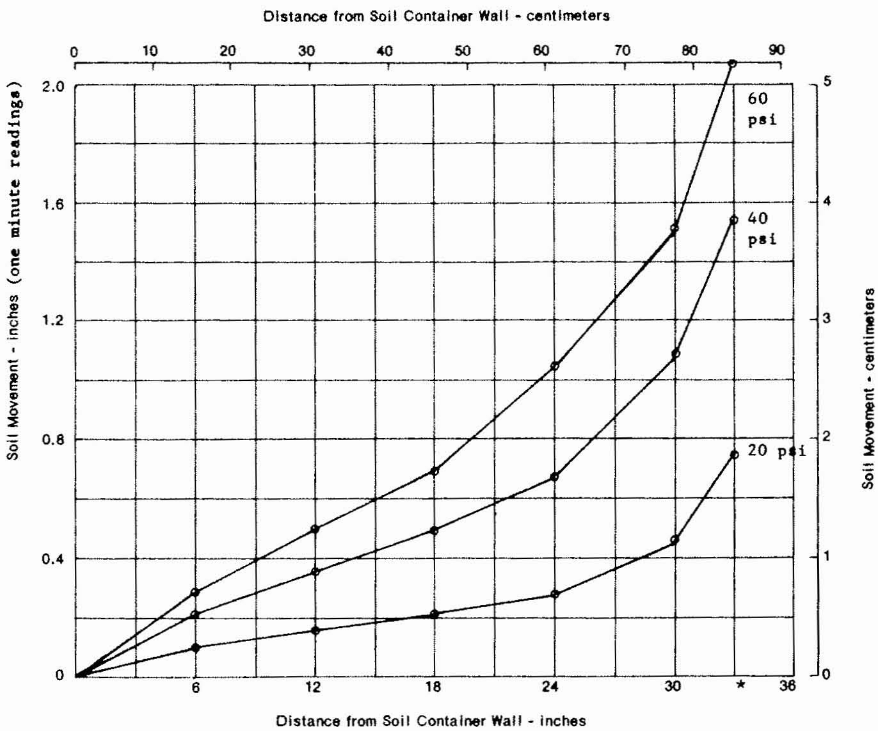

Figure A-19. Soil movement between pipe and soil container wall — east side of 18-inch-diameter FRP pipe with EI/r^3 = 3.0 psi (0.21 kg/cm^2).

*Original Distance to Side of Pipe

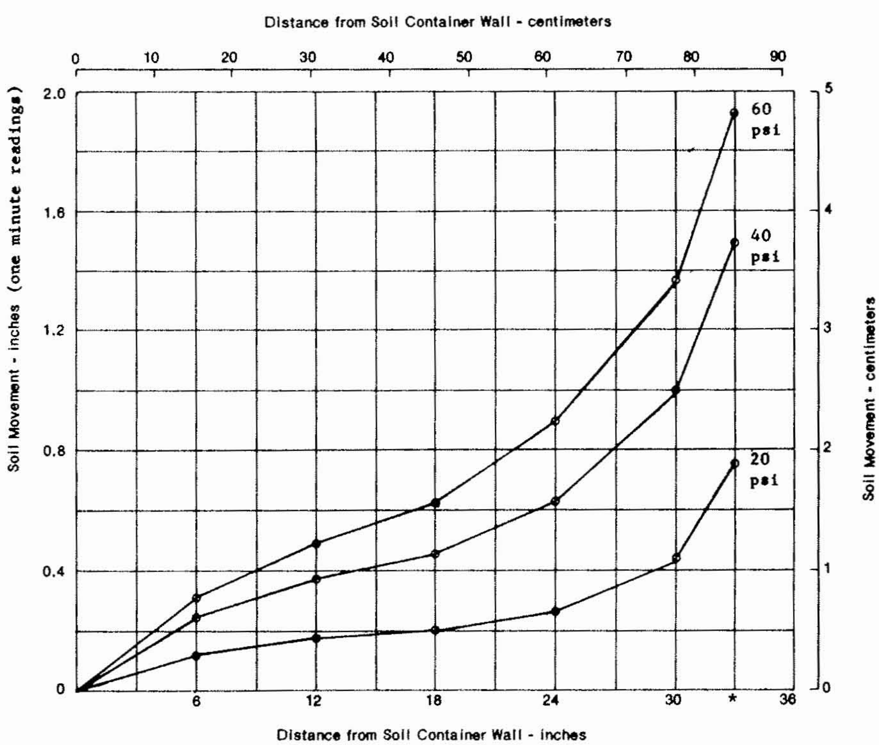

Figure A-20. Soil movement between pipe and soil container wall — west side of 18-inch-diameter FRP pipe with EI/r^3 = 3.0 psi (0.21 kg/cm^2).

*Original Distance to Side of Pipe

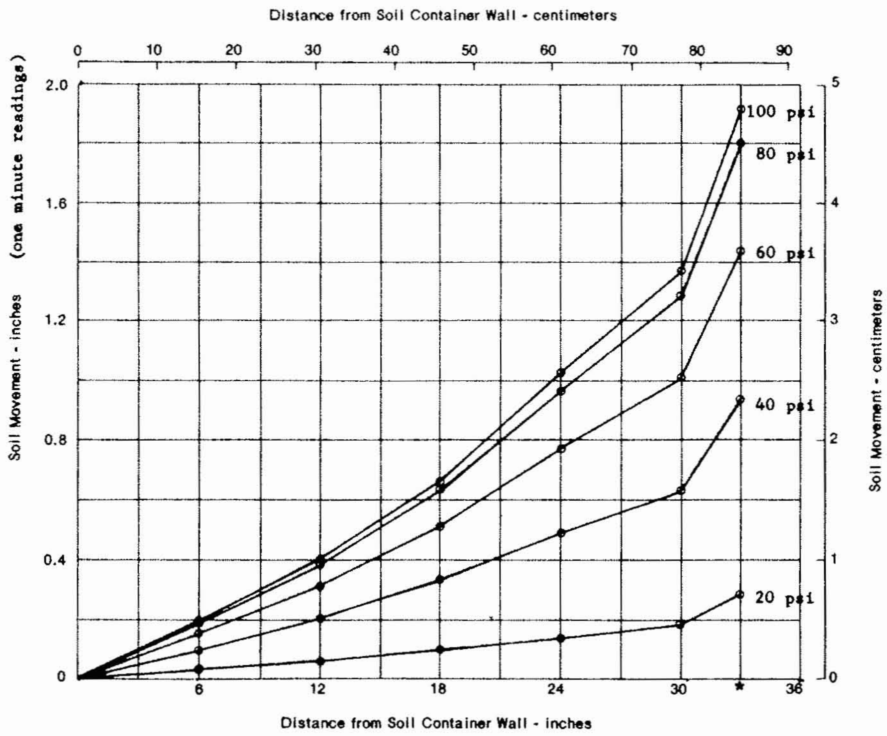

Figure A-21. Soil movement between pipe and soil container wall — east side of 18-inch-diameter PE pipe with EI/r^3 = 8-10 psi (0.56-0.70 kg/cm^2).

*Original Distance to Side of Pipe

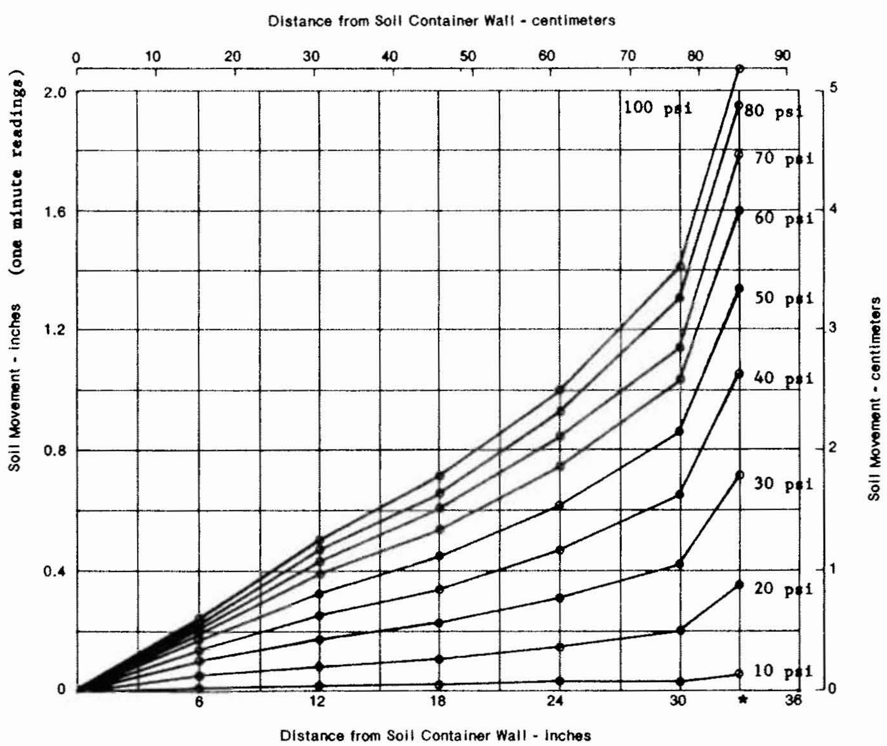

Figure A-22. Soil movement between pipe and soil container wall — west side of 18-inch-diameter PE pipe with EI/r^3 = 8-10 psi (0.56-0.70 kg/cm^2).

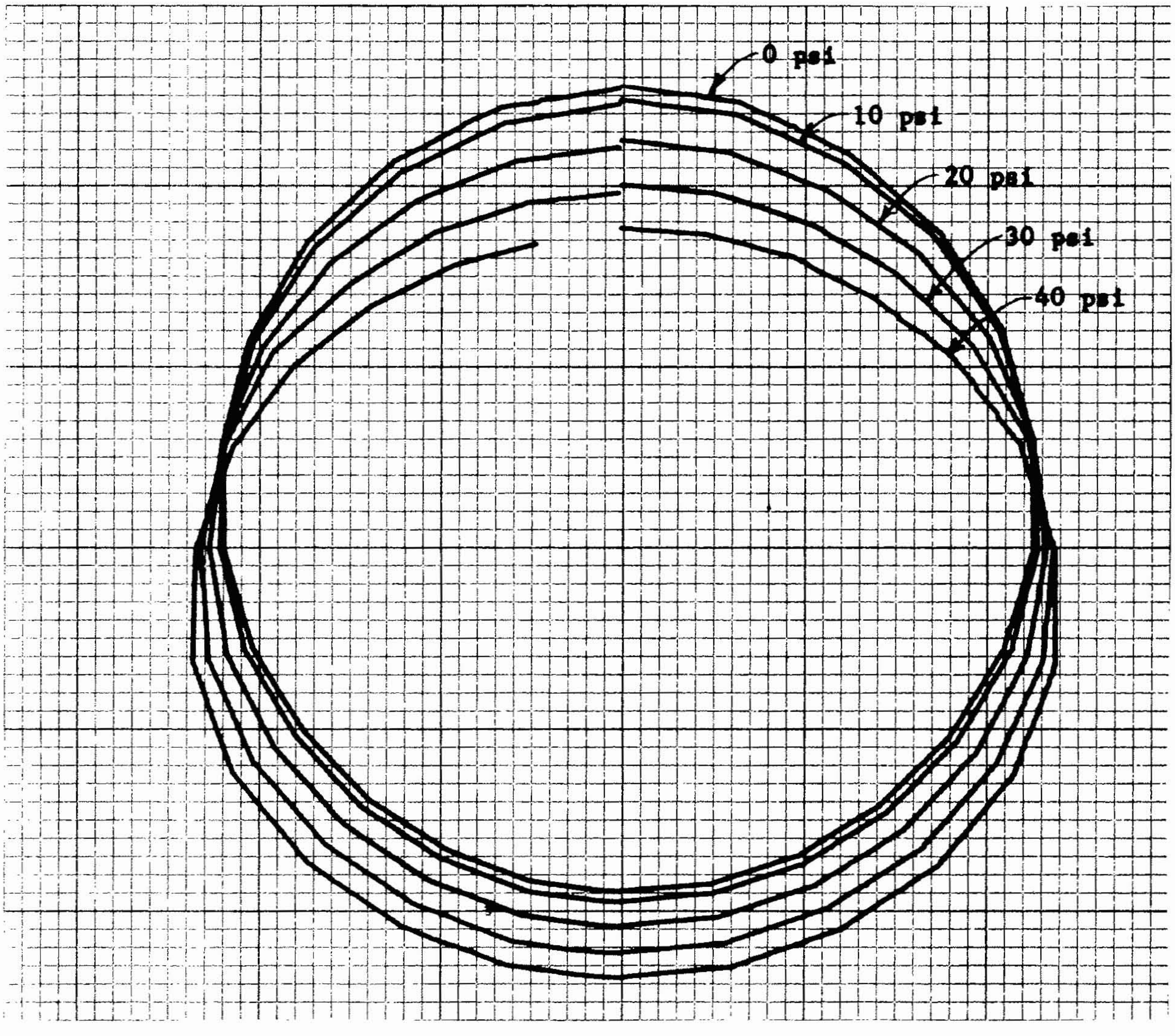

Figure A-23. Cross section of pipe under load, 18-inch inside diameter FRP pipe, EI/r^3 = 19.0 psi (1.34 kg/cm^2).

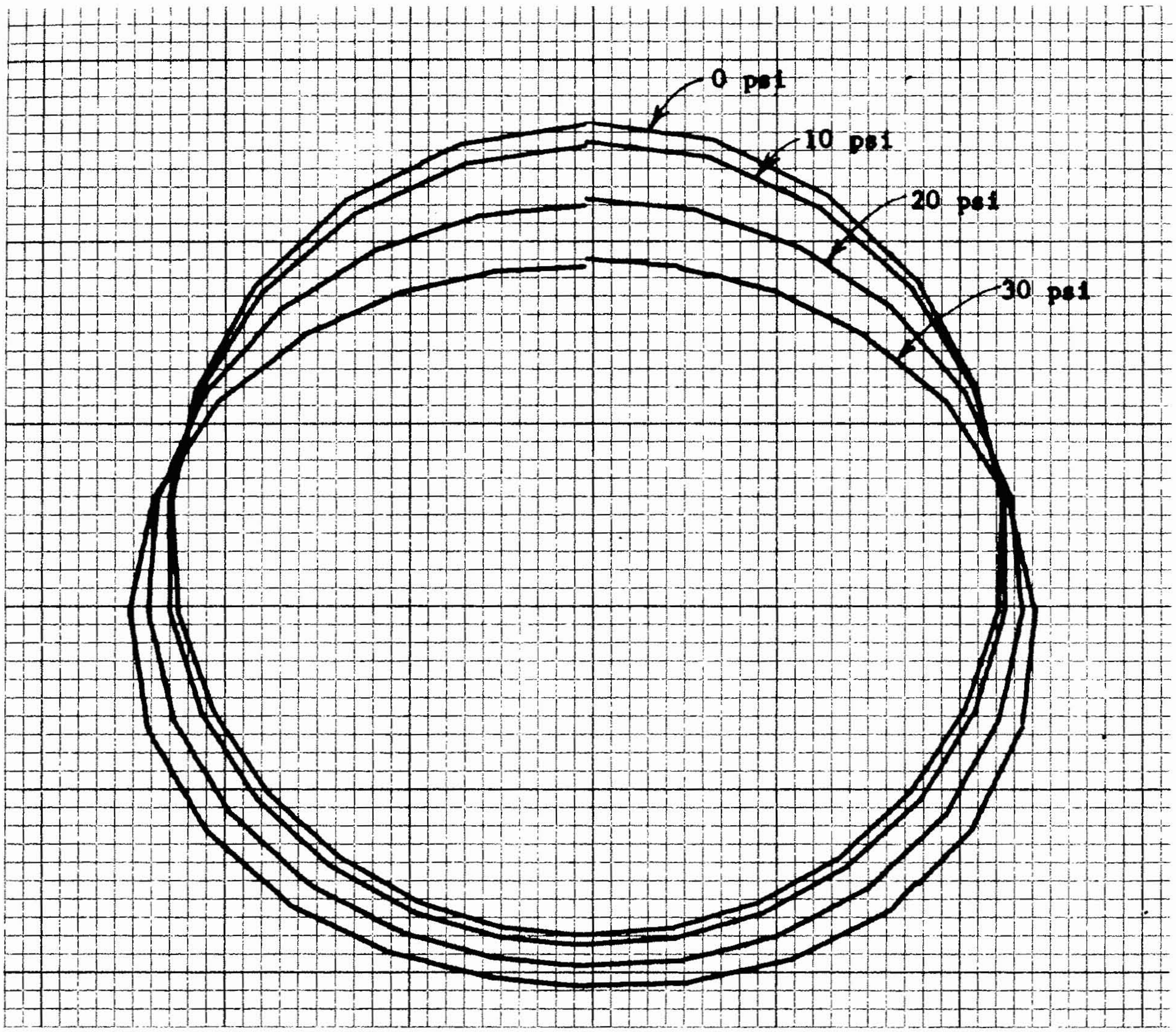

Figure A-24. Cross section of pipe under load, 18-inch inside diameter FRP pipe, EI/r^3 = 4.5 psi (0.32 kg/cm^2).

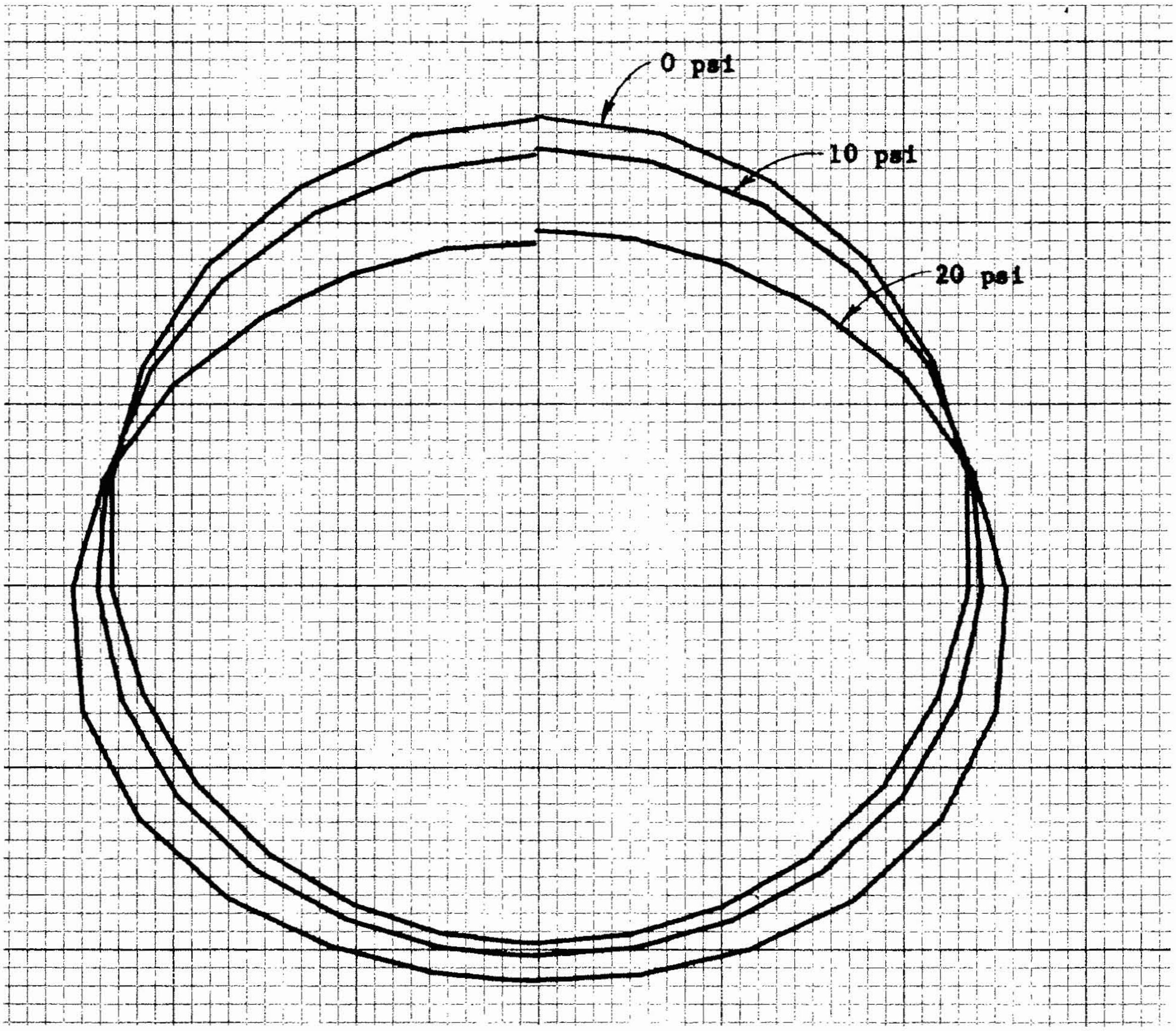

Figure A-25. Cross section of pipe under load, 18-inch inside diameter FRP pipe, EI/r^3 = 3.0 psi (0.21 kg/cm^2).

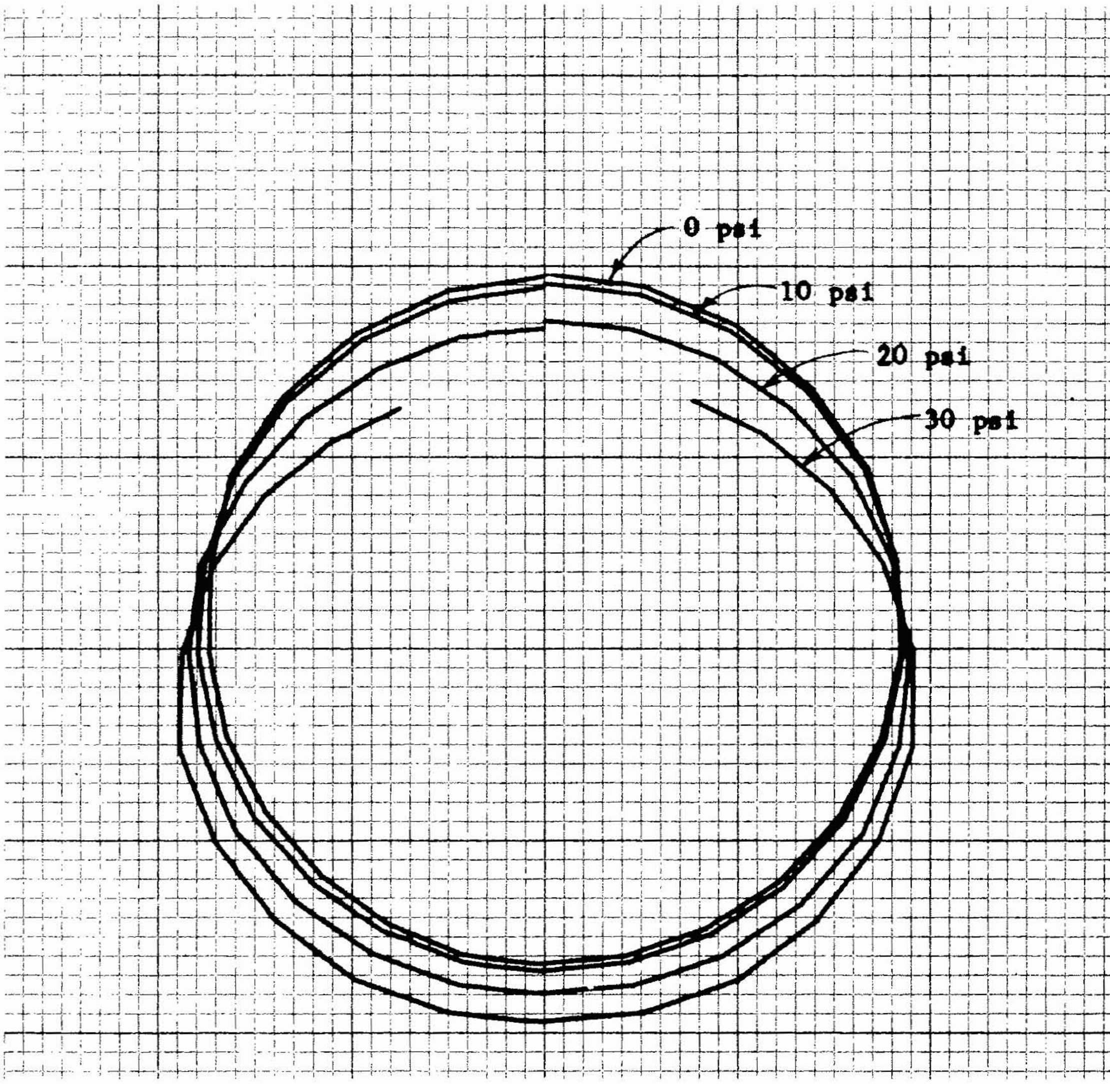

Figure A-26. Cross section of pipe under load, 15-inch inside diameter PVC pipe, EI/r^3 = 7.0 psi (0.49 kg/cm^2).

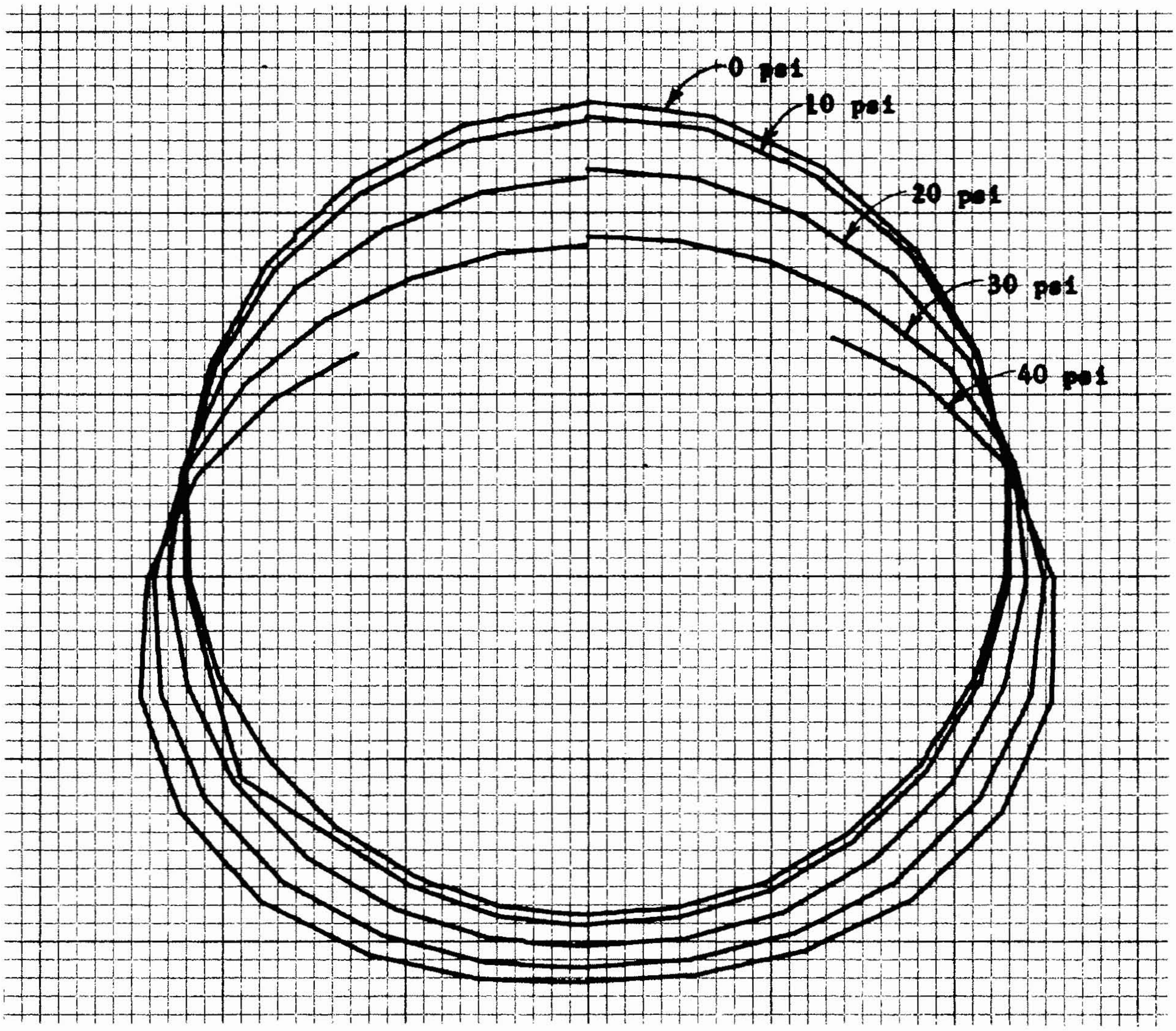

Figure A-27. Cross section of pipe under load, 18-inch inside diameter polyethylene pipe, EI/r^3 = 8-10 psi (0.56-0.70 kg/cm^2).

APPENDIX B

PHYSICAL PROPERTIES OF TEST SOIL

INTRODUCTION

The same soil was used repeatedly for all the load tests, including earlier tests on concrete pipe. The soil was a reddish-brown, lean clay (CL in the Unified Classification System). Standard property tests were periodically performed on samples of the soil to determine if any physical properties had changed. As related to the soil, a "load test" is defined as the placement of the soil in the container, the loading of the soil by the universal testing machine, and its subsequent removal and processing for the next load test. For the first seven tests, which were on concrete pipe, the soil was broken up by shovel after its removal. For the remaining tests, the soil was processed with a commercial soil shredder. The standard property tests showed the soil went through an initial breakdown due to the first nine load tests. Subsequent testing shows that the soil properties have remained fairly constant following this initial breakdown.

The physical properties were determined using standard test procedures outlined in the *Earth Manual*[1] of the USBR. The properties and the time intervals between determinations are presented in Table B-1.

STANDARD PROPERTIES

Gradation Analysis

The curves of the gradation analysis of the soil following the load tests have all fallen within a narrow band as shown in Figure B-1. Compared to the gradation analysis curve of the soil before any tests were run (shown in Figure B-1), the band of curves shows that the soil is about 10 to 15 percent finer due to the load tests. Following the initial breakdown, the gradation of the soil has remained fairly constant.

Atterberg Limits and Specific Gravity

The liquid limit and plasticity index of the soil changed slightly due to the first group of load tests and then remained consistent for subsequent determinations as shown in Table B-1. The specific gravity of the soil remained relatively uniform.

Proctor Compaction Curves

Individual Proctor soil density-moisture curves were too variable to permit comparisons, so since 1968 each time the soil properties were determined, five or six Proctor tests were run and an average curve used. An average curve for one of these determinations is plotted in Figure B-2. The maximum densities and optimum moistures are listed in Table B-1. There appears to be a general trend of the density-moisture curves shifting upwards and to the left, resulting in higher maximum dry density values and lower optimum moisture values. The increase in the Proctor maximum dry density has been 1 pcf (0.02 gm/cc) or less, not enough to seriously affect the percent of Proctor values used to evaluate the soil density values in the soil container. A Proctor maximum dry density value of 120.0 pcf (1.92 gm/cc) was used for all of the load tests.

The density of the soil placed in the soil container was measured by the balloon density method. The volume of the density hole is found by placing a balloon in the hole and filling it with water from a calibrated tank. The volume of the hole is then assumed to be the same as the volume of water used.

[1] U.S. Bureau of Reclamation, *Earth Manual,* 1st Edition, Revised 1963, Denver. Colorado.

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SUMMARY OF PHYSICAL PROPERTIES TEST RESULTS (Proctor Compaction)

TABLE B-1
SHEET ____ OF ____

PROJECT Load tests on buried flexible pipe FEATURE Soil No. 24G-103

IDENTIFICATION				PARTICLE-SIZE FRACTIONS IN PERCENT						CONSISTENCY LIMITS			SPECIFIC GRAVITY				COMPACTION TEST			
				FINES										PLUS NO. 4						
~~SAMPLE NUMBER~~ YEAR TESTED	MONTH TESTED ~~HOLE NUMBER~~	Number of load tests since the last ~~DEPTH (m)~~ determination of physical properties	CLASSIFICATION SYMBOL	SMALLER THAN 0.005 mm	0.005 TO 0.074 mm	SAND NO. 200 (0.074 mm) TO NO. 4 (4.76 mm)	GRAVEL NO. 4 (4.76 mm) TO 3 IN. (76.2 mm)	COBBLES 3 IN. (76.2 mm) TO 5 IN. (127 mm)	OVERSIZE LARGER THAN 5 IN. (127 mm)	LIQUID LIMIT - %	PLASTICITY INDEX - %	SHRINKAGE LIMIT - %	MINUS NO. 4	BULK	APPARENT	ABSORPTION - %	MAXIMUM DRY DENSITY - pcf (gm/cm³)	OPTIMUM WATER CONTENT - %	PENETRATION RESISTANCE - psi (kg/cm²)	
1963		none	SC-CL	19	31	50	0			23	9		2.66				120.2	12.4		
																	(1.925)			
1966	Nov.	9	CL	31	31	37	1			27	13		2.69				119.4	12.0		
																	(1.913)			
1968	April	6	CL	30	30	40	0			28	16		2.70				120.0	12.0		
				31	32	37	0										(1.922)			
1969	Jan.	4	CL	33	31	36	0			28	15		2.70							
				33	31	36	0			28	15									
1969	Nov.	5	CL	30	34	36	0			27	14		2.69				120.7	11.5		
				30	34	36	0			27	15		2.69				(1.933)			
				32	34	34	0													
1971	Jan.	7	CL	32	32	36	0			27	15		2.68				120.4	11.8		
				31	32	37	0			27	14		2.69				(1.929)			
				31	32	36	0			28	16		2.68							
1972	June	7	CL	32	32	36	0			27	15		2.69				121.0	11.5		
				30	34	36	0			27	15		2.69				(1.938)			
				32	32	36	0			28	16		2.69							

NOTE: *Numbers in parentheses are metric equivalents of numbers directly above.*

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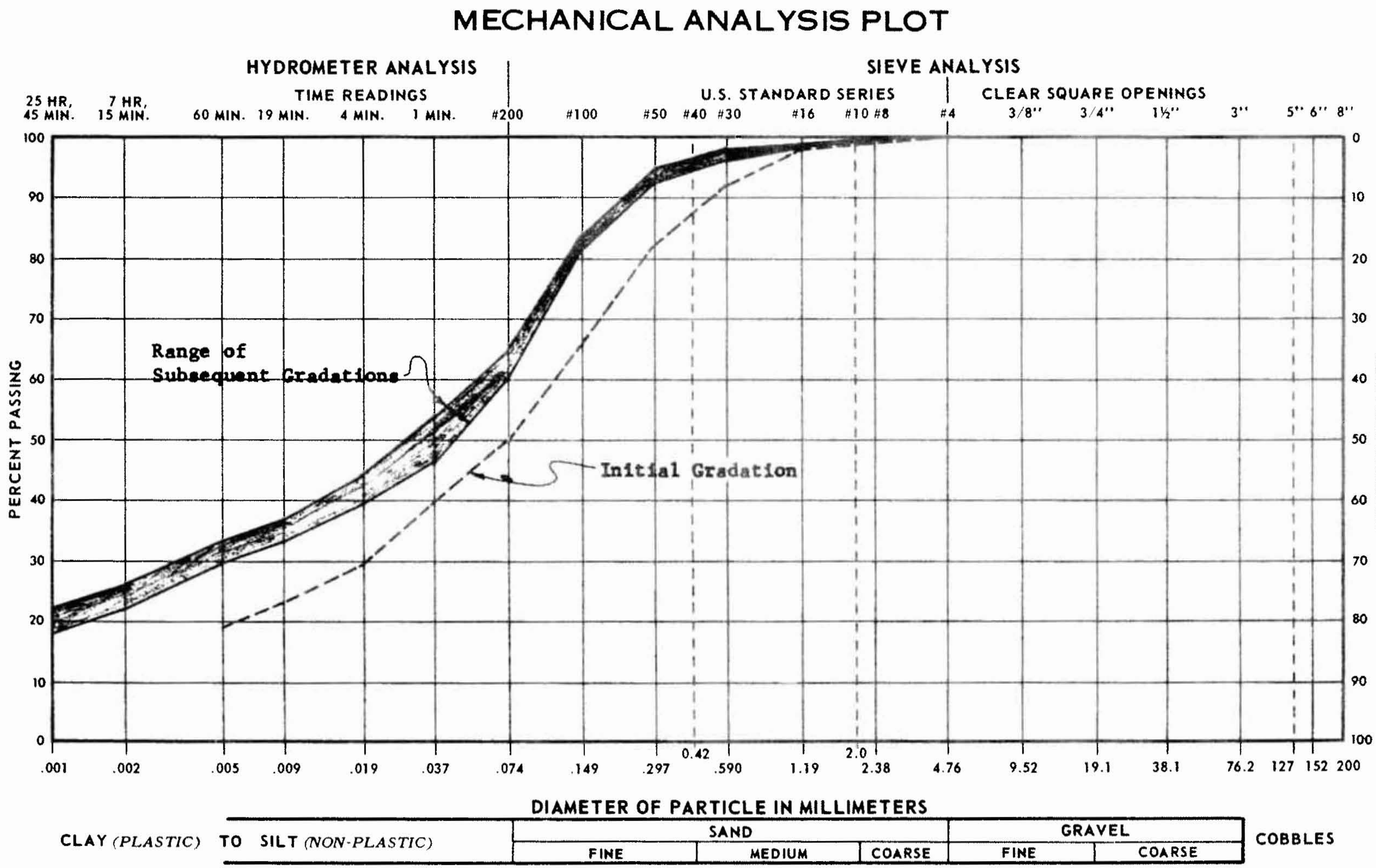

Figure B-1. Gradation tests.

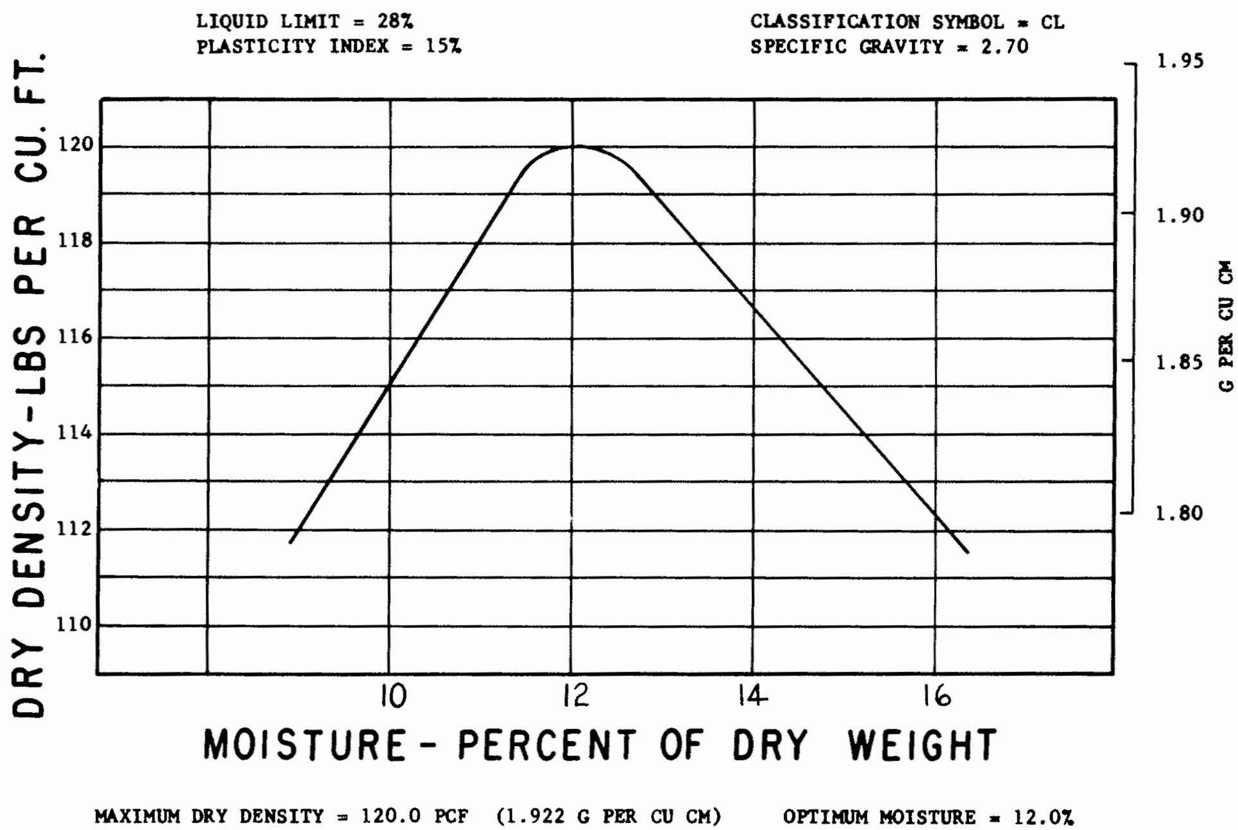

Figure B-2. Proctor compaction curve.

APPENDIX C

REACTION OF FRP, PE, AND PVC PIPE TO HIGH DEFLECTIONS

THERMOPLASTIC PIPE

Test K was performed on a 15-inch (38-cm) outside diameter PVC pipe with a Ring Stiffness Factor of 7.0 psi (0.49 kg/cm^2). Figure C-1 shows the pipe in place in the soil container before any surcharge load was applied. Figure C-2 shows the pipe at 100-psi (7.03-kg/cm^2) surcharge with 29 percent vertical deflection. No cracking or structural distress was visible at this deflection. When the pipe was removed from the soil container, it remained deformed but has slowly rebounded. Two months after the test the vertical diameter of the pipe had returned to 97 percent of the original diameter.

Test L was performed on an 18-inch (46-cm) inside diameter PE pipe with a Ring Stiffness Factor of 8-10 psi (0.56 to 0.70 kg/cm^2). Figure C-3 shows the pipe in place in the soil container before any surcharge was applied. Figure C-4 shows the pipe at 100-psi (7.03-kg/cm^2) surcharge with 42 percent vertical deflection. No cracking or structural distress was visible at this deflection. The pipe was deformed after it was removed from the soil container but slowly rebounded. Two months after the test the vertical diameter had returned to 94 percent of the original diameter.

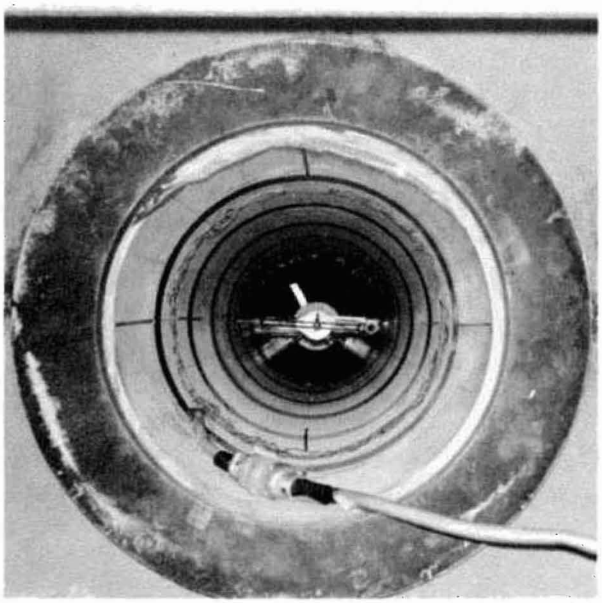

Figure C-1. 15-inch (38-cm) diameter PVC pipe in soil container prior to loading (Test K). Photo P801-D-73861

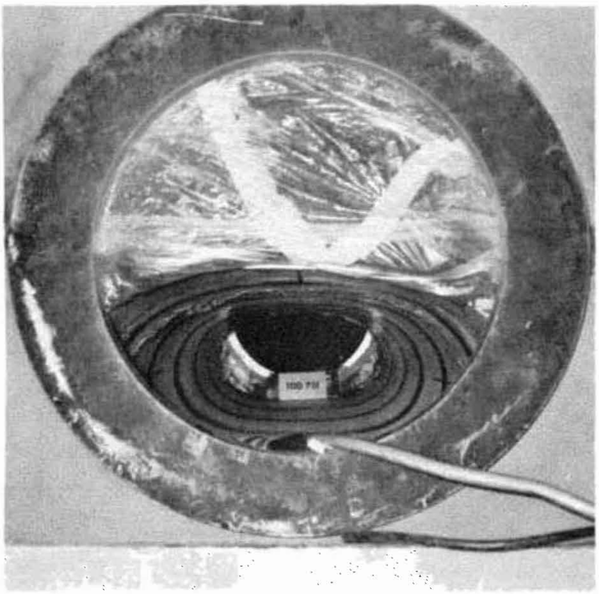

Figure C-2. 15-inch (38-cm) diameter PVC pipe with 29 percent vertical deflection at 100 psi (7.03 kg/cm^2) surcharge. Photo P801-D-73862

GLASS REINFORCED RESIN PIPE

Test E was performed on an 18-inch (46-cm) diameter FRP pipe with a Ring Stiffness Factor of 19.0 psi (1.34 kg/cm^2). Figure C-5 shows the pipe in place in the soil container before any surcharge was applied. The pipe deflected 23 percent vertically at 100-psi (7.03-kg/cm^2) surcharge as shown in Figure C-6.

A slight crazing (fine, hairlike cracks) of the inner surfaces that were under tension was noticed at 12 percent vertical deflection. Under succeeding loads the crazing slowly developed into the cracking pattern shown in Figure C-7.

Test G was performed on an 18-inch (46-cm) diameter FRP pipe (same manufacturer as Test Pipe E) with a Ring Stiffness Factor of 4.5 psi (0.32 kg/cm^2). Figure C-8 shows the pipe in place in the soil container before any surcharge was applied. The pipe deflected 32 percent vertically at 80 psi (5.62 kg/cm^2), the maximum applied surcharge (see Figure C-9). Crazing was noticed in the top and bottom inner surfaces of the pipe, the areas in tension, at about 17 percent vertical deflection. The crazing slowly developed into

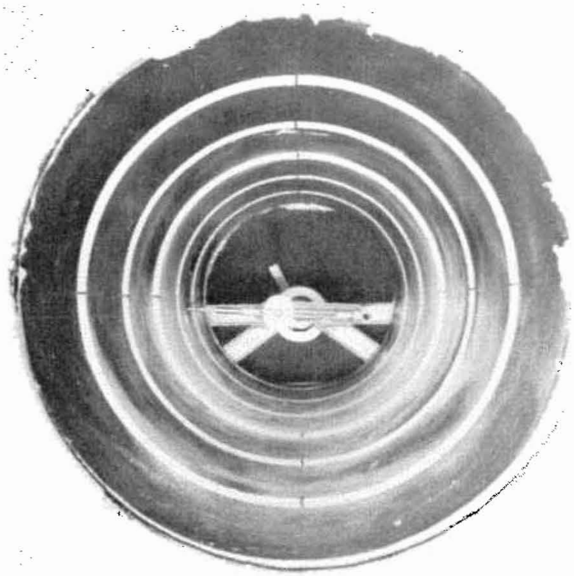

Figure C-3. 18-inch (46-cm) inside-diameter polyethylene pipe in soil container prior to loading (Test L). Photo P801-D-73863

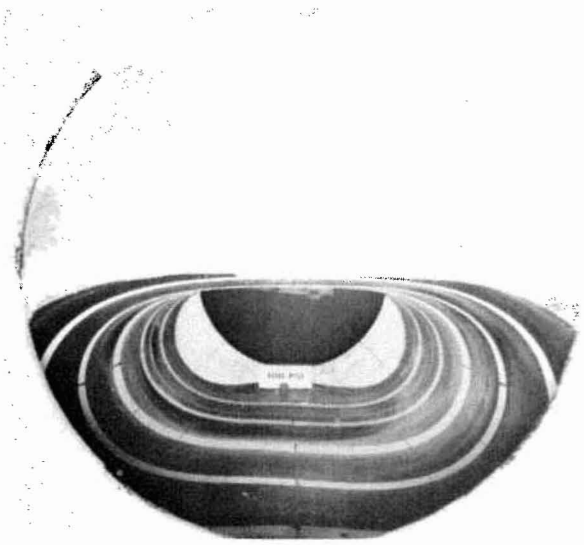

Figure C-4. 18-inch (46-cm) inside-diameter polyetheylene pipe with 42 percent vertical deflection at 100 psi (7.03 kg/cm^2) surcharge (Test L). Photo P801-D-73864

the cracking pattern illustrated in Figure C-10 during the succeeding loadings.

Test H was performed on an 18-inch (46-cm) diameter FRP pipe from a different manufacturer than Test Pipes E and G. It had a Ring Stiffness Factor of 3.0 psi (0.21 kg/cm^2). Figure C-11 shows the pipe in place in the soil container before any surcharge has been

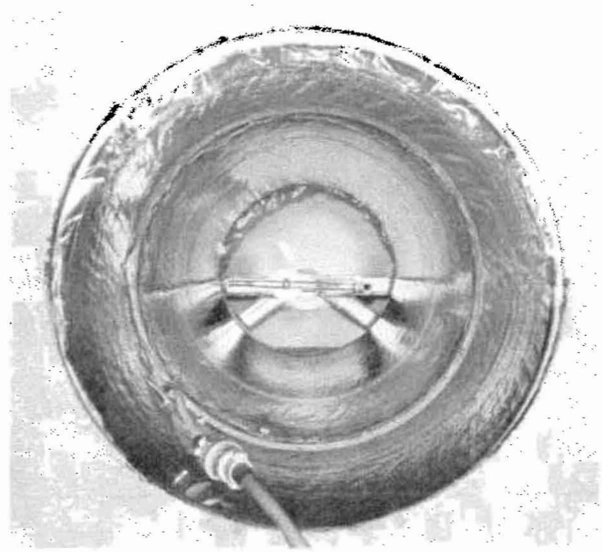

Figure C-5. 18-inch (46-cm) diameter FRP pipe in soil container prior to loading (Test E). Photo P801-D-73865

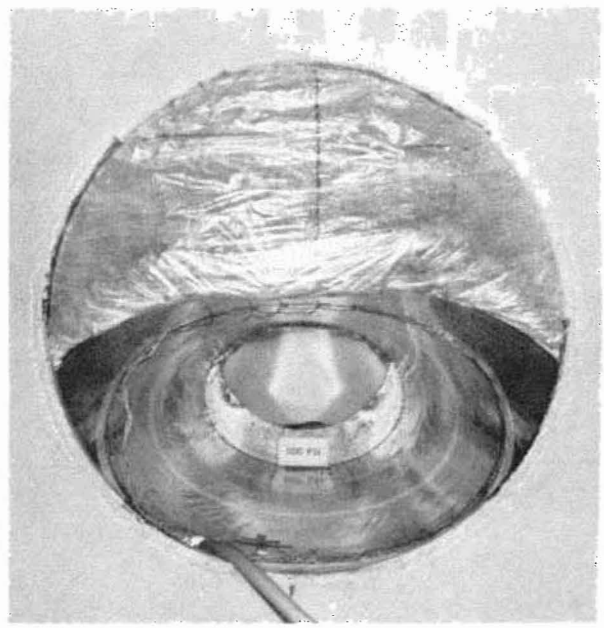

Figure C-6. 18-inch (46-cm) diameter FRP pipe with 23 percent vertical deflection at 100 psi (7.03 kg/cm^2) surcharge (Test E). Photo P801-D-73866

applied. The pipe deflected 38 percent at 70 psi (4.92 kg/cm^2), the maximum applied surcharge (shown in Figure C-12). As the 70-psi (4.92-kg/cm^2) surcharge was being applied, a crack occurred in the bottom of the pipe starting at the south end. The crack can be seen in Figure C-12, and a closeup of the crack is shown in Figure C-13. The crack continued to propagate during the few minutes that the 70-psi (4.92-kg/cm²) surcharge was held constant. The final length of the crack was 34 inches (86 cm).

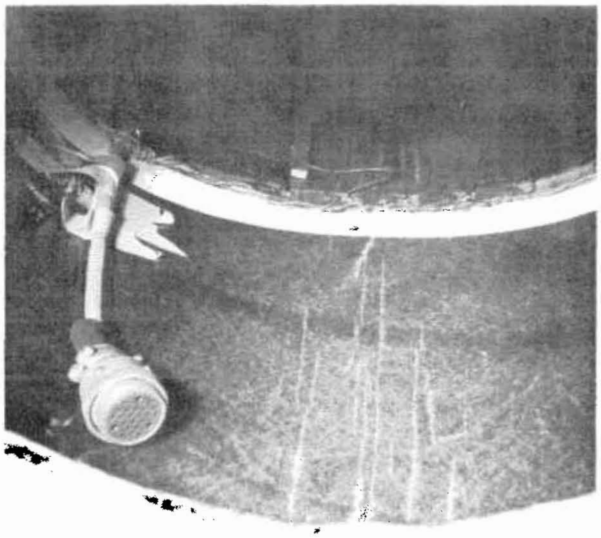

Figure C-7. Cracking pattern in bottom of 18-inch (46-cm) diameter FRP pipe (Test E). Photo P801-D-73867

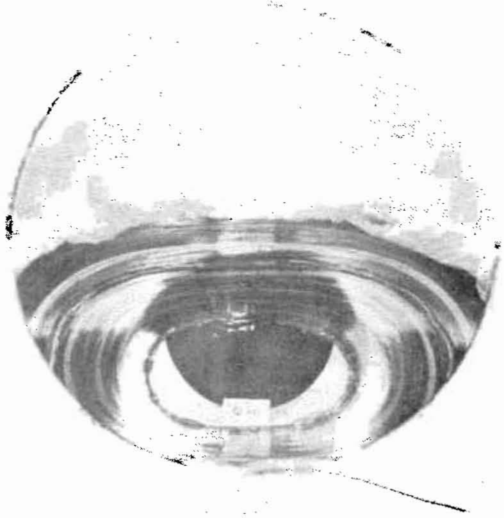

Figure C-9. 18-inch (46-cm) diameter FRP pipe with 32 percent vertical deflection at 80 psi (5.62 kg/cm^2) surcharge (Test G). Photo P801-D-73869

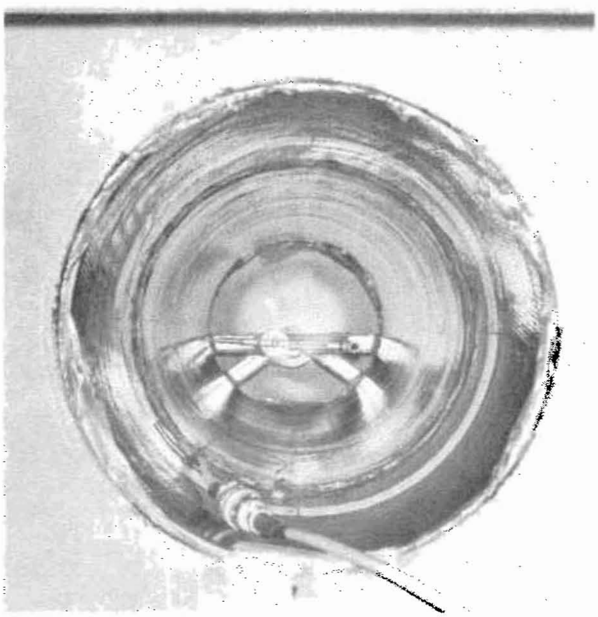

Figure C-8. 18-inch (46-cm) diameter FRP pipe in soil container prior to loading (Test G). Photo P801-D-73868

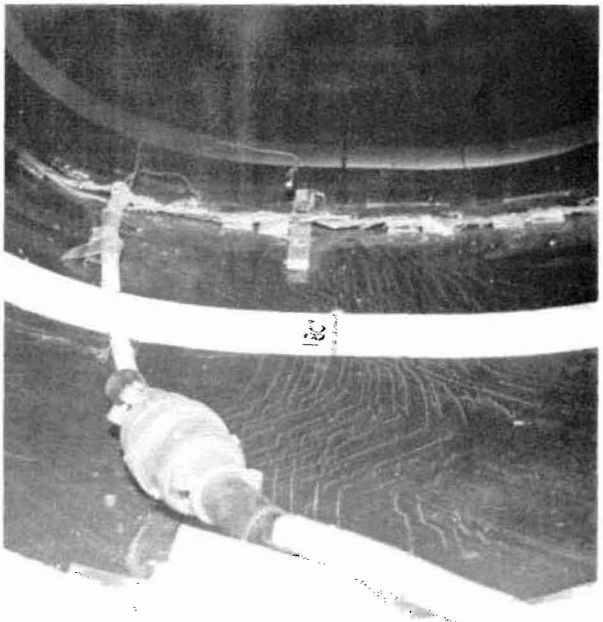

Figure C-10. Cracking pattern in bottom of 18-inch (46-cm) diameter FRP pipe (Test G). Photo P801-D-73870

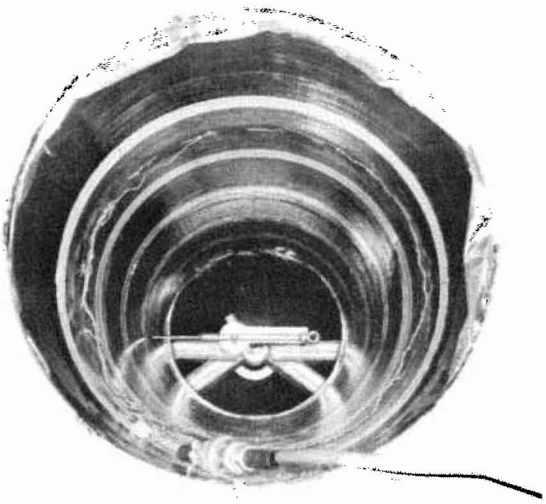

Figure C-11. 18-inch (46-cm) diameter FRP pipe in soil container prior to loading (Test H). Photo P801-D-73871

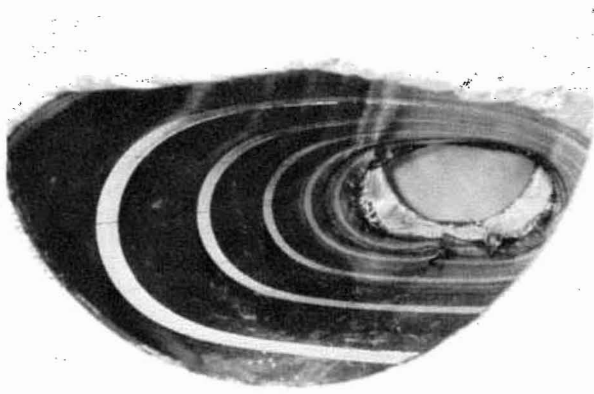

Figure C-12. 18-inch (46-cm) diameter FRP pipe with 38 percent vertical deflection at 70 psi (4.92 kg/cm^2) surcharge (Test H). Notice large crack in bottom of pipe on opposite end. Photo P801-D-73872

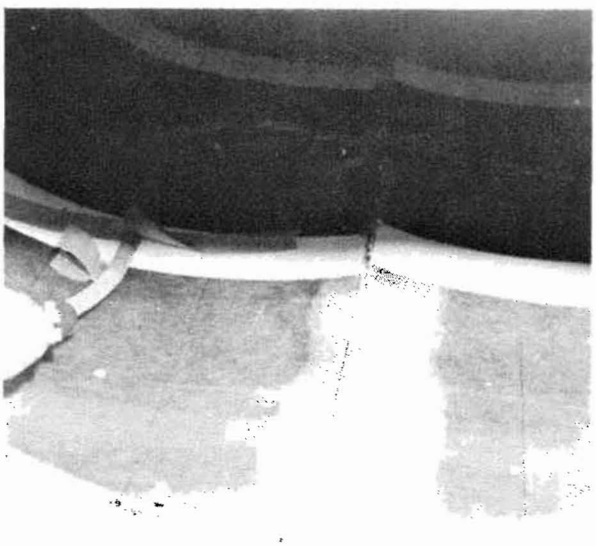

Figure C-13. Large crack in bottom of 18-inch (46-cm) diameter FRP pipe (Test H). Photo P801-D-73873

CONVERSION FACTORS–BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg, that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Inches	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*0.0040469	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*1,233,500	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
Short tons (2,000 lb)	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
Pounds per cubic foot	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
Feet per second	0.3048 (exactly)*	Meters per second
Feet per year	*0.965873×10^{-6}	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	*0.3048	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	*0.028317	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	*0.453592	Kilograms
Pounds	*4.4482	Newtons
Pounds	*4.4482×10^5	Dynes

Table II–Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories
British thermal units (Btu)	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	*1.35582	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*0.09290	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor) transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	*304.8	Liters per square meter per day
Pound-seconds per square foot (viscosity)	*4.8824	Kilogram second per square meter
Square feet per second (viscosity)	*0.092903	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	*35.3147	Millicuries per cubic meter
Milliamps per square foot	*10.7639	Milliamps per square meter
Gallons per square yard	*4.527219	Liters per square meter
Pounds per inch	*0.17858	Kilograms per centimeter

GPO 854-182

ABSTRACT

Laboratory tests were conducted to investigate the behavior of buried flexible pipes. Kinds of pipe tested were figerglass reinforced plastic (FRP), polyvinyl chloride (PVC), and polyethylene (PE). The pipes were buried in a large, steel, soil container in a lean clay backfill. A large universal testing machine was used to apply surcharge loads to the soil surface over the pipe. Measurements of the changing dimensions of the pipe, strain on the inner surface of the pipe, soil movement around the pipe, and soil pressures were made during a 1-day loading sequence. Test results are presented and deflections under load are compared to tests of steel pipe and of reinforced plastic mortar (RPM) pipe. The FRP pipe deflected similar to the RPM pipe, while PVC pipe and PE pipe showed a similarity to steel pipe. Three-edge bearing tests used to determine pipe strength did not provide a reliable basis for predicting the deflection of different kinds of pipe. Deflection values varied as much as 300 percent for different kinds of pipe even though their three-edge bearing load-deflection curves were identical. The study showed that FRP pipe deflects differently than steel, PVC, or PE pipe, and that care must be taken to assure proper bedding of the FRP pipe. (8 ref)

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REC–ERC-73-16
Howard, A K
LABORATORY LOAD TESTS ON BURIED FLEXIBLE PIPE: PROGRESS REPORT NO. 5
Bur Reclam Rep REC-ERC-73-16, Div Gen Res, July 1973. Bureau of Reclamation, Denver, 48 p, 56 fig, 6 tab, 8 ref, 3 append

DESCRIPTORS–/ backfills/ *soil mechanics/ loading tests/ laboratory tests/ cohesive soils/ *buried pipes/ strain gages/ *flexible pipes/ pressure measuring instruments/ *soil pressure/ lateral forces/ resins/ *deflection/ deformation/ *plastic pipes/ stiffness/ polyetheylene/ load cells/ polyvinyl chloride/ glass reinforced plastics/ *pipelines/ strain
IDENTIFIERS–/ *Iowa Formula/ *soil-structure interaction/ fiberglass plastic pipe/ deflection measurement

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