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RPM PIPE DEFLECTIONS ON YUMA PROJECT FIELD TEST

Analysis of 30-inch-diameter reinforced plastic mortar pipe behavior under 4 feet of backfill with various bedding conditions

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16. ABSTRACT

Field tests of reinforced plastic mortar (RPM) pipe were conducted on the Yuma Project. Two test sections of 30-inch-diameter pipe were installed to replace two deteriorated open laterals. Twenty-nine 20-foot sections were placed in the Toronto Lateral in a dry trench using the following types of bedding: (1) compacted natural earth, (2) compacted sand, (3) puddled natural earth, (4) loose sand, and (5) loose natural earth. Thirty 20-foot sections were placed in the Apache Lateral in a wet and unstable subgrade 9 to 18 inches below the water table. Performance of RPM pipe was evaluated under controlled field conditions and deflections of the pipe laid in different bedding conditions were measured. Results from the Toronto Lateral showed the following average vertical pipe deflections: (1) well compacted material, 1 percent; (2) puddled natural earth, 4 percent; (3) loose sand, 6 percent; and (4) loose natural earth, 8 percent. Results from the Apache Lateral showed that the average vertical deflections were 0.7 percent at the spigot end, 1 percent at the bell end, and 2.3 percent at the center of the pipe. Field tests indicate that RPM pipe is a practical alternative to other types if the RPM pipe is installed according to Bureau specifications. (9 references)

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION
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The construction on the Toronto Lateral was directed by Darrell Krull, Chief, Office of Special Studies Branch. The construction on the Apache Lateral was directed by Jesse Durnell, Chief, Engineering Division. T. H. Moser is the Project Manager of the Yuma Projects Office.

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INTRODUCTION

The Bureau of Reclamation (USBR) is now emphasizing the use of closed conduits on its water distribution systems, including replacing deteriorated existing canals with pipelines. Pipelines reduce water losses, reduce maintenance costs, permit the use of land over the conduit, and reduce the hazards to people and animals.

The Open and Closed Conduit Systems (OCCS) Committee of the USBR evaluates different types of pipe and construction methods in an effort to reduce the high initial costs of installing pipelines. In 1967, the USBR began investigating reinforced plastic mortar (RPM) pipe. Laboratory tests have indicated that RPM pipe could be an economical alternative to the types of pipe allowed under USBR specifications. In 1970, the OCCS Committee funded a special test program on the Yuma Project to evaluate the field performance of RPM pipe.

Reinforced Plastic Mortar (RPM) Pipe

RPM pipe is a composite of polyester resin, silicate sand, and glass filament reinforcing. The pipe is built up in layers on a mandrel by a filament winding process modified to incorporate the sand into the process. The result is a pipe that is flexible and lightweight yet provides high tensile hoop strength. RPM pipe also is resistant to a wide variety of chemical solutions. The pipe is manufactured in standard 20-foot (6.1-meter) lengths with bell-and-spigot, rubber-gasketed (O-ring) joints. The joint is essentially the USBR's R-4 joint design. The bell is fabricated as an integral part of the pipe on the mandrel during the winding process. The spigot is cast or molded on the outside of the pipe wall at the end of the pipe.

Results of cooperative laboratory studies on RPM pipe by private industry and the U.S. Government have been published in two USBR laboratory reports.(1)*(2) Another USBR laboratory report (3) compares the structural behavior of RPM pipe buried in a special laboratory test container with that of steel pipe. This report covers the field performance of 30-inch (76-cm) RPM pipe used in the rehabilitation of two open laterals on the Yuma Project. It is an expansion of a report prepared by Henry G. Metzger and submitted by the Yuma Projects Office, Yuma, Arizona.(4)

*Numbers in parentheses designate references at end of text.

Yuma Project, Reservation Division

The Reservation Division of the Yuma Project is one of the oldest Reclamation developments on the Colorado River. Construction was started in 1905 and completed in 1909, with water deliveries starting in 1910. The canals and laterals have degraded significantly; seepage losses are high and unstable banks are common. As a result, frequent breaks in canal and lateral banks disrupt water service to the users.

The water for the project was originally diverted from Laguna Dam, but since 1948 water for the Reservation Division has come directly from the All-American Canal or the Yuma Main Canal that heads at the All-American Canal. With the water supply coming from this source, any rehabilitation of the project could be accomplished by use of a closed-conduit full-pressure system. The normal high water surface of the All-American Canal at the turnouts to the Reservation Division is 30 to 40 feet (9 to 12 meters) above the ground surface elevation of the farm areas.

The soils in the Reservation Division are largely sandy silts with a widely varying ground-water table. The RPM pipe was installed under both high and low ground-water conditions, with no attempt to dewater for the high ground-water condition. Both natural and imported materials were used for the pipe bedding.

On the Toronto Lateral, the pipe was installed in a dry trench with five different beddings to examine the effects of various beddings on the pipe structural behavior. On the Apache Lateral, the pipe was laid below the water table to assess the problems of installing the pipe below water. In addition, on the Apache Lateral the deflections of the bell-and-spigot ends of the pipe were measured and compared to the deflections in the center of the pipe sections.

TORONTO LATERAL

Twenty-nine 20-foot (6.1-meter) sections of 30-inch (76-cm) diameter RPM pipe were installed on the Toronto Lateral in October 1970 on a dry subgrade. The pipe were bell-and-spigot joint type

and were rated for 100-psi (7-kg/cm^2) internal pressure. Figure 1 shows the pipe before installation. The line included the necessary mitered bends and connections to existing structures.

The trench for the pipe had a 5-foot (1.5-meter) bottom width with 3/4:1 side slopes. The subgrade was approximately 9 feet (2.7 meters) below the top of the lateral embankment and 5 feet (1.5 meters) below the bottom of the old lateral. The native material was generally a sandy silt with some areas of clay. The inplace moistures and densities of the trench walls were determined in seven locations and the gradation, consistency limits, specific gravity, maximum density and optimum water content were determined in the laboratory. The physical properties of the soils are shown in Appendix A.

The pipe was laid downstream with the spigot in the downstream direction and joined by hand leveling. Internal vertical and horizontal diameter measurements were made at selected locations in each pipe section. After placement, the pipe was filled with water to determine if it was watertight and to keep it on grade during the placing of the bedding. The pipe was watertight except for a small leak at the concrete mortar pipe closure forming the mitered upstream bend.

There were five types of bedding used on this lateral:

(1) Sixty linear feet (18.3 meters) of compacted sand, saturated and vibrated.

(2) Two hundred and forty linear feet (73.2 meters) of loose sand.

(3) Forty linear feet (12.2 meters) of compacted natural earth, tamped.

(4) One hundred and eighty linear feet (54.9 meters) of loose natural earth.

(5) Sixty linear feet (18.3 meters) of puddled natural earth.

In accordance with USBR specifications, the bedding material was placed to a depth of 0.7 times the outside diameter of the pipe. Prior to backfilling over the pipe, inplace density tests were made on each side of the pipe in the compacted natural earth and in the compacted sand bedding. Density tests for the puddled natural earth and the loose natural earth were made after the backfill had been placed and the beddings had settled. These latter densities represent the material density after the initial pipe deflection and the change in density due to the surcharge of the overlying backfill. The densities and other physical properties of the bedding materials are shown in Appendix A.

The initial pipe deflection values were made about 2 weeks after construction and subsequent deflections measured in March 1971 (4 months), August 1971 (10 months), and March 1972 (16 months). These measurements are discussed in detail in Appendix B.

Figure 2 shows the pipe being placed into the prepared trench, and Figure 3 shows the preparation of the pipe for joining. Dikes were constructed between some of the different types of beddings as shown in Figure 4. The compacted sand bedding

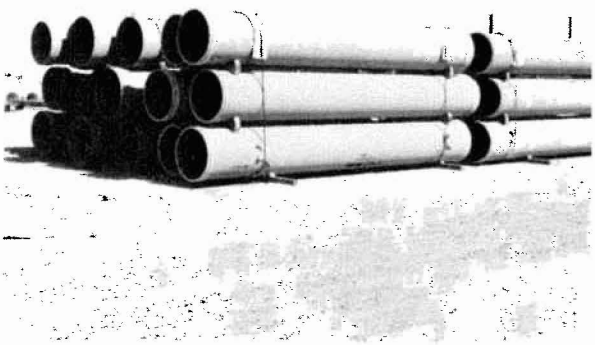

Figure 1. 30-inch-diameter RPM pipe prior to installation in Toronto Lateral, Yuma Project. Photo PX303-1712NA

Figure 2. RPM pipe being lowered into trench on Toronto Lateral, Yuma Project. Photo P35-D-72460NA

Figure 3. Preparation of 30-inch-diameter pipe for joining, Toronto Lateral, Yuma Project. Photo PX303-1321NA

Figure 4. Constructing dikes between different bedding types on Toronto Lateral, Yuma Project. Photo C303-1383NA

was placed by putting water in the trench, dumping in the imported sand, and then vibrating with concrete vibrators as shown in Figure 5. The loose sand bedding was prepared by dumping the sand in and then flooding the sand to settle it with no vibration. The compacted natural earth bedding was constructed by placing the soil in loose layers and compacting each layer with pneumatic tampers. The loose earth bedding was prepared by dumping the material into place and then flooding it to water settle the material. The

Figure 5. Vibrating sand bedding on Toronto Lateral, Yuma Project. Photo CNX303-1715NA

puddled natural earth bedding was constructed by flooding the trench with water and then dumping the soil, as shown in Figure 6, and then settling the soil by working it with shovels as shown in Figure 7.

The backfill over the pipe was pushed into place with a dozer, see Figure 8, and then water settled, as shown in Figure 9.

A surcharge load was applied over one of the pipe sections in the compacted sand bedding to see the effect of surcharge loading on the pipe deflection. Details of the surcharge test section and the results are discussed in Appendix D.

APACHE LATERAL

Thirty 20-foot (6.1-meter) sections of 30-inch (76-cm) diameter RPM pipe were installed in the Apache Lateral in March 1971 on an unstable subgrade 9 inches (23 cm) to 18 inches (46 cm) below the water table. The pipe had bell-and-spigot joints and were rated for 100-psi (7-kg/cm^2) internal pressure. Included in this line was a horticultural turnout and

Figure 6. Dumping soil into water alongside the RPM pipe for puddled earth bedding on Toronto Lateral, Yuma Project. Photo P35-D-72463NA

Figure 8. Backfill being pushed into place over RPM pipe on Toronto Lateral, Yuma Project. Photo PX-303-1353NA

Figure 7. Settling puddled natural earth bedding on Toronto Lateral by working it with shovels, Yuma Project. Photo P35-D-72468NA

Figure 9. Backfill over RPM pipe on Toronto Lateral being water settled, Yuma Project. Photo PX303-1354NA

the necessary vertical bends and connections with existing structures.

The trench for the pipe had an approximate 6-foot (1.8-meter) bottom width with 3/4:1 side slopes. It was difficult to excavate the trench to grade because it was below the water table, and the sandy silt sloughed into the trench. The subgrade was approximately 10 feet (3 meters) below the top of the lateral embankment. In order to get the pipe on grade, the trench was overexcavated, the pipe immediately lowered into the trench, and joined. The pipe was then brought to grade by filling beneath it, maneuvering the pipe to grade, and weighting it with some backfill to prevent floating. No attempt was made to dewater the trench. The pipe was laid downstream with the bell end downstream. The pipe was jointed easily despite the water and soil covering the lower portion of the bell. A completed pipe joint is shown in Figure 10. Gaskets were checked as conditions permitted, but a watertight joint could not be assured.

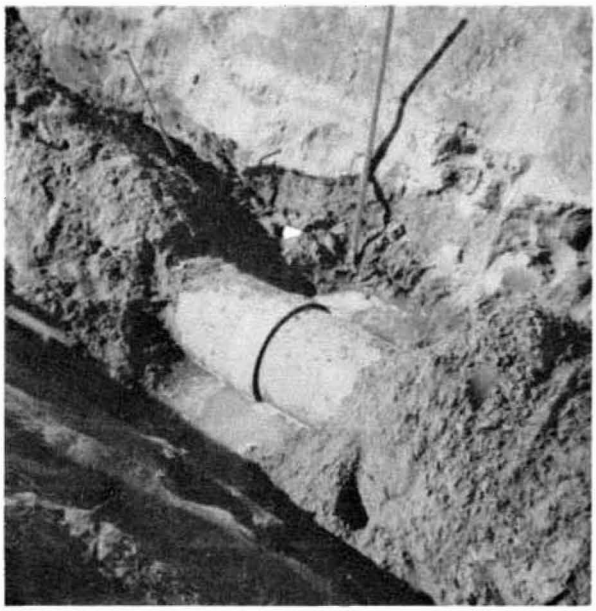

Figure 10. RPM pipe joint on Apache Lateral, Yuma Project. Note height of water table. Photo CNX303-1720NA

Internal vertical and horizontal diameter measurements were made at the bell and the spigot before the pipe was placed. Initial deflection measurements were made 2 months later in May 1971 and subsequent deflections measured in August 1971 (5 months) and in March 1972 (12 months). These measurements are shown in detail in Appendix C.

The pipe bedding was a natural silty sand and placed to a depth of 0.7 times the outside diameter by water settling. The backfill was water settled natural earth and placed to 4 feet (1.2 meters) above the top of the pipe.

TEST RESULTS FROM TORONTO LATERAL

The external 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 bedding material develops a passive resistance that acts to help support the pipe. The resistance of the soil is affected by the type of soil and its density and moisture content. The higher the soil resistance, the less the pipe will deflect.

Several design procedures exist that can be used to predict the deflection of buried flexible pipe. The deflection depends on the soil load on the pipe, the strength of the pipe, the passive resistance of the bedding soil, and the time-consolidation rate (deflection lag factor) of the bedding soil. In the Toronto Lateral installation, the pipe strength and the load on the pipe are the same for each pipe section, but the various bedding materials allow comparisons to be made as to the passive resistance of each type of material and its deflection lag factor.

First, the relative effectiveness of the bedding materials in limiting pipe deflection will be discussed for each condition. Then, the evaluation of the passive resistance as used in the most common design method, the Iowa Formula, will be computed for each bedding condition. Next, the deflection lag factors of each bedding condition will be compared.

Effectiveness of Beddings

There are two basic types of soils used for pipe bedding, cohesive (clay and silt) and cohesionless (sand and gravel). For cohesive bedding material, USBR specifications require that the material be compacted to a minimum of 95 percent of Proctor maximum dry density. The Proctor maximum dry density is determined in the laboratory using Designation E-11 in the Earth Manual.(5) For cohesionless bedding materials, the specifications require a minimum of 70 percent relative density. The relative density method, Designation E-12 of the Earth Manual, determines the required field density as a percentage of the range between the minimum and maximum densities of the soil as determined in the laboratory.

The beddings in this installation using the two types of materials ranged from the worst condition (dumped and flooded) to the best condition (compacted by mechanical methods). In addition, the cohesive material had an intermediate condition of being puddled.

The following table shows the condition of each bedding type and the resulting vertical deflection of the pipe:

Types of Pipe Bedding and Resulting Deflections

Material type	Condition	Construction method	Percent vertical deflection	Bedding type
Cohesionless (sand)	Worst	Dumped and flooded	5.9	Loose sand
	Best	Saturated and vibrated	0.7	Compacted sand
Cohesive (natural earth)	Worst	Dumped and flooded	8.3	Loose natural earth
	Intermediate	Puddled	4.2	Puddled natural earth
	Best	Pneumatically tamped	−0.3	Compacted natural earth

The deformation of the soil at the sides of a pipe depends on its compressibility. The compressibility depends on the type of soil and the degree of compaction. Well-compacted sands and gravels provide good support because they have a close interlocked granular structure and the individual grains are relatively incompressible. Well-compacted cohesive soils are more compressible because their fine particle structure combined with water film does not permit contact and interlocking of particles.

Because of the granular structure of a cohesionless soil it is generally considered to be a better bedding material than cohesive material, and the results indicate this. The loose (dumped and flooded) sand bedding resulted in 25 percent less pipe deflection than the loose (dumped and flooded) natural earth. The compacted sand bedding resulted in slightly more deflection than the compacted natural earth. However, the compacted natural earth bedding densities met the specifications, whereas the compacted sand bedding densities did not. The sand densities were only 30 to 38 percent relative density. If the sand had been compacted to specifications, the deflections probably would have been about the same as for the pipe in natural earth.

Of particular interest is the fact that the intermediate condition, the puddled natural earth, gave better support to the pipe than did loose sand bedding. Listing the various beddings in decreasing effectiveness gives the following table:

Table Bedding Type

Bedding type	Percent vertical deflection
Compacted natural earth	0
Compacted sand	1
Puddled natural earth	4
Loose sand	6
Loose natural earth	8

The average deflection values are compared with the range of deflection values in Figure 11.

Modulus of Soil Reaction

In 1941, M. G. Spangler, Iowa State Engineering Experiment Station, published a design procedure(6) for flexible pipe that still serves as the main design method in current use. Spangler and Watkins(7) later modified the formula to include a more realistic value for the soil parameter. The modified Iowa Formula is given as:

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

where

Table horizontal deflection

ΔX = horizontal deflection of the pipe, inches

D_l = 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

Rearranging the Iowa Formula to find e′ values from pipe deflection gives:

$$e' = 16.39\left(\frac{D_l KW}{\Delta X} - EI/r^3\right)$$

The term EI/r^3 is called the Ring Stiffness Factor and incorporates all of the physical properties of the pipe in one term. Data furnished by the pipe manufacturer gives the EI value of the pipe as 6,835 inch-pounds (78.75 meter/kg) at 5 percent deflection. Using a radius of 15 inches (38 cm), the Ring Stiffness Factor, EI/r^3, becomes 2.03 psi or 2 psi (0.14 kg/cm^2) approximately. The initial deflection values will be used, so a deflection lag factor of 1.0 is used. The bedding constant ranges from 0.110 for a 0° bedding angle (line load on the bottom of the pipe) to 0.083 for a 90° bedding angle (full support under the bottom half of the pipe). Most investigators of the behavior of flexible pipe use a bedding constant of 0.1 as a typical value, and that will be used here.

The load, W, in pounds per linear inch, is assumed to be the weight of the column of soil over the pipe. W is then found from:

W = weight of soil column per linear inch

$$= \frac{\text{(soil density) (soil volume)}}{\text{(1 linear inch)}}$$

$$= \frac{\text{(soil density, } \gamma_{wet}\text{) (backfill depth, h, x pipe diameter, D, x 1 inch)}}{\text{(1 linear inch)}}$$

$$= \gamma_{wet} \times h \times D$$

The dry density of the backfill soil is about 89 pounds per cubic foot (pcf) (1.43 grams/cc). Using a water content of 30 percent, the wet backfill density would be 115 pcf (1.84 grams/cc). The backfill depth averages about 4.5 feet (1.4 meters) or 54 inches. W then becomes:

$$(115 \text{ pcf})\ \frac{1}{1728}\text{in}^3/\text{ft}^3\ (54 \text{ inches})(\text{D in inches})$$

$$= 3.59\ \frac{\text{lbs}}{\text{in}^2}\ (\text{D, inches})$$

Substituting these values into the rearranged Iowa Formula gives:

$$e' = 16.39\left(\frac{1.0 \times 0.1 \times 3.59}{\Delta X/D} - 2\right)$$

$$e' = 16.39\left(\frac{.359}{\Delta X/D} - 2\right)$$

using percent deflection for $\Delta X/D$

$$e' = 16.39\left(\frac{35.9}{\Delta X/D\text{-}\%} - 2\right)$$

where $\Delta X/D$-% is the percent horizontal deflection of the pipe.

The following table gives the e′ values calculated for the various bedding conditions:

Calculated e′ Values

Bedding	$\Delta X/D$ (%)	e′ psi	e′ Kg/cm^2
Loose natural earth	7.8	45	3.2
Loose sand	5.1	83	5.8
Puddled natural earth	3.5	157	11.0
Compacted sand	0.6	948	66.6
Compacted natural earth	0.1	5,851	411.4

Although the modulus of soil reaction, e′, increases over 100 times for the natural earth after compaction, it is consistent with the Iowa Formula. Figure 12 shows a plot of the pipe deflection for various e′ values for a pipe under 4 feet (1.2 meters) of backfill. Pipe deflections are very small for well-compacted beddings which have high e′ values. Poor compaction gives low e′ values and high pipe deflections.

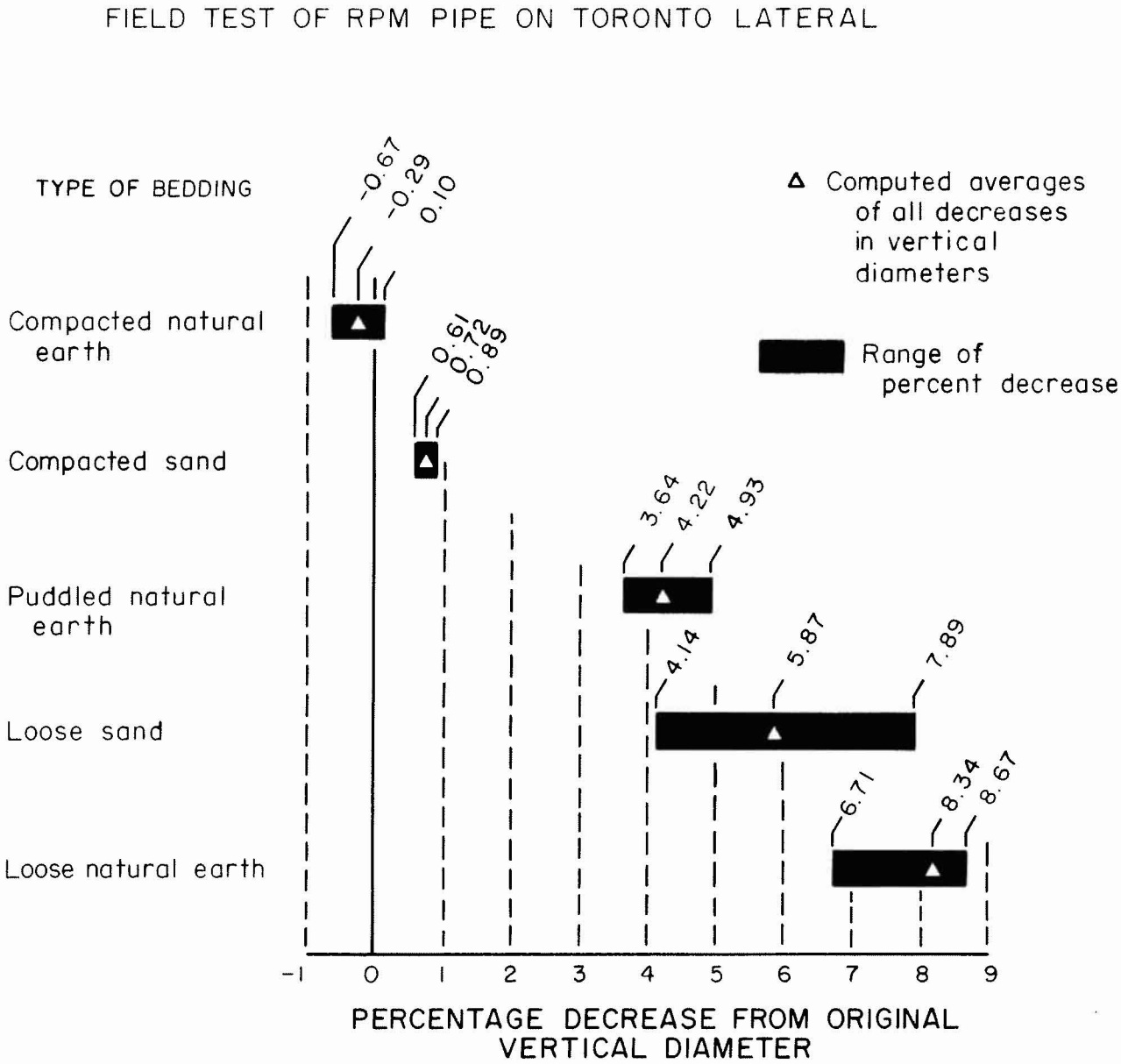

Figure 11. Range and averages of percent vertical deflections measured November 18, 1970.

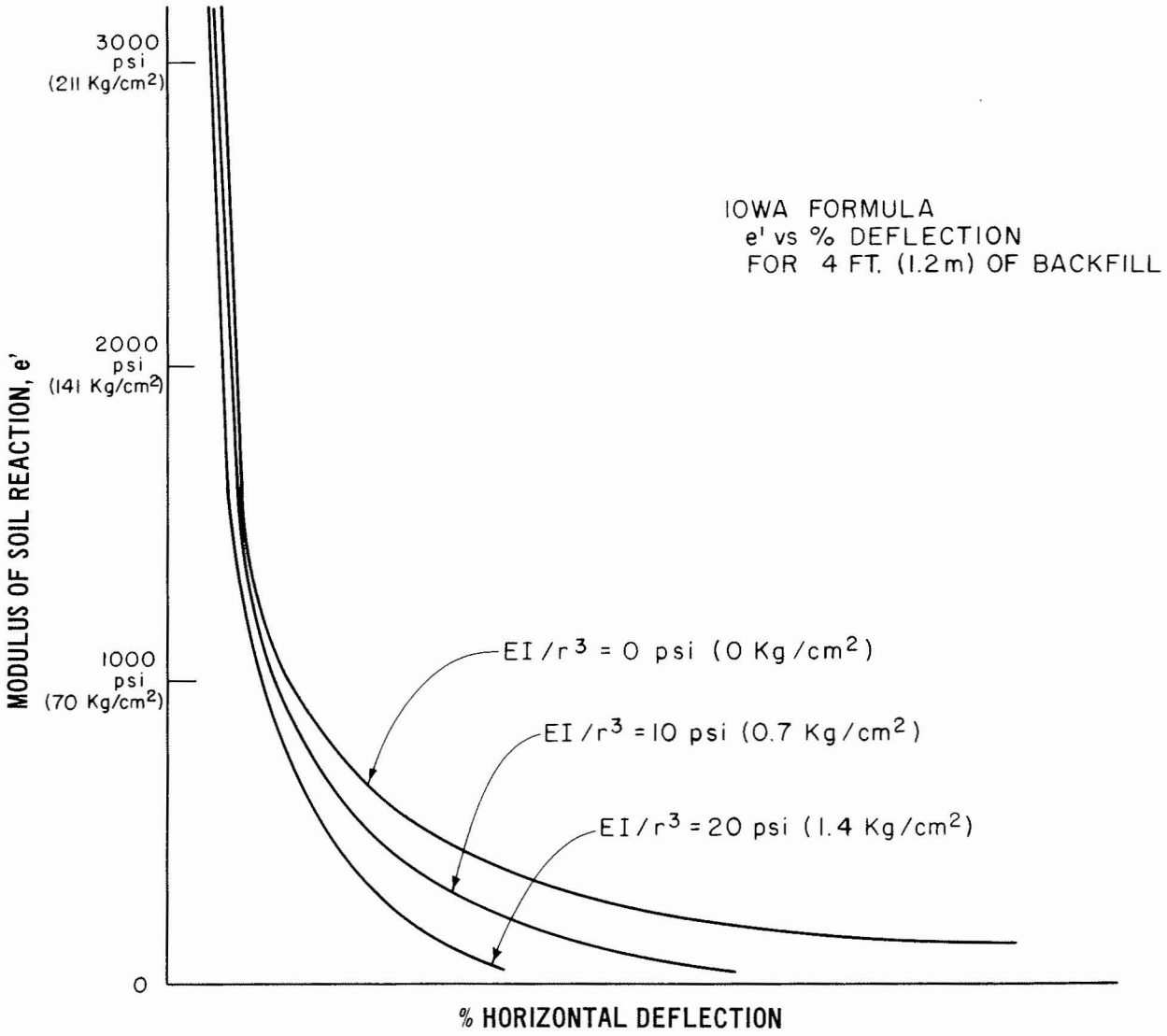

Figure 12. Percent horizontal deflection versus e' from Iowa Formula.

Data from this study also support the recent statement(8) by Professor Spangler that e′ is a semiempirical factor and values should be chosen using experience and judgment.

Deflection Lag Factor

The Deflection Lag Factor, D_l in the Iowa Formula compensates for the time-consolidation rate of the soil at the sides of the pipe. The initial consolidation of the soil takes place soon after a load is applied; however, the soil will continue to consolidate with time, so that the pipe will continue to deflect over a long time period.

Professor Spangler had recommended a value of 1.5 as a maximum value for the Deflection Lag Factor, although the time-consolidation rate for soils varies widely with the type of soil and its density and moisture content and should be determined from laboratory tests.

The increases in pipe deflection with time are shown in Table 1. The pipe bedded in the loose materials showed less percentage increase than the pipe in the well-compacted beddings. Apparently most of the deflection of a pipe bedded in loose material occurs immediately, and time effect is very small.

TEST RESULTS FROM APACHE LATERAL

Only one type of soil and bedding condition was used on the Apache Lateral. Deflection measurements were made on the bell end, the center of the pipe, and the spigot end to evaluate the difference in deflection between the center of the pipe and the stiffer ends of the pipe.

The initial deflection measurement (2 months after construction) showed the following vertical deflections:

Table deflections

Location in pipe	Percent vertical deflection
Spigot end	0.7
Center of pipe	2.3
Bell end	1.0

Table 1

DEFLECTION LAG VALUES FROM TORONTO LATERAL
Increase in Deflection from November 1970 Readings

Bedding description	Diameter	Date of measurement		
		Mar. 1971	Aug. 1971	Mar. 1972
Compacted sand	Vertical	1.34	1.44	1.50
	Horizontal	1.21	1.32	1.43
Loose sand	Vertical	1.00	1.05	1.05
	Horizontal	1.03	1.00	1.04
Compacted natural earth	Vertical	too variable to evaluate		
	Horizontal	too variable to evaluate		
Loose natural earth	Vertical	1.04	1.09	1.10
	Horizontal	1.06	1.06	1.08
Puddled natural earth	Vertical	–	1.04	1.06
	Horizontal	1.08	1.19	1.22
Loose natural earth*	Vertical	1.08	1.08	1.09
	Horizontal	1.03	1.04	1.06

*The loose natural earth was in two lengths, separated by the puddled natural earth section.

The average deflection values are compared with the range of deflection values in Figure 13.

The bell end of the pipe deflected vertically 50 percent more than the spigot end and 100 percent more than the spigot end horizontally.

The center of the pipe deflected vertically 350 percent more than the spigot end and 450 percent more than the spigot end horizontally. A complete listing of the diameter measurements is shown in Appendix C.

The measurements of the original diameters were made on March 10, 1971. The first readings after backfilling were made on May 20-21, 1971 (2 months), August 26-30, 1971 (5 months), and on March 8-9, 1972 (12 months). The increases in the deflection values are shown in Table 2. Over the 10-month period, the vertical deflections of the spigot end increased 13 percent, the center of the pipe 9 percent, and the bell end 30 percent. Since the center of the pipe showed the least increase in deflection, the maximum difference in deflection between the pipe joint ends and the center of the pipe occurred right after installation.

Table 2

DEFLECTION LAG VALUES FROM APACHE LATERAL

Increase in Deflection from May 1971 Readings

Location in pipe	Diameter	Date of measurement	
		Aug. 1971	Mar. 1972
Spigot end	Vertical	0.99	1.13
	Horizontal	1.02	1.24
Center	Vertical	1.03	1.09
	Horizontal	1.05	1.12
Bell end	Vertical	1.13	1.30
	Horizontal	1.04	1.19

SUMMARY AND CONCLUSIONS

Two test sections of 30-inch (76-cm) diameter reinforced plastic mortar (RPM) pipe were installed to replace two deteriorated open laterals on the Yuma Project. Twenty-nine 20-foot (6.1-meter) sections were placed in the Toronto Lateral in a dry trench using five different types of bedding. Pipe deflections were measured at four different times during the 16 months after installation. Thirty 20-foot (6.1-meter) sections were placed in the Apache Lateral in a wet and unstable subgrade with water from 9 to 18 inches (23 to 46 cm) above the subgrade. The deflections of the bell end, the spigot end, and the center of the pipe were measured at 2, 5, and 12 months after installation.

Results from the Toronto Lateral section regarding the effectiveness of the beddings, the modulus of passive resistance, and the time lag are shown in the following table:

Pipe Performance on Toronto Lateral

Bedding type	Initial vertical deflection percent	Initial horizontal deflection percent	Modulus of soil reaction		Deflection lag factor over 16 months
			(psi)	(kg/cm^2)	
Compacted natural earth	−0.3	0.1	5,851	411	1.00
Compacted sand	0.7	0.6	948	67	1.50
Puddled natural earth	4.2	3.5	157	11	1.06
Loose sand	5.9	5.1	83	6	1.05
Loose natural earth	8.3	7.8	45	3	1.10

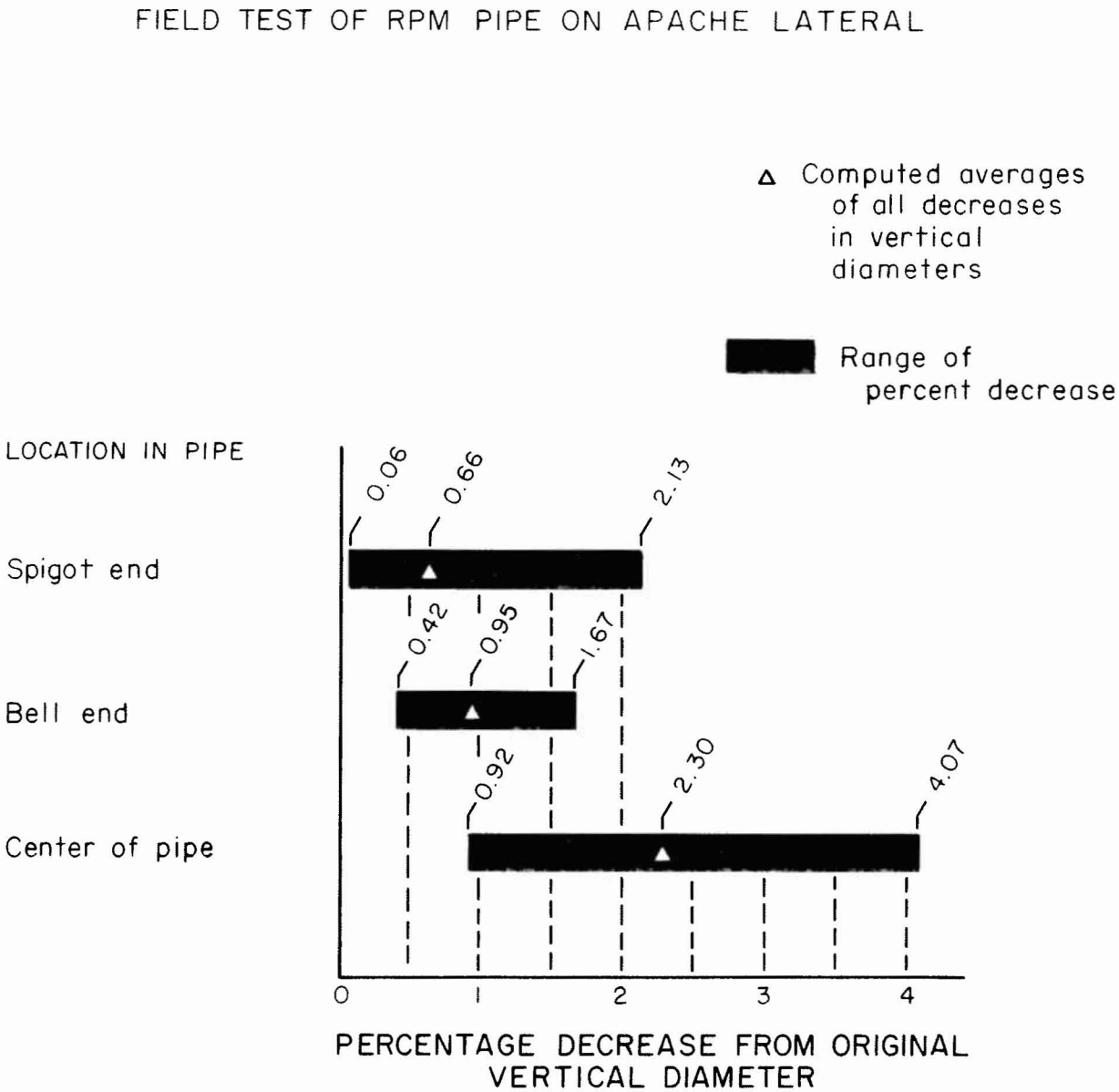

Figure 13. Range and averages of percent vertical deflections measured May 1971.

When the pipe was properly installed with well-compacted bedding material, the pipe deflection was well under the 5 percent design criteria.

The pipe bedded in the looser materials showed less deflection increase with time than did the pipe bedded in the well-compacted beddings.

The results from the Apache Lateral show that the spigot end of the pipe deflected vertically 0.7 percent and the bell end 1.0 percent, while the center of the pipe deflected 2.3 percent. The center of the pipe showed less increase in deflection with time than the spigot end or the bell end.

APPLICATIONS

The field testing of reinforced plastic mortar pipe on the Yuma Project was useful in establishing the practicality of using this new type of pipe on USBR projects. The results also demonstrated the importance of using good bedding material and of assuring that it is compacted according to USBR specifications.

Personnel participating in field tests:

Darrell Krull, Chief, Office of Special Studies Branch
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Alfonso Lorona, Party Chief
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Allen Sullivan, Surveyor

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APPENDIX A
BACKFILL AND BEDDING SOIL PHYSICAL PROPERTIES AND DENSITIES FOR TORONTO LATERAL

The physical properties and in-place densities and moistures of the trench walls, of the material excavated from the trench and replaced as bedding, and of the imported sand for bedding were determined at seven locations along the Toronto Lateral test section. The tests were conducted in accordance with the following designations from the Bureau of Reclamation's Earth Manual:

Table Designations

Gradation analysis	Designation E-6
Soil consistency	Designation E-7
Specific gravity	Designation E-10
Proctor compaction	Designation E-11
Relative density	Designation E-12
Field density	Designation E-24

The native material removed to prepare the trench and used for the natural earth beddings was classified as ML, SP-SM, CL-ML, and CL according to the Unified Classification System along the reach of the test section. Although the native material was often found to be nonplastic, it is considered here as a cohesive soil, since it was basically a silt-clay material, to distinguish it from the cohesionless sand that was imported. In the last third of the test section the native material did have a plasticity index of 6 to 9, and the Proctor compaction test for cohesive materials was used as the density control.

The natural material in the trench walls had an in-place density of about 80 to 90 percent of Proctor maximum dry density. The sand bedding that was saturated and vibrated had relative densities of only 30 to 38 percent compared to 70 percent required by USBR specifications. The loose sand had densities below the minimum laboratory density, probably due to bulking of the sand as it was dumped.

The tamped natural earth had densities ranging from 95 to 97 percent of Proctor maximum dry density compared to 95 percent required by USBR specifications. The densities for the loose natural earth bedding ranged from 90 to 93 percent of Proctor maximum dry density. These densities appear to be rather high compared to the difference in deflections between the tamped natural earth and the loose natural earth. The in-place densities for the loose natural earth were measured after the backfill had been placed over the pipe and water settled. The densities apparently do not represent the bedding densities at the time of the initial pipe deflection but are the soil densities due to the surcharge from the backfill and the subsequent consolidation from the water settling operation.

The physical properties and densities of the soils are listed in Table A-1.

SUMMARY OF PHYSICAL PROPERTIES TEST RESULTS (Inplace Density)

TABLE A- I

PROJECT YUMA PROJECT FEATURE TORONTO LATERAL SHEET 1 OF 2

IDENTIFICATION				PARTICLE-SIZE FRACTIONS IN PERCENT						CONSISTENCY LIMITS			COMPACTION TEST		RELATIVE DENSITY		INPLACE DENSITY			
				FINES																
SAMPLE NUMBER DATE	LOCATION	STATION	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 - %	SPECIFIC GRAVITY	MAXIMUM DRY DENSITY - pcf	OPTIMUM WATER CONTENT - %	MAXIMUM DRY DENSITY - pcf	MINIMUM DRY DENSITY - pcf	DRY DENSITY - pcf	WATER CONTENT - %	PERCENT OF LABORATORY MAX. DRY DENSITY - %	RELATIVE DENSITY - %
	COMPACTED SAND																			
10-27	trench	1+50	ML	4	80	16					NP	2.63	100.3	19.4			85.7	30.9	85.4	
10-27	walls	1+50											100.3	19.4			85.7	26.5	85.4	
10-27	bedding	1+50	SP	0	1	99					NP	2.66			109.2	96.2	100.7	8.2		38
10-27	bedding	1+50	SP								NP				109.2	96.2	98.8	17.6		30
	LOOSE SAND																			
10-28	trench	2+33											104.4	13.8			88.5	27.0	84.8	
10-28	walls	2+33	ML	8	65	27				20	2	2.61	104.4	13.8			87.3	21.5	83.6	
11-18	bedding	2+33	SP								NP				109.2	96.2	95.9	5.3		< 0
11-18	bedding	2+33	SP								NP				109.2	96.2	91.6	3.7		< 0
10-28	trench	3+32											103.6	17.1			94.7	23.5	91.4	
10-28	walls	3+32	ML	2	84	14					NP	2.63	103.6	17.1			86.6	27.6	83.6	
11-18	bedding	3+32	SP								NP				109.2	96.2	90.0	5.6		< 0
11-18	bedding	3+32	SP								NP				109.2	96.2	104.1	6.8		64
	TAMPED NATURAL EARTH																			
10-26	trench	4+33	SP-SM	0	10	90					NP	2.64			103.3	80.5	94.5	7.4		67
10-26	walls	4+33	ML	3	66	31						2.64	100.4	15.9			87.6	23.5	87.3	
10-27	bedding	4+33											100.4	15.9			95.4	13.5	95.0	
10-27	bedding	4+33											100.4	15.9			97.3	15.0	96.9	

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

TABLE I SHEET 1 OF 2

SUMMARY OF PHYSICAL PROPERTIES TEST RESULTS (Inplace Density)

PROJECT YUMA PROJECT FEATURE TORONTO LATERAL

TABLE A-I
SHEET 2 OF 2

IDENTIFICATION				PARTICLE-SIZE FRACTIONS IN PERCENT						CONSISTENCY LIMITS			SPECIFIC GRAVITY				INPLACE DENSITY			
				FINES										COMPACTION TEST						
SAMPLE NUMBER DATE	LOCATION	STATION	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	MAXIMUM DRY DENSITY - pcf	OPTIMUM WATER CONTENT		DRY DENSITY - pcf	WATER CONTENT - %	PERCENT OF LABORATORY MAX DRY DENSITY - %	
	LOOSE NATURAL EARTH																			
10-26	trench	5+12	CL-ML	10	87	3				29	6		2.65	105.8	18.1		85.8	30.4	81.1	
10-26	walls																90.7	22.2	85.7	
11-18	bedding	5+12															96.2	24.8	90.9	
11-18	bedding	5+12															94.7	22.1	89.5	
	PUDDLED NATURAL EARTH																			
10-26	trench	5+92															90.2	11.0	87.1	
10-26	walls	5+92	CL-ML	18	62	20				25	7		2.63	103.6	13.8		85.9	23.4	82.9	
	LOOSE NATURAL EARTH																			
10-27	trench	6+72																		
10-27	walls	6+72	CL	13	85	2				33	9		2.64	106.1	17.7		86.3	31.8	81.3	
11-23	bedding	6+72															86.7	30.7	81.7	
11-23	bedding	6+72															95.4	32.5	89.9	
																	98.2	21.5	92.6	

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

TABLE I SHEET 2 OF 2

APPENDIX B
DEFLECTION MEASUREMENTS ON TORONTO LATERAL

Twenty-nine sections of 30-inch (76-cm) diameter RPM pipe were laid on the Toronto Lateral in October 1970 on a dry subgrade. The pipe were laid downstream with the spigot in the direction of laying.

The pipe were inspected prior to use, laid in the trench, and joined by hand leveling. The inside vertical and horizontal diameters of the pipe were measured at specific locations. All bedding was then placed to a depth of 0.7 times the outside diameter of the pipe and then the remainder of the trench backfilled with the native material.

Deflection measurements were made on November 18, 1970 (3 weeks), March 2, 1971 (4 months), August 25, 1971 (10 months), and March 14-15, 1972 (16 months after backfilling). Summaries of the deflection readings are shown for each type of bedding condition in Tables B-1 through B-6. The loose earth bedding was used in two separate sections along the pipeline, and the summary of each section is shown as a separate table.

Earthen dikes were constructed between some of the different types of beddings. Because of the degree of compaction used to construct these dikes, the pipe at these locations were prevented from deflecting as much as the other pipe, especially in the low density beddings. The diameter measurements of the pipe where the dikes were located are not included in the average deflections. In addition, the diameter measurements of the ends of the pipe in the loose soil beddings next to the compacted earth bedding section were not included in the averages. Their deflections were being influenced by the compacted earth bedding.

Even though the loose earth bedding was used in two different sections along the pipeline, the average deflection values, time-lag values, and the $\Delta X/\Delta Y$ ratios compared very closely (see Tables B-4 and B-6).

The original diameters and subsequent deflection measurements are shown in Table B-7 for all of the measurement locations.

Table B-1

RPM TEST SECTION–TORONTO LATERAL
Compacted Sand Bedding

Deflection Data

Deflection values[1]	Measurement dates							
	Nov. 1970		March 1971		Aug. 1971		March 1972	
	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent
ΔY Average	0.217 (0.551)	0.72	0.290 (0.737)	0.97	0.313 (0.795)	1.04	0.326 (0.828)	1.09
ΔX Average	.170 (.431)	0.57	.205 (.521)	0.68	.224 (.569)	0.75	.243 (.617)	0.81
Increase from Nov. 1970								
ΔY		–	.073 (.185)	33.6	.096 (.244)	44.2	.109 (.277)	50.2
ΔX		–	.035 (.089)	20.6	.054 (.137)	31.8	.073 (.185)	42.9
ΔX/ΔY		78.3		70.7		71.6		74.5

[1] Average of readings at two locations in Pipe No. 1 and one location in Pipe No. 3. Pipe No. 2 is not included because it was used for the special surcharge test location.

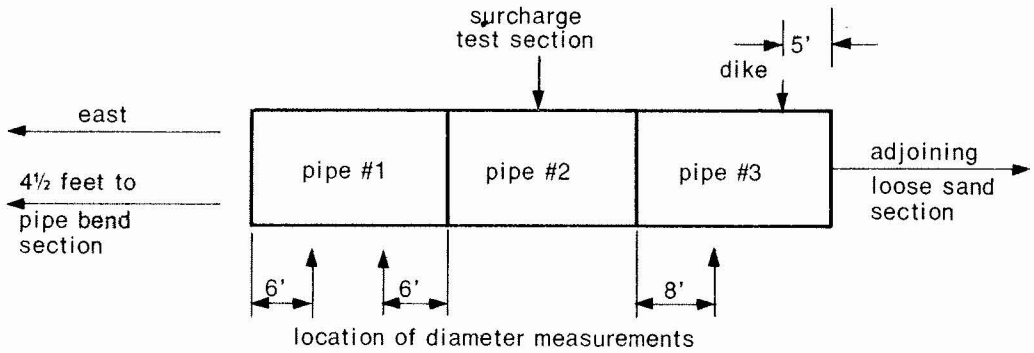


Table B-2

RPM TEST SECTION–TORONTO LATERAL
Loose Sand Bedding

Deflection Data

Deflection values[1]	Measurement Dates							
	Nov. 1970		March 1971		Aug. 1971		March 1972	
	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent
ΔY Average	1.760 (4.470)	5.87	1.757 (4.463)	5.86	1.848 (4.694)	6.16	1.854 (4.709)	6.18
ΔX Average	1.521 (3.863)	5.07	1.565 (3.975)	5.22	1.514 (3.846)	5.05	1.588 (4.034)	5.29
Increase from Nov. 1970								
ΔY		–	–.003 (–.008)	0	.088 (.224)	5.0	.094 (.239)	5.3
ΔX		–	.044 (.112)	2.9	–.007 (–.018)	0	.067 (.170)	4.4
ΔX/ΔY		86.4		89.1		81.9		85.7

[1] Average of all readings except west end of Pipe No. 15 where section joins compacted earth section.

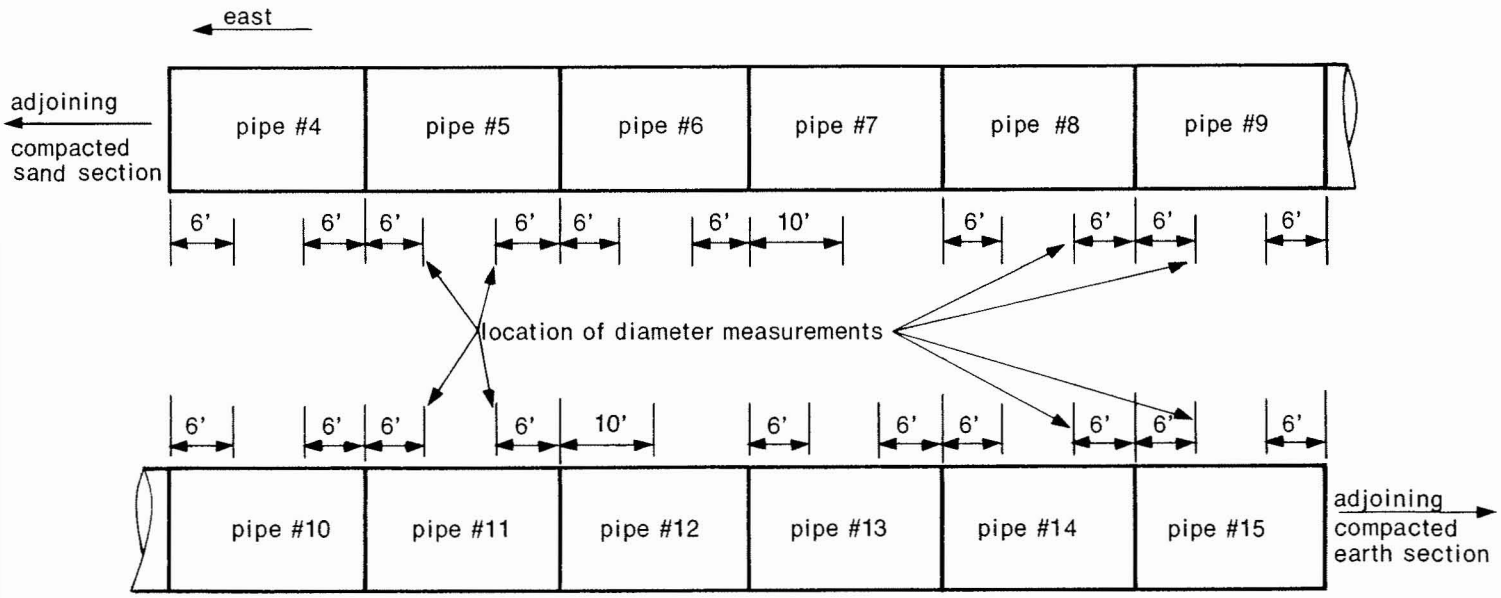


Table B-3

RPM TEST SECTION–TORONTO LATERAL
Compacted Earth Bedding

Deflection Data

Deflection values[1]	Measurement dates							
	Nov. 1970		March 1971		Aug. 1971		March 1972	
	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent
ΔY Average	−0.087 (−0.221)	−0.29	−0.026 (−0.066)	−.09	0.119 (0.302)	0.40	0.043 (.109)	0.14
ΔX Average	0.019 (0.048)	0.06	−0.010 (−0.025)	−.03	−0.033 (−0.084)	−0.11	.043 (.109)	.14
Increase from Nov. 1971								
ΔY			too variable to calculate					
ΔX			too variable to calculate					
ΔX/ΔY			too variable to calculate					

[1] Average of all three readings.

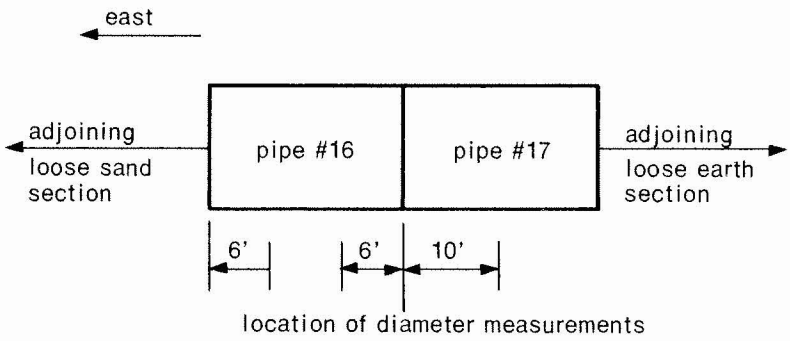


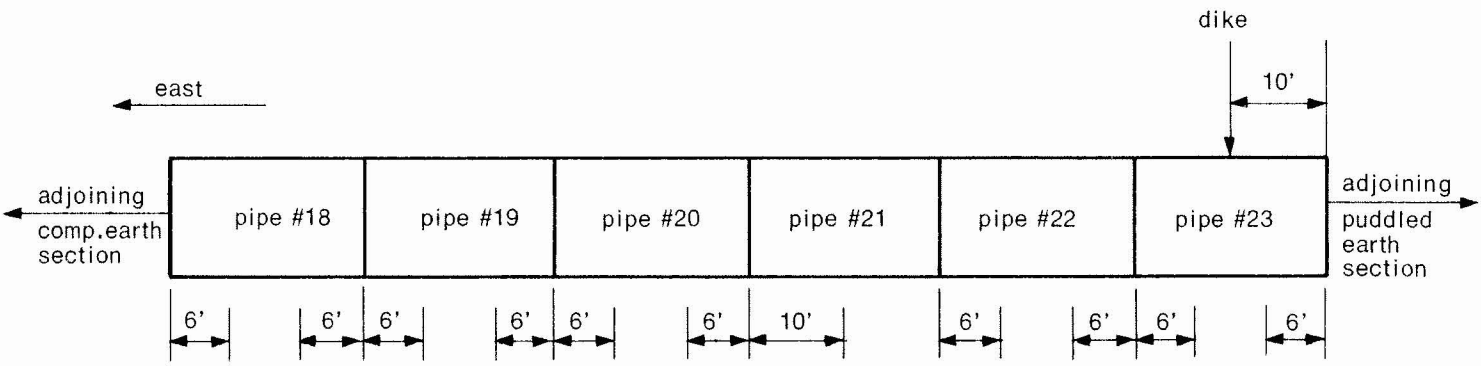
Table B-4

RPM TEST SECTION—TORONTO LATERAL
Loose Earth Bedding

Deflection Data

Deflection values[1]	Measurement dates							
	Nov. 1970		March 1971		Aug. 1971		March 1972	
	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent
ΔY Average	2.458 (6.243)	8.19	2.555 (6.490)	8.52	2.680 (6.807)	8.93	2.697 (6.850)	8.99
ΔX Average	2.256 (5.730)	7.52	2.401 (6.099)	8.00	2.391 (6.073)	7.97	2.427 (6.165)	8.09
Increase from Nov. 1970								
ΔY		—	0.097 (0.246)	4.0	0.222 (0.564)	9.0	0.239 (0.607)	9.7
ΔX		—	0.145 (0.368)	6.4	0.135 (0.343)	6.0	0.171 (0.434)	7.6
ΔX/ΔY		91.8		94.0		89.2		90.0

[1] Average of all readings except east end of Pipe No. 18 next to compacted earth section and both readings of Pipe No. 23 where there was a dike in the center of the pipe.



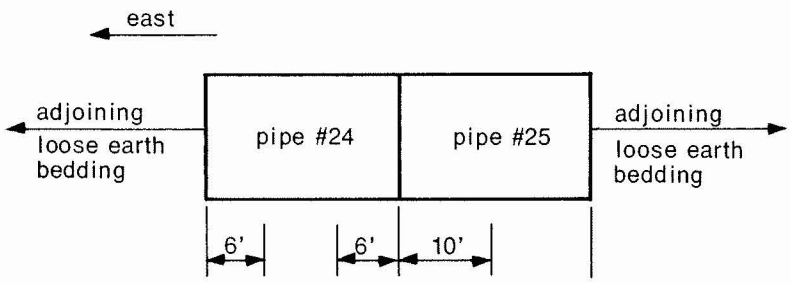
location of diameter measurements

Table B-5

RPM TEST SECTION–TORONTO LATERAL
Puddled Earth Bedding

Deflection Data

Deflection values	Measurement dates							
	Nov. 1970		March 1971		Aug. 1971		March 1972	
	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent
ΔY Averages	1.267 (3.218)	4.22	1.251 (3.178)	4.17	1.319 (3.350)	4.40	1.339 (3.401)	4.46
ΔX Averages	1.046 (2.657)	3.49	1.134 (2.880)	3.78	1.242 (3.155)	4.14	1.276 (3.241)	4.25
Increase from Nov. 1970								
ΔY		–	−0.016 (−0.041)	0	0.052 (0.132)	4.1	0.072 (0.183)	5.7
ΔX		–	0.088 (0.224)	8.4	0.196 (0.498)	18.7	0.230 (0.584)	22.0
ΔX/ΔY		82.6		90.6		94.2		95.3



location of diameter measurements

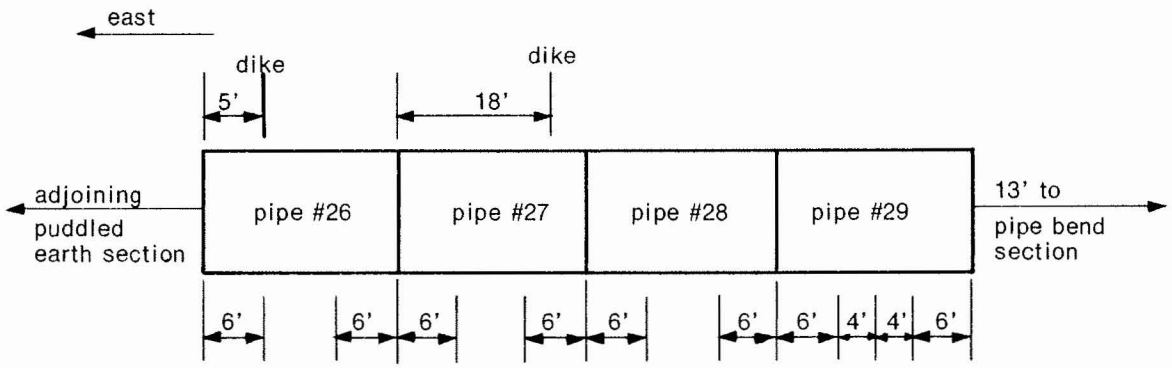
Table B-6

RPM TEST SECTION–TORONTO LATERAL
Loose Earth Bedding

Deflection Data

Deflection values[1]	Measurement dates							
	Nov. 1970		March 1971		Aug. 1971		March 1972	
	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent	inches (cm)	percent
ΔY Average	2.547 (6.469)	8.49	2.748 (6.980)	9.16	2.753 (6.993)	9.18	2.769 (7.033)	9.23
ΔX Average	2.427 (6.165)	8.09	2.504 (6.360)	8.35	2.536 (6.441)	8.45	2.573 (6.535)	8.22
Increase from Nov. 1970								
ΔY		–	0.201 (0.511)	7.9	0.217 (0.551)	8.1	0.222 (0.564)	8.7
ΔX		–	0.077 (0.196)	3.2	0.109 (0.277)	4.5	0.146 (0.371)	6.0
ΔX/ΔY		95.3		91.1		92.1		92.9

[1] Average of all readings except east end of Pipe No. 26 (dike) and west end of Pipe No. 27 (dike).



location of diameter measurements

Table B-7

DEFLECTION MEASUREMENTS–TORONTO LATERAL
Yuma Project RPM Pipe Test Section

Pipe No.	Station of reading	Location[1]	Diameter	Original reading	Date of diameter measurements							
					November 1970		March 1971		August 1971		March 1972	
					reading	change	reading	change	reading	change	reading	change
Compacted sand												
1	1+09	6 ft.	vertical	30.183	29.916	0.267	29.786	0.397	29.812	0.371	29.804	0.379
			horizontal	30.084	30.254	0.170	30.329	0.245	30.352	0.268	30.396	0.312
	1+17	14 ft.	vertical	30.026	29.823	0.203	29.731	0.295	29.701	0.325	29.697	0.329
			horizontal	30.089	30.011	?	30.323	0.234	30.348	0.259	30.353	0.264
2–Surcharge Test Section. See Appendix D.												
3	1+51	8 ft.	vertical	30.165	29.983	0.182	29.986	0.179	29.921	0.244	29.894	0.271
			horizontal	30.117	30.119	?	30.254	0.137	30.262	0.145	30.270	0.153
Loose sand bedding												
4	1+69	6 ft.	vertical	30.111	28.869	1.242	28.847	1.264	28.847	1.264	28.837	1.274
			horizontal	30.137	31.382	1.245	31.476	1.339	31.319	1.182	31.367	1.230
	1+77	14 ft.	vertical	30.119	28.784	1.335	28.798	1.321	28.775	1.344	28.746	1.373
			horizontal	30.171	31.242	1.071	31.281	1.110	31.110	0.939	31.255	1.084
5	1+89	6 ft.	vertical	30.009	38.252	1.757	28.196	1.813	28.091	1.918	28.111	1.898
			horizontal	30.165	31.909	1.744	31.901	1.736	31.901	1.736	31.980	1.815
	1+97	14 ft.	vertical	30.067	28.200	1.867	28.184	1.883	28.146	1.921	28.141	1.926
			horizontal	30.155	31.707	1.552	31.746	1.591	31.723	1.568	31.742	1.587
6	2+09	6 ft.	vertical	30.091	27.724	2.367	27.728	2.363	27.719	2.372	27.691	2.400
			horizontal	30.325	32.271	1.946	32.236	1.911	32.112	1.787	32.316	1.991
	2+17	14 ft.	vertical	29.907	27.743	2.164	27.817	2.090	27.685	2.222	27.685	2.222
			horizontal	30.183	31.964	1.781	32.078	1.895	31.868	1.685	32.075	1.892
7	2+33	10 ft.	vertical	30.160	28.150	2.010	28.017	2.143	27.927	2.233	27.879	2.281
			horizontal	30.153	31.876	1.723	32.058	1.905	31.918	1.765	31.954	1.801
8	2+49	6 ft.	vertical	30.084	28.425	1.659	28.476	1.608	28.347	1.737	28.342	1.742
			horizontal	30.207	31.716	1.509	31.752	1.545	31.699	1.492	31.775	1.568
	2+57	14 ft.	vertical	29.906	28.037	1.869	28.032	1.874	27.911	1.995	27.927	1.979
			horizontal	30.281	31.960	1.679	31.847	1.566	31.810	1.529	32.005	1.724
9	2+69	6 ft.	vertical	30.106	28.603	1.503	28.582	1.524	28.515	1.591	28.456	1.650
			horizontal	30.203	31.611	1.408	31.593	1.390	31.628	1.425	31.683	1.480
	2+77	14 ft.	vertical	30.001	28.459	1.542	28.432	1.569	28.389	1.612	28.378	1.623
			horizontal	30.122	31.532	1.410	31.591	1.469	31.524	1.402	31.586	1.464

[1] Distance of measurement location from east end of pipe.

Table B-7—Continued

DEFLECTION MEASUREMENTS—TORONTO LATERAL
Yuma Project RPM Pipe Test Section

Pipe No.	Station of reading	Location[1]	Diameter	Original reading	Date of diameter measurements							
					November 1970		March 1971		August 1971		March 1972	
					reading	change	reading	change	reading	change	reading	change
10	2+89	6 ft.	vertical	30.107	28.596	1.511	28.501	1.606	28.430	1.677	28.430	1.677
			horizontal	30.217	31.512	1.295	31.559	1.342	31.565	1.348	31.610	1.393
	2+97	14 ft.	vertical	29.968	28.193	1.775	28.236	1.732	28.108	1.860	28.093	1.875
			horizontal	30.152	31.724	1.572	31.777	1.625	31.751	1.599	31.744	1.592
11	3+09	6 ft.	vertical	30.074	28.309	1.765	28.306	1.768	28.179	1.895	28.165	1.909
			horizontal	30.238	31.598	1.360	31.700	1.462	31.704	1.466	31.726	1.488
	3+17	14 ft.	vertical	30.034	28.383	1.651	28.374	1.660	28.310	1.724	28.292	1.742
			horizontal	30.233	31.582	1.349	31.586	1.353	31.581	1.348	31.655	1.422
12	3+33	10 ft.	vertical	30.044	28.190	1.854	28.209	1.835	28.155	1.889	28.153	1.891
			horizontal	30.157	31.753	1.596	31.830	1.673	31.775	1.618	31.847	1.690
13	3+48	6 ft.	vertical	30.161	28.658	1.503	28.790	1.371	28.660	1.501	28.622	1.539
			horizontal	30.163	31.277	1.114	31.385	1.222	31.304	1.141	31.346	1.183
	3+56	14 ft.	vertical	29.966	28.232	1.734	28.116	1.850	28.167	1.799	28.155	1.811
			horizontal	30.108	31.611	1.503	31.651	1.543	31.648	1.540	31.694	1.586
14	3+68	6 ft.	vertical	30.057	28.161	1.896	28.167	1.890	27.972	2.085	27.992	2.065
			horizontal	30.238	31.751	1.513	31.797	1.559	31.817	1.579	31.851	1.613
	3+76	14 ft.	vertical	29.957	27.893	2.064	27.924	2.033	27.806	2.151	27.816	2.141
			horizontal	30.118	31.945	1.827	32.131	2.013	32.015	1.897	32.042	1.924
15	3+88	6 ft.	vertical	30.163	28.278	1.885	28.414	1.749	28.245	1.918	28.237	1.926
			horizontal	30.185	31.933	1.748	31.793	1.608	31.932	1.747	32.000	1.815
	3+96	14 ft.	vertical	30.014	28.889	1.125	29.555	?	28.895	1.119	28.893	1.121
			horizontal	30.116	30.962	0.846	30.938	0.822	31.052	0.936	31.069	0.953
Compacted earth												
16	4+08	6 ft.	vertical	30.058	30.258	-0.200	30.223	-0.165	30.107	-0.049	30.171	-0.113
			horizontal	30.025	29.985	-0.040	29.981	-0.044	29.853	-0.172	30.007	-0.018
	4+16	14 ft.	vertical	30.035	30.124	-0.089	30.005	0.030	29.870	0.165	29.921	0.114
			horizontal	30.025	29.922	-0.103	29.880	-0.145	29.972	-0.053	29.986	-0.039
17	4+32	10 ft.	vertical	30.033	30.004	0.029	29.975	0.058	29.792	0.241	29.904	0.129
			horizontal	30.020	30.219	0.199	30.179	0.159	30.145	0.125	30.210	0.190

[1] Distance of measurement location from east end of pipe.

Table B-7—Continued

DEFLECTION MEASUREMENTS—TORONTO LATERAL
Yuma Project RPM Pipe Test Section

Pipe No.	Station of reading	Location[1]	Diameter	Original reading	Date of diameter measurements: November 1970 reading	November 1970 change	March 1971 reading	March 1971 change	August 1971 reading	August 1971 change	March 1972 reading	March 1972 change
Loose earth												
18	4+48	6 ft.	vertical	30.075	28.589	1.486	28.500	1.575	28.334	1.741	28.345	1.730
			horizontal	30.048	31.635	1.587	31.736	1.688	31.765	1.717	31.760	1.712
	4+56	14 ft.	vertical	30.015	27.498	2.517	27.296	2.719	27.212	2.803	27.184	2.831
			horizontal	30.070	32.419	2.349	32.525	2.455	32.575	2.505	32.569	2.499
19	4+68	6 ft.	vertical	30.096	27.510	2.586	27.343	2.753	27.094	3.002	27.123	2.973
			horizontal	30.203	>32.5	(2.327)*	32.792	2.589	32.810	2.607	32.790	2.587
	4+76	14 ft.	vertical	30.106	<27.5	?	27.170	2.936	27.072	3.034	27.069	3.037
			horizontal	30.051	>32.5	?	32.813	2.762	32.757	2.706	32.828	2.777
20	4+88	6 ft.	vertical	30.112	<27.5	?	27.334	2.778	27.137	2.975	27.103	3.009
			horizontal	30.248	>32.5	?	32.810	2.562	32.919	2.671	32.940	2.692
	4+96	14 ft.	vertical	29.927	<27.5	(2.454)*	27.302	2.625	27.284	2.643	27.273	2.654
			horizontal	30.173	32.504	2.331	32.667	2.504	32.675	2.502	32.694	2.521
21	5+12	10 ft.	vertical	30.141	28.129	2.012	28.029	2.112	27.867	2.274	27.831	2.310
			horizontal	30.138	32.043	1.905	32.083	1.945	32.159	2.021	32.201	2.063
22	5+28	6 ft.	vertical	30.107	27.571	2.536	27.690	2.417	27.487	2.620	27.468	2.639
			horizontal	30.310	>32.5	(2.232)*	32.662	2.352	32.614	2.304	32.638	2.328
	5+36	14 ft.	vertical	30.224	28.184	2.040	28.123	2.101	28.138	2.086	28.101	2.123
			horizontal	30.091	31.882	1.791	32.126	2.035	31.904	1.813	32.036	1.945
23	5+48	6 ft.	vertical	29.999	28.859	1.140	28.788	1.211	28.737	1.262	28.726	1.273
			horizontal	30.296	31.174	0.878	31.069	0.773	31.367	1.071	31.381	1.085
	5+56	14 ft.	vertical	30.028	28.919	1.109	28.869	1.159	28.833	1.195	28.806	1.222
			horizontal	30.233	31.132	0.899	31.198	0.965	31.245	1.012	31.285	1.052
Puddled earth												
24	5+68	6 ft.	vertical	30.205	28.973	1.232	28.991	1.214	28.904	1.301	28.867	1.338
			horizontal	30.161	31.239	1.078	31.346	1.185	31.386	1.225	31.410	1.249
	5+76	14 ft.	vertical	30.323	29.482	1.091	29.156	1.167	29.108	1.215	29.106	1.217
			horizontal	30.041	31.001	0.960	31.062	1.021	31.109	1.068	31.131	1.090
25	5+92	10 ft.	vertical	30.023	28.545	1.478	28.650	1.373	28.582	1.441	28.562	1.461
			horizontal	30.188	31.288	1.100	31.385	1.197	31.620	1.432	31.677	1.489

[1] Distance of measurement location from east end of pipe.
*Estimated change based on $\Delta X/\Delta Y$ ratio of other readings.

Table B-7—Continued

DEFLECTION MEASUREMENTS—TORONTO LATERAL
Yuma Project RPM Pipe Test Section

Pipe No.	Station of reading	Location[1]	Diameter	Original reading	Date of diameter measurements							
					November 1970		March 1971		August 1971		March 1972	
					reading	change	reading	change	reading	change	reading	change
Loose earth												
26	6+08	6 ft.	vertical	30.170	29.039	1.131	29.162	1.008	29.068	1.102	29.123	1.047
			horizontal	30.137	30.818	0.681	30.859	0.722	30.862	0.725	30.877	0.740
	6+16	14 ft.	vertical	30.135	28.106	2.029	28.014	2.121	27.968	2.167	27.927	2.208
			horizontal	30.062	32.087	2.025	32.073	2.011	32.050	1.988	32.073	2.011
27	6+28	6 ft.	vertical	30.054	27.619	2.435	27.525	2.529	27.554	2.500	27.526	2.528
			horizontal	30.250	32.471	2.221	32.530	2.280	32.558	2.308	32.629	2.379
	6+36	14 ft.	vertical	30.070	28.919	1.151	28.002	1.068	28.680	1.390	28.646	1.424
			horizontal	30.048	31.142	1.094	31.043	0.995	31.326	1.278	31.445	1.397
28	6+48	6 ft.	vertical	29.985	<27.5	?	27.318	2.667	27.257	2.728	27.267	2.718
			horizontal	30.301	>32.5	?	32.775	2.474	32.794	2.493	32.804	2.503
	6+56	14 ft.	vertical	30.011	<27.5	?	26.840	3.171	27.090	2.921	27.002	3.009
			horizontal	30.224	>32.5	?	32.871	2.647	32.949	2.725	32.995	2.771
29	6+68	6 ft.	vertical	30.251	<27.5	?	27.298	2.953	27.116	3.135	27.064	3.187
			horizontal	30.161	>32.5	?	33.074	2.913	32.998	2.837	33.034	2.873
	6+72	10 ft.	vertical	30.125	27.525	2.600	27.250	2.875	27.196	2.929	27.167	2.958
			horizontal	30.122	>32.5	(2.5)*	32.664	2.542	32.727	2.605	32.762	2.640
	6+76	14 ft.	vertical	30.120	27.556	2.564	27.198	2.922	27.231	2.889	27.162	2.958
			horizontal	30.011	>32.5	(2.5)*	32.672	2.661	32.804	2.793	32.844	2.833

[1] Distance of measurement location from east end of pipe.
*Estimated change based on $\Delta X/\Delta Y$ ratio of other readings.

APPENDIX C
DEFLECTION MEASUREMENTS ON APACHE LATERAL

Thirty sections of 30-inch (76-cm) diameter RPM pipe were laid on the Apache Lateral in March 1971 on an unstable subgrade 9 to 18 inches (23 to 46 cm) below the water table. No attempt was made to dewater the trench. The pipe were laid downstream with the bell end downstream.

Internal vertical and horizontal diameter measurements were made at the bell end and the spigot end before the pipe were placed. Initial deflection measurements were made on the bell end, the center of the pipe, and on the spigot end 2 months later in May 1971 and then again in August 1971 (5 months) and in March 1972 (12 months). The original diameters and the subsequent deflection measurements are shown in Table C-1. The original diameter measurement values of the center of the pipe are the averages of the diameter measurements on the bell end and the spigot end, since no original diameter measurements were made on the center of the pipe.

Pipe No. 30 had to be replaced, and no original diameter measurements are available. A summary of the readings is shown in Tables C-2 through C-4. The increase in deflections with time was based on the 2-month readings since they were the first deflection measurements taken after installation.

Table C-1

DEFLECTION MEASUREMENTS
APACHE LATERAL
Yuma Project RPM Pipe Test Section

Pipe No.	Station	Measurement location	Diameter	Original reading	Date of diameter measurements: May 1971 reading	May 1971 change	August 1971 reading	August 1971 change	March 1972 reading	March 1972 change
1	20+05	Spigot	Vertical	29.892	29.506	0.386	29.545	0.347	29.501	0.391
			Horizontal	30.210	30.456	0.246	30.455	0.245	30.518	0.308
		Center	Vertical	30.008	29.358	0.650	29.320	0.688	29.294	0.714
			Horizontal	30.109	30.757	0.648	30.717	0.608	30.758	0.649
		Bell	Vertical	30.124	29.815	0.309	29.798	0.326	29.780	0.344
			Horizontal	30.007	30.593	0.586	30.362	?	30.628	0.621
2	20+25	Spigot	Vertical	29.964	29.668	0.296	29.646	0.318	29.645	0.319
			Horizontal	30.113	30.342	0.229	30.359	0.246	30.404	0.291
		Center	Vertical	30.090	29.813	0.277	29.795	0.295	29.782	0.308
			Horizontal	30.145	30.361	0.216	30.434	0.289	30.462	0.317
		Bell	Vertical	30.215	30.037	0.178	30.035	0.180	30.019	0.196
			Horizontal	30.177	30.409	0.232	30.419	0.242	30.425	0.248
3	20+45	Spigot	Vertical	29.781	29.754	0.027	29.781	0.000	29.785	-0.004
			Horizontal	30.278	30.282	0.004	30.257	-0.021	30.240	-0.038
		Center	Vertical	29.954	29.511	0.443	29.465	0.489	29.434	0.520
			Horizontal	30.252	30.784	0.532	30.818	0.566	30.829	0.577
		Bell	Vertical	30.127	29.842	0.285	29.825	0.302	29.793	0.334
			Horizontal	30.226	30.607	0.381	30.626	0.400	30.665	0.439
4	20+65	Spigot	Vertical	29.903	29.573	0.330	29.648	0.255	29.617	0.286
			Horizontal	30.122	30.412	0.290	30.397	0.275	30.423	0.301
		Center	Vertical	30.042	29.183	0.854	29.204	0.838	29.157	0.885
			Horizontal	30.178	31.008	0.830	31.012	0.834	31.039	0.861
		Bell	Vertical	30.181	29.901	0.280	29.828	0.353	29.836	0.345
			Horizontal	30.233	30.593	0.360	30.623	0.390	30.630	0.397
5	20+85	Spigot	Vertical	29.817	29.800	0.017	29.801	0.016	29.792	0.025
			Horizontal	30.247	30.225	-0.002	30.256	0.009	30.272	0.025
		Center	Vertical	30.007	29.364	0.643	29.368	0.639	29.322	0.685
			Horizontal	30.244	30.766	0.522	30.812	0.568	30.861	0.617
		Bell	Vertical	30.197	29.852	0.345	29.822	0.375	29.759	0.438
			Horizontal	30.240	30.544	0.304	30.593	0.353	30.605	0.365
6	21+05	Spigot	Vertical	29.907	29.543	0.364	29.588	0.319	29.567	0.340
			Horizontal	30.191	30.353	0.162	30.372	0.184	30.410	0.219
		Center	Vertical	30.058	28.837	1.222	28.866	1.193	28.825	1.234
			Horizontal	30.191	31.238	1.047	31.278	1.087	31.323	1.132
		Bell	Vertical	30.210	29.709	0.501	29.671	0.539	29.652	0.558
			Horizontal	30.263	30.691	0.428	30.736	0.473	30.762	0.499

Table C-1

DEFLECTION MEASUREMENTS
APACHE LATERAL
Yuma Project RPM Pipe Test Section

Pipe No.	Station	Measurement location	Diameter	Original reading	Date of diameter measurements					
					May 1971		August 1971		March 1972	
					reading	change	reading	change	reading	change
7	21+25	Spigot	Vertical	29.860	29.666	0.194	29.637	0.223	29.625	0.235
			Horizontal	30.169	30.355	0.186	30.421	0.252	30.461	0.292
		Center	Vertical	30.036	29.502	0.534	29.407	0.629	29.395	0.641
			Horizontal	30.191	30.717	0.526	30.724	0.533	30.766	0.575
		Bell	Vertical	30.211	29.745	0.466	29.798	0.413	29.768	0.443
			Horizontal	30.213	30.605	0.392	30.617	0.404	30.640	0.427
8	21+45	Spigot	Vertical	29.888	29.555	0.333	29.429	0.459	29.530	0.358
			Horizontal	30.147	30.269	0.122	30.414	0.267	30.451	0.304
		Center	Vertical	30.050	29.121	0.929	29.094	0.956	29.067	0.983
			Horizontal	30.199	31.112	0.913	31.127	0.928	31.166	0.967
		Bell	Vertical	30.211	29.848	0.363	29.822	0.389	29.734	0.477
			Horizontal	30.250	30.633	0.383	30.645	0.295	30.683	0.433
9	21+65	Spigot	Vertical	30.254	29.614	0.640	29.594	0.660	29.565	0.689
			Horizontal	30.307	30.417	0.110	30.429	0.122	30.456	0.149
		Center	Vertical	30.248	29.554	0.694	29.525	0.723	29.446	0.802
			Horizontal	30.267	30.749	0.482	30.739	0.472	30.781	0.514
		Bell	Vertical	30.241	29.908	0.333	29.928	0.313	29.801	0.440
			Horizontal	30.226	30.506	0.280	30.404	0.178	30.555	0.329
10	21+85	Spigot	Vertical	29.928	29.604	0.324	29.649	0.279	29.625	0.303
			Horizontal	30.160	30.322	0.162	30.359	0.199	30.375	0.215
		Center	Vertical	30.034	29.102	0.932	29.157	0.877	29.112	0.922
			Horizontal	30.218	31.001	0.783	31.060	0.842	31.103	0.885
		Bell	Vertical	30.140	29.818	0.322	29.794	0.346	29.770	0.370
			Horizontal	30.276	30.560	0.284	30.537	0.261	30.573	0.297
11	22+05	Spigot	Vertical	29.814	29.538	0.276	29.550	0.264	29.555	0.259
			Horizontal	30.240	30.437	0.197	30.464	0.224	30.517	0.277
		Center	Vertical	30.012	29.069	0.943	29.061	0.951	29.074	0.938
			Horizontal	30.249	31.084	0.835	31.127	0.878	31.166	0.917
		Bell	Vertical	30.209	30.001	0.208	29.931	0.278	29.916	0.293
			Horizontal	30.257	30.551	0.294	30.555	0.298	30.557	0.300
12	22+25	Spigot	Vertical	29.863	29.784	0.079	29.762	0.101	29.755	0.108
			Horizontal	30.245	30.225	-0.020	30.254	0.009	30.290	0.045
		Center	Vertical	30.026	29.552	0.474	29.528	0.428	29.504	0.522
			Horizontal	30.249	30.771	0.522	30.801	0.552	30.843	0.594
		Bell	Vertical	30.189	29.930	0.259	29.890	0.299	29.869	0.320
			Horizontal	30.253	30.454	0.201	30.503	0.250	30.509	0.256
13	22+45	Spigot	Vertical	29.887	29.725	0.162	29.738	0.149	29.721	0.166
			Horizontal	30.133	30.265	0.132	30.281	0.148	30.328	0.195
		Center	Vertical	30.044	29.514	0.530	29.434	0.610	29.394	0.650
			Horizontal	30.195	30.754	0.559	30.780	0.585	30.827	0.632
		Bell	Vertical	30.200	30.004	0.196	29.929	0.271	29.857	0.343
			Horizontal	30.256	30.502	0.246	30.521	0.265	30.534	0.278

Table C-1

DEFLECTION MEASUREMENTS
APACHE LATERAL
Yuma Project RPM Pipe Test Section

Pipe No.	Station	Measurement location	Diameter	Original reading	Date of diameter measurements					
					May 1971		August 1971		March 1972	
					reading	change	reading	change	reading	change
14	22+65	Spigot	Vertical	29.896	29.739	0.157	29.743	0.153	29.748	0.148
			Horizontal	30.130	30.250	0.120	30.277	0.147	30.296	0.166
		Center	Vertical	30.052	29.587	0.465	29.579	0.473	29.523	0.529
			Horizontal	30.192	30.665	0.473	30.651	0.459	30.676	0.484
		Bell	Vertical	30.207	30.018	0.189	29.987	0.220	29.939	0.268
			Horizontal	30.254	30.440	0.186	30.493	0.239	30.517	0.263
15	22+85	Spigot	Vertical	29.953	29.567	?	29.770	?	29.256	0.697
			Horizontal	30.128	30.277	0.149	30.310	0.182	30.363	0.235
		Center	Vertical	30.075	29.651	0.424	29.632	0.443	29.608	0.467
			Horizontal	30.175	30.648	0.473	30.644	0.469	30.672	0.497
		Bell	Vertical	30.196	30.069	0.127	30.005	0.191	29.937	0.259
			Horizontal	30.221	30.362	0.141	30.373	0.152	30.398	0.177
16	23+05	Spigot	Vertical	29.915	29.741	0.174	29.742	0.173	29.737	0.178
			Horizontal	30.192	30.234	0.042	30.250	0.058	30.264	0.072
		Center	Vertical	30.044	29.451	0.593	29.434	0.610	29.399	0.645
			Horizontal	30.230	30.754	0.524	30.806	0.576	30.836	0.606
		Bell	Vertical	30.172	29.909	0.263	29.798	0.374	29.638	0.534
			Horizontal	30.267	30.338	0.071	30.562	0.295	30.592	0.325
17	23+25	Spigot	Vertical	29.785	29.682	0.103	29.621	0.164	29.722	0.063
			Horizontal	30.261	30.532	0.271	30.389	0.128	30.403	0.142
		Center	Vertical	29.989	29.413	0.576	29.358	0.631	29.341	0.648
			Horizontal	30.266	30.918	0.652	30.970	0.704	30.994	0.728
		Bell	Vertical	30.193	30.026	0.167	29.982	0.211	29.655	?
			Horizontal	30.271	30.451	0.180	30.426	0.155	30.464	0.193
18	23+45	Spigot	Vertical	29.802	29.681	0.121	29.673	0.129	29.986	?
			Horizontal	30.235	30.281	0.046	30.343	0.108	30.354	0.119
		Center	Vertical	30.007	29.246	0.761	29.195	0.812	29.091	0.916
			Horizontal	30.254	31.016	0.762	31.165	0.911	31.191	0.937
		Bell	Vertical	30.212	30.006	0.206	29.894	0.318	29.844	0.368
			Horizontal	30.272	30.549	0.277	30.530	0.258	30.562	0.290
19	23+65	Spigot	Vertical	29.928	29.739	0.189	29.720	0.208	29.682	0.246
			Horizontal	30.125	30.379	0.254	30.314	0.189	30.358	0.233
		Center	Vertical	30.066	29.107	0.959	29.043	1.023	28.968	1.098
			Horizontal	30.191	31.225	1.034	31.166	0.975	31.360	1.169
		Bell	Vertical	30.203	29.800	0.403	29.850	0.353	29.801	0.402
			Horizontal	30.256	30.595	0.339	30.610	0.354	30.641	0.385
20	23+85	Spigot	Vertical	29.808	29.637	0.171	29.653	0.155	29.646	0.162
			Horizontal	30.228	30.298	0.070	30.348	0.120	30.355	0.127
		Center	Vertical	29.984	29.320	0.664	29.283	0.701	29.244	0.740
			Horizontal	30.249	30.763	0.514	30.846	0.597	30.972	0.723
		Bell	Vertical	30.160	29.926	0.234	29.903	0.257	29.873	0.287
			Horizontal	30.270	30.505	0.235	30.510	0.240	30.543	0.273

Table C-1

DEFLECTION MEASUREMENTS
APACHE LATERAL
Yuma Project RPM Pipe Test Section

Sheet 4 of 5

Pipe No.	Station	Measurement location	Diameter	Original reading	Date of diameter measurements					
					May 1971		August 1971		March 1972	
					reading	change	reading	change	reading	change
21	24+05	Spigot	Vertical	29.766	29.714	0.052	29.754	0.012	29.691	0.075
			Horizontal	30.253	30.237	-0.016	30.298	0.045	30.308	0.055
		Center	Vertical	29.966	29.510	0.456	29.455	0.511	29.411	0.555
			Horizontal	30.268	30.750	0.482	30.819	0.551	30.894	0.626
		Bell	Vertical	30.166	29.975	0.191	29.940	0.226	29.843	0.323
			Horizontal	30.283	30.513	0.230	30.507	0.224	30.552	0.269
22	24+25	Spigot	Vertical	29.818	29.705	0.113	29.714	0.104	29.680	0.138
			Horizontal	30.161	30.245	0.084	30.289	0.128	30.344	0.183
		Center	Vertical	30.006	29.505	0.501	29.517	0.489	29.455	0.551
			Horizontal	30.206	30.663	0.457	30.754	0.548	30.815	0.609
		Bell	Vertical	30.194	30.019	0.175	29.991	0.203	29.952	0.242
			Horizontal	30.250	30.471	0.221	30.457	0.207	30.497	0.247
23	24+45	Spigot	Vertical	29.891	29.771	0.120	29.851	0.040	29.827	0.064
			Horizontal	30.215	30.266	0.051	30.269	0.054	30.338	0.123
		Center	Vertical	30.038	29.256	0.782	29.224	0.814	29.161	0.877
			Horizontal	30.233	31.058	0.825	31.141	0.908	31.190	0.957
		Bell	Vertical	30.184	29.889	0.295	29.873	0.311	29.851	0.333
			Horizontal	30.251	30.528	0.277	30.545	0.294	30.570	0.319
24	24+65	Spigot	Vertical	29.832	29.771	0.061	29.740	0.092	29.730	0.102
			Horizontal	30.150	30.259	0.109	30.276	0.126	30.296	0.146
		Center	Vertical	30.002	29.429	0.573	29.404	0.598	29.411	0.591
			Horizontal	30.202	30.813	0.611	30.844	0.642	30.878	0.676
		Bell	Vertical	30.171	29.967	0.204	29.956	0.215	29.918	0.253
			Horizontal	30.253	30.440	0.187	30.445	0.192	30.500	0.247
25	24+85	Spigot	Vertical	29.906	29.748	0.158	29.691	0.215	29.648	0.258
			Horizontal	30.125	30.285	0.160	30.302	0.177	30.329	0.204
		Center	Vertical	30.043	29.289	0.754	29.281	0.762	29.219	0.824
			Horizontal	30.188	30.884	0.696	30.995	0.807	31.045	0.857
		Bell	Vertical	30.179	29.810	0.369	29.796	0.383	29.769	0.410
			Horizontal	30.251	30.589	0.338	30.614	0.363	30.622	0.371
26	25+05	Spigot	Vertical	29.753	29.720	0.033	29.707	0.046	29.681	0.072
			Horizontal	30.251	20.291	0.040	30.359	0.108	30.354	0.103
		Center	Vertical	29.982	29.209	0.773	29.226	0.756	29.184	0.798
			Horizontal	30.253	31.004	0.751	31.010	0.757	31.098	0.845
		Bell	Vertical	30.211	29.979	0.232	29.891	0.320	29.788	0.423
			Horizontal	30.254	30.480	0.226	30.469	0.215	30.548	0.294
27	25+25	Spigot	Vertical	29.892	29.801	0.091	29.818	0.074	29.872	0.020
			Horizontal	30.136	30.237	0.101	30.239	0.103	30.269	0.133
		Center	Vertical	30.038	29.226	0.812	29.139	0.899	29.154	0.884
			Horizontal	30.205	31.119	0.914	31.107	0.902	31.169	0.964
		Bell	Vertical	30.184	29.742	0.442	29.686	0.498	29.723	0.461
			Horizontal	30.274	30.639	0.365	30.722	0.448	30.765	0.491

Table C-1

DEFLECTION MEASUREMENTS
APACHE LATERAL
Yuma Project RPM Pipe Test Section

Sheet 5 of 5

Pipe No.	Station	Measurement location	Diameter	Original reading	Date of diameter measurements					
					May 1971		August 1971		March 1972	
					reading	change	reading	change	reading	change
28	25+45	Spigot	Vertical	30.011	29.686	0.325	29.751	0.260	29.675	0.336
			Horizontal	30.115	30.323	0.208	30.354	0.239	30.396	0.281
		Center	Vertical	30.102	29.340	0.762	29.369	0.733	29.319	0.783
			Horizontal	30.163	30.947	0.784	30.963	0.800	30.997	0.834
		Bell	Vertical	30.192	29.814	0.378	29.789	0.403	29.773	0.419
			Horizontal	30.211	30.503	0.292	30.622	0.411	30.637	0.426
29	25+65	Spigot	Vertical	29.940	29.711	0.229	29.755	0.185	29.725	0.215
			Horizontal	30.138	30.332	0.194	30.349	0.211	30.384	0.246
		Center	Vertical	30.070	29.048	1.022	29.018	1.052	28.977	1.093
			Horizontal	30.188	31.195	1.007	31.168	0.980	31.203	1.015
		Bell	Vertical	30.200	29.824	0.376	29.734	0.466	29.688	0.512
			Horizontal	30.237	30.597	0.366	30.650	0.419	30.665	0.434
30	25+85	Spigot	Vertical	No	29.717	–	29.707	–	29.680	–
			Horizontal	original	30.335	–	30.326	–	30.362	–
		Center	Vertical	readings;	29.869	–	29.746	–	29.736	
			Horizontal	pipe	30.356	–	30.510	–	30.545	–
		Bell	Vertical	section	29.766	–	29.836	–	29.822	–
			Horizontal	was	30.554	–	30.609	–	30.621	–
				replaced.						

Table C-2

DEFLECTIONS OF SPIGOT END

	May 1971	August 1971	March 1972
Average change			
Vertical	0.197 inch (0.501 cm)	0.193 inch (0.490 cm)	0.228 inch (0.579 cm)
Horizontal	0.144 inch (0.366 cm)	0.147 inch (0.373 cm)	0.178 inch (0.452 cm)
Range			
Vertical	0.017-0.640 inch (0.043-1.626 cm)	0.000-0.660 inch (0-1.676 cm)	–0.004-0.697 inch (–0.010-1.770 cm)
Horizontal	–0.022-0.484 inch (–0.056-1.229 cm)	–0.021-0.275 inch (–0.053-0.699 cm)	–0.038-0.308 inch (–0.097-0.782 cm)
Percent deflection			
Vertical	0.66 percent	0.64 percent	0.74 percent
Horizontal	0.48 percent	0.49 percent	0.49 percent
$\Delta X/\Delta Y$	73.1 percent	76.2 percent	79.8 percent
Percent increase from May 1971 reading			
Vertical	–	–1.0 percent	13.2 percent
Horizontal	–	+2.1 percent	23.6 percent

Table C-3

DEFLECTIONS OF BELL END

	May 1971	August 1971	March 1972
Average change			
Vertical	0.286 inch (0.726 cm)	0.322 inch (0.818 cm)	0.371 inch (0.942 cm)
Horizontal	0.286 inch (0.726 cm)	0.296 inch (0.752 cm)	0.341 inch (0.866 cm)
Range			
Vertical	0.127-0.501 inch (0.323-1.273 cm)	0.180-0.539 inch (0.457-1.369 cm)	0.196-0.558 inch (0.498-1.417 cm)
Horizontal	0.071-0.586 inch (0.180-1.488 cm)	0.152-0.473 inch (0.386-1.201 cm)	0.177-0.621 inch (0.450-1.577 cm)
Percent deflection			
Vertical	0.95 percent	1.07 percent	1.24 percent
Horizontal	0.95 percent	0.99 percent	1.14 percent
$\Delta X/\Delta Y$	100 percent	91.9 percent	91.9 percent
Percent increase from May 1971 reading			
Vertical	–	12.59 percent	29.72 percent
Horizontal	–	3.50 percent	19.23 percent
Deflection of bell divided by deflection of spigot			
Vertical	1.45	1.67	1.66
Horizontal	1.99	2.01	1.92

Table C-4

DEFLECTIONS OF CENTER OF PIPE

	May 1971	August 1971	March 1972
Average change			
Vertical	0.690 inch (1.753 cm)	0.711 inch (1.806 cm)	0.752 inch (1.910 cm)
Horizontal	0.668 inch (1.697 cm)	0.701 inch (1.781 cm)	0.750 inch (1.905 cm)
Range			
Vertical	0.277-1.222 inches (0.704-3.104 cm)	0.295-1.193 inches (0.749-3.030 cm)	0.308-1.234 inches (0.782-3.134 cm)
Horizontal	0.216-1.047 inches (0.549-2.659 cm)	0.289-1.087 inches (0.734-2.761 cm)	0.317-1.169 inches (0.805-2.969 cm)
Percent deflection			
Vertical	2.30 percent	2.37 percent	2.51 percent
Horizontal	2.22 percent	2.34 percent	2.50 percent
$\Delta X/\Delta Y$	96.8 percent	98.6 percent	99.7 percent
Percent increase from May 1971 reading			
Vertical	–	3.04 percent	8.99 percent
Horizontal	–	4.94 percent	12.28 percent
Deflection of center divided by deflection of spigot			
Vertical	3.50	3.68	3.37
Horizontal	4.64	4.77	4.21

APPENDIX D
SURCHARGE TEST SECTION

A special surcharge test installation was constructed over one of the pipe in the saturated and vibrated sand bedding section on the Toronto Lateral. The purpose of the installation was to examine the pipe deflection behavior at a load greater than the backfill provided.

After the entire test section had been completed and backfilled, about 10 linear feet (3.0 meters) of backfill over the center of Pipe No. 2 was excavated down to the top of the bedding, as shown in Figure D-1. About 2 feet (0.6 meter) of backfill was replaced and a 6- by 6-foot (1.8-meter) wooden load plate centered (see Figure D-2) over the pipe. As shown in Figure D-3, large concrete blocks were stacked on the load plate to provide the surcharge. Diameter measurements were made at five different locations along the inside of the pipe for each stage of construction. Subsequent measurements were made at 4, 10, and 16 months after construction. The surcharge blocks were then removed after the 16-month readings.

The total weight of the blocks was 38,500 pounds (17.5 kg) resulting in a 7.5-psi (0.53-kg/cm^2) pressure on the soil surface over the pipe.

A summary of the deflections at the five measurement locations in the pipe is given in Table D-1. All of the diameter measurements are itemized in

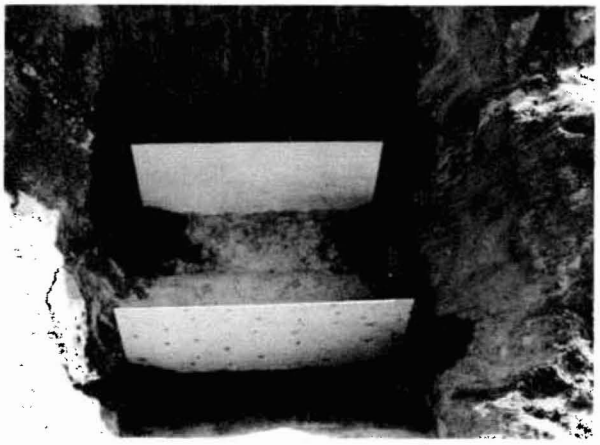


Figure D-1. Reexcavated trench for preparation of surcharge test section on Toronto Lateral, Yuma Project. Photo PX-303-1399NA

Figure D-2. Six-foot square load plate on 2 feet of compacted backfill over RPM on Toronto Lateral, Yuma Project. Photo PX-303-1401NA

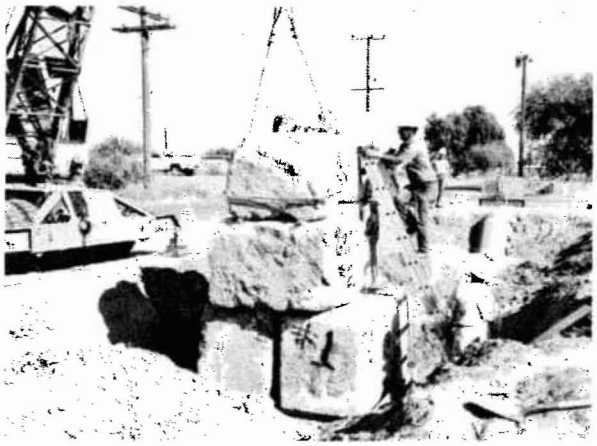


Figure D-3. Surcharge load of eight concrete blocks on load plate over RPM pipe on Toronto Lateral, Yuma Project. Photo PX-303-1404NA

Tables D-2 and D-3. The readings are rather erratic, but some general observations can be made.

The horizontal deflections of the pipe before any backfill was removed were about three times more than the other two pipe in the saturated and vibrated sand bedding. Removing the backfill and then putting some of it back along with the load plate did not affect the deflections. See Table D-2.

Using the pipe diameters measured after replacing the backfill and placing the load plate as base readings, the pipe deflected vertically 0.19 inch

(0.48 cm) or 0.63 percent and deflected horizontally 0.10 inch (0.25 cm) or 0.33 percent due to the surcharge of the eight concrete blocks. The individual values are shown in Table D-3.

Over a 4-month period, the vertical deflection increased 37 percent and the horizontal 4 percent. Over a 10-month period, the vertical deflection increased 75 percent and the horizontal decreased 21 percent. Over the 16-month period, the vertical deflection increased 86 percent and the horizontal deflection increased 27 percent from the base readings.

The change in the horizontal diameter of the pipe from the base reading was almost insignificant due to the high density of the sand bedding beside the pipe. It is important to note that the change in the vertical diameter was noticeably more than the change in the horizontal diameter. This indicates that the pipe was deforming more in a rectangular pattern than in an elliptical pattern. Further discussion of the shapes of deformation of flexible pipe can be found in Reference No. 9, page 13.

Table D-1

SUMMARY OF DATA FROM SURCHARGE TEST SECTION
TORONTO LATERAL

Construction condition	Average of five readings			
	Vertical deflection		Horizontal deflection	
	inches (cm)	percent	inches (cm)	percent
Original bedding and backfill	–		0.638 (1.621)	2.1
Backfill removed	0.675 (1.715)		0.632 (1.605)	
Backfill replaced plus load plate (base reading)	0.620 (1.575)		0.619 (1.572)	
Eight blocks placed (11-70) (change from base reading)	0.185 (0.470)	0.6	0.103 (0.262)	0.3
3-2-71 reading	0.254 (0.645)	0.8	0.107 (0.271)	0.4
change from 11-70		37.3		3.9
8-25-71 reading	0.323 (0.820)	1.1	0.081 (0.206)	0.3
change from 11-70		74.6		–21.4
3-14-72 reading	0.344 (0.874)	1.1	0.131 (0.333)	0.4
change from 11-70		85.9		27.2

Table D-2

DIAMETER MEASUREMENTS AND DEFLECTIONS
SURCHARGE TEST SECTION
TORONTO LATERAL

Distance from end of pipe feet	Diameter	Original reading inches	With original bedding and backfill		Backfill removed		Backfill replaced plus load plate	
			reading inches	change inches	reading inches	change inches	reading inches	change inches
5.5	Vertical	30.120	<29.5		29.404	0.716	29.526	0.594
	Horizontal	30.247	30.837	0.590	30.888	.641	30.857	.610
8.5	Vertical	30.012	<29.5		29.363	.649	29.446	.566
	Horizontal	30.242	30.972	.730	30.893	.651	30.919	.677
10	Vertical	30.009	<29.5		29.230	.779	29.299	.710
	Horizontal	30.197	30.930	.733	30.895	.698	30.877	.680
11.5	Vertical	30.051	<29.5		29.423	.628	29.382	.669
	Horizontal	30.161	30.866	.705	30.804	.643	30.861	.700
14.5	Vertical	30.028	<29.5		29.423	.605	29.469	.559
	Horizontal	30.278	30.711	.433	30.804	.526	30.707	.429

Table D-3

DEFLECTIONS OF PIPE DUE TO SURCHARGE LOAD AND TIME
SURCHARGE TEST SECTION
TORONTO LATERAL

Distance from end of pipe feet	Diameter	Base reading (replaced backfill) inches	4-block surcharge		6-block surcharge		8-block surcharge		March 2, 1971 reading	
			reading inches	change inches	reading inches	change inches	reading inches	change inches	reading inches	change inches
5.5	Vertical	29.526	29.386	0.140	29.354	0.172	29.528	?	29.174	0.352
	Horizontal	30.857	30.861	0.004	30.888	.031	30.746	?	30.908	.051
8.5	Vertical	29.446	29.367	0.079	29.442	.004	29.225	0.221	28.949	.497
	Horizontal	30.919	30.913	−0.006	30.960	.041	30.948	0.029	31.096	.177
10	Vertical	29.299	29.299	0	29.065	.234	29.232	?	28.955	.344
	Horizontal	30.877	30.842	−0.035	30.833	− .044	30.924	0.047	31.072	.195
11.5	Vertical	29.382	29.377	0.005	29.405	− .023	29.254	0.128	29.065	.317
	Horizontal	30.861	30.842	−0.019	30.817	− .044	31.011	0.150	31.013	.152
14.5	Vertical	29.469	29.465	0.004	29.557	− .088	29.262	0.207	29.261	.208
	Horizontal	30.707	30.668	−0.039	30.704	− .003	30.892	0.185	30.786	.079

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	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

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ABSTRACT

Field tests of reinforced plastic mortar (RPM) pipe were conducted on the Yuma Project. Two test sections of 30-inch-diameter pipe were installed to replace two deteriorated open laterals. Twenty-nine 20-foot sections were placed in the Toronto Lateral in a dry trench using the following types of bedding: (1) compacted natural earth, (2) compacted sand, (3) puddled natural earth, (4) loose sand, and (5) loose natural earth. Thirty 20-foot sections were placed in the Apache Lateral in a wet and unstable subgrade 9 to 18 inches below the water table. Performance of RPM pipe was evaluated under controlled field conditions and deflections of the pipe laid in different bedding conditions were measured. Results from the Toronto Lateral showed the following average vertical pipe deflections: (1) well-compacted material, 1 percent; (2) puddled natural earth, 4 percent; (3) loose sand, 6 percent; and (4) loose natural earth, 8 percent. Results from the Apache Lateral showed that the average vertical deflections were 0.7 percent at the spigot end, 1 percent at the bell end, and 2.3 percent at the center of the pipe. Field tests indicate that RPM pipe is a practical alternative to other types if the RPM pipe is installed according to Bureau specifications. (9 references)

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DESCRIPTORS—/ pipelines/ backfills/ soil mechanics/ buried pipes/ field tests/ flexible pipes/ *deflection/ pipes/ deformation/ plastic pipes/ pipe joints/ *pipe tests/ *pipe bedding/ bedding materials/ construction methods/ trenches/ compaction/ pipe laying/ pipe design/ strain/ product evaluation/ performance tests/ loading tests/ measurement/ pipe cover
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