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FIRST PROGRESS REPORT ON EVALUATION OF REINFORCED PLASTIC MORTAR PIPE A GOVERNMENT-INDUSTRY COOPERATIVE STUDY

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16. ABSTRACT

The Bureau of Reclamation, United Technology Center, and Johns-Manville are engaged in a Government-Industry Cooperative Study of basic properties of reinforced plastic mortar pipe (RPM) and its water resources applications. The first progress report of the study comprises laboratory and field programs, and preparation of specifications and design. The laboratory program consists of: (1) Series A - Basin Properties; (2) Series B - Scaling Factors; (3) Series C - Stiffness Correlations; and (4) Load tests on pipe buried in soil. The basic properties are being determined through fatigue, crush, burst, creep, and stiffness studies after exposure in environments of sulfuric acid, pH5; sodium hydroxide, pH9; synthetic soil extract, pH7.4 to 8.2; tap water; and distilled water. Controls and air specimens are also being tested. Scaling factors are to be computed from 12-, 24-, 36-, and 48-in. (30.48-, 60.96-, 91.44-, and 121.92-cm) Class 60 irrigation pipe. Conclusions at this point are: (1) RPM pipe appears to follow the stress aging curve for plastics, (2) good stiffness correlation is shown between classes of irrigation pipe, (3) the Iowa Formula for flexible pipe design may require re-evaluation for use with RPM pipe, and (4) changes in properties caused by the different environmental exposures appear to be similar, with good chemical resistance apparent.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS--/ plastics/ elastomers/ polymers/ *pipes/ mortars/ *plastic pipes/ creep/ durability/ crushing/ fatigue (mechanics)/ stiffness/ laboratory tests/ *performance tests/ scale/ environmental tests/ field tests/ environmental effects/ resins/ strength/ deflection/ properties/ strain/ specifications

b. IDENTIFIERS--/ *pipe tests/ scale effect/ buried pipes/ glass reinforced plastics/ *reinforced plastic mortar pipe/ polyesters/ loading tests

c. COSATI Field/Group

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Many engineers and technicians in the Division of Research participated in the work and in preparation of this report. Major contributors were W. B. Batts, photographic work; C. B. Haverland and A. P. Jaquith, physical properties. Additional contributions to the total program were made by personnel from the Division of Design.

Many engineers and technicians in industry participated in the work and in preparation of this report. Major contributors were Tak Aochi, W. A. Porter, and Jack Tooley of UTC—Division of United Aircraft Corporation; and A. C. Boush, P. A. Rogers, and R. S. Morrison of Johns-Manville Corporation.

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SECTION I

INTRODUCTION

Pipe for water conveyance is of major importance to the Bureau by virtue of projects that include delivery and distribution of water for irrigation and municipal and industrial use throughout much of the Western United States. It has directed the construction of thousands of miles of pipelines during its 66-year history. During the next 6 years, the Bureau expects to construct about 2,000 miles (3,218 km) of pipeline, not including the proposed conversion of nearly 900 miles (1,448 km) of open irrigation canals to underground systems for safety reasons.

The need for the greater use of pipe includes safety, reduced water losses to seepage and evaporation, preservation of water quality, reduced maintenance, and greater land availability for productive use.

With the emphasis on pipe, the Bureau inaugurated an investigation on reinforced plastic mortar (RPM) pipe. The development of economical, improved pipe represents a potential benefit to many pipe users, irrigation district operators, municipalities, and to private industry.

RPM pipe is a composite built from polyester resin, silicate sand, and glass filament reinforcing. The glass reinforcement when properly combined with the resin-sand mortar results in reinforced plastic mortar, or RPM. Two small coupons cut from a piece of pipe and a piece of 8-inch (20.32-cm) pipe are shown in Figure 1. The resin used is a basic isophthalic polyester resin which gives the product excellent resistance to a wide variety of chemical solutions. The sand is a clean, well-graded, high-silica content sand. One size is used in the sand-rich liner to achieve erosion resistance. A larger size issued in the pipe wall as a filler to produce a product at a competitive cost by replacing the more costly resin with the lower cost sand. The reinforcing filament is a particular type of borosilicate glass with a special surface treatment to enhance the adhesion of resin to glass. The layered structure and sand-rich liner are shown in Figure 2.

The pipe is built up in layers on a mandrel on a machine which is essentially a filament winding process modified to incorporate the sand into the process. The pipe is manufactured in standard 20-foot (6.09-m) lengths with bell-and-spigot, rubber-gasketed (O-ring) joints. The joint is essentially the Bureau's R-4 joint. The bell is fabricated as an integral part of the pipe on the mandrel during the winding process. The spigot is cast or molded on the outside of the pipe wall at the end of the pipe. Thus, shorter than standard lengths can be easily made. A cross section of the spigot and the joint are shown in Figures 3 and 4.

RPM pipe was first developed by United Technology Center (UTC), a Division of United Aircraft Corporation, Sunnyvale, California, in 1966 following some discussions on pipe requirements with the Bureau at the Denver Research Center. The Bureau's interest was in obtaining another type of high-quality pipe to compete as an alternate to conventional pipes such as asbestos-cement, concrete, and steel. The Bureau felt that a new reinforced plastics technology could be perfected to produce a new pipe which would have some important advantages while being competitive costwise. However, it was appreciated that a great deal of developmental work by industry would be required.

During the next 2 years of development several different pipes were produced by UTC beginning with rubber-lined pipe, then unlined pipe, then to that currently produced with a resin-sand liner reinforced with a polyester mat. During this period, UTC was actively engaged in testing the various pipes as they were produced. These test results were furnished the Bureau for information and comparison with our own preliminary studies.

In 1968 Johns-Manville negotiated with UTC for a license to produce an RPM pipe under their own trademark. UTC also has negotiated with several foreign firms for licenses to produce RPM pipe.

UTC's pipe, called Techite, is available in sewer pipe and in four classes of pressure pipe in diameter sizes from 8 through 48 inches (20.3 through 121.9 cm).[1]* Larger sizes will be available in the near future. Pipe up to 96 inches (2.438 m) in diameter has been fabricated for demonstration and test purposes. A section of 96-inch (2.438-m) pipe to be used for test purposes is shown in Figure 5. J-M's pipe, called Flextran, is currently available in sizes ranging from 15 through 48 inches (38.1 through 121.9 cm) in diameter for gravity service and for pressure service up to 50 psi (3.52 kg/cm^2). [2] Larger sizes are also planned for the near future as are pressure classes for water conveyance.

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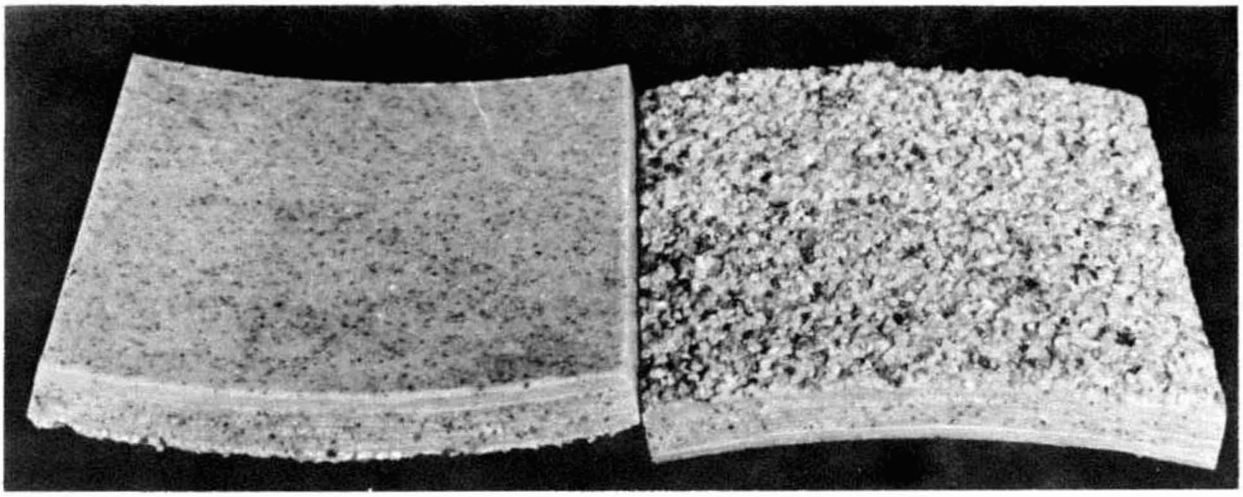
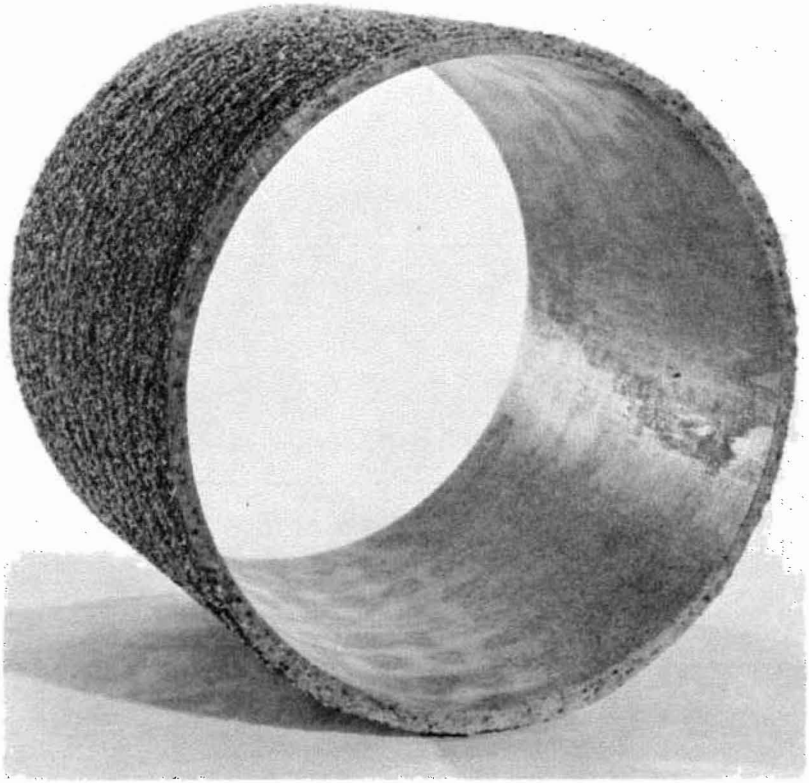
*[1] Numbers in brackets refer to References.



A. Left—Inner surface of RPM pipe. Right—Outer surface of RPM pipe. Photo PX-D-65567



B. 8-inch (20.32-cm) diameter RPM pipe. Photo PX-D-65570

Figure 1

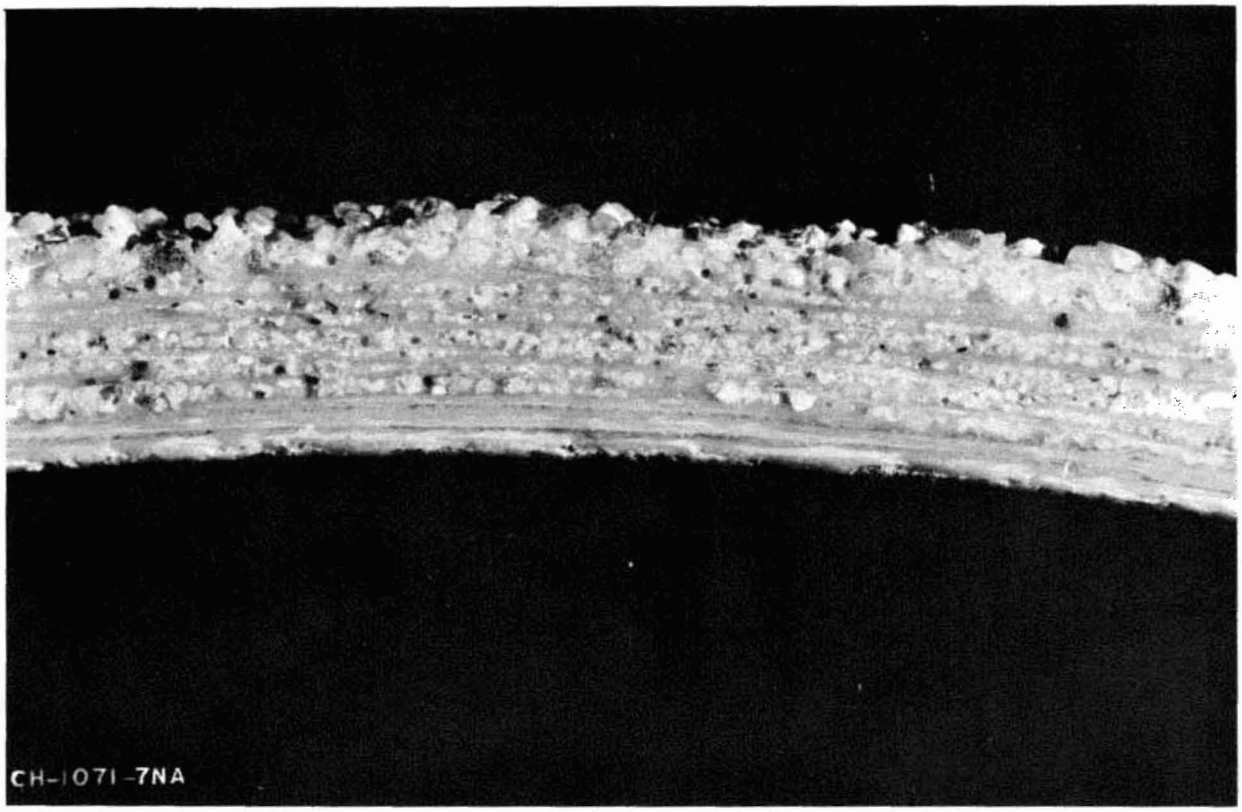


Figure 2. Cross section of RPM pipe showing laminated or layered structure. 4X magnification. Photo PX-D-65568

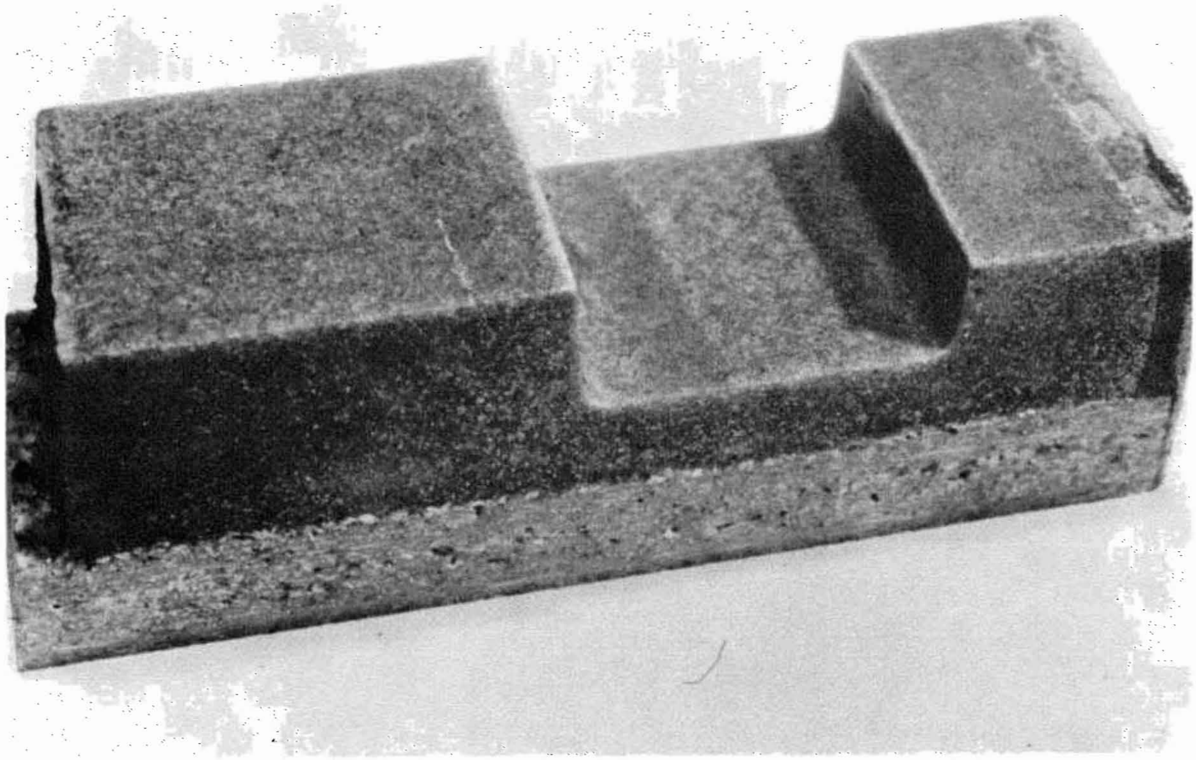
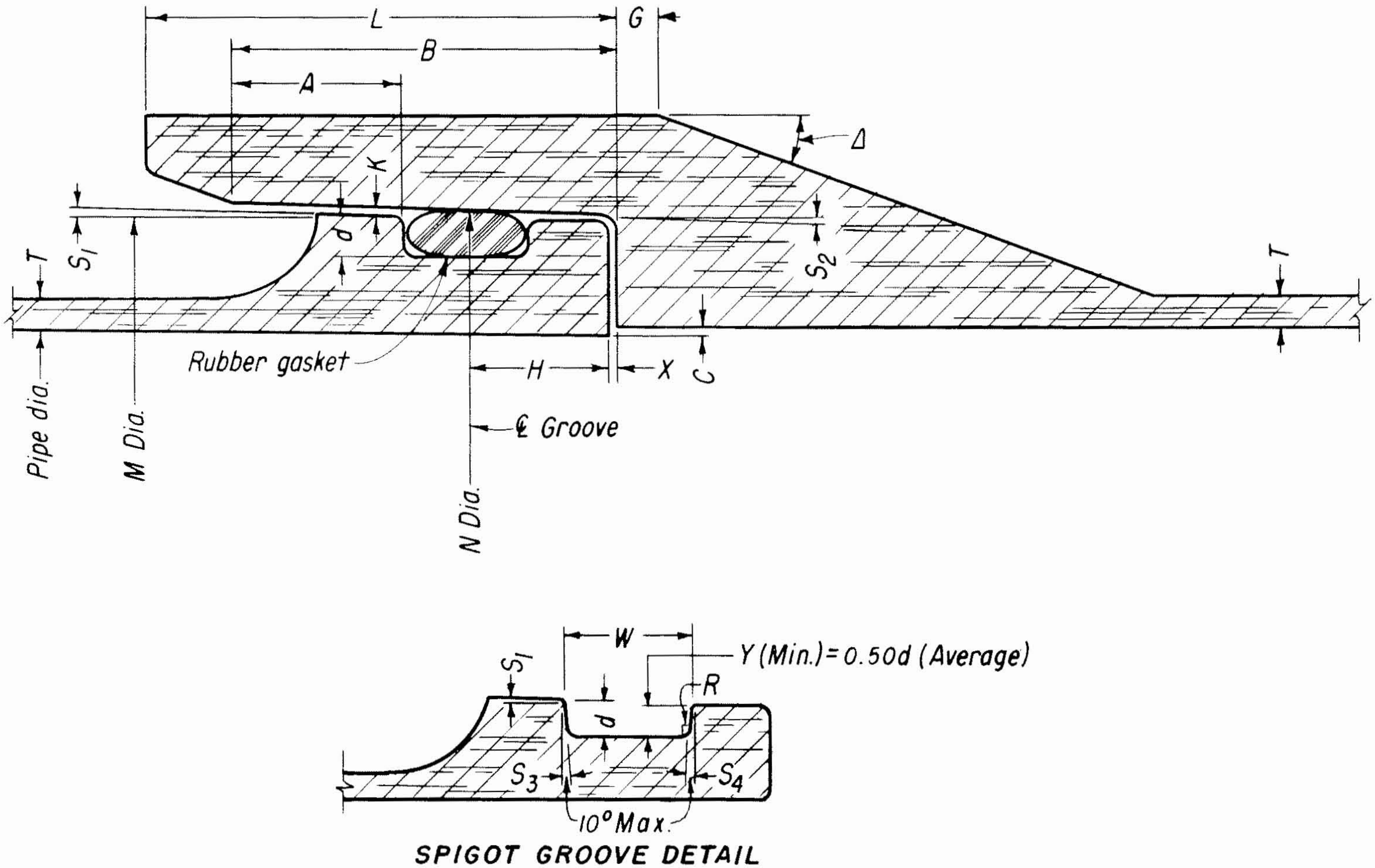


Figure 3. Cross section of molded RPM pipe spigot—48-inch (1.219-meter) diameter pipe. (About 1-1/2 times enlarged.) Photo PX-D-65569



JOINT TYPE R-4

Figure 4. Joint Type R-4. Reinforced plastic mortar pipe.

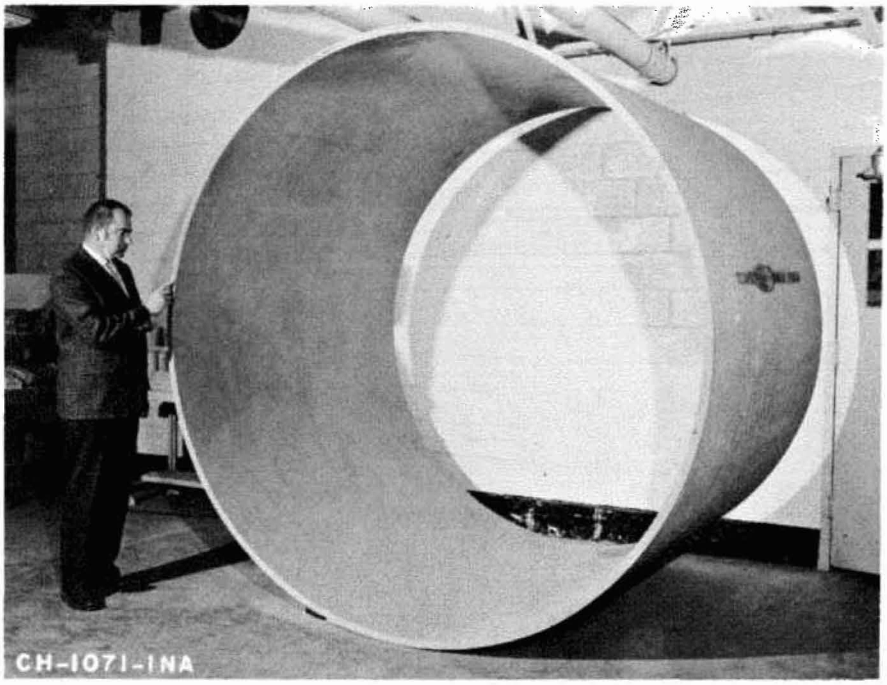


Figure 5. 96-inch (2.438-meter) diameter RPM pipe is shown. Characteristic thin wall is apparent in this large pipe. Photo PX-D-65564

SECTION II

A. SUMMARY AND CONCLUSIONS

The Bureau of Reclamation, and United Technology Center (UTC) and Johns-Manville are engaged in an extensive cooperative study of reinforced plastic mortar (RPM) pipe. The study is called the Government-Industry Cooperative Study of RPM pipe, GICS for short. The ultimate goal is the preparation of Bureau specifications which could, with adequate assurance, result in obtaining a reliable pipe of good durability.

The GICS program is comprised of three parts: Laboratory testing, field testing, and reports and specifications. There will be 2 years of testing and about 1 year for reporting and final preparation of specifications.

Laboratory studies are divided into several series to study basic physical properties of RPM pipe, scaling factors, stiffness correlation and load tests on pipe buried in soil. Field studies are mainly at two locations: at the Westlands Irrigation District in California, and at the Lower Yellowstone Irrigation District in Montana. Preliminary specifications have been prepared and will be revised in the light of program data as they become available.

To date, performance generally is as expected. Changes in the properties due to environmental exposures are of an acceptable magnitude. These data, when plotted on stress aging curves, show the early "large" changes with tapering off in time. This indicates that when the stress level is of an acceptable magnitude such curves can be used for predicting long-term performance of RPM pipe. They may also find some use in determining the maximum stress level under a particular type of loading. If the present performance trends continue, RPM pipe may eventually be specified as by the Bureau of Reclamation an alternate to other types of pipe in water resources applications.

In a lean clay backfill compacted to 90 percent of Proctor maximum dry density, an 18-inch (45.72-cm), Class 60, RPM pipe deflected 46 percent in an elliptical pattern under 100-psi (7.03-kg/cm^2) surface surcharge. An idential pipe under this load, with a backfill compacted to 100 percent of Proctor, deflected 17 percent in a rectangular pattern. At lower loads, 10 to 20 psi (0.703 to 1.406 kg/cm^2), the pipe in 90 percent backfill had a deflection nine times as much as the pipe in 100 percent backfill.

The RPM pipe deflected more than steel pipe of similar ring stiffness; for the pipe in 100 percent backfill, the ratio was about 2:1. To date, the results of the laboratory buried pipe tests indicate that the Iowa Formula for steel pipe design may not apply to the RPM pipe using Ring Stiffness Factors from three-edge bearing tests. The Iowa Formula was developed for steel pipe and may require reevaluation for use on RPM pipe.

B. APPLICATIONS

RPM pipe, when proven, is expected to be specified by the Bureau as an alternate to other types of pipe for water distribution and convey and systems. This new pipe will fit into a large number of systems because of the range of sizes and types that are available.

Data generated to date in this evaluation program have been applicable in the preparation of tentative Bureau specifications. Upon completion of this program, comprehensive specifications will be prepared.

SECTION III

EVALUATION OF REINFORCED PLASTIC MORTAR PIPE

A. INTRODUCTION

While the potential merits of RPM pipe in water resources engineering were recognized, the fact that this new product would have certain disadvantages and limitations was also recognized. Being a new product, little was known about the physical properties of RPM and how these properties were affected by time and exposure. However, since it is essentially a reinforced thermosetting plastic certain things were expected.[3] High strength-to-weight ratios, excellent chemical resistance, flexibility, and product uniformity could be realized. Wet strengths would be less than dry strengths and there would be losses in strength due to age and environment or because of fatigue under cyclic stressing. Creep would occur. Being a pressure vessel, crazing above a certain stress level would occur with weeping as an end result, and since the pipe is flexible changes in the stiffness would have to be evaluated. It should be emphasized that a general property of reinforced thermosetting plastics is the nonlinear character of stress aging in which early effects are very pronounced and long-term effects are minimal. This allows the prediction of long-term aging effects on the basis of rather short-term tests through the use of a stress aging diagram which will be discussed later.[4]

B. GOVERNMENT-INDUSTRY COOPERATIVE STUDY OF RPM PIPE

Recognizing these facts, the Bureau and industry outlined an extensive program of environmental exposure and testing. The industry, recognizing the value of such a program, agreed to participate in the program. Consequently, in June of 1968 an agreement between UTC, J-M, and the Bureau, was reached wherein the division of effort and responsibilities between the three participants were finalized. At that time, the program was christened the "Government-Industry Cooperative Study on RPM Pipe," or the GICS Program for short. The industry participants, UTC, and J-M, have accepted substantial testing responsibilities as their contributions to the program.

The objectives of the GICS Program are to generate sufficient performance data and knowledge to enable the preparation of Bureau specifications which could, with adequate assurance, result in obtaining a reliable pipe of good durability. This includes obtaining necessary data to define the properties, advantages, and limitations to permit design engineers to work with RPM pipe and to obtain necessary test results to determine adequately the long-term durability characteristics of an RPM pipe. The GICS Program is not all inclusive concerning all important materials and engineering properties of RPM pipe and further studies will be needed at the completion of this program. However, data generated to date show that the basic objectives of the program will be met. So far, performance has been essentially as expected with numbers now filling spaces where unknowns existed previously.

The GICS Program is a three-phase program covering laboratory tests, field studies, and specifications and design. Detailed outlines of the program are shown in Figures 6 and 7.

C. LABORATORY PROGRAM

The Laboratory Program is separated into several distinct phases or series designed to evaluate properties of RPM pipe that are important to pipeline use. In Series A changes in certain physical properties after environmental exposure are being evaluated. In Series B performance of large-diameter pipe is being correlated to performance of small-diameter pipe in an effort to establish scaling factors. In Series C stiffness data for the various classes of RPM pipe are being related. Soil box tests are also being conducted to measure the deformation of RPM pipe subjected to external load when buried in compacted soil.

1. Series A—Basic Properties

These tests are being conducted on 12-inch (30.48-cm) lengths of 12-inch (30.48-cm) diameter Class 60 irrigation pipe.

The pipe specimens are being environmentally conditioned in five solutions that represent solutions that might be encountered either internally or externally during service. These are: sulfuric acid, pH of 5; sodium hydroxide, pH of 9; a synthetic soil extract (a salt solution representing the extract drawn from a "typically aggressive" saturated soil), pH between 7.4 and 8.2; Denver tap water; and distilled water. The specimens are totally immersed in the

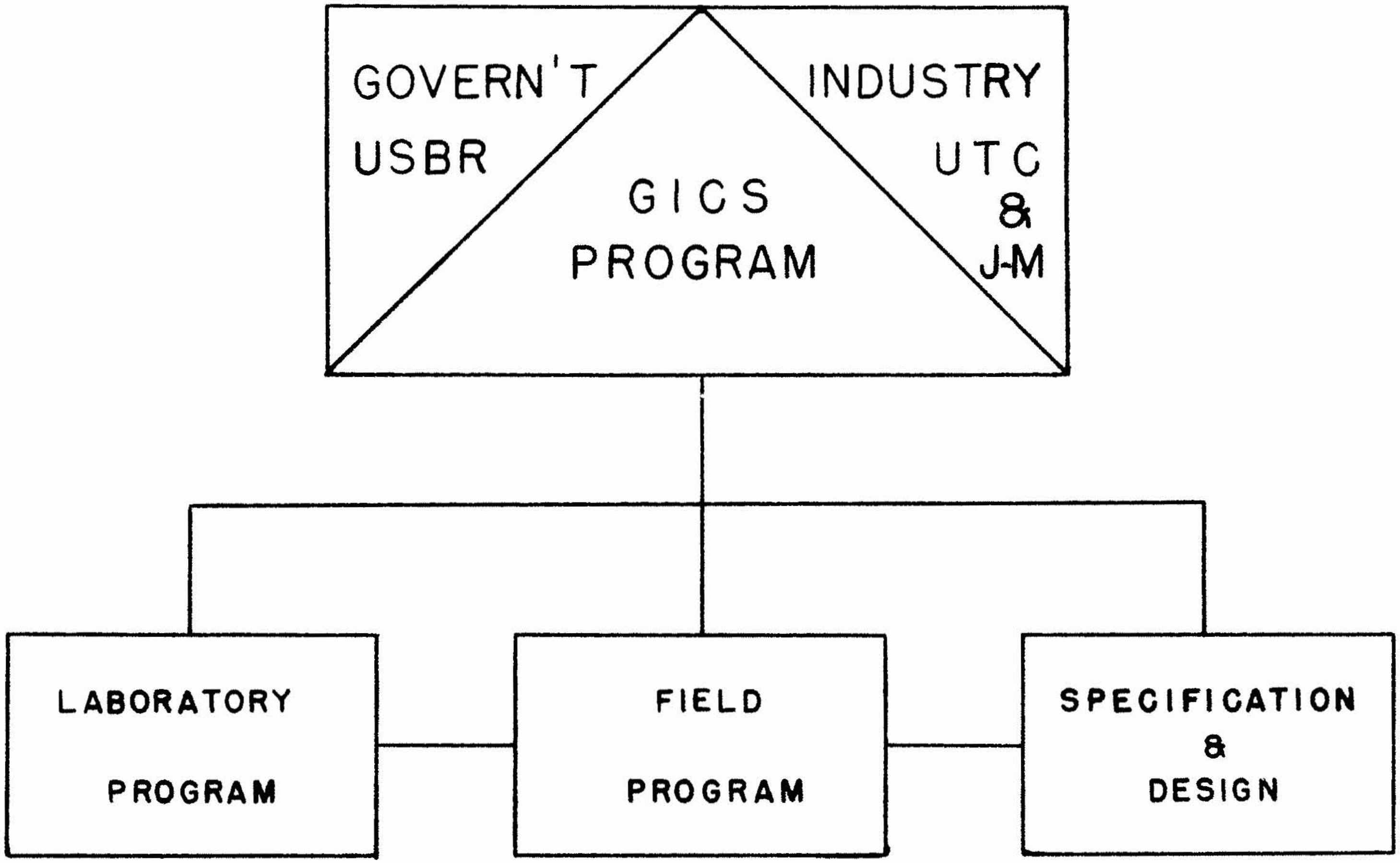


Figure 6. Overall program.

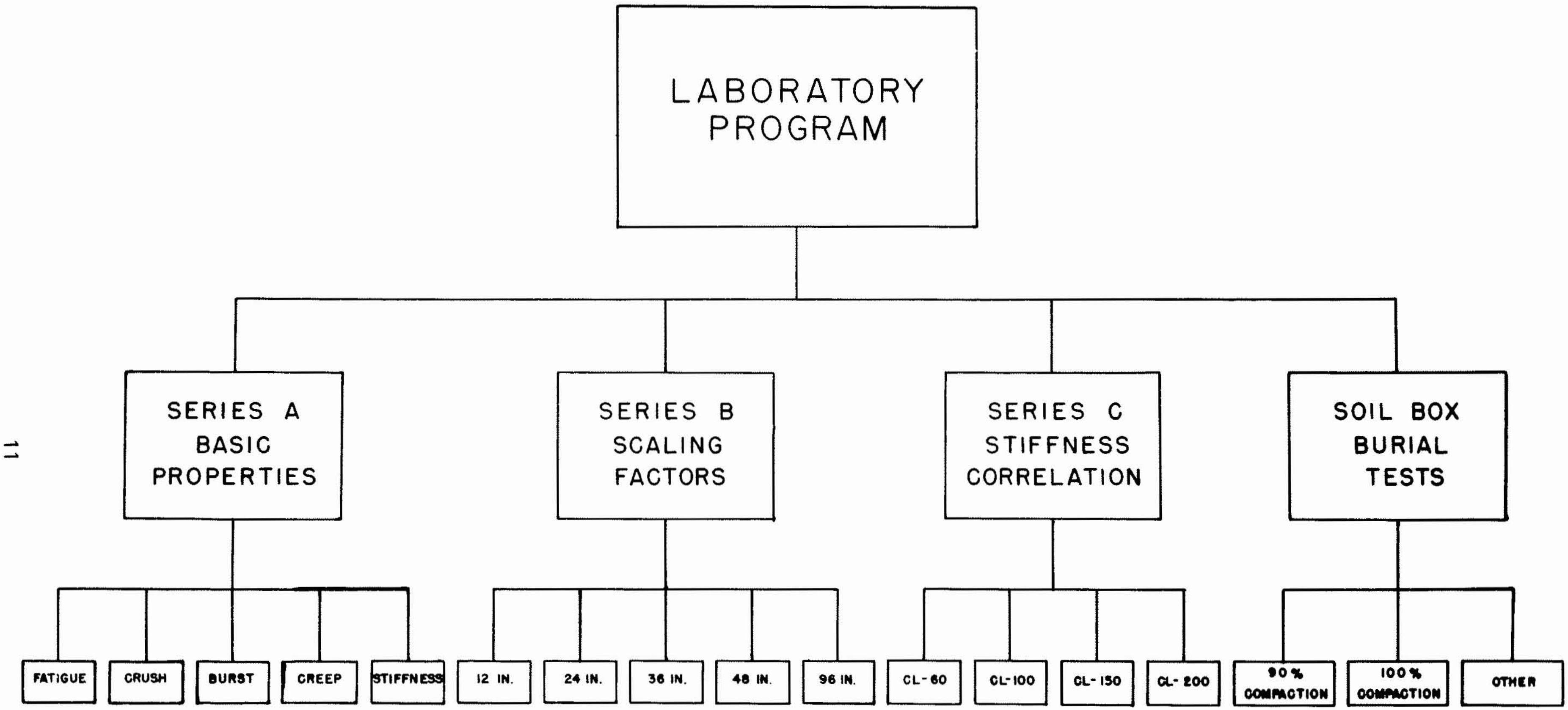


Figure 7. Laboratory program.

solutions for the time periods required for each physical test. The solutions are checked regularly and, when necessary, adjustments made to maintain the required pH. The temperatures of the solutions are the same and remain relatively constant, about 73° F (23° C). The specimens are precisely measured and weighed before exposure and at each time period of test. Specimens are removed from solutions and washed with tap water and stored for 24 hours at about 70° F (21° C). Measurements taken are diameter and length (inches) and hardness (Barcol). After measuring, the specimens are placed in plastic bags for shipment to the industrial participants where specific tests are to be performed. The data taken just prior to test show little or no change occurring during the shipment of samples. At 6 months' and 1 year's exposures there were no measurable dimensional changes, slight increases in weight due to absorption, and slight changes in hardness. There were no significant differences noted among the five solutions, each resulting in similar changes in these data.

1.1. Fatigue Test

Fatigue testing after environmental exposures is being conducted by industry. Two types of tests are being conducted, steady state and cyclic. In the steady state tests the specimen is pressurized to a pressure one-third of the ultimate [in this case, one-third of the ultimate is 310 psi (21.79 kg/sq cm)] and that pressure sustained for 1,000 hours after which the specimen is pressurized to burst. In the cyclic tests the specimens are subjected to a cyclic pressure from zero to one-third ultimate for 250,000 cycles, and then burst. This is well above normal operating pressures and within the normal six to eight safety factor for RPM pipe.

To date the control tests, and the 6-month tests and the 1-year tests have been completed. See data in Table 1. However, some of this work is being repeated due to equipment problems experienced in the early work. The specimens were destroyed without obtaining data. Special equipment was developed for these tests. It is the only piece of equipment of its kind and consequently went through a series of preflight problems, but is now operating satisfactorily.

The data indicate a minimum burst strength retention after both sustained and cyclic pressure loading after immersion in the environmental solutions of about 75 percent, which, as will be seen later, correlates very well with other test data. The mode of failure after fatigue testing was primarily by weeping.

Originally 100,000 pressure cycles were scheduled; however, this was modified to test up to 250,000 cycles. This is roughly equivalent to 125 years' service at 5 cycles per day which probably represents a much more severe service condition than a pipeline would experience during its life. The Bureau currently designs for a 100-year life.

The fatigue tests where equipment failures occurred (controls and 6-month tap water immersion) are being rerun. In addition, tests after 100- and 1,000-hour environmental conditioning are scheduled to better define the ultimate shape of the stress aging curve. At this point the conditioning has been completed and the tests are pending. Tests at various stress levels are also planned to better define the performance properties of the pipe.

1.2 External Load-crush Tests

External load-crush tests are also being conducted by industry. The test is the three-edge bearing test conducted under ASTM: C 497. Load readings are taken at deflections of 5, 10, and 15 percent as well as at ultimate. Of significance at this time are the strength retentions at ultimate after the 1-year immersions in the test solutions. The least retention was 79.5 percent after the distilled water immersion. The others ranged from 84.0 to 87.0 percent retention. The data are shown in Table 2.

1.3 Internal Pressure Tests

Internal pressure tests being conducted by industry are run to evaluate the changes in resistance to leakage and burst strength after exposure.

After 1 year of exposure there is an average strength retention of 69 percent, or still about six times the operating pressure limit. There is no evident trend for the individual environments. The distilled water exposure resulted in the least loss whereas the sulfuric acid showed the greatest loss. The data show good correlation with the data developed in the fatigue tests after 1 year's exposure as far as pressure at ultimate is concerned. However, as was mentioned before, the mode of failure after fatigue stressing was primarily by weeping, whereas the mode of failure in this series was by burst or rupture of the specimen, except in one instance where leakage did occur. Figure 8 shows the before and after photographs of a burst specimen. The data are tabulated in Table 3.

As in the fatigue test series additional data are being

Table 1

FATIGUE TESTS

Material No.	Exposure		Diameter		Length		Weight		Test method*	Failure pressure		Mode and location	Hardness
	Solution	Time	Inches	Centimeters	Inches	Centimeters	Pounds	Grams		psi	kg/cm²		Barcol
14-3	Control		12.02	30.53	11.97	30.40	7.51	3,406	250,000 cycles	700	49.21	Weeped, all over	68
14-9	Control		12.16	30.89	11.82	30.02	7.58	3,438	250,000 cycles	820	57.65	Pipe wall rupture	68
13-6	Control		12.02	30.53	12.03	30.56	**	**	1,000 hours sustained	780	54.84	Pipe wall rupture, center	**
6-7	Tap H_2O	- 0 mo	12.08	30.68	11.98	30.42	6.63	3,008	-	-	-	-	51
		- 6 mo	12.06	30.63	11.96	30.38	6.69	3,034	250,000 cycles	(Cracked at 15,406 cycles)		Test heads were too tight "O" ring pinched pipe causing premature failure	51
1-9	Tap H_2O	- 0 mo	12.02	30.53	11.99	30.45	7.10	3,220	-	-	--		48
		- 6 mo	12.03	30.56	11.95	30.35	7.13	3,235	250,000 cycles	(Cracked at 29,781 cycles)			46
12-5	Tap H_2O	- 0 mo	12.08	30.68	12.05	30.61	7.16	3,248	-	-	-	-	55
		- 6 mo	12.06	30.63	12.02	30.53	7.20	3,264	1,000 hours sustained	900	63.28	Weeped, center	51
7-6	Tap H_2O	- 0 mo	12.10	30.73	12.04	30.58	7.44	3,377	-	-	-	-	49
		- 12 mo	12.09	30.71	11.94	30.33	7.48	3,394	250,000 cycles	400	28.12	Weeped, many places	38
9-6	Tap H_2O	- 0 mo	12.10	30.73	12.08	30.68	7.43	3,370	-	-	-	-	50
		- 12 mo	12.08	30.68	12.00	30.48	7.37	3,342	250,000 cycles	600	42.18	Weeped, small crack center	41
13-10	Tap H_2O	- 0 mo	12.13	30.81	12.09	30.71	6.98	3,164	-	-	-	-	46
		- 12 mo	12.15	30.81	12.08	30.68	7.04	3,192	1,000 hours sustained	780	54.84	***	42
3-9	H_2SO_4	- 0 mo	12.08	30.68	12.03	30.56	7.34	3,328	-	-	-	-	55
		- 6 mo	12.08	30.68	12.03	30.56	7.40	3,355	250,000 cycles	600	42.18	Weeped, crack top	49
5-9	H_2SO_4	- 0 mo	12.07	30.66	12.02	30.53	7.18	3,259	-	-	-	-	56
		- 6 mo	12.07	30.66	12.02	30.53	7.25	3,290	250,000 cycles	800	56.25	Pipe wall rupture, center	50
1-4	H_2SO_4	- 0 mo	12.10	30.73	12.02	30.53	7.36	3,338	-	-	-	-	55
		- 6 mo	12.10	30.73	12.02	30.53	7.36	3,352	1,000 hours	750	52.73	Weeped, all over pipe	48

Table 1 - Continued

Material No.	Exposure		Diameter		Length		Weight		Test method*	Failure pressure		Mode and location	Hardness Barcol
	Solution	Time	Inches	Centimeters	Inches	Centimeters	Pounds	Grams		psi	kg/cm^2		
11-6	H_2SO_4	- 0 mo	12.07	30.66	12.02	30.53	6.96	3,158	-	-	-	-	49
		- 12 mo	12.08	30.68	12.01	30.51	7.02	3,186	250,000 cycles	600	42.18	Pipe wall rupture, center	43
10-6	H_2SO_4	- 0 mo	12.10	30.73	12.03	30.56	7.30	3,310	-	-	-	-	50
		- 12 mo	12.09	30.71	11.99	30.45	7.34	3,330	250,000 cycles	700	49.21	Weeped, one end	39
13-12	H_2SO_4	- 0 mo	12.06	30.63	11.98	30.43	6.89	3,124	-	-	-	-	48
		- 12 mo	12.06	30.63	11.98	30.43	6.95	3,150	1,000 hours sustained	800	56.25	***	42
4-3	NaOH	- 0 mo	12.13	30.81	12.04	30.58	7.42	3,367	-	-	-	-	55
		- 12 mo	12.13	30.81	12.13	30.81	7.48	3,393	250,000 cycles	750	52.73	Weeped, crack center	52
5-3	NaOH	- 0 mo	12.11	30.76	12.02	30.53	7.34	3,332	-	-	-	-	53
		- 6 mo	12.12	30.78	11.99	30.45	7.42	3,366	250,000 cycles	780	54.84	Weeped, crack center	50
1-3	NaOH	- 0 mo	12.09	30.71	12.02	30.53	7.36	3,338	-	-	-	-	52
		- 6 mo	12.09	30.71	12.02	30.53	7.40	3,355	1,000 hours sustained	810	56.95	Weeped, crack center	45
12-6	NaOH	- 0 mo	12.09	30.71	12.06	30.63	7.18	3,257	-	-	-	-	50
		- 12 mo	12.09	30.71	12.02	30.53	7.22	3,272	250,000 cycles	625	43.94	Pipe wall rupture, center	46
10-11	NaOH	- 0 mo	12.05	30.61	12.02	30.53	7.09	3,215	-	-	-	-	46
		- 12 mo	12.07	30.66	12.00	30.48	7.12	3,232	250,000 cycles	675	47.48	Weeped, all over	40
11-9	NaOH	- 0 mo	12.03	30.56	12.02	30.53	7.04	3,193	-	-	-	-	49
		- 12 mo	12.03	30.56	12.02	30.53	7.10	3,219	1,000 hours sustained	775	54.49	***	44
9-13	Dist. H_2O	- 0 mo	12.03	30.56	12.07	30.66	7.75	3,515	-	-	-	-	42
		- 12 mo	12.02	30.53	12.02	30.53	7.78	3,531	250,000 cycles	875	61.52	Pipe wall rupture, center	49
6-13	Dist. H_2O	- 0 mo	12.06	30.63	11.99	30.45	6.68	3,032	-	-	-	-	45
		- 12 mo	12.07	30.66	11.96	30.38	6.75	3,062	250,000 cycles	650	45.70	Weeped, crack center	48
8-13	Dist. H_2O	- 0 mo	12.04	30.63	12.04	30.58	7.30	3,312	-	-	-	-	42
		- 12 mo	12.06	30.63	12.03	30.56	7.36	3,340	1,000 hours sustained	850	59.76	Pipe wall rupture, top	48

Table 1 - Continued

Material No.	Exposure Solution	Exposure Time	Diameter Inches	Diameter Centimeters	Length Inches	Length Centimeters	Weight Pounds	Weight Grams	Test method*	Failure pressure psi	Failure pressure kg/cm²	Mode and location	Hardness Barcol
12-11	Dist. H_2O	- 0 mo	12.12	30.78	12.10	30.73	7.17	3,254	-	-	-	-	50
		- 12 mo	12.06	30.63	12.02	30.53	7.21	3,272	250,000 cycles	600	42.18	Weeped, center	48
7-3	Dist. H_2O	- 0 mo	12.16	30.89	12.08	30.68	7.47	3,390	-	-	-	-	54
		- 12 mo	12.11	30.76	12.03	30.56	7.52	3,412	250,000 cycles	620	43.59	Weeped, center	45
13-9	Dist. H_2O	- 0 mo	12.14	30.84	12.07	30.66	7.06	3,204	-	-	-	-	48
		- 12 mo	12.15	30.86	12.09	30.71	7.13	3,234	1,000 hours sustained	700	49.21	***	43
9-4	Synethic soil	- 0 mo	12.10	30.73	12.05	30.61	7.56	3,430	-	-	-	-	54
	extract	- 6 mo	12.08	30.68	12.00	30.48	7.59	3,442	250,000 cycles	(Weeped at 147,459 cycles)		Weeped, center	48
6-4	Synethic soil	- 0 mo	12.11	30.76	12.02	30.53	7.25	3,288	-	-	-	-	54
	extract	-- 6 mo	12.11	30.76	12.11	30.76	7.30	3,212	250,000 cycles	(Weeped slightly at 231,000 cycles)		Weeped slightly all over	49
1-6	Synethic soil	- 0 mo	12.06	30.63	11.97	30.40	7.20	3,266	-	-	-	-	51
	extract	- 6 mo	12.05	30.61	11.96	30.38	7.22	3,276	1,000 hours sustained	820	57.65	Weeped,mmany places	46
10-4	Synethic soil	- 0 mo	12.11	30.76	12.01	30.51	7.28	3,300	-	-	-	-	56
	extract	- 12 mo	12.11	30.76	11.99	30.45	7.33	3,326	250,000 cycles	550	38.67	Weeped, center	43
7-4	Synethic soil	- 0 mo	12.11	30.76	11.98	30.43	7.56	3,430	-	-	-	-	48
	extract	- 12 mo	12.11	30.76	11.94	30.33	7.60	3,448	250,000 cycles	625	43.94	Weeped, many places	42
4-7	Synethic soil	- 0 mo	12.11	30.76	12.03	30.56	7.51	3,407	-	-	-	-	49
	extract	- 12 mo	12.11	30.76	12.03	30.56	7.57	3,432	1,000 hours sustained	780	54.84	***	44

* At 1/3 ultimate: For 12-inch Cl 60 irrigation pipe, 310 psi (21.79 kg/cm²).
** This measurement was not made.
*** Not reported.

Table 2

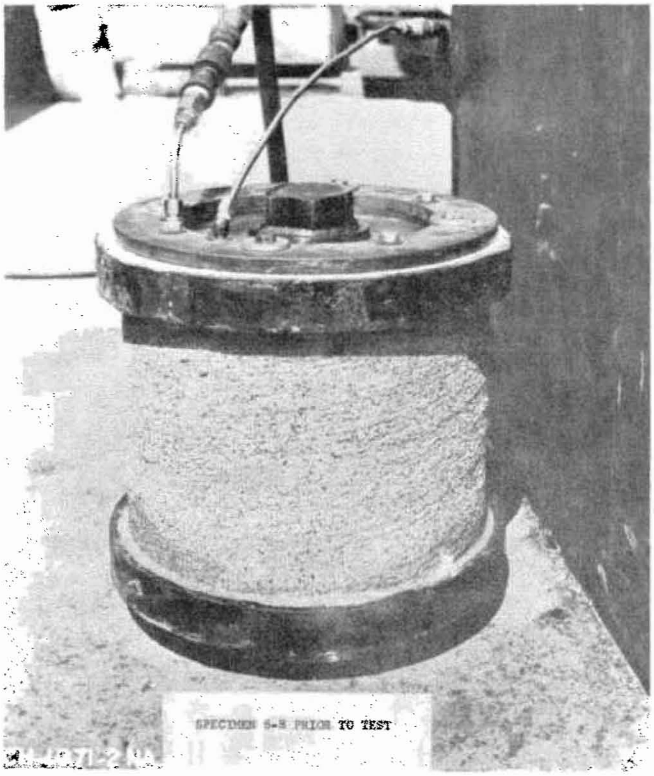
EXTERNAL LOAD - CRUSH TESTS

Material	Exposure		Diameter		Length		Weight		Hardness	Load Versus Deflection							
										5 percent		10 percent		15 percent		Ultimate	
No.	Solution	Time	Inches	Centimeters	Inches	Centimeters	Pounds	Grams	Barcol	Pounds	kg	Pounds	kg	Pounds	kg	Pounds	kg
1-7	Control		12.09	30.71	12.04	30.58	*	*	*	313	142.1	578	262.2	818	371.0	1,650	748.4
3-2	Control		12.05	30.61	12.02	30.53	*	*	*	287	130.2	529	240.0	738	334.8	1,615	732.6
4-11	Control		12.08	30.68	12.00	30.48	*	*	*	287	130.2	526	238.6	728	330.2	1,515	687.2
4-10	NaOH	- 0 mo	12.09	30.71	11.99	30.45	7.36	3,336	52								
		- 12 mo	12.10	30.73	11.97	30.40	7.41	3,362	41	263	119.3	502	227.7	698	316.6	1,350	612.3
6-10	NaOH	- 0 mo	12.09	30.71	11.98	30.43	6.98	3,164	53								
		- 12 mo	12.08	30.68	11.95	30.35	7.07	3,206	48	251	113.9	483	219.1	674	305.7	1,310	594.2
3-4	NaOH	- 0 mo	12.10	30.73	11.94	30.33	7.55	3,425	54								
		- 12 mo	12.16	30.89	11.94	30.33	7.62	3,457	42	287	130.2	577	261.7	780	353.8	1,385	628.2
5-7	Tap H_2O	- 0 mo	12.09	30.71	12.00	30.48	7.15	3,242	44								
		- 12 mo	12.08	30.68	11.94	30.33	7.24	3,284	40	256	116.1	485	220.0	669	303.5	1,320	598.7
9-5	Tap H_2O	- 0 mo	12.07	30.66	12.04	12.58	7.42	3,368	55								
		- 12 mo	12.08	30.68	12.00	30.48	7.46	3,386	45	292	132.4	556	252.2	770	349.3	1,400	635.0
10-5	Tap H_2O	- 0 mo	12.08	30.68	12.01	30.51	7.29	3,308	51								
		- 12 mo	12.10	30.73	11.95	30.35	7.35	3,336	39	267	121.1	470	213.2	704	319.3	1,390	630.5
1-13	Dist. H_2O	- 0 mo	12.02	30.53	11.96	30.38	7.33	3,326	41								
		- 12 mo	12.03	30.56	11.92	30.28	7.37	3,342	44	297	134.7	562	254.9	778	352.9	1,320	598.7
3-13	Dist. H_2O	- 0 mo	12.07	30.65	12.01	30.51	7.26	3,292	49								
		- 12 mo	12.05	30.61	11.90	30.23	7.33	3,325	37	267	121.1	523	237.2	717	325.2	1,280	580.6
5-8	Dist. H_2O	- 0 mo	12.08	30.68	11.99	30.45	7.12	3,232	46								
		- 12 mo	12.10	30.73	11.98	30.43	7.23	3,278	46	255	115.7	483	219.1	668	303.0	1,210	548.8
3-11	Synethic																
	soil	- 0 mo	12.06	30.64	12.02	30.53	7.71	3,496	53								
	extract	- 12 mo	12.08	30.68	11.96	30.38	7.79	3,534	44	294	133.4	552	250.4	756	342.9	1,390	630.5
1-11	Synethic																
	soil	- 0 mo	12.04	30.58	11.99	30.45	7.34	3,328	53								
	extract	- 12 mo	12.04	30.58	11.98	30.43	7.39	3,350	43	293	132.9	558	253.1	773	350.6	1,470	666.8
5-11	Synethic																
	soil	- 0 mo	12.07	30.66	12.02	30.53	7.05	3,196	58								
	extract	- 12 mo	12.06	30.63	12.00	30.48	7.14	3,238	44	252	114.3	486	220.4	672	304.8	1,300	589.7

Table 2 - Continued

Material No.	Exposure Solution	Exposure Time	Diameter Inches	Diameter Centimeters	Length Inches	Length Centimeters	Weight Pounds	Weight Grams	Hardness Barcol	Load Versus Deflection 5 percent Pounds	5 percent kg	10 percent Pounds	10 percent kg	15 percent Pounds	15 percent kg	Ultimate Pounds	Ultimate kg
5-1	H_2SO_4	- 0 mo	12.10	30.73	12.05	30.61	7.21	3,272	54								
		- 12 mo	12.13	30.81	12.01	30.51	7.31	3,318	49	259	117.5	493	223.6	684	310.3	1,230	557.9
9-1	H_2SO_4	- 0 mo	12.13	30.81	12.03	30.56	7.40	3,359	55								
		- 12 mo	12.14	30.84	11.97	30.40	7.45	3,378	48	267	121.1	516	234.1	723	327.9	1,310	594.2
13-1	H_2SO_4	- 0 mo	12.05	30.61	12.07	30.66	7.45	3,378	56								
		- 12 mo	12.07	30.66	12.02	30.53	7.52	3,411	48	296	134.3	562	254.9	783	355.2	1,480	671.3

* These measurements were not made.



A. Before internal pressure test. Photo PX-D-65565

B. After internal pressure test to failure. Photo PX-D-65566

Burst Specimens

Figure 8

Table 3

INTERNAL PRESSURE TESTS

Material No.	Exposure: Solution	Exposure: Time months	Diameter: Inches	Diameter: Centimeters	Length: Inches	Length: Centimeters	Thickness: Inches	Thickness: Centimeters	Weight: Pounds	Weight: Grams	Hardness Barcol	Mode of failure	Failure pressure: psig	Failure pressure: kg/cm^2
E	Control	0	*	*	12.0	30.48	0.24	0.61	7.5	3,400	*	Burst, center	1,050	73.82
F	Control	0	*	*	12.0	30.48	.21	.53	7.5	3,400	*	Burst, near one end	1,050	73.82
G	Control	0	*	*	12.0	30.48	.21	.53	7.7	3,490	*	Burst, center	1,005	70.66
13-8	H_2SO_4	0	12.10	30.73	12.03	30.56	*	*	7.05	3,196	56	-	-	-
	pH-5	12	12.16	30.89	12.10	30.73	.20	.51	7.11	3,227	45	Pipe wall rupture	640	45.00
11-8		0	12.04	30.58	12.05	30.61	*	*	7.03	3,190	60	-	-	-
		12	12.10	30.73	12.08	30.68	.20	.51	7.10	3,220	46	Pipe wall rupture	605	42.54
9-8		0	12.02	30.53	12.04	30.58	*	*	7.20	3,264	53	-	-	-
		12	12.09	30.71	12.07	30.66	.20	.51	7.24	3,284	44	Pipe wall rupture	775	54.49
1-10	NaOH	0	12.04	30.58	12.01	30.51	*	*	7.37	3,342	56	-	-	-
	pH-9	12	12.10	30.73	12.01	30.51	.20	.51	7.41	3,360	42	Pipe wall rupture	825	58.00
3-10		0	12.06	30.63	12.01	30.51	*	*	7.48	3,393	56	-	-	-
		12	12.13	30.81	12.04	30.58	.20	.51	7.56	3,428	43	Pipe wall rupture	750	52.73
10-3		0	12.09	30.71	12.01	30.51	*	*	7.41	3,361	56	-	-	-
		12	12.17	30.91	12.07	30.66	.20	.51	7.45	3,380	45	Pipe pressurized to 625 psig; leak developed. Leaked 0.25 gal/min at 240 psig	625	43.94
7-11	Synthetic	0	12.05	30.61	12.02	30.53	*	*	7.64	3,463	48	-	-	-
	soil	12	12.12	30.78	12.05	30.61	.20	.51	7.67	3,479	44	Pipe wall rupture	725	50.97
3-6	extract	0	12.10	30.73	11.99	30.45	*	*	7.44	3,376	55	-	-	-
		12	12.16	30.89	12.02	30.53	.20	.51	7.52	3,409	48	Pipe wall rupture	550	38.67
4-6		0	12.12	30.78	12.02	30.53	*	*	7.49	3,399	51	-	-	-
		12	12.18	30.94	12.07	30.66	.20	.51	7.56	3,430	43	Pipe wall rupture	835	58.71
3-7	Denver	0	12.10	30.73	11.98	30.43	*	*	7.38	3,346	47	-	-	-
	tap	12	12.15	30.86	12.02	30.53	.20	.51	7.44	3,376	50	Pipe wall rupture	735	51.68
8-6	water	0	12.12	30.78	12.03	30.56	*	*	7.51	3,408	52	-	-	-
		12	12.18	30.94	12.06	30.63	.20	.51	7.58	3,440	44	Pipe wall rupture	620	43.59
11-5		0	12.08	30.68	12.08	30.68	*	*	7.01	3,180	52	-	-	-
		12	12.15	30.86	12.13	30.81	.20	.51	7.08	3,212	45	Pipe wall rupture	690	48.51
4-8	Distilled	0	12.10	30.73	12.02	30.53	*	*	7.44	3,376	48	-	-	-
	water	12	12.17	30.91	12.07	30.66	.20	.53	7.51	3,406	45	Pipe wall rupture	765	53.78
9-7		0	12.05	30.61	12.04	30.58	*	*	7.32	3,318	46	-	-	-
		12	12.11	30.76	12.08	30.68	.20	.53	7.35	3,336	45	Pipe wall rupture	800	56.25
6-8		0	12.07	30.66	11.95	30.35	*	*	6.79	3,080	44	-	-	-
		12	12.12	30.78	12.00	30.48	.20	.53	6.87	3,118	45	Pipe wall rupture	750	52.73

* These measurements were not made.

taken at 100 and 1,000 hours to better define the stress-aging curve, but are not yet available at this time. The stress-aging curve mentioned at several points in this report is merely a plot of the stress or change in a measurement under any particular test versus the log of time. It affords a reliable means of predicting the long-term performance of materials, and is particularly useful with plastics where the majority of the change occurs in a relatively short time. One type of stress-aging curve is as shown in Figure 9.

The initial and 1-year data are Points A and B. The additional tests define the data for Points C and D and the 2-year results for Point E. The long-term performance as a result of the environment is predictable by extrapolating the curve to the right.

1.4 Creep Tests

Creep tests are being conducted by the Bureau. The purpose is to evaluate the creep characteristics of RPM pipe with and without the influence of the test solutions. Creep, in this instance, is the increase in deflection with time under a fixed load. In this regard, it is emphasized that this is strictly a study of a property of the pipe and in no way should the results be related to inservice performance. The tests without side support are not comparable to an in-ground pipe-soil system.

Two tests are being run: Creep from an initial 5 percent deflection and creep from an initial 10 percent deflection. Specimens are being tested in air and in the five solutions previously described. Data are presented in Table 4.

The stress-aging diagrams are shown in Figures 10 through 15. Note that in this case, the deflection under constant load is plotted versus log of time, in which case the slope of the line is positive. This is another type of aging diagram. New tests are being run where failures have been noted.

1.5 Stiffness Factor Tests

Stiffness factor tests are being run by industry after environmental exposure by the Bureau. In this instance, there is a major change in procedure. In all other cases, pipe specimens are exposed and each individual specimen then tested to destruction. For stiffness, one set of specimens is being tested repeatedly. At each time interval, the specimens are removed from the solutions and tested to 5 percent deflection. After testing, the specimens are returned to the solutions for further exposure. The specimens are being tested at 6-month intervals. In addition to the solution exposures, one set of specimens is being exposed to a freeze-thaw environment. Stiffness is tested by the parallel plate method under ASTM: D 2412.

At 5 percent deflection there is about a 14 percent loss in stiffness after 1 year of exposure to all environments. The percent reduction in stiffness decreases as the deflection increases, and there is much less stiffness loss during the last 6 months of exposure than during the first 6 months.

The following tabulation shows the average percent reduction in stiffness for all specimens:

Stiffness—Average results

Time	Average percent reduction in stiffness at deflections of				
	1 percent	2 percent	3 percent	4 percent	5 percent
6 months	21.0	17.5	13.9	12.1	10.4
1 year	24.1	19.0	16.5	16.5	13.6

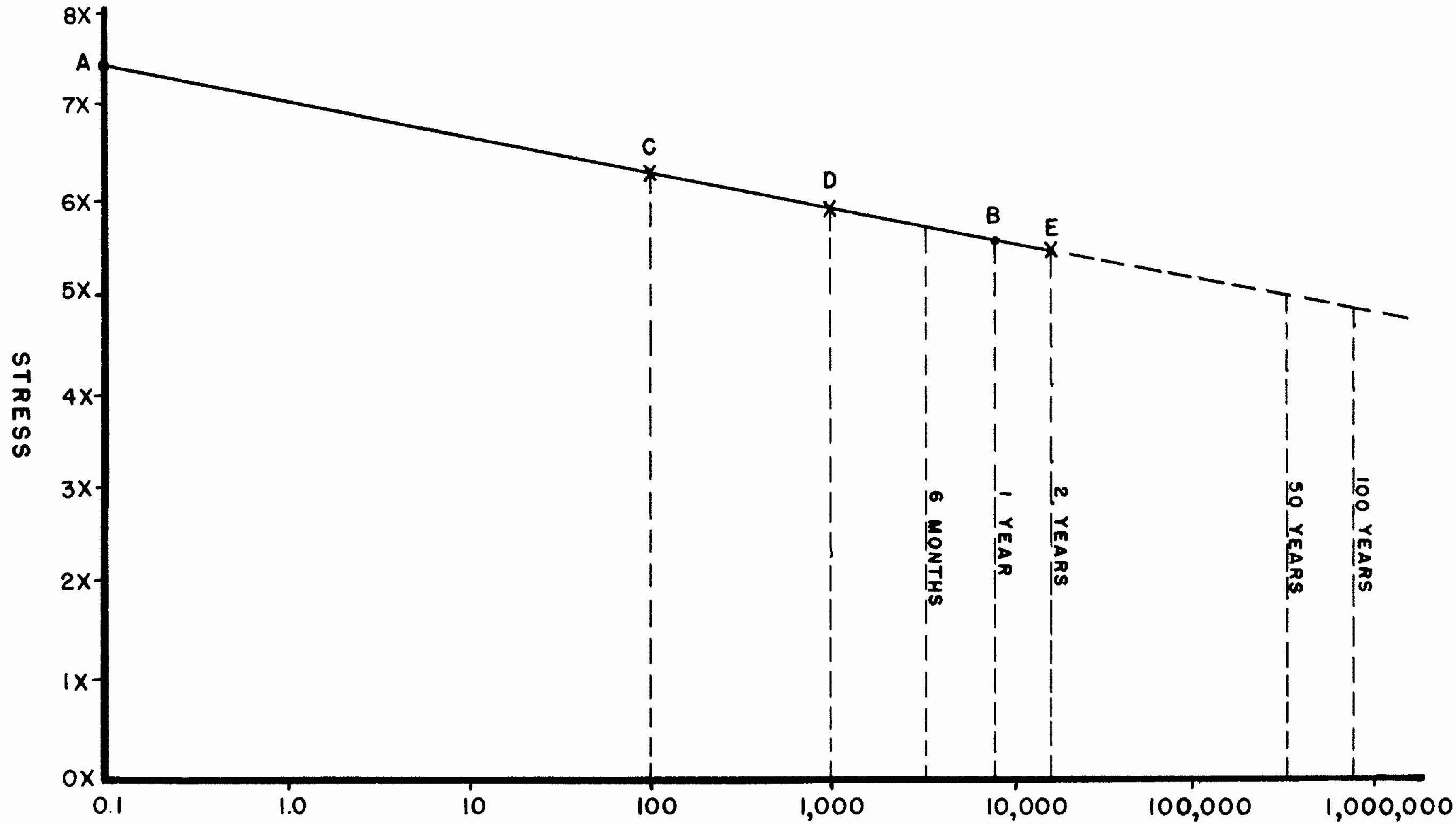


Figure 9. Time-hours. Stress-aging.

Table 4

CREEP

Environment	Initial deflection percent	1-year deflection percent
Air (dry)	9.8	14.0
	5.0	6.5
	5.0	6.8
NaOH	10.0	14.9
	5.0	7.3
	5.1	7.5
H_2SO_4	10.4	*15.7
	5.0	7.2
	5.0	7.6
Synthetic soil extract	10.6	15.4
	5.1	7.8
	4.7	7.0
Distilled H_2O	10.4	*15.7
	4.6	6.7
	5.0	7.7
Tap H_2O	9.9	16.2
	5.2	7.8
	5.1	7.5
Average for five test solutions	10.2	**15.6
	4.8	7.8

* Six-month deflection - specimen failed between 6- and 9-month readings.
** Including specimens which failed.

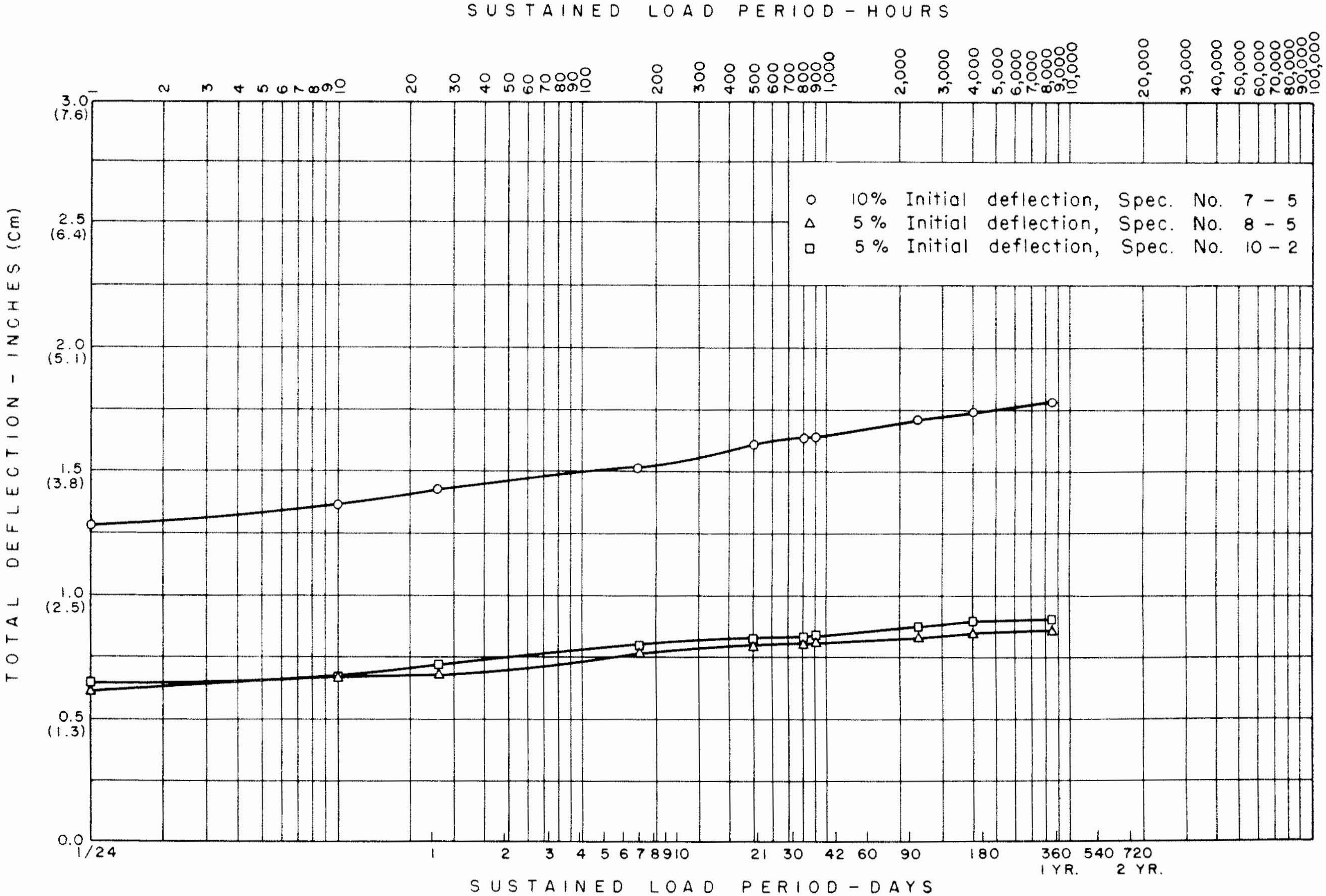


Figure 10. Creep test–Reinforced plastic mortar pipe. Test environment NaOH pH 9.

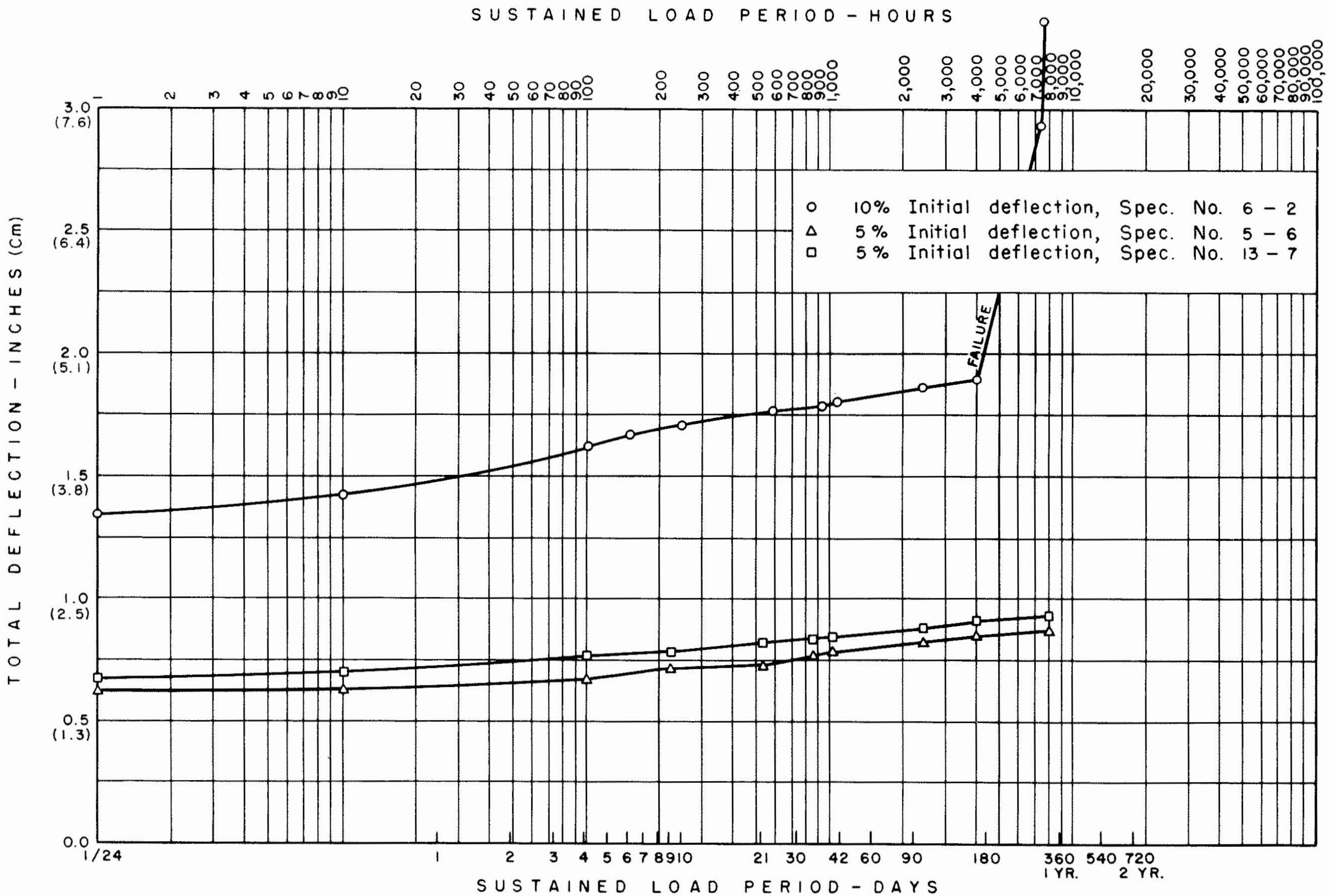


Figure 11. Creep test—Reinforced plastic mortar pipe. Test environment H_2SO_4 pH 5.

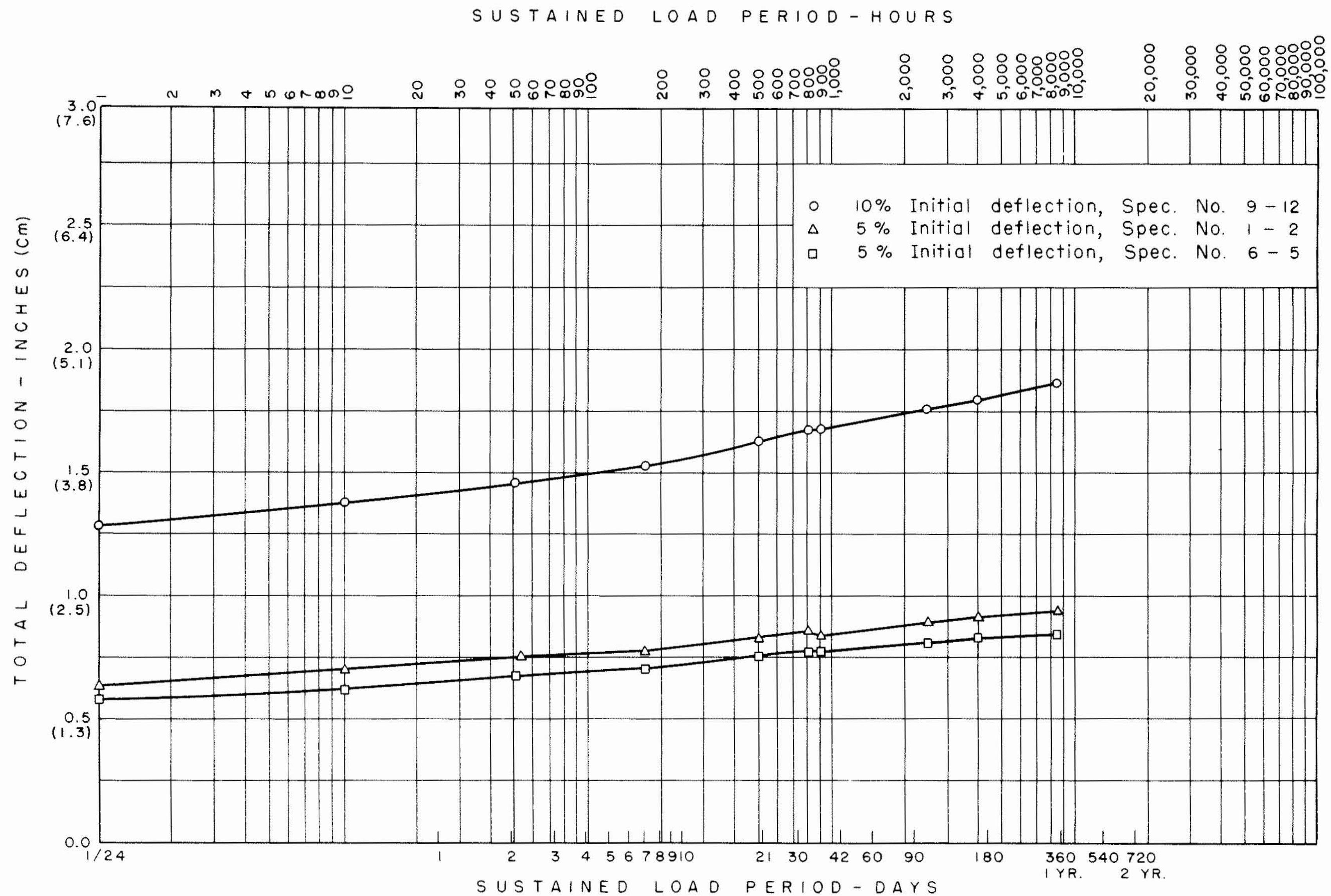
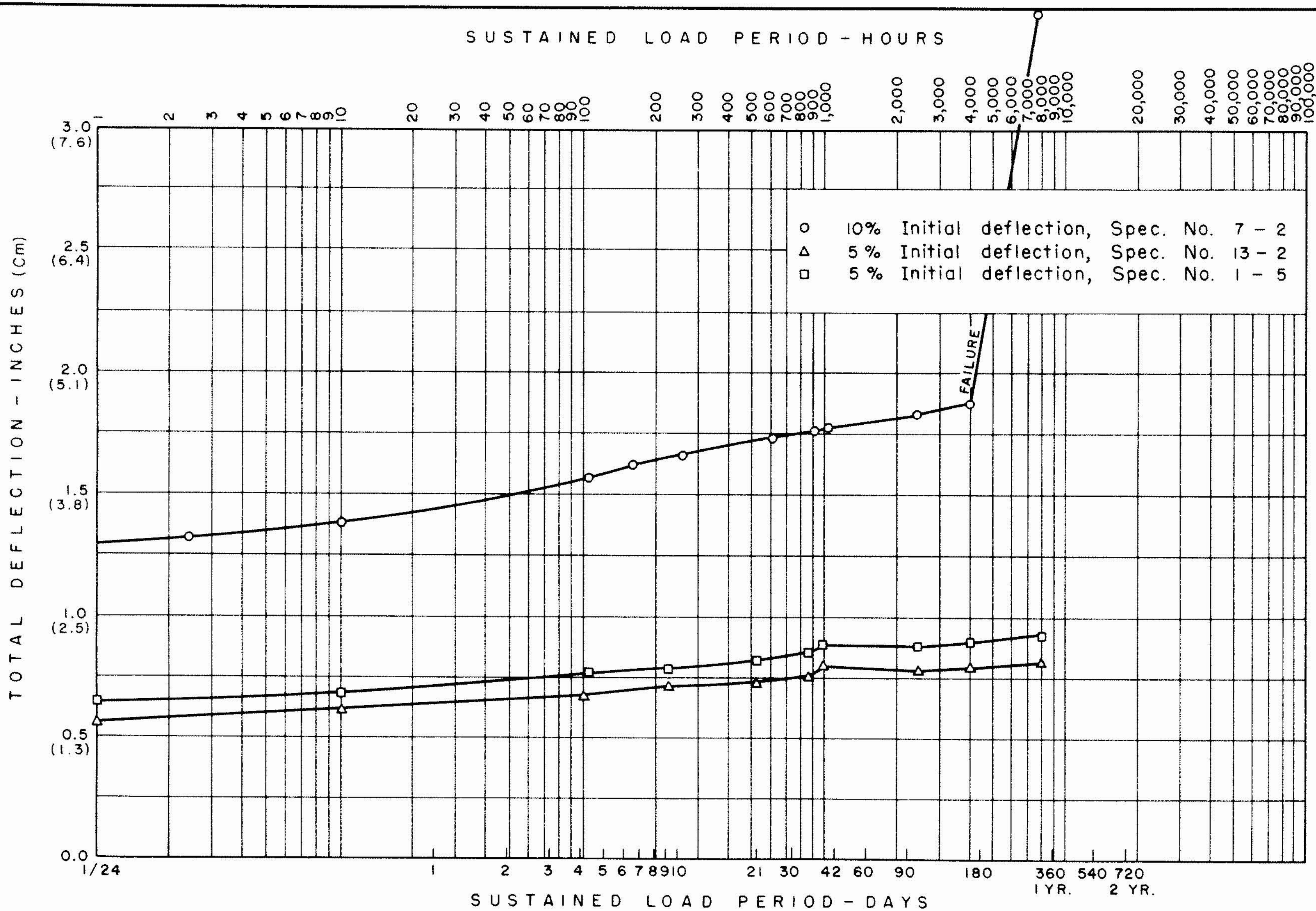


Figure 12. Creep test—Reinforced plastic mortar pipe. Test environment soil extract.



CREEP TEST - REINFORCED PLASTIC MORTAR PIPE

Figure 13. Creep test—Reinforced plastic mortar pipe. Test environment distilled water.

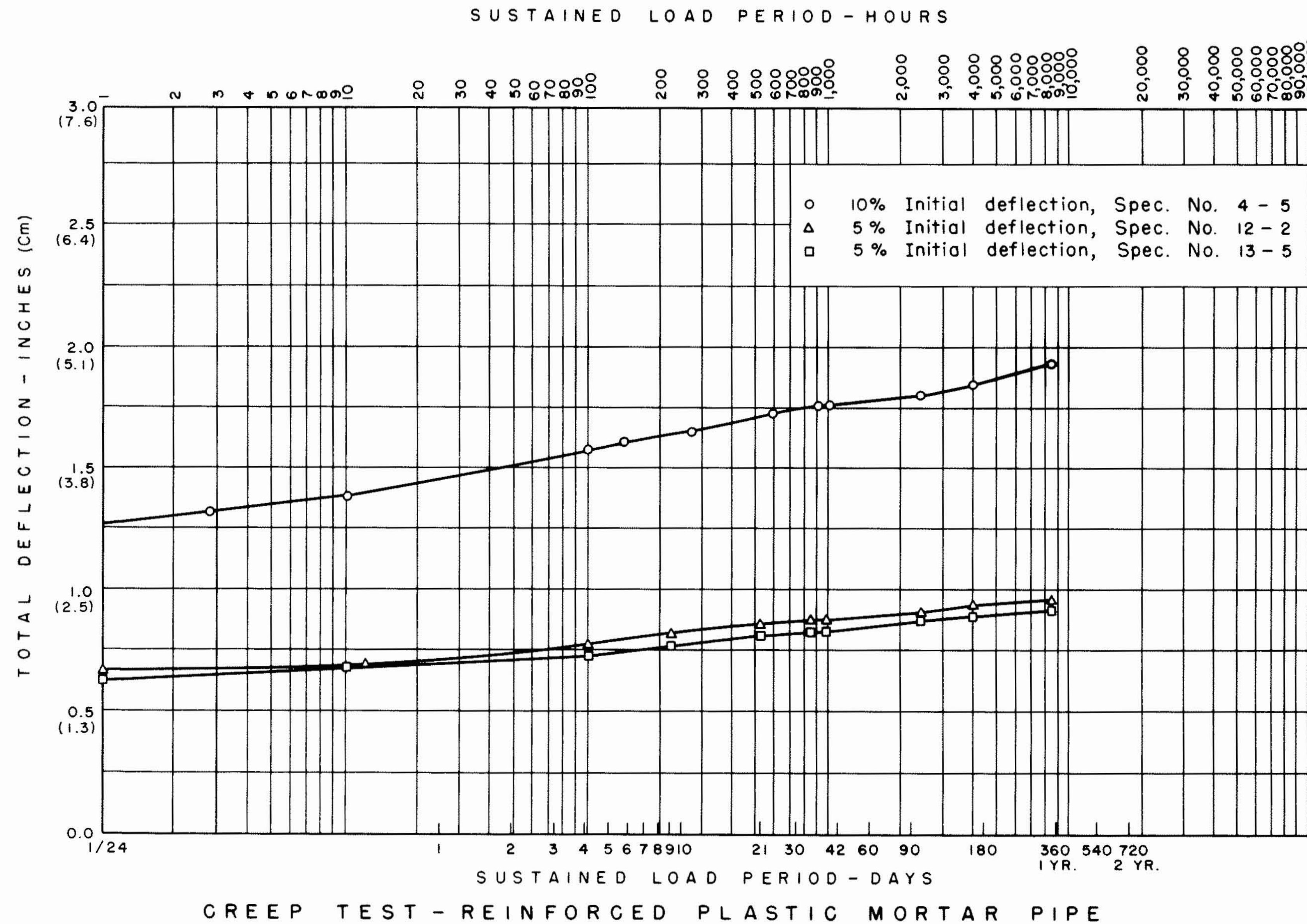


Figure 14. Creep test—Reinforced plastic mortar pipe. Test environment tap water.

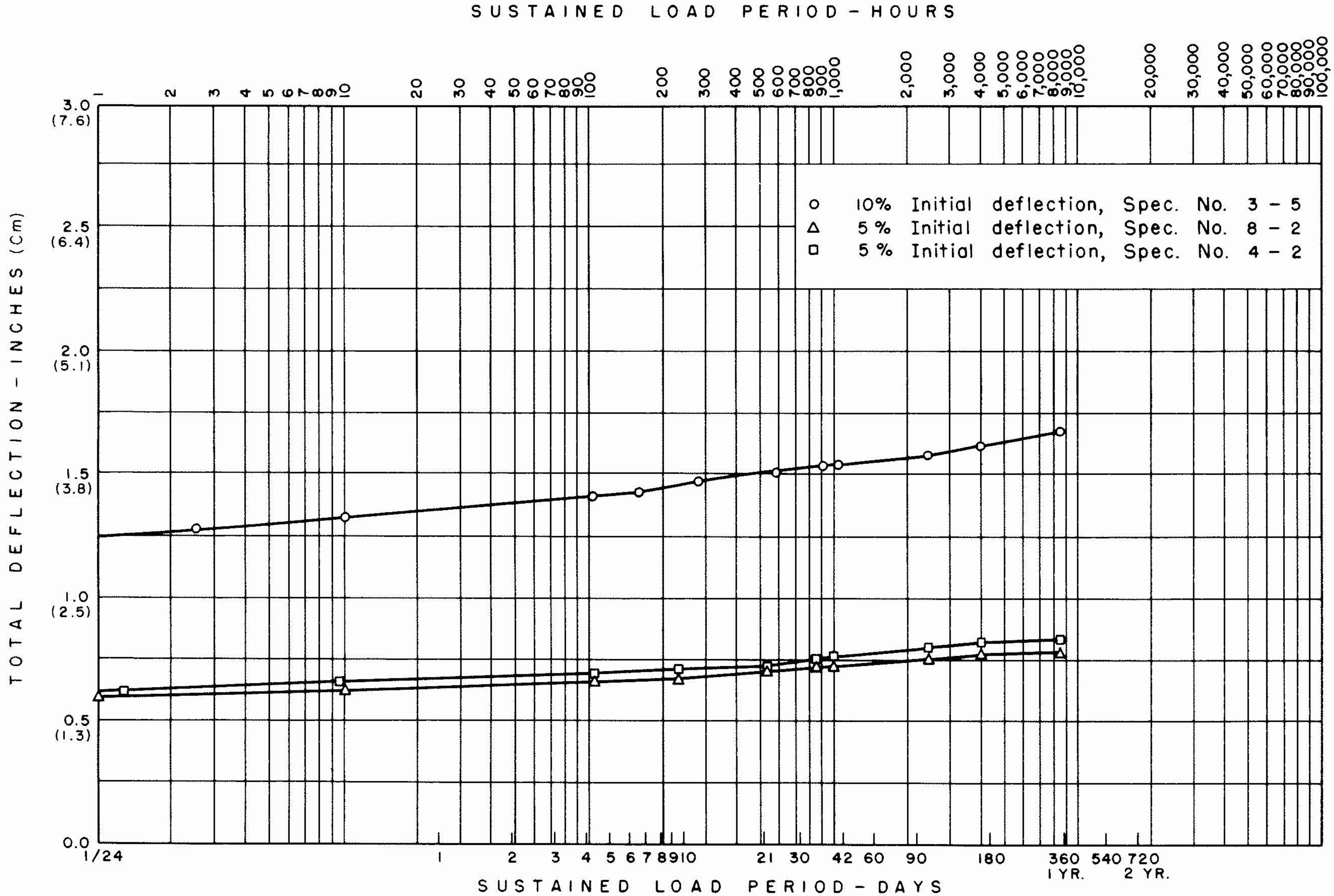


Figure 15. Creep test—Reinforced plastic mortar pipe. Test environment air.

The percent reductions in stiffness for each environment, based on the load and not on the stiffness factor, are as follows:

Environment	Time	Average percent reduction in stiffness at deflections of 1 percent	2 percent	3 percent	4 percent	5 percent
Control	14 months					
H_2SO_4	6 months	10.9	9.1	9.3	10.4	6.9
	1 year	22.6	17.4	14.6	12.7	15.1
NaOH	6 months	14.5	13.7	11.8	9.9	8.2
	1 year	27.3	21.3	18.0	16.1	13.1
Synthetic soil	6 months	18.3	18.3	14.9	13.0	11.7
extract	1 year	19.1	19.6	16.8	15.3	14.1
Tap H_2O	6 months	25.2	16.8	13.7	11.9	11.4
	1 year	28.7	18.3	15.3	13.3	12.5
Distilled H_2O	6 months	27.6	27.6	17.0	13.8	12.1
	1 year	26.0	19.8	17.2	15.1	14.0
Freeze-thaw	6 months	29.5	19.4	16.8	13.5	11.5
	1 year	20.9	17.8	16.9	13.8	12.7

Complete data are shown in Table 5 and plotted in Figures 16 through 22. Since these tests were performed on the same specimen at each time interval the results are especially significant. It is noted that no particular effects were evident after the freeze-thaw exposure.

No fatigue or internal pressure tests have been completed as yet in this series.

A detailed evaluation of the available data has not been made since only data from one test procedure are available.

2. Series B—Scaling Factors

This series of tests was established in an attempt to determine if performance of large-diameter pipe can be correlated to performance of small-diameter pipe. If similar performance is found, scaling factors may be established. Such scaling factors would allow some insight into the probable behavior of larger pipe in some of the other tests.

Data on 12-inch (30.48-cm) diameter pipe are generated in Series A tests. In this series, B, 24-, 36- and 48-inch (60.96-, 91.44-, and 121.92-cm) diameter Cl-60 pipes are being tested in external load-crush tests, fatigue tests, and internal pressure (burst) tests. In addition a section of 96-inch (243.84-cm) pipe will be tested in external load. Creep characteristics will also be evaluated.

At this time, industry has completed external load-crush tests by the three-edge bearing method on three specimens each of 24-, 36-, and 48-inch (60.96-, 91.44-, and 121.92-cm) pipe. Data were recorded at 5, 10, and 15 percent deflections, and at ultimate. Data are shown in Table 6.

3. Series C—Stiffness Correlation

This series was initiated to evaluate the stiffness factor of various classes of pipe in one particular size of pipe. The 24-inch (60.96-cm) size of pipe was selected, and tests have been run by industry on this size of Cl-60, Cl-100, Cl-150, and Cl-200 pipes. Parallel plate loading is the test method and data are recorded at 5, 10, and 15 percent deflections.

The modulus of elasticity is relatively constant up to 5 percent deflections, and independent of class of pipe (glass content). The modulus ranged from 2.3 to 2.8 million with an average of about 2.6 million. The modulus is affected at deflections greater than 5 percent. Data are shown in Table 7 and Figures 23 to 25.

As would be expected from the equation for Stiffness Factor, stiffness varies with wall thickness. A small change in "E" (of EI) results in only a small change in stiffness, but a small change in thickness results in a relatively larger change in stiffness.

Table 5

STIFFNESS FACTOR TESTS

Material No.	Exposure		Diameter		Length		Weight		Hard-ness	Load Versus Deflection									
										1 percent		2 percent		3 percent		4 percent		5 percent	
	Solution	Time months	Inches	Centi-meters	Inches	Centi-meters	Pounds	Grams	Barcol	Pounds	kg	Pounds	kg	Pounds	kg	Pounds	kg	Pounds	kg
8-4	Control	0	*	*	12.00	30.48	7.41	3,361.1	*	71	32.2	145	65.8	224	101.6	294	133.4	352	159.7
		14	*	*	11.99	30.45	7.40	3,356.6	*	73	33.1	143	64.9	210	95.3	274	124.3	333	151.0
A	Control	0	*	*	12.12	30.78	7.05	3,197.8	*	67	30.4	138	62.6	209	94.8	270	122.5	315	142.9
		14	*	*	12.02	30.53	7.00	3,175.1	*	62	28.1	128	58.1	192	87.1	250	113.4	304	137.9
C	Control	0	*	*	11.94	30.32	7.24	3,284.0	*	72	32.7	145	65.8	221	100.2	282	127.9	331	150.1
		14	*	*	11.96	30.37	7.24	3,284.0	*	69	31.3	137	62.1	200	90.7	262	118.8	319	144.7
1-1	H_2SO_4	0	12.12	30.78	12.11	30.76	7.64	3,463	45	88	39.9	167	75.7	242	109.8	310	140.6	375	170.1
	pH-5	6	12.12	30.78	12.06	30.63	7.68	3,482	49	60	27.2	137	62.1	209	94.8	247	112.0	338	153.3
		12	12.12	30.78	12.08	30.68	7.67	3,477	48	68	30.8	139	63.0	205	93.0	268	121.2	326	147.9
3-3	H_2SO_4	0	12.12	30.78	11.97	30.40	7.62	3,456	49	86	39.0	163	73.9	233	105.7	299	135.6	361	163.7
		6	12.12	30.78	11.94	30.33	7.68	3,486	47	76	34.5	145	65.8	214	97.1	276	125.2	334	151.5
		12	12.13	30.81	11.99	30.45	7.68	3,483	44	64	29.0	134	60.8	199	90.3	261	118.4	318	144.2
4-4	H_2SO_4	0	12.13	30.81	12.06	30.63	7.46	3,382	51	82	37.2	154	69.9	221	100.2	283	128.4	341	154.7
		6	12.13	30.81	12.04	30.58	7.50	3,401	46	92	41.7	158	71.7	208	94.3	276	125.2	331	150.1
		12	12.15	30.86	12.03	30.56	7.50	3,402	44	63	28.6	127	57.6	190	86.2	250	113.4	307	139.3
5-5	NaOH	0	12.10	30.73	12.05	30.61	7.18	3,256	52	75	34.0	143	64.9	204	92.5	262	118.8	316	143.3
	pH-9	6	12.10	30.73	12.01	30.51	7.23	3,282	49	67	30.4	127	57.6	182	82.6	235	106.6	288	130.6
		12	12.12	30.78	12.04	30.58	7.25	3,287	41	58	26.3	117	53.1	173	78.5	226	102.5	276	125.2
6-6	NaOH	0	12.09	30.71	12.06	30.63	7.18	3,258	46	78	35.4	149	67.6	214	97.1	276	125.2	332	150.6
		6	12.09	30.71	12.04	30.58	7.24	3,284	46	54	24.5	118	53.5	180	81.6	236	107.0	290	131.5
		12	12.09	30.71	12.03	30.56	7.25	3,290	35	57	25.9	118	53.5	176	79.8	232	105.2	283	128.4
7-7	NaOH	0	12.08	30.68	12.00	30.48	7.24	3,286	44	74	33.6	154	69.9	225	102.1	292	132.4	335	152.0
		6	12.08	30.68	11.98	30.43	7.27	3,296	48	73	33.1	140	63.5	205	93.0	277	125.6	324	147.0
		12	12.09	30.68	12.00	30.48	7.26	3,292	44	50	22.7	116	52.6	178	80.7	238	108.0	295	133.8
7-8	Synethic	0	12.08	30.68	12.00	30.48	7.38	3,347	49	85	38.6	164	74.4	238	108.0	309	140.2	375	170.1
	soil	6	12.08	30.68	11.98	30.43	7.41	3,361	48	58	26.3	130	59.0	198	89.8	264	119.7	327	148.3
	extract	12	12.08	30.68	12.05	30.61	7.40	3,359	45	54	24.5	124	56.2	190	86.2	254	115.2	314	142.4
8-8	Synethic	0	12.12	30.78	12.00	30.48	7.32	3,322	47	81	36.7	153	69.4	221	100.2	285	129.3	345	156.5
	soil	6	12.12	30.78	12.00	30.48	7.38	3,347	47	53	24.0	119	54.0	182	82.6	244	110.7	299	135.6
	extract	12	12.17	30.91	12.06	30.63	7.38	3,348	47	64	29.0	128	58.1	187	84.8	244	110.7	299	135.6
10-10	Synethic	0	12.04	30.58	12.02	30.53	7.26	3,292	45	80	36.3	152	68.9	218	98,9	281	127.5	338	153.3
	soil	6	12.08	30.68	12.00	30.48	7.29	3,307	45	70	31.8	134	60.8	196	88.9	253	114.8	308	139.7
	extract	12	12.13	30.81	12.12	30.78	7.29	3,308	41	61	27.7	125	56.7	186	84.4	243	110.2	296	134.3

Table 5 - Continued

Material No.	Exposure Solution	Exposure Time months	Diameter Inches	Diameter Centi-meters	Length Inches	Length Centi-meters	Weight Pounds	Weight Grams	Hard-ness Barcol	Load Versus Deflection 1 percent Pounds	1 percent kg	2 percent Pounds	2 percent kg	3 percent Pounds	3 percent kg	4 percent Pounds	4 percent kg	5 percent Pounds	5 percent kg
7-9	Tap water	0	12.07	30.66	12.01	30.51	7.35	3,334	43	82	37.2	156	70.8	230	104.3	298	135.2	365	165.6
		6	12.08	30.68	12.01	30.51	7.39	3,350.5	51	52	23.6	123	55.8	191	86.6	256	116.1	317	143.8
		12	12.14	30.84	12.09	30.71	7.38	3,349.5	44	60	27.2	132	60.0	200	90.7	264	119.7	323	146.5
11-11	Tap water	0	12.07	30.66	12.00	30.48	7.12	3,227.5	49	74	33.6	141	64.0	203	92.1	263	119.3	319	144.7
		6	12.05	30.61	12.00	30.48	7.16	3,249.0	48	54	24.5	116	52.6	175	79.4	231	104.8	278	126.1
		12	12.10	30.73	12.09	30.71	7.17	3,252.5	46	55	24.9	118	53.5	176	79.8	332	105.2	285	129.3
12-12	Tap water	0	12.07	30.66	12.05	30.61	7.15	3,242.5	45	74	33.6	144	65.3	209	94.8	269	122.0	326	147.9
		6	12.07	30.66	12.03	30.56	7.18	3,254.5	48	66	29.9	128	58.1	188	85.3	244	110.7	300	136.1
		12	12.13	30.81	12.12	30.78	7.17	3,251.0	40	49	22.2	110	49.9	168	76.2	224	101.6	276	125.2
7-1	Distilled water	0	12.11	30.76	12.07	30.66	7.90	3,583.0	46	104	47.2	197	89.4	285	129.3	363	164.7	435	197.3
		6	12.12	30.78	12.05	30.61	7.94	3,603.5	45	80	36.3	161	73.0	241	109.3	316	143.3	388	176.0
		12	12.18	30.94	12.13	30.81	7.95	3,606.5	44	69	31.3	150	68.0	225	102.1	298	135.2	366	166.0
9-9	Distilled water	0	12.05	30.61	12.01	30.51	7.16	3,246.0	43	76	34.5	148	67.1	218	98.9	281	227.5	338	153.3
		6	12.04	30.58	12.00	30.48	7.19	3,261.0	46	54	24.5	116	52.6	180	81.6	245	111.1	305	138.3
		12	12.10	30.73	12.07	30.66	7.19	3,260.0	45	57	25.9	121	54.9	183	83.0	243	110.2	299	135.6
13-13	Distilled water	0	12.08	30.68	12.04	30.58	6.89	3,126.0	44	67	30.4	131	59.4	193	87.5	251	113.9	307	139.2
		6	12.08	30.68	12.01	30.51	6.94	3,146.5	46	45	20.4	101	45.8	157	71.2	211	95.7	262	118.8
		12	12.14	30.84	12.08	30.68	6.95	3,151.5	44	57	25.9	113	51.3	167	75.4	220	99.8	269	122.0
7-10	Freeze-thaw	0	12.08	30.68	12.02	30.53	7.38	3,345	46	83	37.6	160	72.6	235	106.6	303	137.4	369	167.4
		6	12.08	30.68	12.02	30.53	7.34	3,331	48	55	24.9	125	56.7	192	87.1	256	116.1	319	144.7
		12	12.13	30.81	12.06	30.63	7.33	3,326	46	63	28.6	134	60.8	200	90.7	263	119.3	323	146.5
8-1	Freeze-thaw	0	12.15	30.86	12.03	30.53	7.34	3,329	51	81	36.7	153	69.4	221	100.2	285	129.3	344	156.0
		6	12.15	30.86	12.00	30.48	7.31	3,317	49	54	24.5	119	54.0	183	83.0	244	110.7	301	136.5
		12	12.20	30.99	12.06	30.63	7.31	3,315	47	57	25.9	120	54.4	180	81.6	239	108.4	295	133.8
10-1	Freeze-thaw	0	12.12	30.78	12.00	30.48	7.33	3,325.5	47	70	31.8	141	64.0	216	98.0	271	122.9	328	148.8
		6	12.12	30.78	12.00	30.48	7.31	3,316.5	48	56	25.4	122	55.3	184	83.5	244	110.7	300	136.1
		12	12.18	30.94	12.07	30.66	7.30	3,313.5	50	55	24.9	119	54.0	178	80.7	238	108.0	291	132.0

* These measurements were not made.

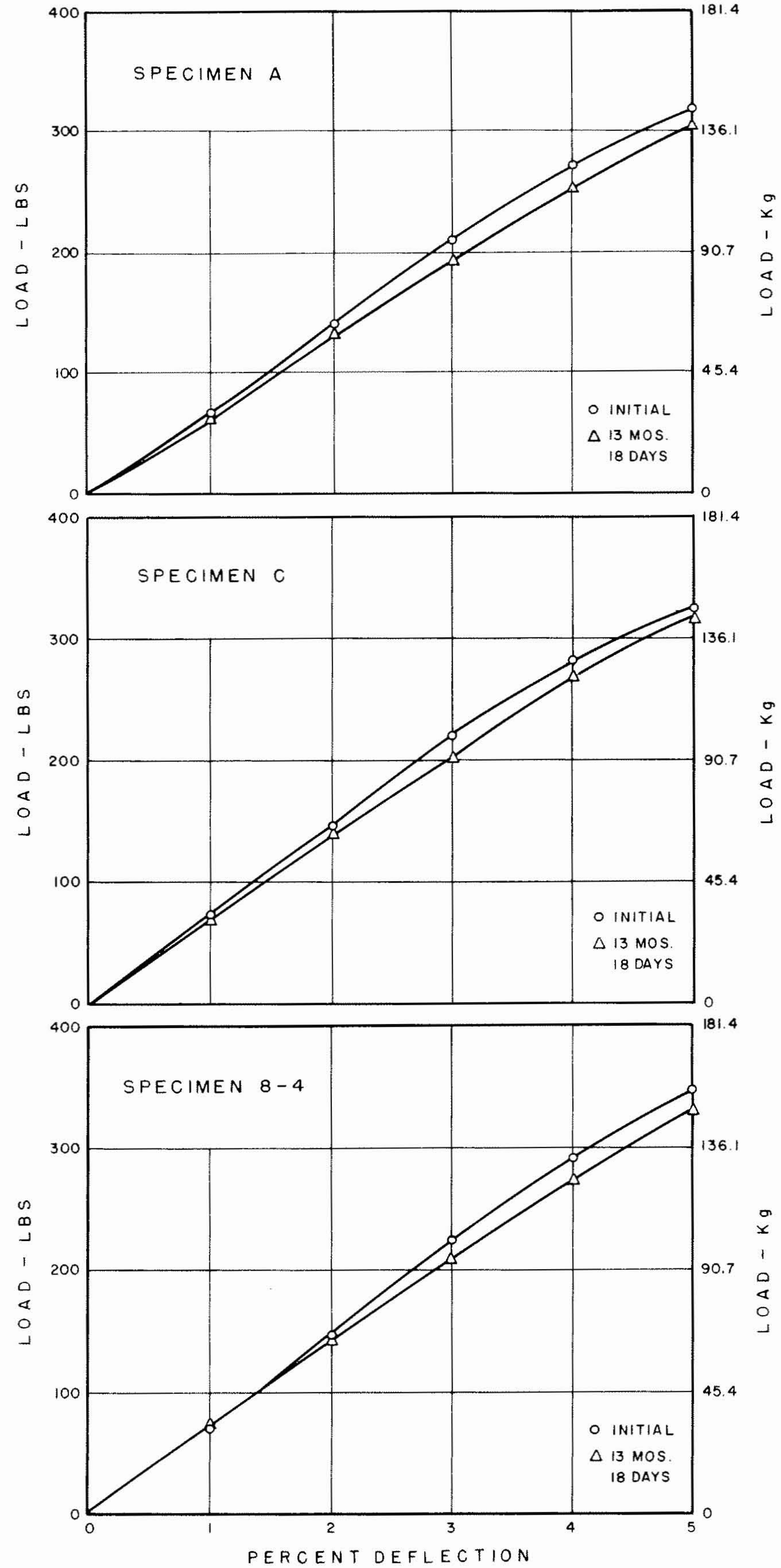


Figure 16. Load vs deflection–control.

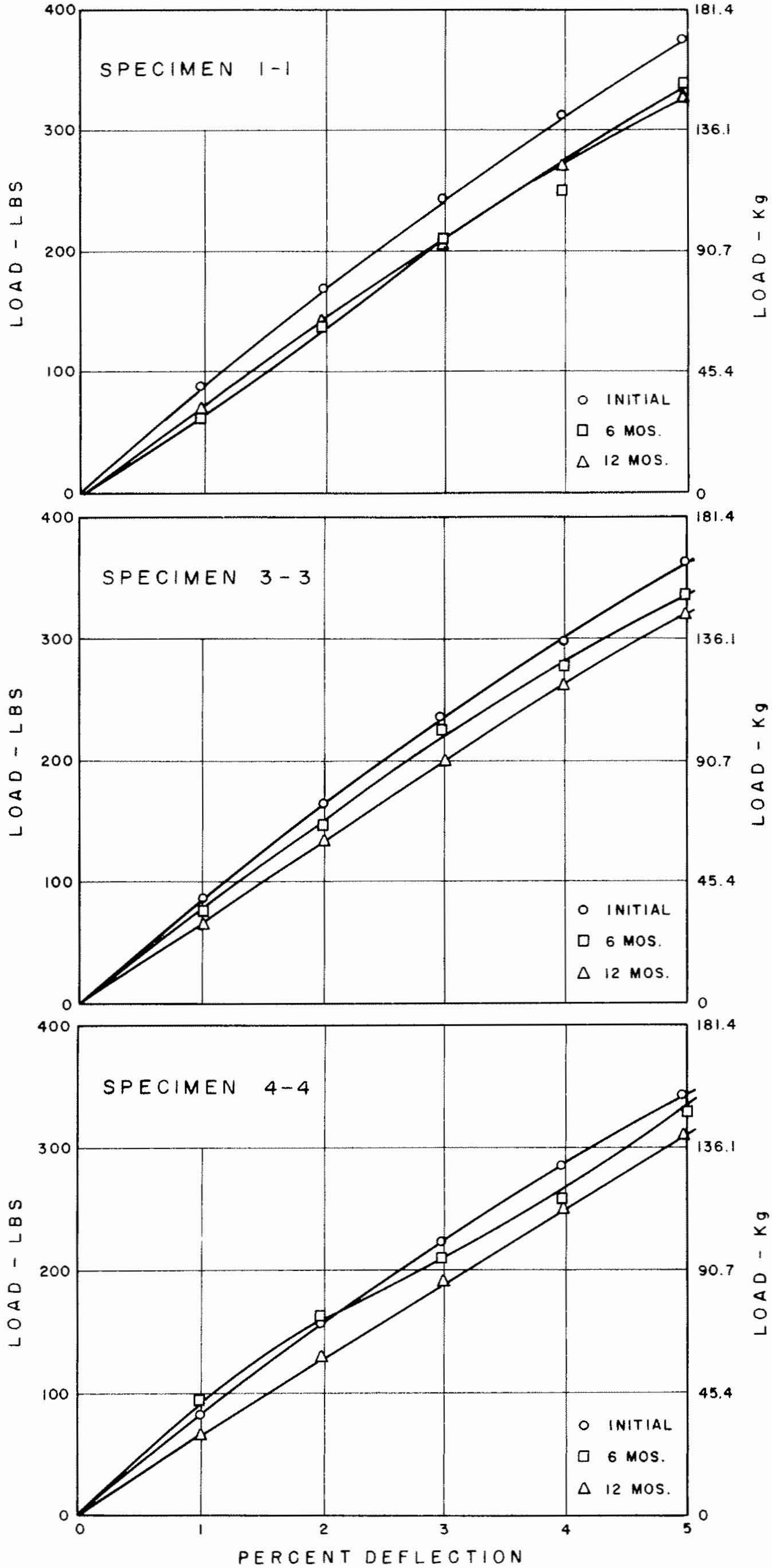


FIGURE 17–LOAD VS DEFLECTION, H_2SO_4

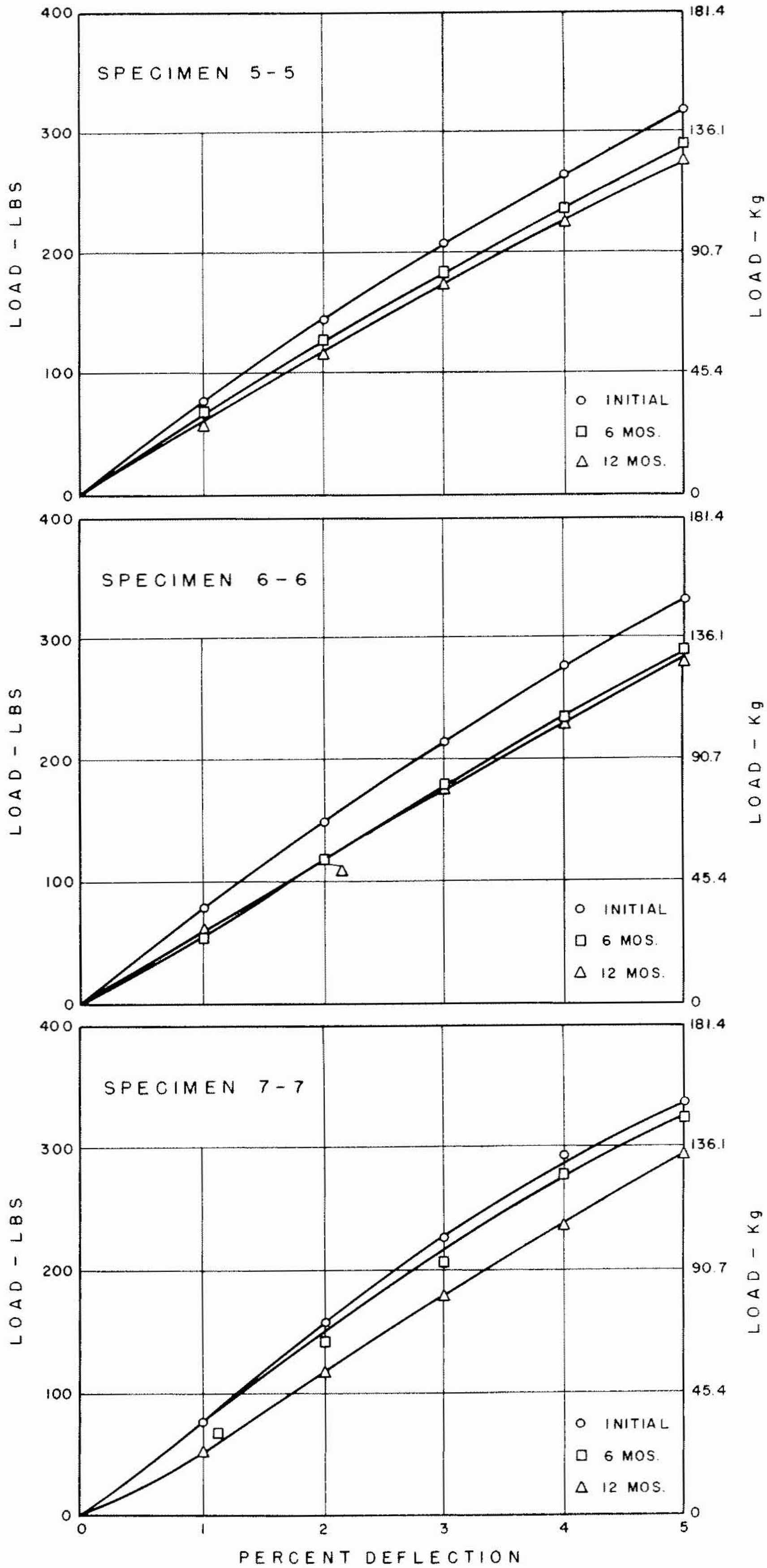


Figure 18. Load vs deflection NaOH.

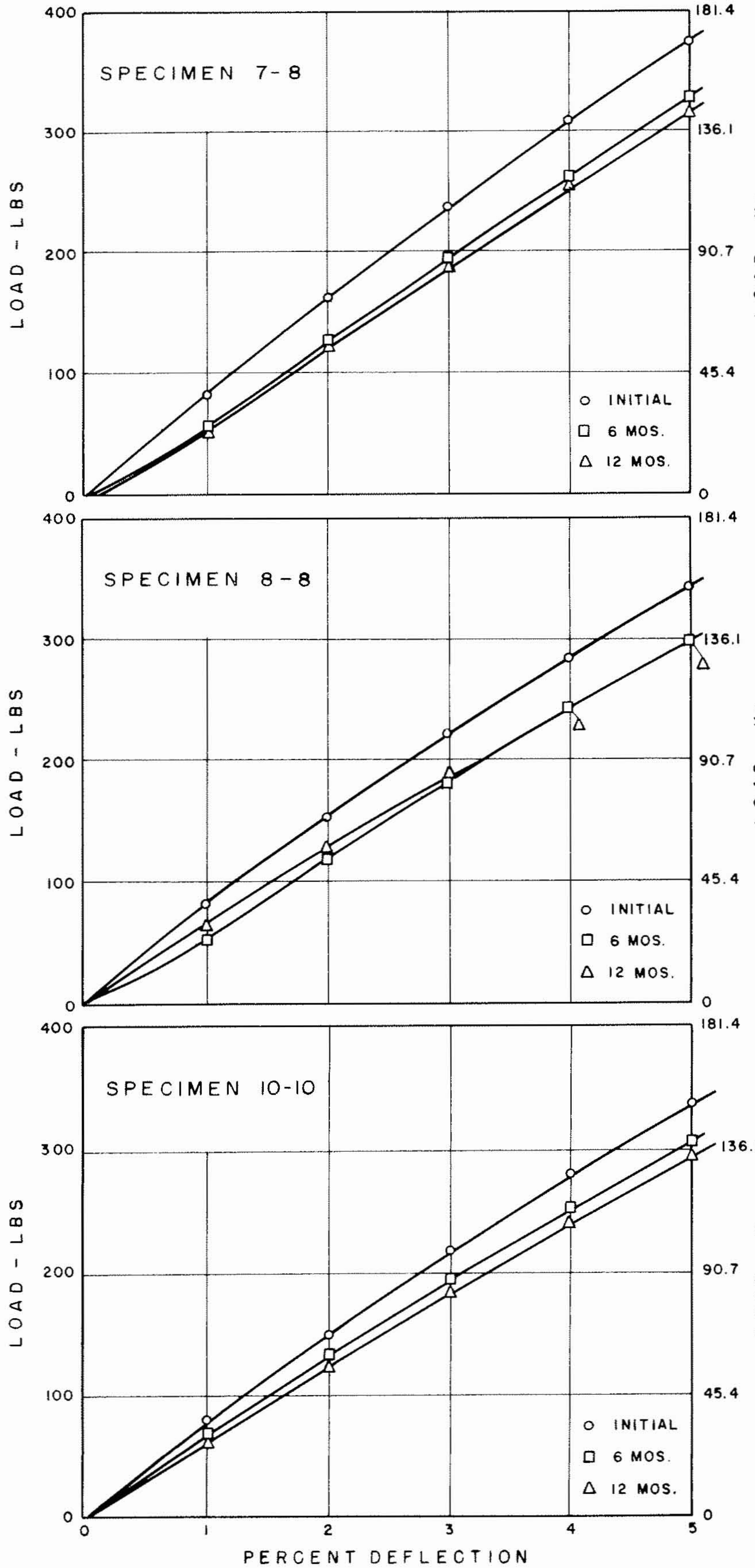


Figure 19. Load vs deflection—synthetic soil extract.

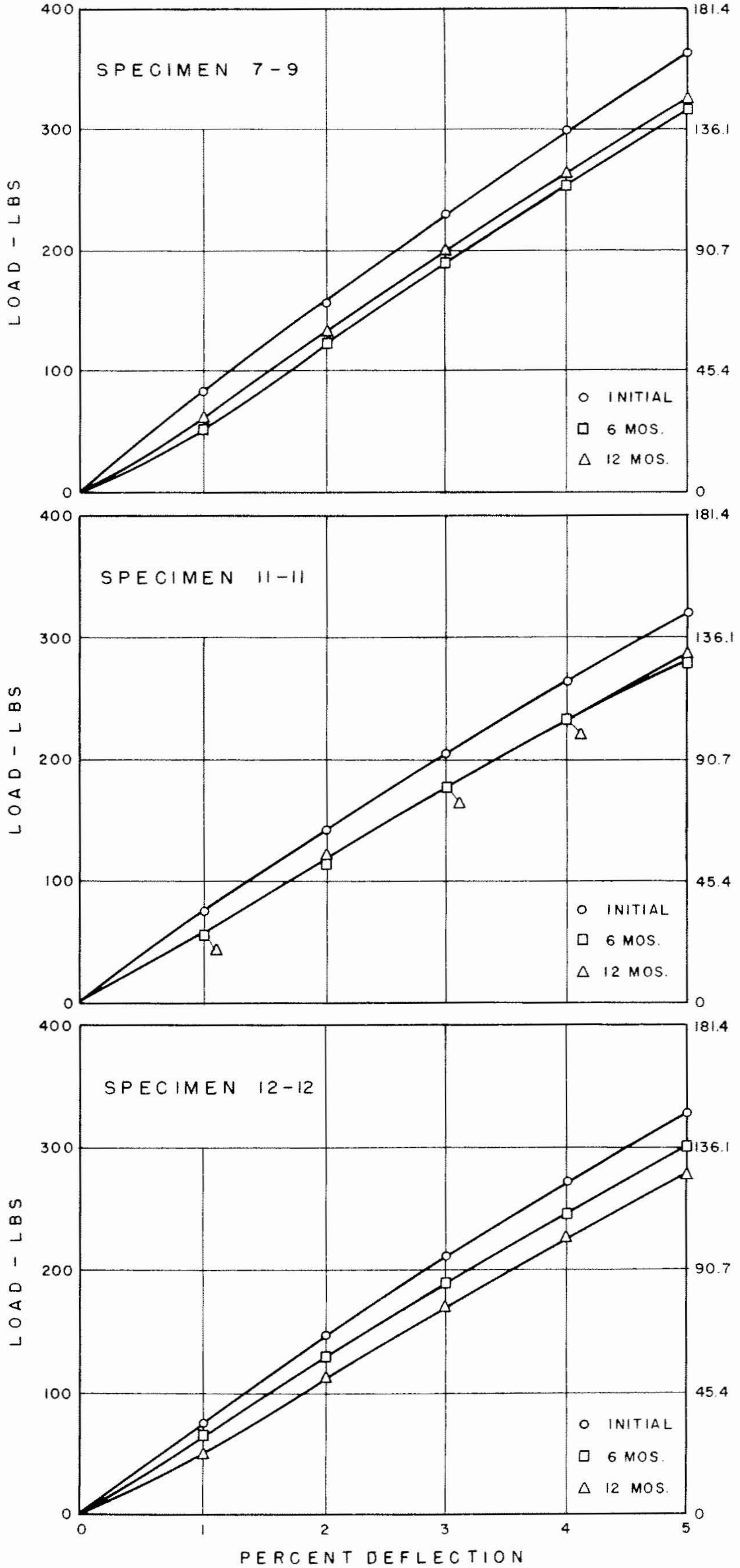


Figure 20. Load vs deflection, tap water.

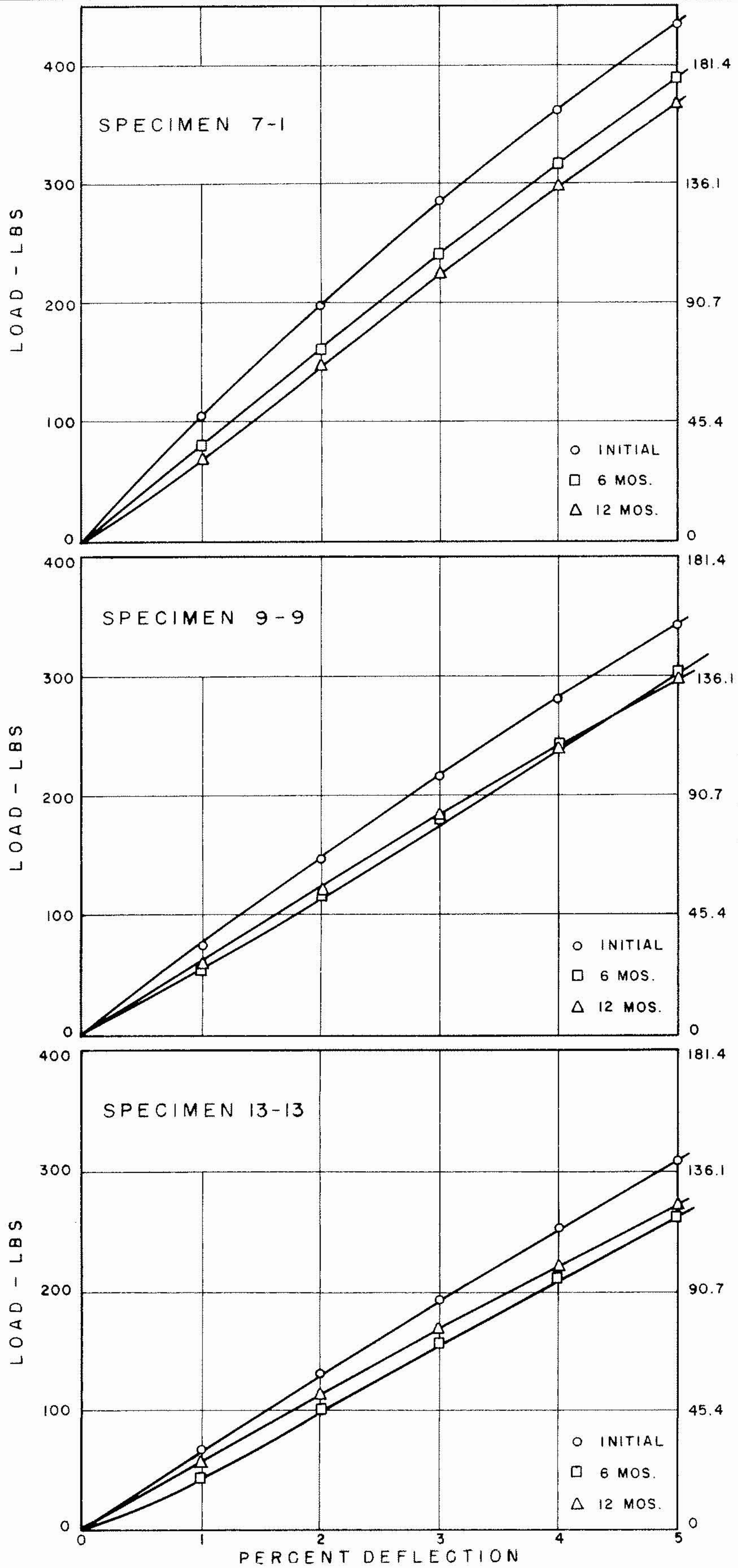


Figure 21. Load vs deflection—distilled water.

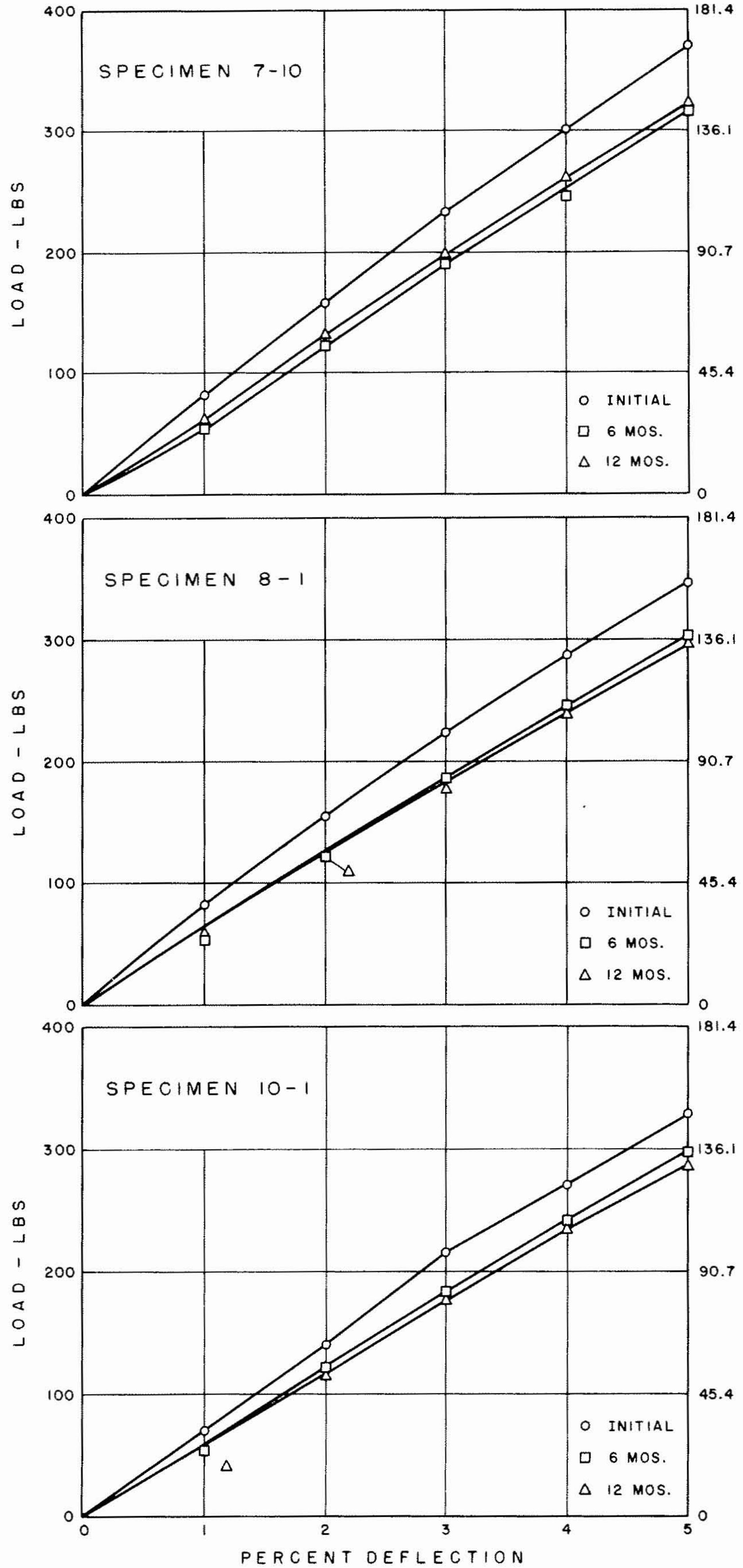


Figure 22. Load vs deflection freeze-thaw.

Table 6

SCALING FACTOR - DIAMETER CORRELATION
CRUSH TEST

Material No.*	Exposure Solution-time	Diameter		Length		Load Versus Deflection							
						5 percent		10 percent		15 percent		Ultimate	
		Inches	Centimeters	Inches	Centimeters	Pounds	kg	Pounds	kg	Pounds	kg	Pounds	kg
1-7	Control	12.09	30.71	12.04	30.58	313	141.97	578	262.18	818	371.04	1,650	**748.4
3-2	Control	12.05	30.61	12.02	30.53	287	130.18	529	239.95	738	334.75	1,615	732.6
4-11	Control	12.08	30.68	12.00	30.48	287	130.18	526	238.59	728	330.22	1,515	687.2
A-1	Control	24	60.96	12.02	30.53	111	50.35	205	92.99	286	189.73	1,007	456.8
A-2	Control	24	60.96	12.03	30.56	100	45.36	189	85.83	269	122.02	1,039	471.3
A-3	Control	24	60.96	12.03	30.56	114	51.71	214	97.07	295	133.81	1,108	502.6
C-1	Control	36	91.44	12.01	30.51	177	80.29	345	156.49	460	208.65	1,200	544.3
C-2	Control	36	91.44	12.00	30.48	176	79.83	341	154.68	455	206.38	1,535	696.3
C-3	Control	36	91.44	12.03	30.56	175	79.38	328	148.78	433	196.41	1,320	598.7
B-1	Control	48	121.92	12.02	30.53	201	91.17	369	167.38	503	228.16	1,968	892.7
B-2	Control	48	121.92	12.02	30.53	195	88.45	355	161.03	492	223.17	1,811	821.5
B-3	Control	48	121.92	12.03	30.56	184	83.46	337	152.87	463	210.01	1,744	791.1

* Cl-60 irrigation pipe.
** From Series A.

Table 7

STIFFNESS CORRELATION TEST

Sample No. and Class	Weight		Length		Thickness		Load Versus Deflection					
							5 percent		10 percent		25 percent	
	Pounds	Grams	Inches	Centimeters	Inches	Centimeters	Pounds	kg	Pounds	kg	Pounds	kg
60-1	18.5	8,391	12.0	30.48	0.26	0.66	228	103.4	392	177.8	728	420.5
60-2	18.2	8,255	12.0	30.48	.26	.66	218	98.9	375	170.1	696	315.7
60-3	18.9	8,573	12.0	30.48	.27	.69	238	108.0	400	181.4	722	327.5
100-1	18.6	8,437	12.0	30.48	.25	.64	231	104.8	386	175.1	**	**
100-2	18.6	8,437	12.0	30.48	.25	.64	225	102.1	382	173.3	722	327.5
100-3	18.6	8,437	12.0	30.48	.27	.69	216	98.0	376	170.6	696	315.7
150-1	19.3	8,754	12.0	30.48	.30	.76	304	137.9	549	249.0	1,102	499.9
150-2	19.3	8,754	12.0	30.48	.29	.74	306	138.8	538	244.0	1,064	482.6
150-3	19.3	8,754	12.0	30.48	.29	.74	314	142.4	545	247.2	1,090	494.4
200-1	21.0	9,525	12.0	30.48	.32	.81	436	197.8	798	362.0	1,615	732.6
200-2	20.7	9,389	11.9	30.23	.31	.79	435	197.3	774	351.1	1,560	707.6
200-3	20.9	9,480	12.0	30.48	.32	.81	440	199.6	786	356.5	1,585	718.9

* All samples are 24-inch- (60.96-cm) diameter pipe.
** The load at 25-percent deflection was not recorded. The load at failure was 1,870 pounds (848.2 kg). Also, the load at failure for Sample No. 100-3 was 1,790 pounds (811.9 kg).

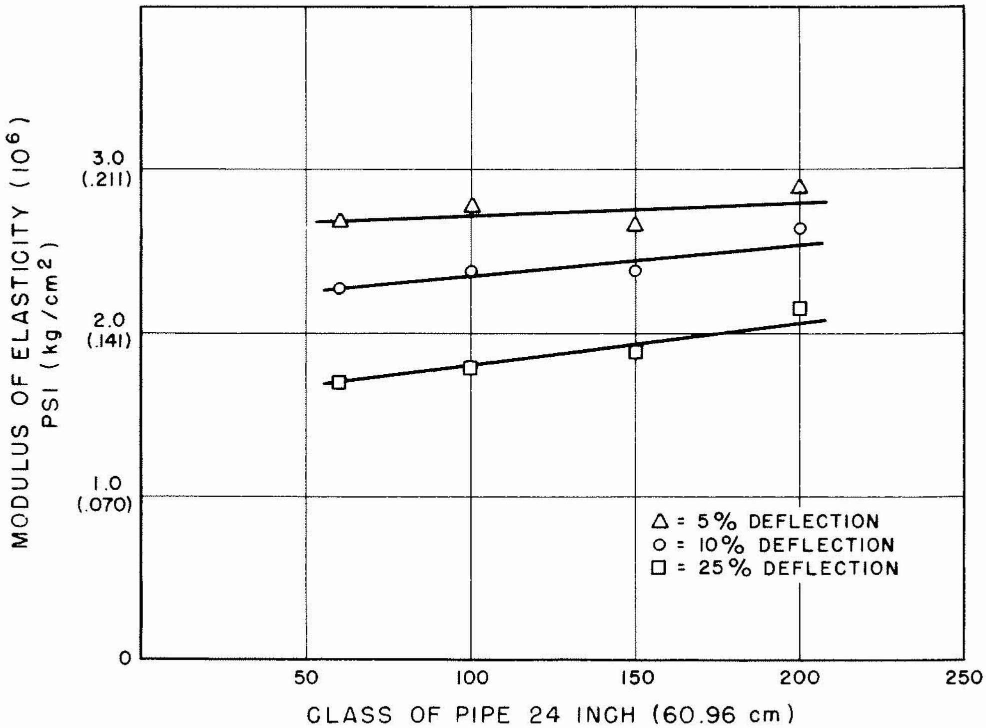


Figure 23. Modulus of elasticity vs class of pipe.

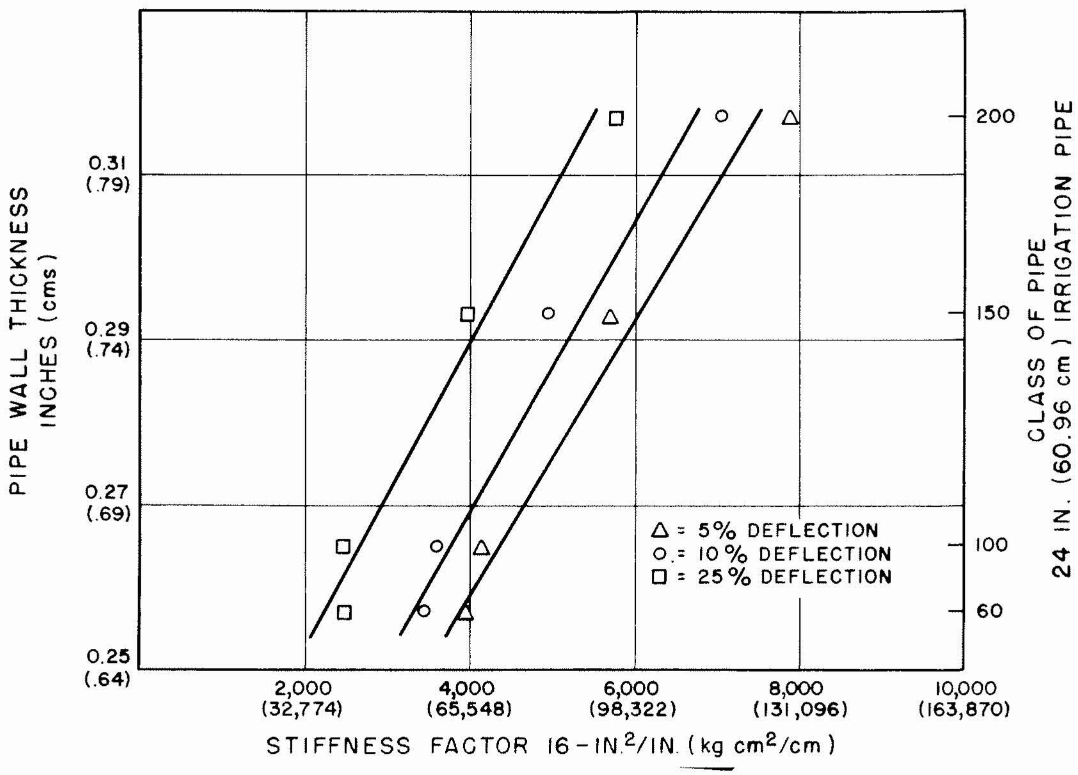


Figure 24. Wall thickness vs stiffness factor.

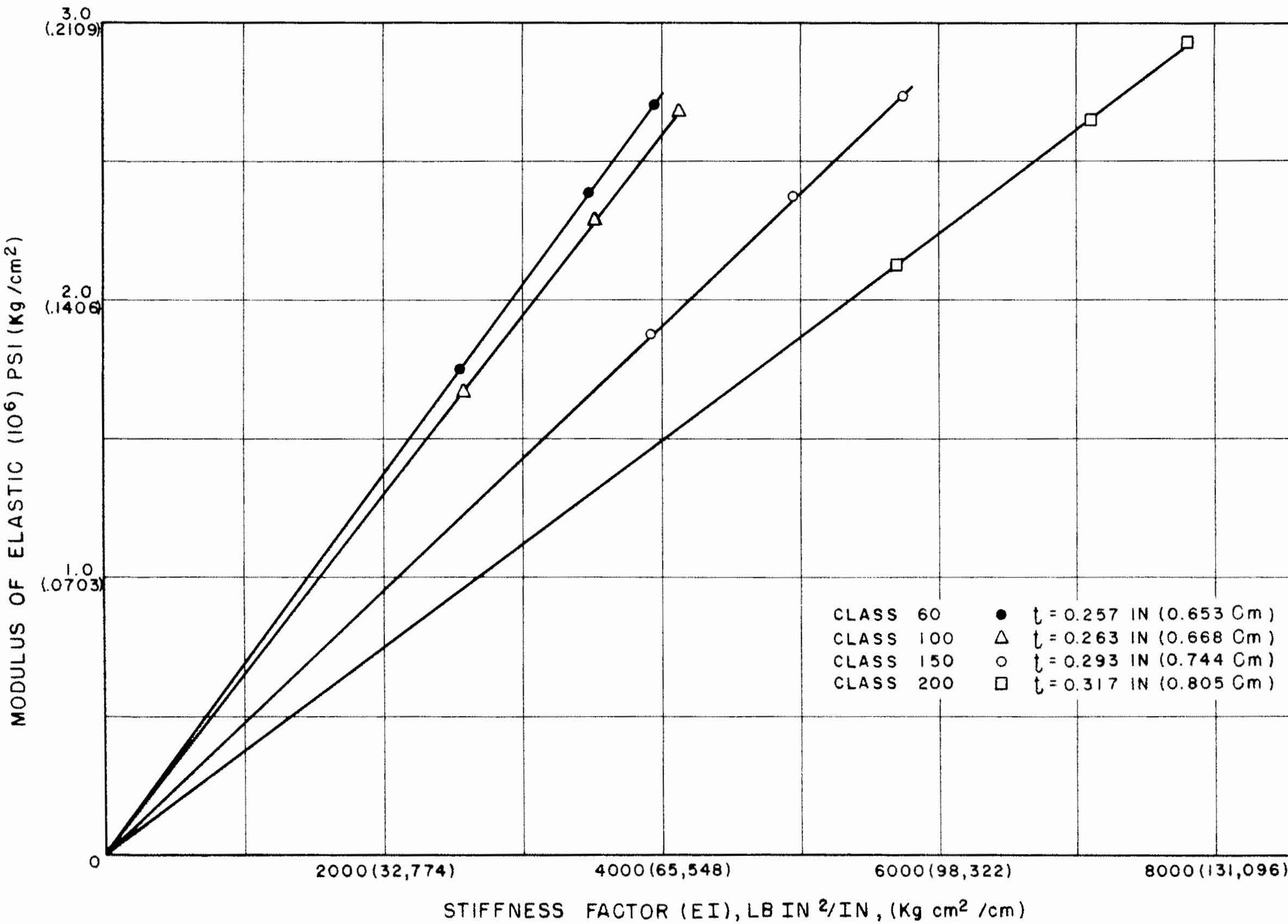


Figure 25. Modulus of elasticity vs stiffness factor.

4. Soil Box Tests

Two tests were conducted on 18-inch (45.72-cm) diameter sections of RPM Class 60 pipe in the equipment the Bureau has for load testing buried flexible pipe. The test pipes were buried in a large container with a lean clay soil at optimum moisture placed around and over the pipe at 90 or 100 percent of its maximum dry density. Surcharge loads were applied with a large universal testing machine. Measurements of soil pressures on the soil container walls, changing dimensions of the pipe, soil movement around the pipe, and strain on the inner surface of the pipe were made during a 1-day loading sequence.

The testing procedures and equipment are described in Report No. EM-763. The two pieces of pipe were identical and with one exception the test procedures and instrumentation were the same for each test. The difference in the two tests was in the density of the soil backfill. Test A (FA-18-RPM) had a backfill density of 90 percent of Proctor maximum dry density and Test B (FB-18-RPM) had a backfill density of 100 percent of Proctor. The structural properties of the pipe as determined from three-edge bearing tests are listed in Table 8, and 9 gives a statistical comparison of the soil density and moisture content for each test.

4.1. Pipe Deflection

Test A had a vertical deflection of 46 percent and Test B had 17 percent under a 100-psi surcharge load. A comparison of the vertical and horizontal deflections at 5 minutes after loading for the two tests is shown in Figure 26. The 60-minute readings are slightly higher but show the same relationship. The higher density reduced the deflections about 90 percent at lower surcharges and about 60 percent at higher surcharges.

In Test A, at about 10 percent deflection, tiny hairline cracks were visible in the tension areas of the inner surface of the pipe. In Test B, these minute cracks never appeared. A hydrostatic test is planned for the test pipe from Test B to see if there are any changes in the watertightness and the internal bursting pressure.

Results from comparative steel pipe tests show that pipe deforms somewhere between an elliptical shape and a rectangular shape. The actual shape ranges between these two extremes depending on the relationship of the pipe stiffness to the soil stiffness. An elliptical pipe is one where high compressive strains occur on the inner surface of the pipe at the horizontal diameter (at 90° and 270° where 0° is the top of the pipe). The rectangular pipe has high compressive strains at four locations, generally at 45°, 135°, 225°, and 315°. These points of high strain are where the plastic hinges form when the pipe fails. These shapes are illustrated in Figure 27. The deformed shape of the pipe under a soil surcharge of 100 psi is shown in Figures 28 and 29. Test A deflected elliptically with the sharpest curvature occurring at 105° and 255° (top of the pipe is 0°). Test B deflected rectangularly with the sharpest curvature occurring on the bottom of the pipe at 135° and 225°. The difference in shape between Tests A and B can be seen by comparing Figures 29 and 30. In both photographs, the pipe is deflected between 15 and 20 percent.

The Iowa Formula for flexible pipe that serves as the main design method was modified to include a more realistic value for the soil parameter by Spangler and Watkins. [5] [6] the modified Iowa Formula is given as:

$$\Delta X = D_1 \frac{K W r^3}{EI + 0.061\, e' r^3}$$

where ΔX = horizontal deflection of the pipe, inches

D_1 = deflection lag factor to compensate for the time-consolidation rate of the soil, dimensionless

K = bedding constant which varies with the angle of the bedding, dimensionless

W = load on the pipe per unit length, pounds per linear inch

r = pipe radius, inches

EI = pipe wall stiffness per unit length, in.-lb

e' = modulus of passive resistance of soil, psi

For the laboratory load tests, D_1 is assumed to be 1.0, K equal to 0.1, and W equal the surcharge pressure (p) distributed over the projection of the pipe diameter. Using these values and rearranging the equation in terms of percent of pipe deflection, it becomes:

$$\Delta X/D = \frac{0.1p}{(EI/r^3) + 0.061\, e'} \times 100$$

The term $\Delta X/D$ is the pipe deflection as a percent of the pipe diameter. The pipe deflection is affected by the load on the pipe, the physical properties of the pipe, and the soil reaction to loading. The term, 0.1p,

Table 8

STRUCTURAL PROPERTIES OF RPM PIPE

Test No.	Diameter		Thickness		Theoretical EI	EI from three-edge bearing test
	Inches	Centimeters	Inches	Centimeters	Inch-pound (m-kg)	Inch-pound (m-kg)
FA-18-RPM	18.058	45.87	0.22	0.5588	2,307 (26.58)	2,200 to 2,600 (25.35 to 29.95)
FB-18-RPM	18.101	45.98	.22	.5588	2,307 (26.58)	2,000 to 2,500 (23.04 to 28.80)

Table 9

SOIL COMPACTION

Test No.	Proctor maximum dry density pcf	Backfill density in percent of Proctor maximum dry density			Soil moisture		
		Range percent	Mean percent	Standard deviation percent	Range percent	Mean percent	Standard deviation percent
FA-18-RPM	120.0	87.6- 93.0	89.7	1.9	11.0-12.1	11.6	0.3
FB-18-RPM	120.0	99.0-102.6	100.6	1.0	11.3-12.5	11.8	0.3

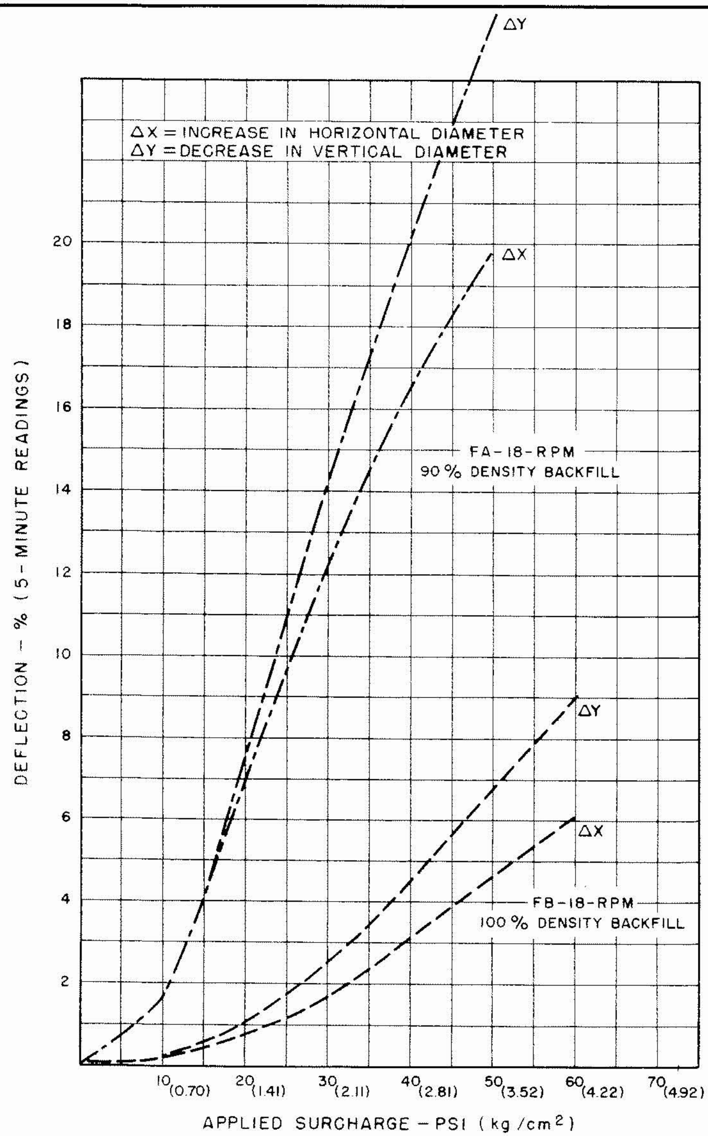


FIGURE 26 - COMPARISON OF FA-18-RPM AND FB-18-RPM

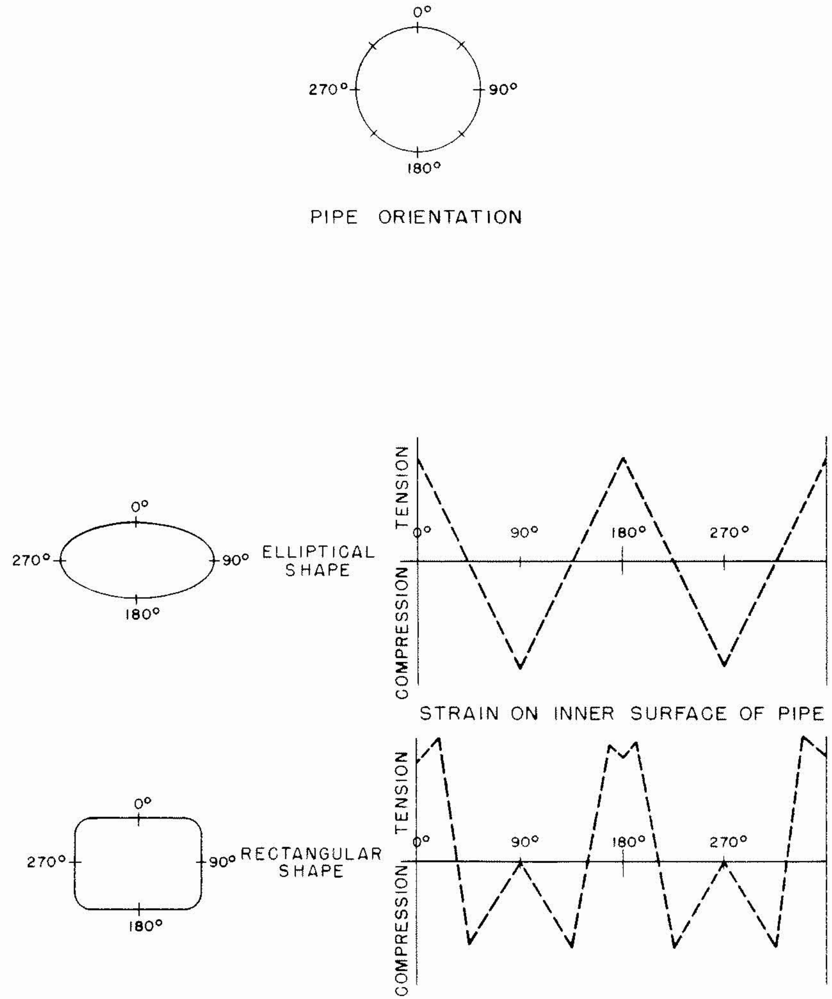


Figure 27. Types of pipe deformation shape.

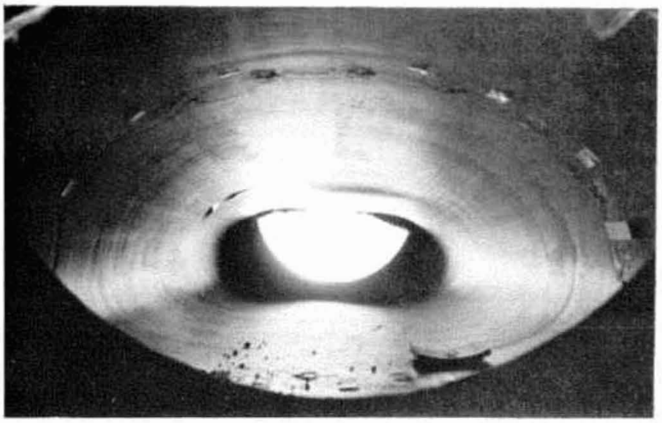


Figure 28. Test A under 100-psi (7.03-kg/cm^2) surcharge.
Photo PX-D-67361

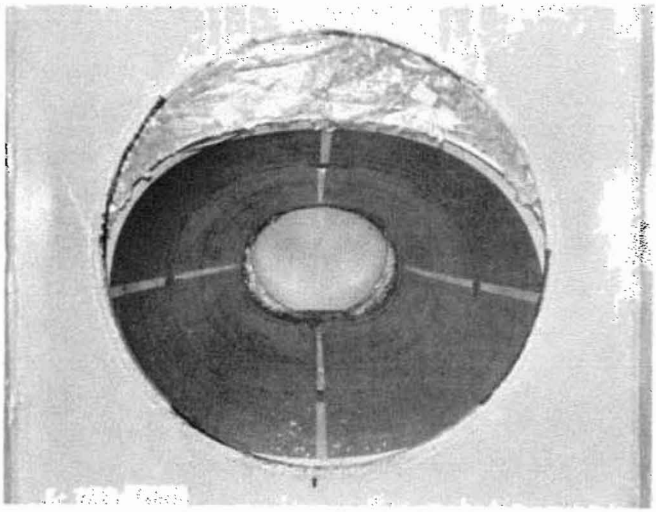


Figure 29. Test B under 100-psi (7.03-kg/cm^2) surcharge.
Photo PX-D-67360

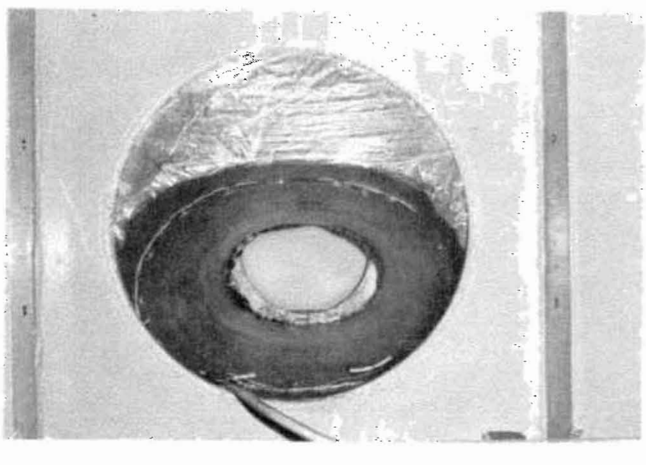


Figure 30. Test A under 40-psi (2.81-kg/cm^2) surcharge.
Photo PX-D-67359

express the load on the pipe and is referred to as the Load Factor. The strength of the pipe is expressed in the EI/r^3 term, the Ring Stiffness Factor. The value 0.061 e' is the Soil Stiffness Factor. For equal Load Factors and Soil Stiffness Factors, the pipe deflection is dependent only on the Ring Stiffness of each pipe.

Results of nine steel pipes tested in the soil container, with soil conditions identical to Test A, showed a good correlation with the Iowa Formula. Figure 31 shows the horizontal deflection of RPM pipe compared with deflections of steel pipe of similar stiffness and the Iowa Formula. The RPM pipe deflected about 50 percent more than the steel pipe. The RPM pipe deformed elliptically while the steel pipe deformed rectangularly.

The curve for the Iowa Formula on Figure 31 is based on an e' of 500 psi (35.2 kg/cm^2) and has been offset on the horizontal axis of surcharge. It was observed in these tests that a 10-psi (7.03-kg/cm^2) "seating load" was required before the pipe had a significant reaction to the surcharge.

Three steel pipes were tested with the soil backfill at 100 percent. Two of these deformed rectangularly and compared closely to the Iowa Formula for an e' of 2,000 psi (140.6 kg/cm^2) and a 20-psi (1.41-kg/cm^2) "seating load". The other pipe deformed elliptically and did not agree with the Iowa Formula. The deformation shape did not affect the horizontal deflections for the steel pipe in the 90 percent backfill but it seems to have an effect in the 100 percent backfill.

The RPM pipe tested in the 100 percent backfill deformed rectangularly. Figure 32 shows the horizontal deflection of the RPM pipe compared to the two steel pipes that deformed rectangularly and the Iowa Formula. The RPM pipe deflected about 100 percent more than the steel pipe of similar stiffness.

The results indicate that the deflection behavior of RPM pipe and steel pipe cannot be compared on the basis of Ring Stiffness Factors. The Iowa Formula was developed for steel pipe and may require reevaluation for use on RPM pipe.

Additional tests are planned to further evaluate the deformation of RPM pipe under earth loads.

4.2 Strain Gage Readings

The circumferential ring of strain gages on the inner surface of the pipe shows strain readings that are in complete agreement with photographs of the pipe shape. Tests A had high compressive strains at 90^o to 112.5^o and 347.5^o and Test B at about 45^o, 135^o and 292.5^o. The strain data are plotted in Figures 33 and 34.

D. FIELD PROGRAM

Under the GICS Program, two field studies are being conducted. The first is a test on 15-inch (38.2-cm) RPM pipe in the Westlands Irrigation District in California. The pipe in test here is an early design pipe, and is rubber lined. The pipe wall, however, is typically RPM so some useful performance data will evolve. The test section, about one-half mile long, was installed about 2 years ago and was first pressurized about 19 months ago. Strain gages were installed in the wall of one pipe section, and strain data recorded at regular intervals since the line was pressurized. In addition, several removable sections of rubber-lined and also unlined pipe were installed in the line. These are being removed at periodic intervals for testing. As yet, no tests have been run on these pipe sections. At this time, the strain data have been compiled and are under critical review by the Bureau and by both industry participants. No conclusions are available at this time.

The second field test under this program is in the Lower Yellowstone Irrigation District near Sidney, Montana. In this test, 39-inch (0.991-m) pipe was used to replace a canal delivering water to a local company. The test section is 1,200 feet (576 m) long and the pipe is buried with 3 feet (0.914 m) to about 5 feet (1.52 m) of cover. Deflection data are being taken periodically, and the pipe closely examined for freeze-thaw damage. During pipe installation, compaction of the soil around the pipe resulted in a slight horizontal deflection, that is, there was a slight decrease in the horizontal diameter with a corresponding increase in the vertical diameter, well within acceptable limits. In service the pipe has returned to normal, slight deflection in the vertical direction is present. Regional personnel will measure soil densities along the pipe backfill for correlation with the deflection data. No effects from freeze-thaw are present, which is as expected. In laboratory freeze-thaw exposure, RPM specimens have gone through thousands of freeze-thaw cycles without serious effect.

In addition to these two GICS field tests, several independent field tests are being or have been run. Klamath Project tested RPM pipe under dynamic loading in buried exposure, and use in sprinkler

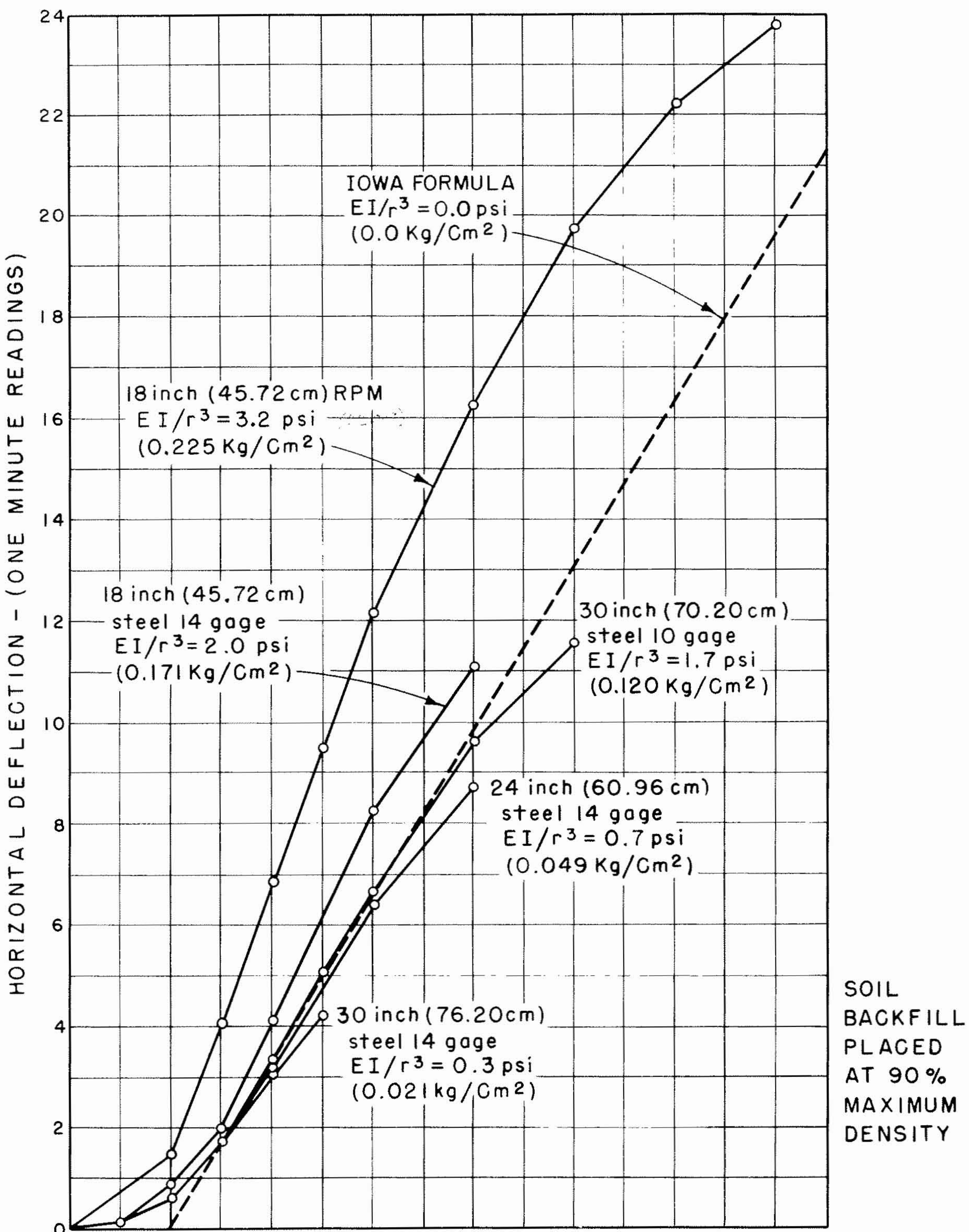


Figure 31. Comparison of Test Series FA with Iowa formula.

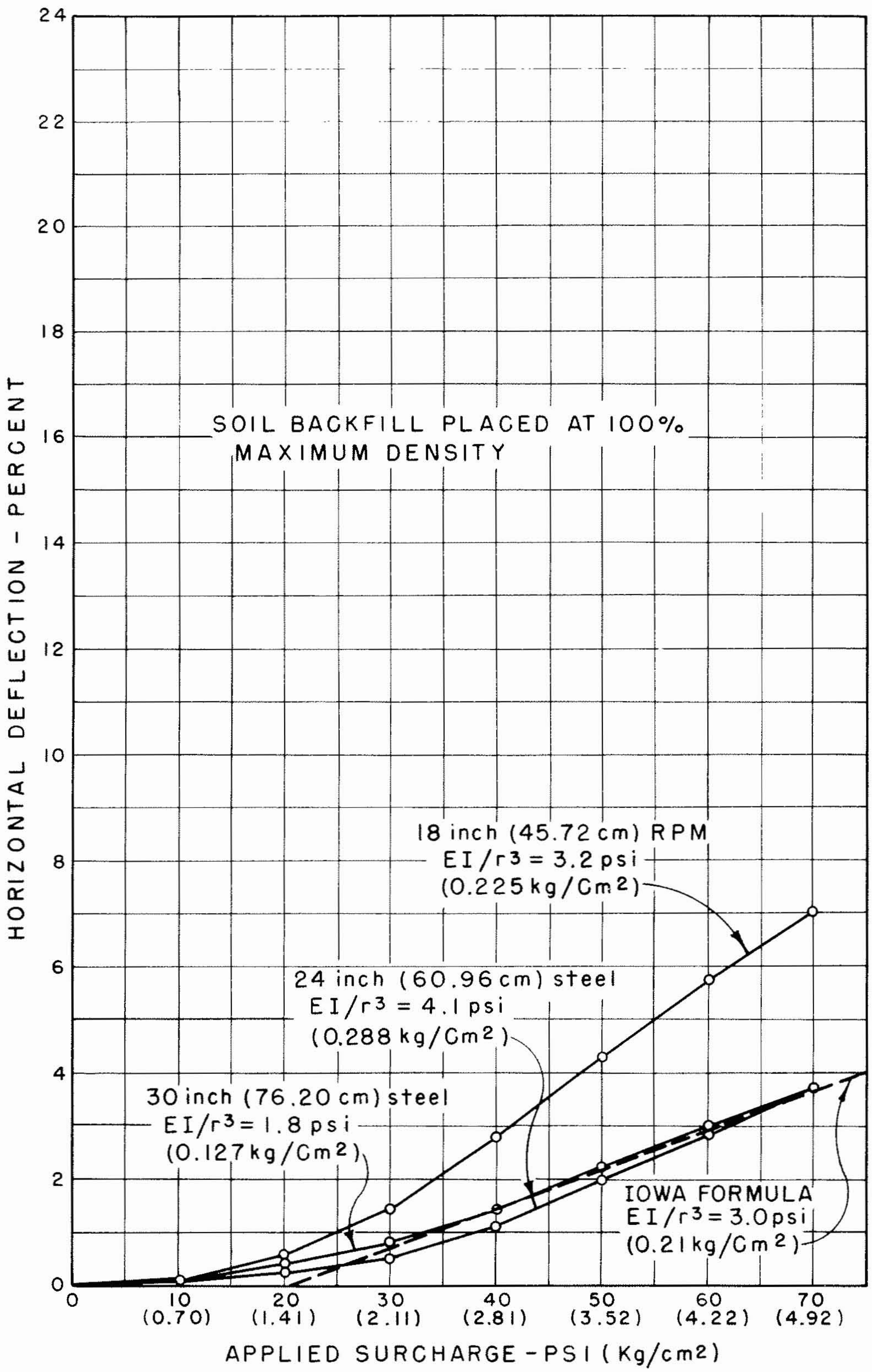


Figure 32. Comparison of Test Series FB with Iowa formula.

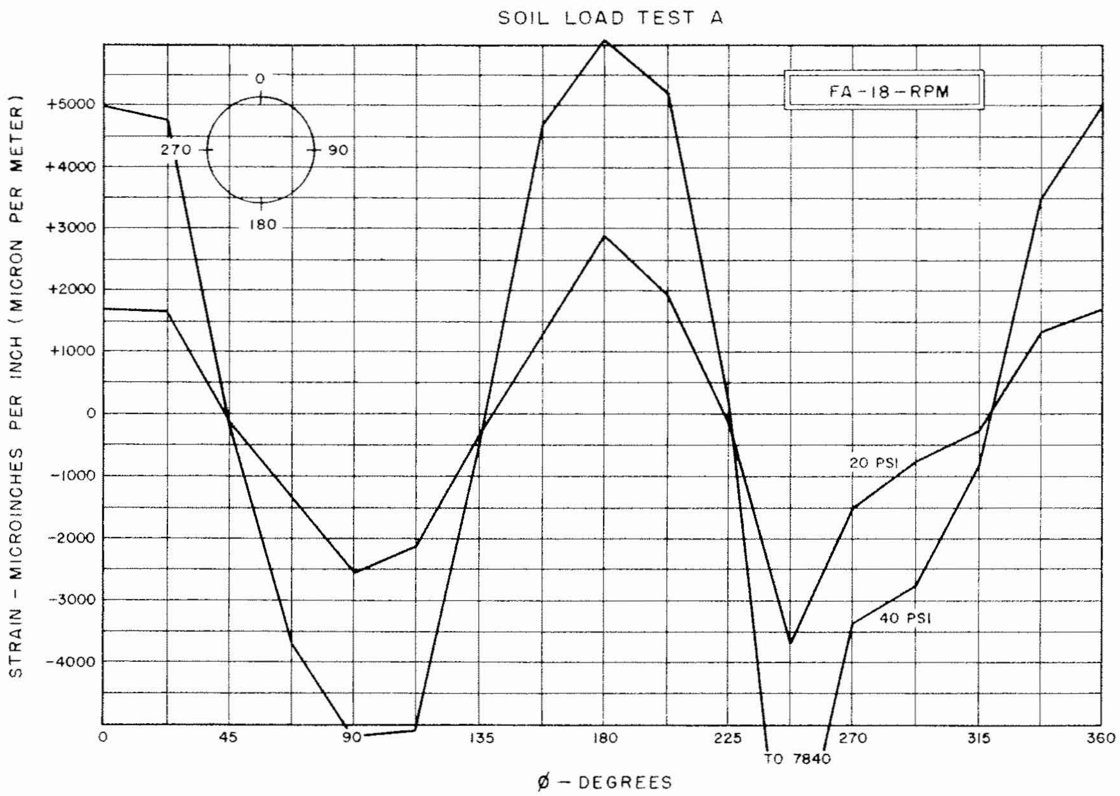


Figure 33. Strain gage readings around inside pipe circumference.

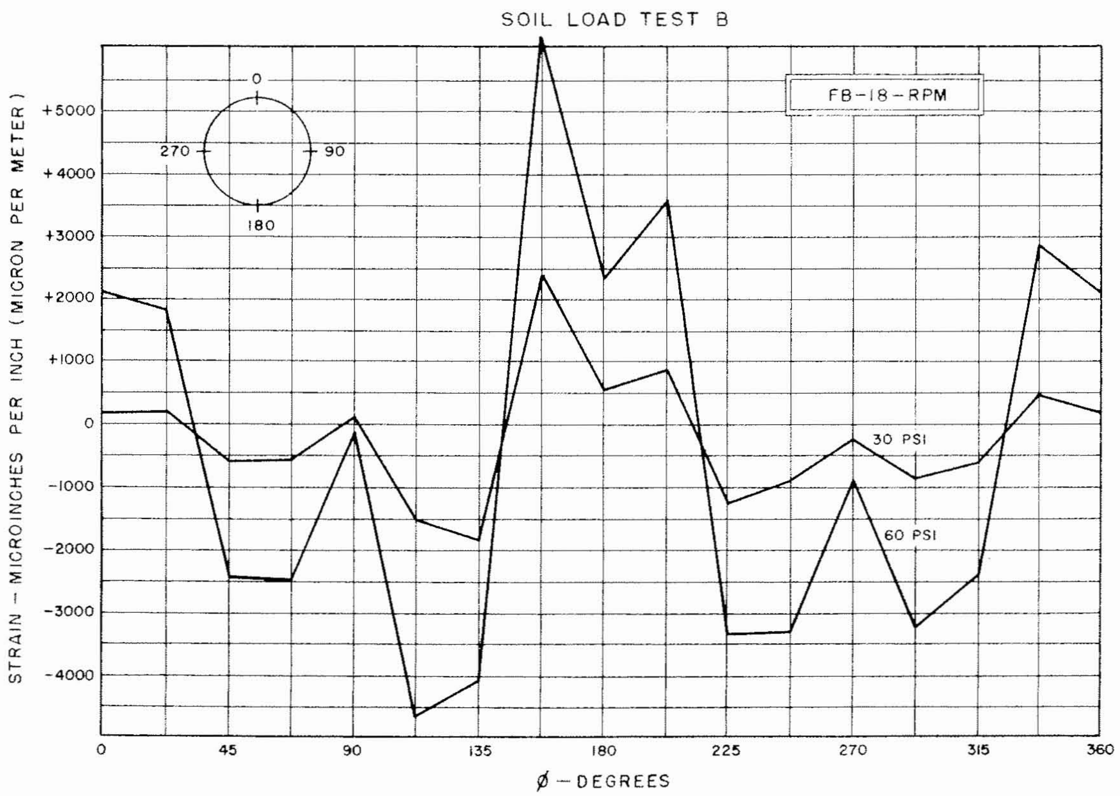


Figure 34. Strain gage readings around inside pipe circumference.

irrigation is being evaluated in a test at South Dakota State University's Redfield Test Farm. Other miscellaneous field trials have been made by various Bureau-related offices, and of course, the industry participants have numerous field tests underway that are not part of this program.

E. FUTURE WORK

The GICS Program was planned for 2 years of environmental exposure and testing, to be followed with the preparation of a final report, and the development of specifications for RPM pipe.

Data discussed in this report are generally 1-year data, that time being July 1969. The program is continuing as planned and is now in the second exposure year. Tests, as previously discussed will be conducted at the scheduled time intervals. A final report will be issued at the end of the program as planned.

F. SPECIFICATIONS AND DESIGN

In the interim, tentative specifications for RPM pressure pipe have been prepared by the Bureau for limited use in procuring pipe for experimental installations, but have not been issued for general Bureau use.[7] These tentative specifications are included as the Appendix to this report. In addition, the Bureau is represented on ASTM-SPI Subcommmittee D-20.23 where ASTM Standards for RPM sewer pipe and RPM pressure pipe are under preparation. Both UTC and J-M are also active in this committee.

REFERENCES

[1] Techite—product data; United Technology Center, Division of United Aircraft, Techite Department, Post Office Box 5222, Sunnyvale, California 94088.

[2] Flextran—product data; Johns-Manville, Flextran Pipe Division, 22 East 40th Street, New York, New York 10016.

[3] Modern Plastics Encyclopedia, 1968, Vol. 45, No. 1A.

[4] Environmental Effects on Polymeric Materials, D. V. Rosato and R. T. Schwartz, 1968, Vol. 1, Chapter 9.

[5] Spangler, M. G., "The Structural Design of Flexible Pipe Culverts," Iowa Engineering Experiment Station Bulletin No. 153, 1941.

[6] Watkins, R. K. and Spangler, M. C., "Some Characteristics of the Modulus of Passive Resistance of Soil: A Study in Similitude," Highway Research Board Proceedings, Vol. 37, 1958.

[7] Tentative Specification for Reinforced Plastic Mortar Pressure Pipe, August 1969, USBR.

V. APPENDIX

Reinforced Plastic Mortar Pressure Pipe

a. Scope.–

(1) General.–Reinforced plastic mortar pressure pipe, 8- through 48-inch diameter, shall be manufactured and tested in accordance with this paragraph.

(2) Definitions.–A lot as used herein means 100 lengths of pipe or fraction thereof of identical class and size manufactured in a single production run.

b. Classes.–Table 1 shows four classes of reinforced plastic mortar pressure pipe. The classes are designated RPM 100, RPM 175, RPM 225, and RPM 300. Table 1 shows the classes of reinforced plastic mortar pressure pipe that correspond with the pipe classification symbols shown on the drawings. The reinforced plastic mortar pressure pipe classification shown in Table 1 establishes the minimum requirements for pipe to be used in the locations shown on the drawings. The classes required under these specifications are:

Table 1

SELECTION TABLE
REINFORCED PLASTIC MORTAR
PRESSURE PIPE

*Size 8 through 48 inches ** Symbol		*Size 8 through 48 inches ** Symbol	
A 25	RPM 100	A 175	RPM 175
B 25	RPM 100	B 175	RPM 175
C 25	RPM 100	C 175	RPM 175
A 50	RPM 100	A 200	RPM 225
B 50	RPM 100	B 200	RPM 225
C 50	RPM 100	C 200	RPM 225
A 75	RPM 100	A 225	RPM 225
B 75	RPM 100	B 225	RPM 225
C 75	RPM 100	C 225	RPM 225
A 100	RPM 100	A 250	RPM 300
B 100	RPM 100	B 250	RPM 300
C 100	RPM 100	C 250	RPM 300

*Size 8 through 48 inches ** Symbol		*Size 8 through 48 inches ** Symbol	
A 125	RPM 175	A 275	RPM 300
B 125	RPM 175	B 275	RPM 300
C 125	RPM 175	C 275	RPM 300
A 150	RPM 175	A 300	RPM 300
B 150	RPM 175	B 300	RPM 300
C 150	RPM 175	C 300	RPM 300

*Pipe sizes are nominal pipe size diameters given in inches.

**The pipe is designated by symbol such as A 25, B 100, etc. The figure 25, 100, etc., denotes the maximum allowable internal pressure head in feet measured to the ℄ of the pipe. The letters A, B, and C denote a maximum of 5, 10, and 15 feet of earth cover, respectively, over top of pipe.

c. Basis of acceptance.–The acceptability of pipe will be determined by the results of tests performed by the contractor at his expense for soundness (hydrostatic proof), ultimate tensile strength, stiffness factor and by inspection during and after manufacture. Certified copies of the results of the above tests shall be furnished to the contracting officer.

d. Materials.–Reinforced plastic mortar pressure pipe shall be composed of borosilicate glass roving reinforcement, siliceous natural sand, polyester resin and catalyst binders with or without inorganic fillers.

e. Laying lengths.–The nominal laying lengths of pipe units shall not exceed 20 feet with a plus or minus tolerance of 1 inch.

f. Joints.–

(1) General.–The joint assemblies shall be so formed and accurately manufactured that when the pipes are drawn together in the trenches, the pipe shall form a continuous watertight conduit with smooth and uniform interior surface, and shall provide for slight movements of any pipe in the pipeline due to expansion, contraction, settlement, or lateral displacement. The rubber gasket shall be the sole element of the joint depended upon to provide watertightness. The

ends of the pipe shall be in planes at right angles to the longitudinal centerline of the pipe. The ends of the pipe units shall be finished to regular smooth surfaces and no point on the surface of the spigot end of a pipe unit shall project beyond the specified plane more than one-eighth inch or be more than one-eighth inch short of the specified plane. The joint design shall be similar to Figure 1. The shape and dimensions of the joint shall provide the following minimum requirements:

(a) The rubber gaskets shall be solid gaskets of circular cross section.

(b) The gasket shall be confined in an annular space formed in a groove in the spigot end of the pipe so that movement of the pipe or hydrostatic pressure cannot displace the gasket. When the joint is assembled the gasket shall be compressed to form a watertight seal.

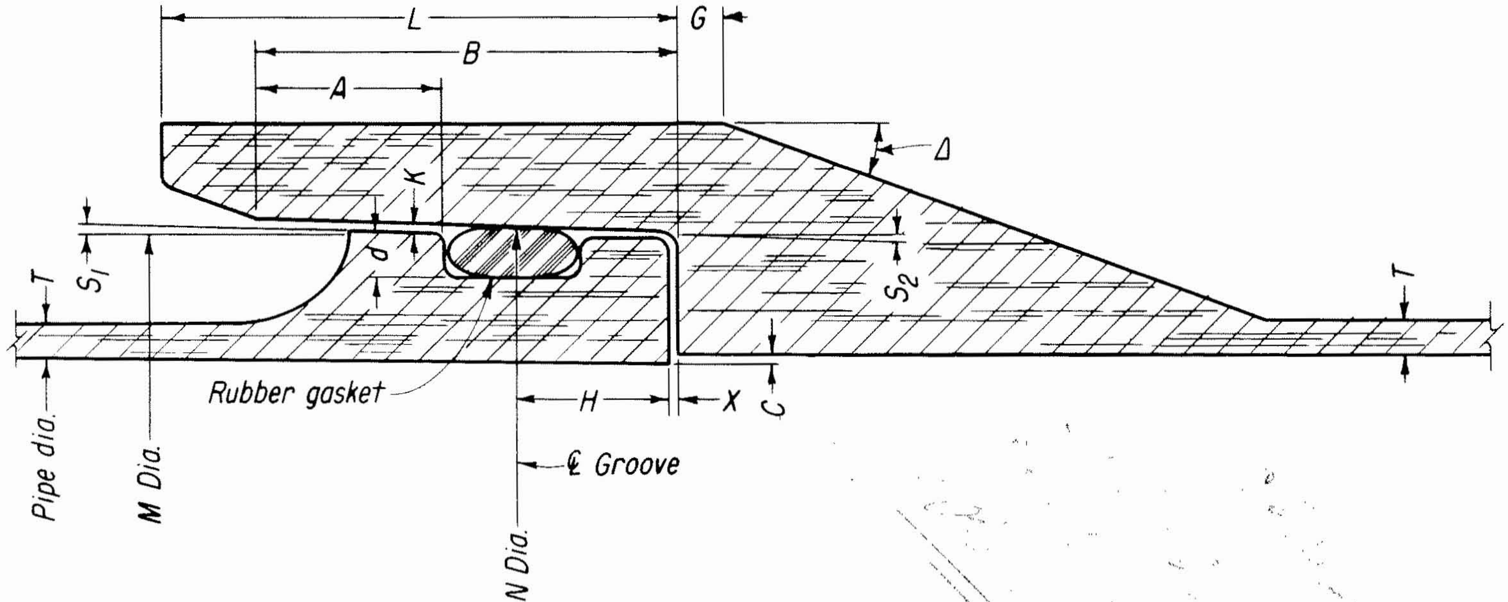
(c) The volume of the annular space provided for the gasket, with the engaged joint at normal joint closure in concentric position, shall not be less than the design volume of the gasket given on the Bureau of Reclamation Joint Data Form. The cross-sectional area of the annular space shall be calculated for minimum bell diameter, maximum spigot diameter, minimum width of groove at surface of spigot and minimum depth of groove. The volume of the annular space shall be calculated considering the centroid of the cross-sectional area to be at the midpoint between the inside bell surface and the surface of the groove on which the gasket is seated at the centerline of the groove.

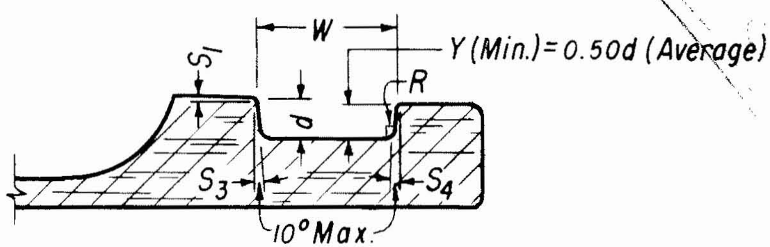
(d) If the design volume of the gasket given on the Bureau of Reclamation Joint Data Form is less than 75 percent of the volume of the annular space in which the gasket is to be contained with the engaged joint at normal joint closure in concentric position, the gasket shall not be stretched more than 20 percent of its unstretched length when seated on the spigot or not more than 30 percent if the design volume of the gasket is 75 percent or more of the volume of the annular space. For determining the volume of the annular space, the cross-sectional area of the annular space shall be calculated for average bell diameter, average spigot diameter, average width of groove at surface of spigot and average depth of groove. The volume of the annular space shall be calculated considering the centroid of the cross-sectional area to be at the midpoint between the inside bell surface and the surface of the groove on which the gasket is seated at the centerline of the groove.

It is further specified that when the design volume of the gasket is less than 75 percent of the volume of the annular space, as calculated above, the gasket shall be of such diameter that when the outer surface of the spigot and the inner surface of the bell come into contact at some point in their periphery, the deformation in the gasket shall not exceed 40 percent at the point of contact nor be less than 15 percent at any point. If the design volume of the gasket is 75 percent or more of the volume of the annular space, the deformation of the gasket, as prescribed above, shall not exceed 50 percent nor be less than 15 percent.

When determining the maximum percent deformation of the gasket, the maximum groove width, the minimum depth of groove, and the stretched gasket diameter shall be used and calculations made at the centerline of the groove. When determining the minimum percent deformation of the gasket, the minimum groove width, the maximum bell diameter, the minimum spigot diameter, the maximum depth of groove and the stretched gasket diameter shall be used and calculations made at the centerline of the groove. For gasket deformation calculations the stretched gasket diameter shall be obtained by the following calculation: Divide the design diameter of gasket by the square root of $(1 + x)$. ("x" equals the design percent stretch divided by 100.)

(e) Each gasket shall be manufactured to provide the design volume of rubber required by the joint design used and within a tolerance of plus or minus 3 percent for gaskets up to and including 1/2-inch diameter and plus or minus 1 percent for gaskets of 1-inch diameter and larger. The allowable percentage tolerance shall vary linearly between plus or minus 3 percent and plus or minus 1 percent for gasket diameters between 1/2 and 1 inch.





SPIGOT GROOVE DETAIL

JOINT TYPE R-4

REINFORCED PLASTIC MORTAR PIPE

Appendix—Figure 1

(f) The tolerances permitted in the construction of the joint shall be those stated for the joint design on the approved Bureau of Reclamation Joint Data Form.

(g) The taper on all surfaces on the bells and/or spigots on which the rubber gaskets may bear during closure of the joint and at any degree of partial closure, except within the gasket groove, shall not exceed 2°.

The bell shall be manufactured so that the surfaces over the Distance A shown on the drawings on which the gaskets may bear during closure shall extend not less than three-fourths inch away from the edge of the gasket when the pipe is laid on tangent and in final position in the trench. To provide the 3/4-inch minimum Distance A, a practicable laying allowance shall be provided between the end of the spigot and the shoulder of the bell.

(h) The surfaces of the bell and spigot in contact with the gasket, and adjacent surfaces that may come in contact with the gasket within the specified joint movement range, shall be free from defects.

(i) The inside surface of the bell adjacent to the bell face shall be flared to facilitate joining the pipe sections without damaging or displacing the gasket.

(2) Approval of joints.—Details of joints showing exact dimensions of the joints and diameter of rubber gaskets, including tolerances, and details of spigot groove and other required data shall be submitted to the contracting officer for approval on the Bureau of Reclamation Joint Data Form.

Any fabrication or procurement of materials performed prior to approval of details shall be at the contractor's risk. Approval by the contracting officer of the pipe details shall be held to relieve the contractor of any part of his responsibility to meet all of the requirements of these specifications or of the responsibility for the correctness of the pipe details.

(3) Rubber gaskets.—The term "rubber gaskets" as used in these specifications shall be construed to include natural rubber or a synthetic rubber compound. Rubber gaskets shall be extruded or molded and cured in such a manner that any cross section will be dense, homogeneous, and free from porosity, blisters, pitting, and other imperfections. The gaskets shall be extruded or molded to the design cross-sectional diameter shown on the approved Bureau of Reclamation Joint Data Form within a tolerance of plus or minus 1/64 inch or plus or minus 1.5 percent of the diameter whichever is the larger. The gaskets shall be fabricated from an elastomeric compound having the following physical properties:

Tensile strength, psi, minimum	2,300
Elongation at break, percent, minimum	425
Shore durometer, Type	35 to 65
Compression set (constant deflection) percent of original deflection, maximum	20
Change in weight, water immersion, percent, maximum (2 days at 70° C)	5
Accelerated aging, oxygen pressure test (48 hours, 158° F, 300 psi) or air oven test (96 hours, 158° F):	
Tensile strength after aging, percent of original, minimum	80
Elongation after aging, percent of original, minimum	80
Increase in Shore durometer after oxygen pressure aging. Maximum increase over original Shore durometer	8

The physical properties of the rubber compound shall be determined by tests performed in accordance with appropriate sections of Federal Test Method Standard No. 601. At the contractor's option, laboratory tests to determine physical properties of the rubber gaskets to be furnished under these specifications shall be performed on test specimens cut from (1) test units taken from the finished rubber product, or (2) substitute samples furnished in accordance with Paragraph 3.5 of Section 6, Federal Test Method Standard No. 601.

PIPE DIAMETER	JOINT TYPE	DIMENSIONS									
		GROOVE WIDTH (W)		R	d		M (DIAMETER)		N (DIAMETER)		
		MINIMUM	MAXIMUM		MINIMUM	MAXIMUM	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM	
1 2 3	4 5 6	7 8 9 10 11 12 13 14	15 16 17 18 19 20 21 22	23 24 25 26 27 28 29 30	31 32 33 34 35 36 37	38 39 40 41 42 43 44	45 46 47 48 49 50 51 52 53	54 55 56 57 58 59 60 61 62	63 64 65 66 67 68 69 70 71	72 73 74 75 76 77 78 79 80	
	R –	.	.	.	.	.	.	.	.	.	

JOINT CLEARANCE K		SLOPE DEGREES				RUBBER GASKET					G	H	J	MAX. HEAD CLASS
						UNSTRETCHED DIAMETER	% STRETCH	DURO-METER		VOLUME CUBIC INCHES				
MINIMUM	MAXIMUM	S_1	S_2	S_3	S_4	DESIGN	DESIGN	MIN.	MAX.	DESIGN				
1 2 3 4 5 6	7 8 9 10 11 12	13 14 15	16 17 18	19 20 21 22	23 24 25 26	27 28 29 30 31 32 33	34 35 36 37	38 39	40 41	42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58	59 60 61 62 63 64 65 66	67 68 69 70 71 72 73 74	75 76 77
.	.	.	.	.	.	.	.			.	.	.	.	

INSPECTION TOLERANCE DISTRIBUTION

BELL	SPIGOT
___ K (Min)	___ K (Min)

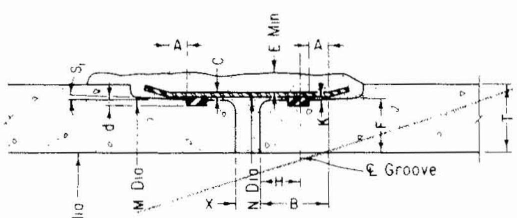
Δ DEG.	A	A_1	B	C	E	F	T	L	X	Y
1 2 3 4	5 6 7 8 9 10 11	12 13 14 15 16 17 18	19 20 21 22 23 24 25 26	27 28 29 30 31 32 33	34 35 36 37 38 39 40 41	42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58	59 60 61 62 63 64 65 66	67 68 69 70 71 72 73	74 75 76 77 78 79 80
.	.	.	.	.	.	.	.	.	.	.

NOTES

Contractor shall submit all information required by the above tables, unless a dimension shown in the tables is not applicable to the specific type of pipe joint furnished, in which case it shall be left blank.

All dimensions shall be given in inches, unless otherwise noted, and are for bell and spigot in concentric position.

Joint clearance dimension K is at closest point within distance A.



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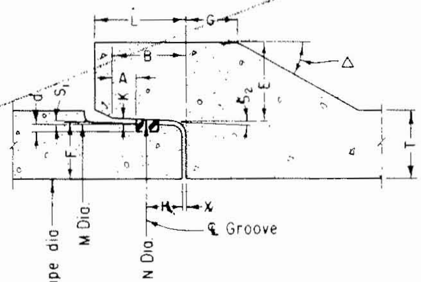
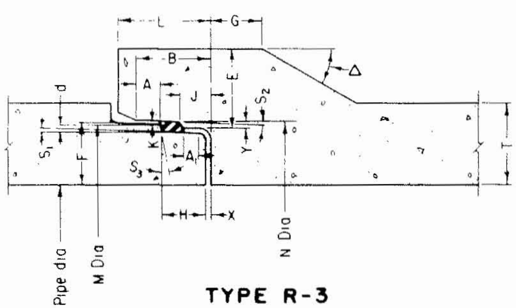
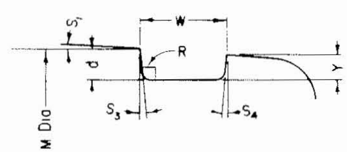


TYPE R-4



TYPE R-3



SPIGOT GROOVE DETAIL

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

JOINT DATA FORM

PIPE DIAMETER________INCHES
MANUFACTURER

____

SPECIFICATIONS NO. ______________

DATE ____________

MANUFACTURER'S NUMBER ______________________

Certified copies of the test reports of the physical properties of the rubber compound used in all rubber gaskets shall be furnished to the contracting officer.

All gaskets shall be stored in as cool a place as practicable, preferably at 70° F or less, and protected from the direct rays of the sun. Gaskets which show evidence of deterioration and other defects, such as surface checking or cracking, will be rejected.

g. Physical test requirements.—

(1) General.—The contractor shall furnish all pipe units and labor, materials, and equipment required for making the tests at no additional cost to the Government: Provided, That pipe units used for Hydrostatic Proof (Soundness) Tests that satisfactorily pass testing requirements and conform to all other provisions of this paragraph including physical inspection, will be acceptable for installation in pipelines and structures.

(2) Hydrostatic Proof (Soundness) Tests.—Each pipe unit shall be tested to withstand without leakage a hydrostatic proof test for soundness of not less than the head designated in Table 2. The hydrostatic proof test shall be conducted by placing the pipe in a hydrostatic pressure testing device which seals the ends of the pipe with gaskets. The test fixture shall be designed so that axial loads are not imparted to the pipe. All air shall be expelled from the pipe and the internal water pressure shall be increased at a uniform rate not to exceed 230 feet of water per second until the specified proof pressure is reached. The pipe shall be maintained at the hydrostatic proof test pressure for a sufficient time to determine that the soundness requirements are met, but for a minimum of 5 seconds.

Table 2
MINIMUM HYDROSTATIC PROOF TEST PRESSURES
(HEAD—FEET OF WATER)

Size	RPM 100	RPM 175	RPM 225	RPM 300
8 through 48 inches	200	350	450	600

(3) Ultimate Hoop Tensile Strength.—

(a) One section 2 feet long shall be selected for hoop strength tests from one pipe length of each lot. Hoop tensile strength shall be determined by the Split-Disc Method, ASTM Designation: D 2290 except that Sections 4 and 5 may be modified to suit the size of specimens to be tested and Sections 6, 8 (d), 8 (f), 9 and 10 shall not apply. Three ring specimens shall be cut from the 2-foot-long sample. The load to fail each specimen shall be recorded and the average of the three tests shall meet the requirements of Table 3 below. The specimen width shall be determined as close to the break as practical. This width shall be used to calculate the load in pounds per inch of width.

(b) If the average of the three specimens fails to meet the requirements in Table 3, two more 2-foot-long sections shall be taken from two additional pipe lengths in the lot and the hoop tensile strength tests shall be repeated on specimens cut from each. Failure of either group of retest specimens to meet the requirements of Table 3 shall cause the lot to be rejected.

Table 3

HOOP TENSILE STRENGTH (POUNDS/INCH OF WIDTH FOR SPLIT DISC FAILURE)

Pipe size (inches)	Pipe class 100	175	225	300
8	780	1,365	1,755	2,340
10	975	1,707	2,195	2,925
12	1,170	2,050	2,630	3,510
14	1,365	2,390	3,070	4,100
15	1,462	2,560	3,290	4,390
16	1,560	2,730	3,510	4,680
18	1,755	3,075	3,950	5,270
20	1,950	3,415	4,390	5,850
21	2,045	3,580	4,600	6,130
24	2,340	4,100	5,260	7,020
27	2,635	4,610	5,930	7,900
30	2,930	5,130	6,600	8,790
33	3,220	5,630	7,250	9,650
36	3,510	6,150	7,900	10,540
39	3,800	6,650	8,550	11,400
42	4,095	7,160	9,220	12,300
45	4,390	7,680	9,880	13,160
48	4,680	8,200	10,550	14,050

(4) Stiffness Factor.—

(a) One section 1 foot long shall be selected for Stiffness Factor tests from one pipe length of each lot. The stiffness factor (SF) at 5 percent deflection shall be determined for the sample using the apparatus and procedure of the Method of Test for External Loading Properties of Plastic Pipe by Parallel Plate Loading (ASTM Designation: D 2412) with the following exceptions:

Section 5.1—The test specimen shall be 12 plus or minus 1/8 inch in length.

Section 5.2—Only one specimen shall be required.

Section 6.1—The specimen shall be conditioned and tested at ambient temperature and relative humidity.

Section 7.1—The wall thickness shall be measured to the nearest 0.01 inch.

Section 7.6—The specimen shall be tested to 5 percent deflection and the stiffness factor determined. Crazing or cracking of pipe surfaces shall not be allowed at a deflection of 5 percent. Specimen shall then be loaded to a deflection of 15 percent without evidence of structural damage.

Structural damage shall be defined as any visible distress of the structural wall evidenced by interlaminar separation, tensile failure of the glass fiber reinforcement and/or buckling.

(b) The Stiffness Factor of the test specimen shall meet the requirements of Table 4.

(c) If the pipe section selected for Stiffness Factor testing fails to meet the requirements of Table 4, two additional 1-foot-long sections shall be taken from the lot and subjected to Stiffness Factor testing. Failure of either retest specimen shall cause the lot to be rejected.

Table 4

FOR RPM CLASSES 100, 175, 225, AND 300

Minimum stiffness factor (SF) at 5 percent deflection

Size	SF minimum (in^2–lb/in)
8	1,000
10	1,000
12	1,200
14	1,400
15	1,400
16	1,670
18	1,950
20	1,950
21	2,100
24	3,000
27	4,000
30	5,500
33	7,400
36	9,200
39	11,500
42	13,500
45	16,000
48	~~18,000~~ 20,000

h. Miscellaneous requirements.—

(1) Diameter tolerances.—The average internal diameter measured 6 inches from each end of the pipe shall not vary from the manufacturer's standard as approved by more than plus or minus 1/4 inch for sizes 8 through 21 inches; plus or minus 5/16 inch for sizes 24 through 36 inches; plus or minus 3/8 inch for sizes 39 through 48 inches. The average internal diameter shall be determined from four equally spaced diametric measurements.

The C dimension required on Figure 1 and the Joint Data Form shall be the nominal offset. Notwithstanding any of the above permissible variations, all pipe and joints shall be so manufactured that when the pipe is laid in the trenches the maximum offset on the inside of the pipe at any joint will not exceed 0.75 percent of the internal diameter of the pipe.

(2) Workmanship and finish.—Each section of pipe shall be examined for the following:

(a) The exterior surface glass fibers or cloth shall be thoroughly wet-out with resins and covered with a sand coating. Wet-out means that glass roving or fibers or cloth shall be thoroughly coated with the resins.

(b) The pipe shall be free of any cracks, porosity, bubbles, flat spots, dry spots, exposed or wrinkled glass fibers, voids or pits greater than 1/4-inch in size by 1/32-inch deep, grooves greater than 1/16-inch deep or ridges greater than 1/16-inch high. Dry spots occur on the exterior or interior surface of the pipe, where the glass roving or cloth is not thoroughly wet-out with resins.

(c) The sealing surface of the bell shall be free of cracks, porosity, bubbles, voids, dry spots, exposed glass roving, and wrinkled veil cloth.

(d) The vertical face of the bell shall be free of cracks, porosity, bubbles, voids, dry spots, flash projection pits, exposed veil cloth or glass roving and free of projections more than one-eighth inch high. Grooves ridges or voids of small size with a good resin bond throughout are exceptions to the above.

(e) Delaminations or cracks of the pipe wall.

(f) The pipe ends shall be square within plus or minus one-eighth inch.

(g) The inner surface of each pipe shall be composed of resin filled with aggregate. No glass fiber reinforcement shall penetrate the interior surface of the pipe wall, and the inner surfaces of the bell-and-spigot groove.

(3) Marking.—The following shall be clearly marked on the ~~interior and~~ exterior surfaces of the pipe:

(a) The class and size, as indicated in Table 1.

(b) The date of manufacture.

(c) The name or trademark of the manufacturer.

i. Rejections.—Pipe will be rejected that fails to conform to any one of the specifications requirements or because of the presence of detrimental defects such as, but not limited to the following:

(1) Any pipe with damage to the shell which extends through the body of the pipe.

(2) Damage to the outside surface of pipe on which the final layer of glass roving is scuffed or loosened.

(3) Leaks through the shell of the pipe that occur during the hydrostatic proof test.

(4) Bells and spigots that do not meet the joint detail dimensional requirements.

(5) Pipe with wrinkles on the interior surface caused by mandrel extraction in excess of 1/16 inch.

(6) Pipe with pits on the interior surfaces that are numerous and greater than 1/32 inch deep or with a few pits greater than 1/16 inch deep.

(7) Pipe failing the hydrostatic proof test.

(8) Pipe with exterior surfaces, including the exterior surfaces of bells and spigots, on which the resin has run, built up, and caused projections, thus exposing the final application of glass roving.

If the contractor disagrees with the contracting officer's rejection of any pipe unit, he shall file written notice within 1 week of rejection action and before the pipe unit is disposed of, so that evidence of the condition of the pipe may be preserved.

j. Repairs.—

(1) Individual pipe units may be repaired when the defects, not subject to rejection under Subparagraph i., are the result of occasional imperfection in pipe manufacture or accidental damage during handling.

(2) Individual pipe units that are rejected under Subparagraph i., may be accepted with or without repairs at the sole discretion of the contracting officer when such action would be in the best interest of the Government and in accordance with Subparagraph 10b., of the General Provisions.

(3) All repairs must be made by methods approved by the contracting officer and such repairs must be sound and properly finished and cured, and the repaired pipe conform to the requirements of these specifications as to dimensions and tolerances. Hydrostatic tests may be required on any repaired pipe if deemed necessary by the contracting officer. The hydrostatic test, if required on repaired pipe, shall be made by the contractor at no additional cost to the Government.

(4) As provided in Subparagraph k., acceptance of pipe with repairs may be suspended when the defects are the result of the contractor's failure to maintain proper quality control or if the defects result from failure to provide proper handling facilities.

k. Quality control.—In addition to the requirements of Clause No. 9 of the General Provisions, the contractor shall institute appropriate quality control procedures to insure that all pipe units produced shall be of first grade and quality conforming to these specifications. All work on pipe units shall be performed in a skillful and workmanlike manner.

If the results of production indicate that proper quality control procedures are not being maintained as evidenced by repeated manufacture of imperfect pipe units, repeated failure of pipe units to pass the required physical tests, numerous shutdowns of the plant due to failures of the plant or equipment or similar matters, or if there are significant changes in materials, mix proportions or production procedures, the contracting officer may, at his discretion, suspend further acceptance of repaired pipe units in whole or in part, or suspend further acceptance of pipe units in whole or in part. These procedures shall be effective until the contractor, within a reasonable period, demonstrates substantial improvement in quality control procedures.

Fittings for Reinforced Plastic Mortar Pressure Pipe

a. General.—Tees, tapers, adapters, couplings, curves and bends, connections at structures and encasements shall be furnished and installed by the contractor as shown on the drawings and in accordance with this paragraph. Tees, tapers, adapters, and bends shall be fabricated of steel. All joints between steel tapers, adapters, and bends and reinforced plastic mortar pressure pipe shall be rubber gasket joints. Rubber gasket joints in tees, tapers, adapters, couplings, curves and bends, and connections at structures and encasements shall conform to Subparagraph f., in Reinforced Plastic Mortar Pressure Pipe paragraph. Welding shall conform with the requirements of the American Welding Society Code AWS B3.0.

After installation, the inside and outside annular joint spaces of metal fittings used for bends, tapers, and adapters shall be filled with a preformed plastic sealing compound conforming to Interim Federal Specification SS-S-00210: Provided, That for 21-inch and smaller diameter pipe the inside annular joint spaces shall be filled with preformed plastic sealing compound by placing the preformed plastic sealing compound onto the end of the metal fitting before the adjacent pipe is installed.

b. Materials.—

(1) Steel for tees, tapers, adapters, couplings, and bends shall conform to the applicable paragraph in the construction specifications.

(2) Bolts and nuts shall conform to Federal Specifications FF-B-571a and FF-B-575b.

(3) Cement-mortar lining and cement-mortar coating shall conform to Federal Specification SS-P-385a: Provided, That lining and coating thicknesses shall be as shown on the drawings and cement for mortar lining and coating shall conform to the applicable paragraph in the construction specifications, except no direct payment will be made for cement used in mortar lining and mortar coating.

(4) Concrete in encasements, blocking, and collars shall conform to the applicable paragraph in the construction specifications.

c. Steel fittings.—

(1) Types E and J tees.—Types E and J tees shall be fabricated as shown on the drawings.

Types E and J tees shall be blocked with earth or concrete as shown on the drawings.

(2) Tees for air valves.—Tees for air valves shall be fabricated as shown on the drawings.

(3) Tees for manholes.—Tees for manholes shall be fabricated as shown on the drawings.

(4) Tapers and adapters.—Tapers and adapters shall be steel tapers and adapters fabricated as shown on the drawings. Tapers and adapters shall not be shorter than the length shown on the drawings. Tapers and adapters shall have ends which will fit the type of joint in the adjacent pipeline. The thickness of the taper and adapter and the thickness of the mortar lining and coating shall be as shown on the drawings. Flanges shall be approved by the contracting officer. Concrete collars shall be constructed on the tapers and adapters as shown on the drawings.

d. Curves and bends.—Where shown on the plan and profile drawings, changes in alinement and grade shall be made with miter bends, otherwise changes in alinement and grade shall be made by pulling the pipe joints. Where pipe joints are pulled a full laying of pipe shall be used on both sides of each joint. Miter bends shall be fabricated and encased with concrete as shown on the drawings.

The contractor may submit details of other methods of providing curves in pipelines for consideration by the Government, and if deemed satisfactory, will be approved and shall be installed at no additional cost to the Government.

e. Connections at structures and encasements.—Where reinforced plastic mortar pressure pipe adjoins a concrete structure or where reinforced plastic mortar pressure pipe is encased in concrete, except at concrete cutoff or thrust collars, a rubber gasket joint shall be provided at or adjacent to the nearest face of such structure or encasement and the distance between the pipe joint and the concrete face shall not exceed 18 inches for pipe 36 inches in diameter and smaller or one-half the diameter of the pipe for pipe larger than 36 inches in diameter.

f. All connections between reinforced plastic mortar pressure pipe and other types of pipe shall be made with rubber gasket joints. The design of steel fittings to connect reinforced plastic mortar pressure pipe to other types of pipe, including concrete encasements, shall be submitted to the contracting office for approval.

g. Approval of fittings.—One copy and one reproducible of details for fabricated steel fittings showing exact dimensions of joints and diameter of rubber gasket including tolerances, and other major dimensions shall be submitted by the contractor, for approval, to the Project Construction Engineer.

GPO 830-584

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
	MASS	
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
	FORCE/AREA	
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
	MASS/VOLUME (DENSITY)	
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
	MASS/CAPACITY	
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
	BENDING MOMENT OR TORQUE	
Inch-pounds	0.011521	Meter-kilograms
	1.12985 x 10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582 x 10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
	VELOCITY	
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873 x 10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
	ACCELERATION*	
Feet per second^{2}	0.3048*	Meters per second^{2}
	FLOW	
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
	FORCE*	
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	1.4482 x 10^{-5}*	Dynes
	WORK AND ENERGY*	
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
	POWER	
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
	HEAT TRANSFER	
Btu in./hr ft^{2} deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^{2} deg F	1.4880*	Kg cal m/hr m^{2} deg C
Btu/hr ft^{2} deg F (C, thermal conductance)	0.568	Milliwatts/cm^{2} deg C
	4.882	Kg cal/hr m^{2} deg C
Deg F hr ft^{2}/Btu (R, thermal resistance)	1.761	Deg C cm^{2}/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^{2}/hr (thermal diffusivity)	0.2581	Cm^{2}/sec
	0.09290*	M^{2}/hr
	WATER VAPOR TRANSMISSION	
Grains/hr ft^{2} (water vapor transmission)	16.7	Grams/24 hr m^{2}
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 856-384

ABSTRACT

The Bureau of Reclamation, United Technology Center, and Johns-Manville are engaged in a Government-Industry Cooperative Study of basic properties of reinforced plastic mortar pipe (RPM) and its water resources applications. The first progress report of the study comprises laboratory and field programs, and preparation of specifications and design. The laboratory program consists of: (1) Series A–Basic Properties; (2) Series B–Scaling Factors; (3) Series C–Stiffness Correlations; and (4) Load tests on pipe buried in soil. The basic properties are being determined through fatigue, crush, burst, creep, and stiffness studies after exposure in environments of sulfuric acid, pH5; sodium hydroxide, pH9; synthetic soil extract, pH7.4 to 8.2; tap water; and distilled water. Controls and air specimens are also being tested. Scaling factors are to be computed from 12-, 24-, 36-, and 48-in. (30.48-, 60.96-, 91.44-, and 121.92-cm) Class 60 irrigation pipe. Conclusions at this point are: (1) RPM pipe appears to follow the stress aging curve for plastics, (2) good stiffness correlation is shown between classes of irrigation pipe, (3) the Iowa Formula for flexible pipe design may require re-evaluation for use with RPM pipe, and (4) changes in properties caused by the different environmental exposures appear to be similar, with good chemical resistance apparent.

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