

**PAPER PRESENTED AT
ASCE CONFERENCE**

PIPELINES 2008

**Atlanta GA
July 24, 2008**

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Flowable Fill and the Ridges Basin Inlet Conduit

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Abstract

Flowable fill was used as the embedment material for an 84-inch diameter corrugated metal pipe (CMP) casing subsequently backfilled with 40-feet of cover. While the Bureau of Reclamation frequently uses flowable fill for pipe embedment, this particular installation was carefully monitored because of the unusually high depth of cover. The space between the casing and the 72-inch carrier pipe meant only minimal pipe deflection could be tolerated. Backfilling over the pipe started one week after the flowable fill was placed. Pipe diameter measurements were made after placement of the flowable fill and before backfilling, and then again 4.5 years later. The pipe deflection was insignificant.

Introduction

In 2002, an 84-in diameter corrugated metal pipe (CMP) casing pipe was installed using flowable fill as the embedment material. The pipe was then backfilled with 40 feet of cover. The carrier pipe was not threaded through the casing until 2007. Flowable fill was selected as the embedment material because of speed of installation and to limit potential excessive deflection of the flexible CMP pipe. Flowable fill gives a higher resistance to deflection than compacted soil. Pipe diameter measurements were made after the flowable fill was placed and before backfilling to check circularity and to evaluate using flowable fill under high fills. In 2007, 4.5 years after installation, the pipe diameters were again measured to verify the circularity and to see how the flowable fill had performed. The 2007 measurements showed that very little deflection or change in pipe shape had occurred in the CMP pipe. The installation was part of the Ridges Basin Inlet Conduit of the Animas-La Plata Project, a pumped storage system being built by the U. S. Bureau of Reclamation.

Project Description

The pumped-storage project is currently under construction in southwestern Colorado near the town of Durango. A reservoir behind Ridges Basin Dam will provide off-stream storage. Water from the Animas River will be pumped to an outlet structure through an inlet conduit at a flow rate of 280 cubic feet per second. From the outlet structure the water flows downhill to the reservoir. The 72-inch diameter welded steel inlet conduit is 2.1-miles long.

Where the inlet conduit crosses Bodo Ridge, hydraulic considerations meant the centerline of the 72-inch carrier pipe had to be about 43 feet below the highest ground surface. The depth was determined by comparing the cost of earthwork to the annual cost of pumping extra elevation. Cut-and-cover was less expensive than tunneling.

In 2002, three high-pressure gas lines had to be relocated before construction of the dam could begin. The new gas lines would cross the inlet conduit at Bodo Ridge. Because the new gas lines were required to be relocated prior to the inlet conduit being constructed, an 84-inch casing pipe was installed so the inlet conduit could be threaded through at later date, which turned out to be in 2007. With a cover height of about 40 feet, the least expensive option for the casing pipe was CMP. After the casing pipe was constructed, the ends were capped off and the trench backfilled over the ends of the casing. The casing pipe had to be 650 ft long so that the excavation to subsequently expose the ends of the casing would not affect the gas lines.

The pumping characteristics for the pumping units at the pumping plant were based on a weir wall at the end of the 72-inch inlet conduit. The end of the 72-inch pipe needed to be higher than the last pipe bend so an additional air valve would not be required. The slope of the pipe needed to be as close to the minimum as possible to minimize the pumping head. The design slope was 0.00063, slightly higher than the Reclamation minimum of 0.0004.

The typical trench cross-section is shown in Figure 1. The upper portion of the excavation had side slopes of 1:1 down through slope wash and weathered bedrock. Once competent bedrock was reached, a five-foot bench was constructed, and below this level the trench had to be excavated by blasting. The slopes of this portion of the trench were $\frac{1}{4}$:1. Because of raveling of the rock walls, wire mesh was draped down the slopes to protect the workers (see Figure 2). At about 18-inches above the elevation of the top of the pipe, another five-foot wide bench was constructed with a side slope of $\frac{1}{4}$:1 down to an elevation about four-inches below the bottom of the pipe. The bottom of the trench was to be 10-feet wide. The trench width at springline of the pipe would then be 12 feet, resulting in about 2.5-feet of clearance between the pipe and the trench walls. Of course, the blasting resulted in dimensions only approximating the design values.

The pipeline invert slope was critical but the grade, alignment, and circularity were also important because of the limited space inside the casing pipe to thread the steel pipeline. The Reclamation standard laying tolerance of 1/8-inch per foot of pipe, the manufacturing tolerances of the pipe diameter, the banding of the CMP joints, and the anticipated CMP deflection, had to be considered.

Flowable fill was specified to be the embedment material for the 84-inch CMP casing pipe to avoid the longer time required to compact soil in 6-inch lifts beside the pipe and to perform quality assurance density testing. Also, the E' (modulus of soil reaction) of the flowable fill would be higher than compacted soil embedment; thus the pipe deflection would be less.

Pipe Design

The casing pipe is an 84-inch diameter, 16 gage, galvanized steel CMP with 3x1 helical corrugations, meeting the requirements of ASTM A 760-01, Type 1. The pipe sections were joined with coupling bands. The carrier pipe is a 72-in welded steel pipe with mortar lining and flexible coating. The outside diameter would be about 74 inches. Assuming a need for a nominal five inches clearance around the casing pipe, an 84-in diameter CMP was selected. The pipe diameters were first measured before the CMP was laid in the trench. The ASTM standard allow for plus/minus 1% variation in diameter from the nominal diameter. The average pipe diameter was about $\frac{1}{4}$ to $\frac{1}{2}$ -inch less than 84-inches and about half the pipe measured 83-inches on the end. If a section of pipe was oblong with a significantly larger

diameter, the pipe was marked so the pipe could be installed with the larger diameter in the vertical direction.

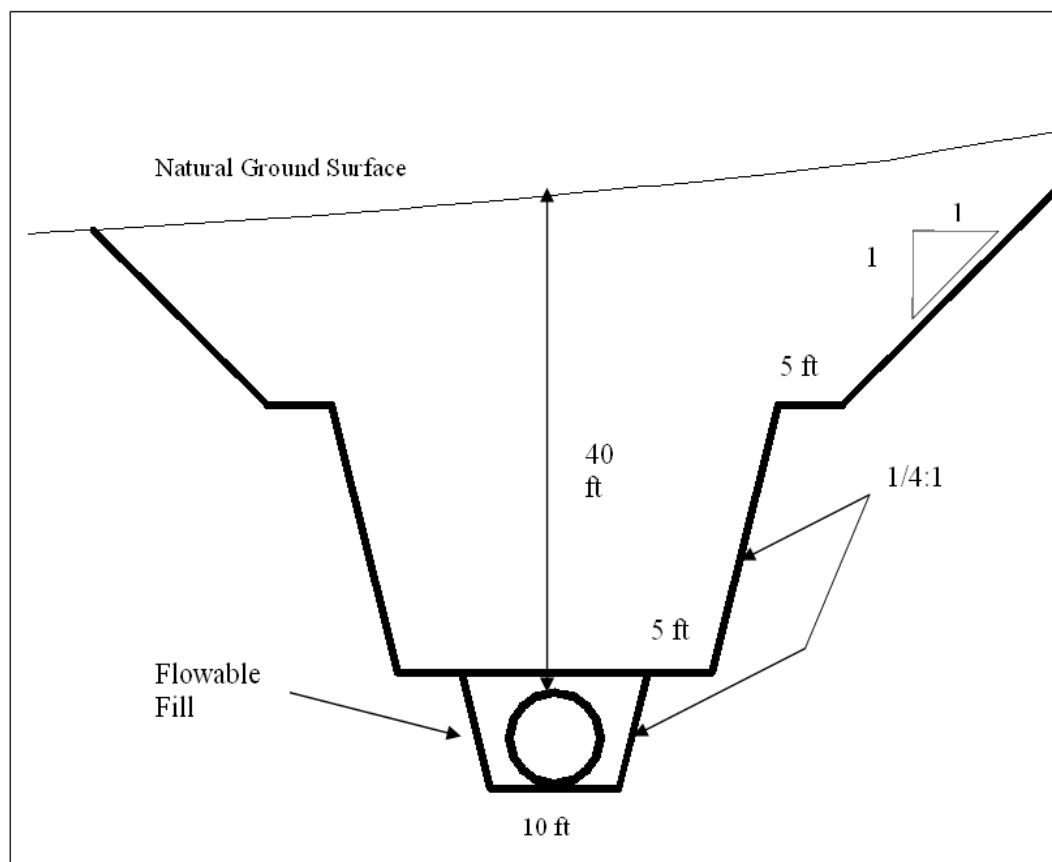


Figure 1 Trench Cross-Section

Using the Reclamation Equation (Howard 1996), the estimated pipe deflection was about 1% based on a composite E' (Modulus of Soil Reaction) of 6000 lb/in³ (Howard 1996). To calculate the composite E' , the E' of the flowable fill was assumed to be 3000 lb/in³ and the E' of the trench walls was assumed to be 10000 lb/in³.

Flowable Fill Mix Design

The gradation for the aggregate for the flowable fill was specified as follows:

1. Maximum 20 percent fines (passing the No. 200 US Standard sieve)
2. Maximum 50 percent passing the No. 100 US Standard sieve
3. Maximum particle size not to exceed 3/8-inch

The actual average aggregate gradation was 4% gravel (100% passing the 1-1/2-in sieve), 83% sand, and 13% silty fines. The soil was classified as Silty Sand (SM).

The cement was specified as ASTM C150, Type II, the mix water as conforming to ASTM C94, and any pozzolans were to meet ASTM C 618. The mix was to have a maximum water-cement ratio of 3.5:1 (by weight). The compressive strength was specified as 100 psi minimum at 7 days, in accordance with a Reclamation standard that is the equivalent of ASTM 4832. The mix was to be such that all the aggregate would remain in suspension with no segregation during placement. Additionally, the slurry was to be uniform in composition and consistency throughout each batch.

The flowability was described to be “flows easily in openings.”

Flowable Fill Installation

Because of the ragged rock foundation, clean, washed gravel was placed on the trench bottom to provide a level surface. The gravel also served as a drain and water was pumped out using a sump pump. As shown in Figure 2, a three-foot wide, four-inch thick, concrete strip was placed in the center of the trench to ensure the casing would be at the proper grade. “Threading the needle,” inserting a 74-inch OD pipe through an 84-inch casing, meant tight control on the grade and alignment of the casing pipe.



**Figure 2 Concrete Strip Foundation for Pipe
(note wire mesh protection on trench walls)**

The pipe was then laid on two 4x4 wooden blocks, about three feet from each end of the pipe, on the concrete strip. The specifications had called for two soil pads, or other compressive material, at each end of each pipe. The contractor elected to use the wooden blocks to speed up the installation and to assure the tight grade control. Accordingly, the contractor increased the flowable fill strength for the first lift.

The flowable fill was then placed around and over the pipe. The first lift was placed so the top of the lift was 3-in above the bottom of the pipe to prevent flotation. The pipe was so light (87 lbs/linear foot) that 4-in of flowable fill would have floated the pipe. For the calculation, a wet density of 130 lbs/ft³ was assumed for the flowable fill. This lift was allowed to set up before the remainder of the flowable fill was placed. For additional protection against flotation, the contractor elected to cast metal straps into the concrete strip and these straps wrapped around the outer circumference of the pipe. The contractor also bolted the pipe to the concrete strip to further help protect against flotation and to also

maintain alignment. The flowable fill placement, the straps, and the wooden blocks can be seen in Figure 3.

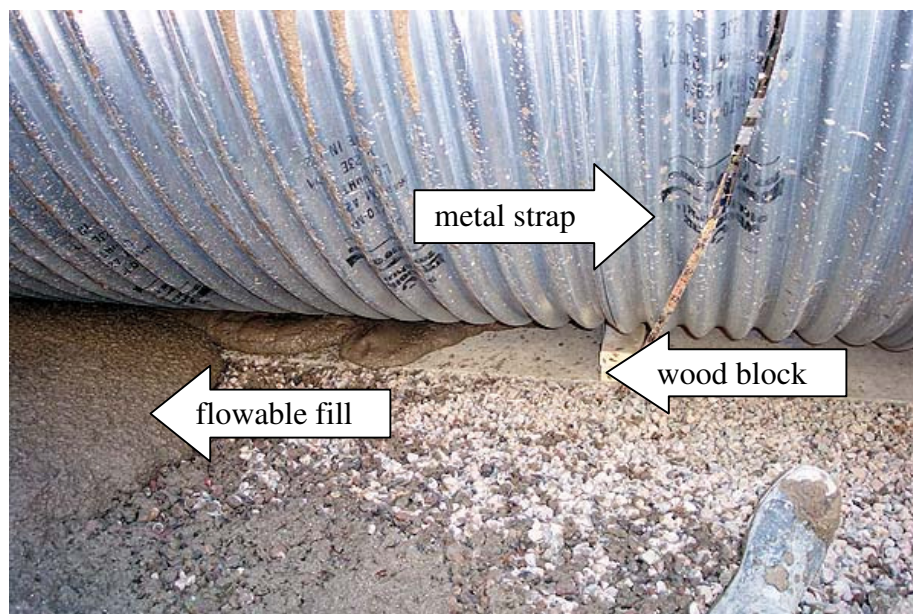


Figure 3 Straps, wooden blocks, flowable fill placement

The remaining flowable fill was placed in lifts of 6, 9, 14, and 10.5-inches to the springline of the pipe. The remaining lifts were 10.5-inches thick to the top of the pipe.

The flowable fill was then slightly mounded over the top of the pipe so there was about 18-inches of flowable fill over the pipe. This mounding over the pipe was to provide protection for the pipe from the heavy equipment that was to be used to spread and compact the remaining backfill. At the ends of the casing pipe, wooden barriers were constructed across the entire trench width to serve as an end form for the flowable fill. When the wooden forms were removed, the lifts were visually apparent as shown in Figure 4. After one week, soil backfill began being placed over the pipe. The first lift was 18-inches thick and uncompacted. Subsequently, the remaining backfill was compacted to 100% Proctor standard density (95% was required) for the length of the casing in the right-of-way for the gas lines, about 465-feet. The backfill was a Lean Clay (CL) native material compacted to six inch lifts using a sheeps-foot roller. The backfill outside of the right-of-way was uncompacted.



Figure 4 End view showing Flowable Fill Lifts

The flowable fill was mixed at a local concrete batch plant and transported to the site using ready mix trucks.

The flowable fill for the first lift was designed for a compressive strength of 1000 psi at 7 days to assure that the wooden blocks would not be hard spots under the pipe. The remainder of the flowable fill was designed for a compressive strength of 100 psi at 7 days. The compressive strength test results indicated an average 7-day strength of 1220 psi (2 tests) for the first lift and an average of 167 psi (14 tests) for the remaining lifts, with a range of 122 to 209 psi.

Pipe Diameter Measurements

The pipe diameter measurements are the inside diameter of the pipe, measured on the peaks of the corrugations. In 2002, the pipe diameter measurements were made by a survey crew to 0.01 foot. In 2007, the diameter measurements were made to the closest 1/16-inch using a pipe diameter measuring device. Diameters were measured approximately at the same stationing. A coating of silt prevented the exact locations from being found in 2007. Some 2007 readings had to be moved because of the depth of water in the invert. Vertical diameters were established by visually noting the middle point of water in the corrugation valleys, and then using a plumb bob to establish the crown of the pipe. The vertical diameter was divided in half, a laser beam set at that height, a mark made on a peak on one side and the pipe measuring device swung along the laser line on the other side until the shortest diameter was indicated and then recorded. In 2007, when the pipe diameter measuring device showed a significant variation from 84-inches, the readings were checked with a tape measure. Additionally, some diagonal diameters were measured to see if there was any squaring of the pipe.

Because the exact same locations were not measured, the 2002 and 2007 readings cannot be precisely compared to calculate deflection, only general comments can be made.

Results

The measurement results are summarized in Table 1. The 2002 and the 2007 readings show that the pipe is basically circular. Deflection due to backfill loading is negligible. The variation from the nominal 84-inches and the variation between horizontal and vertical were about the same in 2007 and 2002.

Table 1

Comparison of 2002 and 2007 Diameter Readings
Diameter Measurements in Feet and Percent Diameter Change
(reduction in diameter from nominal diameter is negative value)

	<u>2002</u>		<u>2007</u>	
Number of Readings	68		11	
	<u>Ft.</u>	<u>%</u>	<u>Ft.</u>	<u>%</u>
	<u>Note 1</u>	<u>Note 2</u>	<u>Note 1</u>	<u>Note 2</u>
Average Vertical Diameter	7.01	0.15	6.99	-0.15
Average Horizontal Diameter	6.99	-0.15	6.99	-0.15
Maximum Vertical Diameter	7.20	2.86	7.11	1.57
Minimum Vertical Diameter	6.87	-1.86	6.88	-1.71
Maximum Horizontal Diameter	7.18	2.57	7.08	1.14
Minimum Horizontal Diameter	6.79	-3.00	6.85	-2.14
<i>Minimum Allowable</i>	<i>6.66</i>	<i>-5</i>	<i>6.66</i>	<i>-5</i>

Note 1 – Diameter in feet

Note 2 – Reduction of pipe diameter from nominal diameter, expressed as percent of nominal diameter

Pipe Diameter Measurement

Table 1 gives the results in feet and in terms of percent pipe diameter reduction. The main concern about the casing pipe was having enough space in the pipe so the carrier pipe could be easily threaded through the casing pipe. The intent was to have a minimum three-inch annular opening around the 74-inch OD carrier pipe to have enough space to maneuver the carrier pipe, and that any deviations in line and grade would not hamper the threading operation. Thus, the inside diameter of the CMP could not be less than 80 inches, or a 4-inch reduction in diameter which is 5% of the nominal diameter of 84 inches. The percent pipe diameter reductions shown in Table 1 are negative for diameters less than 84 inches and positive for diameters larger than 84 inches.

After the pipe was placed in the trench and the flowable fill placed to 18-inches above the pipe, the average vertical diameter was 0.15% larger than the nominal diameter and the average horizontal diameter was 0.15% smaller than the nominal diameter. However, the largest individual measured pipe vertical diameter reduction was 1.9% and the largest individual measured pipe vertical diameter increase was 2.9%. The largest individual measured pipe horizontal diameter reduction was 3% and the largest individual measured pipe horizontal diameter increase was 2.6%. Thus, the largest measured reduction in diameter was 3%; the maximum allowable was 5%.

After installation with the flowable fill, and before backfill had been placed, the maximum pipe diameter variation was plus/minus 3% from the nominal diameter.

In 2007, the average vertical diameter was 0.15% smaller than the nominal diameter (a decrease in diameter of 0.3 percentage points from 2002) and the average horizontal diameter was 0.15% smaller than the nominal diameter (no change since 2002). The variation in individual diameter measurements was the same or less than the 2002 readings. However, the exact same locations for the maximum variations were not measured.

Deflection Due to Load and Time

To determine the pipe deflection due to load, the initial pipe diameter is the diameter measured in 2002 before any backfill is placed over the pipe and the final pipe diameter is the pipe diameter measured in 2007. The difference in the two values divided by the nominal diameter, expressed as a percent, is the pipe deflection due to load. The average vertical diameter decreased 0.3% over a 4.5-year period. During the same time period, there was no change in the average horizontal diameter. Considering that the diameters were not measured at the exact same location, measured by different personnel, and measured by different methods, the deflection should be considered insignificant. The 2007 measurements are considered to be representative because the values measured for maximum and minimum vertical and horizontal diameters were similar. The 2007 measurements at close proximity to the 2002 measurements were also very similar. As illustrated in Figure 5, the pipe is basically circular.



Figure 5 **Paint on Corrugation Illustrating Circular Pipe**

For similar installations, an E' (Modulus of Soil Reaction) value of 25,000 lbs/in² for the flowable fill would be a reasonable assumption. Using this value in the Reclamation Equation for estimating flexible pipe deflection would result in about 0.3% deflection (Time Lag Factor is assumed to be 1.0). (Howard 1996)

Despite the close attention to assuring the proper grade, intermittent puddles up to two inches deep remained in the pipe after it had been pumped out.

For this project, the inherent variation in pipe diameter from manufacturing and the diameter variations caused during installation far overshadowed any diameter reduction due to backfill load and time. Use of flowable fill for embedment material provided excellent support for the pipe.

Carrier Pipe Installation

Each 25-foot section of the bell-and-spigot 72-inch carrier pipe was carted into the casing and welded to the previous section. Plastic blocks were inserted between the carrier pipe and the casing to cathodically isolate the carrier pipe from the casing. The annular space between the two pipe was grouted, in lifts, through ports built into the carrier pipe.

Summary and Conclusions

An 84-in corrugated metal pipe (CMP) casing pipe was installed using flowable fill embedment with 40-feet of cover over the pipe. Pipe diameter measurements were taken before backfilling and then 4.5 years after installation.

Deflection Due to Load and Time

1. The average vertical diameter decreased 0.3 %. There was no change in the average horizontal diameter.
2. Considering that the diameters were not measured at the exact same location, measured by different personnel, and measured by different methods, the deflection should be considered insignificant.
3. The 2007 measurements are considered to be representative because the values measured for maximum and minimum vertical and horizontal diameters were similar. Measurements at close proximity to the 2002 measurements were also very similar.
4. For similar installations, an E' (Modulus of Soil Reaction) value of 25,000 lbs/in² would be a reasonable assumption.

Pipe Diameter Measurements

5. In order to be able to thread the carrier pipe through the CMP casing pipe, a reduction in the pipe diameter of 5% was the maximum allowable. The largest measured pipe diameter reduction was 3%.
6. After installation with the flowable fill, and before backfill had been placed, the maximum pipe diameter variation was plus/minus 3% from the nominal diameter.

For this project, the inherent variation in pipe diameter from manufacturing and the diameter variations caused during installation far overshadowed any diameter reduction due to backfill load and time. Use of flowable fill for embedment material provided excellent support for the pipe.

Acknowledgements

Thanks to Rick Ehat, Project Construction Engineer, and Alan Gates, Field Engineer, and the staff at the Ridges Basin Construction Office in Durango CO.

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