Technical Report

Technical Report 4.104

Re: The Structural Performance of Buried 48 inch Diameter N-12® HC Polyethylene Pipes

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Introduction

Manufacturing techniques make it possible to provide smooth inner and outer wall for profile-wall pipes. See Figure 1 for the profile of a typical wall cross-section of ADS N-12 HC polyethylene pipe. This particular (Honeycomb Wall) profile design is based on research performed for ADS by Dr. Les Gabriel of California State University - Sacramento.

Plastic pipes are attractive because of their resistance to corrosion and abrasion. Profile-wall polyethylene pipes have been used successfully as buried culverts. The profile-wall (essentially internal ribs) adds ring stiffness to the pipe to maintain the cross-sectional shape during installation and to support the soil overburden. The inner and outer walls also increase longitudinal stiffness of the pipe. The plastic inner wall has a very low frictional resistance for improved flow characteristics. Polyethylene relaxes with time if the ring configuration is held constant. In good backfill, the soil holds the pipe in a constant cross section, at a given height of cover; so pipe stresses relax and the soil takes its share of the vertical load. The statically-indeterminate soil-structure interaction is mutually beneficial. The pipe serves as a form for the soil arch and the soil supports and protects the pipe against vertical loads by arching action of the soil. The profile-wall increases the ability of the pipe to perform under high earth loads. However, a dimpling effect in the wall can take place at excessive depths of cover.

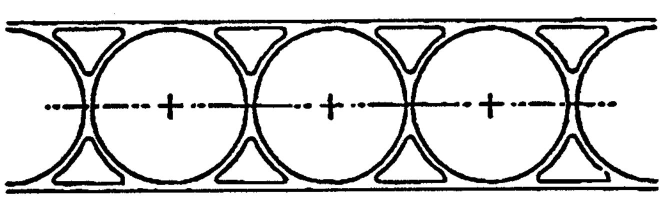
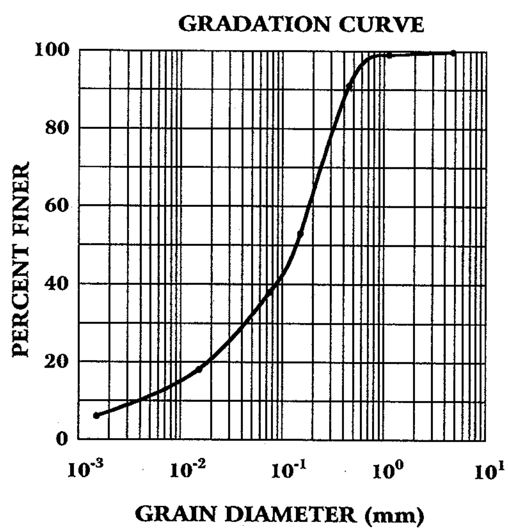


Figure 1. Profile of typical wall cross-section of ADS N-12 HC polyethylene pipe.

Procedure

High density profile-wall (Honeycomb Wall Design) polyethylene pipes of 48 inch ID were tested at Utah State University to provide information on structural performance. The primary objective of the tests was to determine structural performance characteristics as a function of depth of cover. The observed parameters (dependent variables) were ring deflection, any visual evidence of distress, and structural performance limits. The independent variables were soil type, soil density (compaction), and the vertical soil load simulating height of soil cover.

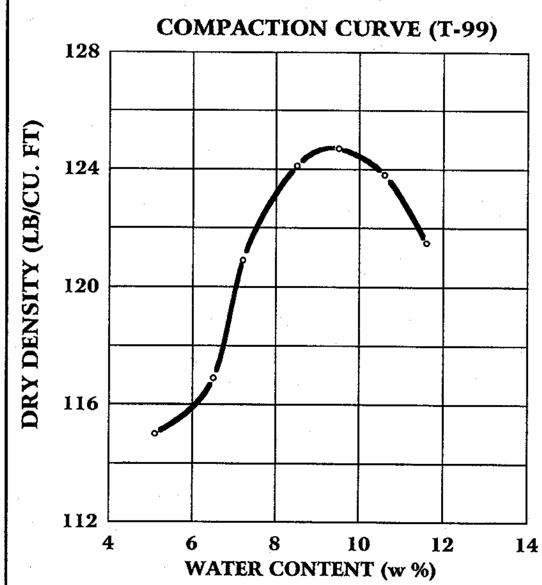
The basic soil type was silty sand and is designated as a Class III soil by ASTM D2321. This soil is classified as SM according to the Unified Soil Classification System. SM soil is used because it is common; it is of lesser quality than most soils specified as backfill (and so is a worst case test); and it can be compacted over a wide range of soil densities. See Figure 2 and Figure 3 for soil gradation and Proctor data.



Atterberg Limits
Liquid Limit - NA
Plastic Limit - NA
Plastic Index - NA

Soil Classification:
SM
Specific Gravity: 2.72

Figure 2. Gradation Curve and Classification for Silty Sand Soil.



Maximum Dry Density - 124.7 lb./cu. ft.
Optimum Moisture - 9.5 Percent

Figure 3. Standard Proctor Curve for Silty Sand Soil.

During August 1994, tests were performed on profile-wall polyethylene pipes. These tests permitted an investigation of the performance limits of the pipes subjected to external soil pressures. Tests were performed in the USU large soil cell into which the sample pipe is buried and onto which a vertical soil load is applied by means of 50 hydraulic cylinders (See Figure 4). Details are as follows:

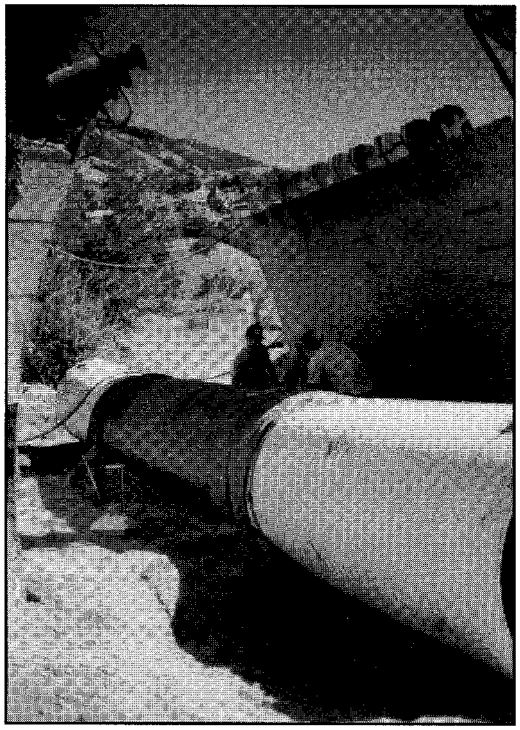


Figure 4. Test pipe (black) being placed, along with two white access pipes, in large pipe test cell at Utah State University.

Test Number 1

Pipe: 48" dia. N-12 HC Polyethylene
Embedment soil: Silty Sand
Compaction: 75% Standard Proctor

Test Number 2

Pipe: 48" dia. N-12 HC Polyethylene
Embedment soil: Silty Sand
Compaction: 85% Standard Proctor

Test Number 3

Pipe: 48" dia. N-12 HC Polyethylene
Embedment soil: Silty Sand
Compaction: 96.5% Standard Proctor

Figure 4 shows the test pipe (black pipe) being placed in the large soil test cell. The white pipes in the figure are not being tested but are used to provide access to the pipe being tested. Figure 5 is a photo of the loading rams used to apply the vertical load simulating a soil embankment. Figure 6 and Figure 7 show the embedment soil being compacted to the required density. Figure 8 shows part of the process used to fill the test cell and Figure 9 shows the compaction process as the test cell is almost full. Figure 10 is a photograph of the loading beams being lowered into place. Figure 11 shows the test cell full with vertical load being applied.

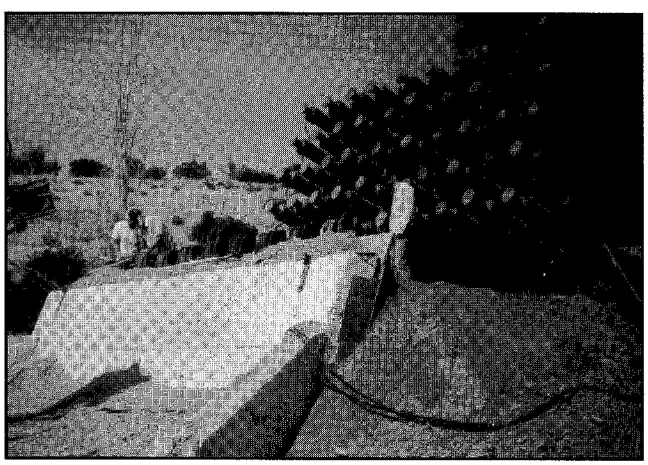


Figure 5. Photograph showing loading rams (total of 50).

Figure 6. Soil being compacted around the pipe to be tested.

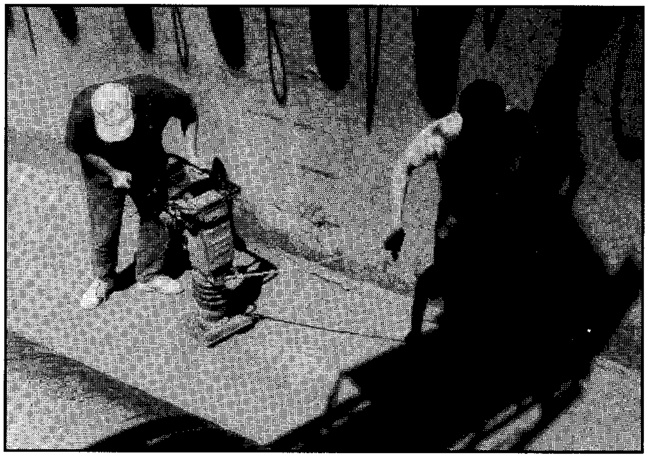


Figure 7. Soil being compacted around the pipe to be tested.

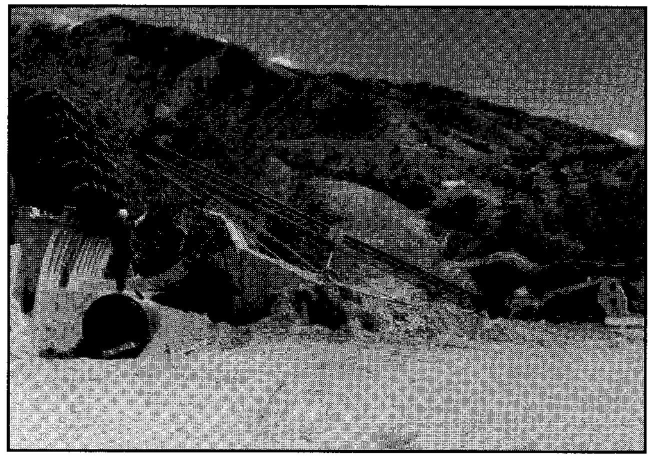


Figure 8. Process used to fill the test cell.

Figure 9. Soil being compacted as test cell filling is near completion.

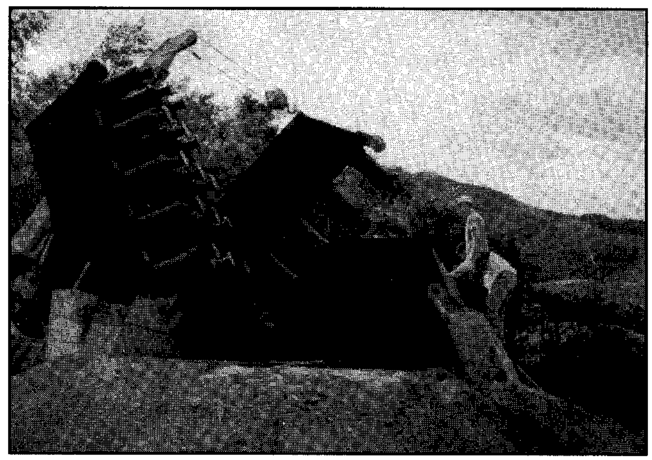


Figure 10. Lowering loading beams into place.

Figure 11. Loading beams down and locked — testing in progress.

Results

Test Number 1 — 75 Percent Compaction — Silty Sand

The pipe was placed in soil compacted to 75 percent of Standard Proctor Density, and the vertical soil load was increased to 4,800 lbs./ft^2 (40 feet of cover based on a soil weight of 120 lbs./ft^3). At 28 feet of cover and about 10 percent vertical deflection a dimpling pattern on the inside wall became noticeable to the eye. This pattern, which is the beginning of localized buckling, started at about the 3 o'clock and 9 o'clock positions. The center distance between dimples was about the same as the internal rib spacing. This pattern was somewhat like a wavy checker-board in appearance and of course just the beginning of localized instability of the inner wall. However, this dimpling was small and would in no way impair the structural performance of the pipe.

As the soil load increased these dimples became slightly more pronounced but did not cause a performance limit. At 34 feet of cover, a hinge-line in the wall began to form at the 3 and 9 o'clock positions. This hinge-line (crease) is due to high compression stresses produced by a combination of ring compression, ring bending, and localized buckling. As the load was increased from 34 feet of cover, this hinge became more pronounced. Buckling of a pipe in soil is not like classical buckling. In classical buckling, once the critical load is reached catastrophic failure is imminent. **However, in a buried pipe it takes another increment of load to produce another increment in the buckling phenomenon.** Loading was terminated at 40 feet of cover. Data for this test are given in Figure 12.

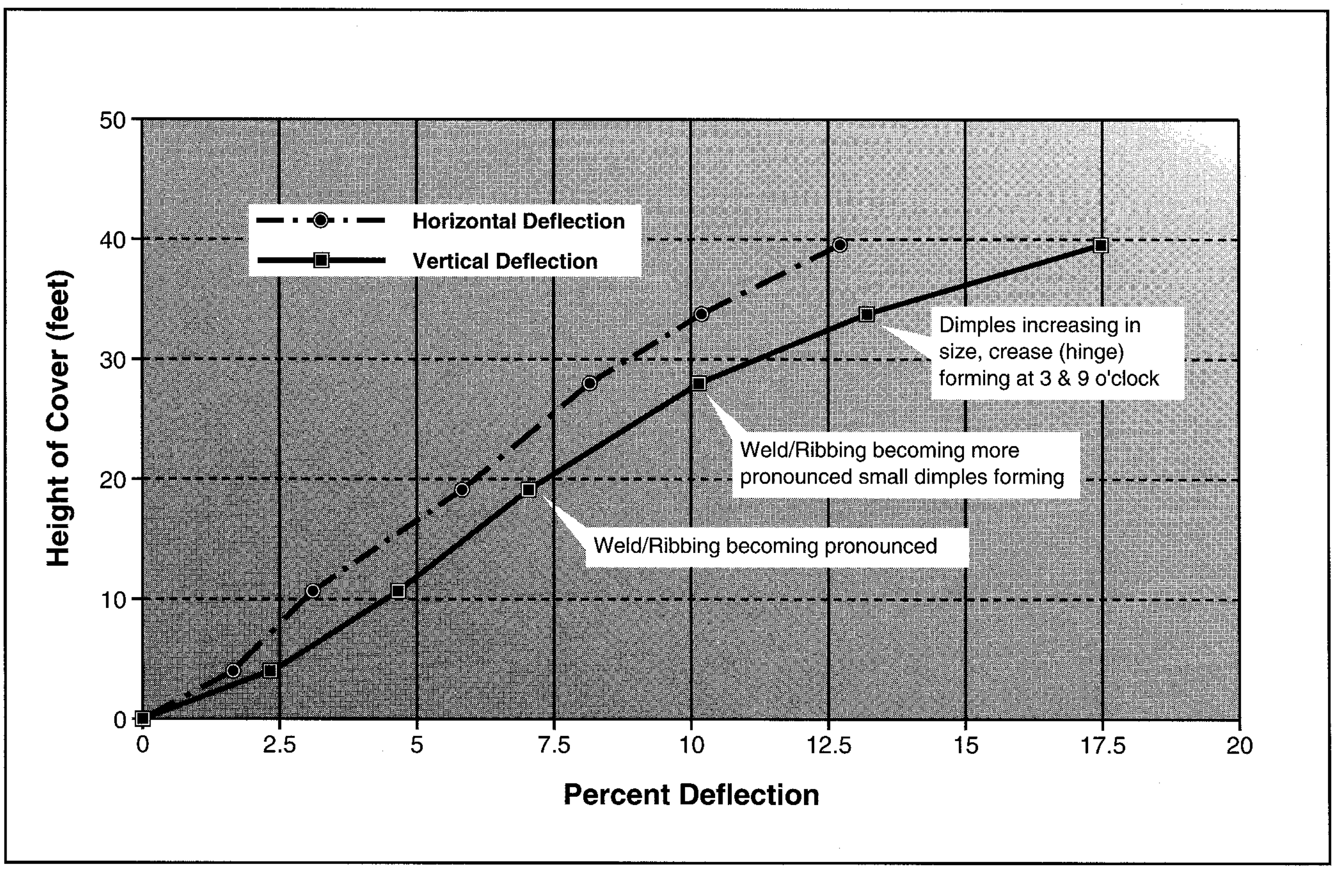


Figure 12. ADS Test Number 1 — 48-inch diameter pipe tested in silty sand soil compacted to 75 percent Standard Proctor Density.

Test Number 2 — 85 Percent Compaction — Silty Sand

In test number 2, the pipe was installed in soil compacted to 85 percent of Standard Proctor Density and was loaded to a vertical soil load of 7,820 lbs./ft^2 which is equivalent to 65.2 feet of cover. At about 19 feet of cover and about 3 percent vertical deflection the weld/ribbing began to become pronounced (more visible). At about 29 feet of cover and about 5 percent deflection small dimples began forming near the 3 and 9 o'clock positions. Again, this dimpling was extremely small and would in no way impair the structural performance of the pipe.

As the soil load was increased these dimples became more pronounced and were concentrated in the 3 and 9 o'clock positions but did not cause a performance limit. At 60 feet of cover a hinge (crease) began to form in the wall at the 9 o'clock position (west side). As the load was increased from 60 feet, the hinge became more pronounced. Loading was terminated at 65.2 feet of cover. Data for this test are given in Figure 13.

The term "general buckling" is used in this report to describe the formation of hinges at the 3 and 9 o'clock positions. These plastic hinges are primarily due to a combination of localized bucking and wall yielding caused by thrust in the wall of the pipe. A secondary cause of the hinges is ring deflection.

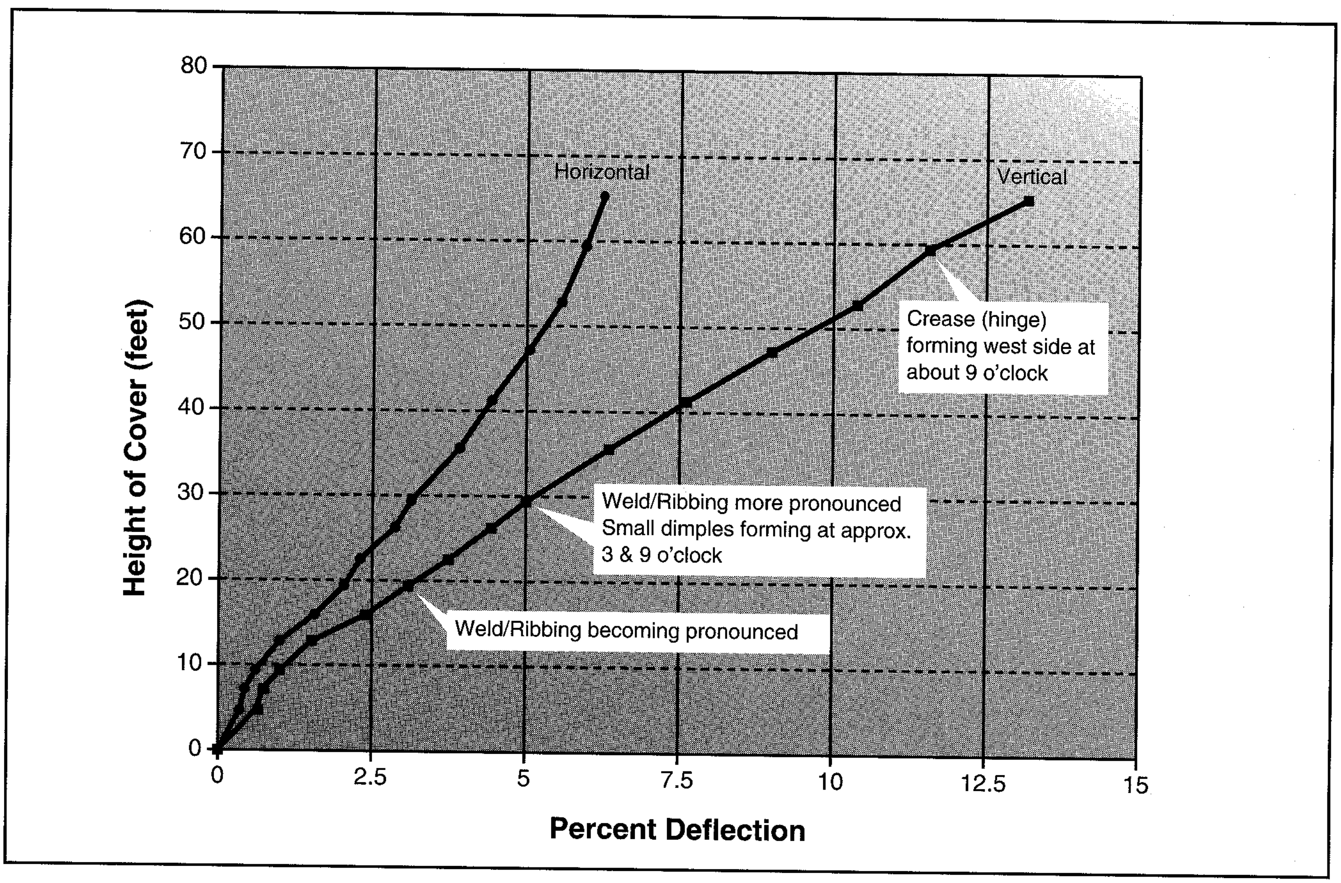


Figure 13. ADS Test Number 2 — 48-inch diameter pipe tested in silty sand soil at 85 percent Standard Proctor Density.

Test Number 3 — 96.5 Percent Compaction — Silty Sand

The pipe was placed in soil compacted to 96.5 percent of Standard Proctor Density, and the vertical soil load was increased to 21,600 lbs./ft^2 (180 feet of cover based on a soil weight of 120 lbs./ft^3). At 62 feet of cover and about 1.35 percent vertical deflection the weld/ribbing started to become pronounced visually. At 120 feet of cover a slight dimpling pattern began. This pattern started at about the 2 o'clock and 10 o'clock positions and then spread to the 3 o'clock and 9 o'clock positions. The center distance between dimples was about the same as the internal rib spacing. This pattern was somewhat like a wavy checker-board in appearance and of course just the beginning of localized instability. However, this dimpling was extremely small and, in my opinion, would in no way impair the structural performance of the pipe.

As the soil load increased these dimples became more pronounced and concentrated toward the 3 and 9 o'clock positions but did not cause a performance limit. At 169 feet of cover, this dimpling became much more pronounced. General localized buckling of the wall began at the 3 and 9 o'clock positions at 180 feet of cover. At this point the test was terminated. Data for this test is shown in Figure 14.

Figure 15 gives the vertical deflection curves for the pipes tested in three soil densities. This shows graphically the importance of soil density in controlling the pipe deflection. Figure 16 shows approximated vertical deflection curves for intermediate soil densities (dashed lines).

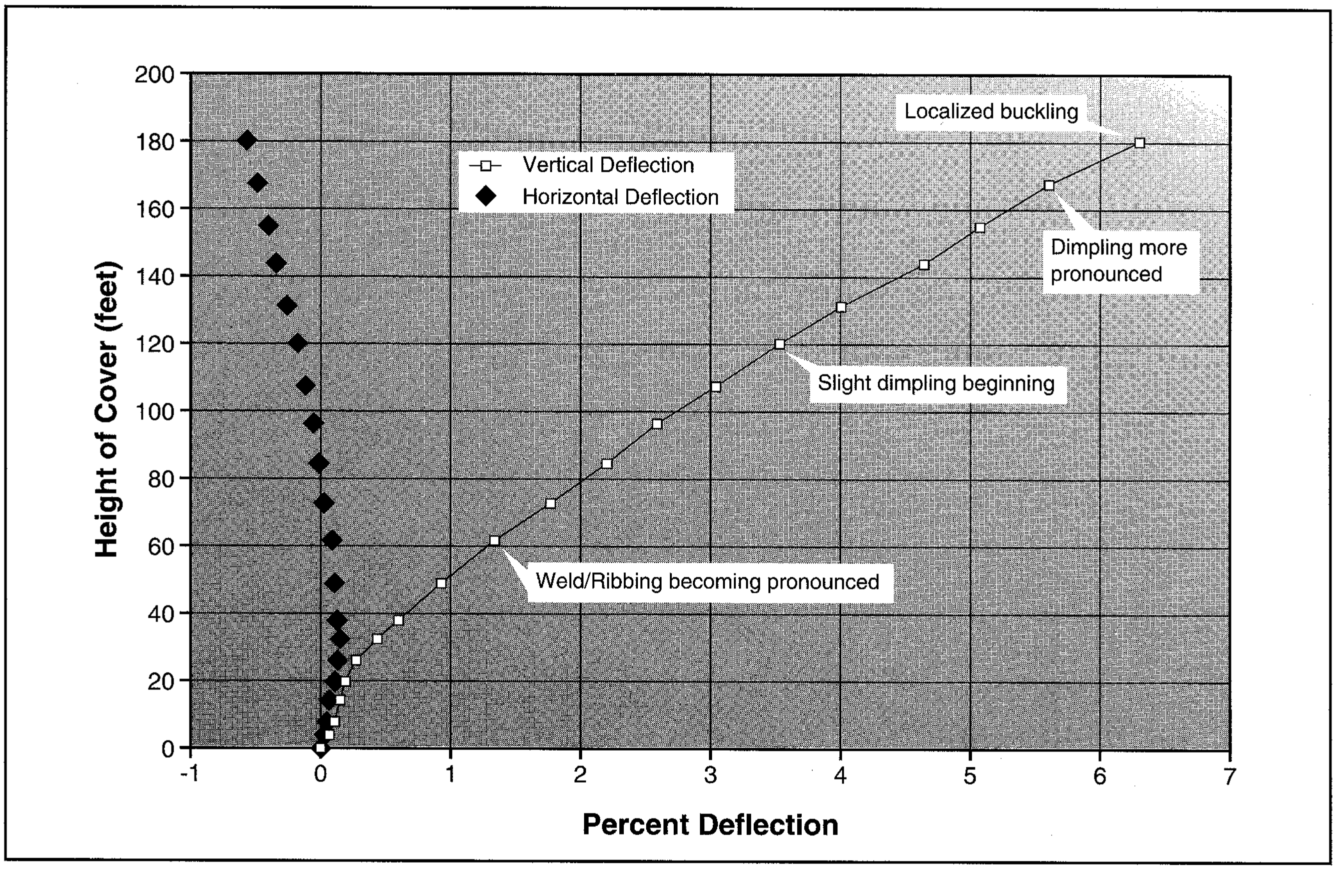


Figure 14. ADS Test Number 3 — Pipe tested in silty sand compacted to 96.5 percent Standard Proctor Density.

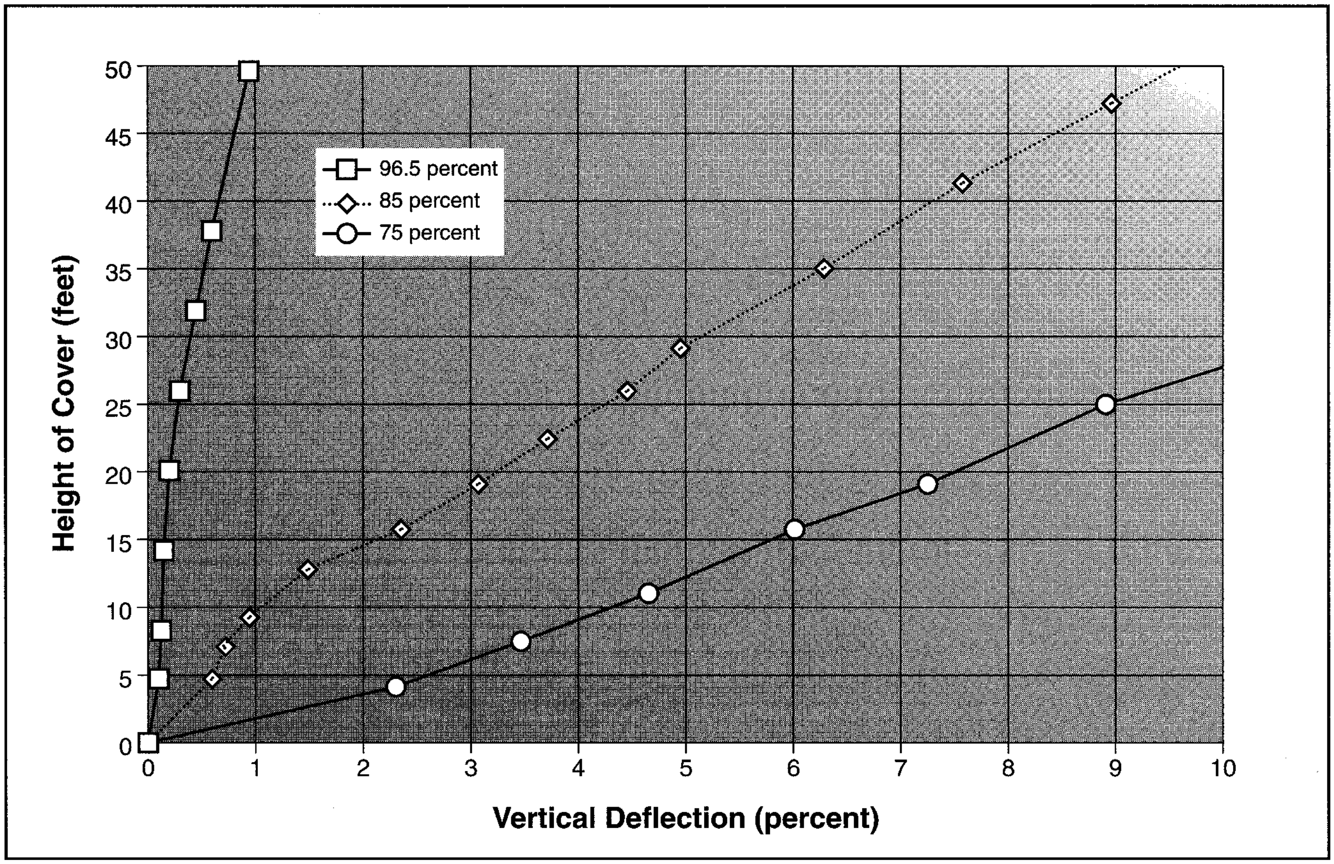


Figure 15. Vertical pipe deflections for the three soil densities tested.

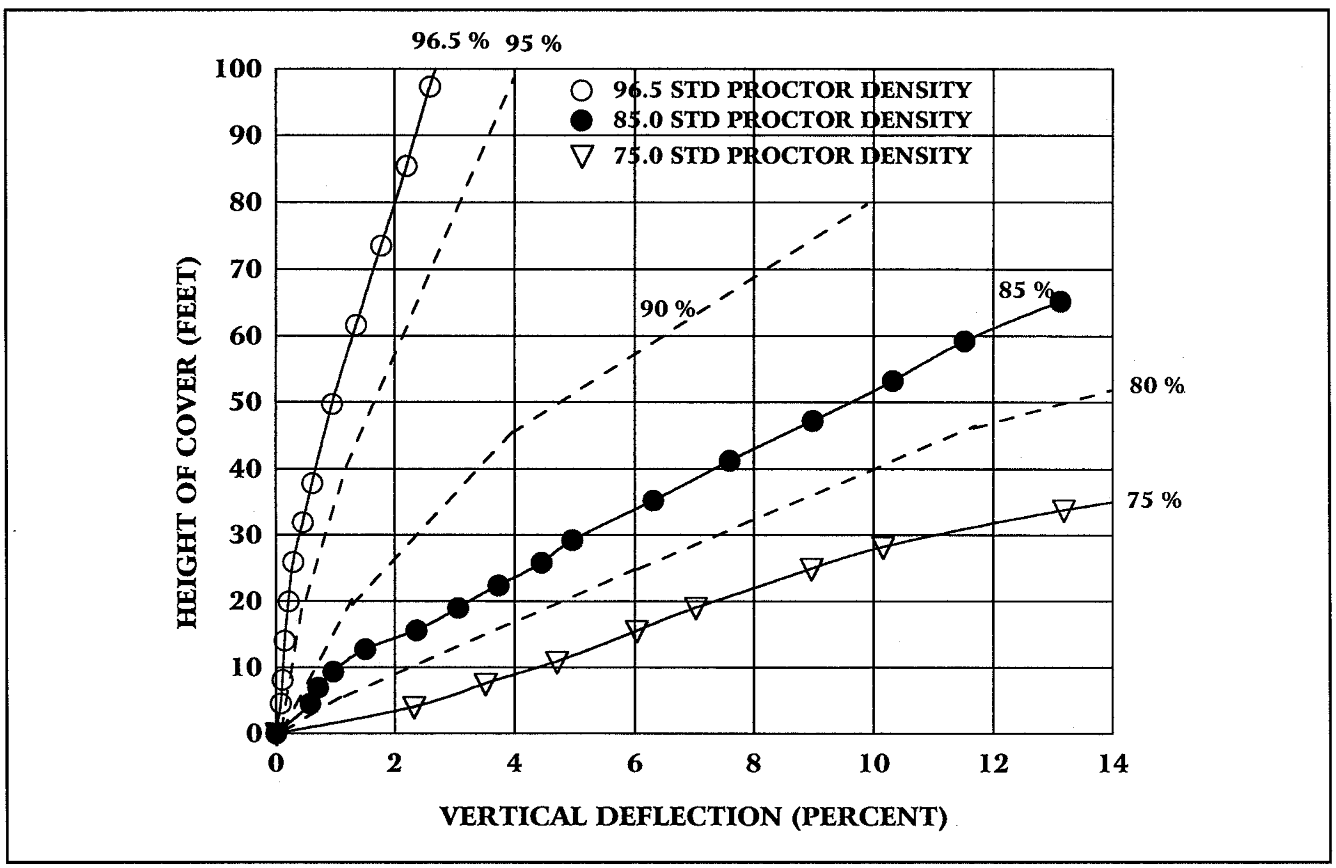


Figure 16. Vertical deflections for the pipes tested in the three soil densities. The dashed lines are approximated for intermediate densities.

Summary and Conclusions

Noteworthy is the high load that can be applied without distress to the pipe ring. Clearly the pipes deflect more in loose soil than in dense soil because loose soil compresses more. The pipes do not collapse, even in loose soil.

From a structural point of view, there are no reasons why high density polyethylene pipes cannot perform well. The soil should be granular and carefully compacted if the pipe is buried under high soil cover, or under heavy surface loads. Granular pipe-zone-backfill material at moderate to high densities assures that the pipes will perform well even at high earth covers. Incipient dimpling occurred at equivalent depths of cover in the range of 28 feet to 120 feet. This incipient dimpling load is a function of soil density. Dimpling is not a structural performance limit.

The load at which a formation of a hinge line (crease) takes place is a function of the soil density. For a relatively poor installation (75 percent Standard Proctor) the hinge line begins to form at about 34 feet of cover. For a good installation (85 percent Standard Proctor Density) the hinge line begins to form at about 60 feet of cover. For an excellent installation (96.5 percent Standard Proctor) the hinge line starts to form at about 180 feet of cover.

The deflections at which this performance limit occurs are 13 percent, 12 percent, and 5.5 percent for Proctor densities of 75 percent, 85 percent, and 96.5 percent respectively. If deflection is controlled to 5 percent this performance limit will not occur.

Proctor Density	Load at Performance Limit	Deflection at Performance Limit
75%	34 feet of cover	13 percent
85%	60 feet of cover	12 percent
96.5%	180 feet of cover	5.5 percent

The pipe cross-section started out circular and became elliptical as the height of cover increased. For the 75 percent dense soil this deviation from a circle to an elliptical shape was quite pronounced and for the 85 percent dense soil the deflected shape was elliptical but less pronounced. The shape of the pipe in the 96.5 percent dense soil remained closer to being circular even for extremely high heights of cover. None of the test pipes ever exhibited a so-called squaring or a square shape at any load. This result is just what one would expect. The ratio of ring-compression stress to bending stress, for the 75 percent dense soil, is very low (much less than one). For the 85 percent dense soil this ratio is low but may approach a value of one. The ratio of ring compression stress to bending stress, for the pipe tested in soil compacted to 96.5 percent of Standard Proctor Density, is much greater than unity.

For polyethylene which has a fairly low modulus, ring compression stresses cause circumferential ring shortening. This ring shortening is small for pipes installed with low heights of cover and in low to moderately compacted soils. For high density soils at high earth covers this circumferential ring shortening is very significant and is the primary deformation that takes place. This circumferential shortening is extremely beneficial in the performance of the pipe. The decrease in circumference relieves the pipe ring of some of the soil pressure and causes the surrounding granular pipe zone material to carry a higher percentage of the load. This works on exactly the same principle as the slotted bolt hole in corrugated metal pipe. The extremely high loads, that the pipe in test number three was able to withstand, in a very large measure was because of the substantial circumferential shortening that took place.

Comments on Young's Modulus for Polyethylene

Many erroneously believe that the modulus, for plastics like PVC and polyethylene, decreases with time, but that is just not so. It is a simple task to prove or disprove this contention. Take a sample of pipe that has been under load for a long period of time and run a test for modulus. This testing has been accomplished and is reported in the literature. PVC pipe that had been in service for 15 years was removed and tested for strength, modulus, etc. One section was even locked in its deflected shape; the deflected shape held and then the section was placed in a testing machine to ascertain the modulus. The modulus was determined to be the same as when the pipe was newly manufactured.

One may ask, where does the idea of a decreasing modulus come from? Again the answer is simple, it comes from the notion of a "creep modulus." The so-called "creep modulus" is the initial stress divided by the long-term strain. In a sense, it is fictitious because it is arrived at by dividing a long-term strain value into a short-term stress. The normal or **real modulus** is the instantaneous short-term strain divided into the instantaneous stress. I don't mean to imply that the creep modulus does not have application. I do mean to suggest that it is an invented term that has almost no application in design. This invented term has been misused by those who wish to describe the behavior of plastics with terms similar to those used to characterize steel and concrete — at the same time recognizing differences in behavior. If the so-called "creep modulus" is used to calculate pipe stiffness then it should also be used to calculate circumferential shortening. Again this augmented shortening is beneficial as it reduces the load on the pipe.

Most civil engineers have never had a course on the behavior of plastics. If they did, the instructor may have been another civil engineer who had never had a course but was self taught and passed on his or her misconceptions. Plastics are not new to engineers. Mechanical engineers have long understood plastics even before petroleum based plastics were in wide use. Steel, at elevated temperatures, is a plastic and must be designed on a life basis not a yield-stress or ultimate-stress basis.