FIELD TEST DEFLECTIONS OF REINFORCED PLASTIC MORTAR PIPE

Amster K. Howard, Bureau of Reclamation,
U.S. Department of the Interior, Denver

Two test sections of 30-in.-diameter (76 cm) reinforced plastic mortar (RPM) pipe were installed to replace two deteriorated open irrigation laterals. Twenty-nine 20-ft (6.1 m) sections of pipe were placed in one section in a dry trench with five different types of bedding. Pipe deflections were measured at four different times during the 16 months after installation. Results showed the following average initial vertical pipe deflections: (a) well-compacted material, 1 percent; (b) puddled natural earth, 4 percent; (c) loose sand, 6 percent; and (d) loose natural earth, 8 percent. Thirty 20-ft (6.1 m) pipe lengths were placed in the other section in a wet and unstable subgrade. Deflections of the bell end, spigot end, and center of the pipe were measured at 2, 5, and 12 months after installation. Results showed that the average initial 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. These field tests indicate that RPM pipe will deflect less than 5 percent if it is installed according to U.S. Bureau of Reclamation specifications.

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

The Open and Closed Conduit Systems (OCCS) Committee of USBR evaluates different types of pipe and construction methods in an effort to reduce the high initial costs of installing pipelines. In 1967, 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.

DESCRIPTION OF PIPE AND TEST SITES

Reinforced Plastic Mortar 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 and that provides high tensile hoop strength. RPM pipe also is resistant to a wide variety of chemical solutions. The pipe is manufactured in standard 20-ft (6.1 m) lengths with bell-and-spigot, rubber-gasketed (O-ring) joints. 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 federal government have been published in two USBR laboratory reports (1 and 2). Another USBR laboratory report (3) compares the structural behavior of RPM pipe

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buried in a special laboratory test container with that of steel pipe and is one of a series of reports on flexible pipe behavior (4, 5, 6, 7, 8). This paper covers the field performance of 30-in. (76 cm) RPM pipe used in the rehabilitation of two open laterals on the Yuma Project and is based on two USBR reports (9 and 10).

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, and water was delivered from 1910 on. 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 with 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 ft (9 to 12 m) above the ground surface elevation of the farm areas.

The soils in the Reservation Division are mostly sandy silts with a widely varying groundwater table. RPM pipe was installed under both high and low groundwater conditions with no attempt to dewater for the high groundwater 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-ft (6.1 m) sections of 30-in.-diameter (76 cm) RPM pipe were installed on the Toronto Lateral on a dry subgrade in October 1970. The bell-and-spigot joint pipes were rated for 100-psi (689 kPa) internal pressure. The line included the necessary mitered bends and connections to existing structures.

The trench for the pipe had a 5-ft (1.5 m) bottom width with ¾:1 side slopes. The subgrade was approximately 9 ft (2.7 m) below the top of the lateral embankment and 5 ft (1.5 m) below the bottom of the old lateral. The native material was generally a sandy silt with some areas of clay. The in-place moistures and densities of the trench walls were determined in seven locations. The gradation, consistency limits, specific gravity, maximum density, and optimum water content were determined in the laboratory.

The pipe was laid downstream with the spigot in the downstream direction and was 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 so that it could be kept on grade during the placing of the bedding. The pipe was watertight except for a small leak at the concrete mortar pipe closure that formed the mitered upstream bend.

There were five types of bedding used on this lateral:

1. 60 lin ft (18.3 m) of compacted sand, saturated and vibrated;
2. 240 lin ft (73.2 m) of loose sand;
3. 40 lin ft (12.2 m) of compacted natural earth, tamped;
4. 180 lin ft (54.9 m) of loose natural earth; and
5. 60 lin ft (18.3 m) 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. Before backfilling was put over the pipe, in-place density tests were made on each side of the pipe in the compacted natural earth and in the compacted sand bedding. For the puddled natural earth and the loose natural earth, density tests were made after the backfill had been placed and the beddings had settled. These densities represent the material density after the initial pipe deflection and the change in density caused by the surcharge of the overlying backfill.

The initial pipe deflection values were made about 2 weeks after construction, and subsequent deflections were measured in March 1971 (at 4 months), August 1971 (at 10 months), and March 1972 (at 16 months).

The compacted sand bedding was placed by dumping in the imported sand, flooding the sand with water, and then vibrating this with concrete vibrators as shown in Figure 1. 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 placed by dumping the earth into place and then flooding it to water-settle the material. The puddled natural earth bedding was constructed by flooding the trench with water, dumping the soil, and settling it by working it with shovels (Fig. 2). The backfill over the pipe was pushed into place with a dozer and then water-settled.

Apache Lateral

Thirty 20-ft (6.1 m) sections of 30-in. (76 cm) diameter RPM pipe were installed in the Apache Lateral in March 1971 on an unstable subgrade, 9 to 18 in. (23 to 46 cm) below the water table. The pipe had bell-and-spigot joints and was rated for 100-psi (689 kPa) internal pressure. Included in this line were a horticultural turnout and the necessary vertical bends and connections with existing structures.

The trench for the pipe had an approximate 6-ft (1.8 m) 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 sluffed into the trench. The subgrade was approximately 10 ft (3 m) below the top of the lateral embankment. The trench was overexcavated and the pipe was immediately lowered into the trench and joined so that the pipe could be put on grade. The pipe was then brought to grade by filling beneath it, maneuvering it 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 joined easily in spite of the water and soil that covered the lower portion of the bell. Gaskets were checked as conditions permitted, but a watertight joint could not be ensured.

Internal vertical and horizontal diameter measurements were made at the bell and the spigot before the pipe was placed. Initial deflection measurements were made in May 1971 (at 2 months) and subsequently in August 1971 (at 5 months) and in March 1972 (at 12 months).

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

PIPE DEFLECTIONS UNDER LOAD

Flexible Pipe Behavior

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 of the passive resistance of each type of material and its deflection-lag factor.

Figure 1. Compacting sand bedding with internal vibrators, Toronto Lateral.

Figure 2. Dumping loose earth around RPM pipe, Toronto Lateral.

Table 1. Bedding condition for pipe, Toronto Lateral.

Material Type and Condition	Construction Method	Vertical Deflection (percent)	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

Table 2. Pipe deflections, Toronto Lateral.

Bedding	Vertical Deflection (percent)	In-Place Soil Density
Compacted natural earth	0	Proctor density, 95 to 97 percent
Compacted sand	1	Relative density, 30 to 38 percent
Puddled natural earth	4	Not determined
Loose sand	6	Below laboratory minimum density
Loose natural earth	8	Proctor density[a], 90 to 93 percent

[a]Measured after backfill was placed over the pipe and water settled; this does not represent bedding densities at the time of initial pipe deflection.

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 [determined in the laboratory with designation E-11 (11)]. For cohesionless bedding materials, the specifications require a minimum of 70 percent relative density. From the relative density method (11), the minimum field density is established as a percentage of the range between the minimum and maximum densities of the soil as determined by laboratory tests.

The five types of beddings in this installation ranged from the worst condition (dumped and flooded) to the best condition (compacted by mechanical methods). In addition, the puddled cohesive material provided an intermediate condition. Table 1 gives the condition of each bedding type and the resulting vertical deflection of the pipe.

Soil deformation at the sides of a flexible pipe depends mostly on the soil's compressibility, which 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 because individual grains are relatively incompressible. Well-compacted cohesive soils are more compressible because their fine-particle structure combined with water films does not permit contact and interlocking of particles. (Deflection of the pipe on the Toronto Lateral was well under 5 percent when it was property installed with well-compacted bedding.)

Because of the granular structure of a cohesionless material, 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, as indicated by the density test results, was compacted to only 30 to 38 percent relative density. The reasons for this unusually low density for saturated and vibrated sand are not known. However, for test purposes, it provided an additional density condition for comparison purposes. If the sand had been compacted to specifications, the deflections probably would have been about the same as for the pipe in compacted natural earth. That the intermediate condition, the puddled natural earth, gave better support to the pipe than did loose sand bedding is of particular interest.

Table 2 gives the various beddings according to decreasing effectiveness. The average deflection values are compared with the range of deflection values in Figure 3.

Modulus of Soil Reaction

In 1941, Spangler published a design procedure (12) for flexible pipe that still serves as the main design method. Spangler and Watkins (13) later modified the formula to include a more realistic value for the soil parameter. The modified Iowa formula is

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

where

ΔX = horizontal deflection of the pipe, in inches;
D_1 = deflection lag factor to compensate for the time-consolidation rate of the soil, dimensionless;
K = bedding constant that varies with the angle of the bedding, dimensionless;
W = load on the pipe per unit length, in lb/lin in.;
r = pipe radius, in inches;
EI = pipe wall stiffness per unit length, in in.-lb; and
e' = modulus of soil reaction, in psi.

Rearranging the Iowa formula to find e' values from pipe deflection gives

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

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 give the EI value of the pipe as 6,835 in.-lb (0.772 kJ) at 5 percent deflection. When there is a radius of 15 in. (38 cm), EI/r^3 becomes 2.03 psi or 2 psi (13.79 kPa) approximately. The initial deflection values will be used; therefore a deflection lag factor of 1.0 is used. The bedding constant ranges from 0.110 for a 0-deg bedding angle (line load in the bottom of the pipe) to 0.083 for a 90-deg (1.6 rad) bedding angle (full support under the bottom half of the pipe). Most investigators of flexible pipe behavior use a bedding constant of 0.1 as a typical value, and that will be used here.

The load, W, in lb/lin in., is assumed to be the weight of the column of soil over the pipe. W is then found from

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

where

γ_{wet} = wet soil density,
h = backfill depth, and
D = pipe diameter, in inches.

The dry density of the backfill soil is about 89 lb/ft^3 (1425 kg/m^3). If one used a water content of 30 percent, the wet backfill density would be 115 lb/ft^3 (1842 kg/m^3). The backfill depth averages about 4.5 ft (1.4 m) or 54 in. W then becomes

$$(115\ \text{lb/ft}^3)\ \frac{1}{1{,}728}\ \text{in.}^3/\text{ft}^3\ (54\ \text{in.})\ (D) = 3.59\ \frac{\text{lb}}{\text{in.}^2}\ (D)$$

Substituting these values into the rearranged Iowa formula gives

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

$$e' = 16.39\left(\frac{0.359}{\Delta X/D} - 2\right)$$

With percent deflection for $\Delta X/D$

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

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

Table 3 gives the e′ values calculated for the various bedding conditions. 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 4 shows a plot of the pipe deflection for various e′ values for a pipe under 4 ft (1.2 m) of backfill. Pipe deflections are very small for well-compacted beddings that have high e′ values. Poor compaction gives low e′ values and high pipe deflections.

The data from this study also support the recent statement (14) by Spangler that e′ is a semiempirical factor and values should be chosen by 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. Initial consolidation of the soil takes place soon after a load is applied. The soil will continue to consolidate with time, and the pipe will continue to deflect over a long time period.

Figure 3. Range and averages of percentage of vertical deflections (measured November 18, 1970), Toronto Lateral.

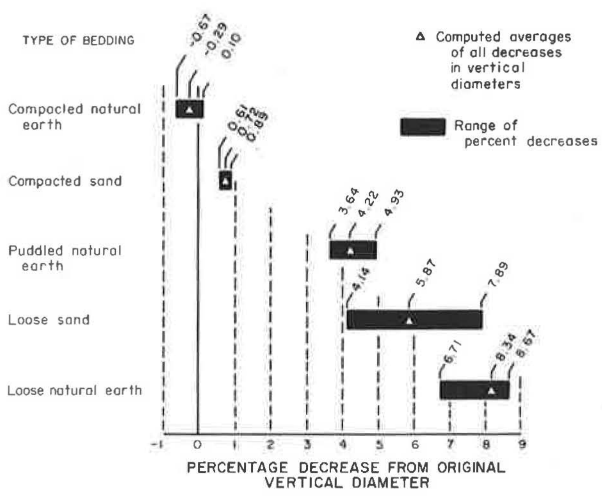
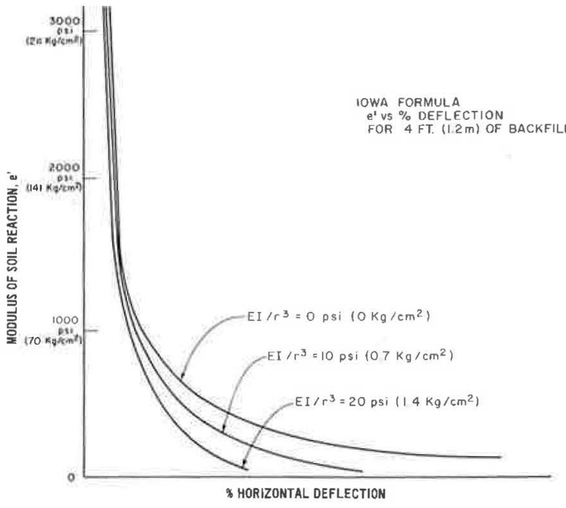


Table 3. Modulus of soil reaction values, Toronto Lateral.

Bedding	Average ΔX/D (percent)	e', psi
Loose natural earth	7.8	45
Loose sand	5.1	83
Puddled natural earth	3.5	157
Compacted sand	0.6	948
Tamped natural earth	0.1[a]	5,851

Note: 1 psi = 6894.757 Pa.
[a]Maximum deflection measured.

Figure 4. Percentage of horizontal deflection versus e' from Iowa formula for 4 ft (1.2 m) of backfill.



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

The increases in pipe deflection with time are given in Table 4. 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.

Average pipe deflections for each of the bedding conditions, the modulus of soil reaction, and the time lag are given in Table 5.

DEFLECTIONS OF JOINTS

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 in 29 of the pipe sections and were averaged 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 that average vertical deflections were, for the spigot end, 0.7 percent; for the center of the pipe, 2.3 percent; and for the bell end, 1.0 percent. These average deflection values are compared with the range of deflection values in Figure 5.

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.

The measurements of the original diameters were made on March 10, 1971. The first readings after backfilling were made on May 20 to 21, 1971 (at 2 months), August 26 to 30, 1971 (at 5 months), and on March 8 to 9, 1972 (at 12 months). The increases in the deflection values are given in Table 6.

Over the 10-month period, the vertical deflections of the spigot end increased 13 percent, of the center of the pipe 9 percent, and of the bell end 30 percent. Because 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.

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Table 4. Deflection-lag values, Toronto Lateral.

Bedding	Diameter	Date of Measurement		
		March 1971	Aug. 1971	March 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[a]	Vertical	1.08	1.08	1.09
	Horizontal	1.03	1.04	1.06

Note: Increase in deflection from November 1970 readings.

[a]The loose natural earth was placed in two reaches separated by the puddled natural earth section.

Table 5. Summary of results, Toronto Lateral.

Bedding	Initial Vertical Deflection (percent)	Initial Horizontal Deflection (percent)	Modulus of Soil Reaction (psi)	Deflection Lag Factor Over 16 Months
Compacted natural earth	-0.3	0.1	5,851	–
Compacted sand	0.7	0.6	948	1.50
Puddled natural earth	4.2	3.5	157	1.06
Loose sand	5.9	5.1	83	1.05
Loose natural earth	8.3	7.8	45	1.10

Note: 1 psi = 6894.757 Pa.

Figure 5. Range and averages of percentaging vertical deflections (measured May 1971), Apache Lateral.

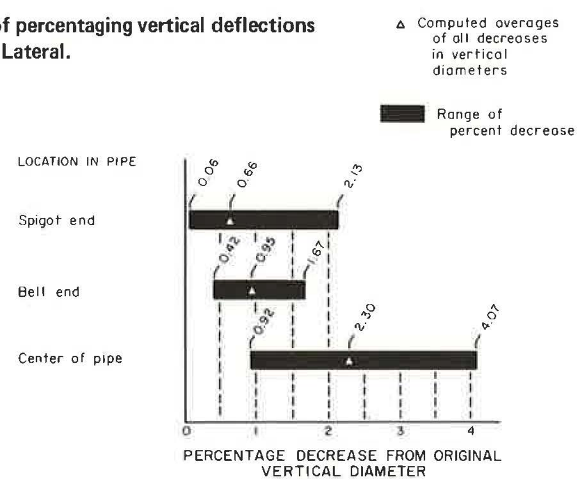

Table 6. Deflection-lag values, Apache Lateral.

Location in Pipe	Diameter	Date of Measurement	
		Aug. 1971	March 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

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