THE EFFECTS OF ULTRAVIOLET RADIATION ON PVC PIPE

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ABSTRACT

A study was undertaken to quantify and document the actual effects of natural ultraviolet (UV) radiation on the important mechanical properties of PVC pipe. Quantities of PVC pipe were placed on exposure racks at locations throughout North America.

Over a two year evaluation period, pipe samples were periodically removed and tested to measure any changes in the following mechanical properties: (1) tensile strength, (2) modulus of tensile elasticity, and (3) impact strength. In addition, at the conclusion of the test period, pipe flattening and stiffness tests were performed on many of the pipes.

The evaluation results were summarized and analyzed. Analysis of the data revealed that both tensile strength and modulus of tensile elasticity remained virtually unchanged after two years of exposure to sunlight, and impact strength did not drop below that of most other pipe materials.

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INTRODUCTION

PVC (polyvinyl chloride) pipe has achieved widespread acceptance throughout the world for use in potable water distribution systems and for the conveyance of wastewater. PVC pipe owes much of its acceptance and operating success to its exceptional resistance to aggressive environments that limit the operating life of other pipe materials. But, like most polymeric materials, PVC can experience degradation resulting from exposure to ultraviolet (UV) radiation. To limit the effects of UV on PVC pipe, an inhibitive additive is included in the material formulation.

The primary source for potentially damaging UV radiation is the sun. Obviously, buried plastic water and/or sewer pipelines are well shielded from sunlight. However, all plastic pipe is subject to some outdoor exposure prior to being installed in the ground. This exposure may take place at a storage facility and/or on the job site. The length of exposure varies and is dependent upon such factors as stock rotation and demand for particular sizes.

The ultimate consumer acceptance of any plastic pipe product should be dependent upon the demonstrated ability of the plastic to retain its desirable physical properties following reasonably long exposures to direct sunlight. To provide users and consumers of PVC pipe with such information, the Uni-Bell PVC Pipe Association conducted a comprehensive two-year study to properly quantify and document the effects of natural UV radiation on PVC pipe intended for buried use. This paper presents the results of the Uni-Bell study. In addition, a datum point for 15 year exposure has been added and is summarized in Appendix A.

UV DEGRADATION

UV degradation is nature's way of breaking down and reclaiming materials of organic composition, e.g., plant waste, animal waste, wood, plastics, etc. Only about five percent of the sunlight reaching the earth's surface is within the UV wavelengths of 290 to 400 nanometers.[8]

Most polymers (i.e., plastics) contain chemical groupings or additives that can absorb such radiation and thereby undergo initiating degradation reactions. Degradation can take place when the energy level of the radiation is great enough to break the chemical bonds within the polymer chains. The degradation occurs only on the exposed surface of plastic pipe and does not penetrate deep into the pipe wall. Penetration depths of less than 0.002 inch are the rule for PVC pipe. Within the affected zone of reaction, the structure of the plastic is permanently altered. In the case of PVC pipe, the polyvinyl chloride molecule is converted to a complex structure typified by polyene formations. The polyene molecule often contributes a light yellow coloration to PVC pipe.[9]

Because degradation is dependent upon solar radiation, all UV degradation ceases when exposure to UV radiation is terminated. Thus, buried pipelines will not continue to degrade. In fact, any opaque shield, no manner how thin, will effectively prevent UV degradation. The most common method used to protect above ground PVC pipe from the sun is painting with an acrylic or latex (water-based) paint. Preparation of the surface to be painted is very important. The pipe should be cleaned to remove moisture, dirt, and oil, and then wiped with a clean, dry cloth. Petroleum-based paints should not be used, since the presence of petroleum will prevent proper bonding of paint to pipe. In addition, PVC pipes intended for outdoor use (e.g., PVC above-ground irrigation pipe) may be formulated with special additives, similar to those used in PVC house siding, that effectively prevent any significant UV degradation.

INHIBITING ADDITIVES

Most plastic pipe products are formulated to include additives that inhibit UV degradation. Even products intended for underground use should utilize sufficient inhibitive additives to prevent any significant deterioration during exposure periods of storage, shipping, handling and installation. Such outdoor exposure is inevitable.

The common inhibitive additive used in PVC water and sewer pipe in North America is rutile titanium dioxide. Rutile titanium dioxide has proven to be very beneficial to weathering resistance. Nearly all of the ultraviolet radiation is absorbed by the rutile titanium dioxide additive.[1, 2] The quantities of rutile titanium dioxide typically used in PVC water and sewer pipe range from 0.5 to 2.0 parts per hundred by weight. Such is also the case for the PVC pipe utilized in this study.

NATURAL VS. LABORATORY WEATHERING

UV resistance of a plastic pipe can be evaluated by one of two methods: (1) rigorously controlled laboratory studies that attempt to simulate an outdoor environment, or (2) studies that subject pipe to actual weather conditions. Laboratory studies make possible the evaluation of a variety of climatic conditions at one location and conditions can be intensified to accelerate time. But, it is difficult to duplicate Mother Nature and artificial weathering tests have not correlated well with the results obtained from natural weathering.[10] Consequently, the decision was made to expose pipe samples to actual weather conditions in this study to eliminate any chance for weather simulation error.

PROJECT DESCRIPTION

In 1977, the member companies of the Uni-Bell PVC Pipe Association agreed to participate in a comprehensive two-year evaluative study. Each member company collected a minimum of 12 sequential lengths of PVC pipe from a normal extrusion run. In addition, several companies collected samples from more than one manufacturing facility to further expand the data base. This resulted in a total of 13 test lots each comprised of 12 lengths of pipe.

All pipes were SDR 35 pipe manufactured to meet the requirements of ASTM D 3034 and had a nominal six-inch diameter. The actual PVC material was determined, verified and recorded for each lot of pipe tested.

One length of pipe from each test lot was immediately tested without exposure to sunlight in order to establish datum mechanical property values. Another length of pipe from each test lot was placed in a storage location protected from all UV radiation, sunlight and excessive heat. This pipe was later tested as a control sample to provide data on PVC pipe aged two years without UV exposure.

The remaining 10 pipe samples from each test lot were mounted horizontally on specially designed elevated exposure racks and placed in unshaded outdoor areas. In most cases, flat roof tops afforded maximum exposure and assured non-disturbance throughout the testing period. Each exposure rack was designed to provide for parallel spacing of the pipes to minimize shading of adjacent pipes. Figures 1 and 2 show some typical exposure racks of pipe. All northern exposure sites utilized elevated racks to either prevent or minimize snow cover during the winter months.

Figure 3 shows the locations of 12 sites where the UV exposure of 130 lengths of PVC pipe took place. Ten pipe lengths were stored at each location except for Denver, Colorado, where 20 pipes were aged. The test locations provided exposure to a broad range of climatic conditions that ranged from hot and dry to cold and humid. All pipe samples were positioned in the exposure racks with the print side down, i.e., the identifying pipe marking which is stamped on the pipe. Thus, the side of the pipe opposite to the printed side could be easily identified as the side of maximum UV exposure after removal from the rack.

Exposure of all pipe lengths did not begin on the same date. UV exposure was initiated as early as September of 1977 but no later than February of 1978. All exposure was completed by March of 1980.

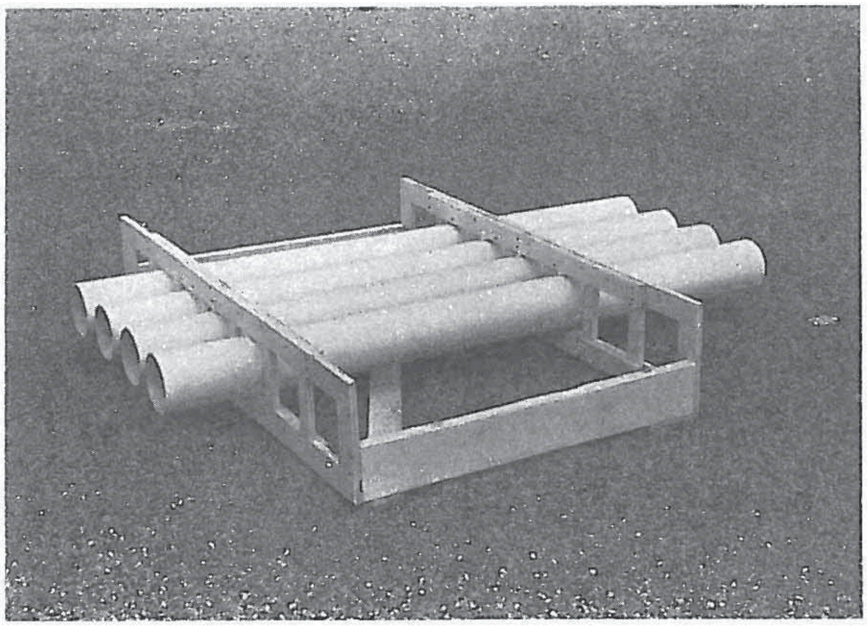

FIGURE 1
UNSHADED ROOF-TOP EXPOSURE AREA

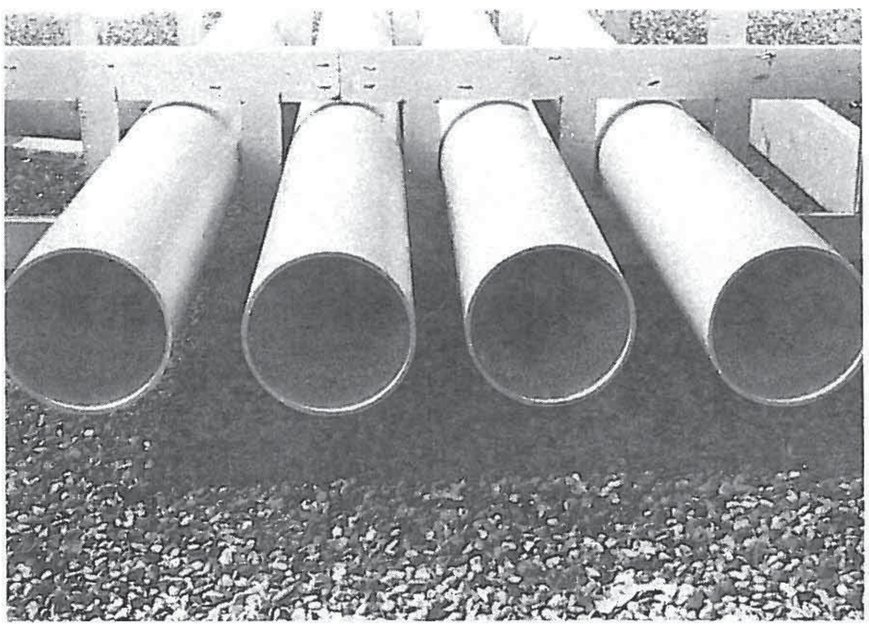

FIGURE 2
PIPES SPACED IN STORAGE RACK TO MAXIMIZE EXPOSURE TO SUNLIGHT

FIGURE 3

LOCATIONS OF THE 12 UV AGING SITES

EVALUATION METHODS AND FREQUENCY

Over the two-year evaluation period, pipe samples were removed from the exposure racks at regularly scheduled intervals to determine and quantify variation in the following important mechanical properties:

- Impact Strength
- Tensile Strength
- Modulus of Tensile Elasticity

In addition, pipe stiffness and flattening tests were conducted on many of the oldest pipe samples following the two years of exposure.

During the first 12-month period, a sample of PVC pipe was removed from each test lot at 2-month intervals and tested. Throughout the second year, testing was conducted every three months.

Impact strength values for all pipe samples were determined in accordance with the procedure defined in the "Standard Test Method for Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)," ASTM D 2444-70[6]. For this evaluation, the test protocol called for the use of a 20-pound tup A and a type-B flat plate holder (refer to ASTM Method D 2444-70). The specimen length used for impact testing was six inches. Each pipe specimen was impacted on that portion which had been exposed to direct sunlight (the side opposite the printed pipe marking). Average impact resistance values were calculated in accordance with Section 11 of ASTM Method D 2444-70.

Tensile strength and modulus of tensile elasticity testing was conducted in accordance with the "Standard Test Method for Tensile Properties of Plastics," ASTM D 638-77,[7] on flattened sections cut from the exposed PVC pipe wall (the wall opposite the pipe marking).

Tensile testing was conducted on three test specimens cut from each pipe tested, using a two-inch extensiometer. Each test specimen was prepared using either gauge blocks or a standard template cutter. Tensile testing was performed with orientation of test pull in the pipe longitudinal axis direction. All tensile strength values were determined at the point of yield.

Modulus of tensile elasticity testing was also conducted on three test specimens cut from the exposed pipe wall and prepared using gauge blocks or a standard template cutter. A two-inch extensiometer was utilized to perform modulus testing. The orientation of test pull was in the longitudinal axis direction for modulus of tensile elasticity testing. All modulus of tensile elasticity values were computed using the average initial cross-sectional area of the test specimen.

Pipe stiffness and pipe flattening tests done at the conclusion of the two-year test period were conducted in accordance with the "Standard Test Method for External Loading Properties of Plastic Pipe by Parallel-Plate Loading," ASTM D 2412-77.[5] Average pipe stiffness was determined by testing three specimens, each six inches long, at five percent deflection.

TEST RESULTS

Testing was conducted at nine separate test facilities and at nine different locations. This arrangement served to minimize the problems associated with single laboratory bias. However, the multi-laboratory approach did present a few problems. Several test laboratories could not run impact tests beyond the ASTM Standard D 3034 limit of 220 ft-lbf.[4] This resulted in a higher than normal standard deviation among the initial average impact strength values and a lower than actual mean average impact strength value for the pipes tested during most of the first year. This problem was virtually non-existent in the second year of testing due to decreases in actual average impact strength.

Duplication of test results between two or more test facilities was another problem which had to be considered. Since testing was conducted at a number of laboratory locations, the relative changes in test results obtained within each individual testing laboratory were considered most meaningful. The consideration of relative changes satisfied the purpose of the evaluation and eliminated introduction of interlaboratory discrepancy. Thus, the values given in Table 1 were derived by first compiling the changes in test values, as a percentage of the initial or datum properties, for each location. These individual percentage changes or deviations were then tabulated and a mean percent deviation calculated for each time period.

Small increases in average impact strength were recorded for some pipe samples. However, to be conservative and considering the accuracy of the impact test, all net increases in impact strength were interpreted as zero change rather than assigning them a positive value. Measured increases in tensile strength and modulus of tensile elasticity values were recorded and considered without modification in deriving values for Table 1.

Figure 4 is a graphical representation of the information given in Table 1.

IMPACT STRENGTH - DATA ANALYSIS

The most dramatic changes resulting from extended UV exposure were observed in impact strength values. A gradual decline in impact strength was observed during the two-year test period. The significance of such a decline to PVC pipe users cannot be interpreted properly without also examining the reported strength values.

TABLE 1
TABLE OF MEAN PERCENT DEVIATIONS FROM INITIAL VALUES

Aging Period (Months)	Average Impact Strength, (%)	Modulus of Tensile Elasticity, (%)	Tensile Strength, (%)
2	-3.7	+3.2	-1.3
4	-7.0	-0.8	0.0
6	-7.6	-4.3	0.0
8	-7.9	-2.2	+1.0
10	-9.7	-1.4	+2.0
12	-14.7	-3.1	-0.3
15	-16.7	-0.3	-1.5
18	-13.5	-2.7	-2.3
21	-12.8	-4.2	-1.5
24	-20.3	-3.9	-0.8
Control	-4.4	+1.0	-1.3

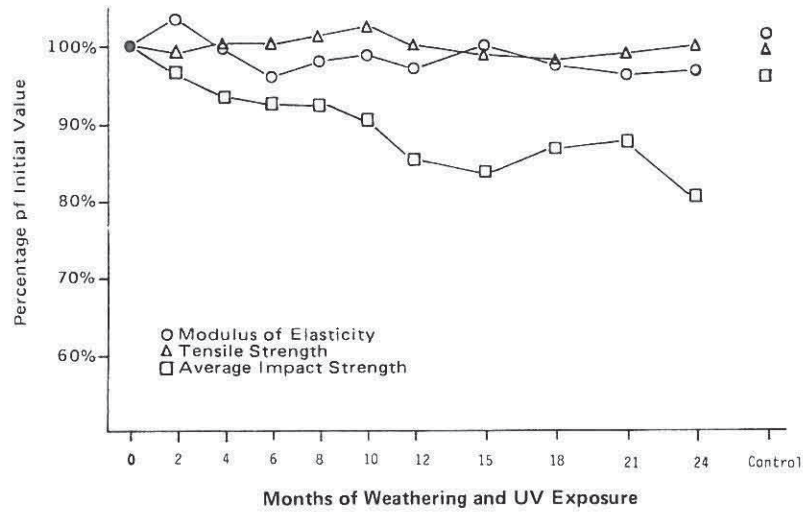

FIGURE 4
GRAPHICAL REPRESENTATION OF MECHANICAL PROPERTY CHANGES OVER THE 24-MONTH EVALUATION PERIOD

Following exposure periods of two, four, six and eight months, the mean impact strengths computed from the reported average test results consistently exceeded 260 ft-lbf. Such mean impact strengths surpass the initial 210 ft-lbf manufacturer's quality control impact strength requirement specified in ASTM D 3034 for nominal 6 inch diameter pipe by nearly 25 percent.[4] The lowest single average impact strength reported after 8 months of UV exposure was 203 ft-lbf, or 96 percent of the initial ASTM requirement.

After a full year of exposure to natural UV radiation and a broad range of adverse climatic conditions, the computed mean impact strength of all the samples tested exceeded ASTM's recommended initial minimum value of 210 ft-lbf by 29 ft-lbf, (i.e., the 12 month mean was 239 ft-lbf). The lowest single average value reported was 168 ft-lbf, or 80 percent of the ASTM initial value. The reported standard deviation, calculated in accordance with Section 11 of ASTM Method D 2444-70, for the lone 168 ft-lbf average value was ±7.67 ft-lbf.

Two years of weathering and direct sun exposure resulted in an overall mean impact strength of 228 ft-lbf, or 108 percent of the ASTM initial value. The lowest single average impact strength after two years of exposure was 158 ft-lbf. However, the lowest single average impact strength reported throughout the entire evaluation period was 139 ft-lbf following 15 months of exposure. The 139 ft-lbf value represents 66 percent of the ASTM initial value. The reported standard deviation associated with the lone 139 ft-lbf average value was ±4.4 ft-lbf.

Commonly used alternative sewer pipe products have average impact strengths that are usually below 100 ft-lbf and weigh considerably more per foot than PVC sewer pipe, making them more susceptible to impact damage. Thus, even the lowest impact strengths reported during this two year evaluation should not concern PVC pipe consumers or impair PVC pipe's performance.

TENSILE STRENGTH - DATA ANALYSIS

Tensile strength is directly related to a pipe's ability to withstand internal pressures. The pressure rating or pressure class of a pipe is dependent upon the pipe wall thickness and the tensile strength of the pipe material.

The mean tensile strength deviations shown in Table 1 indicate that two years of weathering and UV exposure have no effect on the tensile strength of PVC pipe. The small deviations, which were reported, are within the normal range of repeatability for the tensile strength test. The largest single sample average reduction reported was only eight percent.

MODULUS OF TENSILE ELASTICITY - DATA ANALYSIS

Pipe stiffness is a function of pipe diameter, pipe wall thickness and modulus of tensile elasticity of the pipe material. Given the accuracy and repeatability of the test for modulus of tensile elasticity, the small mean deviations displayed in Table 1 show that tensile modulus is not significantly altered by two years of UV exposure. The lowest reported average modulus of tensile elasticity was 387,000 psi, which is 97 percent of the ASTM D 1784-78 requirement.[3]

PIPE FLATTENING AND STIFFNESS - DATA ANALYSIS

Pipe stiffness and flattening tests were conducted on many of the pipe samples after the two years of UV exposure. No comparisons could be made with initial values because such tests were not run on the pipe when new. Therefore, this data had to be examined in relation to the ASTM requirements for new pipe. A minimum pipe stiffness of 46 psi at 5 percent deflection and the ability to be flattened to a condition of 60 percent deflection without evidence of splitting, cracking or breaking are initially required of SDR 35 PVC pipe by ASTM D 3034.[4]

After the two years of exposure all of the pipes tested still exceeded these minimum requirements.

REGIONAL INFLUENCE

A comparison between test results from southern exposure locations, such as those in Florida, Alabama, Mississippi and Texas, and more northern exposure locations, such as those in Quebec, New York, Ohio and Oregon, was inconclusive. Impact strength reductions were not necessarily greater at southern exposure locations. However, comparison between the results from western exposure locations (Colorado, Kansas, Oregon and Texas) and more eastern exposure locations (New York, Ohio, Alabama, Tennessee and Quebec) did reveal slightly greater impact strength reductions in the west. It is theorized that the semi-arid climate of the western exposure locations provided less cloud cover than the more humid locations east of the Mississippi River. Thus, the duration and overall intensity of UV radiation was probably greater in the west.

SUMMARY AND CONCLUSIONS

After two years of exposure under some of the worst radiation conditions to be found in North America, the resulting test data indicates that modulus of tensile elasticity and tensile strength of PVC pipe are for all practical purposes unchanged. This is especially true considering the accuracy and repeatability of the various tests conducted, and in view of the fact that all tests were conducted on the exposed side of the pipe. In addition, a datum point for 15 year exposure has been added and is summarized in Appendix A.

The fact that tensile strength was not affected means the pressure rating or pressure class of PVC pipe has remained constant. In addition, the modulus of tensile elasticity data is evidence that PVC pipe's ability to resist external soil loads and traffic loads has not been adversely altered by two years of direct sunlight exposure. The results of pipe flattening and pipe stiffness tests conducted at the end of the two year period serve to further substantiate these conclusions.

In a previous 24-month weathering study, the performance of PVC pipe was equally impressive. No significant changes in the tensile strength at yield was observed.[11]

Reductions in pipe impact strength were apparent after two years of exposure to weathering and ultraviolet radiation. However, considering PVC pipe's high initial impact strength, the reductions were not significant enough to warrant concern. Even the lowest reported average impact strength values exceed those of many alternative buried pipe materials. Pipe breakage due to impact loads encountered during normal handling and installation is not a problem with PVC pipe.

The desirable mechanical properties of PVC pipe formulated for buried use were not adversely affected to a significant extent by two full years of outdoor weathering and direct exposure to sunlight.

ACKNOWLEDGMENTS

The work in this paper was performed by member companies of the Uni-Bell PVC Pipe Association. An extensive testing program such as this one has involved many people whose contributions were crucial to its success. To all those employees, lab technicians and project engineers who contributed their time, effort and interest to this endeavor, heartfelt thanks are expressed on behalf of the Association.

Special appreciation goes to the Uni-Bell Technical Committee that developed the test protocol for the evaluation and coordinated the entire effort.

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APPENDIX A

TESTING ON PVC PIPE WITH 15 YEARS OF UV EXPOSURE

The following is a summary of testing conducted on 15-year old PVC pressure pipe that had been continuously exposed to sunlight. The pipe was returned to its plant of origin for testing and evaluation.

TABLE A1

PIPE AND UV EXPOSURE DETAILS

PVC Pressure Pipe Specifics	350 mm (14-inch), DR18, PR 235 psi
	Certified to CSA B137.3
	Manufactured on May 23, 1986
	Pipe was severely faded to a maximum depth of 0.002 inches over approximately 180 degrees of its exterior surface.
Storage Location	Outdoors City of Saskatoon Public Works Yard 330 Ontario Avenue Saskatoon, Saskatchewan
Climate	Saskatoon averages 2380 hours of sunshine per year

TEST RESULTS – OCTOBER 12, 2001

Test	Standard Requirement	Actual Results
Quick Burst	755 psi (CSA)	Pipe burst at 980 psi
Impact Resistance	175 ft-lbs at 0 degrees Celsius	5 of 5 passed at 175 ft-lbs
		5 of 5 passed at 330 ft-lbs
Flattening	2" sample to 95% of the outside diameter (CSA)	3 of 3 passed
	6" sample to 60% of the outside diameter (AWWA)	3 of 3 passed
Dimensions	Wall Thickness (May range from 21.6 mm to 24.2 mm per CSA)	Passed (Ranged from 22.31 to 22.96 mm)
	Average Outside Diameter (May fall between 388.25 mm and 389.00 mm per CSA)	Passed (388.59 mm)
Extrusion Quality	Acetone Immersion (CSA)	Passed (20 minutes and no attack)

Even though the PVC pipe endured severe conditions of ultraviolet exposure from 15 years of daytime sunlight, the pipe exhibited no loss of physical strength and should be considered very suitable for ordinary usage.

FIGURE A1

THIS LARGE DIAMETER PRESSURE PIPE WAS STORED OUTDOORS, UNPROTECTED FOR 15 YEARS

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