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LABORATORY LOAD TESTS ON BURIED FLEXIBLE PIPE – PROGRESS REPORT NO. 6

Steel and Fiberglass Reinforced Resin Pipe in Sand Backfill

Amster K. Howard
Engineering and Research Center
Bureau of Reclamation

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16. ABSTRACT

Two steel pipe, one reinforced plastic mortar, and one fiberglass reinforced plastic pipe, each about 18 inches (46 centimeters) in diameter and 71 inches long were load-tested in a laboratory soil container. All pipe were buried in a sand backfill. Increasing surcharge increments were applied to the soil surface over the pipe. Data were collected on pipe deflection and shape, soil pressure, soil movement around the pipe, and strain on the inner surface of the pipe. Conclusions are: (1) Pipe tested in sand backfill (relative densities from 78 to 89 percent) deflected similarly—less than 1 percent at 100 psi (7.0 kg/cm^2) surcharge—regardless of pipe stiffness or pipe material. (2) Compared to tests on similar pipe in a low-density lean clay backfill, the sand backfill reduced pipe deflections over 95 percent. (3) The modulus of soil reaction of the sand backfill ranged from 6,000 psi (420 kg/cm^2) to 30,000 psi (2,100 kg/cm^2) depending on the calculation method used. The Iowa Formula predicts the percent deflection based on a ratio of the external pipe load to a combination of pipe strength and soil strength. The tests show that: (1) when high strength bedding is used, pipe material or strength has little effect on pipe deflection; and (2) when the soil is a poor material or is poorly compacted, pipe material or strength significantly affects pipe deflection. (Nine references)

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS--/ backfills/ *soil mechanics/ loading tests/ *buried pipes/ test procedures/ *flexible pipes/ soil pressure/ lateral forces/ glass reinforced plastics/ *steel pipes/ strain/ deflection/ deformation/ laboratory tests/ *plastic pipes/ polymers/ stiffness/ resins/ sands/ cohesionless soils/ *pipes/ pipe bedding

b. IDENTIFIERS--/ fiberglass plastic pipe/ Iowa Formula/ *soil-structure interaction/ reinforced plastic mortar pipe/ soil modulus

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Earth Sciences Branch
Division of General Research
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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
Rogers C. B. Morton, Secretary
Gilbert G. Stamm, Commissioner

ACKNOWLEDGMENT

This study was conducted under the supervision of Chester W. Jones, Head, Special Investigations and Research Section. Harold J. Gibbs is Chief of the Earth Sciences Branch. The report was reviewed by C. W. Jones and Henry Johns.

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INTRODUCTION

A 1971 estimate of pipeline needs by the Bureau of Reclamation (USBR) indicated that about 8,500 miles (14,000 km) of pipelines will be required by 1985 to service present and future water distribution projects. Pipe in sizes up to 108 inches (275 cm) in diameter operating under heads up to 600 feet (183 meters) will be required. The Earth Sciences Branch, Division of General Research (USBR), has been investigating the load-deflection characteristics of flexible pipe in an effort to provide designers with additional information about the soil parameters involved in flexible pipe design.

The initial work was done on steel pipe buried in low-density clay in a large soil container. The results were presented in the first two progress reports in this series.[1 2*] Additional work on steel pipe buried in a high-density clay backfill was discussed in the third progress report.[3] The combined studies on the steel pipe were summarized in a technical paper.[4] The next phase of the testing covered tests on plastic-base pipe (reinforced plastic mortar, fiberglass reinforced plastic, polyethene, and polyvinyl chloride) in the low-density lean clay backfill. These results are covered in Progress Reports 4[5] and 5[6]. A paper covering the entire testing program through mid 1972 was presented in early 1973.[7]

This report presents the results of tests on steel, reinforced plastic mortar (RPM), and fiberglass reinforced plastic (FRP) pipe buried in a sand backfill.

There are two general types of soil used for flexible pipe bedding, cohesive, and cohesionless. Cohesive material (predominately clay and silt) is generally compacted by mechanical tampers and is controlled by the Proctor moisture-density relationship. The maximum density of the cohesive material is determined in the laboratory, and the field density of the bedding material is expressed as a percentage of that maximum density. USBR specifications require at least 95 percent of Proctor maximum dry density for cohesive bedding material.

Cohesionless material (predominately sand and gravel) is generally compacted by saturation and internal vibration and is controlled by the relative density test method. The minimum and maximum density of the cohesionless material is determined in the laboratory and the field density of the bedding material is expressed as a percentage of the range between the minimum and maximum densities. USBR specifications require at least 70 percent relative density.

*Numbers designate references at end of text.

A cohesive material, the lean clay (CL in Unified Classification System), was compacted to either 90 or 100 percent of Proctor to give a low-modulus and a high-modulus backfill, respectively, and pipe were tested in both conditions.

The cohesionless material, a sand with 30 percent gravel (SP in Unified Classification System), was placed at 70 percent relative density or higher to give a second type of high-modulus backfill. Because of the interlocking of the granular structure of a cohesionless soil, it provides better support for the pipe than does a cohesive material at the same degree of denseness.

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-consolidation rate of the soil must be considered since the pipe will continue to deflect as the supporting soil at the sides of the pipe consolidates with time. The relationship then becomes:

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

The most common pipe deflection prediction equation is the Iowa Formula developed by Professor M. G. Spangler of Iowa State University.[8 9] The equation is given as:

$$\Delta X = D_1 \frac{KW\,r^3}{EI + 0.061\,e'r^3}$$

where:

ΔX = horizontal deflection of the pipe, inches
D_1 = deflection lag factor to compensate for the time-consolidation 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:

$$\Delta X/D = D_1 \frac{KW/D}{EI/r^3 + 0.061\,e'}$$

so that

$$\text{pipe percent deflection} = (\text{time-lag}) \frac{\text{load on the pipe}}{\text{pipe modulus} + \text{soil modulus}}$$

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 of passive resistance that the soil gives the pipe. The e' value is a modification[9] 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 semiempirical factor that is based on experience and judgment.

The laboratory load tests on buried flexible pipe were conducted 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, the 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.

When the value of the soil modulus becomes high enough, the effect of the pipe modulus (Ring Stiffness Factor) on the pipe deflection becomes negligible. This is illustrated in Figure 1 showing how the percent pipe deflection varies for different e' values and different Ring Stiffness Factors. One particular value for the load on the pipe is used for this illustration. Different load values would shift the position of the curves.

For low soil modulus values, such as e' = 500 psi, the pipe deflection is more dependent on the Ring Stiffness Factor of the pipe. Figure 2 shows the pipe deflections for a series of steel pipe of various stiffnesses from the tests in the low-density lean clay to illustrate this point. When the density of the clay was increased, thus increasing the modulus, the deflections of steel pipe were less than they were in the low-density soil, as shown in Figure 3. The high-modulus value also reduced the effect of the pipe strength on the deflection. The tests in the two

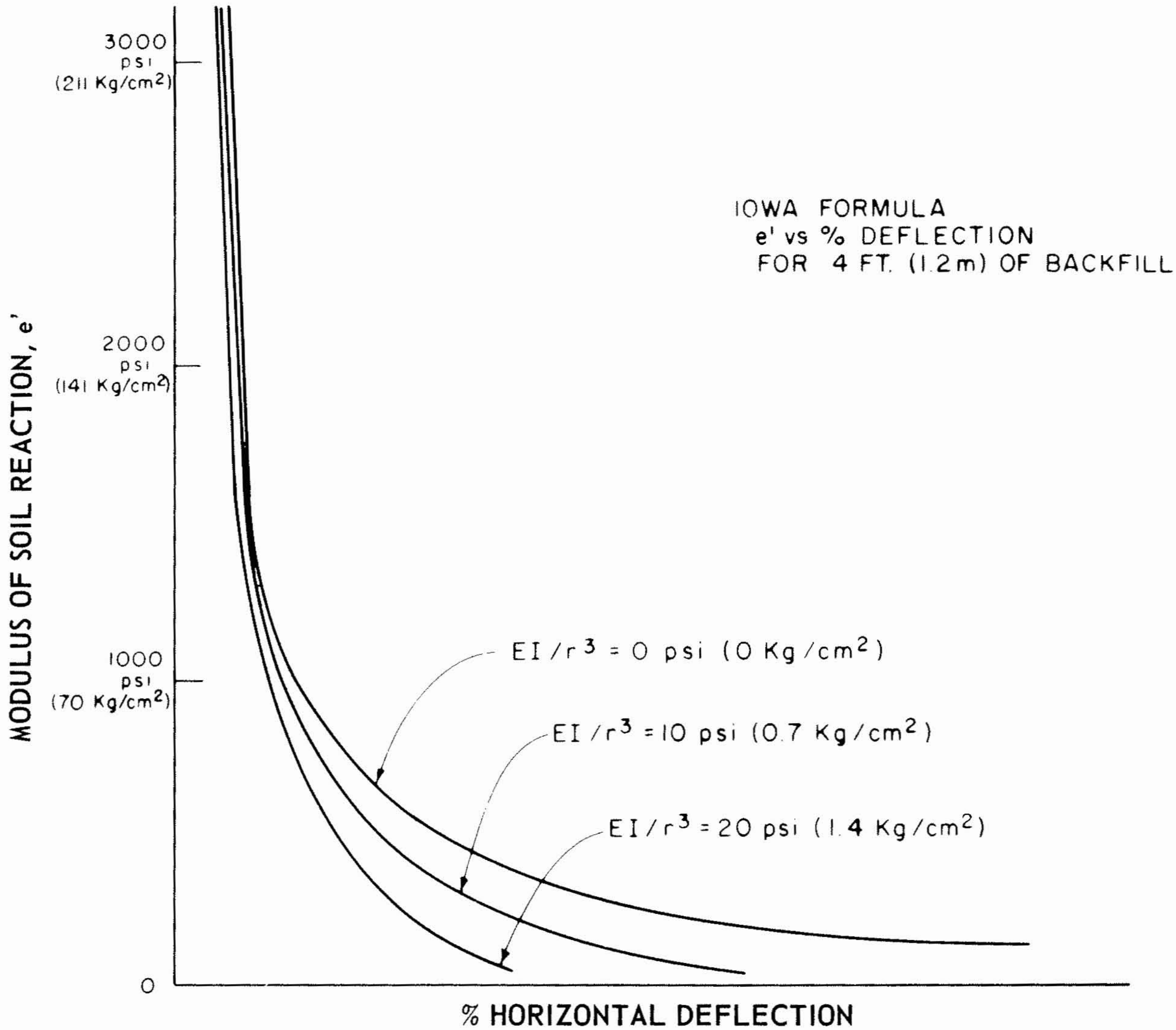

Figure 1. Percent horizontal deflection versus e' from Iowa Formula.

different density levels in the clay supported the basic relationships in the Iowa Formula, as illustrated in Figure 1.

The tests in the sand backfill were run to determine if this relationship held true for a different type of soil.

DESCRIPTION OF TEST

The 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 inplace in the container is shown in Figure 4. 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 stiffiness.

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 polyethylene film. The soil was placed in loose lifts and vibrated 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

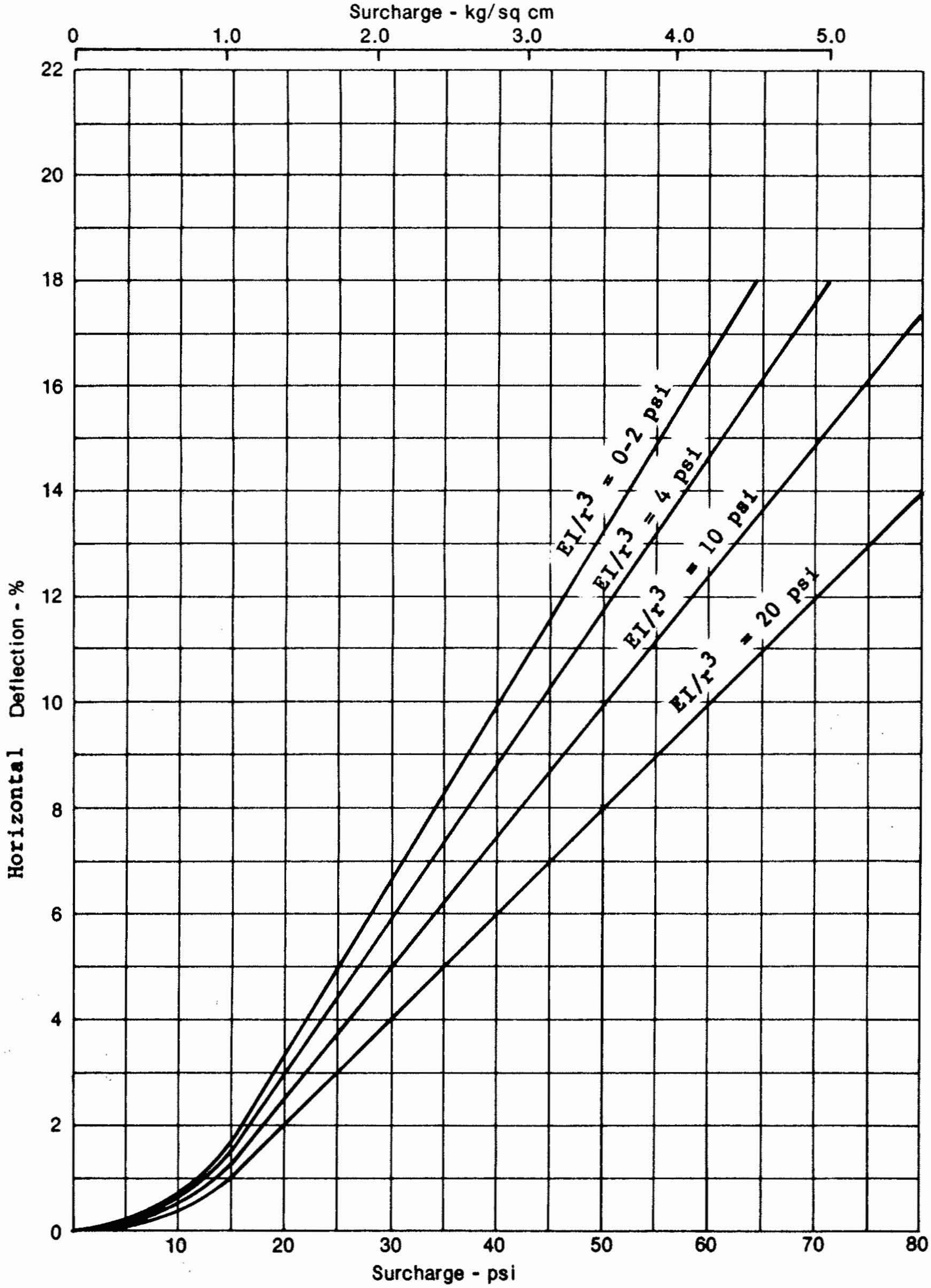

Figure 2. Steel pipe deflections for various EI/r^3 values in low-density clay.

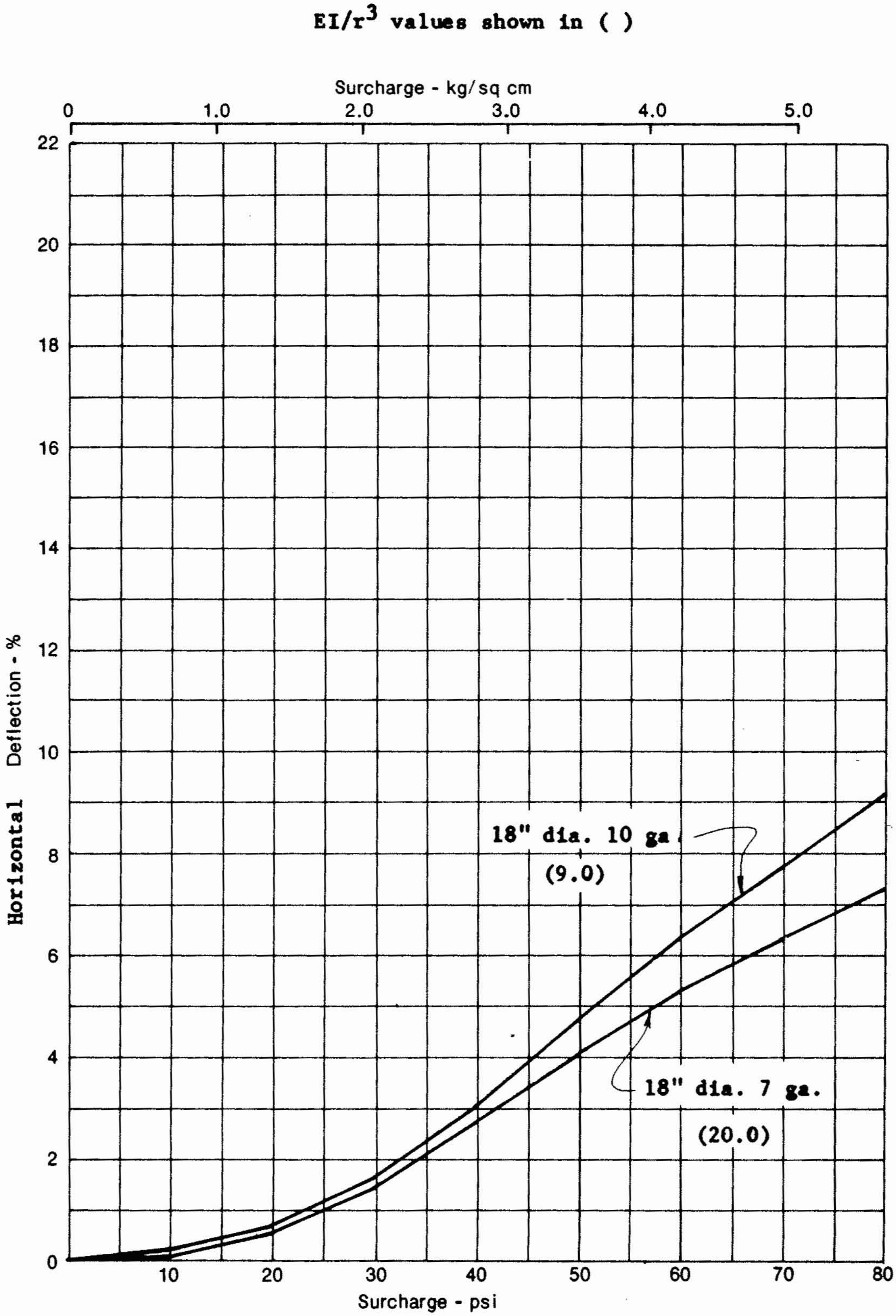

Figure 3. Horizontal deflection of steel pipe in high-density clay.

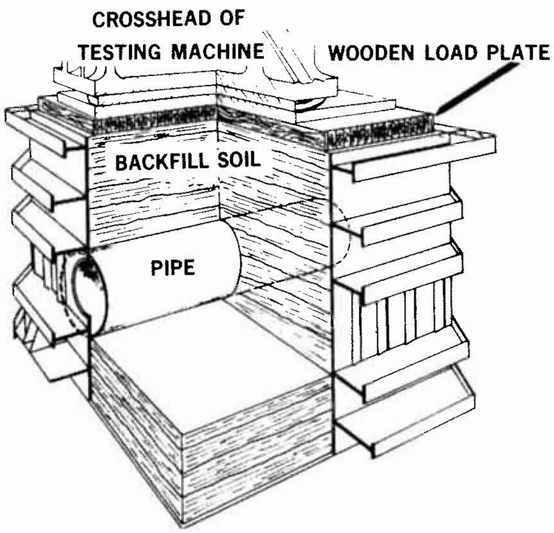

Figure 4. Soil container for buried pipe load test.

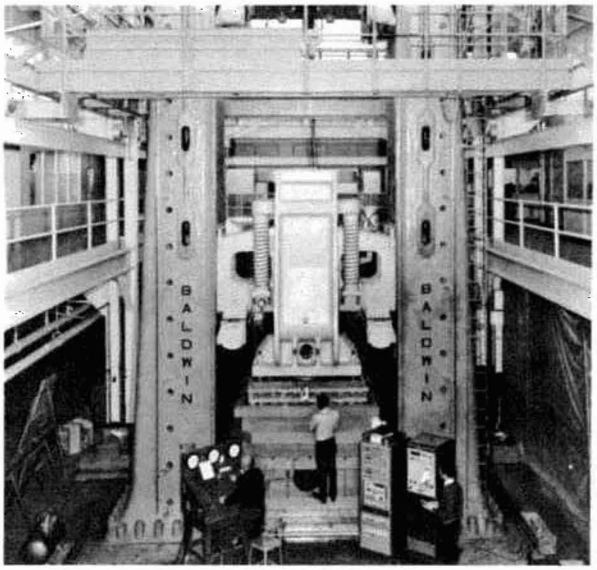

Figure 5. Load test setup and equipment. Photo PX-D-63288

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 placed and vibrated 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. A wooden load plate was then 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 minute and 60 minutes after each load was applied. Reading intervals between these times varied with the type of data required. Figure 5 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 about the one-fourth point 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.

TEST RESULTS

There were four pipe tests in the sand backfill, two steel pipe, an RPM pipe, and an FRP pipe. One steel pipe was five times stiffer, EI/r^3 = 23 psi (1.6 kg/cm^2), than the other steel pipe, EI/r^3 = 4.5 psi (0.3 kg/cm^2), to provide a deflection comparison for pipe of different stiffnesses. The FRP pipe, EI/r^3 = 18 psi (1.3 kg/cm^2), was compared to the stiffer steel pipe, EI/r^3 = 23 psi (1.6 kg/cm^2), to see how pipe of similar stiffness but different materials deflected. The RPM pipe was selected for the same purpose as the FRP pipe but its Ring Stiffness Factor was lower than expected, EI/r^3 = 13 psi (0.9 kg/cm^2), so that it served as a test with an intermediate stiffness value.

The physical properties of the pipe and their Ring Stiffness Factors are listed in Tables 1 and 2, respectively. There were holes cut in the steel pipe to mount pressure cells and in Table 2 the stiffness values are shown for both before and after the holes were cut. The densities and moisture contents for the sand backfill are shown in Table 3.

The 1-minute horizontal deflections of the four pipes are shown in Figure 6. The upper portion of the figure shows the deflection plotted to the scale used in the previous deflection plots. The lower portion shows the deflections on an expanded scale. The deflections of the pipe were all less than 1 percent. The pipes are considered to have deflected identically regardless of the pipe stiffness or the pipe material.

The average densities for all of the sand placed in each container test ranged between 78 and 89 percent relative density, as shown in Table 3. The most critical density is that of the sand beside the pipe since this is the area of the backfill that resists the pipe deflection.

Table 1

PHYSICAL PROPERTIES OF PIPE TESTED

Pipe description	Diameter[1]		Wall thickness[2]		Length[3]	
	inches	cm	inches	cm	inches	cm
18-inch-dia RPM	18.013	45.75	0.407	1.034	70.844	179.94
18-inch-dia FRP	17.872	45.39	0.426	1.082	70.875	180.02
18-inch-dia, 12-gage steel	17.751	45.09	0.105	0.267	70.984	180.30
18-inch-dia, 7-gage steel	17.655	44.84	0.181	0.460	70.953	180.22

[1] Average of 8 measurements on south end of pipe.
[2] Average of 16 measurements on south end of pipe.
[3] Average of 4 measurements.

The densities of the individual lifts of sand are shown in Figure B-8 in Appendix B. The densities of the sand lifts beside the pipe were compared to the individual pipe deflection curves to determine if the sand density explained the slight variations in deflections shown on the expanded portion of Figure 6. The relative densities of these lifts of sand are shown on the figure and have no apparent relation to the slight differences in deflection. The RPM pipe test had the lowest density for this lift, 72 percent relative density, and the FRP pipe test had the highest density, 94 percent relative density. The deflections of the RPM pipe were only about 10 percent higher than those for the FRP pipe. USBR specifications require cohesionless backfill (sand and/or gravel) to be placed at 70 percent relative density or higher. For the particular sand used in this study, it apparently made little difference if the sand were placed at 70 percent relative density or 90 percent relative density.

The vertical and horizontal deflections for the RPM pipe in the high-density sand and in the low-density lean clay are shown in Figure 7. Using the high-density sand reduced the deflections about 98 percent. The Ring Stiffness Factors for the two pipe were about 13 to 17 psi (0.9 to 1.2 kg/cm^2).

Figure 8 shows the vertical and horizontal deflections of a FRP pipe, EI/r^3 = 19 psi (1.3 kg/cm^2), in the low-density lean clay and of a FRP pipe, EI/r^3 = 18 psi (1.3 kg/cm^2), in the sand backfill. The higher modulus sand backfill reduced the pipe deflection about 97 percent.

One particular size of steel pipe, 7-gage, 18-inch (46-cm) diameter pipe (three different sections), was load tested in all three soil backfill conditions, low-density clay, high-density clay, and the sand. The vertical and horizontal deflection curves are shown in Figure 9. As illustrated, increasing the density of the clay from 90 to 100 percent of Proctor maximum dry density reduced the pipe deflection about 50 percent. The sand backfill reduced the deflections about 95 percent.

The type of soil used for the bedding can be as significant a factor in the resulting deflection of the pipe as the density of the soil. The sand at a relative density of 70 percent had a density of 124 pcf (1.99 $gram/cm^3$). The lean clay compacted to 100 percent Proctor maximum dry density had a density of 120 pcf (1.92 $gram/cm^3$). The deflection of the 18-inch (46-cm), 7-gage steel pipe was about 90 percent less (see Figure 9) for the sand backfill test than the 100 percent clay backfill test. The moisture content of the clay could also affect the deflection. However, in the clay tests the moisture contents were all about the same, close to the optimum moisture of 12 percent.

Successful use of the Iowa Formula for predicting flexible pipe deflections requires selection of the proper value of the modulus of soil reaction, e'. As shown, e' depends on the type of soil and its density and moisture content. Values of e' must be selected according to experience and judgment since there is no laboratory test on the soil alone that can provide the proper numbers. The laboratory tests on buried flexible pipe were used to find e' values for the soils used in this test series.

There are two methods for determining the modulus of soil reaction of the soil. The first method is to find by trial and error what value of e' would give the measured deflections at the given loads. The second is to use the horizontal deflections of the pipe and the pressures on the pipe at the horizontal diameter. As

Table 2

RING STIFFNESS FACTORS, EI/r^3, OF PIPE TESTED

Pipe description	Nominal[1]		Theoretical[2]		Empirical[3]							
					Without holes				With holes			
					Low		High		Low		High	
	psi	kg/cm^2	psi	kg/cm^2	psi	kg/cm^2	psi	kg/cm^2	psi	kg/cm^2	psi	kg/cm^2
18-inch RPM	–	–			12.7	0.89	14.2	1.00	–	–	–	–
18-inch FRP	–	–			17.9	1.26	18.1	1.27	–	–	–	–
18-inch, 12-gage steel	3.92	0.276			4.3	0.30	4.5	0.32	4.2	0.30	4.4	0.31
18-inch, 7-gage steel	19.77	1.390			23.3	1.64	24.3	1.71	22.0	1.55	23.8	1.67

[1] E for steel = $30(10)^6$ psi, pipe radius to nearest inch, nominal value for wall thickness.
[2] E values from tensile test coupons, measured values of wall thickness and radius (steel only).
[3] Based on horizontal deflections on south end of pipe.

$$EI/r^3 = 0.136\ P/\Delta X$$

P = load/linear inch
ΔX = horizontal deflection in inches

Table 3

SOIL BACKFILL PROPERTIES

Pipe description	Soil density		Percent relative density[1]	Approximate moisture content (percent)[2]
	pcf	gram/cm^3		
18-inch-dia RPM	127.1	2.036	78	11
18-inch-dia FRP	128.9	2.065	83	11
18-inch-dia 12-gage steel	131.0	2.098	88	10
18-inch-dia 7-gage steel	131.2	2.102	89	8

[1] Minimum dry density = 103.9 pcf (1.66 gram/cm^3), maximum dry density = 135.5 pcf (2.17 gram/cm^3), see Figure B-8.
[2] Soil container was drained before and during tests.

defined by Spangler, e' is the ratio of the pressure on the soil at the horizontal diameter of the pipe to the horizontal movement of the pipe multiplied by the pipe radius.

The tests in the low-density lean clay exhibited a deflection lag during initial loading. A seating load is common in soils testing. In these tests, about 10 psi (0.7 kg/cm^2) surcharge as a seating pressure was applied before the load-deflection curve became linear. The lag in deflection was attrituted to the frictional resistance between the soil and the container wall. After about 10-psi pressure was reached, the horizontal load-deflection curves were linear and the slopes of the curves compared well with theoretical Iowa Formula curves using an e' of 500 psi (35.2 kg/cm^2) and the appropriate Ring Stiffness Values. Figure 10 shows the empirical curves for the steel pipe with EI/r^3 value of 0 to 2 psi (0 to 0.14 kg/cm^2) compared to an Iowa Formula curve for $EI/r^3 = 0$ psi and e' of 500 psi. The theoretical Iowa Formula was shifted over 10 psi on the surcharge scale to account for the seating load. Figure 11 shows the empirical curve for steel pipe with $EI/r^3 = 10$ psi (0.7 kg/cm^2) compared to a theoretical Iowa Formula curve for $EI/r^3 = 10$ psi and e' = 500 psi. The correlation in these two figures is very good as were the comparisons for the other two stiffness groups.

The trial and error e' value for the tests in the low-density clay was 500 psi (35.2 kg/cm^2). Direct e' values were calculated for these tests using the increments of increase of the horizontal deflection of the linear portions of the load-horizontal deflection curves and the increase in the total of the pressures measured on the sides of the pipe. For the pipe that deflected elliptically, the direct e' values ranged between 396 and 758 psi (27.8 and 53.3 kg/cm^2). The average value was 544 psi (38.2 kg/cm^2) which compares well with the trial and error e' of 500 psi. The rectangularly deformed pipe had direct e' values of 249 to 420 psi (17.5 to 29.5 kg/cm^2) with an average of 328 psi (23.1 kg/cm^2). These pipe had horizontal deflection curves that compared well with the theoretical curves, but their side pressures were generally lower than the ellipitcally shaped pipe. The rectangularly deformed pipe must have a different side pressure distribution, with lower pressures right at the horizontal diameter, than the elliptically deformed pipe.

For the tests on the steel pipe in the 100 percent Proctor density lean clay, the trial and error e' value was determined to be 920 psi (64.7 kg/cm^2). The direct e' values ranged from 997 to 1,566 psi (70.1 to 110.1 kg/cm^2) with an average of 1,208 psi (84.9 kg/cm^2).

The trial and error e' value for the tests in the sand backfill was about 20,000 to 30,000 psi (about 1,400 to 2,100 kg/cm^2). Using the pressures measured at the side of the pipe and the horizontal deflection, the direct e' value for the 12-gage steel pipe was about 7,000 psi (about 490 kg/cm^2) and the direct e' value for the 7-gage steel pipe ranged between 6,000 and 9,000 psi (about 420 and about 630 kg/cm^2). The trial and error e' values were three to four times more than the direct e' values. The difference was due to the fact that the pressures on the pipe in the sand backfill were a smaller percentage of the applied surcharge pressure than the pressures on the pipe in the clay backfill.

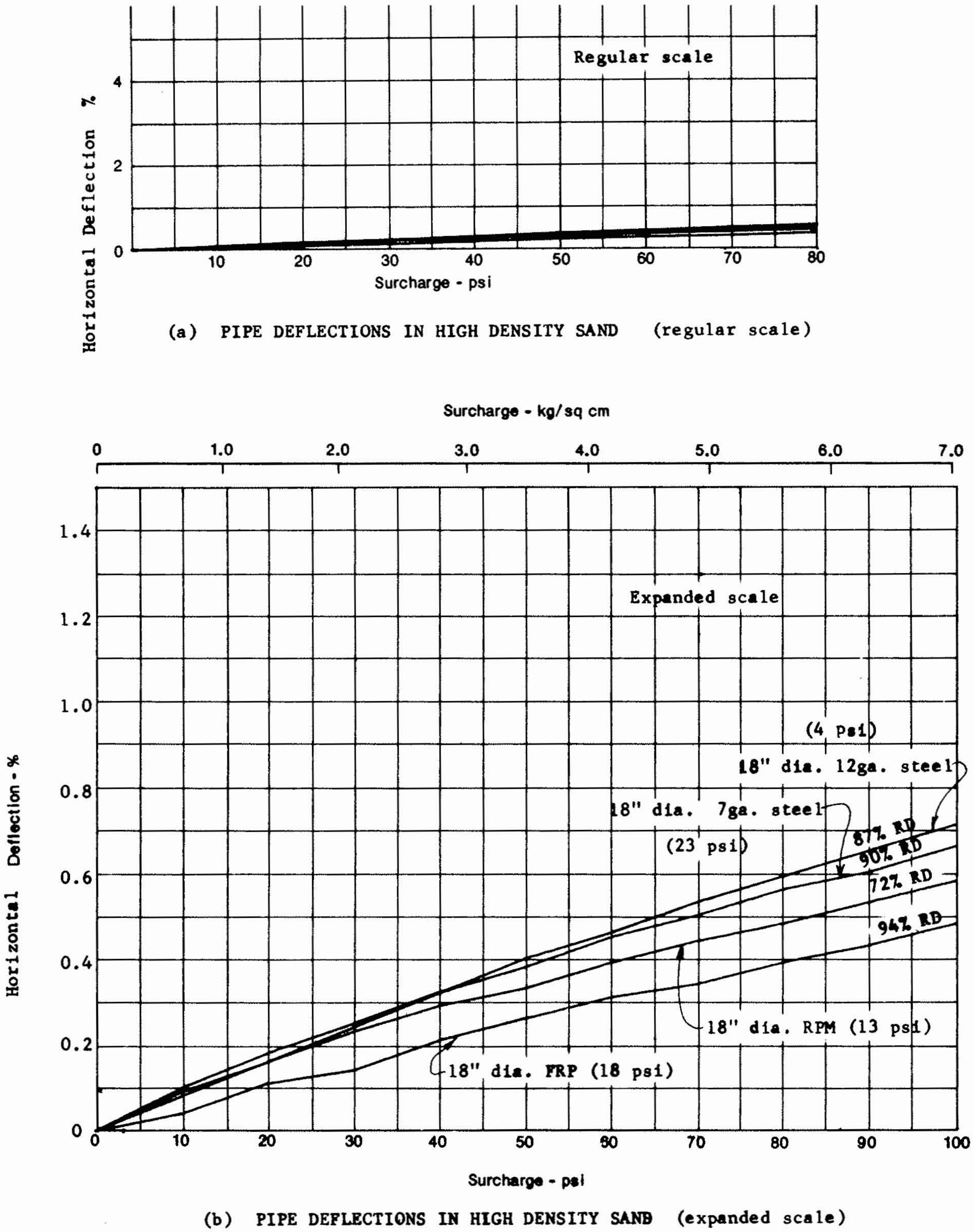

Figure 6. Load horizontal deflection curves for tests in sand backfill.

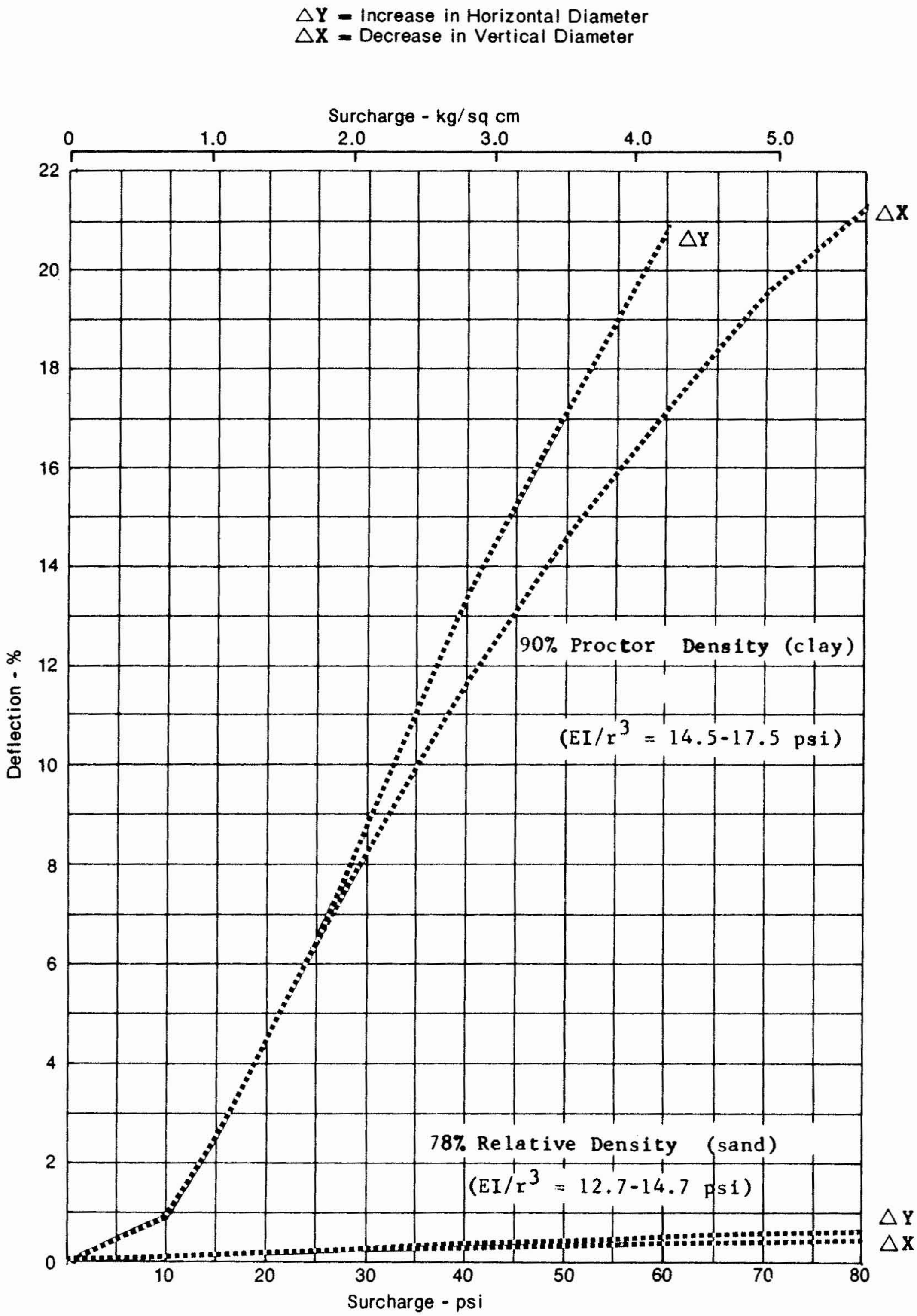

Figure 7. Deflection of 18-inch-diameter RPM pipe in low-density lean clay and high-density sand.

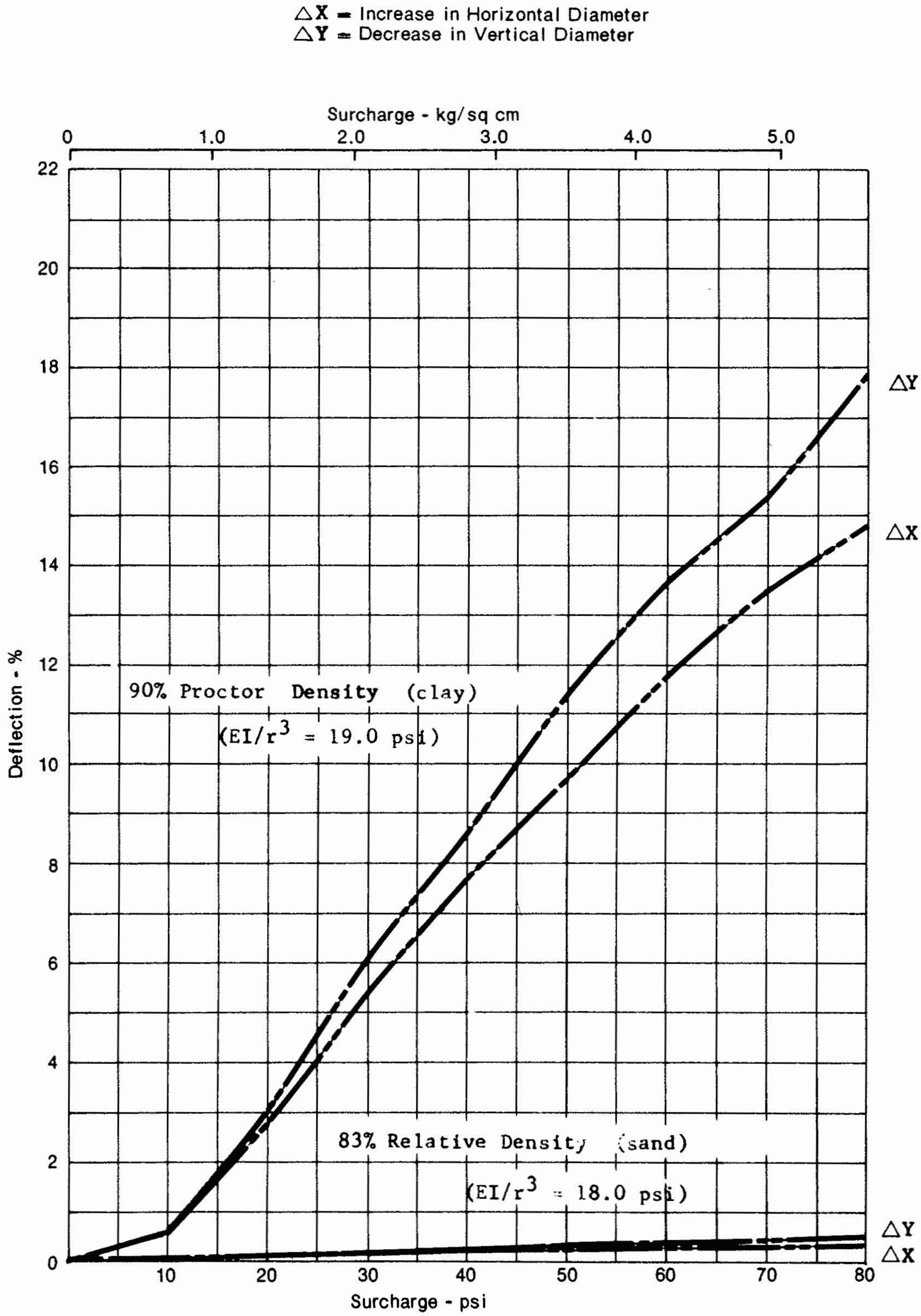

Figure 8. Deflection of 18-inch-diameter FRP pipe in low-density lean clay and high-density sand.

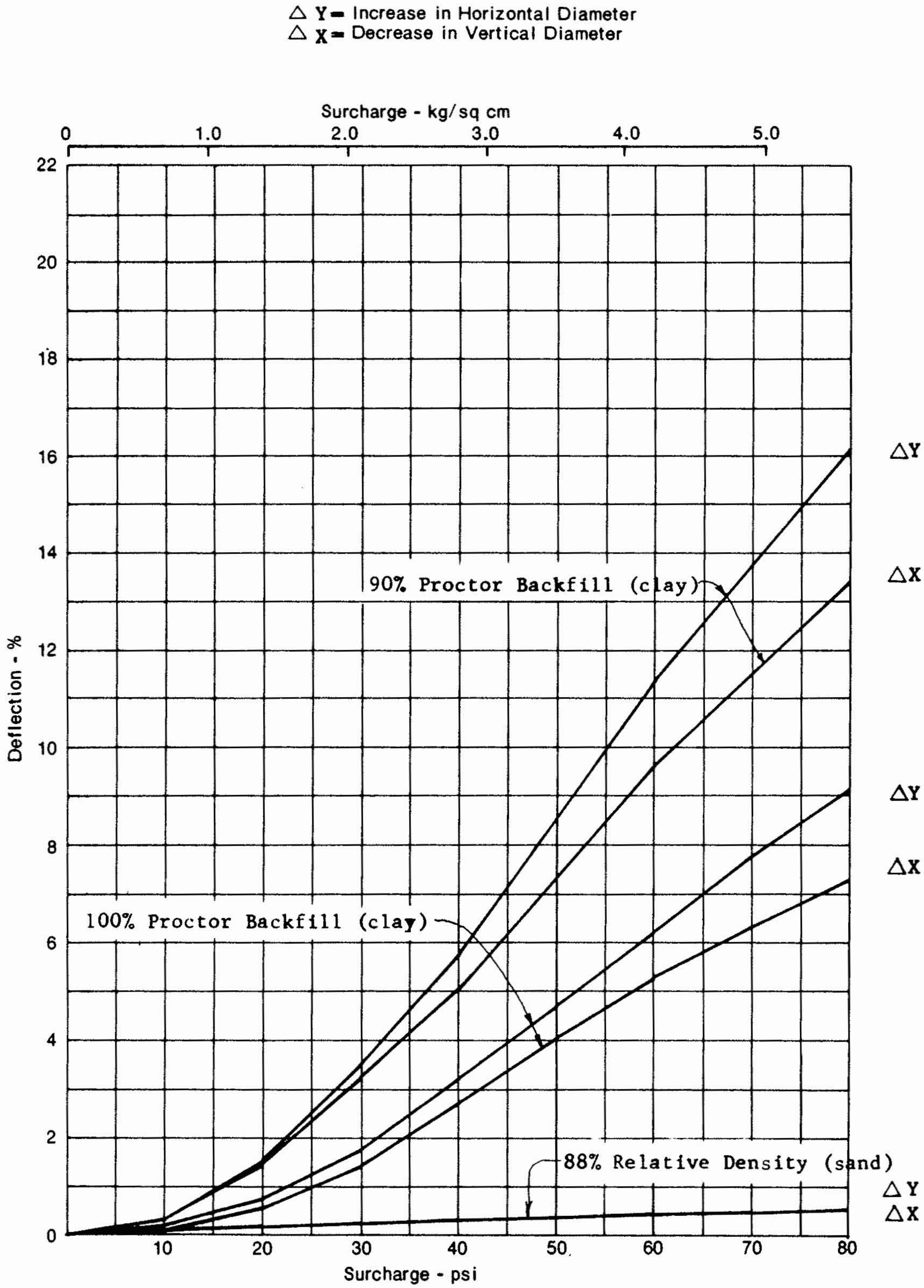

Figure 9. Deflection of 18-inch-diameter, 7-gage steel pipe in three different backfill conditions.

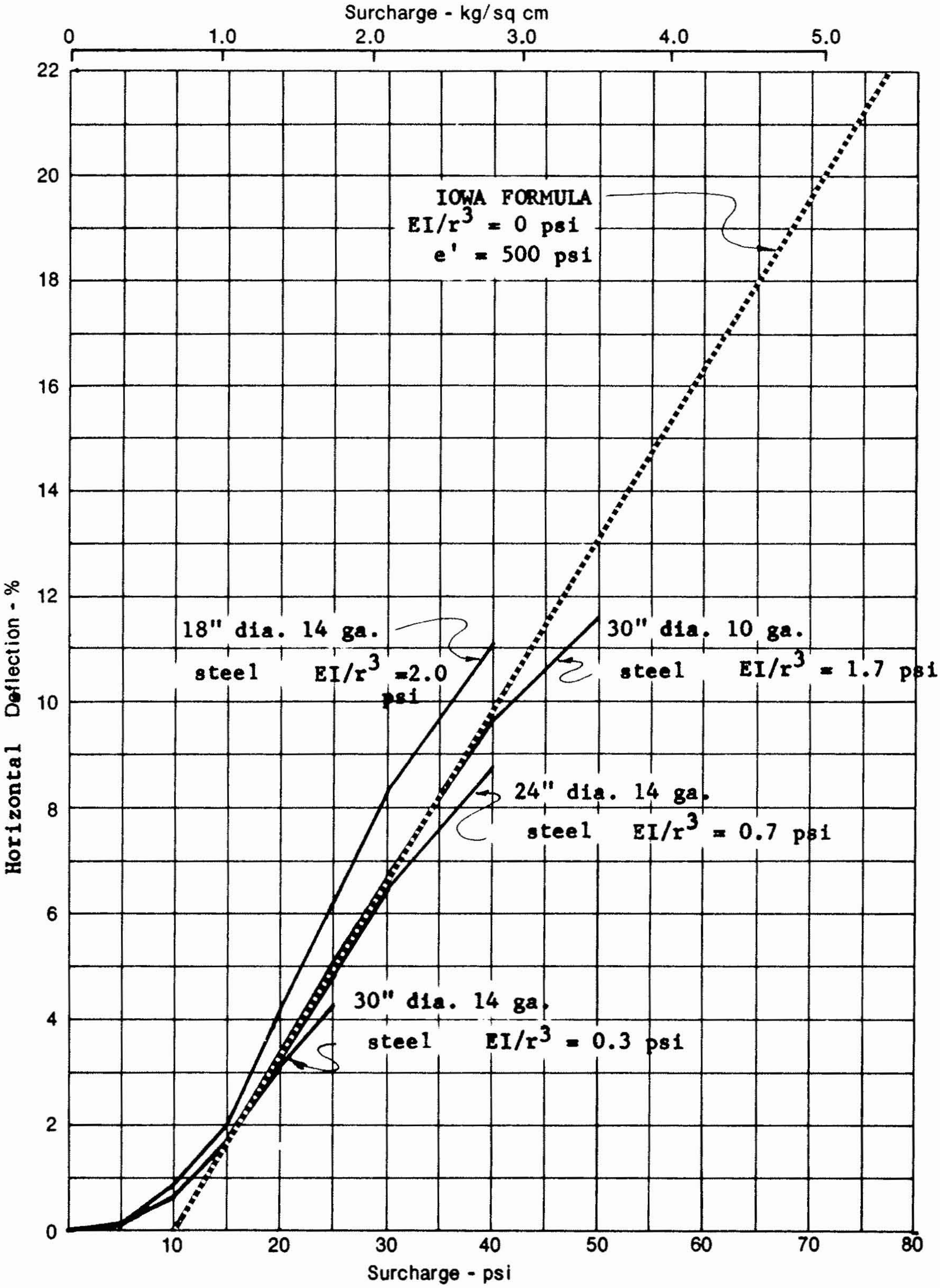

Figure 10. Horizontal deflection of steel pipe in (EI/r^3 = 0-2 psi) in low-density clay compared with the Iowa Formula.

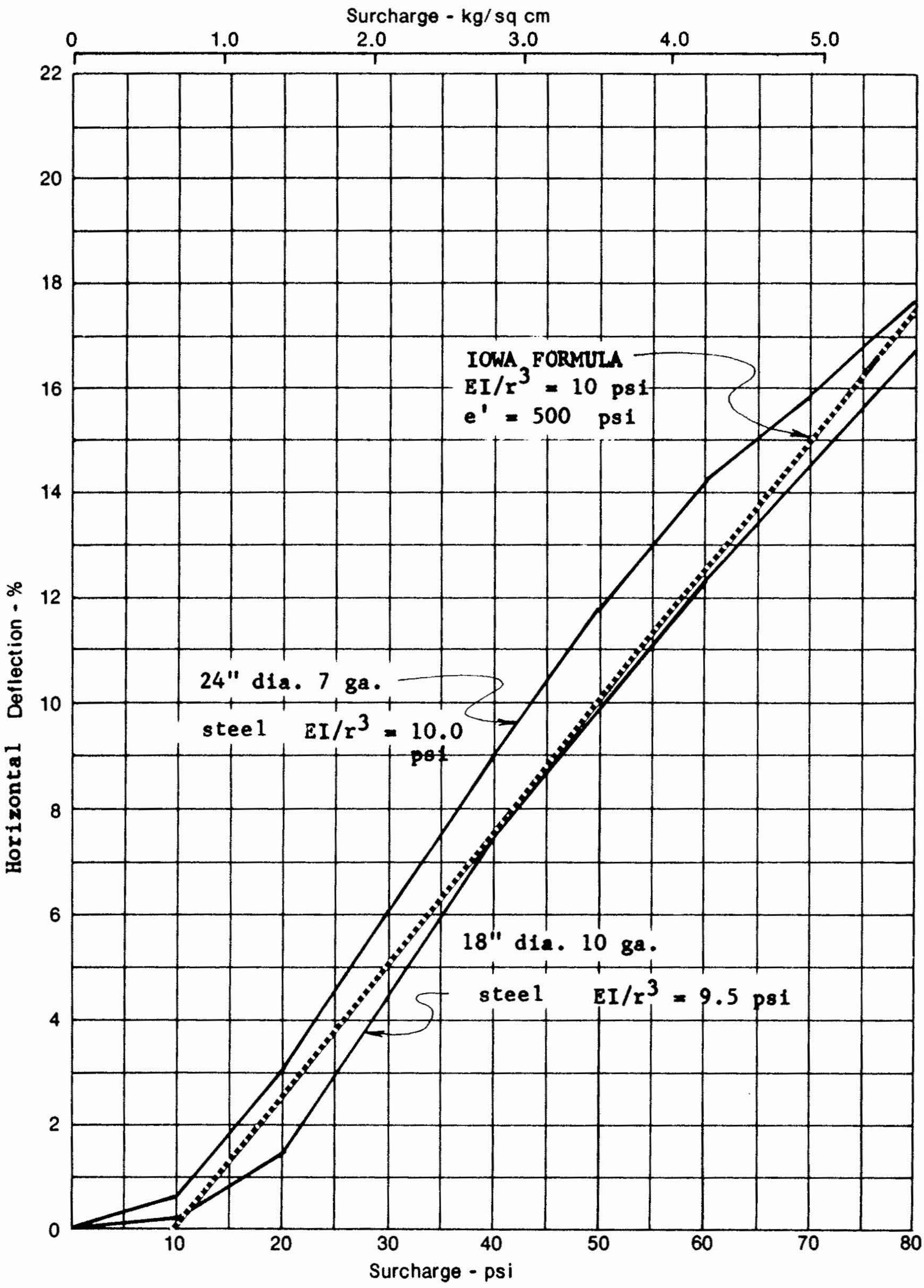

Figure 11. Horizontal deflection of steel pipe (EI/r^3 = 10 psi) in low-density clay compared with the Iowa Formula.

SUMMARY AND CONCLUSIONS

Two steel, one reinforced plastic mortar (RPM), and one fiberglass reinforced plastic (FRP) 18-inch (46-cm) diameter pipe were buried in a sand backfill and load tested in a large soil container. Previous testing programs used a lean clay backfill to study the load-deflection characteristics of flexible pipe. Sand was used for these tests to make the same type of evaluation for a different type soil.

Increasing increments of surcharge were applied to the soil surface over the pipe with a large universal testing machine. Data were collected on the pipe deflection and shape, soil pressures, soil movement around the pipe, and strain on the inner surface of the pipe. The pipe deflections were compared to the previous tests in a clay backfill with the following conclusions:

(1) The pipe deflected similarly, less than 1 percent deflection at 100 psi (7.0 kg/cm^2) surcharge, regardless of the pipe stiffness or the pipe material. The densities of the sand backfill ranged between 78 and 89 percent relative density.

(2) Compared to tests on similar pipe in a low-density lean clay backfill, the sand backfill reduced the deflections of the pipe over 95 percent.

(3) The modulus of soil reaction, e', of the sand backfill ranged from 6,000 to 30,000 psi (420 to 2,100 kg/cm^2) depending on the calculation method used.

The Iowa Formula predicts the percent deflection based on a ratio of the external load on the pipe to a combination of pipe strength and soil strength. The test program to date has shown that when bedding of high strength is used, the pipe strength or type of material has little or no affect on the deflection of the pipe. When the soil is poor or is poorly compacted, the tests showed that the pipe strength and type of material significantly affect the pipe deflection.

APPLICATIONS

In 1967, Professor M. G. Spangler recommended that the soil parameter, e', in the Iowa Formula for predicting flexible pipe design be based on experience and judgment. The laboratory studies of buried flexible pipe have dramatically illustrated how the selection of bedding material and its compaction can affect the deflection of buried pipe. The use of a constant value of e' for all soil, compacted to 90 Proctor or over can no longer be justified.

PERSONNEL PERFORMING TESTS

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

M. L. Berry	L. J. Cox
B. A. Callow	R. I. Kingery
C. T. Coffey	D. R. Kottenstette

Photography by W. M. Batts

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8. Spangler, M. G., "The Structural Design of Flexible Pipe Culverts," Bulletin 153, Iowa State Engineering Experiment Station, 1941

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APPENDIX A

INDIVIDUAL TEST RESULTS

The results of the individual tests are shown graphically in Figures A-1 to A-14 in the following order:

Load-deflection curves	A-1 to A-4
Soil pressures on steel pipe	A-5 to A-6
Soil pressures on container walls	A-7 to A-10
Strain gage readings around inside pipe circumference	A-11 to A-14

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

Previous reports on flexible pipe load tests have included data on the soil movement between the pipe and the container walls and the changing shape of the pipe under the various loads. Because of the small amount of pipe deflection in the sand backfill tests, graphical results of the soil movement and pipe shape showed no perceptible differences and are not presented.

LOAD DEFLECTION CURVES

The 1-minute horizontal and vertical deflection curves are shown for each individual test in Figures A-1 through A-4. The 60-minute readings for the deflections were about the same as the 1-minute readings; the deflections changed very little with time in the sand backfill. The $\Delta X/\Delta Y$ ratios for each pipe test are shown on the graphs where ΔX is the horizontal deflection and ΔY is the vertical deflection. The $\Delta X/\Delta Y$ ratios for the two steel pipe were about 0.9 to 1.0. The $\Delta X/\Delta Y$ ratios for the RPM pipe and FRP were about 0.7 to 0.75. The deflection curves were generally linear up to about 40 psi (2.8 kg/cm^2) and then linear from that point on to 100 psi (7.0 kg/cm^2) at a slightly reduced slope.

PRESSURES ON STEEL PIPE

The steel pipe had four pressure cells mounted midway in the pipe, flush with the outside surface of the pipe, with one cell each at the ends of the horizontal and vertical diameters. The measured pressures for the two steel pipe in the sand backfill are shown in Figures A-5 and A-6.

In the low-density clay tests, the soil pressures on the top of the pipe were about 75 percent of the applied surcharge.[1 2*] In the high-density clay tests, the top soil pressures were about 50 percent of the applied surcharge pressure.[3] For the 7-gage steel pipe in sand, the top pressures were about 55 percent of the surcharge pressure (see Figure A-5), and for the 12-gage steel pipe the top pressures were about 40 percent of the surcharge pressure.

For the steel pipe tested in the low-density clay tests, the average soil pressures at the side of the pipe (the horizontal diameter) were about equal to the applied surcharge.[1] The pipe that deformed elliptically had about 25 percent higher pressures while the rectangularly deformed pipe had about 25 percent lower than the applied surcharge pressure. In the high-density clay tests, the elliptically deformed pipe had side pressures of about 150 percent of the surcharge while the rectangularly deformed pipe had side pressures of about 50 to 100 percent of the surcharge pressures.[3] For the two steel pipe in the sand tests, the side pressures were about 50 to 60 percent of the vertical surcharge pressure.

The pressure on the bottom of the steel pipe in the clay tests varied considerably and were apparently dependent on the uncontrollable differences in compacting the soil under the bottom surfaces of the pipe.[1 2] In the sand backfill tests, the bottom pressures were about 30 percent of the surcharge pressure.

The "ring compression" theory[4] of culvert design assumes that the pipe is bedded in high-density, low-compressible soil and the soil pressures are uniform about the pipe. The pipe then performs as a compression ring under uniform radial pressure and the pipe is designed based on the compressive stress in the pipe wall being less than the yield stress of the pipe wall material. Pipe deflection and bending stresses are considered negligible.

Since the method requires the use of high-quality, high-density bedding, it is practical only for short lengths of pipeline, such as drainage culverts under highways and railroads.

These sand backfill tests met the requirements for bedding necessary in the ring compression theory. In the case of the stiffer steel pipe (Figure A-5), the pressures were uniform around the pipe except for the bottom of the pipe where the pressure was only half of the other pressures. The pressures on the more flexible 12-gage pipe (Figure A-6) varied from 30 to 60 percent of the applied surcharge and could not be considered uniform.

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*Numbers designate references at end of Appendix.

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 sidewall) 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 from the surcharge load. Another four cells were 2 feet (0.6 meter) from the top of the container and measured the lateral pressures from the surcharge load without any significant pressures from the deflecting pipe. Because of the small difference in elevation and the large surcharge applied, the lateral pressures from the surcharge are assumed to be the same at each cell location.

In the tests of 24- and 30-inch (61- and 76-cm) diameter pipe in the low-density clay backfill, the pressures on the container wall opposite the pipe were definitely higher than those above the pipe.[1 2] For the 18-inch (46-cm) diameter pipe in the low-density clay backfill and for all sizes of pipe tested in the high-density clay backfill, the cells opposite the pipe generally measured pressures about the same as those cells above the pipe.[1 2 3]

In the low-density clay tests, the lateral pressures were about 50 percent of the applied vertical surcharge and in the high-density clay tests, they were about 75 percent of the surcharge.[1 2 3]

Graphs showing the soil pressures on the container wall for each of the tests in the sand backfill are presented as Figures A-7 to A-10.

In three of the four tests, the lower cells showed about the same pressures as the upper cells. The average pressure for each of the tests ranged from 15 to 33 percent of the applied vertical surcharge.

The other test, on the FRP pipe (Figure A-8), had widely varying pressures with the upper cells showing higher pressures than the lower cells. The only difference between this test and the other tests was that the initial moisture content of the sand lift at the upper cells was much lower (6 percent) than the sand lift at the lower cells (12 percent). The initial moisture content for the other tests ranged from 9.5 to 12.2 percent for the lifts at the cell locations.

STRAIN GAGE READINGS AROUND PIPE CIRCUMFERENCE

A circumferential ring of 18 SR-4 type strain gages was mounted to the inner surface of the pipe at about the one-fourth point. The strain gage readings are shown as Figure A-11 to A-14.

If the pipe were acting as a pure compression ring, the gages would show an equal compressive strain at all locations. If the pipe were acting in pure bending, half the pipe would show tensile strains and the other half compressive strains. The strain gage patterns in the figures show the typical bending strain curves but shifted downward so that most of the pipe was under compression. The pipe was neither acting as a pure compression ring nor in pure bending. The pipe test in the low-density clay acted more as though they were in pure bending, so that the effect of higher compressive stresses in the pipe wall are obvious in the sand tests.

At the same amount of vertical deflection, as expected, the strains for the RPM and FRP pipe were much higher than the two steel pipe since the modulus of elasticity of the plastic base pipe was much lower than for the steel pipe.

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1. Howard, A. K., "Laboratory Load Tests on Buried Flexible Pipe—Progress Report No. 1," Report No. EM-763, Bureau of Reclamation, Denver, Colorado, June 1968

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3. Howard, A. K., "Laboratory Load Tests on Buried Flexible Pipe—Progress Report No. 3—Steel Pipe in High Density, Cohesive Soil," Report No. REC-ERC-71-35, Bureau of Reclamation, Denver, Colorado, September 1971

4. White, H. L., and Layer, J. P., "The Corrugated Metal Conduit as a Compression Ring," Proc. HRB, Vol. 39, 1960

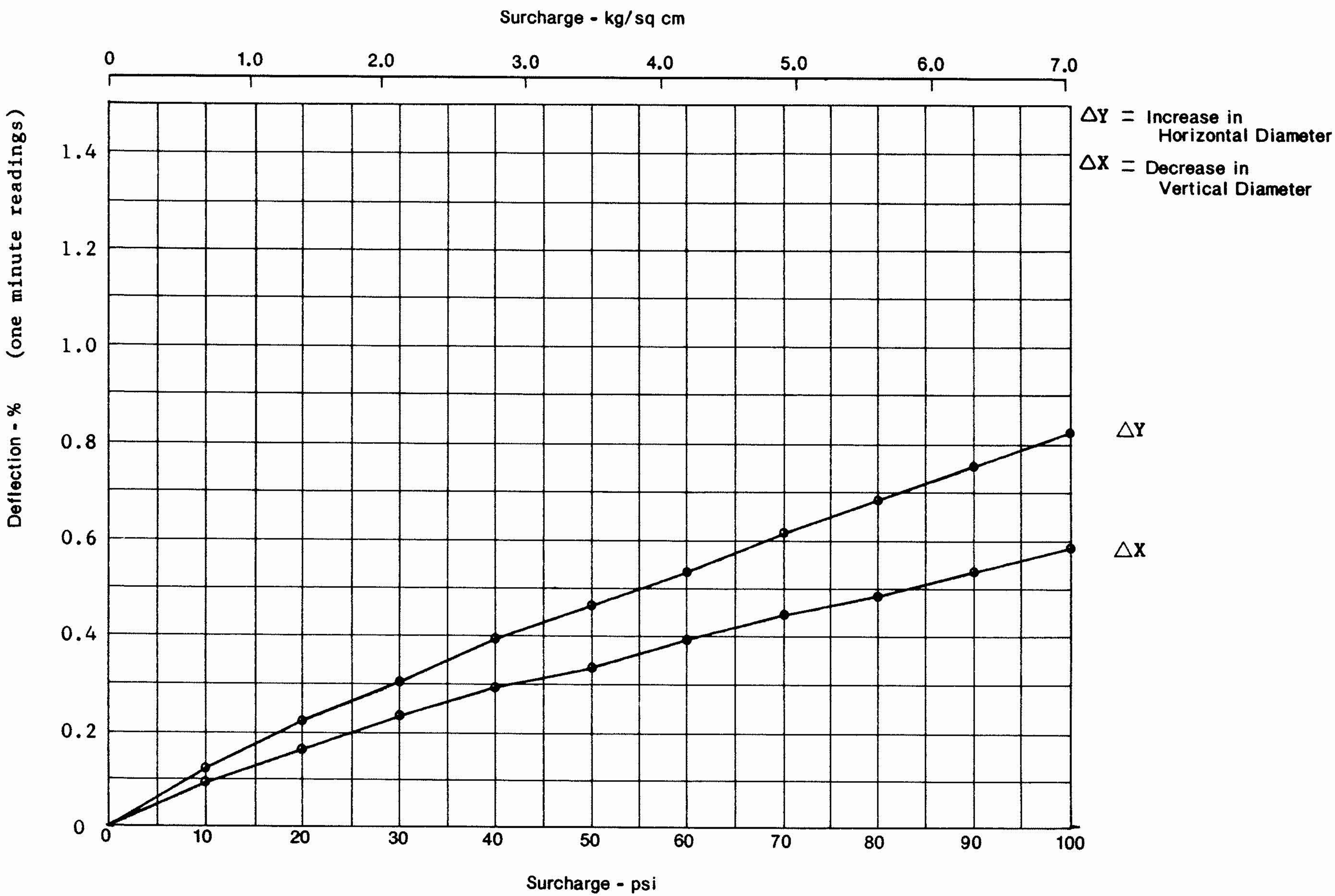


Figure A-1. Load-deflection curves, RPM pipe.

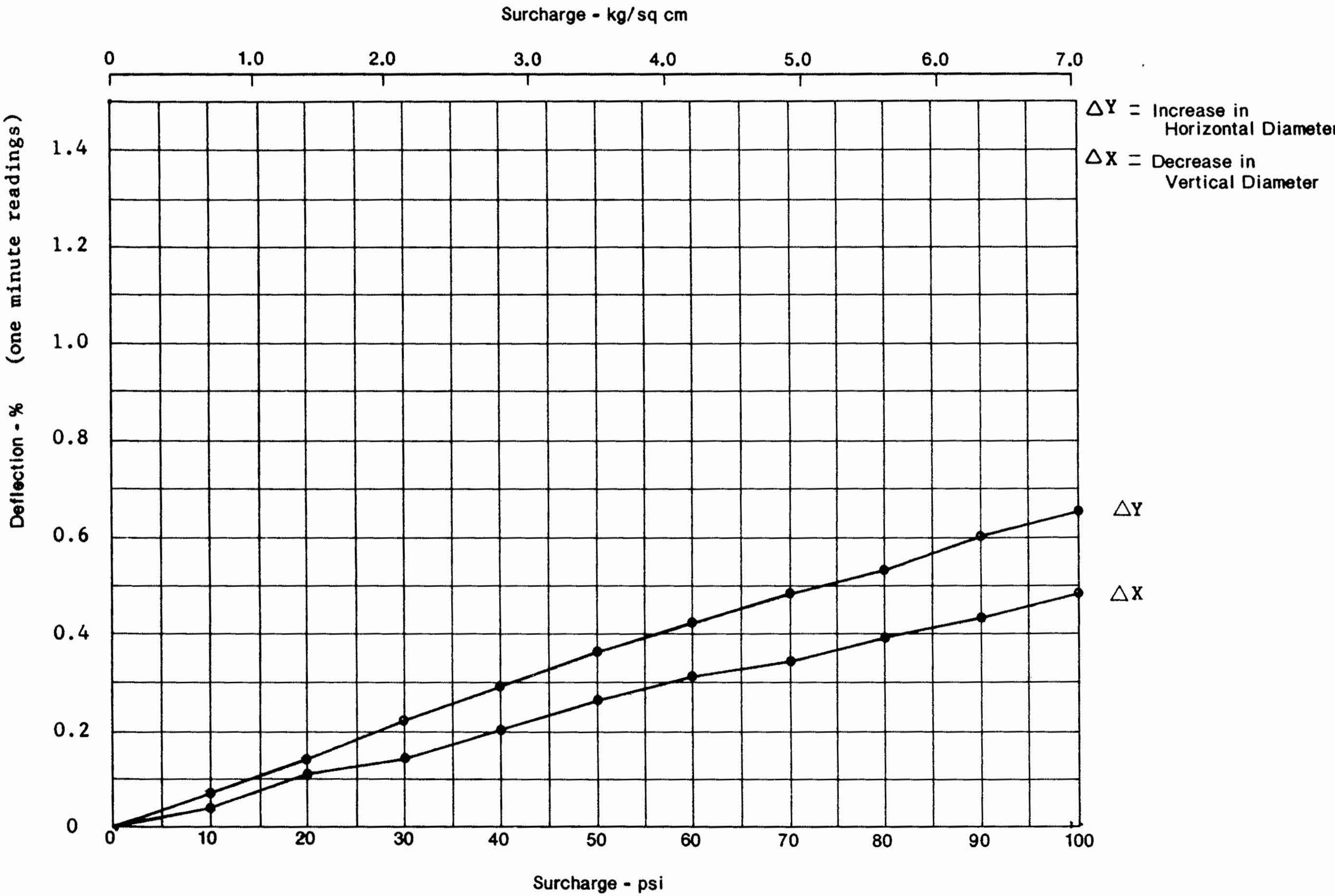


Figure A-2. Load-deflection curves, FRP pipe.

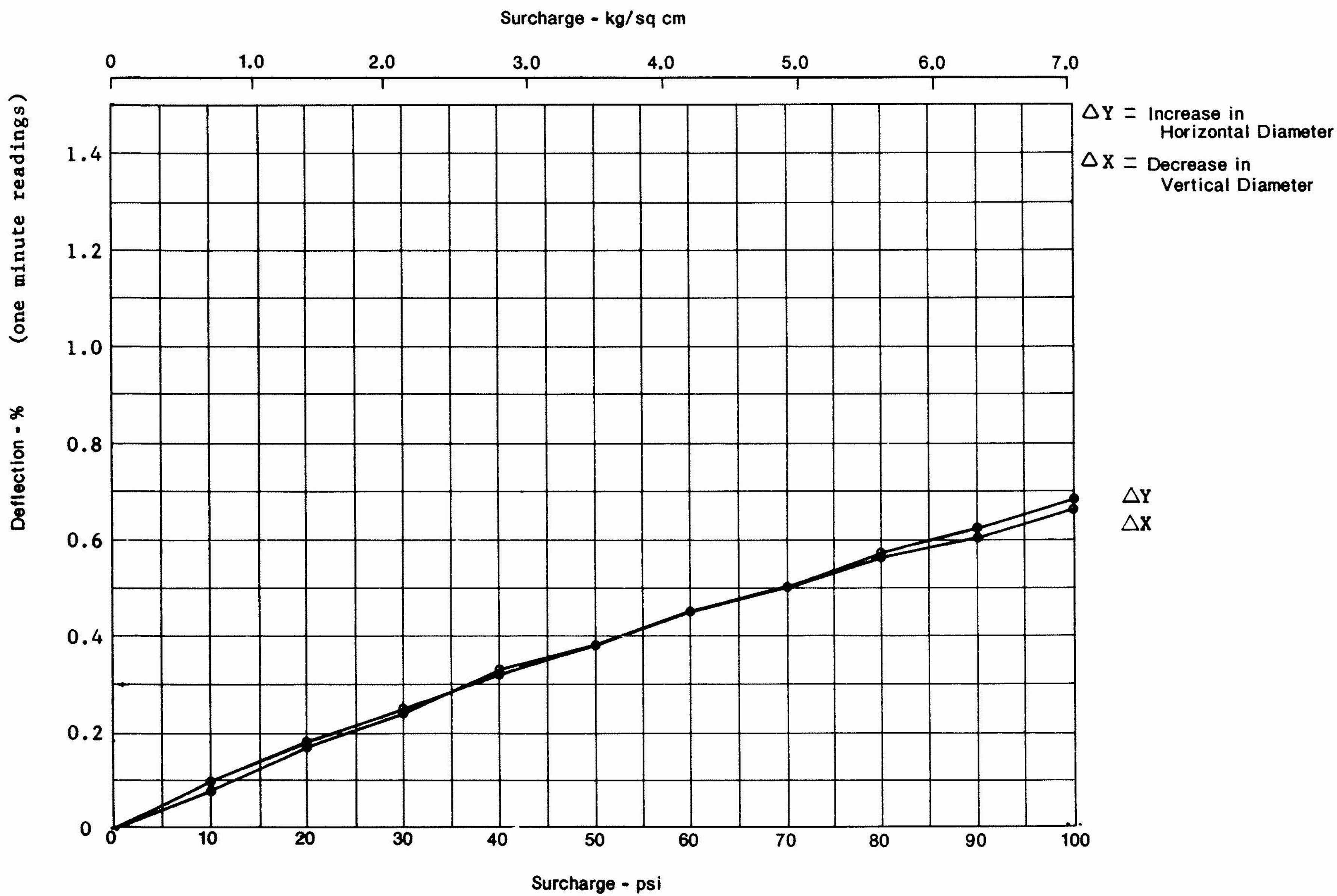


Figure A-3. Load-deflection curves, 7-gage steel pipe.

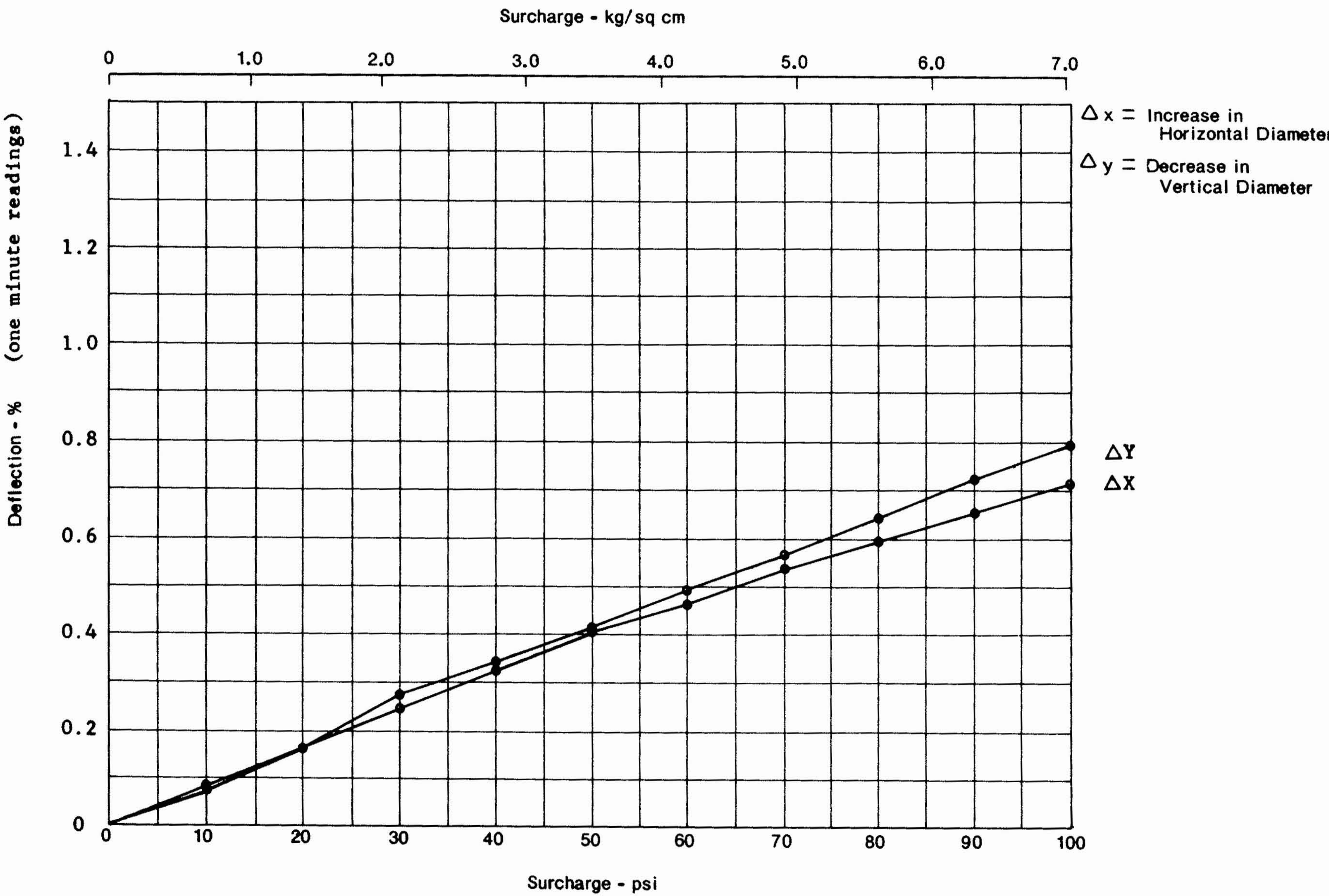


Figure A-4. Load-deflection curves, 12-gage steel pipe.

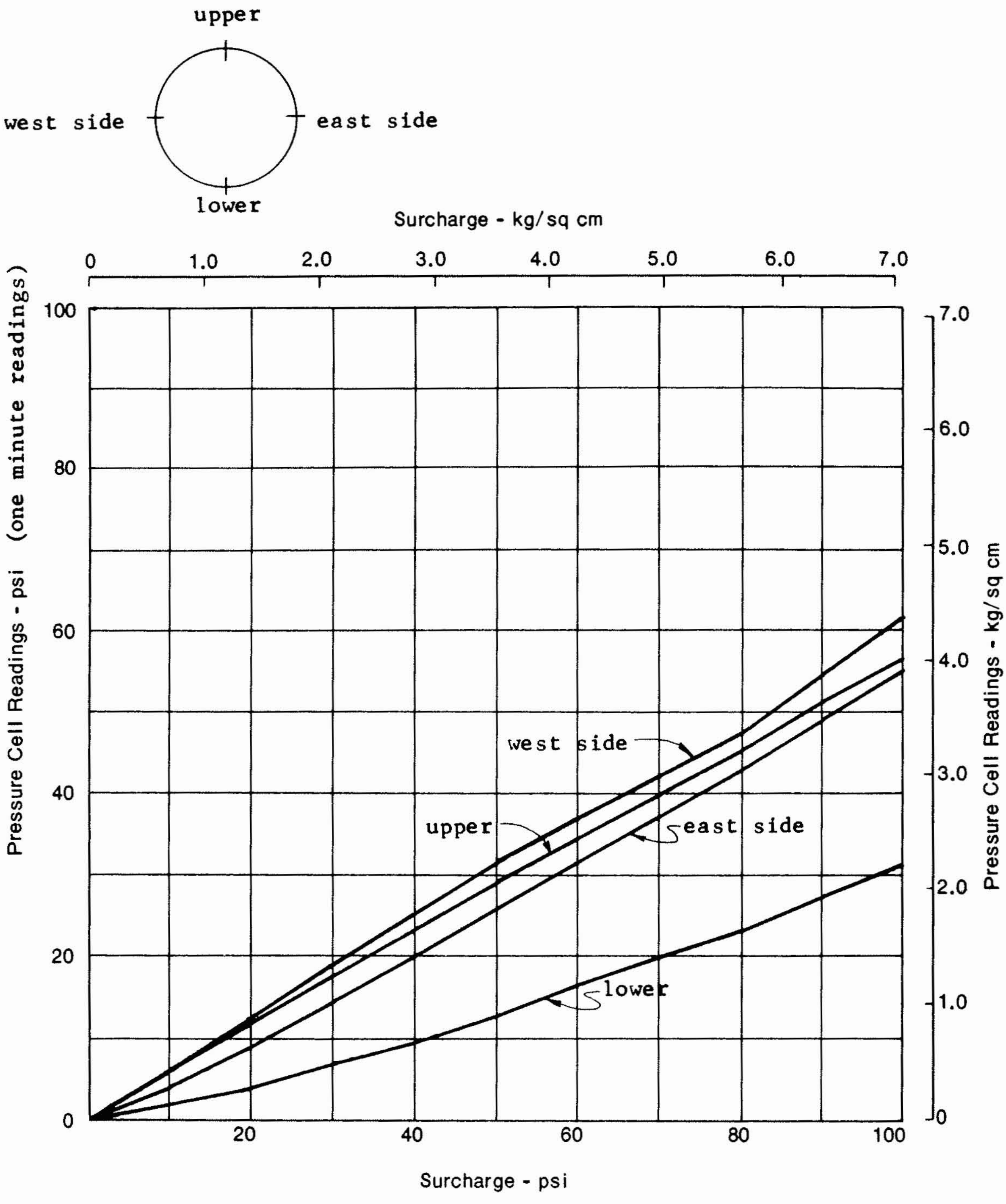


Figure A-5. Soil pressures on the 7-gage steel pipe.

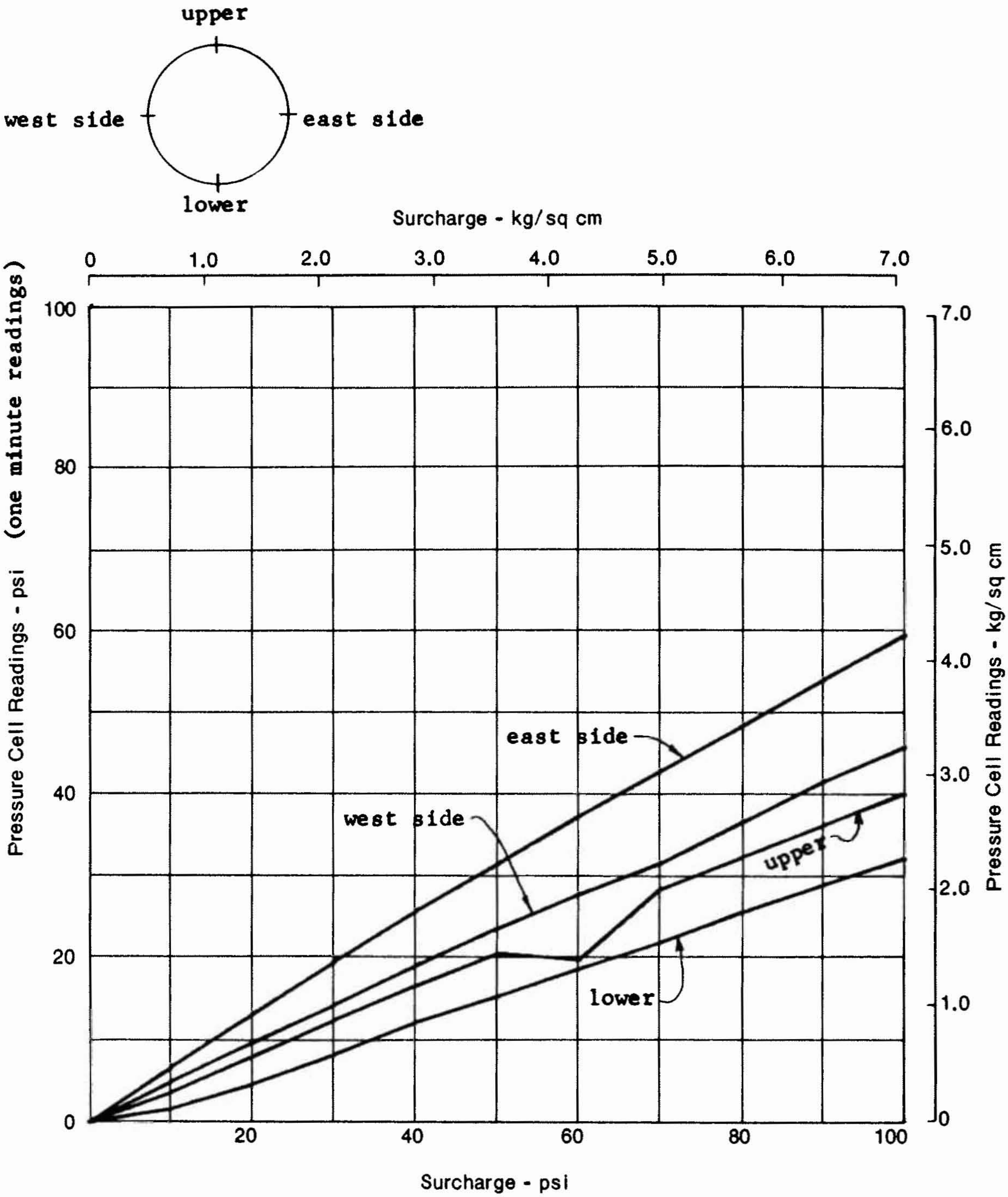


Figure A-6. Soil pressures on the 12-gage steel pipe.

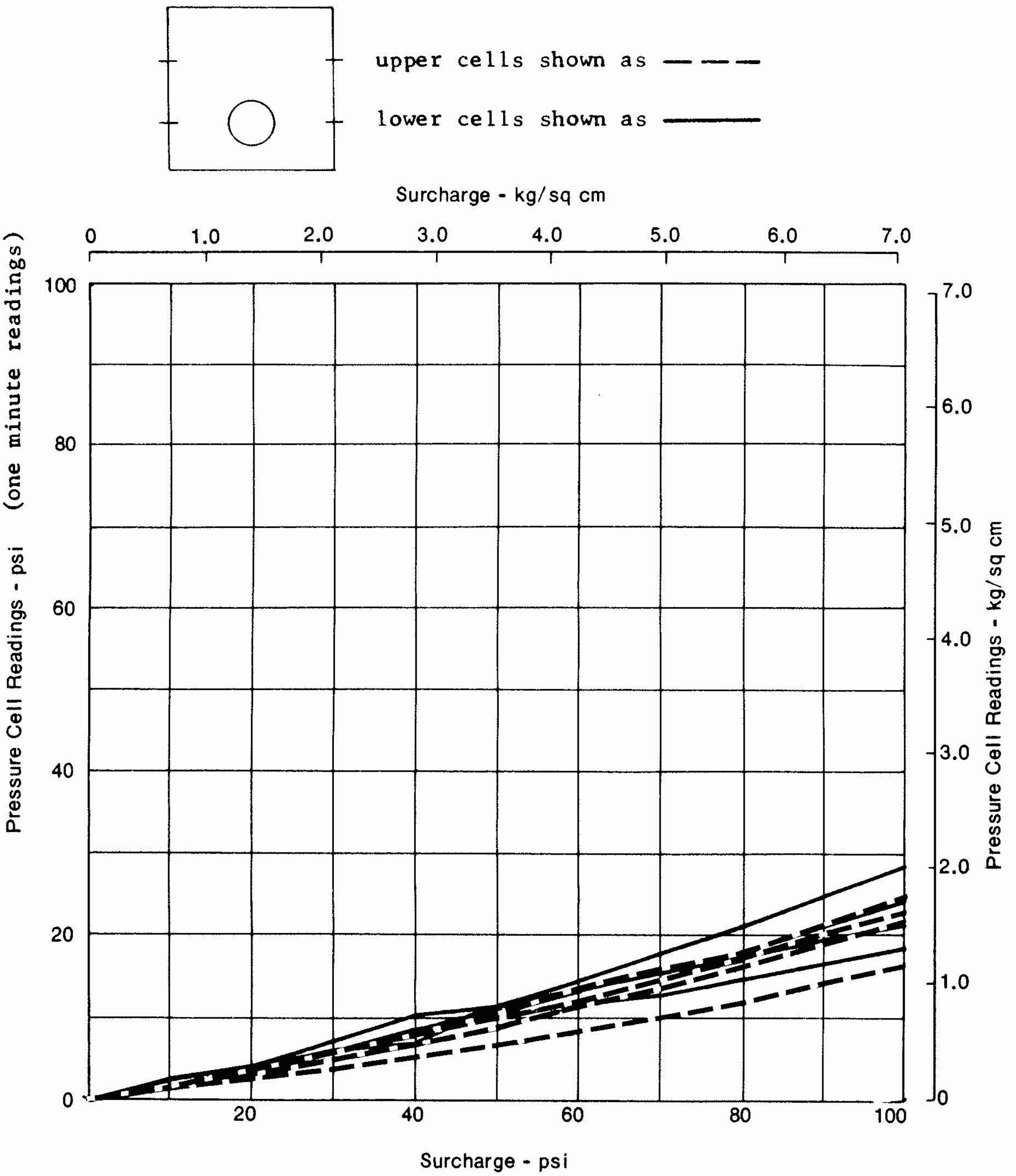


Figure A-7. Soil pressures on container walls, RPM pipe.

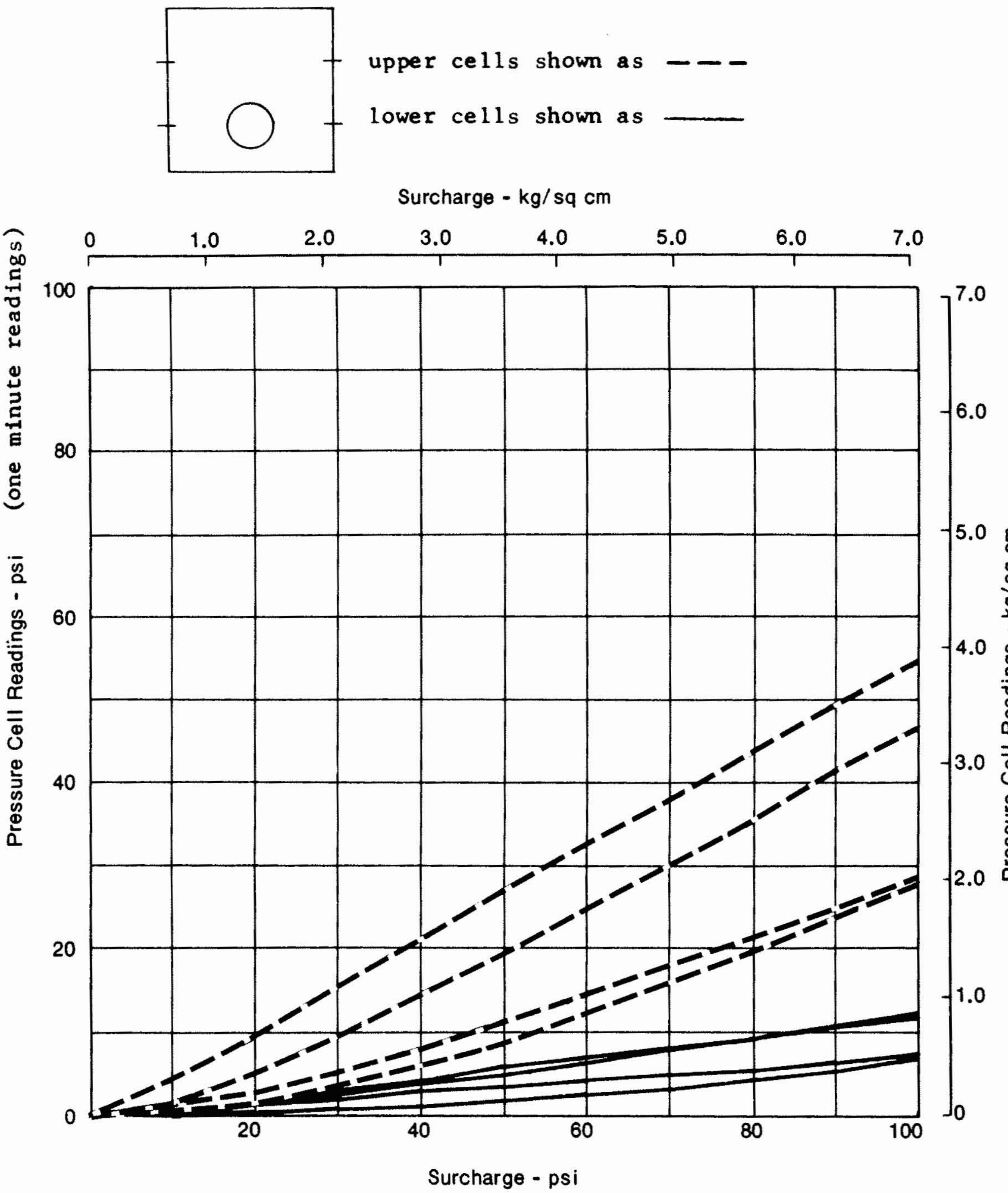


Figure A-8. Soil pressures on container walls, FRP pipe.

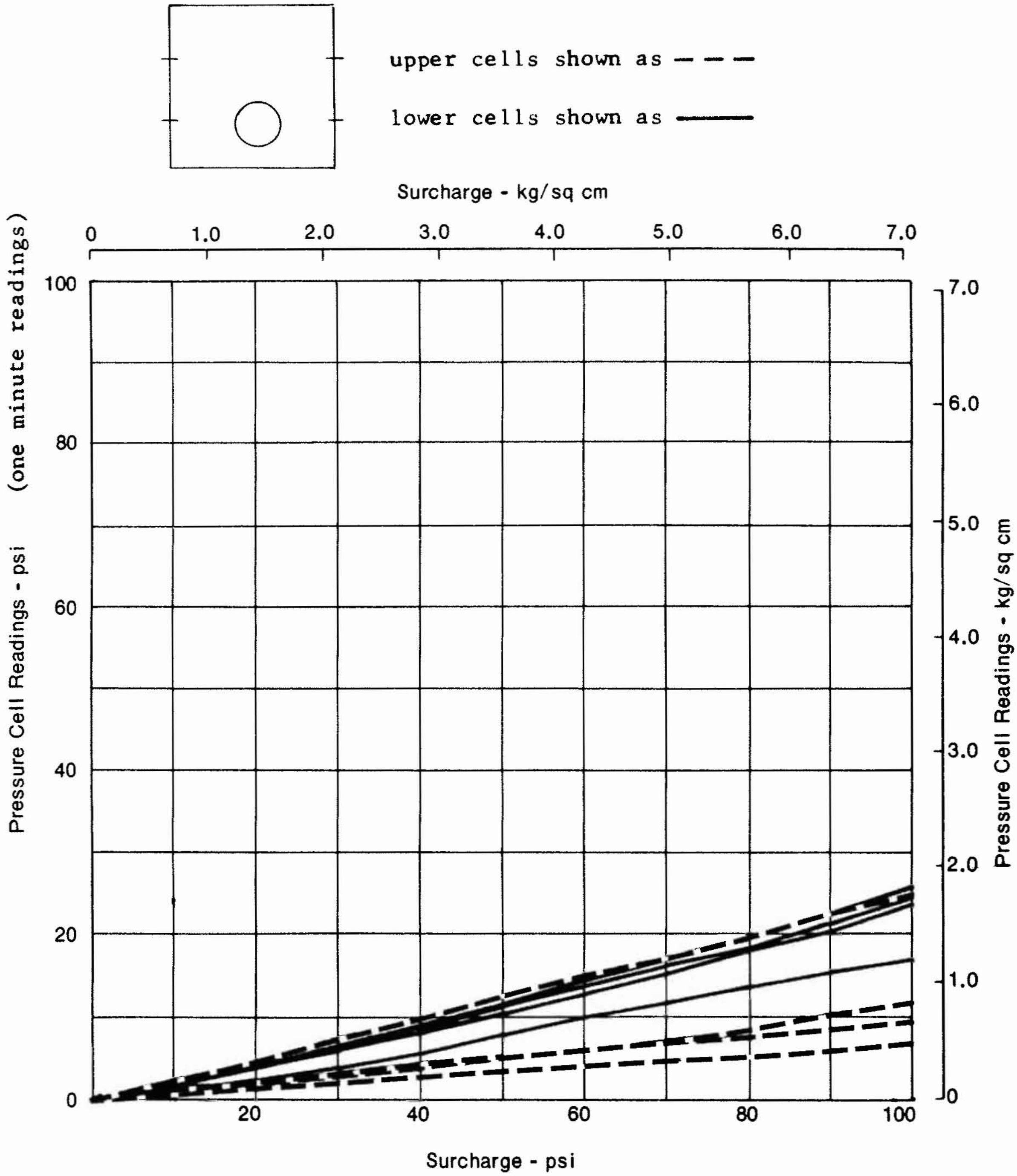


Figure A-9. Soil pressures on container walls, 7-gage steel pipe.

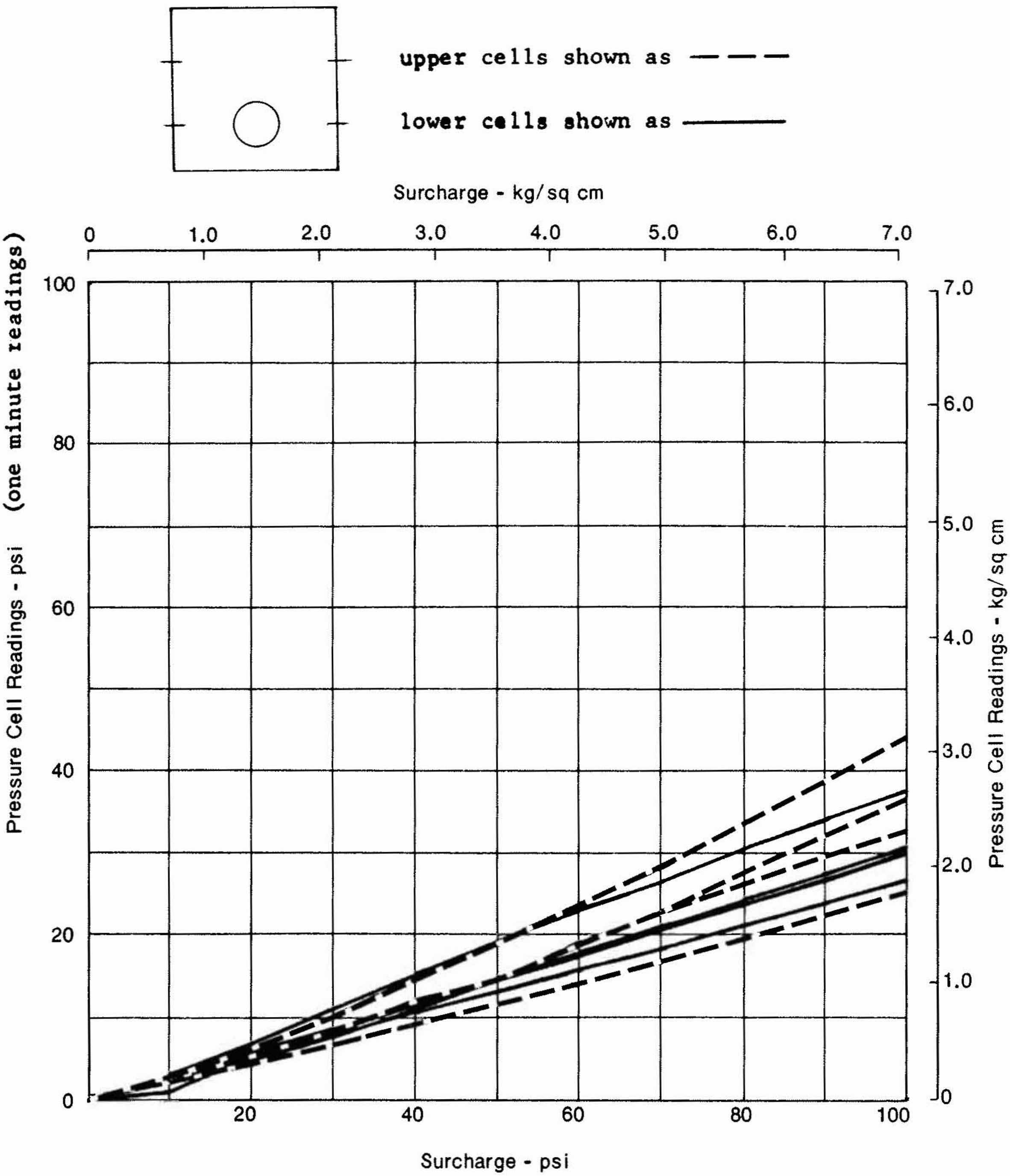


Figure A-10. Soil pressures on container walls, 12-gage steel pipe.

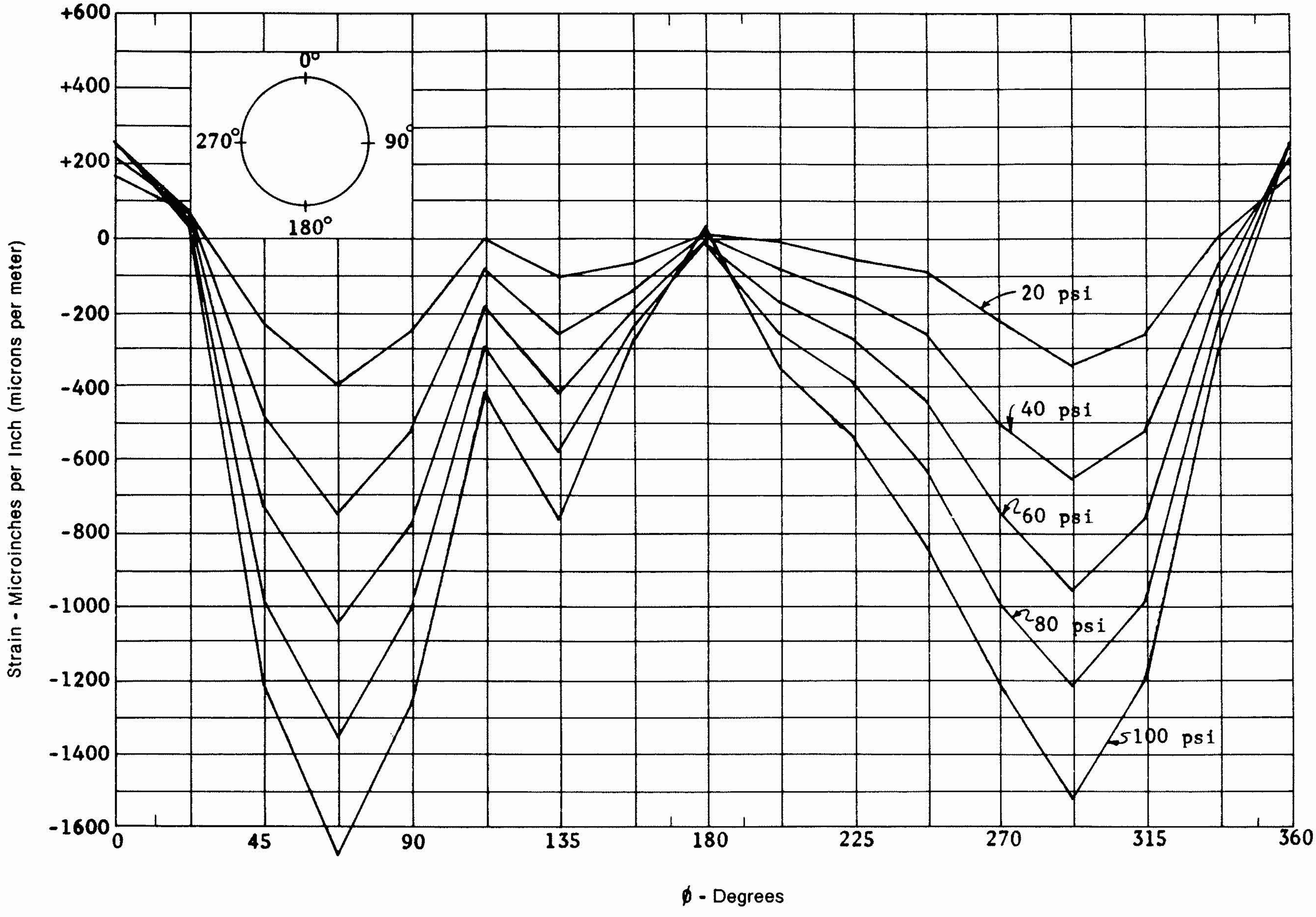


Figure A-11. Strain gage readings around inside pipe circumference, RPM pipe.

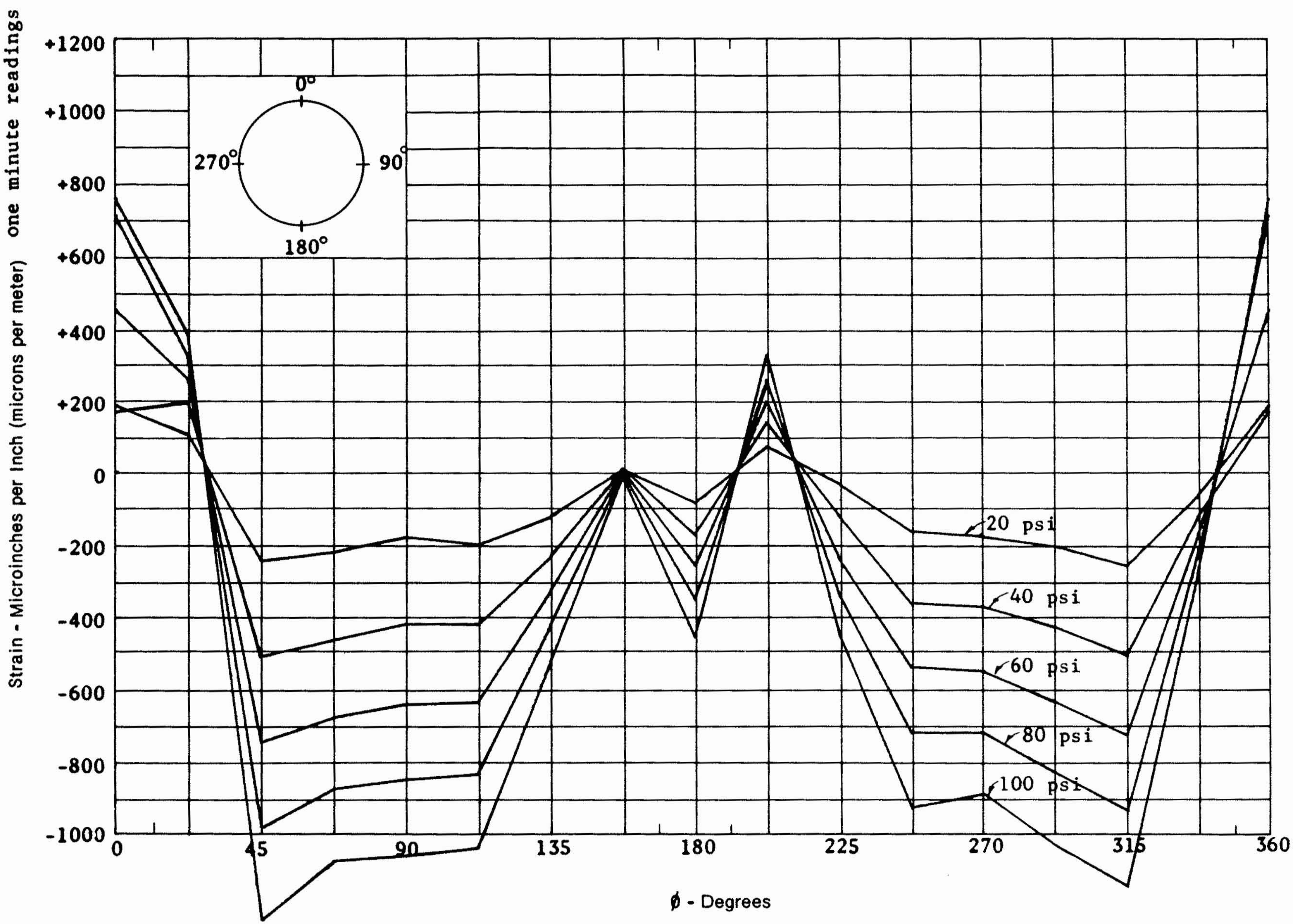


Figure A-12. Strain gage readings around inside pipe circumference, FRP pipe.

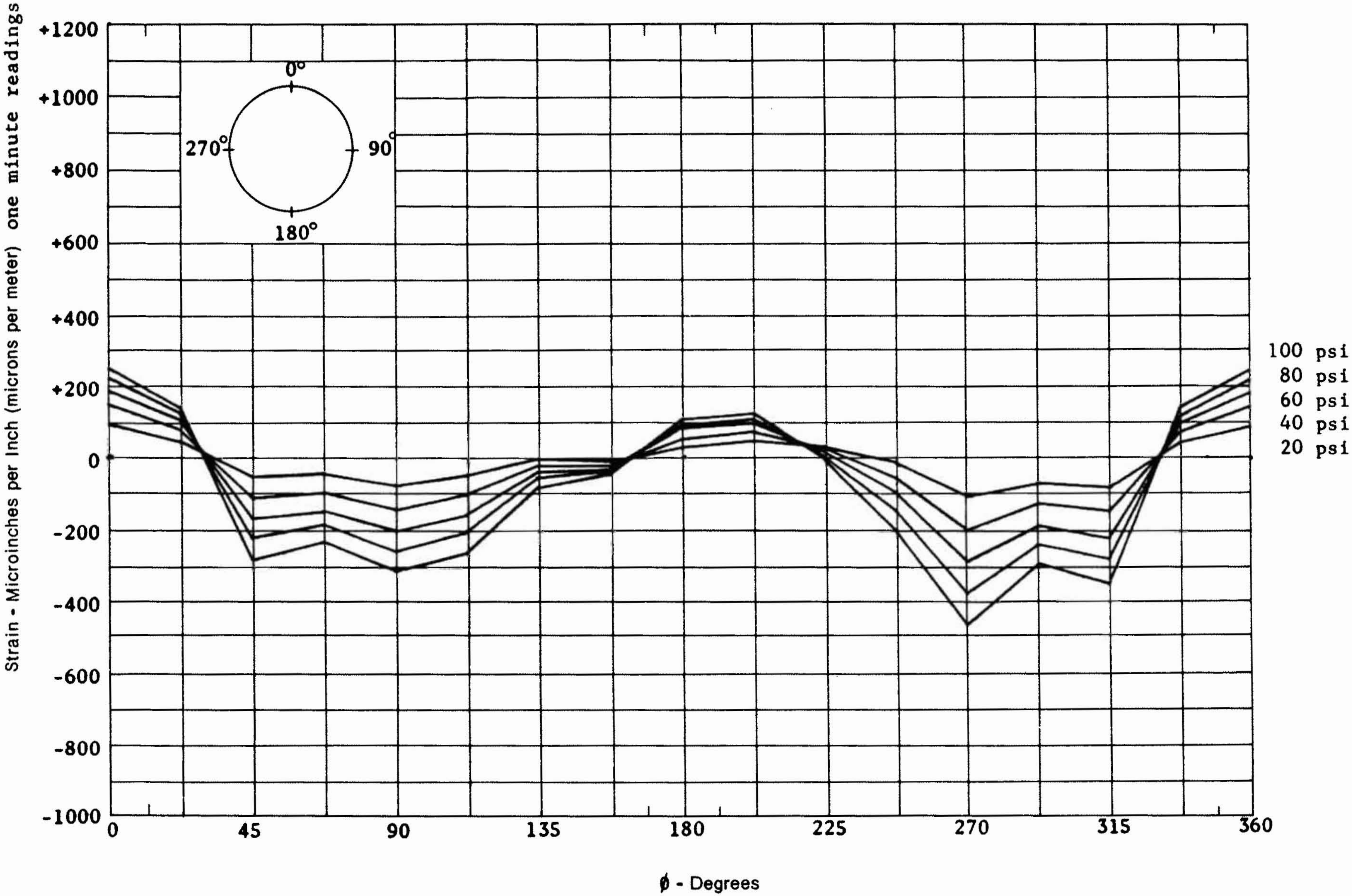


Figure A-13. Strain gage readings around inside pipe circumference, 7-gage steel pipe.

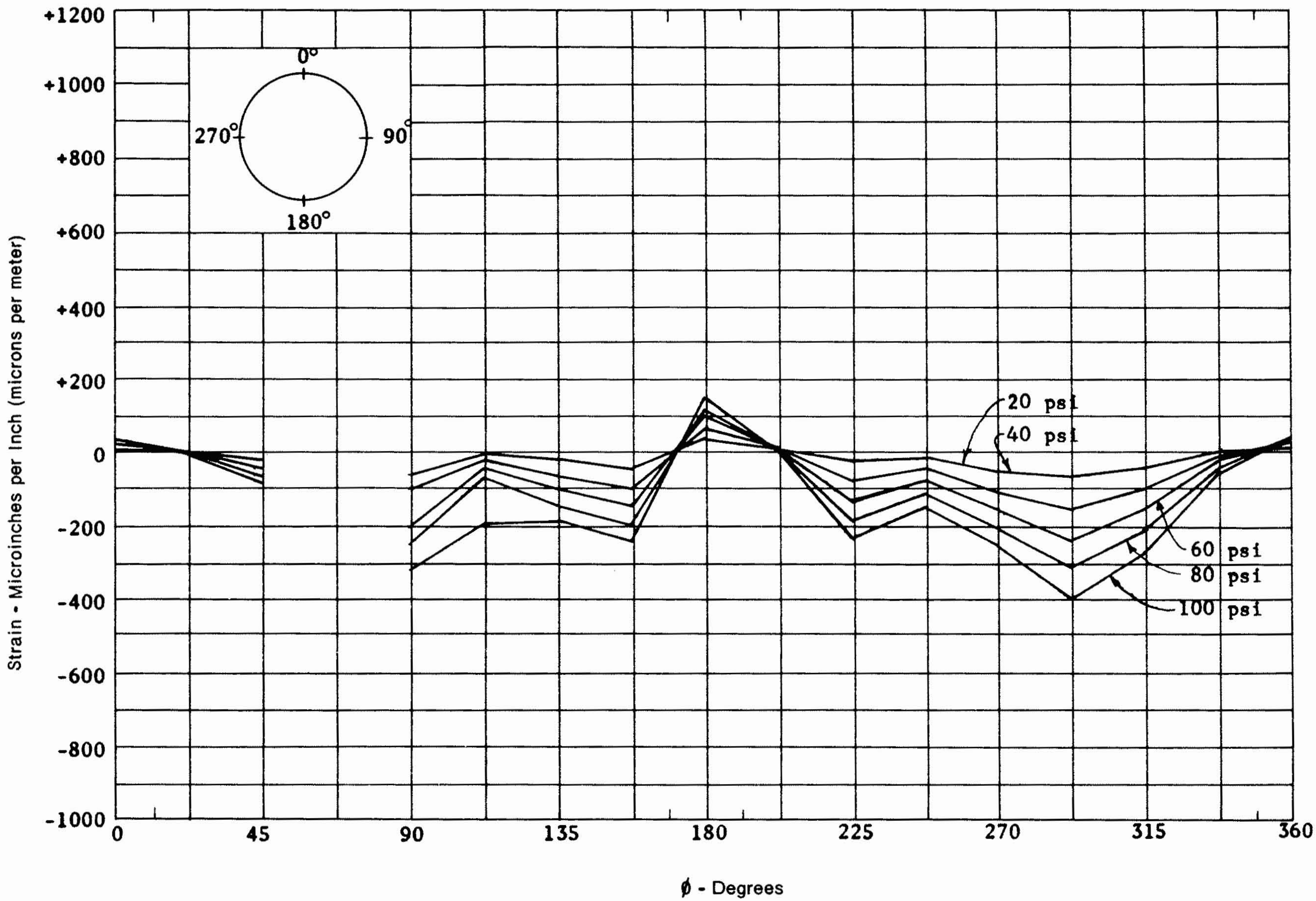


Figure A-14. Strain gage readings around inside pipe circumference, 12-gage steel pipe.

APPENDIX B

TEST DETAILS AND SOIL PROPERTIES

Physical Properties of the Pipe

The physical properties of the pipe are shown in Table B-1. Before the soil container test, each pipe was run in a three-edge bearing test to get the Ring Stiffness Factor, EI/r^3, of the pipe. For the steel pipe, the three-edge bearing tests were run before and after holes were cut into the pipe to mount the pressure cells. The Ring Stiffness Factors are listed in Table B-2 showing the slight differences in Ring Stiffness of the ends of the pipe. The values for the south end of the pipe (as positioned in the load test) are used for comparisons since this is where the deflections were measured with the inside micrometer. The pressure cells were mounted in the pipe before they were placed in the container.

Table B-1

PHYSICAL PROPERTIES OF THE TEST PIPE

Test description	Pipe diameter				Wall thickness				Length	
	North		South		North		South			
	inches	cm	inches	cm	inches	cm	inches	cm	inches	cm
18" RPM	18.045	45.83	18.013	45.75	0.425	1.08	0.407	1.03	70.844	179.94
18" FRP	17.873	45.40	17.872	45.39	0.474	1.20	0.426	1.08	70.875	180.02
18" 12-gage steel	17.785	45.17	17.751	45.09	0.105	0.27	0.105	0.27	70.984	180.30
18" 7-gage steel	17.637	44.80	17.655	44.84	0.180	0.46	0.181	0.46	70.953	180.22

Table B-2

RING STIFFNESS FACTORS OF THE TEST PIPE
EI/r^3

Test description	Percent vertical deflection	North end				South end			
		Vertical		Horizontal		Vertical		Horizontal	
		psi	kg/cm²	psi	kg/cm²	psi	kg/cm²	psi	kg/cm²
18" dia. RPM	4.8	12.5	0.88	12.7	0.89	12.3	0.86	12.7	0.89
18" dia. FRP	4.5	19.7	1.39	20.4	1.43	17.6	1.24	17.9	1.26
18" 12-gage steel									
before holes	4.7	4.1	0.29	4.4	0.31	4.1	0.29	4.3	0.30
with holes	4.9	4.0	0.28	4.2	0.30	4.0	0.28	4.2	0.30
18" 7-gage steel									
before holes	2.6	23.1	1.62	23.0	1.62	22.7	1.60	23.8	1.67
with holes	2.8	21.7	1.53	22.1	1.55	22.3	1.57	22.5	1.58

Preparation of the Soil Container

The first test was run on the 18-inch-diameter FRP pipe. During preparation for this test, various methods of compacting the sand were tried to find the most effective way of obtaining the required density. Using the best method, the other three tests were prepared as follows:

> The sand from the previous test was removed down to the level of the bottom of the pipe and wasted. The next test pipe, with the circular stiffeners in place, was then braced into place. The soil surface was smoothed, the soil surface elevations were obtained with a surveyor's level, and the container was weighed. Three lifts of soil were used to bring the soil surface up to the top of the soil container. For each lift, about 1 inch of water for each 6 inches of loose material was placed in the container (Figure B-1) and the loose sand dumped into place (Figure B-2) and then vibrated, as shown in Figure B-3. Two internal concrete vibrators were used to compact the sand until the water rose to the soil surface. The soil surface was smoothed, the elevations obtained (Figure B-4), the container weighed using load cells on each corner of the container (Figure B-5), and the wet density calculated.

Moisture samples were taken at three different depths in the lift and an average moisture for the lift used to calculate the dry density. The densities of the individual lifts and for the whole soil container are shown in Figure B-8. Using this method, the densities were higher than the 70 percent relative density value desired.

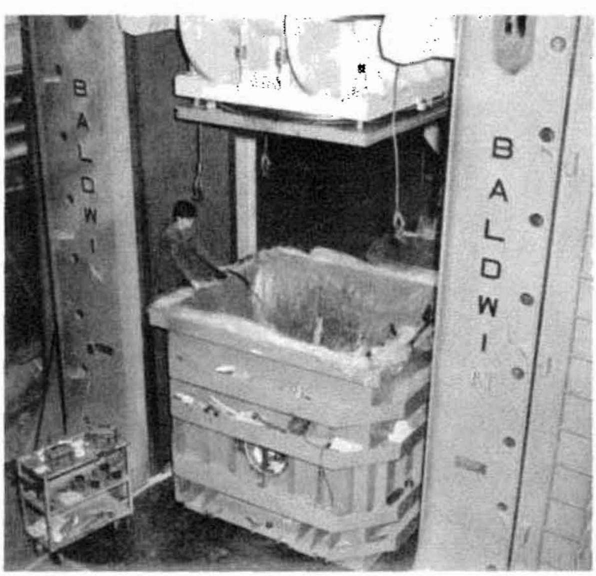


Figure B-1 Water added to soil container before loose soil is placed into container. Photo P801-D-73330

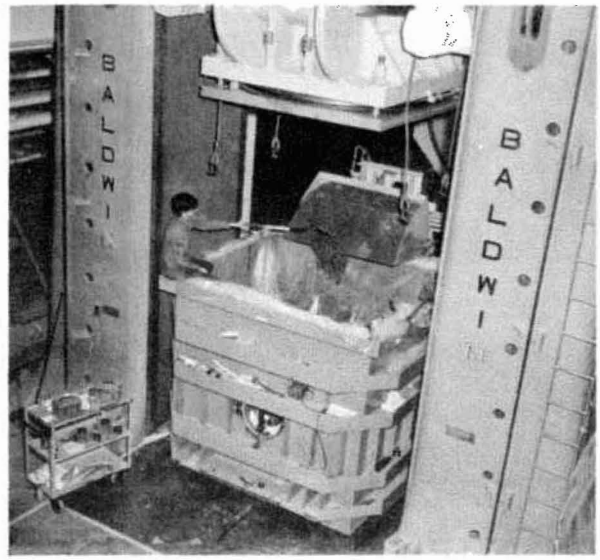


Figure B-2. Loose sand being dumped into soil container. Photo P801-D-73331

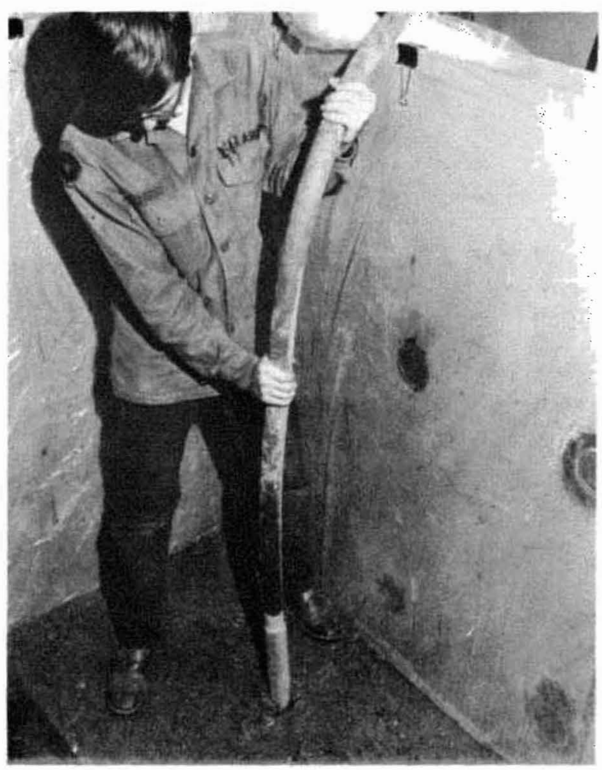


Figure B-3. Sand backfill being compacted by internal concrete vibrator. Photo P801-D-73326

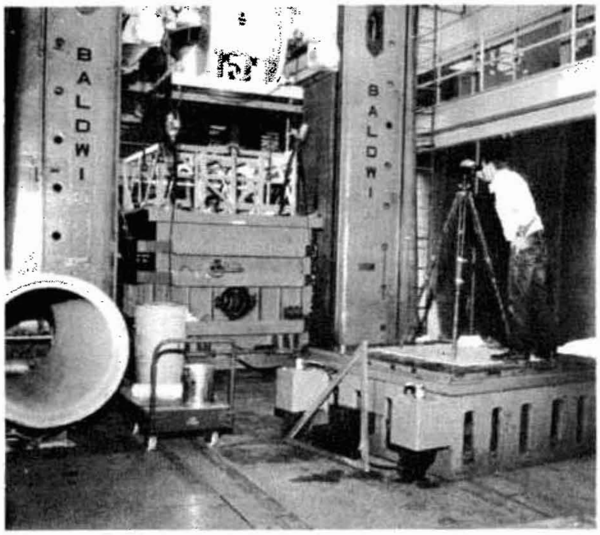


Figure B-4. Elevation of soil surface determined by surveyor's level. Photo P801-D-73327

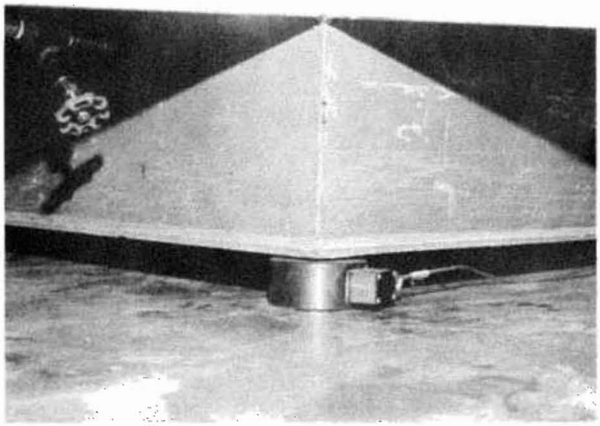


Figure B-5. Weight of sand backfill lift determined by weighing soil container on load cells. Photo P801-D-73329

The compacted soil came up to within 2 inches of the top of the soil container. Loose concrete sand was then placed on the soil surface and leveled at the top of the container to provide a smooth surface on which to place the wooden load plate. The drains at the bottom of the container were then opened and the container drained for 2 to 4 days before the test. The drains were also open during the day of the test.

The day before the test, the pipe stiffeners and braces were removed and all instrumentation connected. On the morning of the test, all instruments were read and these readings used as zero values for the measurements made during the test. Even with the stiffeners in place, all four pipe were elongated slightly in the vertical diameter due to compacting the soil on the sides of the pipe. Figures B-6 and B-7 show interior views of the pipe with the instrumentation in place.

Soil Properties

The soil used was a poorly graded sand, with about 27 percent gravel, classified as SP in the Unified

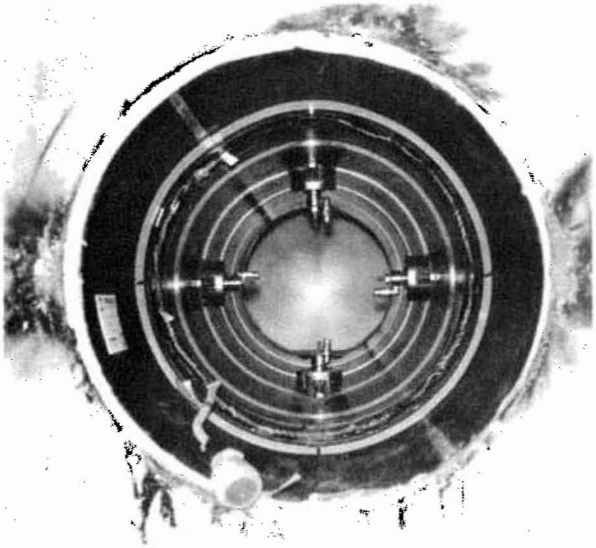


Figure B-6. Interior view of a steel pipe showing the four soil pressure cells and the circumferential ring of SR-4-type strain gages. Photo P801-D-73328

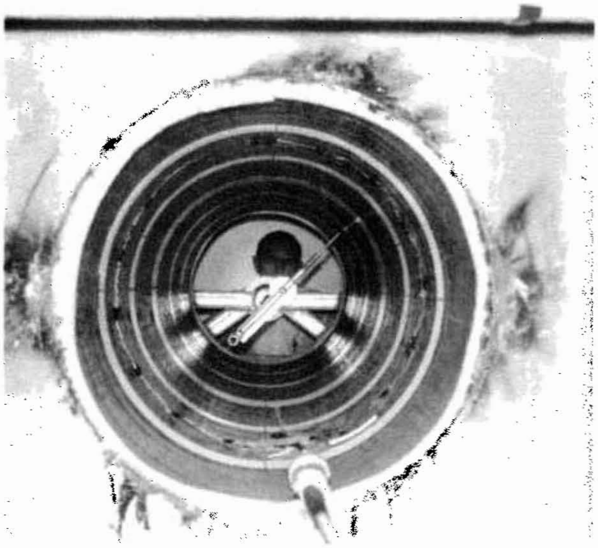
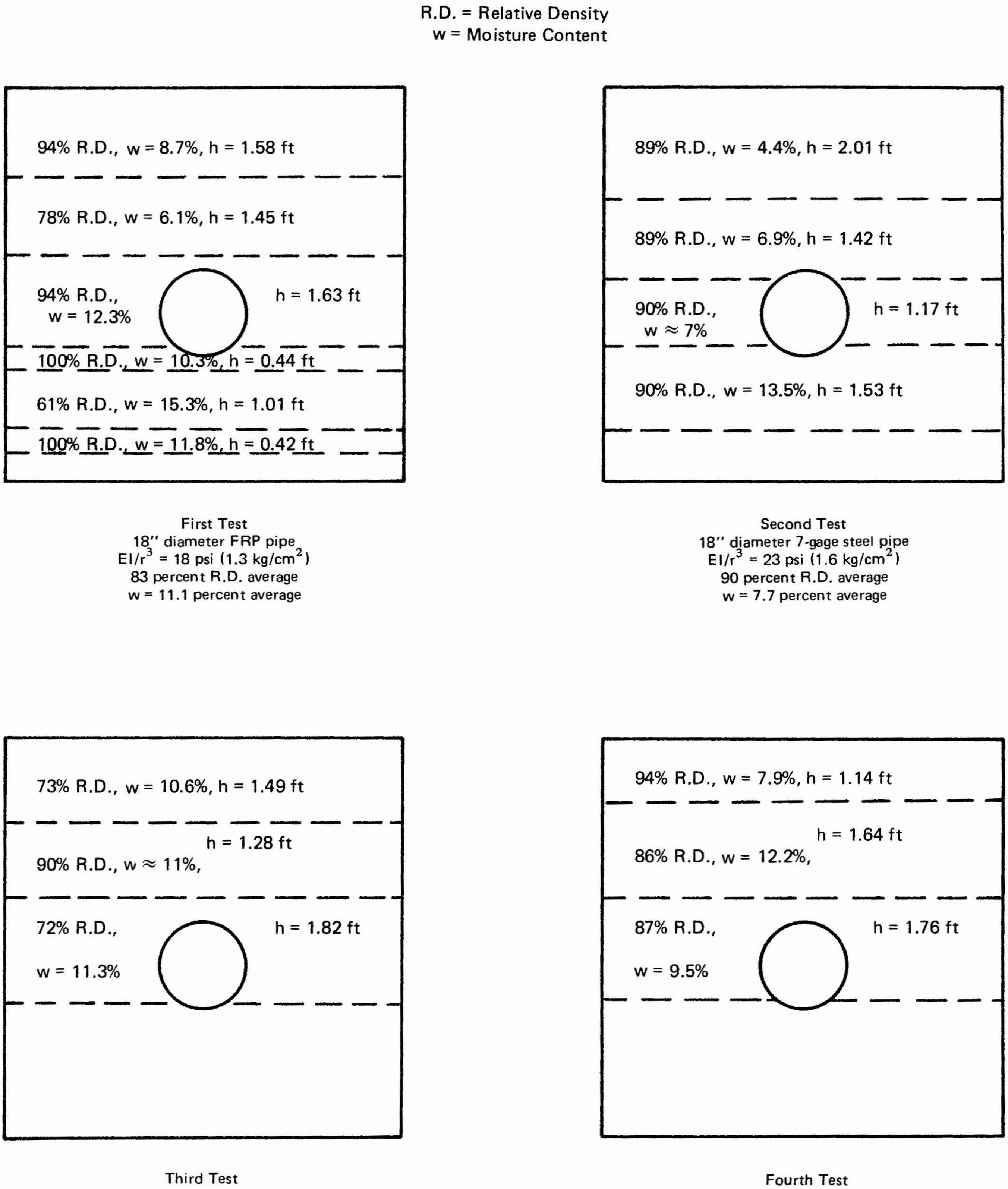


Figure B-7. Interior view of the RPM pipe showing the revolving dial gage used to measure the pipe shape. Photo P801-D-73332



First Test
18" diameter FRP pipe
EI/r^3 = 18 psi (1.3 kg/cm^2)
83 percent R.D. average
w = 11.1 percent average

Second Test
18" diameter 7-gage steel pipe
EI/r^3 = 23 psi (1.6 kg/cm^2)
90 percent R.D. average
w = 7.7 percent average

Third Test
18" diameter RPM pipe
EI/r^3 = 13 psi (0.9 kg/cm^2)
78 percent R.D. average
w = 11 percent average

Fourth Test
18" diameter 12-gage steel pipe
EI/r^3 = 4.5 psi (0.3 kg/cm^2)
88 percent R.D. average
w = 10.1 percent average

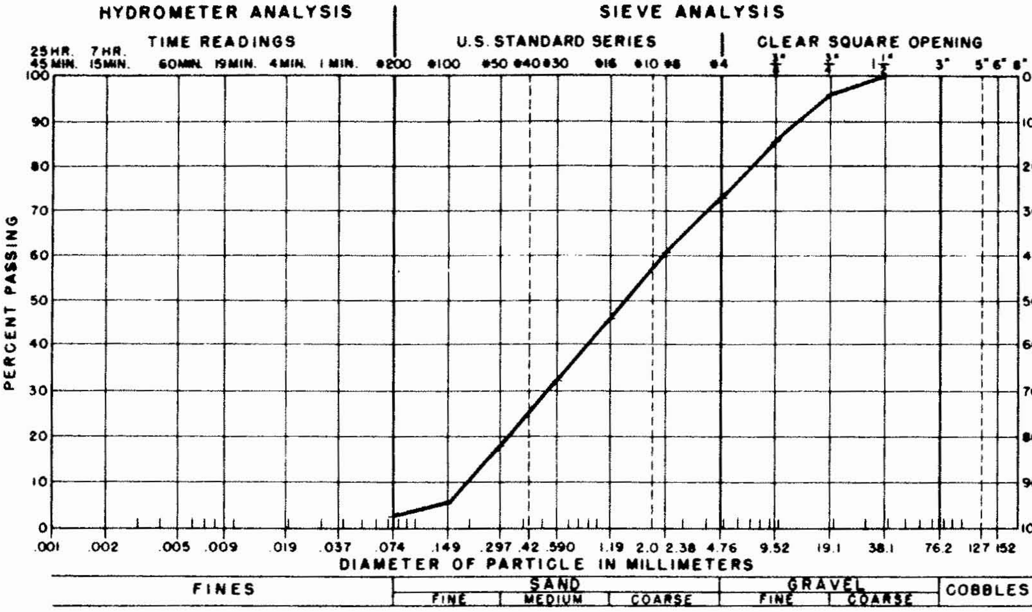
Figure B-8. Densities and moisture contents of sand backfill tests.

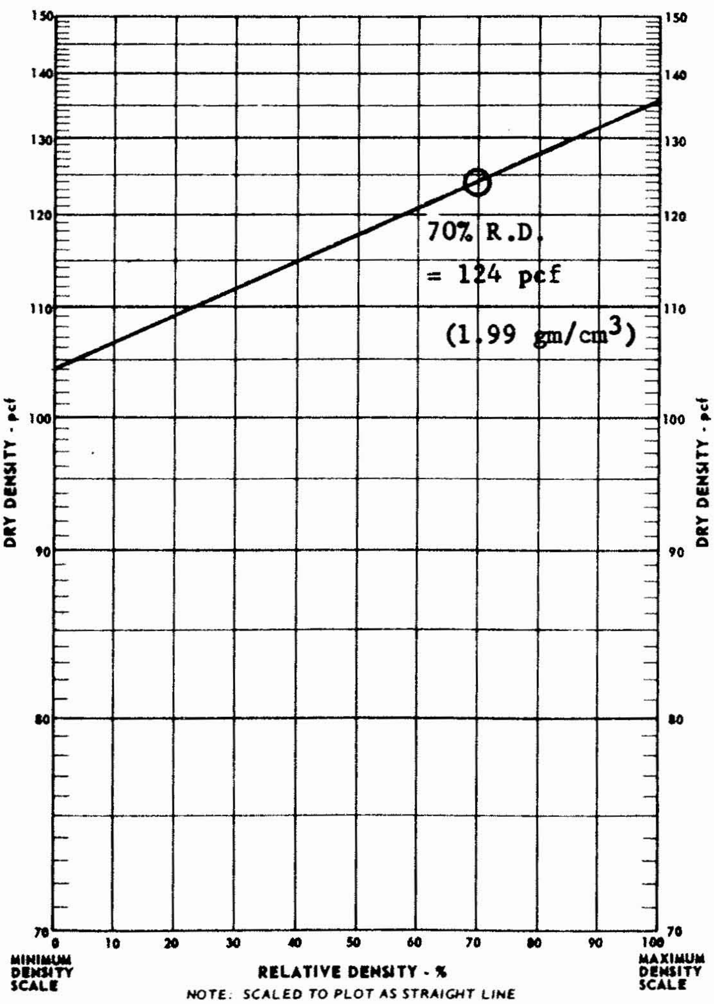
Classification System. The physical properties of the soil are shown in Figure B-9. As shown on the figure, 70 percent relative density was equivalent to a dry density of 124 pcf (1.99 gram/cm^3). All properties were determined by procedures described in the Bureau of Reclamation's *Earth Manual*.*

Because of the possibility of particle breakdown due to the high loads on the soil, the soil was not reused. The physical properties shown are the averages of six separate samples taken from the soil stockpile used as the source for the backfill material.

*Bureau of Reclamation, *Earth Manual*, 1st Edition, Revised 1963, Denver, Colorado.

PHYSICAL PROPERTIES SUMMARY PLOT (Relative Density)





Classification Symbol **SP**

Gradation Summary
- Gravel **27** %
- Sand **70** %
- Fines **3** %

Atterberg Limits
- Liquid Limit **NP** %
- Plasticity Index ____ %
- Shrinkage Limit ____ %

Specific Gravity
- Minus No. 4 ____
- Plus No. 4
- Bulk ____
- Apparent ____
- Absorption ____ %

Relative Density
- Minimum Density **103.9** PCF (**1.66** gm/cm^3)
- Maximum Density **135.5** PCF (**2.17** gm/cm^3)
- In-place Density ____ PCF (____ gm/cm^3)
- Percent Relative Density ____

Permeability Settlement
- Placement Condition ____
- Coef of Permeability ____ ft/yr (____ cm/sec)
- Settlement Under ____ psi Load ____ % (____ kg/cm^2)

Notes: ____

Sample No. **39T-6** Hole No. ____ Depth ____ ft (____ m)

GPO 836-273

Figure B-9. Sand for flexible pipe studies.

7-1750 (3-71)
Bureau of Reclamation

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	$^{*}0.965873 \times 10^{-6}$	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	$^{*}4.4482 \times 10^5$	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	Kiiovolts 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

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ABSTRACT

Two steel pipe, one reinforced plastic mortar, and one fiberglass reinforced plastic pipe, each about 18 inches (46 centimeters) in diameter and 71 inches long were load-tested in a laboratory soil container. All pipe were buried in a sand backfill. Increasing surcharge increments were applied to the soil surface over the pipe. Data were collected on pipe deflection and shape, soil pressure, soil movement around the pipe, and strain on the inner surface of the pipe. Conclusions are: (1) Pipe tested in sand backfill (relative densities from 78 to 89 percent) deflected similarly—less than 1 percent at 100 psi (7.0 kg/cm^2) surcharge—regardless of pipe stiffness or pipe material. (2) Compared to tests on similar pipe in a low-density lean clay backfill, the sand backfill reduced pipe deflections over 95 percent. (3) The modulus of soil reaction of the sand backfill ranged from 6,000 psi (420 kg/cm^2 to 30,000 psi (2,100 kg/cm^2 depending on the calculation method used. The Iowa Formula predicts the percent deflection based on a ratio of the external pipe load to a combination of pipe strength and soil strength. The tests show that: (1) when high strength bedding is used, pipe material or strength has little effect on pipe deflection; and (2) when the soil is a poor material or is poorly compacted, pipe material or strength significantly affects pipe deflection. (Nine references)

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REC-ERC-73-9
Howard, A K
LABORATORY LOAD TESTS ON BURIED FLEXIBLE PIPE: PROGRESS REPORT NO. 6
Bur Reclam Rep REC-ERC-73-9, Div Gen Res, June 1973. Bureau of Reclamation, Denver, 44 p, 34 fig, 5 tab, 9 ref, 2 append

DESCRIPTORS—/ backfills/ *soil mechanics/ loading tests/ *buried pipes/ test procedures/ *flexible pipes/ soil pressure/ lateral forces/ glass reinforced plastics/ *steel pipes/ strain/ deflection/ deformation/ laboratory tests/ *plastic pipes/ polymers/ stiffness/ resins/ sands/ cohesionless soils/ *pipes/ pipe bedding
IDENTIFIERS—/ fiberglass plastic pipe/ Iowa Formula/ *soil-structure interaction/ reinforced plastic mortar pipe/ soil modulus

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