Key

INVESTIGATION OF NONMETALLIC WATERSTOPS

PRELIMINARY LABORATORY AND FIELD EXPOSURE TESTS

TECHNICAL REPORT NO. 6-546

Report 1

May 1960

[redacted]

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

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PREFACE

The investigation reported herein was authorized by the Chief of Engineers by first indorsement, dated 1 October 1956, to a letter, dated 26 September 1956, from the U. S. Army Engineer Waterways Experiment Station, subject, "Project Plan for Waterproofing and Experimental Joint Studies in Durability Tests of Non-Metallic Waterstops."

The work was conducted by the Concrete Division of the Waterways Experiment Station under the supervision of Messrs. Thomas B. Kennedy, James M. Polatty, Cecil H. Willetts, Rembert L. Curry, W. O. Tynes, L. Pepper, E. C. Roshore, and B. J. Houston. Mr. Houston was project leader and prepared this report.

Directors of the Waterways Experiment Station during this investigation were Col. A. P. Rollins, Jr., CE, and Col. Edmund H. Lang, CE. Technical Director was Mr. J. B. Tiffany.

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SUMMARY

Requirements for rubber waterstops are given in Corps of Engineers Guide Specifications CE 1402; however, these specifications did not give requirements for waterstops made from plastics, which have recently been introduced and proposed for use in Corps of Engineers construction.

This investigation was intended to provide information on the comparative performance of various types of nonmetallic waterstops. The investigation is not yet complete in that additional tests are contemplated and weathering tests are still in progress; future results will be reported as they are obtained.

In the part of the investigation reported herein, laboratory tests were performed on nonmetallic waterstop materials (several types of rubber, polyethylene, and polyvinylchloride) of several compositions under varying conditions and exposures. Samples have also been exposed since 1957, in stressed and unstressed conditions, both free and with ends embedded in concrete, to freezing-and-thawing in sea water, wetting-and-drying in sea water, to air and sun outdoors, and to air indoors. The following results have been obtained: (a) Polyvinylchloride plastics tested were not, on the average, as strong in tension nor as elastic as the natural, service, and neoprene rubbers tested, but were stronger and more elastic than the butyl rubber; the polyethylene tested had approximately the same strength as the polyvinylchloride. (b) Polyvinylchloride was slightly harder than rubber, ~~while polyethylene was considerably harder. (c) Polyvinylchloride and~~ butyl rubber absorbed practically no water as compared with 6.1, 8.5, and 16% absorbed by natural, service, and neoprene rubber, respectively. (d) Polyvinylchloride waterstops did not lose plasticizers in the presence of alkalies. (e) Polyvinylchloride and butyl rubber were not materially affected by oxygen under pressure and heat, while service and neoprene were slightly affected and natural rubber was appreciably affected. (f) Polyvinylchloride had almost as much elastic recovery at low temperatures as rubber, but the rate of recovery was much slower. (g) Natural and service rubber tested deteriorated when exposed to air and sunlight. Under stress and weathering, service rubber deteriorated quicker than natural rubber. Polyvinylchloride showed no adverse effect. (h) When under stress and exposed to weathering and/or low temperatures, neoprene rubber relaxed.

After considering comments and suggestions from various manufacturers and users of nonmetallic waterstops, a specification for polyvinylchloride waterstops was prepared for use by the Corps of Engineers, and is included as Appendix A.

KEY

Manufacturer	Symbol	Product
Electrovert, Inc. 124 E. 40th Street New York 17, New York	WES-PVC 1	Sheets, standard grade, PVC
	WES-PVC 2	Type IV, Durajoint, standard grade, PVC, finished waterstop
	WES-PVC 3	Type V, Durajoint, standard grade, PVC, finished waterstop
	WES-PVC 1A	Sheets, arctic grade, PVC
	WES-PVC 2A	Type IV, Durajoint, arctic grade, PVC, finished waterstop
	WES-PVC 3A	Type V, Durajoint, arctic grade, PVC, finished waterstop
Servicised Products Corp. 6051 West 65th Street Chicago 38, Illinois	WES-PVC 4	Dumbbell, PVC, finished waterstop
	WES-NR 1	Dumbbell, natural rubber, finished waterstop
	WES-Neor 1	Dumbbell, neoprene rubber, finished waterstop
	WES-SR 1	Dumbbell, service rubber, finished waterstop
Water Seals, Inc. 9 South Clinton Street Chicago, Illinois	WES-PVC 5	Dumbbell, PVC, finished waterstop

Manufacturer	Symbol	Product
Goodyear Box 3339, Terminal Annex Station Los Angeles 54, California (Los Angeles Plant)	WES-Butyl 1	Dumbbell, butyl rubber, finished waterstop
	WES-Butyl 1A	Sheets, butyl rubber
	WES-Neor 2	Dumbbell, neoprene rubber, finished waterstop
	WES-Neor 2A	Sheets, neoprene rubber
	WES-NR 2	Dumbbell, natural rubber, finished waterstop
	WES-NR 2A	Sheets, natural rubber
	WES-SR 2	Dumbbell, service rubber, finished waterstop, designed for 2000-psi tensile strength
	WES-SR 2A	Sheets, service rubber, designed for 2000-psi tensile strength
	WES-SR 3	Dumbbell, service rubber, finished waterstop, designed for 3000-psi tensile strength
	WES-SR 3A	Sheets, service rubber, designed for 3000-psi tensile strength
Canadian Industries, Ltd. Box 10 Montreal, Quebec, Canada	WES-Pel 1	Sheets, standard polyethylene
	WES-Pel 2	Sheets, high molecular weight polyethylene
Edoco Technical Products, Inc. 2400 East Artesia Boulevard Long Beach 5, California	WES-PVC 8 WES-PVC 8A	E-Z Seal, PVC, 6 in. wide, E-Z Seal, PVC, 4 in. wide, finished waterstop
B. F. Goodrich Industrial Products Co. Marietta, Ohio	WES-PVC 9	Sheets, Mfg. No. A, PVC
	WES-PVC 9A	Sheets, Mfg. No. B, PVC
	WES-PVC 9A(2)	Dumbbell, Mfg. No. B, PVC, finished waterstop
	WES-PVC 9B	Sheets, Mfg. No. C, PVC

INVESTIGATION OF NONMETALLIC WATERSTOPS

PRELIMINARY LABORATORY AND FIELD EXPOSURE TESTS

PART I: INTRODUCTION

Information Available on Performance of Nonmetallic Waterstops

1. Waterstops are embedded between joints or lifts of concrete structures to prevent leakage through the joint. They may be made of rubber or metal, and, in recent years, of plastics, mainly polyvinylchloride. Much has been reported on the performance of rubber and metal waterstops, but because of its comparatively recent introduction as a waterstop material, little was known of the performance of polyvinylchloride in this role. The Hydro-Electric Power Commission of Ontario, Canada, has conducted some investigations and prepared specifications permitting use of polyvinylchloride waterstops under certain conditions, and a few manufacturers have published information on performance of plastic waterstops. However, the information available is very limited.

Need for Appropriate Specifications for Polyvinylchloride Waterstops

2. With the growing production of polyvinylchloride waterstops, appripriate purchase specifications were needed by the Corps of Engineers. Polyvinylchloride is often compared to rubber (both materials being produced from flexible, resilient compounds) for which physical requirements specifications are available.* However, such a comparison is only justifiable as a comparison between items serving the same functional purpose but otherwise differing in performance and qualifications. As performance requirements for waterstops in concrete structures vary greatly, depending on location, type of structure, etc., it is likely that under some conditions one material will perform better while under other conditions another material will perform better. For these reasons data on the physical

* See paragraph 18 of reference 5, and reference 7 in the References at end of this report.

performance of polyvinylchloride waterstops were needed before appropriate specifications could be established.

Background and Planning for Test Program

3. A conference was held in 1956 between representatives of the Office, Chief of Engineers, and the Waterways Experiment Station at which plans were formulated to conduct an investigation to evaluate the durability of polyvinylchloride waterstops of a variety of shapes when exposed under different conditions of stress to different types and severities of exposure. Physical properties such as tensile strength, ultimate elongation, etc., were also to be determined. Results of these tests were to be compared with results of similar tests on other kinds of nonmetallic waterstops.

Scope of This Report

4. This report covers only a part of the over-all program and includes results of laboratory physical and chemical tests, and a description of field weathering tests (not completed) on 18 samples of nonmetallic waterstops. Further results will be reported as they are obtained.

Test Specimens

5. The specimens tested included, in addition to eight different samples of polyvinylchloride (designated herein as PVC 1 through 5, 8, and 9), two samples of polyethylene, two samples of natural rubber (NR 1 and 2), two samples of neoprene rubber (Neor 1 and 2), three samples of service rubber (SR 1, 2, and 3), and a sample of butyl rubber. Some of the samples were furnished in sheets and some as finished waterstops. Results of the tests on the polyethylene and rubber specimens were to be compared with results of tests of polyvinylchloride.

PART II: TEST METHODS AND PROCEDURES

Laboratory Tests

Standard test methods

6. All the samples of finished waterstops and sheet material included in the test program were subjected to laboratory tests. The samples are listed in table 1. The test methods used are those given in CE 1402, paragraph -18,[5*] plus two developed by Ontario Hydro, and were as follows:

Test	Method	Publication
Tensile strength, psi	No. 4111	Federal Std No. 601†
Elongation at break	No. 4121	Federal Std No. 601†
Tensile stress at 300% elongation, psi	No. 4131	Federal Std No. 601†
Durometer hardness, Shore type A	D 676-55T††	ASTM Book of Standards
Water immersion, % change in weight	No. 6631	Federal Std No. 601†
Compressive set, % (heat-treated 22 hr at 158 F)	D 395-55 "Method B"‡	ASTM Book of Standards
Oxygen pressure test	No. 7111	Federal Std No. 601†
Effect of alkalies Accelerated extraction	Ontario Hydro Designation C-245-55	See references 3 and 4

† References in CE 1402, paragraph -18, are to Federal Standard No. ZZ-R-601a which was superseded by No. 601 (reference 7 of this report).
†† Reference in CE 1402, -18, is to D 676-49T.
‡ Reference in CE 1402, -18, is to D 395-49T.

Special test, low temperature recovery

7. One sample of four polyvinylchloride and eight rubber specimens was cast into two 6- by 6-in., reinforced-concrete cubes as shown in fig. 1. The cubes, with embedded waterstops, were stripped at one day,

* Raised numbers refer to similarly numbered items in the References at end of this report.

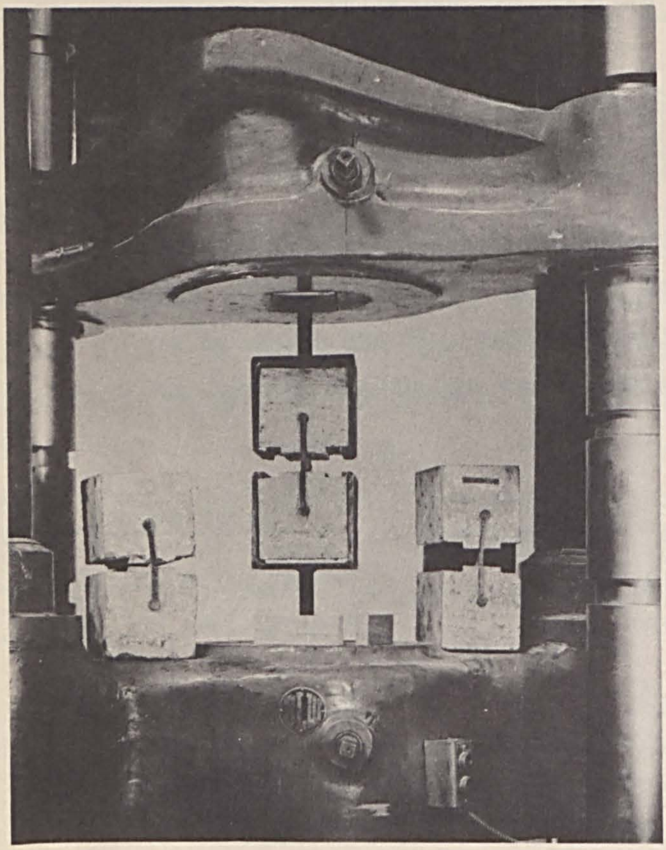

Fig. 1. Method of stressing embedded waterstop specimen

cured 14 days at 100% humidity, and maintained at 42 ± 3 F for 24 hr. Then the waterstops were stretched by pulling the cubes apart for 1 in. at a rate of 1/4 in. per hr. The specimens were kept at 42 ± 3 F during the stretching process. The spacer blocks were then inserted and four measurements of the gap distance taken. After 63 days storage at 42 ± 3 F, the gaps were remeasured and the spacer blocks removed. The gaps were measured twice a day thereafter until no additional recovery could be observed.

Exposure Tests

Unstressed and stressed specimens

8. These specimens were attached to seasoned oak boards and subjected to the types of exposure described in the following subparagraphs. The unstressed specimens were hung by one end from the boards (see fig. 2,

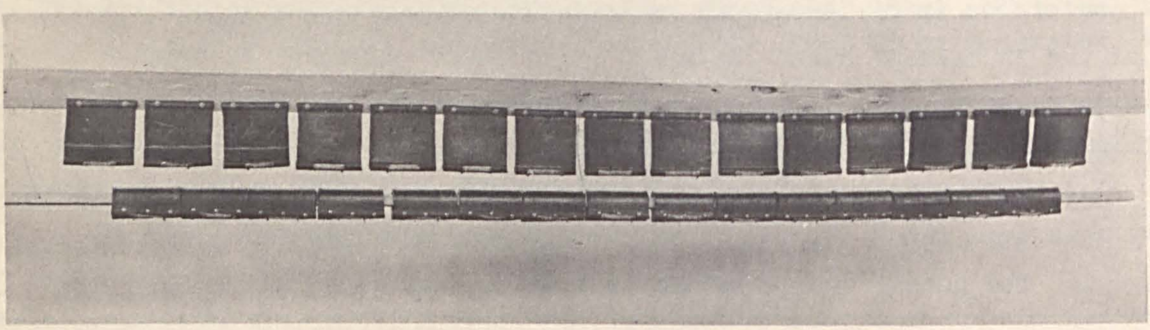

Fig. 2. Method of attaching waterstop samples for weathering tests unstressed (above) and stressed (below)

top) and companion, stressed specimens were bent into the shape of a horseshoe and strung on the boards (see fig. 2, bottom).

a. Treat Island, Maine, Exposure Station. Three specimens of each of the stressed and unstressed waterstop samples listed in table 2 were placed at half-tide elevation on the exposure rack, and during the winter are subjected to cycles of freezing-and-thawing in sea water.

b. St. Augustine, Florida, Exposure Station. Companion specimens to the ones listed in table 2, except PVC 2A and PVC 3A, were placed at half-tide elevation on the exposure rack as shown in fig. 3, and are being subjected to salt-water wetting-and-drying. The two waterstops being tested at Treat Island but not being tested at St. Augustine were especially compounded for low temperature use, and for economic reasons would probably never be used except in areas of extremely cold weather.

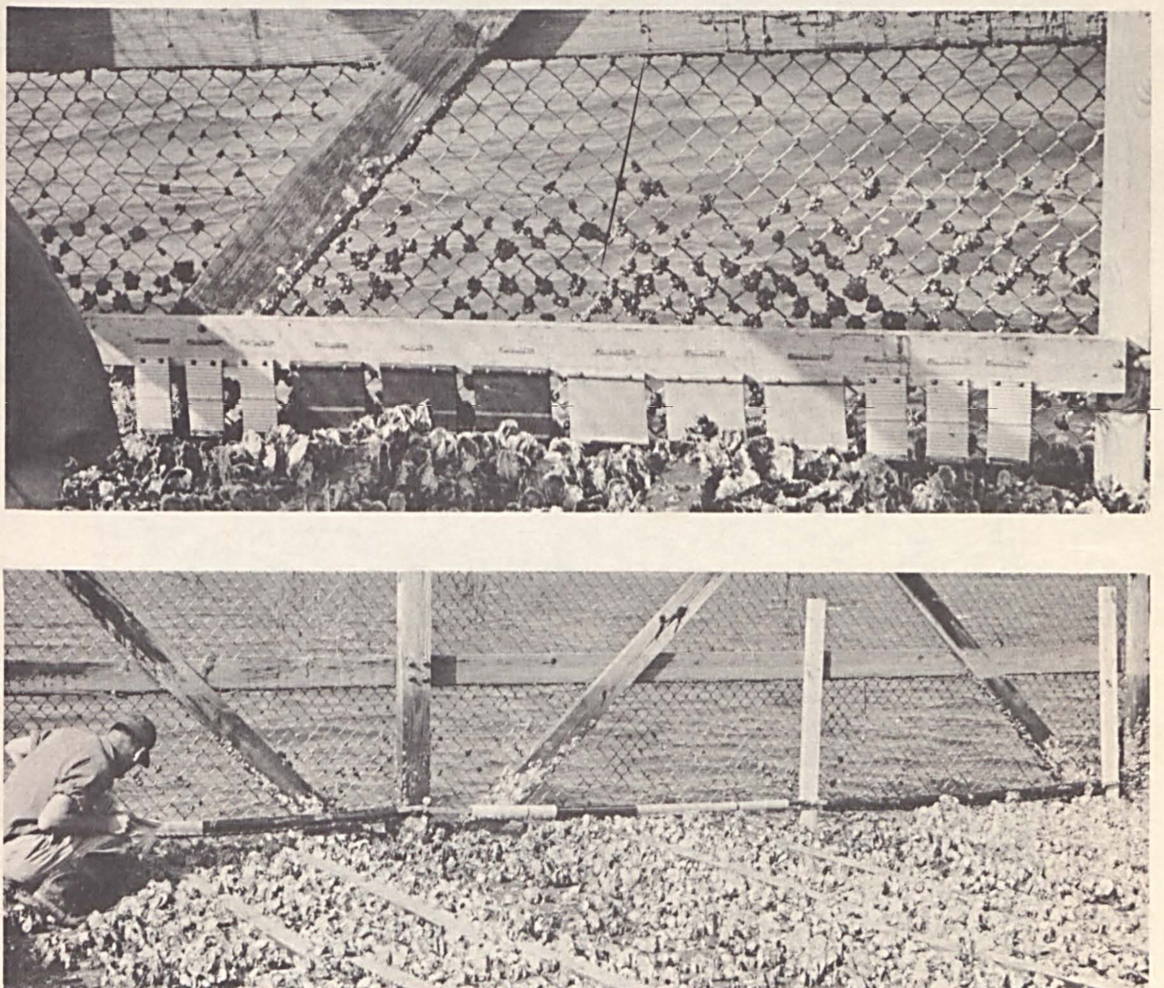

Fig. 3. Unstressed (top) and stressed (bottom) waterstop specimens on the exposure rack, St. Augustine, Fla.

c. Jackson, Mississippi (outdoors). The stressed and unstressed specimens listed in table 3 were placed in the field at the WES Jackson Installation for weathering by air and sunlight. The arrangement of these specimens is shown in fig. 4.

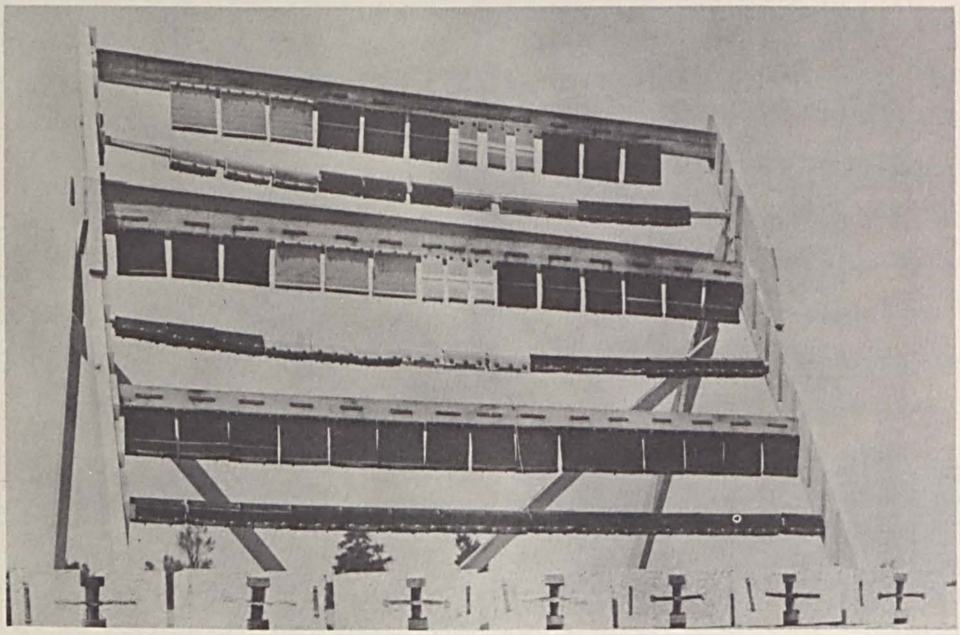

Fig. 4. Waterstop specimens, stressed, unstressed, and embedded, stored in the field at Jackson, Miss., for weathering

d. Jackson, Mississippi (indoors). Companion specimens to those listed in table 3 were placed inside a building to determine effects of exposure to air without sunlight. These specimens were arranged as shown in fig. 5.

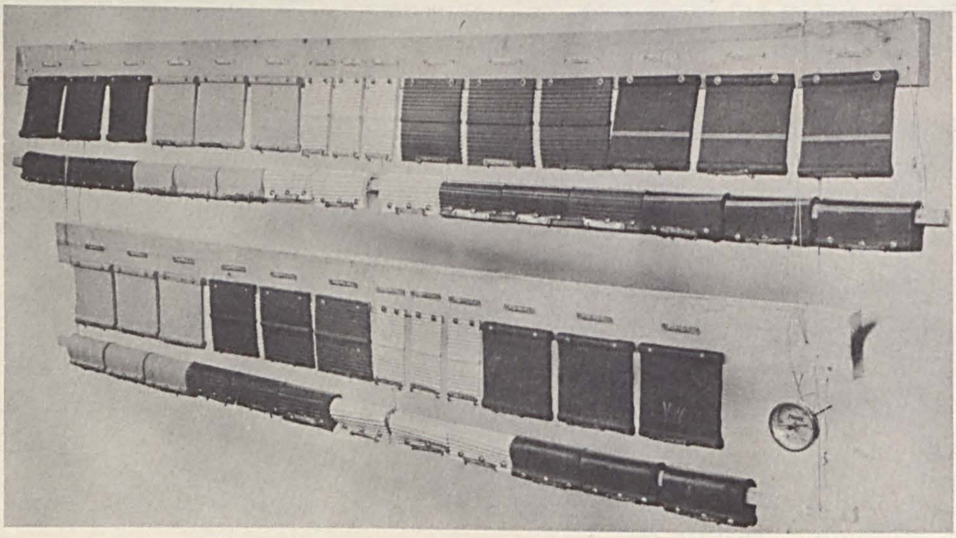

Fig. 5. Waterstop specimens, both stressed and unstressed, stored inside at Jackson, Miss.

Embedded specimens

9. Specimens 6 in. in length were cut from finished waterstop material, embedded in two, 6- by 6-in., reinforced-concrete cubes, allowed to cure for 7 days at 100% humidity, and then the concrete cubes were pulled apart 1 in. Seasoned oak spacer blocks were placed between the two concrete cubes to hold the specimens in the stretched position. The procedure used and equipment required for stressing the specimens are shown in fig. 1. The specimens were exposed at the same locations as the stressed and unstressed specimens except that no embedded specimens were exposed inside the building at Jackson. The specimens exposed outdoors at Jackson are shown in fig. 4 (the bottom row of specimens). Specimens exposed at St. Augustine are shown in fig. 6.

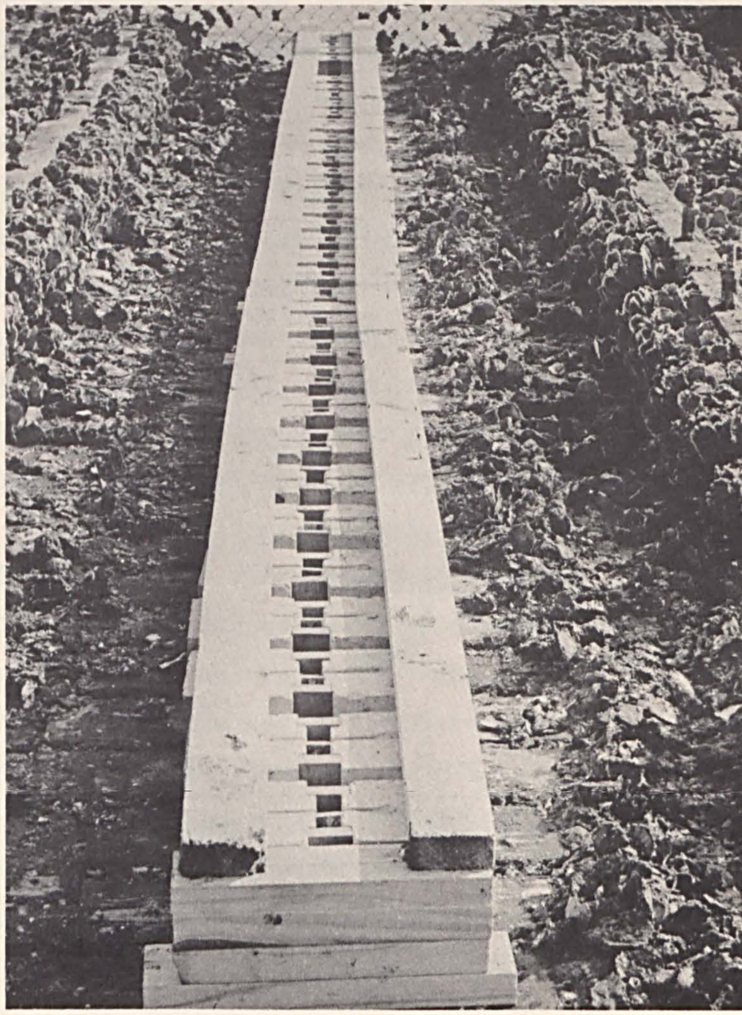

Fig. 6. Embedded waterstop specimens on the exposure rack, St. Augustine, Fla.

PART III: RESULTS AND DISCUSSION

Laboratory Tests

Standard tests

10. Results of the laboratory tests are shown in table 1 and are discussed below. In some of the tests, part of the samples were taken from sheets and others were prepared from finished waterstops. All of the materials used in the tests described in paragraphs 11-31, except when comparing test specimens taken from sheets submitted by the manufacturer with specimens prepared from the finished waterstop, were grouped into general types such as natural rubber, neoprene rubber, etc., and the results for each type material averaged. This average includes results of tests on samples from different manufacturers, many of whom submitted more than one sample of the same type material with each sample designed for a different strength or special property.

11. Tensile strength. All of the natural rubber and neoprene rubber samples tested were designed by the manufacturers to have a tensile strength of 3000 psi. Five samples of service rubber were tested, three of which were designed for 2000-psi and two for 3000-psi tensile strengths. Eight samples of PVC were tested, two designed for 1200-lb tensile strength, the rest for 1800- to 2500-lb tensile strength. The following tabulation gives the average tensile strengths of all the materials tested along with the range of the strengths. The strengths of the individual materials are given in table 1.

	Avg psi	Range Low	Range High
Natural rubber (NR)	2940	2640	3220
Neoprene rubber (Neor)	2920	2830	3030
Service rubber (SR)	2410	1880	3120
PVC	1900	940	2660
Polyethylene (Pel)	1850	1600	2110
Butyl rubber	790	780	800

12. Some manufacturers submitted samples of the finished waterstops along with sheet samples of the same materials. When this was the case,

dumbbell specimens were prepared from the finished waterstop and also from the sheets for tensile-strength tests. The following tabulation permits a comparison of the results of these tests, and of these results with tensile strengths: (a) specified by the Corps of Engineers for rubber waterstop,[5] (b) specified by the Corps of Engineers for PVC waterstop (see Appendix A), and (c) specified by Ontario Hydro[3] and tentatively by The Society of the Plastics Industry[6] for PVC waterstop.

Material Tested	Test Results Tensile Strength, psi: Sheets	Test Results Tensile Strength, psi: Finished Product	Tensile Strength, psi, Specified by: Corps of Engineers: Sheets	Corps of Engineers: Finished Product	Ontario Hydro: Type A*	Ontario Hydro: Type B*	Society of Plas Ind Fin. Prod.
NR	2640	3220	2500 (minimum)				
Neor	3030	2910	2500 (minimum)				
SR**	1880	2040	2500 (minimum)				
SR†	2810	3120	2500 (minimum)				
PVC††	2500	2660	1750	1400	1200	1400	Same as CE finished product
PVC‡	2040	1610	1750	1400	1200	1400	Same as CE finished product
Butyl	780	800	2500 (minimum)				

* Type A is a flat, corrugated waterstop, and type B, an oversize, labyrinth-shaped waterstop. Both are described on p 1280 of reference 4.
** Designed for 2000-psi tensile strength.
† Designed for 3000-psi tensile strength.
†† Standard grade PVC for general use.
‡ Arctic grade PVC designed for low-temperature use.

13. Elongation at break. The percentage elongation at break of each of the test materials, including samples from both sheet and finished products, is as follows:

Material Tested	Average Elongation, %	% Range: Low	% Range: High
Polyethylene	675	650	700
NR	475	425	500
Neor	390	375	400
SR	385	300	450
PVC	340	275	400
Butyl	265	225	300

Although the polyethylene showed the highest percentage of elongation at break, there are some indications that this may not be the true picture, since the polyethylene samples seemed to elongate without breaking but with no elastic recovery when the stress was removed. All types of rubber except butyl were more resilient than PVC.

14. The following tabulation presents comparisons of the results of tests on samples taken from sheets and on samples taken from finished waterstop of the same material, and of these results with minimum elongation at break: (a) specified by the Corps of Engineers for rubber waterstop,[5] (b) specified by the Corps of Engineers for PVC waterstop (see Appendix A), and (c) specified by Ontario Hydro[3] and tentatively by The Society of the Plastics Industry[6] for PVC waterstop.

Material Tested	Test Results Elongation, %: Sheets	Test Results Elongation, %: Finished Product	Minimum Elongation, %, Specified by Corps of Engineers: Sheets	Corps of Engineers: Finished Product	Ontario Hydro: Type A*	Ontario Hydro: Type B*	Society of Plas Ind Fin. Prod.
NR	425	500	450	450			
Neor	400	375	450	450			
SR**	300	325	450	450			
SR†	450	400	450	450			
PVC††	300	300	350	280	250	220	Same as CE finished product
PVC‡	375	275	350	280	250	220	Same as CE finished product
Butyl	225	300	450	450			

* Type A is flat, corrugated, and type B, oversize, labyrinth-shaped.
** Designed for 2000-psi tensile strength.
† Designed for 3000-psi tensile strength.
†† Standard grade for general use.
‡ Arctic grade for low-temperature use.

15. Tensile stress at 300% elongation. All tests were made on samples prepared from finished waterstops. However, after the first series of tests, this test was discontinued as it was not considered to add to the information that is obtained from the tensile strength and ultimate elongation tests. The average and range of test results are tabulated as follows;

detailed results are given in table 1. Corps of Engineers specifications for rubber[5] specify a minimum tensile stress of 900 psi; there are no specifications covering tensile stress of plastic waterstops.

Material Tested	Average psi	Range, psi Low	High
Neor	1970	1460	2470
SR	1880	1720	2120
PVC	1570	940	2610
NR	1540	1460	1610
Butyl	777	777	777

16. Durometer hardness. All of the test materials except NR 2A (sheet sample) were tested for durometer hardness. Average and range of results for each material are given below; detailed results are given in table 1.

Material Tested	Average Hardness	Range Low	High
Polyethylene (Pel)	96	96	96
PVC	79	69	87
Butyl	75	72	78
SR	69	65	76
NR	61	59	63
Neor	63	54	71

Two of the PVC samples showed a hardness of 69 and 70 while the rest of the PVC samples ranged from 73 to 87, which indicates that, while polyvinylchloride usually is harder than rubber, it can be compounded so as to be almost as soft. The polyethylene tested was much harder than either the PVC or rubber tested.

17. Comparisons of results of tests on samples taken from sheets and samples taken from the finished waterstops, and of these results with Corps of Engineers specifications for rubber waterstop[5] are as follows:

Material Tested	Test Results Avg Durometer Hardness: Sheets	Finished Product	Range Specified by Corps of Engineers: Sheets	Finished Product
PVC (std grade)	87	82		
PVC (arctic grade)	80	73		
Butyl	78	72	60-70	60-70
SR (2000 psi)	76	68	60-70	60-70
SR (3000 psi)	70	67	60-70	60-70
Neor	71	63	60-70	60-70

Possibly the reason the sheets tested harder than the finished waterstop was that the ASTM thickness requirement of 1/4 in. for the test samples[1] could not be complied with when testing sheets.

18. Compressive set. Compressive-set tests were performed on selected samples of the rubber and PVC finished waterstops; the number of disks required to achieve the desired original thickness varied from 2 to 5. The average and range of results for each material tested are given below. The samples were tested under constant deflection, and the results are reported as a percentage of the original deflection.

Material Tested	Average Compressive Set % of Original Deflection	Range Low	Range High
Neor	21	17	25
NR	26	22	29
SR	33	26	42
Butyl	35	35	35
PVC	78	75	80

The compressive set recorded for PVC probably was not a true indication because PVC characteristically recovers slowly. In the compressive-set test method, ASTM Designation: D 395-55,[2] the sample is allowed to cool, after the load has been removed, for a period of 30 minutes; then the thickness is measured. PVC is known to recover slowly for about 16 days.

19. CE Specification 1402[5] (CRD-C 513-57) for rubber waterstop specifies a maximum compressive set of 30% when tested under constant deflection "Method B."

20. Change in weight, water immersion. All tests were run on samples prepared from finished waterstop. The average and range of results are as follows:

Material Tested	Water Absorption, %			Water Soluble Materials, %		
	Average	Range Low	Range High	Average	Range Low	Range High
Butyl	1.5	1.5	1.5	0.001	0.001	0.001
PVC	2.4	1.0	3.4	0.004	0.000	0.006
NR	6.1	4.6	7.6	0.003	0.001	0.005
SR	8.5	8.1	9.3	0.003	0.003	0.004
Neor	16.0	13.8	18.2	-0.002	-0.001	-0.002

21. CE Specification 1402[5] for rubber waterstop specifies a maximum of 5% absorption by weight after only 2 days immersion in water at 69-71 C instead of 7 days as required by Test Method No. 6631 of Federal Test

Method Standard No. 601 which was the method used in this investigation. Also "Water Absorption, %" was calculated from data obtained by this test method but is not a calculation required in the test method. No specifications are available for materials other than rubber.

22. Effect of alkalies. The strength and make-up of the solution used in this test are the same as the strongest alkaline solution ever produced by freshly placed concrete. It is considered that a loss of weight by the PVC, through the action of alkalies produced by adjacent concrete, early in the hardening and curing stages of concrete would result in undesirable organic matter reaching the fresh concrete with attendant harmful results.

23. The tests were performed on samples of finished waterstop. The average results are as follows; the range of values and detailed results are given in table 1.

Material Tested	Average Weight Change, %		Average Thickness Change, %		Average Durometer Hardness Change	
	7 Days	30 Days	7 Days	30 Days	7 Days	30 Days
Butyl	0.04	0.05	0.82	1.24	1	2
PVC	0.19	0.29	-2.01	-2.30	-4	0
SR	0.30	0.64	-1.52	-1.43	0	0
NR	0.33	0.72	0.24	-1.08	0	0
Neor	0.51	0.99	-0.94	-1.76	1	2

24. The Corps of Engineers specifications for PVC (see Appendix A) and the proposed specifications of the Committee on Plastic Waterstops of The Society of the Plastics Industry[6] specify that there shall be no loss of weight to exceed -0.10% at 7 days and -0.30% at 28 days and allow a gain in weight at 7 days of 0.00 to +0.25%, and at 28 days of 0.00 to +0.40%. The specifications also specify a change in thickness after 28 days of ±1.0%, and a change in Shore durometer reading after 7 days of ±5. The PVC tested passes these specifications except for change in thickness. Since the tests were conducted on samples prepared from finished waterstop, instead of sheet samples as required by the CE specifications, the results may not be completely reliable.

25. Accelerated extraction test. This test was designed to determine if the PVC samples would lose plasticizers when immersed in an alkaline solution and become hard and brittle as PVC is in the unplasticized state. After the tests were in progress it was discovered that, due to a

mistake in the printed copy of the method being followed, the solution used for submerging the sample was of the wrong alkali concentration. The test was then discontinued and additional test samples ordered. The results will be reported in a later report.

26. Oxygen pressure test, Federal Method 7111.[7] Rubber undergoes degradation when exposed to oxygen and sunlight, which causes hardening and eventual cracking. It has been estimated that this hardening and cracking takes about 35 years when the waterstop is embedded in concrete. The oxygen pressure test was designed to determine the resistance of rubber to aging. Unfortunately this test is useful only as a comparison of different rubbers. There is no known correlation between the life of any application of rubber and the results of the oxygen pressure test, due to the many variables that affect the service life. This test is pertinent because rubber waterstops embedded in a concrete dam would not be exposed to sunlight but probably would be exposed to air on the downstream side and air absorbed in water on the upstream face. Rubber in tension deteriorates much faster than rubber completely relaxed.

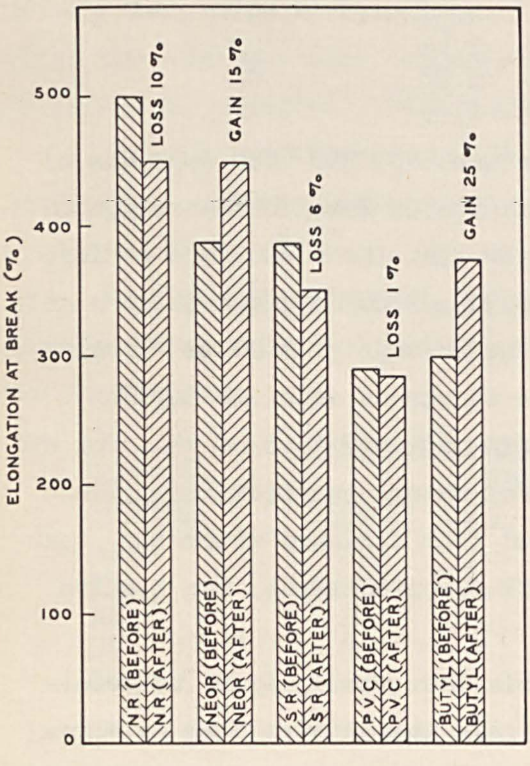

Fig. 7. Effect of oxygen-aging on elongation at break

27. The averaging results of oxygen pressure tests on samples of all the rubber materials and PVC are shown graphically in figs. 7 and 8. These results indicate that the PVC specimens were not adversely affected by oxygen-aging, gaining slightly in both tensile strength and tensile stress at 300%, and remaining practically the same in the elongation-at-break test. Butyl rubber was also not adversely affected, gaining in tensile strength, tensile stress, and elongation at break. The natural rubber tested was most affected, losing an average of 33% in tensile strength.

28. Low temperature recovery test. This test was designed as a

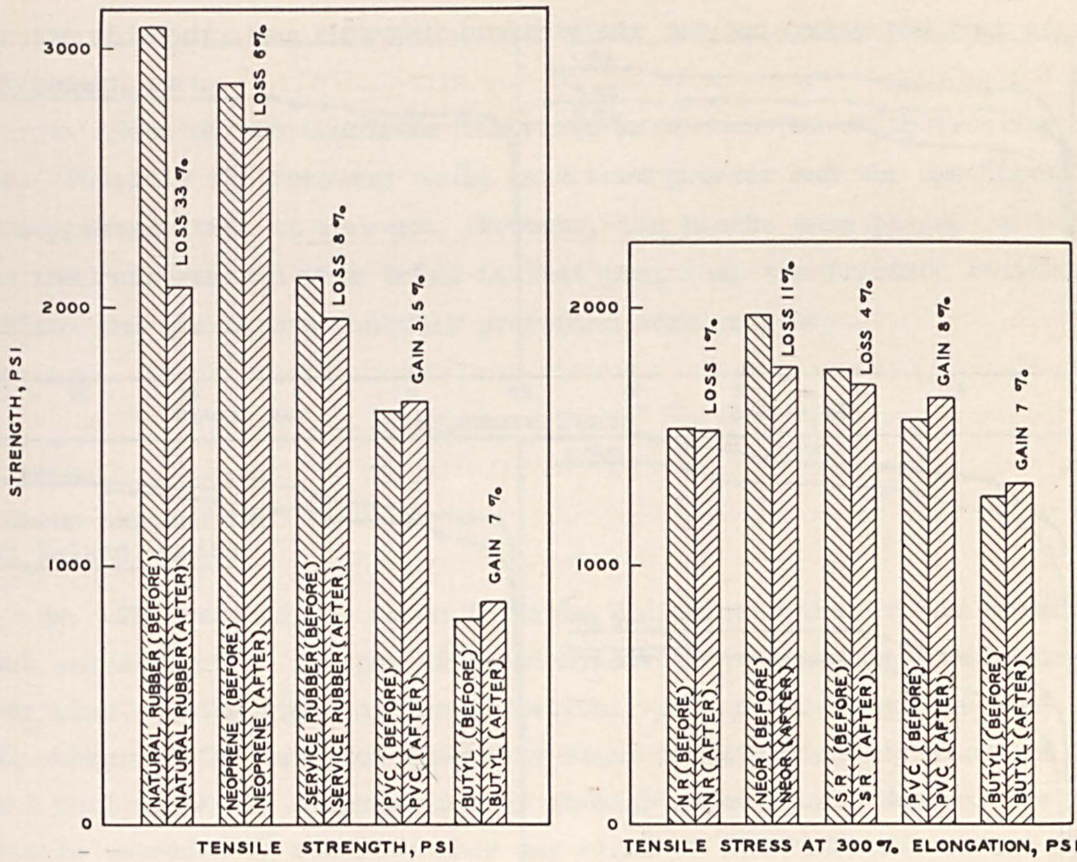

Fig. 8. Effect of oxygen-aging on tensile strength and stress

result of a conference on 6 February 1958 at the Office, Chief of Engineers, between representatives of the Corps of Engineers, Bureau of Reclamation, and various manufacturers of nonmetallic waterstops. It was the consensus of those present that the compressive-set test is not relevant when applied to plastics, since PVC is not immediately responsive to release of pressure and, therefore, showed a compressive set that is not necessarily true since recovery would eventually be made. In order to determine whether this opinion is valid, the test described in paragraph 7 was devised.

29. The results are shown in table 4 and graphically in fig. 9. These results indicate that PVC does not have as much instantaneous recovery as natural, service, or butyl rubber but eventually will recover as much; it recovers slowly for about 16 days. The recovery at lower temperature would undoubtedly be slower. Most of the recovery, however, is completed in 2 to 3 days. Neoprene rubber had practically no recovery at all,

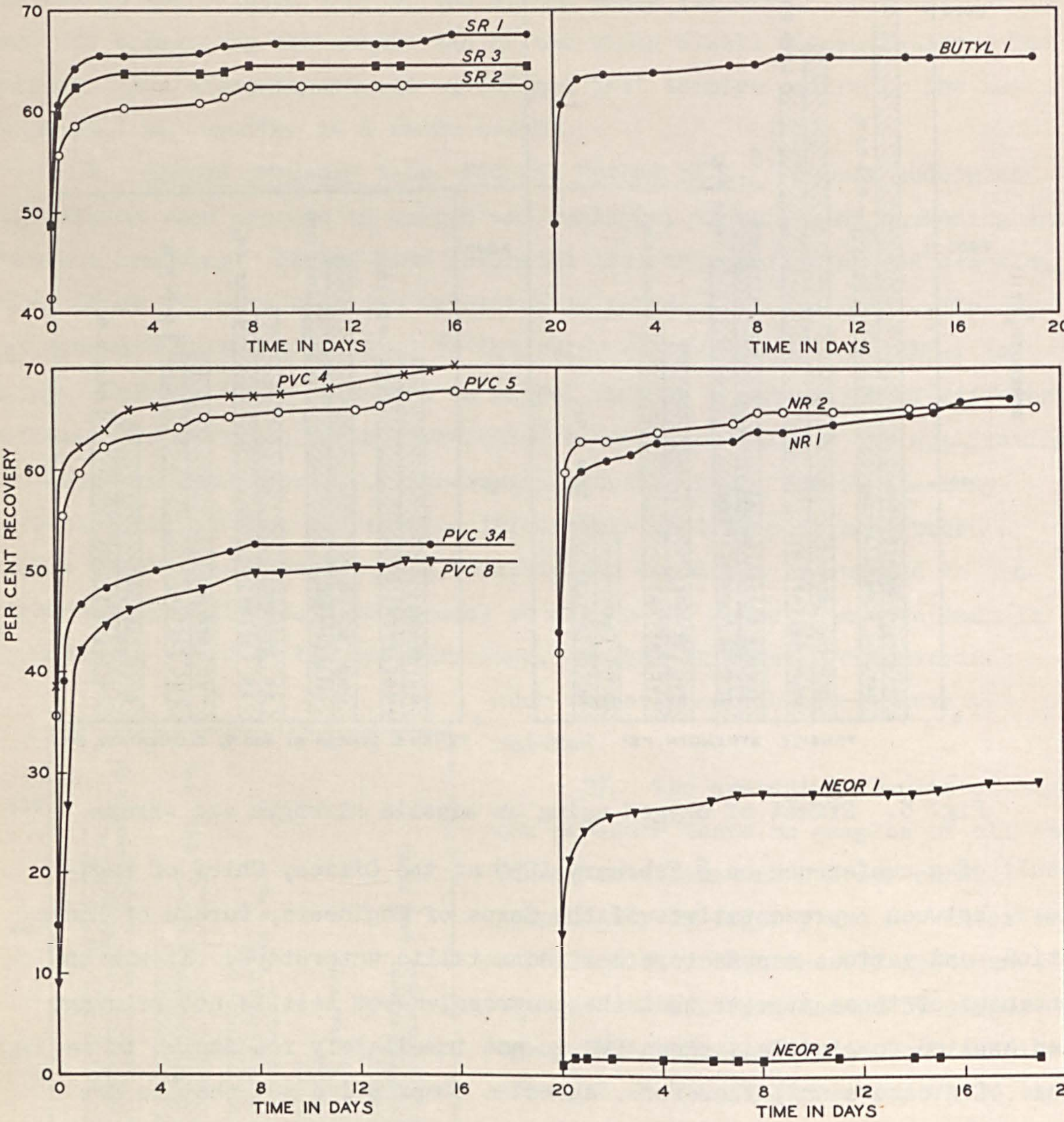

Fig. 9. Low temperature recovery of nonmetallic waterstops

as the specimens seemed to relax after being stretched and exposed to low temperature, and thus relieved the stress.

30. Two of the PVC specimens, PVC 2 and 2A, which were 3/16 in. thick, tore before they could be stretched 1 in., and therefore could not be tested for low-temperature recovery. Another sample, PVC 3, of similar design but 3/8 in. thick, could not be tested because the concrete cubes in

which the waterstop was embedded broke before the waterstop had been stretched an inch.

31. None of the specimens recovered more than 70% of their original shape. Possibly the recovery would have been greater had the specimens been completely free to recover. However, the blocks were placed on the floor and measurements were taken in that position; the friction between the floor and the blocks probably prevented some recovery.

Exposure Tests

Specimens exposed at Treat Island, Maine

32. The results, as shown in table 2, indicate that of the materials tested service rubber is most affected by adverse weathering with natural rubber also showing signs of deterioration. PVC, neoprene rubber, and butyl rubber so far have not shown any signs of deterioration except a slight curling of the neoprene-rubber straight specimens. None of the specimens embedded in concrete show any signs of deterioration as far as can be visually determined, which indicates that rubber embedded in concrete not exposed to sunlight will have a longer service life. The two of the three embedded specimens of PVC 2A that were completely torn in two (see table 2) were the same specimens described previously in the low-temperature recovery tests as being too thin to stretch an inch. The breakage did not seem to be caused by the weathering. Also the two of the three embedded specimens of PVC 3 whose concrete blocks cracked were the same as discussed previously in the low-temperature recovery tests as breaking out of the concrete before they could be stretched an inch.

Specimens exposed at St. Augustine

33. The specimens stored at St. Augustine have not been inspected. The results will be reported in a later report.

Specimens exposed at Jackson, Mississippi (indoors)

34. The specimens stored as shown in fig. 5 were installed in May 1957 and have not been exposed for a sufficient time to show any deterioration.

Specimens exposed at
Jackson, Mississippi (outdoors)

35. The specimens exposed as shown in fig. 4 were inspected monthly. The results, as shown in table 3, indicate the following:

a. None of the unstressed specimens showed any signs of deteriorating except that two samples of PVC changed color, probably due to mildew.

b. Of the stressed specimens tested, service rubber was most affected by weathering, with natural rubber, butyl rubber, and neoprene rubber showing signs of deterioration. Except for color change of two PVC samples, only PVC 2 showed any sign of deterioration and that was very slight.

c. Of the embedded, stressed specimens tested, none of the PVC showed any effect from weathering. Butyl rubber and natural rubber showed no signs of deterioration. The service rubber was torn completely in two. The neoprene rubber relaxed in the presence of stress and weathering until the spacer blocks began to fall out, as was previously noted in the discussion of the low-temperature recovery test results.

Corps of Engineers Specifications for PVC

36. The Corps of Engineers specifications for PVC, written in cooperation with users and manufacturers of PVC waterstops, are included as Appendix A.

PART IV: PROPOSED TESTS AND CONCLUSIONS

37. The results and analysis thereof developed in this investigation give a fairly complete picture of how the several kinds of nonmetallic waterstops compare as far as the particular physical properties tested are concerned. The weathering tests give good information on the performance of waterstops when exposed to salt-water freezing-and-thawing, salt-water wetting-and-drying, air and sunlight, and air but not sunlight. There are other properties for which information is needed and which are to be tested and reported at a later date, such as: accelerated extraction of plasticizers; effect of alkalies; water-retention properties of nonmetallic waterstops; weathering in contaminated fresh water such as is encountered in actual field structures; weathering in fresh, warm water; strength of splices; cold temperature brittleness; and stiffness. When all these tests are completed, the information will be analyzed to determine the need for further study.

38. The information developed thus far suggests the following:

a. Polyvinylchloride on an average is not compounded to be as strong in tension as natural, neoprene, and service rubber, but is stronger than butyl rubber. This, however, is a matter of compounding and not necessarily the order in which these materials would always fall. PVC can be compounded with strengths in excess of 2500 psi, which is well above the specification limits of 1750 and 1400 psi for sheet and finished product samples, respectively, required by the Corps of Engineers specifications for PVC (Appendix A). From the limited information developed, samples prepared from finished waterstop are slightly stronger than similar samples taken from sheets.

b. The PVC tested is not as elastic as natural, neoprene, or service rubber but is more elastic than the butyl rubber tested, as shown by the elongation-at-break test. Tests of polyethylene indicate that it is more elastic than any of the rubbers, but this may not be the true picture because polyethylene elongates or stretches far above its elastic limits before breaking in tension. The minimum elongation of 350% for samples from sheets of PVC, as required by the Corps of Engineers specifications for PVC, may not be easily met by manufacturers of PVC waterstop. According to the results of the limited number of tests, there is no difference in elongation whether the samples are taken from sheets or from finished waterstops.

c. The plastics tested were harder than the rubbers tested but can be compounded to be as soft.

d. In the low-temperature recovery test the PVC tested recovered almost as much as rubber after stretching, but this is not indicated by the compressive-set test. The reason for this is that PVC recovers much slower than rubber, taking about 16 days for complete recovery. However, most of the recovery is completed in 3 to 4 days. Plastics are not capable of nearly as much instantaneous recovery as rubber.

e. Butyl rubber and PVC absorbed practically no water. Natural and service rubbers absorbed an average of 6.1 to 8.5%, respectively, and neoprene rubber averaged 16.0%. None of the rubbers tested except butyl are within the limits of a maximum absorption of 5% by weight specified by Corps of Engineers specifications[7] for rubber waterstops; however, the limit does not apply as the specimens were immersed for 7 days instead of 2 days as required in the specifications.

f. In the effect-of-alkalies test, none of the materials tested lost weight after 30 days testing. The PVC was within the limits specified by the Corps of Engineers specification for PVC except for change in thickness at 30 days.

g. The oxygen-aging test results indicated that butyl rubber and PVC were not affected. Natural rubber was most affected, losing an average of 33% in tensile strength, with service and neoprene rubber affected to a lesser extent.

h. Of the specimens exposed to natural weathering, natural and service rubber deteriorated when exposed to air and sunlight. Under stress and weathering, service rubber was more affected than natural rubber. PVC showed no adverse effect except color changes in some cases.

REFERENCES

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2. ________, "Standard Methods of Test for Compression Set of Vulcanized Rubber." 1955 Book of ASTM Standards, Philadelphia, Pa., Designation: D 395-55, Part 6.

3. Hydro-Electric Power Commission of Ontario, "Waterstops for joints in concrete," by B. Kellam and M. T. Loughborough. Journal of the American Concrete Institute, vol 30, No. 12 (June 1959), pp 1268-1283.

4. ________, "Excerpts from technical clauses of typical specification for plastic waterstops as used by Ontario Hydro," appendix to "Waterstops for joints in concrete," by B. Kellam and M. T. Loughborough. Journal of the American Concrete Institute, vol 30, No. 12 (June 1959), pp 1283-1286.

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6. The Society of the Plastics Industry, Inc., The Committee on Plastic Waterstops, "Proposed Industry Standards for Polyvinyl Chloride Waterstops." Draft No. 1, 13 August 1959, revised 20 January 1960.

7. U. S. General Services Administration, Rubber, Sampling and Testing. Federal Test Method Standard No. 601, 12 April 1955.

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* Also published as Method CRD-C 569-59 in U. S. Army Corps of Engineers, Handbook for Concrete and Cement.

Table 1

Laboratory Test Results of Nonmetallic Waterstops

Sample No.	Type Material	Sampled From	Oxygen Pressure Test: Tensile Strength psi*: Before	Tensile Strength: After	Tensile Strength: % Change	Elongation at Break %*: Before	Elongation: After	Elongation: % Change	Tensile Stress at 300% Elongation*: Before	Tensile Stress: After	Tensile Stress: % Change	Durometer Hardness**	Compressive Set Method B†	Water Immersion††: Water Soluble Material g/in.²	Water Immersion: Change in Weight g/in.²	Water Immersion: Water Absorbed %	Effect of Alkalies‡: Weight Change, % 7 Day	Weight Change, % 30 Day	Length Change, % 7 Day	Length Change, % 30 Day	Width Change, % 7 Day	Width Change, % 30 Day	Thickness Change, % 7 Day	Thickness Change, % 30 Day	Durometer Hardness 7 Day	Durometer Hardness 30 Day
PVC 1	Standard PVC	Sheets	2495			300						87														
PVC 2 } PVC 3 }	Standard PVC	Finished product	2662	2559	-4	300	294	-2	2610	2559	-2	82	78.1	0.000	0.006	1.0	0.06	0.62	0.18	0.00	0.72	0.17	-3.68	-5.93	-4	0
PVC 1A	Arctic grade PVC	Sheets	2043			375						80														
PVC 2A } PVC 3A }	Arctic grade PVC	Finished product	1615	1687	+4	275	250	-9	1615	1687	+4	73	74.8	0.004	0.007	1.2	0.09	0.08	-0.19	-0.29	-3.70	-4.10	-2.91	-5.02	-3	1
PVC 4	Geon PVC, 1200 psi	Finished product	945	1050	+11	275	250	-9	945	1050	+11	69	80.2	0.005	0.020	3.0	0.53	0.45	0.06	0.15	-0.04	0.10	-1.01	-0.17	-3	-1
PVC 5	Geon PVC, 1200 psi	Finished product	1172	1306	+11	325	375	+15	1099	1306	+19	70	77.6	0.006	0.023	3.4	0.08	0.02	0.17	0.07	0.14	0.23	-0.45	1.93	-4	-1
PVC 8 } PVC 8A }	PVC	Finished product	2122			375						80														
PVC 9	Mfg. No. A PVC	Sheets	2253			400						82														
PVC 9A	Mfg. No. B PVC	Sheets	1866			375						82														
PVC 9B	Mfg. No. C PVC	Sheets	1857			375						82														
NR 1	Natural rubber	Finished product	2964	1977	-33	500	425	-15	1464	1240	-15	63	22.1	0.005	0.035	7.6	0.43	0.87	0.11	0.11	-0.31	0.16	-0.58	-1.61	0	0
NR 2	Natural rubber	Finished product	3223	2193	-32	500	475	-5	1612	1798	+12	59	29.1	0.001	0.022	4.6	0.23	0.57	0.21	0.03	0.03	-0.17	1.07	-0.54	0	1
NR 2A	Natural rubber	Sheets	2642			425						-														
Neor 1	Neoprene rubber	Finished product	2829	2604	-8	400	525	+31	1463	1207	-17	54	17.3	-0.002	0.082	13.8	0.62	1.20	0.14	0.16	0.12	0.09	-2.15	-2.15	+1	+4
Neor 2	Neoprene rubber	Finished product	2909	2782	-4	375	375	0	2473	2339	-5	63	25.2	-0.001	0.097	18.2	0.40	0.78	0.07	0.13	0.25	0.21	0.28	-1.37	1	1
Neor 2A	Neoprene rubber	Sheets	3026			400						71														
SR 1	Service rubber	Finished product	2218	1997	-10	450	400	-11	1793	1507	-16	65	25.7	0.003	0.039	8.2	0.32	0.73	0.25	0.36	0.21	0.14	-2.79	-2.44	0	0
SR 2	Service rubber‡‡	Finished product	2036	1922	-6	325	325	0	1722	1897	+9	68	42.2	0.004	0.054	9.3	0.28	0.60	-0.25	-0.15	-0.21	0.43	-0.68	-0.25	1	1
SR 2A	Service rubber‡‡	Sheets	1879			300						76														
SR 3	Service rubber§	Finished product	3117	2560	-18	400	375	-6	2118	2184	+3	67	29.8	0.003	0.041	8.1	0.29	0.59	0.43	0.72	0.30	0.02	-1.08	-1.59	0	0
SR 3A	Service rubber§	Sheets	2812			450						70														
Butyl 1	Butyl rubber	Finished product	800	853	+7	300	375	+25	777	833	+7	72	35.4	0.001	0.007	1.5	0.04	0.05	-0.12	-0.21	-0.04	0.17	0.82	-1.24	1	2
Butyl 1A	Butyl rubber	Sheets	777			225						78														
Pel 1	Hypolon-A sulfonated-chlorinated polyethylene	Sheets	1598			650						96														
Pel 2	High molecular weight (2.5-3.0 carbon black) polyethylene	Sheets	2110			700						96														

* The test methods used are those given in Federal Standard No. 601 (reference 7 of this report).
** ASTM Method D-676.
† ASTM Method D-395.
†† No. 6631 Federal Standard 601.
‡ Ontario Hydro Report 55-403.
‡‡ Designed for 2000-psi tensile strength.
§ Designed for 3000-psi tensile strength.

Table 2

Condition in December 1959 of Waterstop Specimens Exposed at Treat Island, Maine

Sample No.	Date Installed	Condition of Specimens		
		Stressed	Unstressed	Embedded
PVC 2	May 1957	Good	Good	Good
PVC 3	May 1957	Good	Good	Concrete block cracked in 2 of the 3 specimens
PVC 2A	May 1957	Good	Good	2 specimens out of 3 completely torn
PVC 3A	May 1957	Good	Good	Good
PVC 4	May 1957	Good	Good	Good
PVC 5	May 1957	Good	Good	Good
PVC 9A(2)	Aug 1958	Good	Good	Good
Butyl 1	Nov 1957	Good	Good	Good
NR 1	May 1957	After 11 months exposure, slight cracking occurred; after 31 months, still slight	Good	Good
NR 2	Nov 1957	After 4 months exposure, slight cracking occurred; after 31 months, still slight	Good	Good
Neor 1	May 1957	Good	After 11 months, specimen started curling	Good
Neor 2	Nov 1957	Good	Good	Good
SR 1	May 1957	After 7 months exposure, specimens started cracking. Now one deep crack entire length.	At 17 months exposure, specimen slightly cracked	Good
SR 2	Nov 1957	At 1 month, slight cracking; at 11 months, badly cracked.	At 1 yr slightly cracked	Good
SR 3	Nov 1957	At 7 months, specimen suddenly cracked entire length.	Good	Good

Table 3

Condition in December 1959 of Waterstop Specimens Exposed at Jackson, Miss. (Outdoors)

Sample No.	Date Installed	Condition of Specimens: Stressed	Unstressed	Embedded
PVC 2	May 1957	Slight crazing on top of bend	Good	Good
PVC 3	May 1957	Good	Good	Good
PVC 2A	May 1957	Good	Good	Good
PVC 3A	May 1957	Good	Good	Good
PVC 4	May 1957	Good except color change	Good except color change	Good except color change
PVC 5	May 1957	Good except color change	Good except color change	Good except color change
Neor 1	May 1957	Cracked	Good	Specimen relaxed, spacer blocks loose
Neor 2	July 1957	Good	Good	Specimen relaxed, spacer blocks loose
Butyl 1	July 1957	Cracked	Good	Good
NR 1	May 1957	Cracked	Crazed	Good
NR 2	July 1957	Crazing	Good	Crazing
SR 1	May 1957	Badly cracked	Crazed	Cracked
SR 2	July 1957	Cracked	Good	Completely torn in two
SR 3	July 1957	Badly cracked	Crazing	Badly cracked

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Table 4

Cold Weather Recovery of Waterstops

Age	Per Cent Recovery of Embedded Waterstops Stressed 1 in. at 40 F											
	PVC 3A	PVC 4	PVC 5	PVC 8	NR 1	NR 2	Neor 1	Neor 2	SR 1	SR 2	SR 3	Butyl 1
Immediately	14.7	38.4	35.4	8.9	44.0	41.9	13.9	1.2	48.8	41.3	48.6	48.5
7 hours	38.9	---	55.3	26.2	---	59.6	21.1	1.8	60.6	55.4	59.5	60.5
1 day	46.4	62.2	59.6	41.8	59.8	62.7	24.1	1.8	64.2	58.4	62.3	63.2
2 days	48.2	63.9	62.1	44.3	61.0	62.7	25.3	1.8	65.5	---	---	63.5
3 days	---	65.9	---	45.8	61.3	---	25.9	---	65.5	60.2	63.6	---
4 days	50.0	66.2	---	---	62.5	63.6	---	1.5	---	---	---	63.7
5 days	---		64.0	---	---	---	---	---	---	---	---	---
6 days	---	---	65.2	48.0	---	---	27.1	1.5	65.8	60.8	63.6	---
7 days	51.8	67.1	65.2	---	62.8	64.5	27.7	1.5	66.4	61.4	63.9	64.3
8 days	52.4	67.1	---	49.5	63.7	65.7	27.7	1.5	---	62.3	64.5	64.3
9 days		67.3	65.5	49.5	63.7	65.7	---	1.5	66.7	---	---	65.2
10 days		---	---	---	---	---	27.7	---	66.7	62.3	64.5	---
11 days		67.9	---	---	64.3	65.7	---	1.8	---	---	---	65.2
12 days		---	65.8	50.2	---	---	---	---	---	---	---	---
13 days		---	66.1	50.2	---	---	27.7	---	66.7	62.3	64.5	---
14 days	---	69.1	67.1	50.8	65.2	66.1	27.7	1.8	66.7	62.3	64.5	65.2
15 days	52.4	69.6	---	50.8	65.8	66.1	28.0	1.8	67.0			65.2
16 days		70.2	67.4		66.7		---		67.6			
17 days		---	---		---		28.9		---			
18 days		70.2	---		67.0		---		---			
19 days		---	67.4		---	66.1	28.9		---			65.2
20 days		---	67.4		---		28.9		67.6			
21 days		70.2			67.0		28.9		67.6	62.3	64.5	
22 days	52.4	70.2			67.0	66.1		1.8				65.2
23 days												
24 days												
25 days												
26 days												
27 days			67.4	50.8								
28 days	52.4	70.2					28.9		67.6	62.3	64.5	
29 days					67.0	66.1						65.2
30 days								1.8				

Note: 1. PVC 2. The embedded waterstop tore after approximately 3 hr of stretching or at an elongation of about 3/4 in. The test was repeated with the same results.

2. PVC 3. The concrete block in which the waterstop was embedded broke before the waterstop could be stretched 1 in. on three separate attempts.

3. PVC 2A. The specimen tore in two at about 24 hr on the first attempt and at approximately 72 hr on the second attempt.

APPENDIX A

CRD-C 572-60A

CORPS OF ENGINEERS SPECIFICATIONS FOR POLYVINYLCHLORIDE WATERSTOPS

Scope

1. These specifications cover polyvinylchloride waterstops.

General Requirements

2. (a) Waterstops.- The waterstops shall be of the shape and dimensions shown on the drawings accompanying the project specifications. They shall be produced by an extrusion process such that, as supplied for use, they will be dense, homogeneous, and free from holes and other imperfections. The cross section of the waterstop shall be uniform along its length and shall be symmetrical transversely so that the thickness at any given distance from either edge of the waterstop will be uniform.

(b) Material.- The waterstops shall be extruded from an elastomeric plastic compound, the basic resin of which shall be polyvinylchloride (PVC). The compound shall contain any additional resins, plasticizers, stabilizers, or other materials needed to insure that, when the material is compounded, it will meet the performance requirements given in this specification. No reclaimed PVC shall be used.

Inspection and Testing

3. All material and all waterstops will be subject to rigid inspection and testing in order to insure that the supplied waterstops meet the requirements of these specifications. Every facility shall be provided for representatives of the Government to perform careful sampling and inspection of the finished waterstop. The sampling of finished waterstop and all testing of sheet material, finished waterstop, and job-made splices will be done by and at the expense of the Corps of Engineers.

Samples

4. (a) Sheet Material.- A minimum of 2 sq ft of material in the form of sheets 1/16 to 1/8 in. thick shall be obtained from the manufacturer with an accompanying affidavit to the effect that the sheet samples are in all respects from the same material as the one that is and will be used in the manufacture of the finished waterstops and furnished by the Contractor. Test specimens will be of the shape and dimensions specified in the individual test methods, and shall be cut with their long dimensions parallel to the "grain" of the sheet when "grain" of the sheet is visible; when no "grain" is visible, all specimens will be cut with their long dimensions parallel to each other.

(b) Waterstop.- A 12-in.-long sample will be cut from each 200 ft of finished waterstop. The sample will be cut into pieces of convenient size and reduced in thickness by buffing to between 1/16 and 1/8 in., according to the method specified in CRD-C 567, or by slicing, using equipment of the type shown in Fig. 1 (Note). At least five dumbbell-shaped specimens will be cut from the buffed or sliced sample using die III of CRD-C 568,

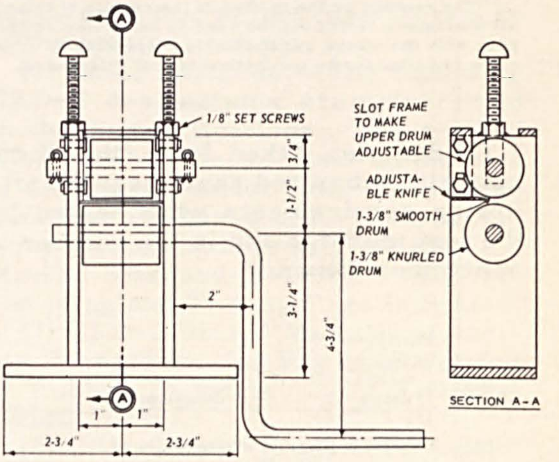

Fig. 1. Waterstop sample slicer. Based on sketch provided by B. F. Goodrich Co., Akron, Ohio. Not to scale

with the long axis of the dumbbell parallel with the direction of extrusion.

Note.- Information on this equipment may be obtained from Ralph W. Murphy, B. F. Goodrich Co., Marietta, Ohio.

Test Conditions

5. Tests will be conducted in a standard laboratory atmosphere of 70 to 75 F and 50 ± 2 per cent relative humidity, unless otherwise specified in the testing methods.

Detailed Requirements

6. The waterstops or the material from which the waterstops are fabricated shall meet the following performance requirements.

(a) Samples taken from the finished waterstop shall meet the requirements listed below when tested by the test method and in the number of specimens shown:

Method of Test CRD-C	Number of Specimens Tested[a]	Requirement
568	At least 5	Tensile strength, using die III, not less than....... 1400 psi
		Ultimate elongation, using die III, not less than....... 280%

[a]The average or the median of the results of tests of all specimens tested will be used to determine compliance with the stated requirements, depending on which value is called for by the method of test referenced.

(b) Samples taken from the sheet material submitted shall meet the following requirements when tested by the test methods and in the number of specimens shown:

Method of Test CRD-C	Number of Specimens Tested	Requirement
568	At least 5	Tensile strength, using die III, not less than....... 1750 psi
		Ultimate elongation, using die III, not less than....... 350%
570	At least 3	Low temperature brittleness, no sign of failure, such as cracking or chipping at .... -35 F
571	At least 3	Stiffness in flexure, 1/4-in. span, not less than......... 400 psi

Paragraph No.	Number of Specimens Tested	Requirement
		Accelerated Extraction
7(a) below	5	Ultimate elongation, using die III, not less than....... 300%
		Tensile strength, using die III, not less than....... 1500 psi
		Effect of Alkalies
7(b) below	1	Change in weight after 7 days, between.......... -0.10 and +0.25%
		Change in Shore durometer reading after 7 days, not more than .... ±5
		Change in weight after 28 days, between .... -0.30 and +0.40%
		Change in thickness after 28 days, not more than .... ±1.0%

(c) Samples taken across job-made splices should meet the following requirements when tested by the test method shown:

Method of Test CRD-C	Number of Specimens Tested	Requirement
568	As directed	Tensile strength, using die III, not less than.....1120 psi

Methods of Testing

7. (a) Accelerated Extraction Test.- Five tensile test specimens conforming to the shape and dimensions given in CRD-C 568, using die III, will be cut from the sheet material submitted and each weighed to the nearest 0.001 g. The specimens will be placed in a one-liter tall-form beaker with spout. The beaker will be filled within 2 in. of the top with a solution made by dissolving 5.0 g of chemically pure sodium hydroxide and 5.0 g of chemically pure potassium hydroxide in one liter of distilled water. The specimens will be completely immersed and the top of the beaker covered with a watch glass. The beaker will then be placed in a constant temperature bath, and the temperature of the solution maintained between 140 and 150 F. A 1/4-in.-diameter glass tube will be inserted

into the spout of the beaker to within 1/2 in. of the bottom of the beaker. Air will then be gently bubbled through the solution at the rate of about one bubble per second. The solution will be changed every 24 hr, the new solution being warmed to 150 F before replacing the old. Once daily, each of the five specimens will be removed from the beaker (preferably at the time of renewing the solution) and rinsed lightly with distilled water. Each specimen will then be superficially dried with a clean cloth. Ten minutes after the specimens have been thus dried the group of five specimens will be weighed and the weight recorded. The sequence of testing will be carried out continuously for a period of not less than 14 days; after which period, provided the specimens have reached constant weight (Note), they will be tested for tensile strength and elongation. Tensile strength will be calculated from the total load at failure, the nominal width, and the thickness as determined prior to exposure to the extraction test. If the tests for tensile strength and elongation cannot be made within one hour after completion of the weighings that demonstrated that constant weight has been achieved, the specimens will be stored immersed in fresh alkali solution at room temperature. Prior to being tested for tensile strength and elongation, the specimens will be removed, rinsed, dried, stored for 10 min, and weighed. The tensile strength and elongation will be determined not more than 72 hr after the weighings which demonstrated that constant weight had been achieved.

Note.- Constant weight is assumed to have been achieved when the weights of the group of specimens on three successive weighings do not differ from each other by more than 0.05 per cent of the original weight. If constant weight has not been achieved after 90 days, the exposure will be terminated, the specimen tested for tensile strength and elongation, and a note added to the report indicating the weight losses between the last three successive weighings and the fact that constant weight, as here defined, was not achieved.

(b) Effect-of-Alkalies Test.- A specimen weighing about 75 g will be cut from the sheet material supplied. The specimen will be washed in tap water, rinsed with distilled water, wiped with a clean cloth, and allowed to dry in laboratory air for approximately one hour. Its thickness to the nearest 0.001 in., measured in three places, and weight to the nearest 0.001 g will be recorded. The durometer reading, using the Shore durometer (Type A), will be taken in accordance with CRD-C 569. The specimen will be completely immersed in a freshly made solution containing 5.0 g of chemically pure sodium hydroxide and 5.0 g of chemically pure potassium hydroxide in one liter of distilled water, kept at 70 to 75 F. The solution will be replaced by a similar fresh solution at a similar temperature every seven days. At the end of seven days the specimen will be removed, rinsed with distilled water, the surfaces wiped with a clean cloth, and allowed to dry in laboratory air for approximately one hour. The weight and durometer hardness will be measured and recorded. The specimen will be reimmersed for a further period of 21 days, at the end of which time the thickness will be measured, and the weight will again be measured. After 7 and 28 days, any changes in weight, and after 28 days, any changes in thickness will be recorded as a percentage of the weight and thickness of the original sample.

(c) Other Methods.- The following CRD-C designations are referred to in these specifications. The method used will be that in effect on the date of advertisement for bids. These designations are based on ASTM designations and methods from Federal Test Method Standard No. 601, "Rubber: Sampling and Testing," as indicated.

(1) CRD-C 567: "Methods of Sample Preparation for Physical Testing of Rubber Products" (ASTM Designation: D 15).

(2) CRD-C 568: "Tensile Strength" (Federal Test Method Standard No. 601, Method 4111).

(3) CRD-C 569: "Hardness, Durometer" (Federal Test Method Standard No. 601, Method 3021).

(4) CRD-C 570: "Method of Test for

Brittleness Temperature of Plastics and Elastomers by Impact'' (ASTM Designation: D 746).

(5) CRD-C 571: ''Method of Test for Stiffness in Flexure of Plastics'' (ASTM Designation: D 747).

Rejection

8. The waterstop may be rejected if it fails to meet any of the requirements of these specifications.