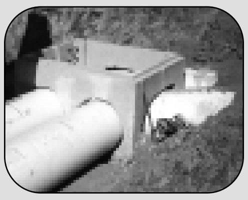
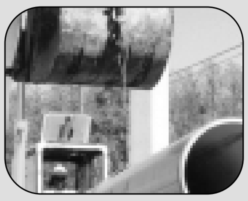


48" C905 Pipe Helps Community To Grow

See Page 5



C905 Case Histories Revisited

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Uni-Bell Welcomes Huber As New Member

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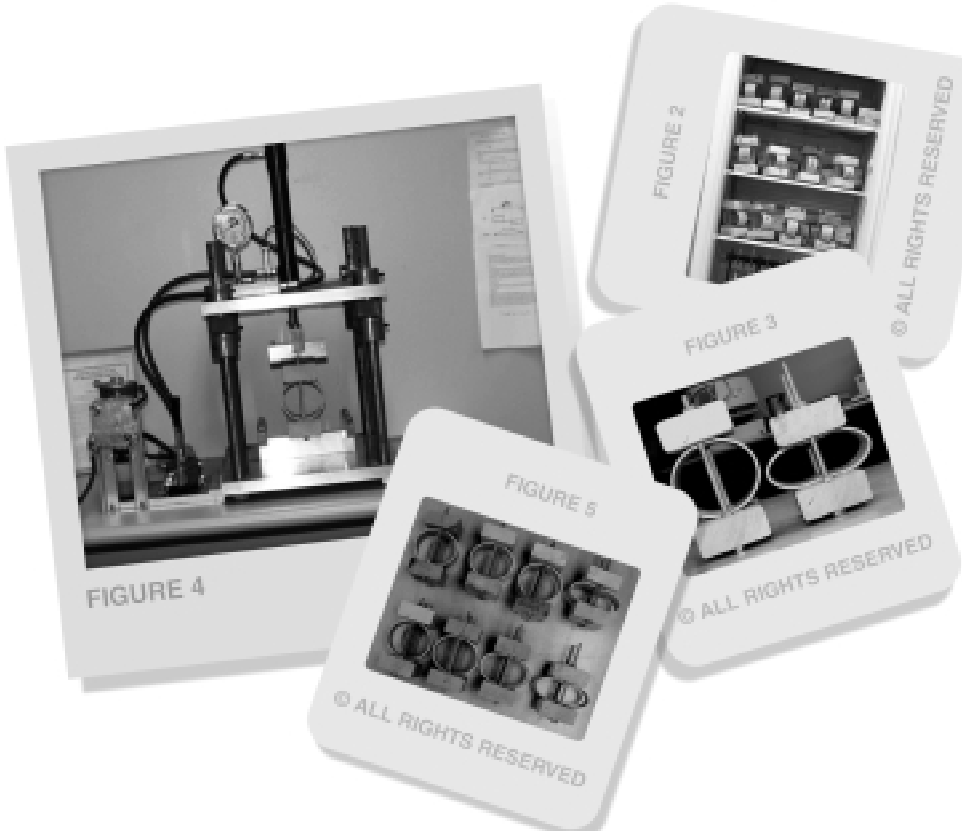
22-Year Stress Relaxation And Strain Limit Testing of PVC Pipes

By Dr. A. P. Moser

Editor's Note: Knowledge of a plastic pipe material's capacity to endure long-term strain without cracking is important for proper design and performance. With the author's permission, we are able to share with you a portion of the pre-publication working copy of Professor Moser's final report. It has been edited to fit the space available. The complete final report will be available for publication later this year.

Introduction

This paper is a report of continuing tests that were started in January of 1977. Samples of PVC pipe were placed on long-term test under various levels of constant strain. The objectives of the tests were to determine stress relaxation characteristics and constant strain failure data.



The use of PVC pipe as sewer pipe in the United States began in the early to mid-1960's as early manufacturers of PVC resin looked for potentially high volume applications for their resin. Throughout the sixties, PVC pipe of various types were provided for gravity sewer applications. Formal ASTM Standards were adopted in 1972, launching a virtual explosion of PVC sewer pipe use. Today, over 90% of all sewer pipes in sizes 4-15 inches used in the United States are made of PVC.

The first issue of ASTM D3034 contained material requirements for a single PVC cell class of 12454B as described in ASTM D1784. The second issue, published in 1973, contained a 13364B cell class as a second option. This option increased the material's modulus of elasticity from 400,000 to over 500,000 psi through the introduction of higher amounts of calcium carbonate. These higher modulus materials are often called filled compounds. The filled compounds exhibit slightly less tensile strength and tensile elongation, but do not compromise any of the finished product requirements of ASTM D3034. Sewer pipes of both compounds have found wide use in the past 26 years.

CONTINUED ON PAGE 2

SUPPLY SITUATION UPDATE

Industry Positioning To Satisfy Growing Demand

By Dave Eckstein
Deputy Executive Director

We live in a world of instant gratification. Fast food, one-hour photo, electronic mail, and, typically, PVC pipe. Our industry, in striving to meet the desires of our customer, has implemented systems such that one or two day delivery is the norm. Manufacturing facilities all over North America ship direct to job sites, as well as to inventory.

Customers accustomed to the need for months of lead-time on certain products for the job could take advantage of PVC pipe's delivery schedule by ordering only as and when needed.

The 1999 construction season proved an exception to the rule. At times, certain product sizes and types required delivery notice of months instead of days. Several factors contributed to the tight supply and some of those may continue to be in effect this year.

Three major factors contributing to 1999's supply situation were the railroad, raw material supply, and strong demand.

RAILROAD

The PVC pipe industry relies, almost exclusively, on rail shipment for delivery of raw material. Two major changes have reshaped the railroads. Just as our industry, mainly in the West and the South, began to recover from the effects of the Union Pacific merger with Southern Pacific in 1997, Conrail's break-up into Norfolk Southern Corp. and CSX Transportation Inc. rocked the Northeast. At times, shipments were delayed or even lost.

The rail situation appears to be sufficiently behind us that it can be considered a non-factor. The reor-

*SEE **"POSITIONING"** ON PAGE 4*

Stress Relaxation And Strain Limit Testing of PVC Pipes

CONTINUED FROM PAGE 1

Two fundamental questions which arose in the early 1970's are expressed as follows: 1) What particular PVC compounds are suitable as sewer pipe? and 2) What material property limits should be used for structural design purposes? At least partial answers to these questions have been published in the literature over the years. An initial proposal by Chambers and Heger in 1975 was to limit strain to 50 percent of an assumed ultimate strain of only 1 percent. This suggestion was shown by research to be too conservative and was never followed (see Janson, 1981; Molin, 1985; Moser, 1981).

Tests to help fully answer questions concerning strain limits were established in 1975 and 1977, at Utah State University. An early reporting of the results of these tests was published by Moser (1981), and Bishop (1981). The last published report of the data was by Moser, Shupe, and Bishop (1990). These tests have continued and data from these tests are now reported herein.

STRESS RELAXATION TESTS

Researchers have shown that buried pipe and soil systems stabilize to an equilibrium condition which typifies a fixed deflection or fixed strain condition (see Moser 1990). Therefore, data from constant deformation tests (fixed strain tests) can be used in predicting performance of PVC pipe.

Stress relaxation tests were performed on ring sections cut from PVC pipe (see Figure 3). These test specimens were each diametrically deformed to a specified deflection. The load necessary to hold each deformation constant has been measured at various time intervals. This series of tests has been in progress for over 22 years.

Each specimen was maintained at one of three temperatures: ambient (70˚F), 40˚F, and 0˚F. The ambient temperature was held to +/-5˚F. A refrigerator was used to maintain the 40˚F temperature and was found to fluctuate between 38˚F and 41˚F. The 0˚F specimens were placed in a freezer and the temperature varied between -5˚F and 0˚F. The purpose of the lower temperature test was to slow down the stress relaxation that would amplify any tendency toward brittle fracture.

Two PVC compounds were tested: filled and unfilled. The filled compound contained thirty parts calcium carbonate by weight and is designated as ASTM cell class 12364B, and the unfilled compound is designated as ASTM cell class 12454B.

Some of the pipe ring test specimens were notched prior to deflection to produce stress and strain intensifiers that would amplify any tendency for brittle fracture. The notches were placed along the length in four places corresponding to the locations of the highest tensile stresses - twelve and six o'clock positions on the inside surface, and the three and nine o'clock positions on the outside surface. These longitudinal notches were cut to a depth of 0.012 +/- 0.006 inches. In all, there are 91 specimens being tested in the study that started January 1977 (see Table 2 for details).

Groups	Sets	Deflections of Specimens 1	2	3	4	5	6
Group 1		(in percent)					
Specimens were filled and unnotched	Set 1, Ambient	5	10	15	25	50	
	Set 2, 40˚ F	5	10	15	25	50	
	Set 3, 0˚ F	5	10	15	25	50	
Group 2							
Specimens were filled and unnotched	Set 1, Ambient	5	10	15	25	50	
	Set 2, 40˚ F	5	10	15	25	50	
	Set 3, 0˚ F	5	10	15	25	50	
Group 3							
Specimens were filled and notched	Set 1, Ambient	5	10	15	25	40	
	Set 2, 40˚ F	5	10	15	25	35	
	Set 3, 0˚ F	5	10	15	25	35	
Group 4							
Specimens were filled and notched	Set 1, Ambient	5	10	15	25	40	35
	Set 2, 40˚ F	5	10	15	25	40	
	Set 3, 0˚ F	5	10	15	25	40	
Group 5							
Specimens were unfilled and unnotched	Set 1, Ambient	5	10	15	25	50	
	Set 2, 40˚ F	5	10	15	25	50	
	Set 3, 0˚ F	5	10	15	25	50	
Group 6							
Specimens were unfilled and notched	Set 1, Ambient	5	10	15	25	50	
	Set 2, 40˚ F	5	10	15	25	50	
	Set 3, 0˚ F	5	10	15	25	50	

Table 2: Grouping of the 91 pipe specimens in the stress relaxation tests.

Figures 8 shows stress relaxation data that plot as straight lines on log-log axes. As of August 1999, after more than 22 years, none of the test specimens had failed. The data are similar for pipes manufactured from both filled and unfilled PVC compounds when tested at the same temperature. The slopes of the stress relaxation lines show that the relaxation rate is less for lower temperatures in both the filled and unfilled PVC pipe compounds. Thus, lower temperature testing may be representative of longer duration constant strain conditions at higher temperatures. Calcium carbonate additions, up to 30 parts by hundred weight evaluated in this study, do not cause brittle failure to occur with time. All of the test specimens that did not fail initially have not failed with time. The difference in the stress relaxation curves for filled and unfilled PVC is that more force was required to deflect the unfilled specimens. The unfilled PVC specimens had thicker pipe walls that gave them a pipe stiffness higher than the filled PVC pipe specimens. Had the same wall thickness been used for both the filled and unfilled specimens, the filled specimens would have been stiffer due to a higher elastic modulus.

Buried PVC pipes maintain the same capacity to resist additional deflection increments as when initially installed, i.e., modulus does not decrease with time.

In comparing the stress relaxation curves for the notched and un-notched specimens, within the filled and unfilled groups respectively, no significant difference could be observed. The increased strain at the base of the notches had no apparent effect on the stress relaxation characteristics of either filled or unfilled PVC. Therefore, it was concluded that PVC is not notch sensitive when it is deformed diametrically in a constant deflection test.

It is interesting to note the relaxation that has taken place in the 22-year period is small. The total stress relaxation associated with the 5 percent initial deflection is small for the ambient temperature and is negligible for the 40˚F and 0˚F temperatures. A slightly higher relaxation rate occurs with higher initial deflections. This is evident because the slope of the relaxation line is steeper for specimens that have the greatest imposed deflection or initial load.

BENDING STRAIN vs RING DEFLECTION

Ring deflection produces bending in the pipe wall that in turn leads to bending strains. The bending strains can be calculated using the following equation. The equation requires input values for ring deflection ($\Delta y/D$), and the dimension ratio (D/t). The equation is based on the pipe deforming into an elliptical shape. The assumption of an elliptical shape has been shown to be a very close approximately for PVC pipe.

Example:

$$\varepsilon = \pm\left(\frac{t}{D}\right)\left(\frac{3\frac{\Delta y}{D}}{1-2\frac{\Delta y}{D}}\right)$$

ε = maximum strain in pipe wall due to ring bending. (Can be assumed to occur at the crown or invert of the pipe.)

t = pipe wall thickness.

D = pipe diameter.

Δy = vertical decrease in diameter.

For example, if t = 0.132, D = 4, and the ring deflection is 10 percent, the bending strain is calculated as follows:

$$\varepsilon = \pm\left(\frac{0.132}{4}\right)\left(\frac{3(0.10)}{1-2(0.10)}\right) = 0.0124$$

or 1.24 percent strain.

Stiffness data for the stress relaxation specimens are given in Table 3. Stiffness measurements conducted at the end of the 13-year and 22-year test periods are incremental stiffnesses. Each specimen was deflected an additional 5 percent from its preset value. The stiffnesses were then calculated by dividing the incremental load per length by the 5 percent incremental deflection. These long-term values are the instantaneous stiffnesses and are the stiffnesses that resist any additional deflection. These data show that pipe stiffnesses and modulus for PVC pipe do not decrease with time.

UNIAXIAL CONSTANT STRAIN TESTS

The specimens used for these tests were taken from filled and unfilled DR 35 PVC pipe. Strips of PVC were

Sample			Pipe Stiffness					
			5 Percent			25 Percent		
Filled	Notched	Temperature[1]	Initial[2]	13 years[3]	22 years[3]	Initial[2]	13 years[3]	22 years[3]
yes	no	0	71	69	70	39	63	64
yes	yes	40	76	74	74	38	65	62
yes	yes	0	75	69	70	41	63	63
no	no	40	101	89	90	60	91	90
no	no	0	102	91	92	65	110	109
no	yes	40	101	96	98	63	87	89

[1] Constant temperature during 22 year test. Sample conditioned to 73˚ F for stiffness testing.
[2] Pipe stiffness determined by secant method after being held at the specified deflection for 1 hour.
[3] 13 and 22 year stiffness determined by applying an additional 5% deflection increment to the specified deflection.

Table 3: Pipe stiffness of constant strain ring samples.

Specimen Number	Notched	Filled	Cross-sectional area (sq in)	Strain level	Starting Time 91978)	Failure time	Temperature
3	No	No	.0531	48%	March 26	No failure	0˚F
4	No	No	.0526	50%	March 26	No failure	0˚F
7	Yes	No	.0530	1.0%	March 27	No failure	0˚F
8	Yes	No	.0525	1.5%	March 27	No failure	0˚F
13	No	Yes	.0560	90%	March 30	No failure	0˚F
14	No	Yes	.0564	95%	March 30	No failure	0˚F
17	Yes	Yes	.0554	1.5%	March 30	No failure	0˚F
18	Yes	Yes	.0561	2.0%	March 30	No failure	0˚F

Table 4: Uniaxial constant strain failure data. Unfilled specimens taken from the circumferential direction of pipe.

obtained from the pipe either in the horizontal or the circumferential directions. The circumferential strips were straightened in an oven set at 180˚F. Dog-bone type specimens were machined from these strips. Each specimen was pulled to a predetermined strain. Some specimens were notched. The notches (in the two parallel sides of the specimen) were 0.024 +/- 0.006 inches deep. Notching the samples intensifies the strain. The intensified strain in combination with maintaining a lower temperature will accelerate brittle fracture, if it is going to occur.

These specimens were strained in a range of 1.0 to 95 percent. The specimens were then placed in the freezer at 0˚F. The samples have now been on test for almost 22 years. No failures have occurred, even in the notched specimens. The tests show that under a constant strain condition, if the initial strain can be achieved, failure will not occur (see Table 4).

CONCLUSIONS

1. Stress relaxation in filled and unfilled PVC can be approximated by a straight line on log-log paper and the relaxation rate is temperature dependent. The rate of relaxation decreased with a decrease in temperature.
2. Filled or unfilled PVC does not appear to be notch sensitive when loaded under constant deformation.
3. Buried PVC pipes maintain the same capacity to resist additional deflection increments as when initially installed, i.e., modulus does not decrease with time.
4. PVC pipes, manufactured from compounds of cell classes 12364B and 12454B, do not lose stiffness with time.
5. Apparent or creep modulus is an inappropriate property to predict long-term deflection of buried PVC gravity sewer pipe. Pipes continue to respond to additional deflection increments by resisting movement at the same stiffness as newly made pipe.

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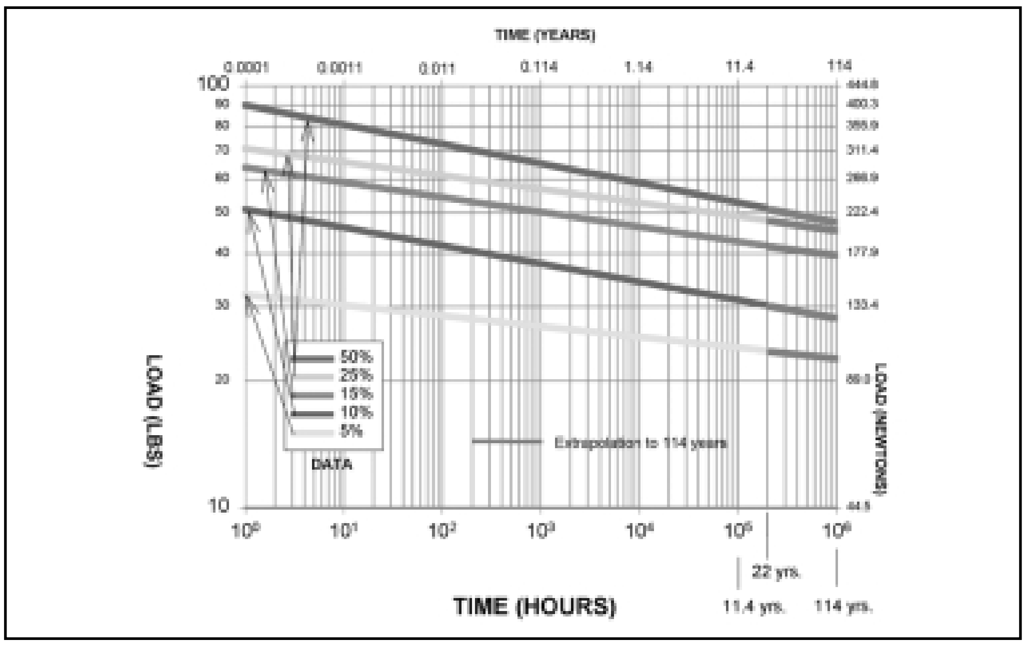
Figure 8: Relaxation curves for filled, unnotched PVC pipe rings at specified deflections and a temperature of 40˚ F.



ENR
Engineering News-Record
1874 125th ANNIVERSARY 1999

PVC Pipe Recognized By Engineering News-Record

For 125 years, the magazine *Engineering News-Record* has charted the progress, events, and accomplishments of the construction industry. In the October 18th edition, entitled "125 Years... 125 Innovations", the editors celebrated their anniversary by selecting and profiling the top 125 industry innovations.

We are pleased to point out that PVC pipe made the list! The following excerpt is taken directly from the "Materials and Construction Processes" section of ENR's article:

"The development of plastics at the turn of the century had profound implications for much of construction. Perhaps the most revolutionary of the new polymers was polyvinyl chloride or PVC. German scientists produced the first commercial PVC pipe in 1931, some of which is still in use today. PVC pipe was introduced in North America in 1951 and has since grown to dominate the smaller diameter water and sewer pipe markets with its combination of lightness, strength, ease of installation and resistance to corrosion."*

Congratulations to everyone involved with the successful manufacture, installation and use of PVC pipe. Given PVC pipe's durability and corrosion resistance, we look forward to successful service for the next 125 years.