PVC PIPE news

BACK TO BASICS

TIME DEPENDENT VARIABLES FOR FLEXIBLE SEWER PIPE

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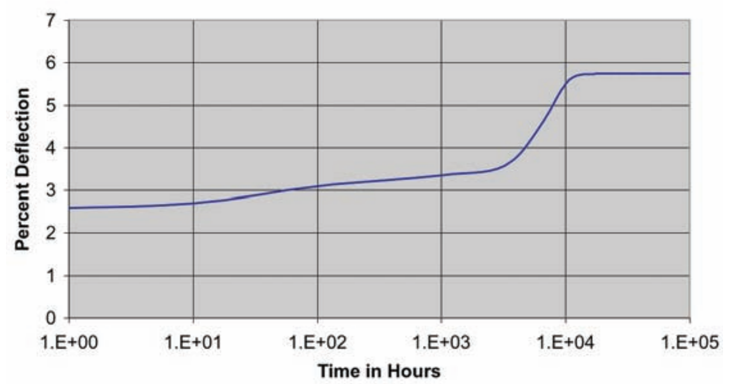
So, you have a 10-inch PVC pipe, and it is installed 22-feet deep in an embankment condition. A silty sand was the embedment material, and it was compacted to 83% standard Proctor density. The PVC pipe was your garden variety sewer pipe - SDR 35 with a 46 lb/in-in stiffness. The pipe's deflection response, measured over fifteen years, is shown in Figure 1. (The sidebar to the left, *A More Typical Deflection Response*, discusses this unusual increase in deflection 150 days after installation, as well as showing a more characteristic deflection response.)

Figure 1. Deflection Response with Time



In discussing Figure 1, the typical conversation covers the basics of the pipe/soil deflection mechanism. Equation 1 and Figure 2 capture the fundamental components of the theory reviewed.

A MORE TYPICAL DEFLECTION RESPONSE

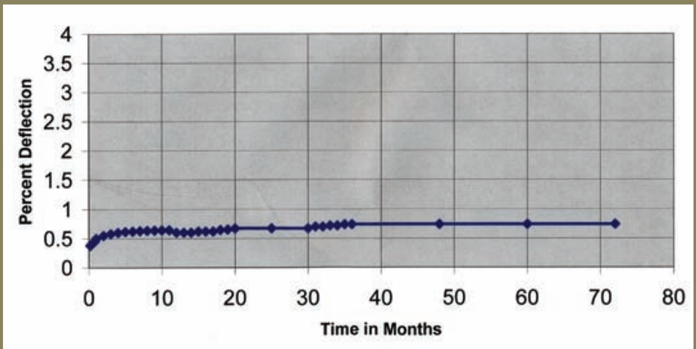
The interesting deflection response plotted in Figure 1 in the companion piece, *Back to Basics: Time Dependent Variables for Flexible Pipe*, may raise some additional questions in your mind. What caused the increase in deflection 150 days after the installation? (Since the x-axis is plotted in hours, the rise at 150 days is shown at 3.6 x 10^3 hours.)

The test pipe was installed in September, 1975. At that time, the pipe in the 22-foot deep embankment lay above the groundwater table. When the snow pack in Logan, Utah melted in the Spring, the groundwater table rose and saturated the embedment material in the pipe zone. For the silty sand common to the area, the critical density is about 92% of standard Proctor density. Thus, when the groundwater saturated the sand, it became more dense. The dead load on the pipe increased, and the deflection mechanism established a new equilibrium point. Deflections were measured over a 15-year period in the investigation, and subsequent groundwater table movements had no noticeable effect on the deflection readings.

A similar investigation began in October, 1989. The pipe was again placed in an embankment condition, to the same depth of 22-feet, and used the same type of wind-blown silty sand as the embedment material. In this investigation, the diameter was 18-inches, and the sand was compacted to 93% of standard Proctor density. When the embankment was placed, the groundwater level was below the pipe. The next two years were dry. During the snowmelt in the Spring of 1992, 30 months after the investigation began, the water table rose above the pipe zone. This time, however, because the embedment was compacted in excess of its critical density, there was little in the way of additional deflection response. Deflection measurements over the following 40 months were not influenced by the seasonal water table variations. The deflections measured during the study are plotted in Figure A.

Figure A is a more typical plot of a flexible pipe's deflection response with time. The placement of the backfill causes an initial deflection. With a good installation, the loads do not increase much with time, so there is little additional compaction in the haunch area as a result of the deflection mechanism. When that is the case, deflections increase only slightly with time.

Figure A. Deflection Response with Time
Compaction 93% Standard Proctor
22 Foot Embankment, 46 lb/in-in Stiffness

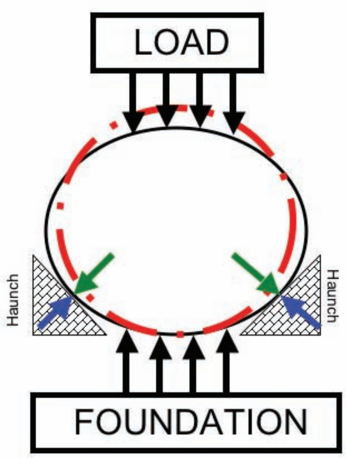


Equation 1

$$\text{Deflection} = \text{Constant}\left(\frac{\text{Load}}{\text{Pipe Stiffness} + \text{Soil Stiffness}}\right)$$

Figure 2

Basic Components of the Flexible Conduit Theory



Calculating the load that the pipe will ultimately experience from the weight of the soil above it is not difficult. The soil pressure at the crown of the pipe is given in Equation 2.

Equation 2

$$P = \gamma_w \cdot H$$

Where: γ_w = Unit Weight of Soil, lbs/ft^3

H = Height of Cover, ft

The silty sand has a unit weight of 120 lbs/ft^3 and the cover height is 22 feet. Thus, the soil pressure at the crown is 2640 lbs/ft^2 or 18.33 psi. The more challenging question is, "When will the soil pressure reach 18.33 psi?" If the sand was well compacted in lifts when burying the pipe, the dead load reaches its maximum relatively quickly. If the sand were poorly placed with no compactive effort, it will take much longer for the dead load to reach the ultimate load of 18.33 psi.

The fundamentals of the Flexible Conduit theory are provided in Figure 2. The load at the crown of the pipe causes the pipe's vertical diameter to compress and the horizontal diameter to expand. Before the load was applied, the pipe's cross section was circular, which is represented by the broken red line. After the application of the load and the reaction of the foundation, the pipe's cross section is elliptical, which is shown by the solid black line. The diagonal green arrows represent the pipe pushing out and down against the embedment material as it deforms from a circle into an ellipse. The blue arrows in the haunch represent the equal-and-opposite reaction there, as the haunch pushes back against the pipe while it experiences ring deflection. If the pipe were between two parallel plates, the stiffness of the pipe alone would be resisting the load. In a buried situation, the stiffness of the pipe and the stiffness of the soil work in tandem to resist the load, which is shown conceptually in Equation 1.

From here, the normal conversation goes on to quantify the various inputs: deflection lag factor, bedding constant, dead load, live load, pipe stiffness, and modulus of soil reaction. With those inputs, the long-term deflection is calculated using the Modified Iowa Formula (Equation 3). The calculated deflection is then compared to the allowable deflection of 7.5% for gravity sewer pipe. Uni-Bell's technical report, *UNI-TR-1, Deflection: The Pipe/Soil Mechanism*, is one of many resources that has all of this information in detail.

Equation 3

$$\%\frac{\Delta Y}{D} = \frac{(D_L KP + KW')(100)}{0.149\frac{F}{\Delta Y} + 0.061E'}$$

Where:

D_L	=	Deflection Lag Factor
K	=	Bedding Constant
P	=	Prism Load (soil pressure), lbs/in^2
W'	=	Live Load, lbs/in^2
$F/\Delta Y$	=	Pipe Stiffness, lbs/in-in
E'	=	Modulus of Soil Reaction, lbs/in^2

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Using UNI-TR-1 as a reference, one could calculate the long-term deflection (%DY/D) for the scenario described above. The inputs for the Modified Iowa Equation for this case are listed below.

Knowns:	D_L	=	1.0
	K	=	0.1
	P	=	18.33 lbs/in^2
	W'	=	0 lbs/in^2
	F/ΔY	=	46 lbs/in-in
	E'	=	400 lbs/in^2

Inputting these knowns into Equation 3 results in the following:

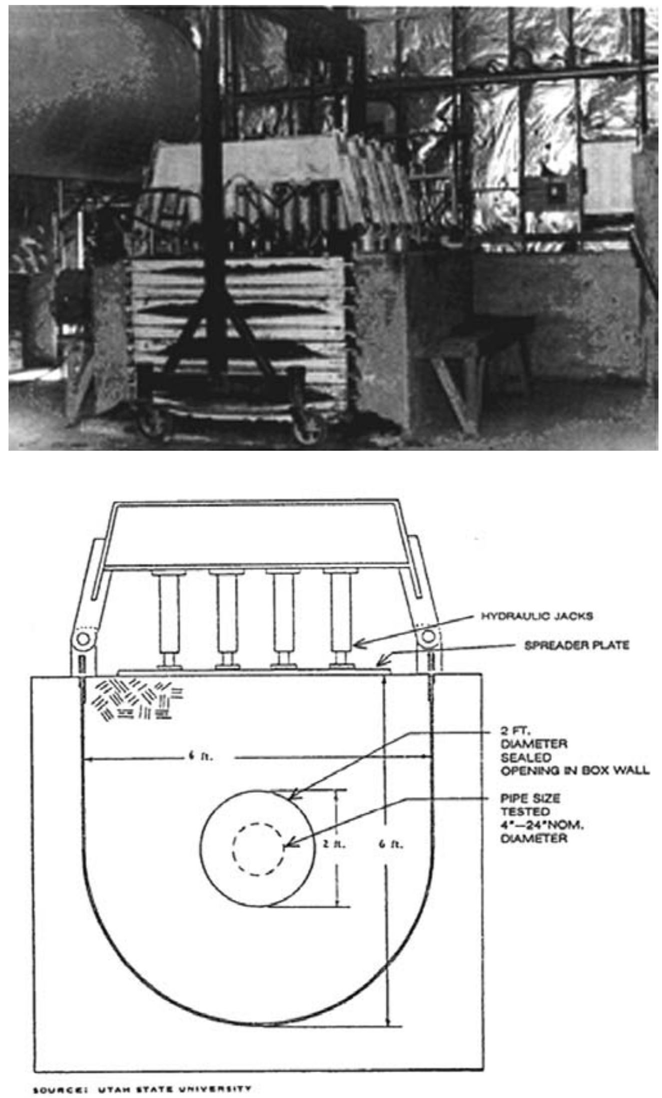
$$\frac{[(1.0)(0.1)(18.33)+(0.1)(0)](100)}{[(0.149)(46)+(0.061)(400)]} = 5.9\%$$

The typical conversation then covers the inputs in more detail, but the 5.9% calculated above is normally the final objective. Since that value is less than the allowable deflection of 7.5%, the design is considered acceptable. (Note that the deflection calculated closely matches the long-term deflections recorded in the field and shown in Figure 1.)

Occasionally the conversation takes a different turn. Intellectually, the Modified Iowa Formula is accepted, but the gut has nagging doubts because of a property called creep. The complexity inherent in buried structures does nothing to calm those doubts, either. Fortunately, academics have already wrestled with the problem and have found interesting ways of isolating the various time-dependent factors. As a reminder, those time dependent variables are that (1) loads increase with time, (2) soil densities in the embedment zone change as the pipe experiences ring deflection, and (3) pipe properties of viscoelastic materials change over time.

The soil cell pictured and sketched in Figure 3 was one of the tools researchers used in their investigations. Note that the 10-inch pipe being investigated is not too large for this soil cell. If it were too large, the sides and floor would be too close and influence the results. In those cases, a bigger soil cell located outside is used. The outdoor soil cell can accommodate much larger diameters.

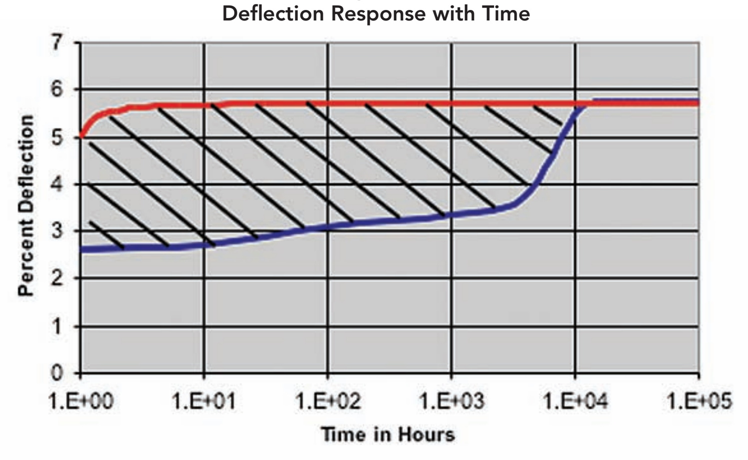
Figure 3. Utah State University Soil Cell



A pipe of the same diameter (10 inches) and stiffness (46 lb/in-in) was installed inside the soil cell in the same manner it was installed in the field (silty sand compacted to 83% standard Proctor density). The hydraulic jacks were then cranked up so as to produce a soil-pressure of 18.33 psi at the crown of the pipe. The red line in Figure 4 shows the deflection response that was measured after applying the 18.33 psi, which is the soil pressure ultimately produced by the dead load in this particular

22-foot deep installation. For reference, the deflection response measured in the field is also shown in Figure 4 with the blue line. The only difference between the two plots is that in one case (in the soil cell) the long-term loads were applied instantaneously. In the other case (in the field), it took months to reach the long-term loads.

Figure 4
Deflection Response with Time



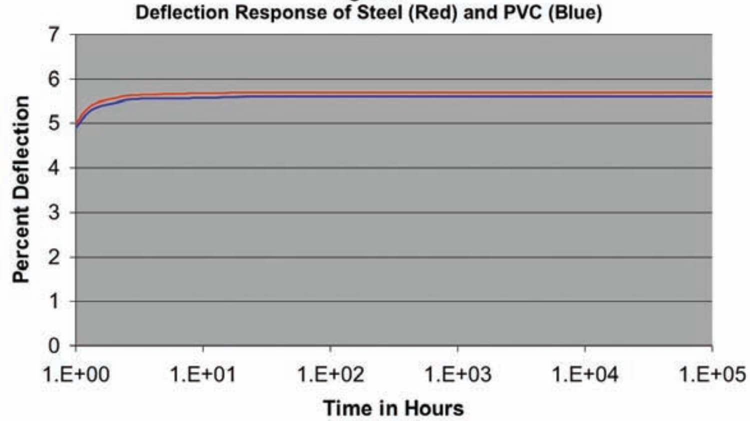
Red Line - Deflection Response Measured in the Soil Cell
Blue Line - Deflection Response Measured in the Field

The interesting change that occurred after about five months into the investigation resulted from the spring thaw in Utah. The groundwater table level rose as the snow melted, and this resulted in greater loads as the silty sand consolidated and settled. In the soil cell case, loads do not change with time. They are applied right away through hydraulic jacks. In the field scenario though, it took months for the ultimate load to reach the pipe as well as the addition of water through a change in the water table level. The area hatched with dark black diagonal lines represents the difference due to the change in loads with time. In both cases, the densities in the haunch improved as the pipe pushed out and down. In both cases, there was load relief at the crown as the vertical diameter compressed and the embedment carried some of the load through soil arching. In both cases, the viscoelastic properties of PVC gravity sewer pipe are captured in the load-deflection-response measurements.

But how do researchers isolate the viscoelastic properties of PVC and other plastics in their investigations? Figure 5 has the answer. A pipe of the same short-term stiffness, but with different long-term properties, was used. Steel is a linear elastic material at typical operating temperatures for gravity sewer pipe. Figure 5 shows the deflection response of steel pipe with the same short-term stiffness as the PVC under investigation and with the same diameter. The installation was the same (silty sand compacted to 83% of standard Proctor density) as was the load (18.33 psi). As Figure 5 shows, the deflection response is the same. Tests like these show that the viscoelastic properties of PVC are negligible in gravity sewer applications. Thus, the key point when installing flexible pipe is the quality of the embedment material in the haunch. For a very deep installation, or for a shallow installation with significant live loads, the haunch must be well compacted. In other scenarios, the quality of the embedment material may not be as critical and less compactive effort may be acceptable.

With a clear understanding of academia's research efforts, the nagging doubts about the property called creep fade as a concern. Attention is focused where it matters, good material and compaction at the haunch for those more challenging installations.

Figure 5
Deflection Response of Steel (Red) and PVC (Blue)



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