DURABILITY OF CEMENT DRAIN TILE AND CON-
CRETE IN ALKALI SOILS: THIRD PROGRESS RE-
PORT (1919-20)

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ABSTRACT

This paper reports the results of inspection in 1919 and 1920 of experimental drain tile and concrete block installations at eight alkali-bearing projects in the West. The investigation has been carried on since 1913, and the conclusions to date are that the best quality of concrete will disintegrate when exposed to severe alkali attack, and that installations of concrete in soils containing more than 0.1 per cent of salts of the sulphate type should be preceded by an examination of surrounding conditions.

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I. INTRODUCTION

The field investigation of the durability of cement drain tile and concrete in alkali soils and waters was started in 1913. A report giving details of manufacture and installation of test specimens was issued in 1915 as B. S. Technologic Paper No. 44, Investigation of the Durability of Cement Drain Tile in Alkali Soils, containing also the results of the first year's tests. This report is now out of print.

In 1917 a second report was issued as B. S. Technologic Paper No. 95, Durability of Cement Drain Tile and Concrete in Alkali Soils, containing results of the third year's tests. This report included the results of the tests of drain tile in 1916, after three years' exposure, and the results of inspection, after one year's exposure, of a large series of concrete blocks which were installed in 1915.

The field work was interrupted from 1916 to 1919 by press of war work, and again resumed in the fall of 1919 by tests and inspections at all drain and block sites.

Reference should be made to the previous report, B. S. Technologic Paper No. 95, for detailed information as to the manufacture, installation, and results of inspections of test specimens. Only the latest test data and sufficient of the early history of the investigation to give the reader some idea of the scope of the investigation are included herein.

TABLE 1.—Schedule of Mixtures and Processes of Manufacture of Drain Tile

Installation	Series	Proportions cement-sand by volume	Consistency ^a	Manufacture	Curing	Notes
Original installation.	1	1:2½	Plastic.....	Handmade.....	Sprinkling...	Dipped in cement grout. Dipped in hot tar. 10 per cent ferrous sulphate in mixing water.
	2	1:2½	Quaking....	do.....	do.....	
	3	1:2	Plastic.....	do.....	Steam.....	
	4	1:2	do.....	do.....	do.....	
	5	1:2	do.....	do.....	do.....	
	6	1:2	do.....	do.....	do.....	
	7	1:3	do.....	Packer-head machine.	do.....	Sand cement used. From factory stock pile.
	8	1:4	do.....	do.....	do.....	
	9	1:1½	do.....	do.....	Sprinkling	
	10	1:1½	do.....	do.....	Steam.....	
	11	1:3	do.....	do.....	Sprinkling	
	12	1:4	do.....	do.....	do.....	
	13	1:2½	do.....	do.....	Steam.....	
	14	1:3	Fluid.....	Handmade.....	Sprinkling	
	15	1:3	do.....	do.....	do.....	
	16	1:4	Plastic.....	Packer-head machine.	Steam.....	
1914 replacement.	17	1:1½	Quaking....	On jigging machine.	Damp sand...	½ inch maximum size aggregate.
	18	1:2	do.....	do.....	do.....	
1915 replacement.	19	1:2½	Plastic.....	Tamping machine.	48 hours steam.	Aggregate up to ½ inch.
	20	1:2½	do.....	do.....	96 hours steam.	
1919 replacement	21	1:3	do.....	Packer-head machine.	Steam.....	

^a Plastic consistency=Damp sand consistency. As wet as would permit immediate removal of the jacket. Quaking consistency=Not fluid, but wet enough to require retention in the molds for several hours. Fluid consistency=Soupy mixture which was easily poured from a bucket.

II. EARLY HISTORY OF FIELD INVESTIGATION PRIOR TO 1919

1. PROGRAM AND SCOPE OF DRAIN TILE INVESTIGATION

This field investigation, started in 1913, was the outcome of a laboratory investigation started in 1908 by the technologic branch of the U. S. Geological Survey to determine the effect of alkali waters and sea water on cements and concretes. These investigations were transferred by act of Congress to the Bureau of Standards in 1910, and the results were published in 1912.¹ Briefly, these investigations showed that practically all cements are attacked by alkali water upon exposure in the laboratory, and complete disintegration may be obtained under certain conditions. Similar investigations have been made by other laboratories with similar results.²

As the result of a field survey of structures exposed to alkali waters in the Western States, it was felt that the laboratory investigation should be supplemented with a thorough field investigation in which large-sized test specimens would be exposed to the natural field conditions.

An advisory committee was formed in 1913, composed of representatives of Drainage Investigations, Department of Agriculture, the Reclamation Service, Department of the Interior, the American Association of Portland Cement Manufacturers, and the Bureau of Standards. This committee has since been enlarged, in 1919, by the addition of members representing the Portland Cement Association, the American Concrete Pipe Association, and the Engineering Institute of Canada.

A program was drawn up which provided for the manufacture of 16 varieties, or types, of cement drain tile, 8 inches in diameter and 12 inches long, to be installed in working drains in the Western States. To replace tile removed for test, five additional types have since been provided for installation in the drains at intervals, as listed in Table 1.

A list of all drain tile provided for test, as well as essential data relating to their manufacture, are included in Table 1. The tile of the original series were manufactured during the summer of 1913 at a commercial cement tile plant at Armstrong, Iowa. Good practice was followed in the manufacture of these tile and

¹ B. S. Tech. Paper, No. 12, Action of Salts in Alkali Water and Sea Water on Cements.

² Montana State Agricultural College, Circular No. 8, 1910; Bulletin No. 81, 1910. Colorado Agricultural Experiment Station, Bulletin No. 132.

every precaution was taken to make as good and uniform tile as the proportions of materials used would permit.

After a curing period of at least one month carload shipments were made to each of the following places where they were installed in working drains.

Tile shipped to the following districts were installed in concentrated alkali soils where there was sufficient ground water available in the soil to result in flow during a portion of the year: Garland, Wyo.; Fort Shaw, Mont.; Huntington, Utah; Sunnyside, Wash.; Yuma, Ariz.; Roswell, N. Mex.; Grand Junction and Montrose, Colo.

To obtain comparative test data, shipments were also made to Crookston, Minn., and Columbia, Mo., where the tile would be exposed only to fresh water. Another shipment was made to Iowa State College, Ames, Iowa, for storage in the open, exposed to the atmosphere.

Referring to the tile used in the original installation of 1913, as listed in Table 1, it will be seen that proportions varied from 1 cement-1½ aggregate to 1 cement-4 aggregate. For most series a plastic consistency was employed which was as wet as could be used with the packer-head machine and yet permit the immediate removal of the jacket. The hand-tamped tile were molded in sheet metal forms. Series 2 was molded of a quaking consistency mortar which was sticky and slightly flowable, requiring that the forms be kept in place for several hours. Series 14 and 15 were of a soupy, creamy consistency, which was poured from a bucket. Series 3 to 6, inclusive, were similar as to cement and aggregate content, but received different treatments after molding. Series 4 was dipped in neat cement grout after 24 hours. Series 5 was dipped in hot coal tar pitch after 30 days, while 10 per cent ferrous sulphate by weight was used in the mixing water of series 6. Steam-cured tile were exposed to exhaust steam for a total period of 96 hours. The water-cured tile were held in the curing rooms for a period of 12 days, during which time they were sprinkled twice daily without exposure to steam.

To replace tile removed for test in 1914, series 17 and 18 tile were manufactured and furnished by the Universal Portland Cement Co., Chicago.

Series 19 and 20 tile used for replacement in 1915 were manufactured by the Utah Concrete Pipe Co., Salt Lake City, Utah.

In 1919 tile removed for test were replaced by tile manufactured by the Zeidler Concrete Pipe Co., Muscatine, Iowa, and furnished by the American Concrete Pipe Association.

Locations of the drains and concrete block sites in the Western States are shown in the frontispiece, Fig. 1, and the distribution of the various types of the tile in each drain for convenience of removal for test is shown in Fig. 2.

2. PROGRAM AND SCOPE OF CONCRETE BLOCK INVESTIGATION

To determine the effect of alkali waters on concrete placed above and below the ground line a large number of concrete blocks were molded and installed in 1915. In order that actual field conditions might be duplicated blocks of concrete 10 inches square and $2\frac{1}{2}$ feet long were provided, to be placed vertically, with the lower end embedded in the ground to a depth of 1 foot. Two vertical steel reinforcing rods were placed in each block, 2 inches from each face, and a third rod formed a loop projecting from the top which aided in handling. One series of blocks was molded at Denver, a central point, where an excellent quality of aggregate was available, in order to insure a uniform and good quality of concrete. Representative lots of these blocks were shipped to all projects where tests were to be made. Another series of similar blocks was molded at each project and after curing for 30 days was set in place in the soil, while a third series was molded in place immediately exposed to alkali water. At each project the cement in use there was used and the aggregates were of those then available in commercial quantities near the site of construction work on the projects.

The manufacture of one set of blocks at Denver insured a good quality of concrete which would be installed on all projects, thereby permitting direct comparisons to be made of the severity of alkali action at the block sites of the different projects, as well as to give an idea of the relative qualities of the many concretes made with local materials.

Concrete blocks were manufactured and installed at Orman, S. Dak.; Powell, Wyo.; Fort Shaw, Mont.; Sunnyside, Wash.; Fallon, Nev.; Mesquite, N. Mex.; Montrose and Grand Junction, Colo.

FIG. 2.—Arrangement of drain tile. The "A" sections contain two tile of each series and were thus arranged for convenience in removal for testing. There are 10 "A" sections followed by "B" sections each of which is composed of all the remaining tile of one type

In the following table is shown a list of concrete blocks manufactured and installed on each project:

TABLE 2.—List of Concrete Blocks Molded and Installed in 1915

[All blocks molded in smooth wood molds unless otherwise indicated. Blocks are 10 inches by 10 inches square and 30 inches long.]

Place of installation	Molded at Denver: "A" series (proportions by volume)		Molded at project			
			Central yard: "B" series (proportions by volume)		In place in alkali soil: "C" series (proportions by volume)	
	1:1½:3	1:2½:5	1:1½:3	1:2½:5	1:1½:3	1:2½:5
Orman, S. Dak.	2	2	2	2	2	2
	a 2	a 2				
	b 2	b 2				
Powell, Wyo.	2	2	2	2	2	2
	a 2	a 2				
	b 2	b 2				
Fort Shaw, Mont.	2	2	2	2	2	2
Sunnyside, Wash.	2	2	2	2	2	2
Mesquite, N. Mex.	2	2	2	2	2	2
Fallon, Nev.	2	2	2	2	2	2
Montrose, Colo.	2	2	2	2	2	2
Grand Junction, Colo.	2	2	2	2	2	2
	a 2	a 2				
	b 2	b 2				

a Molded in steel-lined molds.
b Molded in rough-wood molds.
c Blocks of both proportions of sand cement concrete and natural cement concrete were also molded at Denver for installation at Grand Junction.

Throughout the block work care was taken to produce the best possible quality of concrete. All materials were weighed to insure accuracy and thoroughly mixed by shoveling in batches sufficiently large for a single block. Sufficient mixing water was used to result in a plastic quaking concrete which handled and placed easily. For the Denver blocks equal quantities of water were used for all blocks of the same proportion. The same procedure was followed at each project. The consistency was not fluid as is commonly used in reinforced concrete construction work, and was probably slightly stiffer than could be used in many structures.

With the variations in brands and constituents of Portland cement used and with the different gradations of aggregates available on the different projects, a large variety of concretes were obtained in this manner, all of which are linked up in such a manner that definite conclusions can be drawn for all through the results obtained with the Denver blocks which were installed at all projects. Full records were kept of quantities of cement, sand, gravel, and water used, and samples of each were obtained for complete laboratory tests and analyses.

3. METHODS OF FIELD TESTS AND INSPECTIONS

As indicated in Fig. 2, the tile originally installed were so grouped that excavation of a continuous trench 32 feet long would allow the removal of a section consisting of 2 each of the 16 types. Field tests made in 1914, 1915, and 1916 consisted of the removal of one or more such sections and crushing tests made near the drain by means of a portable hydraulic tile testing machine which was designed and built at the Bureau. Samples of all broken tile were obtained and observation was made as to the condition of each, such as apparent amount of moisture and white salts in the walls. Samples of soils and waters were obtained for chemical analysis. During the early part of the investigation water samples were also obtained for analysis each spring.

The concrete blocks were inspected in 1916 after one year's exposure. This consisted of visual inspection of each block above and below the water or ground line. Samples of soil waters to which the blocks were subjected were secured for chemical analysis.

4. SUMMARY OF RESULTS OF FIELD INSPECTION PRIOR TO 1919

(a) DRAIN TILE

The condition of the drain tile after three years' exposure may be summarized briefly as follows:

Since the resistance of the tile to alkali action is found to vary more generally with the consistency of the mixture and the method of manufacture, the following grouping is made for convenience of reference:

(a) Plastic consistency, machine-made. Series 8, 12, and 16 (proportions 1:4); 7 and 11 (1:3); 9 and 10 (1:1½); 13 (1:2½); 19 and 20 (1:2½ replacement tile 1915).

(b) Plastic consistency, handmade. Series 1 (1:2½); 3, 4, 5, and 6 (1:2).

(c) Quaking consistency, handmade. Series 2 (1:2½); 17 (1:1½); and 18 (1:2).

(d) Fluid consistency, handmade. Series 14 (1:3) and 15 (sand cement 1:3).

Considering group (a), one or more of the tile of each series have been found to contain varying quantities of salts at one or more of the projects. Tile of the proportion 1 part cement to 4 parts sand, plastic consistency (series 8, 12, and 16), have been found in this condition in all drains where exposed to alkali waters, and at 5

of the 8 projects swelling, cracking, and partial disintegration have occurred. Tile made of 1 part cement to 3 parts sand (series 7 and 11), plastic consistency, with a few exceptions, have given no indications in the crushing tests that they have been seriously affected, although alkali salts have been found in the walls of many of the tile, and in one case swelling and cracking were observed.

Tile of group (b) have been found generally to contain salts at all projects where exposed to alkali water. In some cases cracking and swelling have been observed. None of these tile are made of mixtures leaner than 1 part Portland cement to $2\frac{1}{2}$ parts sand. The inefficiency of hand tamping of a plastic or dry mixture is clearly shown by these tile. The resistance of these tile to alkali exposure is apparently no greater than that of the leanest mixture of group (a). No positively beneficial effects have resulted from the addition and the use of ferrous sulphate in the mixing water of series 6, or by a coating of neat cement grout (series 4), or by a coating of tar (series 5). While the coatings of series 4 and 5 have had some apparent beneficial effects in retarding action in waters of low concentration, the retarding action appears to be negligible where concentrations are high. All tile of these 3 series were made in the proportion of 1 part cement to 2 parts sand.

Of group (c), the tile of series 2, quaking consistency, were hand tamped, and those of series 17 (1 part cement to $1\frac{1}{2}$ parts sand) and 18 (1 part cement to 2 parts sand) were made on a jiggling device. No salts have been found in the interior of the walls of these tile when tested, but one tile of series 17, at Roswell, and one tile each of series 17 and 18, at Montrose, were attacked and disintegrated on the outer surface in contact with the soil. With few exceptions, these tile when tested have appeared dry or wet in spots only in the interior of the walls. The tile of series 2 (1 part cement to $2\frac{1}{2}$ parts sand, quaking consistency) are the only tile which have to date (1916) shown no disintegration nor alkali salts in the walls at any of the projects where exposed to alkali waters.

In group (d) are included series 14 (1 part Portland cement to 3 parts sand, fluid consistency) and series 15 (1 part sand-cement to 3 parts sand, fluid consistency). The sand cement tile have shown alkali salts in the pores, and in numerous cases have shown a softening of the wall at several of the projects, which action was

first noted at Montrose in 1914, when the first years tests were made. Series 14, most nearly comparable with series 2 group (c) in quality, has usually been found dry, or damp only in spots when tested. A small amount of alkali was visible in the end of one tile each of series 14 at Montrose and Grand Junction in 1916.

Nothing has been found in the results of tests or the appearance of the tile at Crookston, exposed to fresh water, which would indicate any harmful constituents in the soil or water.

While many of the individual tile in fresh water at Columbia, Mo., showed an increase in strength over the results of previous tests, all tile excepting series 17 to 20, which have been exposed only 2 years and 1 year, respectively, and series 5, tar coated, showed evidences of disintegration on the lower, outer surface, indicated by the apparent dissolving away of cement, leaving the sand grains coated with a brown stain. This action was in every case confined to the outer $\frac{1}{8}$ circumference in direct bearing on the bottom of the trench. The other portions of the tile were apparently unaffected. While the tile of the 1:4 proportions (series 8, 12, and 16) were in some cases badly pitted, the richer and denser tile showed only slight surface action.

The condition of the tile removed from section 5 at Columbia in 1919 is shown in Fig. 3. The tile of series 3, most seriously affected, is of the plastic, hand-tamped type, while series 2, apparently only slightly affected on the surface, is representative of the best quality. The tar coating of the series 5 tile has been penetrated.

While results of crushing tests are of some value in indicating durability in alkali soils, a visual inspection of the crushed tile offers a better means of measuring the result of exposure to such conditions.

(b) CONCRETE BLOCKS

After one year's exposure none of the 1:1½:3 proportion blocks molded at Denver with selected aggregates (series "A") have shown signs of disintegration on any of the projects. The 1:2½:5 proportion blocks have also been unaffected with the exception of those installed at Fort Shaw and Grand Junction.

It is noticeable that the "C" series blocks made with local aggregate and molded in place exposed to alkali waters are in better condition than the "B" series blocks made of the same materials but placed in the ground after 28 days curing at Orman, S. Dak., Fort Shaw, Mont., Mesquite, N. Mex., Montrose, and

FIG. 3.—*Tile removed from drain at Columbia, Mo., in 1919, affected apparently by acid action*

The tar coating of series 5 had been penetrated as shown. The uneven tamping of handmade tile is shown by the appearance of the rings. A hole was easily scraped through the wall of this tile. The only apparent effect on the series 2 tile is the erosion and roughening of the surfaces, exposing sand grains.

Grand Junction, Colo. At Powell, Wyo., the reverse condition is found, the "C" series blocks having been slightly affected while the "B" series blocks were in good condition. Three of the four sand-cement blocks installed at Grand Junction were slightly scaled and pitted, while the fourth, a 1:2½:5 proportion made so dry that a rough appearing block resulted, was apparently unaffected.

Natural cement blocks were entirely disintegrated at Grand Junction 3 months after being installed. Low temperatures no doubt aided in this rapid action.

TABLE 3.—Individual Results of Crushing Tests of Experimental Cement Drain Tile, 1919
[Total breaking load in pounds. See B. S. Tech. Paper, No. 95, for previous tests.]

Series No.	Results after exposure to fresh water at—				Results after exposure to alkali water—												
	Columbia, Mo.		Crookston, Minn.		Garland, Wyo.		Fort Shaw, Mont.		Sunnyside, Wash.		Yuma, Ariz.		Roswell, N. Mex. Sec. 5	Montrose, Colo. Sec. 5	Grand Junction, Colo. Sec. 5	Huntington, Utah. Sec. 5	
	b Sec. 5	Sec. 6	Sec. 5	Sec. 6	Sec. 5	Sec. 6	Sec. 5	Sec. 6	Sec. 5	Sec. 6							
aAmes, Iowa	1a.....	1770	2330	2950	3000	c 3430	c 3330	c 2860	c 2670	d 2050	c 2930	c 3070	c 2750	d 3110	d 2340	c 2900	
	1b.....	3850	2580	3590	3500	c 3290	c 3280	c 3280	c 3060	c 3160	c 3060	c 3270	c 2900	c 3830	d 2130	c 3430	
	2a.....	3370	2330	3300	3300	c 3710	c 3260	c 3170	c 3310	c 3250	c 3370	c 3170	c 3440	4000	c 3570	c 3130	
	2b.....	3570	2440	3550	2900	c 3500	c 3090	c 3320	c 3390	c 3740	c 3120	c 3260	c 3420	3950	c 3370	c 3370	
	3a.....	2940	3000	(f)	2880	c 2860	c 2040	c 2370	c 2530	c 2530	h 2850	c 2350	c 2790	d 1950	d 1850	d 2400	
	3b.....	2370	2780	3190	2970	c 2360	c 2650	c 2190	c 3250	c 2050	c 2800	c 2480	c 3080	d 1800	d 1850	d 2030	
	4a.....	3820	2910	2890	2675	c 2680	c 2460	c 2130	c 2670	c 2650	c 2750	c 2880	c 3450	c 3230	d 2700	d 2180	
	4b.....	3620	2340	2600	2600	c 2830	c 2830	c 2600	c 3150	d 2230	d 2760	c 3100	c 2900	c 2650	c 3400	d 1290	
	5a.....	3050	2250	3600	(f)	c 2860	c 2410	c 2410	c 2750	h 3010	c 2770	c 3320	c 2920	c 2810	c 3100	c 2220	c 3190
	5b.....	2330	2120	3600	3400	c 2420	c 2990	c 2900	c 2610	c 2710	c 2470	c 3180	c 2200	c 2710	c 2780	c 2380	c 2380
	6a.....	2830	2460	2370	2190	d 2110	c 2080	c 1930	c 2260	c 2390	c 2160	c 2330	c 1980	c 2450	d 2800	d 1070	d 1070
	6b.....	3150	2060	2650	2650	d 2840	c 2280	c 2700	c 2470	c 2700	c 2850	c 2920	c 2350	c 3150	d 2840	d 2600	d 550
	bAmes, Iowa	14a.....	3130	1900	3600	3600	c 2840	c 3140	2520	2730	c 2600	c 3350	c 2830	c 3180	3700	c 3140	2680
14b.....		2950	2000	3900	2950	c 3050	c 2420	2570	2700	c 3320	c 2970	c 3120	c 3410	3940	c 3200	2780	
15a.....		2080	1500	1320	2200	h 2030	h 1470	c 1420	h 1540	h 2170	h 1850	h 2060	h 2000	d 800	d 1350	c 1720	
15b.....		2150	940	1520	1300	h 1710	h 1930	c 1640	h 1720	h 1540	h 1850	h 2100	h 2000	d 1150	d 1290	c 2200	
7a.....		1320	850	(f)	(f)	c 1320	c 1010	c 1240	c 1190	c 1130	c 1490	h 1100	c 1240	d 1740	c 1440	d 1170	
7b.....		1540	1010	1175	1440	c 790	c 1120	c 1310	c 1650	c 1000	c 1120	c 1480	c 1480	c 1000	c 1240	d 1110	
8a.....		940	850	(f)	590	c 1000	c 1040	c 1100	c 1100	d 760	c 980	c 1190	c 1180	c 1260	d 600	d 680	
8b.....		1130	640	690	(f)	c 770	c 830	c 970	c 1190	c 940	c 1070	c 1000	c 1160	c 1060	c 950	c 950	
9a.....		1900	1280	1290	(f)	c 1820	c 1620	c 1410	c 1300	c 2070	c 1770	c 2270	c 1780	c 1400	c 1850	c 1300	
9b.....		2000	1180	1200	(f)	c 1610	c 1580	c 1600	c 1730	c 1900	c 1660	2070	c 1390	c 1850	c 1650	c 1710	
10a.....		1840	1090	1340	(f)	h 1610	c 1620	c 1600	c 1830	c 1130	c 1950	c 1640	c 1450	c 1810	c 1750	c 1670	c 1070
10b.....		1750	980	1170	1140	c 1620	c 1350	c 1400	c 1600	c 1570	c 1810	c 1570	c 1900	c 1350	c 1240	c 1670	c 2010
cAmes, Iowa		11a.....	1650	1070	1080	875	c 1440	c 1550	c 1170	c 1350	c 1230	c 1470	c 1400	c 1450	c 1430	c 1540	c 1410
	11b.....	1770	1170	1120	1300	c 1250	c 1250	c 1340	c 1520	c 1460	h 1280	c 1450	c 1450	c 1580	h 1280	c 1370	
	12a.....	1300	780	830	1000	c 820	c 820	(h, c)	c 1170	h 1000	c 1250	c 1020	c 1040	d 20	c 1060	c 1100	
	12b.....	1600	760	930	1190	c 1010	c 920	c 1130	c 1060	d 550	c 1200	c 1130	c 1020	c 1330	d 670	c 1280	
	13a.....	1700	1190	2000	740	c 1250	c 1600	c 1440	c 1490	c 1600	c 1470	c 1570	c 1340	c 1450	d 1250	c 1690	
	13b.....	1500	1075	1320	1220	c 1710	c 1510	c 1280	c 1600	c 1390	c 1770	c 1590	c 1350	c 1550	1540	c 1060	

16a.....	1640	1000	680	1100	()	c 1120	c 1850	c 1310	c 1130	c 1240	c 1220	c 1200	c 1020	d, e 0	d, e 0	c 1270
16b.....	1400	920	740	1000	650	c 580	c 1000	c 1230	c 1300	c 1210	c 870	c 1190	c 930	d, e 0	d, e 0	c 1080
17a.....	1660	1050	.....	( )	.....	g 1780	.....	g 1680	.....	g 1750	.....	g 1630	f 1540	f, e 0	1810	c 1420
17b.....	2000	1250	.....	( )	.....	g 1690	.....	g 1180	.....	g 1650	.....	g 1400	f 1340	f, e 0	1450	g 11130
18a.....	1780	1120	.....	( )	.....	g 1520	.....	g 1880	.....	g 1520	.....	g 1520	1550	f 1480	1550	g 1110
18b.....	1850	1060	.....	( )	.....	g 1600	.....	g 1730	.....	1380	.....	g 1700	f 1320	f, e 0	1550	g 1220
19a.....	2220	1430	1370	2000	()	g 1690	g 1710	c 1740	.....	c 1610	g 1680	c 1550	g 1560	1950	1600	c 1680
19b.....	2060	1490	1440	2250	()	g 1920	g 1680	g 1700	.....	g 1580	g 1430	c 1930	g 1620	g 1650	2070	c 1720
20a.....	2050	1370	1320	1630	1850	g 1780	g 1720	g 1690	.....	g 1650	g 1540	c 1700	g 1530	g 1680	1870	c 1530
20b.....	1620	1610	1250	1700	1690	g 1850	1690	g 1520	.....	g 1540	g 1480	c 1600	g 1400	g 1550	1890	c 1400

^a Stored in warm dry room for two months previous to test.

^b Disintegration in evidence on all tile of series 1 to 20. See page 62, B. S. Tech. Paper, No. 95. Some action noted in 1919 on tar-coated series 5.

^c Moisture and alkali apparent in fractured surfaces. No cracking, swelling, or disintegration apparent.

^d Saturated; large amount of alkali; cracked; disintegrated.

^e Swollen; cracked; broken in removal from drain. Considered as "0" in strength averages.

^f Cracked, longitudinally, apparently by freezing of water in drain while full.

^g Damp; wet spots in fractured surfaces.

^h Saturated; entire face of one or more fractured surfaces wet.

ⁱ Old crack in wall; probably by presence of salt and swelling just inside outer surface. See Fig. 4. Fractured surfaces appear dry.

^j Disintegration evidenced by presence of salt and swelling just inside outer surface. See Fig. 4. Fractured surfaces appear dry.

TABLE 4.—Average Results of Crushing Tests of Experimental Cement Drain Tile on 8 Alkali Projects, 1919

[See individual test results in Table 3. See B. S. Tech. Paper No. 95 for previous test results.]

Average results for series No. —																					Aver- are all series.	
Place of exposure to alkali water.		1	2	3	4	5	6	14	15	7	8	9	10	11	12	13	16	17	18	19	20	
	Garland, Wyo.....	3120	3240	2580	2700	2740	2235	2860	1785	1060	910	1655	1550	1385	940	1520	885	1735	1560	1775	1760	1900
	Fort Shaw, Mont.....	3100	3240	2275	2710	2665	2340	2630	1545	1345	1090	1510	1605	1345	1120	1455	1242	1680	1805	1720	1605	1900
	Sunnyside, Wash.....	2735	3420	2600	2555	2740	2525	3060	1585	1095	935	1850	1720	1360	900	1505	1135	1700	1450	1575	1550	1900
	Tuma, Ariz.....	3080	3230	2620	3080	2905	2395	3135	1960	1385	1130	1875	1640	1435	1110	1460	1225	1515	1610	1775	1705	2015
	Roswell, N. Mex.....	2825	3430	2935	2940	2760	2800	3025	2030	1120	1215	1625	1580	1505	1185	1500	975	1440	1435	1595	1555	1975
	Montrose, Colo.....	3470	3075	1875	3225	2940	2820	3820	975	1490	830	1725	1495	1330	335	1395	0	0	975	2010	1880	1830
	Grand Junction, Colo.....	1170	3470	925	1495	2300	1300	3170	1320	1365	1065	1780	1670	1350	1170	1375	0	1630	1550	1575	1725	1535
	Huntington, Utah.....	2515	3400	2215	2290	2785	810	2730	1960	1140	815	1540	1605	1390	1085	1665	1175	1275	1165	1700	1465	1735
	Grand average, 8 alkali proj- ects.....	2750	3425	2255	2625	2730	2155	3055	1645	1250	1000	1095	1610	1390	980	1485	820	1370	1445	1715	1655	1850
	Maximum individual.....	3830	4000	3080	3450	3320	3150	3940	2200	1740	1260	2270	2010	1580	1330	1770	1310	1810	1880	2070	1890	.....
	Minimum individual.....	0	3090	0	1290	2200	0	2420	1290	790	600	1300	1200	1120	0	1060	0	0	0	1550	1400	.....

III. FIELD INVESTIGATION OF 1919

1. DRAIN TILE

(a) RESULTS OF INSPECTIONS AND TESTS

All drains were visited, and tests were made of not less than two tile of each series at each project. Individual results of crushing tests of tile, together with observed quantities of salts in the walls, are shown in Table 3. In Table 4 are shown the average results of crushing tests at each project.

In general, the condition of the tile was quite similar to that found in 1916. Average strength results, as well as appearance of the tile with respect to salts in the walls, had not been greatly changed by the three additional years of exposure.

At Fort Shaw, Mont., there had been no appreciable change in the condition of the tile in the test sections at the upper end, but at the lower end a cave-in in the line indicated more serious and complete cases of disintegration than had previously been found in this drain. The lower end of the drain line lies in low ground on the edge of a shallow lake. Under ordinary conditions the shore of the lake is heavily carpeted with salt. Excavation of the caved-in section showed that the 16 grouped tile of series 15 were entirely disintegrated and collapsed. Two adjacent tile of series 7 were also disintegrated, and the grouped tile of series 14 were found to have considerable quantities of salts in their walls, as evidenced by chipping of the ends during excavation, but none of the series had collapsed. The condition of the tile in this portion of the drain indicates that samples of the drain water taken twice yearly from the upper and lower ends of the line have not been representative of the concentrations which have been present locally in the soil immediately surrounding many of the tile. The upper end of the line lies in boggy ground and normally the entire flow is supplied from this source. The soil surrounding the tile at the lower end is, however, high in soluble salts and generally moist, so that at times these tile may be in contact with relatively high concentrations. Further reference will be made to this condition at Fort Shaw.

Condition of the tile at Roswell showed little change from that of 1916. The tile of series 17 and 18 were again found to have been affected by the same surface disintegration first noted in 1916, as shown in Fig. 4.

At Montrose, as in 1916, series 17 and 18 were found disintegrated, as shown in Fig. 4, except that the action had pene-

FIG. 4.—Alkali action on tile of wet consistencies (quaking and fluid) at Montrose, Colo., and Roswell, N. Mex., removed from drains in 1916

(a) Series 17, proportion 1-1½, Montrose, Colo.; (b) series 18, proportion 1-2, Montrose, Colo.; (c) series 17, Roswell, N. Mex.; (d) series 14 proportion 1-3, Montrose, Colo.

FIG. 5.—Tile of series 2 removed from the reserve supply in the upper end of the drain at Montrose in 1919

Four of a total of 12 removed were disintegrated in this manner. Inspection of these tile in 1920 after installation in new drain at Montrose showed the action to be progressing.

trated so far into the walls that 3 of the 4 tile were broken in removal from the drain. The test sections at Montrose are located at the lower end of the drain and the "B" sections, made up of all the surplus tile of each series as shown in Fig. 2, are located at the upper end which was excavated through shale. In removing 12 tile of series 2 from the "B" section for replacement in a new drain a few miles distant, referred to later in detail, it was found that 4 tile had been disintegrated at the ends as shown in Fig. 5. Concentrations found in the drain at Montrose by taking samples at the outlet end have never been high enough to account for this disintegration, and it seems probable that tile placed in the shale are at times exposed to seepage water much higher in concentration than the average of the water flowing through the drain.

It has been noticeable from the beginning of the field tests that the tar-coated tile appear to be most completely saturated of any tile removed from the drains. With very few exceptions the coatings appear to be in perfect condition, both with respect to freedom from alkali action and as to uniformity of coating. Adherence of the tar coat to the concrete surface generally appears to be good, and it is not believed that penetration of this coating by moisture is due to any avoidable defect in the coating.

(b) **INSTALLATION OF NEW DRAIN NEAR MONTROSE**

A new drain was installed northwest of Montrose, near North Mesa Siphon in a small tract of land which has become boggy as a result of seepage of water from higher ground and concentrations of mineral salts from the soil. The concentration of salts in the seepage water at this point is unusually high, about 5 per cent, and advantage was taken of this condition to install a short drain composed of 4 series of experimental tile. These tile were placed in 6 separate sections, each section comprising 2 tile of each of the 4 series, permitting yearly tests for six years. The following series of tile are represented in this drain:

SERIES 21.—1919 replacement tile similar to those installed in all drains after removing the test sections.

SERIES 20.—1915 replacement tile made in Salt Lake City. These tile had been lying in crates at the site of the drain at Grand Junction for four years. No signs of weathering or deterioration were apparent; probably exposure to the weather has increased their resistance to possible alkali action.

SERIES 2.—These tile were removed from the upper end of the drain at Montrose, where they had been in place for six years. As previously mentioned 4 of this group had been disintegrated on the end.

SERIES "A".—Some of the series 21, 1919, replacement tile were treated by soaking in a 5 per cent solution of magnesium fluosilicate for a period of one hour.

(c) INSPECTION OF NEW MONTROSE DRAIN IN 1920

In June, 1920, an inspection was made of the tile placed in the new drain near North Mesa Siphon in December, 1919. One section comprising 2 tile of each series was removed and condition noted as follows:

SERIES 21.—Some disintegration and swelling apparent. Tile had not collapsed.

SERIES 20.—No signs of disintegration or salts in wall.

SERIES 2.—Disintegration, apparent when tile were installed, had made additional progress.

SERIES A.—These tile were swollen, disintegrated, and collapsed. The two tile of the same series in the adjoining section to be removed for inspection at some later date were also completely disintegrated.

These results show (1) marked deterioration for the 1919 replacement tile, series 21; (2) progressive action on the series 2 tile, which have always been found in good condition except in shale at the upper end of the Montrose drain; and (3) no action on series 20 tile, which have occasionally been found with slight amounts of salt in the walls in other drains, but with practically normal crushing strengths. The presence of magnesium fluosilicate, generally used as a concrete hardener and waterproofer, seems to have accelerated disintegration. These limited tests would not be considered as conclusive evidence of the effect of such treatment for exposure to all conditions.

(d) CHEMICAL TEST DATA

For convenience in making comparisons, the average results of chemical analyses of water samples taken at the outlet of drains up to 1917 are included in Table 5, with the analyses of water samples secured during the 1919 inspection. Chemical analyses of soils and waters from the new drain at Montrose, near North Mesa Siphon, are shown in Table 6.

Generally, concentrations were lower in 1919 than were found in previous years. Little variation is shown in the relative quantities of the constituents in the water of any drain. One exception is the great increase of calcium content at Montrose in 1919 and decrease in sodium and magnesium.

Comparing the values of Tables 5 and 6 it will be seen that the concentration of the seepage water in the new drain at North Mesa Siphon is far in excess of any concentration ever detected at any of the eight old drains. No doubt the disintegration of series 2 tile at Montrose and the deterioration of series 14 tile at Fort Shaw can only be accounted for by concentrations approaching that found in the new drain.

TABLE 5.—Analyses (Percentage Reacting Values) of Waters in Experimental Drains

[For explanation of reacting values and method of calculation, see B. S. Technologic Paper, No. 95, pp. 37-43]

Location	Per cent soluble solids in water		Percentage reacting values											
			Na		Ca		Mg		Cl		SO ₄		CO ₂	
	a1	b2	1	2	1	2	1	2	1	2	1	2	1	2
Garland, Wyo.....	0.33	0.20	32.0	33.2	10.3	9.8	7.7	7.0	3.2	1.8	40.6	36.6	6.2	11.6
Fort Shaw, Mont.....	.20	.12	30.6	29.0	6.6	7.4	12.8	13.6	1.6	.7	34.2	25.2	14.2	24.1
Sunnyside, Wash.....	.40	.24	24.7	20.4	14.0	17.8	11.3	11.8	5.1	6.3	38.1	37.0	5.8	6.7
Yuma, Ariz.....	.11	.11	23.5	26.3	15.3	12.9	10.2	10.8	15.4	14.2	12.9	17.4	21.7	18.4
Roswell, N. Mex.....	.46	.49	23.9	25.4	19.4	18.5	6.7	6.1	27.1	28.1	20.0	19.0	2.9	2.9
Montrose, Colo.....	.50	.23	9.2	.8	15.8	40.6	25.0	8.6	.5	.....	46.0	46.3	3.5	3.7
Grand Junction, Colo...	c.85	d.33	25.9	25.5	10.1	11.3	14.0	13.2	17.7	16.2	28.7	25.1	1.9	3.5
Huntington, Utah.....	.30	No flow.	18.3	.....	20.1	...	11.6	.....	1.8	.....	40.8	...	7.4	.....

a 1=average results of analyses, including 1916 inspection.
b 2=analyses of samples taken in 1919. Samples taken at outlet.
c 1.7 per cent nitrates.
d 5.2 per cent nitrates. Concentration unusually low, probably because of flooding of drains of adjacent tract during irrigation at time sample was taken.

TABLE 6.—Analyses of Soils and Waters from New Drain Near North Mesa Siphon, Montrose

[Drain installed and samples taken in 1919]

Sample and location	Per cent soluble solids in soil or water	Percentage reacting values for samples taken in November, 1919						
		Na	Ca	Mg	Cl	SO ₄	CO ₂	NO ₂
Seepage water at outlet.....	4.80	36.5	1.5	12.0	4.0	43.2	1.1	1.7
Soil—top 6 inches, upper end of line.	3.87	26.7	17.7	5.6	2.8	46.6	.6	.....
Soil—bottom trench, upper end of line.....	6.05	21.8	25.7	2.5	1.6	48.3	.1	.....
Soil—top 6 inches, lower end of line.	5.76	25.4	17.7	6.9	2.4	47.3	.3	.....
Soil—bottom trench, lower end of line.....	7.06	9.1	38.3	2.6	.8	49.0	.2	.....
Seepage water at outlet June, 1920..	2.72	30.2	4.0	15.8	6.6	41.7	1.7	Present.

The analyses of a number of soil samples secured in 1919 immediately in contact with tile which were badly disintegrated aid in emphasizing that concentrations to which individual tile may be exposed may be greatly in excess of the average concentrations as determined by analyses of water samples taken a short distance below at the outlet. These results are shown in Table 7. The analyses of the three soil samples from locations only a few feet apart, at Fort Shaw, illustrate the wide differences in salt content which may be found. The presence of over 5 per cent soluble salt in the soil immediately above a tile is certain to result in high concentrations when sufficient seepage water is present. These results indicate how greatly the salt content of the soil varies only a few feet apart, and are of especial value in pointing out how misleading the analyses of a single sample may be.

TABLE 7.—Analyses (Percentage Reacting Values) of Soils and Alkalies from Tile Drains, 1919

Project	Material and location of sample	Per cent soluble solids in sample	Percentage reacting values					
			Na	Ca	Mg	Cl	SO ₄	CO ₃
Fort Shaw, Mont..	Soil under tile of series 7, at cave-in at lower end of line	3.15	2.6	42.5	4.9	.....	48.9	1.1
	Soil 6 inches below surface at series 14 and 15, where serious disintegration occurred	1.26	19.2	11.5	19.3	.....	46.5	3.4
	Soil, same location just above tile....	5.74	4.4	42.5	3.1	.....	49.5	.6
	Alkali on surface of ground, same location .....	.....	31.2	4.4	14.1	0.6	49.2	.2
								
Sunnyside, Wash.	Soil—4 inches to 6 inches below ground surface.....	2.12	22.7	19.1	8.2	4.7	44.3	1.0
	Soil—below tile in drain.....	.16	35.7	11.6	2.7	.....	6.9	43.1
	Alkali on surface of ground .....	.....	37.1	1.4	11.5	6.3	43.5	.2
Roswell, N. Mex..	Soil—bottom of trench	5.82	17.0	30.2	2.8	9.0	38.9	2.1
	White deposit in soil.....	13.37	3.4	45.9	.7	.8	49.0	.2

2. CONCRETE

(a) RESULTS OF INSPECTION

To give an idea of the change in conditions of the concrete blocks taking place after inspection in the fall of 1916, the results of inspections of that year are included with those of 1919 in Table 8.

TABLE 8.—Condition of Concrete Blocks Molded and Placed in 1915. Results of Inspections in 1916 and 1919

Project	Block number ^a	Proportion	Condition in 1916	Condition in 1919
Orman, S. Dak. ^b	1 A	1:1½:3	Good.....	Good
	2 A	1:1½:3	do.....	Do.
	3 A	1:1½:3	do.....	Do.
	4 A	1:1½:3	do.....	Do.
	5 A	1:1½:3	do.....	Slight disintegration ¼ inch deep, one side at ground
	6 A	1:1½:3	do.....	Good
	32 A	1:2½:5	do.....	Disintegration ¼ inch deep all sides up to 8 inches from ground
	33 A	1:2½:5	do.....	Same as 32
	34 A	1:2½:5	do.....	Corners disintegrated at ground line
	35 A	1:2½:5	do.....	Disintegrated through at ground line
	36 A	1:2½:5	do.....	Slight disintegration all sides to top exposing gravel
	37 A	1:2½:5	do.....	Same as 36
	120 B	1:1½:3	Disintegrated 8 inches up above ground, swollen. Concrete soft	Disintegrated through at ground line
	121 B	1:1½:3	Not so bad as 120. Disintegration extends up 2 inches above ground	Disintegration 2 inches deep all sides at ground line
	122 B	1:2½:5	Surfaces shelled off 8 inches above ground. Concrete at ground soft	Complete disintegration. Pile of gravel remains
	123 B	1:2½:5	Same as 122.....	Same as 122
	219 C	1:1½:3	Pitting of surfaces at ground. Concrete is hard	Two sides disintegrated ½ inch deep up 8 inches from ground
	220 C	1:1½:3	Pitted at ground showing aggregate slightly worse than 219	Same as 219
	222 C	1:2½:5	Pitting and shelling 2½ inches deep. Soft at water level	Complete disintegration
	223 C	1:2½:5	Disintegration more advanced than 222	Disintegration through at ground line
	301 B	1:1½:3	Molded in 1916.....	Disintegration 2 inches deep, all sides at ground
	302 B	1:1½:3	Washed sand and gravel.....	Good
Powell, Wyo...	7 A	1:1½:3	Good.....	One surface scaled above water line
	8 A	1:1½:3	do.....	Slight surface scaling above waterline
	9 A	1:1½:3	do.....	Slight scaling, exposing sand grains up 6 inches
	10 A	1:1½:3	do.....	Heavy shelling of surface one side to top, exposing large aggregate
	11 A	1:1½:3	do.....	Slight surface scaling
	12 A	1:1½:3	do.....	Good
	38 A	1:2½:5	do.....	Two surfaces badly shelled off to top
	39 A	1:2½:5	do.....	Same as 38, slightly worse
	40 A	1:2½:5	do.....	Very slight surface scaling.
	41 A	1:2½:5	do.....	Heaving shelling off 2 sides to depth of ½ inch
	42 A	1:2½:5	do.....	Shelling ½ inch deep, all sides to top
	43 A	1:2½:5	do.....	Surfaces scaled to 6 inches of top
	101 B	1:2½:5	do.....	Shelling ½ inch deep at water line
	102 B	1:2½:5	do.....	Slight surface scaling above waterline
	103 B	1:1½:3	do.....	Good
	104 B	1:1½:3	do.....	Do.
	201 C	1:1½:3	do.....	Slight surface scaling 2 inches to 3 inches above water line
Fort Shaw, Mont.	202 C	1:1½:3	Very slight surface pitting above water line	Slightly worse than 201
	203 C	1:2½:5	Considerable scaling of surfaces at water line	Surfaces shelled to depth of 1 inch; large aggregate exposed
	204 C	1:2½:5	Same as 203.....	Same as 203
	19 A	1:1½:3	Good.....	Good.
	20 A	1:1½:3	do.....	Do.
	50 A	1:2½:5	Some surface pitting exposing sand grains	All surfaces scaled to top
	51 A	1:2½:5	Same as 50.....	Not so bad as 50
	107 B	1:1½:3	Good.....	No scaling. One corner spalled off at water line
	108 B	1:1½:3	do.....	Good

^a "A" designates blocks molded at Denver. "B" designates blocks molded at project with local materials and cured for one month before installation in soil. "C" designates blocks molded at project and exposed immediately to seepage water.

^b Small cracks apparent on top of all blocks radiating out from steel at top.

TABLE 8.—Condition of Concrete Blocks Molded and Placed in 1915. Results of Inspections in 1916 and 1919—Continued

Project	Block number	Proportion	Condition in 1916	Condition in 1919
Fort Shaw, Mont. (Con.).	109 B	1:2½:5	Some surface pitting and scaling at water line	Heavy shelling, all surfaces exposing stones. Corners spalled
	110 B	1:2½:5	Not so bad as 109.....	Not so bad as 109
	207 C	1:1½:3	Good	Good
	208 C	1:1½:3	do.....	Do.
	209 C	1:2½:5	do.....	Do.
	210 C	1:2½:5	do.....	Do.
Sunnyside, Wash.	21 A	1:1½:3	do.....	Slight shelling of surfaces at ground line
	22 A	1:1½:3	do.....	Same as 21
	52 A	1:2½:5	do.....	Same as 21 exposed deep and higher on block
	53 A	1:2½:5	do.....	Same as 21
	1S B	1:2½:5	do.....	Surfaces shelled ¼ inch to ¾ inch deep at ground line extending up 4 inches
	2S B	1:2½:5	do.....	Slightly worse than 1S
	3S B	1:1½:3	do.....	Same as 21
	4S B	1:1½:3	do.....	Do.
Fallon, Nev....	27 A	1:1½:3	do.....	Good
	28 A	1:1½:3	do.....	Do.
	58 A	1:2½:5	do.....	Do.
	137 B	1:1½:3	do.....	Do.
	138 B	1:1½:3	do.....	Do.
	140 B	1:2½:5	do.....	Do.
	141 B	1:2½:5	do.....	Do.
	237 C	1:1½:3	do.....	Do.
	238 C	1:1½:3	do.....	Do.
	240 C	1:2½:5	do.....	Do.
	241 C	1:2½:5	do.....	Do.
Mesquite, N. Mex. ^a	23 A	1:1½:3	do.....	Split by large cracks down sides
	24 A	1:1½:3	do.....	Split by large cracks, swollen surfaces badly shelled
	54 A	1:2½:5	do.....	Upper portion badly cracked, some swelling
	55 A	1:2½:5	do.....	Top sloughed off, worse than 54
	143 B	1:1½:3	Slight scaling of surfaces.....	Split by cracks, some swelling
	144 B	1:1½:3	Same as 143.....	Same as 143, cracks smaller
	147 B	1:2½:5	Surfaces scaled 4 inches above ground line exposing sand grains	Large cracks in tops and sides. Top sloughed off
	146 B	1:2½:5	Same as 147.....	Many large cracks. Lumps of concrete easily broken out
	243 C	1:1½:3	Slight scaling of surfaces. Less than 143.....	Large aggregate exposed, deep pitting. Small cracks in top
	244 C	1:1½:3	Same as 243.....	Same as 243, not so bad
	245 C	1:2½:5	do.....	Large aggregate exposed, sounds hollow when tapped
	247 C	1:2½:5	do.....	Same as 246
Montrose, Colo.	25 A	1:1½:3	Good.....	Good
	26 A	1:1½:3	do.....	Do.
	56 A	1:2½:5	do.....	Surfaces scaled up to 5 inches of top.
	57 A	1:2½:5	do.....	Same as 56, except deeper
	125 B	1:1½:3	Surface scaled up to 3 inches of top, exposing fine aggregate	Same condition as in 1916
	126 B	1:1½:3	Worse than 125.....	Do.
	128 B	1:2½:5	Similar to 125.....	Heavy shelling ½ inch deep at ground line extending 3 inches up
	129 B	1:2½:5	Worse than 125.....	Shelling off of surfaces 1 inch deep up to top of block
	225 C	1:1½:3	Good.....	Good
	226 C	1:1½:3	do.....	Do.
	228 C	1:2½:5	Surfaces scaled to height of 1 inch, exposing small aggregates	Same as in 1916
	229 C	1:2½:5	Same as 228.....	Same as in 1916; corners spalled

^a In 1919 all blocks in this group were badly affected by alkali.

TABLE 8.—Condition of Concrete Blocks Molded and Placed in 1915. Results of Inspections in 1916 and 1919—Continued

Project	Block number	Proportion	Condition in 1916	Condition in 1919
Grand Junction, Colo. ^a	13 A	1:1½:3	Good.....	Good
	14 A	1:1½:3	do.....	Do.
	15 A	1:1½:3	do.....	Do.
	16 A	1:1½:3	do.....	Do.
	17 A	1:1½:3	do.....	Very slight scaling one side
	18 A	1:1½:3	do.....	Good
	44 A	1:2½:5	Slight surface scaling up 6 inches, exposing sand grains	Heavy scaling all surfaces 10 inches up
	45 A	1:2½:5	Same as 44.....	Same as 44
	46 A	1:2½:5	Good.....	Do.
	47 A	1:2½:5	do.....	Do.
	48 A	1:2½:5	do.....	Not so bad as 44
	49 A	1:2½:5	do.....	Same as 48
	63 A	1:1½:3	One surface scaled 6 inches up from ground	Deep pitting on 3 surfaces
	64 A	1:1½:3	Same as 63.....	Not so bad as 63
	65 A	1:2½:5	Heavy scaling to depth of 1 inch on three sides	Heavy shelling from ground to top
	b 66 A	1:2½:5	Good.....	Heavy shelling and pitting 1 inch deep at ground, not so bad as 65
	131 B	1:1½:3	do.....	Good
	132 B	1:1½:3	do.....	Do.
	134 B	1:2½:5	Heavy shelling ¾ inch deep all sides	Heavy shelling ¾ inch deep, up 4 inches from ground
	135 B	1:2½:5	Same as 134, not so bad.....	Same as 134. Worse condition
	303 B	1:1½:3	Molded in 1919.....	Good
	304 B	1:1½:3	do.....	Do.
	305 B	1:2½:5	do.....	Do.
	306 B	1:2½:5	do.....	Do.
	231 C	1:1½:3	Good.....	Good. Large cracks in top and 8 inches down one side, do not radiate from steel
	232 C	1:1½:3	do.....	Good
	233 C	1:2½:5	do.....	Do.
	234 C	1:2½:5	do.....	Do.

^a Seepage during past three years has not been sufficient to keep soil saturated to desired extent.

^b Blocks 67 and 68, natural cement, proportions 1:1½:3, were installed in 1915 and completely disintegrated before the following spring.

In general, blocks which were affected in 1916 were more seriously affected in 1919, the action having been progressive. Due to changes in conditions of exposure at the various projects the rate of disintegration has, in some cases, been very marked, and in others little apparent change has taken place in the 3-year period.

Disintegration is usually first evidenced by a scaling of the neat cement film on the surfaces of a block at and just above the ground line, exposing sand grains. Further action results in exposing particles of the coarse aggregate, giving the block the appearance of having been subjected to erosion. Later, spalling of larger chunks of concrete will be apparent, and if the level of the soil water is at or above the ground surface the concrete may become soft and mushy. The softening and spalling of the surfaces is often accompanied by the formation of large cracks radiating out from the handle steel. The totally embedded bars may also contribute to the failure of the block by corrosion and the resulting

expansion. The disintegrating action is not, however, always confined to the concrete above the surface where evaporation is high, but the lower portion of the block, which is probably always moist, may be equally affected.

No doubt the rapidity of disintegration is in some cases, especially on the northern projects, aided by extreme weather conditions, but the extent of such action can not be definitely determined. The scaling of the neat cement film, the first step in disintegration, were action to proceed no further, might be explained as due entirely to freezing weather and temperature changes, yet even where extreme cold occurs it appears that this may be only a contributing factor and that salt in solution is the primary cause of the trouble. That such scaling may occur without freezing weather was demonstrated at Montrose in 1916. The blocks were installed in the fall of 1915 after water had been turned out of the adjacent canal, so that the water level during the winter was below the ground surface. In the spring the amount of seepage was sufficient to flood the ground surrounding the blocks to a depth of more than 1 foot, the water level standing slightly below the tops. Inspection in the fall of the same year showed that the surfaces of many of the blocks had been badly scaled, the action being apparent up to the water level reached during the summer. Scaling of surfaces is also very apparent at Powell where the water level varies considerably, often standing as high as the tops of the blocks. Concrete structures made of the same materials as the B and C series blocks exposed to the same climatic conditions in a near-by fresh-water reservoir at Powell are in good condition and show no signs of surface action.

In describing the condition of the blocks listed in Table 8, those which have been apparently unaffected in any way have been described as "Good." The numbers of blocks listed as "Good" in 1916 and found to be affected to a greater or less extent in 1919 is most marked at Orman, S. Dak., Powell, Wyo., Sunnyside, Wash., Mesquite, N. Mex., and Grand Junction, Colo. At Fort Shaw, Mont., there has been little change in the three years. Here conditions have apparently been quite uniform ever since the blocks were installed. At Fallon, Nev., none of the blocks have been injured in any manner to date. At Fort Shaw and Sunnyside disintegration has been lacking or confined to surface scaling or pitting, exposing sand and gravel particles. Deeper pitting and disintegration have been noted at Powell, Montrose, and Grand

FIG. 6.—View of five blocks at Mesquite in 1919 showing cracking and disintegration
From left to right these blocks are numbered as follows: 143, 147, 146, 54, and 55.

Junction. Serious disintegration of entire blocks has occurred at Orman, S. Dak., and Mesquite, N. Mex. The appearance of some of the blocks at Mesquite in 1919 is shown in Fig. 6. From left to right these blocks are numbered as follows: 143, 147, 146, 54, and 55. It will be noted that the top portions of blocks 146 and 55 are badly disintegrated, and the view of block 143 gives some idea of the serious cracking of the mass above the water, showing a step in the disintegration not quite so far advanced as for the first two mentioned. Owing to the drying up of the block site at Grand Junction after the first year as a result of the silting up of the adjacent canal, only slight changes have occurred there since 1916. The quantity of soil water present at Grand Junction since that time has not been sufficient to develop the extreme conditions which the quantity of salts present in the immediate locality would seem to justify. Conditions at Orman have been continuously bad, and several of the blocks have shown apparent signs of deterioration. The blocks at Mesquite had been little affected previous to inspection in 1916, but all may now be considered as complete failures.

Relative severity of exposure conditions at all of the projects can be judged by the condition of the Denver block (A series) at each, since these are of a uniformly high quality of concrete, similar in every respect.

(b) CHEMICAL TEST DATA

Chemical analyses of waters to which the concrete blocks have been exposed are included in Table 9. Since conditions are continually changing, the samples obtained at any project are not sufficient to furnish a complete record. There is no certainty that maximum concentrations have been detected at any site by means of the few samples taken. This is especially true for the 3-year period from 1916 to 1919 when field work was suspended.

With the exception of Fallon, all water samples obtained are of the sulphate type. At Fallon the carbonate radical is practically as high as the sulphate, but taking concentration into account it is seen that the carbonate is little higher than in normal waters. No apparent deterioration whatever has occurred in the concrete blocks installed at Fallon.

Most serious disintegration of concrete blocks has occurred at Mesquite and Orman, and the analyses show that concentrations in excess of 3 per cent have been present at least once.

TABLE 9.—Analyses of Surface and Subsoil Waters at Block Sites, 1915 to 1919

Location	Date	Per cent soluble solids in water	Percentage reacting values					
			Na	Ca	Mg	Cl	SO ₄	CO ₃
Orman, S. Dak.	Fall, 1915.....	1.46	24.7	3.5	21.8	0.6	47.9	1.5
	Spring, 1916.....	.93	22.8	9.3	17.9	.1	45.4	4.5
	Fall, 1916.....	1.36	23.7	21.8	4.5	.5	47.2	2.3
	Fall, 1919:							
	Surface water at site.....	3.31	18.3	9.4	22.3	.4	46.6	3.0
	Subsoil water above site.....	.51	10.5	15.4	24.1	.2	45.9	3.9
Powell, Wyo....	Fall, 1915.....	.81	42.5	4.2	3.3	3.3	41.9	4.8
	Spring, 1916.....	.70	41.8	4.0	4.2	3.3	41.5	5.2
	Fall, 1916.....	.67	41.4	4.2	4.4	3.9	39.6	6.6
	Fall, 1919.....	.41	43.1	3.3	3.6	3.2	38.2	8.6
	Fall, 1915.....	.40	36.5	2.4	11.1	2.0	47.3	.7
	Spring, 1916.....	.95	33.0	6.7	10.3	1.7	47.0	1.3
Fort Shaw, Mont.	Fall, 1916.....	2.44	34.7	2.7	12.6	1.3	47.7	1.0
	Fall, 1919.....	1.67	32.0	4.7	13.3	2.0	46.3	1.6
	Fall, 1915.....	.22	19.7	13.9	16.4	8.5	36.9	4.6
Sunnyside, Wash.	Spring, 1916.....	.22	29.2	7.0	13.8	6.2	41.1	2.7
	Fall, 1916.....	.22	26.6	6.9	16.5	8.3	47.3	4.4
	Fall, 1919.....	.23	29.2	6.6	14.2	8.9	35.1	6.0
	Fall, 1915.....	.13	44.8	2.4	2.8	9.0	22.7	18.3
Fallon, Nev.	Spring, 1916.....	.13	46.7	2.1	1.2	8.5	21.2	20.3
	Fall, 1916.....	.12	46.4	2.7	.9	9.6	22.1	18.3
	Fall, 1919.....	.10	44.9	2.7	2.4	8.5	21.2	20.3
	Fall, 1915.....	.86	43.2	5.5	1.3	21.7	29.4	.9
Mesquite, N. Mex.	Spring, 1916.....	3.02	43.4	3.7	2.9	14.8	34.6	.6
	Fall, 1916.....	2.64	42.8	4.0	3.2	23.5	25.8	.7
	Fall, 1919.....	.47	39.4	7.0	3.6	13.0	36.1	.9
	Fall, 1915.....	1.61	30.3	4.4	15.3	.7	48.0	1.3
Montrose, Colo..	Spring, 1916.....	1.09	29.5	6.9	13.6	.7	47.0	2.3
	Fall, 1916.....	1.78	28.4	5.6	16.0	.7	48.6	.7
	Fall, 1919.....	.65	16.4	17.4	16.2	.4	48.5	1.1
	Fall, 1915.....	2.51	39.3	3.2	7.5	2.2	47.2	.6
Grand Junction, Colo.	Fall, 1916.....	.32	30.6	16.6	2.8	.8	46.6	1.6
	Fall, 1919.....	1.02	45.6	7.3	7.2	1.1	47.5	.9

The great variations which occur at the same time in seepage waters only a short distance from each other is illustrated by the samples obtained at Orman in 1919. Blocks here are placed below a wasteway in soil which is usually moist, due to seepage from a canal. In 1919 a few inches of water stood over the surface of the ground surrounding the blocks. The concentration of salts in this water was 3.31 per cent. Subsoil water obtained a few feet away in the direction of the canal had a concentration of 0.51 per cent, while a large pool below the block site contained 0.93 per cent salt.

These analyses covering the period from the beginning of the investigation permit the statement that concentrations not less than those indicated for each project have occurred at the stated times but give little idea of what maximum concentrations may have been present before or after these samples were taken or may have been present in other locations even a short distance away.

3. SUMMARY OF RESULTS

(a) DRAIN TILE

Durability of cement drain tile for any given concentration appears to vary with richness of mix and consistency. Hand-tamped tile are less resistant to action than machine-made tile made of the same mortars.

Tile made with sufficient mixing water to result in such a consistency that they must be retained in the molds for several hours have proved more durable than richer mix tile of the machine-made type of such a dry consistency that the jacket may be stripped immediately. Results to date have indicated the 1915 replacement tile, series 19 and 20, made with a combination packing and tamping machine of a consistency permitting immediate removal of the jacket, to be more resistant to alkali action than richer mixes of the same consistency made on the packer-head type of machine or by hand. As a class it may be said that wet mix tile have been much less affected by alkali action than dry mix tile.

Inspection of drain tile and concrete structures in other localities where the alkali salts are of the chloride or carbonate types seem to justify the conclusion that these waters are not so severe as waters of the sulphate type which are found in all of our drains in the alkali districts. Results have shown that it is impossible to estimate the maximum concentrations to which tile in the drain may be exposed by analyses of water flowing in the drain. In waters of the sulphate type severity of action appears to vary with the concentration of soluble salts. The number of types of tile affected by alkali varies roughly with concentration of water as determined by analyses of water samples taken at the outlet. In all cases where disintegration of the best quality of tile has occurred samples of the soil immediately in contact with such tile have revealed concentrations much higher than are indicated by the drain water.

To date, one or more marked cases of disintegration have been noted in every type of tile except series 19 and 20. The fact that appreciable quantities of salt have been found in the walls of this type in some cases would indicate that this type has probably not been exposed to the extreme concentrations found for some of the test specimens of series 2, 17, and 18.

(b) CONCRETE

The concrete blocks have all been exposed to waters of the sulphate type. Owing to variation and change in ground water conditions at some of the sites, some blocks have not been exposed to the extreme conditions which might be indicated by analyses of surrounding soils. While the Denver "A" series blocks have generally been more resistant to alkali than the blocks molded on the projects, these blocks have been seriously affected where concentrations have been high.

As in the case of drain tile, it may be stated that severity of action on the concrete blocks appears to vary with concentration of soluble salts. While there is no record of the maximum concentrations encountered, conditions have been such on one project that all blocks installed may be considered as complete failures.

With the same aggregates, lean mixtures are more seriously and rapidly affected than rich mixtures. Durability appears to be dependent upon impermeability, which is mainly dependent upon richness of mix and gradation of aggregates.

IV. CONCLUSIONS

While any conclusions drawn from the results of the investigation to date must be considered as tentative, it is believed that the scope of the work, the variety and types of concretes included, together with the widely different exposure conditions have resulted in extending the knowledge of what occurs when such material is exposed to alkali soils and waters. No doubt further extension of this investigation, as well as independent investigation by others who are interested in the use of concrete under such conditions, will result in more detailed conclusions and accurate limitations, but the work to date has consistently emphasized certain precautions which should be observed by anyone using cement under such conditions.

1. CONCRETE

1. Results to date indicate that materials of good quality and proper workmanship are of great importance in the production of concrete which is to be exposed to alkali soils and waters.

2. Action noted on surfaces of concrete blocks of best quality after 1 year exposure in sulphate waters has in most cases been progressive, depending upon conditions of exposure.

3. Extent and rapidity of disintegration in sulphate waters depends upon concentration of salts in waters to which the concrete is exposed.

4. In blocks containing reinforcing rods disintegration appears to be aided and accelerated in some cases by corrosion of embedded steel and consequent cracking of the concrete, as has been observed in some reinforced concrete structures exposed to sea water.

5. Structures placed in alkaline soils or exposed to alkaline seepage waters should be given all possible protection by drainage.

6. Seepage waters and alkaline soil conditions may be encountered which will disintegrate concrete of the best quality, and proper consideration should be given to soil and water conditions and protection by drainage and other means when it is proposed to expose concrete structures to conditions similar to those in which these test blocks have been placed.

7. Alkali salts are not uniformly distributed throughout the soil or large bodies of seepage waters, and it will be difficult to determine in advance the concentrations to which a structure may later be exposed. A systematic scheme for sampling soils will furnish information as to the quantities and types of salts available for solution, while analyses of seepage waters will indicate the concentrations present at the time of sampling. Disintegration is brought about only by those salts which are in solution as indicated by analyses of water samples, while the soil analyses merely represent reserve supplies which may bring about changes in the existing solutions with changing conditions of rainfall, flooding, etc. The problem of drawing conclusions as to the most severe conditions which may occur becomes more difficult when the source of supply of the salt is through underground seepage from some distant point.

8. For the same concentration of soluble salts, and for the same aggregates, resistance of mass concrete to alkali action appears to vary with cement content or richness of mix, within the limits employed in these tests.

2. CEMENT DRAIN TILE

1. The use of concrete tile in soils containing alkali salts of the sulphate type in considerable quantities is hazardous, in view of the fact that the best quality of drain tile has been disintegrated during an exposure of less than six years.

2. Porous or permeable tile, due to the use of lean mixtures, or relatively dry consistencies, are subject to disintegration in sulphate waters of relatively low concentrations.

2. Dense tile of the best quality, exposed to sulphate waters, are under certain conditions subject to disintegration, depending upon concentration of salts in seepage water, and alkali and moisture conditions in the soil immediately surrounding the tile.

4. Disintegration may be manifested in sulphate waters by physical disruption caused by expansion resulting from the crystallization of salts in the pores, *but it is primarily due to chemical action between the salts in solution and the constituents of the cement.* In the case of dense tile of low permeability exposed to sulphate waters, disintegration may occur at or just inside the surface skin and progress into the wall of the tile.

5. A thin outer skin of apparently unaffected concrete is apparent in the case of disintegration of the best quality of tile. While this relatively thin layer may be either immune to attack by salts in solution, or perhaps be very slowly attacked, results indicate that this carbonized coating is not in itself waterproof, and alkali water may pass through this coating into the mass.

6. In sulphate waters with a concrete or mortar of given quality the disintegrating effect seems to vary with the concentration of the solution.

7. Tile made by the process commonly used, which allows the removal of forms immediately after molding, are more susceptible to disintegration where exposed to sulphate soils or waters than are tile made of wetter consistency which requires their retention in the molds for a period of hours.

8. *The use of hand tamped tile of plastic consistency*, such that the jacket can be removed immediately after molding, can not be recommended for use in sulphate soils and waters. Tile of plastic consistency, molded in the packer-head type of machine, are more resistant to alkali action than the hand tamped tile, but the best quality of packer-head machine tile have been affected in waters of high salt concentration.

9. Steam cured tile show no greater resistance to alkali action than tile which are cured by systematic sprinkling with water.

10. Tile made of sand cement have less resistance to alkali action than tile made of Portland cement of the same proportions.

11. The tar coating as used was not effective in preventing the absorption of alkali water into the walls of the tile.

12. The cement-grout coating is not effective in preventing the absorption of alkali water.

13. No advantage was found in introducing ferrous sulphate into the cement mixture. The use of this material resulted in a reduction of the crushing strength of the tile.

14. If cement drain tile are to be used in soils and waters containing 0.1 per cent or more salts of the sulphate type, their installation should be preceded by an examination of subsurface alkali conditions. Decision as to the advisability of using cement drain tile should be based upon thorough examination of subsurface conditions and quality of product which it is proposed to use, and upon a comparison of the data so obtained with the data presented in this report. Such an examination may indicate portions of an area where the use of cement tile should be avoided. Quantities of alkali salt present can be determined by chemical analyses of the soils. Concentrations to which tile may be exposed can be determined by chemical analyses of the ground waters. In drawing conclusions allowance must be made for the constantly changing concentrations of alkali in the seepage water, which at times may differ as much as several hundred per cent in adjacent areas. There can be no assurance that the concentrations found at any time are the maximum to which the tile will ever be exposed. Quality of cement drain tile can best be measured by permeability tests. With other conditions equal, tile of lowest permeability will be the most durable. There appears to be little definite relation between permeability and the related factors of porosity, absorption, and density.

V. APPENDIX A.—ABSORPTION TESTS ON TILE OF SERIES 1 TO 21

The results of absorption tests on samples of the tile in storage at Ames, Iowa, are shown below. These tests were conducted by W. J. Schlick, drainage engineer, Iowa State College, in 1920, using portions of tile remaining after the 1919 crushing tests of the Ames storage tile were completed.

Series number	Crushing strength	Per cent absorption, average of six pieces		Ratio, boiling to immersion	Series number	Crushing strength	Per cent absorption, average of six pieces		Ratio, boiling to immersion
		Standard boiling test	72-hour immersion test				Standard boiling test	72-hour immersion test	
	Pounds					Pounds			
1.....	3850	11.0	7.3	1.51	11.....	1710	8.4	6.1	1.38
2.....	3470	9.1	7.9	1.15	12.....	1450	10.7	6.6	1.62
3.....	2655	11.4	9.3	1.23	13.....	1600	9.7	6.6	1.47
4.....	3720	10.1	7.2	1.40	14.....	3040	9.8	8.8	1.11
5.....	2690	13.2	9.0	1.47	15.....	2120	11.5	9.8	1.17
6.....	2990	13.8	8.9	1.55	16.....	1520	9.7	6.5	1.49
7.....	1580	8.6	6.0	1.43	17.....	1830	6.9	6.8	1.01
8.....	1035	10.7	6.4	1.67	18.....	1815	6.3	6.5	.97
9.....	1950	9.4	5.9	1.52	19.....	2140	6.9	5.3	1.30
10.....	1795	7.8	5.9	1.34	20.....	1835	7.4	5.3	1.40
					21.....	1210	8.5	5.4	1.57

Absorption values were determined by boiling specimens for 5 hours as specified in the A. S. T. M. specification for tests of drain tile and also by immersion for 72 hours in water at room temperature. Generally the value found for immersion is considerably less than for the 5-hour boil. It is worthy of note that the tile of highest impermeability which have shown greatest resistance to alkali action show practically the same quantities absorbed by the two methods. The differences in permeability are in part due to greater cement content in some cases, but generally to the use of a greater quantity of mixing water than is commonly used in the manufacture of drain tile in the packer-head type of machine. It is possible that further study will indicate the *rate* of absorption to be a measure of the durability in alkali waters, within the ranges of consistencies employed in the manufacture of tile and for equal cement contents. The absorption value obtained is alone of little value in indicating quality, since the poorest and best tile have practically the same absorption percentage. These tests suggest that permeability rather than porosity or density may be a criterion of resistance to alkali action.

VI. APPENDIX B.—THE PRESENCE AND DISTRIBUTION OF SALTS IN THE SOIL AND THEIR ACTION ON CEMENT AND CONCRETE.

The foregoing investigation has to date dealt mainly with observation and tests of mortar and concrete specimens in the form of drain tile and concrete blocks which have been exposed to alkali soils and waters in various districts of the West. Such laboratory work as has been carried on has been in connection with physical tests of cement, aggregates, and concrete and mortar test specimens, together with chemical analyses of materials used, and samples of soils, waters, and alkalies to which the

specimens have been exposed. A discussion of the conditions which have brought about the necessity for studies of the effect of alkali on concrete, together with a summary of the results of other investigations, may be of interest.

Long exposure of rocks to the elements has resulted in their disintegration to form soil through which are found distributed the soluble salts of sodium, calcium, and magnesium. Years of rainfall in the humid regions have resulted in the leaching of the greater portion of the soluble salts from the soil, but in the arid and semiarid regions of the West relatively small quantities have been removed except where by irrigation or other means large quantities of water have been available with good natural drainage conditions. The accumulation of these salts in those regions is usually referred to as "alkali deposits." What is known as "white" alkali is usually a mixture of the sulphates and chlorides of sodium, calcium, and magnesium, while "black" alkali, so called because of its tendency to dissolve vegetation or organic matter and stain the surface of the soil a brown or black color, contains a large percentage of sodium carbonate together with smaller amounts of the white alkali. The white alkali is the most widely distributed type, and experience has shown that it is more injurious to concrete.

Disintegration of concrete structures is usually noted, and is most marked, at and just above the ground line and will vary with soil water conditions. Where the alkali water level is constantly below the limits of soil capillarity, disintegration may be entirely confined to portions below the ground surface. Disintegration at or near the surface is, no doubt, accelerated by frost action and alternate wetting and drying, but these effects are only contributory.

The appearance of concrete affected by alkali salts varies with the quality of the concrete, the concentration of the solution, and duration and condition of exposure. With good quality concrete of low permeability the first stage of the action is marked by the flaking or shelling off of the surface skin of neat cement of rich mortar, exposing sand grains and aggregate particles. As the action continues larger aggregate particles are exposed, and the new surface has the appearance of being abraded, and white deposits of salts appear in the pores. (See Fig. 4.) In the last stage the material loses its identity as concrete and appears to be a mixture of aggregate particles distributed throughout a soft, white, puttylike paste. This change may be accompanied by a considerable increase in volume. Disintegration of concrete of low permeability is essentially a surface action which gradually progresses into the mass. In some cases the outer skin appears to be immune to attack, but it does not entirely prevent the penetration of alkali water, which in reacting with the inner portion causes swelling which shatters the surface skin.

Rapidity of penetration of the action is dependent upon permeability of the concrete, and concentration of salt in solution. Chipping away the affected portion will usually reveal concrete just beyond which is apparently unaffected.

In the case of permeable concrete or mortar mixtures of the type commonly used in hand-tamped drain tile or sewer pipe, a somewhat different and more rapid action occurs. The comparative ease of penetration of alkali water through the wall exposes a large volume of cement to the action of the salts and a rapid swelling and increase of volume results, the whole mass finally breaking down to form the typical white puttylike paste.

The deterioration of concrete in alkali soils when first noted and studied was generally ascribed to the use of poor aggregates or improper methods of mixing and placing concrete, and it was believed that disintegration was brought about merely by the crystallization of alkali salts in the pores of the concrete. Since these salts in crystal form occupy a greater volume than in solution, it was thought that the mechanical forces exerted were sufficient to disrupt the mass and fully account for the disintegration noted. If this theory were true, disintegration could be avoided by producing concrete of low permeability which would prevent appreciable quan-

tities of salt from entering. Laboratory investigation has shown that disintegration is not due to disruptive forces exerted by the salts in crystallizing, but rather to the chemical reaction between salts in solution and constituents of the cement. Disintegration is primarily due to chemical action, and any disruption which may occur under certain conditions as the result of crystallization is secondary.

The constituents of the cement attacked by the salts are lime, silica, and alumina. During the process of hardening of concrete, calcium hydrate is formed, and it is this material which is most readily attacked. The sulphates of sodium and magnesium in alkali waters react with the calcium hydrate to form calcium sulphate and sodium and magnesium hydrates. The part played in the process of disintegration by these newly formed compounds is not well understood and no doubt varies with the permeability of the concrete and quantity and movement of the alkali waters, but the final effect can not be disputed since the changes produced in the laboratory under controlled conditions have been verified by the inspection of good quality concrete which has been exposed to somewhat similar conditions in the field.

As a result of investigations in various chemical laboratories in which the solvent action of various salt solutions on cement and concrete has been measured, certain definite conclusions have been drawn. Studies made by Burke and Pinckney, at Montana State Agricultural College and reported in Bulletin No. 81, may be summarized as follows:

The disintegration of cement by alkali salts is principally due to reaction between these salts and the calcium hydroxide necessarily present in set cement. As a result of these reactions relatively insoluble *new compounds* are formed in the body of the cement structure. These new compounds have greater weight and require greater space than the $\text{Ca}(\text{OH})_2$ replaced. New compounds force apart the particles of cement, thus weakening or breaking the binding material.

The results of a laboratory investigation at the University of Wyoming Experiment Station, reported by Steik in Bulletin No. 122, lead to the conclusion that "The ultimate cause of the disintegration of cement is by the alkalies forming compounds with the elements of the cement which subsequently are removed from the cement by solution."

The results of an extensive laboratory and field investigation of the action of the salts in sea water on cement, conducted by Bates, Phillips, and Wig of the Bureau, are reported in B. S. Tech. Paper, No. 12. Their work indicated that in the presence of sea water and similar sulphate-chloride solutions, "the most soluble element in the cement is lime. If the lime of the cement is carbonated, it is practically insoluble."

Thus it is seen that such investigations as have been carried on in the chemical laboratories have led to the agreement that certain constituents of the cement are attacked and dissolved by salts in solution. It has been found possible in the laboratory by artificial solutions to destroy almost completely test pieces of Portland cement mortars and concretes. It was also believed that laboratory conditions were probably more severe than exposure conditions which might ordinarily be encountered in the field. For the purpose of studying the behavior of mortars and concretes of known and good quality when exposed to the normal alkali soil conditions, the investigation described in detail in the foregoing pages was planned and started in 1913. The results, so far obtained, indicate that field conditions may be fully as severe and destructive to good quality concrete as were the early experiments carried out under laboratory conditions.

WASHINGTON, October 11, 1921.