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DURABILITY OF CEMENT DRAINTILE AND CONCRETE IN ALKALI SOILS

(CONTAINING RESULTS OF THIRD YEAR'S TESTS)

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I. INTRODUCTION

The disintegration of concrete when exposed to strongly alkaline soils and waters in arid regions of the western part of the United States has been a subject of discussion by engineers and users of cement for the past 10 or 15 years. There are many concrete structures in these districts which do not appear to be affected by the salts, but there are some which were apparently made of good materials and were well fabricated which show indications of being attacked.

There are many engineers who believe that well-fabricated concrete will not disintegrate when exposed to these alkali salts and that many cases of failure which have been reported have not been caused primarily by the alkali but resulted from the use of poor aggregate, improper methods of fabrication, or other causes which resulted in a poor quality of concrete.

A laboratory investigation was started in 1908 by the technologic branch of the United States Geological Survey to determine the effect of alkali waters on cements and concretes. In 1910 this work was transferred, by act of Congress, with all structural materials investigations, to the Bureau of Standards. The investigations were continued and the results were published in 1912.[1] Briefly, these investigations showed that practically all

[1] Technologic Paper No. 12, "Action of the salts in alkali water and sea water on cements."

cements are attacked by alkali waters upon exposure in the laboratory, and complete disintegration can be obtained under certain conditions. Similar investigations have been made by other laboratories with similar results.[2]

Disintegration in the laboratory can apparently be obtained in two ways. If the cement specimen is somewhat porous and it is constantly supplied with a salt solution which is permitted to crystallize in the pores, disintegration may result from the mechanical force exerted. If hydrated cement is brought into intimate contact with certain sulphate or chloride solutions, the uncarbonated lime of the cement is subject to comparatively rapid solution, with a resulting decomposition of the cement.. Laboratory tests, however, must always be interpreted with caution, as conditions often differ somewhat from service, and it is on this account that a field investigation was undertaken in which cement mortar and concrete mixtures of various qualities could be brought into intimate contact with alkali salts under natural conditions.

The Bureau of Standards has made a field survey of concrete structures exposed to alkali waters in several of the Western States. There is a tendency for the cement user to attribute to alkali all failures occurring in these districts, if any alkali is visible in the surrounding soil. Therefore, such failures as occur in the eastern part of the United States, due to poor materials or improper methods of fabrication, are often excused in the irrigated districts as failures due to alkali.

A description of several of the structures which were examined will serve to illustrate the conditions as they exist.

In Fig. 1 * is shown a small concrete structure known as a "turnout" for irrigation water, which was built about 1907. One portion of this structure is completely disintegrated while another portion when examined in 1912 showed no signs of disintegration. This sound portion is a beam on the lower side extending into the wing walls exposed to the earth at each end and located so that half of it is above the concentrated alkali water and half below. The composition of the salts was found to be as follows:

	Per cent
Water soluble	65.33
Insoluble	31.19
Loss at 110° C.	3.14

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

* For convenience of comparison all illustrations are grouped in numerical sequence at the conclusion of text.

Analysis of water-soluble portion:

	Per cent
CaO	0.04
MgO	.38
Na_2O	43.60
K_2O	.11
SO_3	53.58
CO_2	2.19
Cl	.77

The following method was used for determining the water-soluble portion:

Five grams of the sample were heated to 110° C for 18 hours or until constant weight was obtained. This gave "loss at 110° C." This dried residue was digested with 50 cc of water, filtered, and washed until practically free from salts soluble in water. The "insoluble" was dried at 110° C and weighed. Aliquot parts of the solution were taken for determination of soluble salts.

The form marks were still visible on the beam when examined in 1912, and it did not appear to have been affected in the least by the alkali salts. The remainder of the structure is completely disintegrated, so that it can be torn apart with the hands, and the pores are filled with salts. This canal has never been used for the purpose of distributing irrigation water, and the structure is exposed to the concentrated seepage water which collects from the higher surrounding land and which flows through the ditch.

The beam was molded and cured in the yard and set into place in the "turnout" several days later, at the time the turnout was cast. No records were available to show the composition or method of molding, but it was stated that probably the same materials and proportions were used in both parts of the structure. The primary cause of failure of the disintegrated portion may not be the alkali salts, although it would appear that alkali might be responsible. The excellent condition of the beam, however, would demonstrate that concrete can be made which will resist, at least for a number of years, the action of concentrated alkali of the character found at this locality. A careful examination was again made in 1915 and 1916, and it was noted that the ends of the beam embedded in the soil showed signs of disintegration, apparently due to alkali, but the middle section exposed to the alkali water remained in good condition. This beam will be observed from time to time in order that the progress of the disintegration may be noted.

Fig. 2 shows the lower end of a small concrete gate culvert, which is badly disintegrated. Alkali salts are visible on the surface

of the soil surrounding the culvert at the lower end. The water carried through the culvert is fresh irrigation water. The walls of the culvert at the upper end appear sound and normal. An analysis of the disintegrated concrete taken from the walls at the lower end gave the following results. Two analyses were made of the sample, (a) of the solid lumps, (b) of the soft or crumbly portion.

	(a)	(b)
	Per cent	Per cent
Insoluble: Sand, etc	79.26	65.80
Soluble in HCl (1 to 10):		
SiO_2	3.29	3.60
Fe_2O_3	1.20	.80
Al_2O_3	1.57	2.06
CaO	7.02	13.64
MgO	.60	.55
SO_3	.14	.25
Cl	Trace.	Trace.
CO_2	4.67	8.82
Water, etc., at 500° C	2.18	4.39

The foregoing analyses computed to a "sand and moisture free" basis give:

	(a)	(b)
Soluble in HCl (1 to 10):	Per cent	Per cent
SiO	17.80	12.12
Fe_2O_3	6.49	2.69
Al_2O_3	8.50	6.93
CaO	37.98	45.90
MgO	3.25	1.85
SO_3	.76	.84
CO_2	25.22	29.67

After calculating the amount of MgO and CaO necessary to satisfy the CO_2 and SO_3 there is left in (a) 9.8 per cent CaO and in (b) 10.1 per cent CaO.

These analyses show no abnormality which would account for the disintegration. The sodium and potassium were not determined, but they were evidently not in excess of 1 per cent. The SO_3, Cl, and MgO were also normal. Therefore it would seem that the failure could not have been caused by the alkali, although no other explanation can be offered without a knowledge of the materials used, method employed, and weather conditions at the time of fabrication. This information is not available.

The concrete wing wall of a large culvert shown in Fig. 3 was cited as a case of disintegration due to alkali salts. Upon investigation it was found that there was a bend in the creek at the point where the culvert is located, and during flood the creek carried bowlders 12 to 20 inches in diameter which would be thrown against the wall.

Alkali salts are visible in the pores where the surface is eroded to a considerable depth, but the cement and concrete appears hard, and the presence of the alkali would seem to be incidental and contributory rather than the initial cause of disintegration. The composition of the alkali salts taken from the surface was as follows:

Soluble in HCl (1 to 10) (calculated on 100 per cent basis):	Per cent
CaO	0.91
MgO	.48
Na_2O	41.32
K_2O	Trace.
SO_3	55.98
Cl	.16
CO_2	Trace.

In Fig. 4 is shown a large railroad culvert with a portion of an old concrete structure remaining in the foreground. The concrete remaining from the old structure is completely disintegrated, so that it can be torn apart with the fingers, and alkali salts are found in the pores. The new culvert, which is about eight years old, appears to be sound and normal with the exception of a few spots near the ground line which can be scraped away with a knife. The culvert as a whole does not evidence good workmanship in fabrication.

The surface of the surrounding soil is covered with alkali salts having the following composition:

	Per cent
Water-soluble	8.45
Insoluble	78.35
Loss at 110° C	13.98

Analysis of water-soluble portion:

	Per cent
CaO	36.16
MgO	.71
Na_2O	5.37
K_2O	.24
SO_3	57.28
Cl	.24

In Fig. 5 is shown a small concrete retaining wall the coping of which is disintegrated and referred to as a failure due to alkali

salts. The surface of the soil surrounding this wall, both at the top and along the sides, shows the presence of alkali salts. The wall is sound and hard at all points examined excepting the coping, where disintegration is shown. Since structures are found in the East, where no alkali salts are present, which appear just as the one shown with the coping sloughed off due to frost action on a very weak section in the concrete that results from the use of watery mixtures, it is quite possible that the disintegration of the coping in this structure is due to that cause. In mixtures in which an excessive amount of water is used the fine material in the aggregate and cement will float to the surface in the forms as they are filled and collect at the top of the form, resulting in a very porous and weak section which is readily attacked by frost.

It is practically impossible to analyze some of the failures which have occurred and state definitely the part played by the alkali salts, as a result of which it was deemed desirable to make field tests in which concrete of known composition and fabrication would be exposed in some of the worst-known alkali districts in the West.

It was decided that the investigation should be started by exposing various cement mixtures in the form of draintile, because of its economic importance. It will probably become necessary to drain the greater part of all lands under irrigation, and much of this drainage will require the use of tile. The cost of drainage has been estimated at approximately $25 per acre, from which it is seen that many millions of dollars must be spent for this purpose. At the present time there are few known deposits of clay available for the manufacture of satisfactory clay tile in these districts, while materials for the manufacture of cement tile are usually found close at hand, but many engineers are skeptical of the permanency of cement tile, as a number of failures have occurred which have been reported to have been caused by the alkali salts.

It was recognized that the results obtained with the tile tests would not predicate the behavior of mass concrete, for the normal exposure of the latter is quite dissimilar from that of draintile. Therefore, the investigation was expanded in 1915, as proposed in the previous report, by the installation of generous-size blocks of concrete of known composition.

The size of the blocks and the conditions under which they were placed will make the results of the investigation applicable to normal concrete construction in the field under similar conditions.

The blocks were placed so that the lower ends extended into the ground water. This was done in order to observe the effect of the mechanical force exerted by frost action and by the crystallization of the alkali salts absorbed by capillarity into the pores of the concrete above the ground-water surface.

The program covering this branch of the investigation will be found on page 13 under the heading "Outline of investigation."

It is desired to thank the United States Reclamation Service for furnishing the labor necessary to install and replace the drains and prepare concrete blocks on the Belle Fourche, S. Dak.; Shoshone, Wyo.; Sun River, Mont.; Yakima (Sunnyside), Wash.; Truckee-Carson, Nev.; Yuma, Cal.; Rio Grande, N. Mex.-Tex.; Uncompahgre Valley, Colo.; and Grand Valley, Colo.; projects; also the drainage division of the Office of Public Roads and Rural Engineering, Department of Agriculture, for furnishing labor for installing and replacing the tile in the drains at Crookston, Minn.; Columbia, Mo.; Grand Junction, Colo.; Roswell, N. Mex.; and Huntington, Utah. Assistance was rendered by the following individuals in supervising and carrying out this work:

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Denver, Colo.—J. Y. Jewett, of the United States Reclamation Service.

Roswell, N. Mex.—S. W. Cooper and D. E. Heizer, of drainage investigations, Office of Public Roads and Rural Engineering, and H. W. Vauchelet, drainage engineer.

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The Universal Portland Cement Co., and C. W. Boynton, W. M. Kinney, and E. V. Aldridge, Chicago, Ill., for manufacturing and donating the 1914 replacement tile.

The Utah Concrete Pipe Co. and N. L. Morris, Salt Lake City, Utah, for manufacturing and donating the 1915 replacement tile.

The chemical division of the Bureau of Standards, S. S. Voorhees, G. J. Hough, and H. A. Bright, for chemical analyses of alkalies, soils, and waters, and H. A. Davis, of the Bureau, for physical tests of aggregates in connection with the concrete investigation of 1915 and 1916.

II. OUTLINE OF INVESTIGATION

1. PROGRAM AND SCOPE OF DRAIN-TILE INVESTIGATION

An advisory committee was organized composed of S. H. McCrory, chief of drainage investigations, Department of Agriculture; F. W. Hanna, supervising engineer of the United States Reclamation Service (later succeeded by E. C. Bebb, engineer, Reclamation Service); L. R. Ferguson, engineer, Portland Cement Association; and Rudolph J. Wig and G. M. Williams, of the Bureau of Standards. This committee held several meetings and finally developed a program which required the manufacture of about 8800 cement drain tile made up of 16 different varieties, as shown in the schedule below.

Schedule of Mixtures and Processes of Manufacture of the Tile

Series	Proportions cement sand, by volume	Consistency	Manufacture	Curing
1	1:2½	Plastic	Handmade	Sprinkling
2	1:2½	Quaking	do	Do.
3	1:2	Plastic	do	Steam
4 [a]	1:2	do	do	Do.
5 [b]	1:2	do	do	Do.
6 [c]	1:2	do	do	Do.
7	1:3	do	Machine-made	Do.
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 [d]	1:3	do	do	Do.
16 [e]	1:4	Plastic	Machine-made	Steam

[a] Dipped in neat cement grout, 20 to 24 hours after molding.
[b] Dipped in hot tar 6 weeks after molding.
[c] Ten per cent ferrous sulfate, by weight, added to mixed water.
[d] Sand-cement used in place of Portland cement.
[e] From factory stock pile. Northwestern States Portland cement. Age probably 6 months when above series were made.

The tile were made as described later, under contract at a commercial tile plant and under the supervision of a representative of the Bureau of Standards. Work was commenced in July and completed in September, 1913, and shipments were made in October, which allowed a curing period of one month for the last tile made. Although it was anticipated that some of the tile of the leaner mixtures which are satisfactory in the humid regions would fail in these alkali soils, the program was arranged to include tile made from the leanest to the richest commercial mixtures.

The tile were installed in operating drains on eight projects in what were thought to be the most concentrated alkali soils available in the West and in districts where there was practically no alkali for comparison. The locations of these drains are as follows:

Alkali districts: Garland, Wyo.; Fort Shaw, Mont.; Huntington, Utah; Sunnyside, Wash.; Yuma, Ariz.; Roswell, N. Mex.; Grand Junction, Colo.; Montrose, Colo.

Fresh-water districts: Crookston, Minn.; Columbia, Mo.

One set of tile of each type also was stored in the open exposed to the atmosphere at Ames, Iowa, for reference and test.

The program requires the removal of at least two tile of each type at each project every year for test and inspection. Sufficient

tile were made and installed to continue the investigation 10 years or longer if necessary.

To replace the tile which were removed for test during 1914 a supply of 8-inch cement tile were furnished by the Universal Portland Cement Co. A description of the materials and methods used for the manufacture of these tile is included under the heading "Manufacture of drain tile." (See p. 26.) The first group of each of these series, numbered 17 and 18, were removed and tested in 1915 after one year's exposure.

Tile removed for test during 1915 were replaced by cement tile manufactured and donated by the Utah Concrete Pipe Co., Salt Lake City, Utah.

The methods of manufacture of these tile are given on page 29 under "1915 replacement tile."

No experimental tile were installed for test in 1916. The test tile were replaced with whatever material was available in the market.

2. PROGRAM AND SCOPE OF CONCRETE INVESTIGATION

The following investigation was outlined by the advisory committee for the purpose of determining the effect of alkali salts in the soil and ground water on concrete. Throughout the West many concrete structures are exposed to strongly alkaline soils and ground waters, and in some localities structures have failed or shown signs of disintegration, as referred to in the introduction. In order that actual field conditions might be duplicated, blocks of concrete 10 inches square and 2½ feet long were molded, under the supervision of a representative of the Bureau of Standards, and installed on projects of the United States Reclamation Service in soils where concrete structures have apparently been affected by alkali. The blocks were placed vertically with about 1 foot embedded in the ground and a portion exposed to the atmosphere. One series of blocks was molded at Denver, a central point, where an excellent quality of aggregate was available, in order to secure a uniform and good quality of concrete. These blocks were shipped to the various projects. Another set of blocks was molded at each project and after curing was set in place, while a third set 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 at present available in commercial quantities near the site of construction on the projects. Details of the manufacture

of these three series will be found in Section VIII, page 66, "Manufacture and installation of concrete."

With a record of the methods and aggregates used and with the results of observations over a few years, a more definite knowledge of the durability of concretes exposed to alkali soils will be obtained.

Where failures occur it is proposed to make a study of the aggregates available for concrete at those projects, and with the knowledge obtained from the tests it will probably be possible to state what treatment of the materials is needed in order to improve the quality of the concrete. In case any or all of the test specimens show evidence of injury due to alkali, tests will be made of the value of surface treatment by various methods as a protection against such action. It is also proposed that some bituminous treatment be tried to prevent the further deterioration of some of the concrete structures which now show disintegration apparently due to alkali salts.

The specifications under which these blocks were made follow:

PORTLAND-CEMENT CONCRETE

1. Proportions (by volume).—Two proportions only shall be used as follows: (*a*) 1 part Portland cement to 1½ parts fine aggregate to 3 parts coarse aggregate. (*b*) 1 part Portland cement to 2½ parts fine aggregate to 5 parts coarse aggregate.

2. Materials.—Aggregates shall be of the best quality which are at present available on the projects in commercial quantities.

The water used for mixing in each locality shall be the best that is obtainable in sufficient quantity for construction work at a reasonable cost.

Samples of the aggregates and mixing water shall be taken for such examination and analysis as may seem desirable.

The cement shall be that in use on the projects where the blocks are made and shall pass the United States Government specifications for Portland cement.

3. Consistency.—A mushy consistency, one which can be easily spaded but not containing sufficient water to be spouted, shall be used throughout.

4. Size and Shape of Specimens.—All sections shall be of square cross section, 10 inches by 10 inches by 2½ feet long, cast vertically in wooden molds with planed surfaces, except as indicated later under "A" specimens, page 15.

5. Rods for Corrosion Tests.—Two half-inch square or round steel rods which have been previously cleaned of rust and dirt shall be placed vertically in each specimen, 2 inches from one and 3 inches from the adjoining faces. These rods shall be 24 inches long and extend to within 3 inches of the top and bottom of the specimens.

In the top of each specimen, for the purpose of observing the corrosion of metal exposed to the atmosphere and to aid in handling the blocks, shall be inserted a similar rod, 24 inches long, bent U shaped, with the legs 9½ inches in length embedded approximately 8 inches in the concrete.

6. Mixing and Molding.—The test specimens shall be prepared at some central point such as Denver and also at each of the projects where the specimens are to be placed.

Wherever possible a mixing machine shall be used in preparing the concrete, but when one is not available the mixing shall be done by hand. In every case care shall be taken to produce a homogeneous mass of uniform consistency. At each project or with each different material trial batches shall first be prepared to determine the amount of material necessary to slightly more than mold one specimen and to determine the proper consistency, after which separate batches based upon the quantities so determined shall be used for each specimen.

All specimens shall be molded vertically and be well spaded so as to obtain a dense homogeneous mass which completely fills the form.

In the process of mixing and molding it is not intended to use any methods which would be impracticable in actual construction work, but only those which will produce as good a concrete as that which can be made commercially when all reasonable and practical precautions are taken.

Those specimens molded at the central point will hereafter be referred to as "A" specimens and those molded at some convenient point on each project as "B" specimens, while those molded in place exposed immediately to alkali salts and water will be referred to as "C" specimens.

A tabulated list of concrete blocks molded in 1915 is shown on page 16, Table 1.

(*a*) *"A" Specimens.*—These specimens shall be molded at some central point, using the best available local aggregates. Forms are to be removed after four days and the blocks are to be sprinkled for three additional days, after which they shall be held for at least three weeks before shipment is made. Two specimens of each mixture, a total of four, shall be shipped to each project. Before shipment each specimen shall be placed in a strong wooden crate to prevent chipped corners or other injuries. In addition to the above 12 blocks of each proportion shall be prepared in a similar manner, except that six shall be molded in wooden forms made of rough unplaned lumber while the remaining six shall be cast in metal molds with smooth surfaces.

(*b*) *"B" Specimens.*—These specimens shall be molded at some convenient point on each project. Forms are to be removed after four days and the blocks are to be sprinkled for three additional days, after which they shall remain in the yard for at least three weeks before being placed in position for test. At each project four "B" specimens shall be prepared, two of each mixture.

(*c*) *"C" Specimens.*—These specimens shall be molded in place on the test site at each project. The forms shall be removed at the end of seven days and no further treatment shall be given to the specimens. Two specimens of each of the two proportions shall be molded at each project.

7. Installation of Specimens.—Specimens shall be placed on each project in a locality where large quantities of alkali salts are known to be present in the soil and where seepage water stands on the surface of the ground during portions of the year or where the ground water rises to the surface during certain seasons of the year.

SAND-CEMENT CONCRETE

Four "A" specimens shall be molded of each proportion, using sand cement (see p. 66), and shall be prepared in the same manner as that specified for the Portland-cement specimens. It is proposed to install these specimens at Grand Junction, Colo.

NATURAL-CEMENT CONCRETE

Four "A" specimens, two of each proportion, using natural cement, shall be prepared in a manner similar to that specified for the Portland-cement specimens. It is proposed to install these specimens at Grand Junction, Colo.

8. Projects.—It is proposed that installation of these specimens be made on the following projects of the United States Reclamation Service: Belle Fourche, S. Dak.;

Shoshone, Wyo.; Sun River, Mont.; Yakima (Sunnyside), Wash.; Rio Grande, N. Mex.-Tex.; Uncompahgre Valley, Colo.; Grand Valley, Colo.; Truckee-Carson, Nev.

TABLE 1

List of Concrete Blocks Molded During the Fall of 1915, Type of Cement and Proportions

Project	Molded in yard at project. Portland cement		Molded in alkali soil at project. Portland cement		Molded at Denver					
					Portland cement		Sand cement		Natural cement	
	1:1½:3	1:2½:5	1:1½:3	1:2½:5	1:1½:3	1:2½:5	1:1½:3	1:2½:5	1:1½:3	1:2½:5
Belle Fourche, S. Dak.	2	2	2	2	2	2	.....	.....	.....	.....
	.....	.....	.....	.....	[a] 2	[a] 2	.....	.....	.....	.....
	.....	.....	.....	.....	[b] 2	[b] 2	.....	.....	.....	.....
Shoshone, Wyo.	2	2	2	2	2	2	.....	.....	.....	.....
	.....	.....	.....	.....	[a] 2	[a] 2	.....	.....	.....	.....
	.....	.....	.....	.....	[b] 2	[b] 2	.....	.....	.....	.....
Sun River, Mont.	2	2	2	2	2	2	.....	.....	.....	.....
Yakima (Sunnyside), Wyo.	2	2	2	2	2	2	.....	.....	.....	.....
Rio Grande, N. Mex.-Tex.	2	2	2	2	2	2	.....	.....	.....	.....
Grand Valley, Colo.	2	2	2	2	2	2	2	2	2	2
	.....	.....	.....	.....	[a] 2	[a] 1	.....	.....	.....	.....
	.....	.....	.....	.....	[b] 2	[b] 2	.....	.....	.....	.....
Uncompahgre Valley, Colo.	2	2	2	2	2	2	.....	.....	.....	.....
Truckee-Carson, Nev.	2	2	2	2	2	2	.....	.....	.....	.....

[a] Made in rough wooden molds. [b] Made in metal molds.

III. MANUFACTURE OF DRAINTILE

1. ORIGINAL SERIES, 1913 INSTALLATION

(*a*) **Factory and Equipment.**—The cement draintile used in this investigation were made at the tile plant of the Armstrong Cement Works, Armstrong, Iowa. This factory has for a number of years been producing large quantities of cement tile, varying in size from 4 to 30 inches, for use in northern Iowa.

The factory building consists of a concrete block and frame structure, which houses the mixers and tile making machines, with a large low-roofed concrete block addition to one side, which is divided into curing chambers. A railroad switch used for the delivery of materials and shipment of the finished product parallels the building on the opposite side.

Sand is received in dump-bottom coal cars and dropped into a pit, from which it is drawn by a chain drag to the foot of a bucket elevator. After being elevated the sand is dropped into either of two storage bins, or is carried overhead on a belt directly to a

sand-storage box, placed above the hopper of a batch mixer. In making commercial tile this hopper is filled with sand to a fixed height, depending upon the proportions desired, and the cement is added. The gate is then opened and the material passes into the batch mixer, which consists of a cylindrical steel drum mounted on rollers. The interior of the mixer contains scoops or buckets, which carry the material up and drop it during rotation. This mixer is very satisfactory in use, mixing the sand and cement uniformly and quickly, but the time required varies considerably, due to the varying amounts of moisture in the sand. A very damp sand generally requires two or three times as many revolutions of the mixer as does a dry sand.

After the cement and sand are thoroughly mixed dry the mass is dropped into another hopper just above a continuous mixer or pug mill. (See Fig. 6.) As the dry material is fed into the upper end of the trough of the pug mill, water is sprayed in through a perforated pipe, the amount being regulated by the man at the mixer. To obtain a uniform mixture an experienced man is required, as the rate of feed of the material and the amount of moisture in the sand vary constantly.

This factory is equipped with several tile machines, the Schenck being used in making all the experimental machine-made tile. This machine is of the revolving packer type, the tile being formed between the stationary metal jacket and the packer, which is drawn upward and out of the tile as it revolves.

The car system is in use for handling the smaller sizes of tile after molding. The equipment consists of a suitable number of three-deck cars equipped with springs and roller bearings, transfer trucks, and trackage into the curing chambers and out to the various points in the storage yard.

Steam curing of concrete products is used exclusively for curing the regular output of this factory, but all rooms are equipped with water pipes for sprinkling the product, which was the method desired for several of the series of our experimental tile. Cars containing small tile are pushed into low-roofed block-walled rooms, about 90 feet long, holding 11 cars, with enough clearance on one side to allow a man to pass along the cars and sprinkle the tile. Large tile, wheeled on carts, are cured in two large rooms having concrete floors. Exhaust steam from the engine of an electric lighting plant, owned by the same company, is piped to

the various rooms and utilized for curing. Steam was available 16 hours per day.

(*b*) **Materials.**—The cement used in this work was Hawkeye brand Portland cement, supplied under contract by the Iowa Portland Cement Co., Des Moines, Iowa. Approximately 240 barrels of Portland cement were required. For the manufacture of series 15, a sand cement was supplied by the United States Reclamation Service, from the sand-cement mill in operation at Arrowrock, Idaho. The results of chemical and physical tests of the cements are given in Table 2.

The sand used was shipped in from Mason City, Iowa, being the material regularly used in the factory.

Analysis and tests of sand are shown in Table 3. The water was pumped from a well at the factory. Power was furnished to the entire equipment by a 20-horsepower electric motor, receiving current from the electric lighting plant.

(*c*) **Machine-Made Tile.**—These tile made on the Schenck cement-tile machine (Fig. 7) are 12¼ inches in length, three-fourths inch thick, with an inside diameter of 8 inches.

TABLE 2

Results of Tests of Cement Used in Manufacture of Cement Draintile

HAWKEYE PORTLAND CEMENT

Sample	Specific gravity	Fineness		Time setting		Soundness		
		100-mesh	200-mesh	Initial	Final	A	W	S
		Per cent	Per cent	h m	h. m.			
1	3.16	94.0	77.8	5 45	10 15	Sound.	Sound.	Sound
2	3.15	93.8	76.6	5 55	9 45	...do..	...do..	Do.
3	3.16	94.0	77.0	5 50	9 40	...do..	...do..	Do.
4	3.16	93.6	77.4	5 55	9 35	...do..	...do..	Do.
5	3.15	94.4	78.8	5 50	9 00	...do..	...do..	Do.

Chemical Analysis

	Per cent
SiO_2	22.94
Fe_2O_3	4.20
Al_2O_3	4.90
CaO	62.08
MgO	1.27
SO_3	1.64
Loss	1.57
Insoluble residue	.29

TABLE 2—Continued

Tensile Strength (pounds per square inch)

[Average of three briquettes]

Sample	7-day mortar	7-day neat	28-day mortar	28-day neat
1	205	543	290	725
2	200	562	279	711
3	224	517	325	718
4	220	533	308	722
5	257	584	321	647

SAND CEMENT

Specific gravity	Fineness		Time of setting		Soundness
	100-mesh	200-mesh	Initial	Final	
	Per cent	Per cent	h. m.	h. m.	
2.89	99.4	90.4	2 40	6 45	Sound

Chemical Analysis

	Per cent
Soluble in HCl:	
SiO_2	13.00
Fe_2O_3	3.46
Al_2O_3	1.40
CaO	37.78
MgO	1.65
SO_3	.87
Ignition loss	2.41
Insoluble in HCl:	
SiO_2	31.52
Al_2O_3	6.54
MgO	.59

Possible Composition

Cement	61.3
Clay and silicious material	38.7

Tensile Strength (pounds per square inch)

[Average of three briquettes]

7-day mortar	7-day neat	28-day mortar	28-day neat
180	457	295	537

TABLE 3

Results of Tests of Sand Used in the Manufacture of Cement Draintile, 1913 Installation

[Specific gravity of sand=2.655]

	1:3 mortar briquettes	
	7-day	28-day
Washed sand	282	388
Sand as received	237	348
Sieved to pass No. 20; held on No. 30	191	283
Standard Ottawa sand	205	290

Granular Analysis of Sand

[Uniformity coefficient=3.30; per cent of silt=3.9]

Sand passing sieve No.—	Per cent
200	0.89
100	1.56
80	5.31
50	18.04
40	27.81
30	46.35
20	67.26
10	84.61
Retained on No. 10	15.38

Sand was brought to the proportioning hopper, as stated above, except that it was first dropped into a large box placed on a platform scale on the upper mixing platform. All proportions were determined by weight, every batch of sand used being weighed and then dropped in the hopper above the batch mixer, where the cement was added. The material was then dropped into the batch mixer, which revolved continuously, the slide of the hopper again closed, and another batch of the material prepared. Usually one batch would be passing through the pug mill, a second being mixed in the batch mixer, and a third being prepared in the proportioning hopper so that the pug mill could be operated continually to its full capacity.

Usually one man can prepare the batches and keep the pug-mill hopper filled, but on account of the extra labor caused by the weighing of the sand two men were used while the "machine" tile were being made. Two men were also required to regulate the water supply and shovel the mixed material into the elevator boot of the Schenck machine. One man is required to operate the machine, two men are used in stripping jackets from the tile (which were placed on the car decks only a step or two away from

the machine), one man is required in the sand pit, and another to push out loaded cars and bring back the empty cars, so that a total of nine men were required to operate the machine at its highest efficiency.

The quantity of water required for various batches of each series was measured by passing the water supply through a barrel whose contents were known for each inch in depth. The amount was then determined by measurement.

Due to the variation in the amount of moisture in the sand and to the use of a continuous mixer in which the water was added, it was impossible to add a predetermined or fixed quantity of water to every batch of dry material. In every case an attempt was made to make the mixture as wet as possible and still allow the immediate removal of the jacket. Too small or too great an amount of water in case of the lean mixtures will cause the tile to crumble or crack in removing the jacket or collapse during the shifting of the car. A rich mixture containing a small excess of water will usually hang together, due to the "stickiness" of the cement, but it is likely to be distorted unless the jacket is stripped with unusual care. Too little or too much water will usually cause immediate trouble at the machine, greatly cutting down the output. The proper amount is indicated very plainly by the weblike markings of neat cement on the outer surface of the tile.

The cars in use (Fig. 8) hold ninety-seven 8-inch tile, but usually the number of good tile was less, due to the sorting out of the culls, which were caused either by the failure of the machine to work properly or by carelessness on the part of the strippers in removing the jackets. This loss can be avoided and the green material remolded if the damaged tile are removed at once.

After placing in the curing room the tile were sprinkled twice, if to be steam cured—once in the evening of the day made and again during the following morning, steam having been turned on during the night. The steam-cured tile were exposed to steam for a total period of 96 hours, 16 hours per day, after which they were piled in the storage yard. The water-cured tile were sprinkled twice daily for a period of 12 days and then removed and piled in the storage yard.

The temperature of the moist air in the curing rooms varied from 110 to 120° F during the period in which the steam was on.

The water-cured tile were allowed to harden under much more favorable conditions than are usually understood by the term

"water curing." Too often "water cured" means that tile are stored in an open shed, or, at best, in a large room containing many doors and windows, and sprinkled one or more times a day. In the case of these experimental water-cured tile the cars were run into the long, narrow curing rooms, which are continually damp, with wet floors, and perfectly protected from the sun and air currents. The amount of evaporation under these conditions is small compared to that in a large room or shed.

(*d*) **Handmade Tile.**—The handmade tile were made of two types, the semiwet series and the wet series. These tile have an inside diameter of 8 inches, with smooth walls 1½ inches thick and 12¼ inches long, made in sheet-metal molds provided especially for this work. (See Fig. 9.) The great difficulty in the use of such molds is in keeping the core centered so that the walls of the resulting tile will be of uniform thickness. Several methods were tried to secure the proper results, and the one found simplest and most satisfactory consisted of a wooden base with two concentric circles of small headless nails projecting up about three-eighths inch above the boards. These nails were placed on the inner and outer circumference of two circles having diameters of 8 and 11 inches, respectively. This arrangement provided for the centering of the lower end, but it required careful use of the tamping iron to obtain a uniform wall thickness at the top. Molds made of heavier metal would be more satisfactory in this respect, but the cost would have been excessive for this experimental series.

The process of proportioning and mixing of the materials up to the addition of the mixing water was in every way similar to that of the machine-made tile.

Series 1, 3, 4, 5, and 6 were of the plastic consistency, containing as much water as would allow the immediate removal of core and jacket. However, it was found that the material for these handmade tile had to be slightly drier than that which could be used on the machine, probably due to less pressure being exerted in hand tamping, making the tile less dense.

The semiwet handmade tile (fig. 10) were molded on the concrete floor of one of the large curing rooms and were sprinkled in the evening of the day molded. The following morning they were again sprinkled and then placed on cars and shifted into the low-roofed curing rooms, where the steam or water treatment was continued for the proper length of time. In the manufacture of

series 6, 10 per cent of ferrous sulfate, by weight, was added to a known weight of water in the measuring barrel, and this solution, kept well stirred, was used in mixing.

The tile of series 14 and 15 were made of a much wetter consistency than those of the other series. These tile contained sufficient water so that they could be easily poured into the mold from a small bucket. The tamping iron was used along the walls of the mold to aid in removing air bubbles from the surfaces. The tile of series 2 were of an intermediate consistency, and required considerable tamping in small layers in order to prevent the formation of "rings" or roughened surfaces. The tile of these series were piled in one of the long curing chambers and sprinkled twice daily for at least 10 days.

(*e*) **Consistency of Mixtures Used.**—The following consistencies were used in the manufacture of the tile:

Plastic.—As much water was added to the dry-mortar mixture as would permit the immediate removal of the jacket from the tile. This condition is indicated by the weblike marks of neat cement and water on the outer surface of the wall. This consistency was used for making the tile of series 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, and 16.

Quaking.—Moisture could easily be brought to the surface by tamping. The material would settle about three-eighths inch in the mold during the first two hours after molding. This consistency was used for making the tile of series 2.

Fluid.—This material was of such a consistency that it could be easily poured into the mold. It would settle one-half to three-fourths inch in the molds during the first four hours after molding. This consistency was used for making the tile of series 14 and 15.

(*f*) **Detailed Description of Each Type of Tile.**—Following is a description of the tile of each of the various series, together with any notes on manufacture peculiar to each.

Series 1.—Proportions, by weight, 1 part Portland cement to 2½ parts sand, plastic consistency, hand tamped, and cured by sprinkling. An average of 7.7 tile was obtained from each bag of cement.

Series 2.—Proportions, by weight, 1 part Portland cement to 2½ parts sand, quaking consistency, hand tamped, cured by sprinkling with water. An average of 7.2 tile was obtained from each bag of cement.

Series 3.—Proportions by weight, 1 part Portland cement to 2 parts sand, plastic consistency, hand tamped, stored in air for

first 24 hours, then a total of 102 hours in steam. An average of 7.6 tile was obtained from each bag of cement.

SERIES 4.—Proportions same as series 3. Cured 24 hours in air, then dipped in neat cement grout, loaded on cars and exposed to steam for a period of 102 hours. An average of 6.9 tile was obtained from each bag of cement allowing for cement required for grouting.

SERIES 5.—Proportions and method of curing same as series 3. Tile then stored in yard and dipped in boiling tar when six weeks old. An average of 7.2 tile was obtained from each bag of cement.

SERIES 6.—Proportions and method of curing same as series 3, except that 10 per cent of ferrous sulfate, by weight, was added to mixing water. An average of 7 tile was obtained per bag of cement.

SERIES 7.—Proportions by weight, 1 part Portland cement to 3 parts sand, plastic consistency, machine-made, steam cured. These tile were loaded on cars and placed in the curing chambers immediately after making. Steam was turned on within a few hours and continued for a total period of 96 hours. An average of 14 tile was obtained per bag of cement.

SERIES 8.—Proportions, by weight, 1 part Portland cement to 4 parts sand, plastic consistency, machine-made, cured in steam for a total period of 96 hours. An average of 18.8 tile was obtained per bag of cement.

SERIES 9.—Proportions, by weight, 1 part Portland cement to 1½ parts sand, plastic consistency, machine-made, cured by sprinkling with water for a period of 12 days. An average of 8.7 tile was obtained per bag of cement.

SERIES 10.—Proportions, by weight, 1 part Portland cement to 1½ parts sand, plastic consistency, machine-made, cured in steam for a period of 96 hours. This series differs from series 9 only in the method of curing. An average of 8.7 tile was obtained per bag of cement.

SERIES 11.—Proportions, by weight, 1 part Portland cement to 3 parts sand, plastic consistency, machine-made, cured by sprinkling for a period of 12 days. This series differs from series 7 only in the method of curing. An average of 13.7 tile was obtained per bag of cement.

SERIES 12.—Proportions, by weight, 1 part Portland cement to 4 parts sand, plastic consistency, machine-made, cured by sprinkling for a period of 12 days. This series differs from series 8

only in the method of curing. An average of 18.4 tile was obtained per bag of cement.

SERIES 13.—Proportions, by weight, 1 part Portland cement to 2½ parts sand, plastic consistency, machine-made, cured in steam for a total period of 96 hours. An average of 12 tile was obtained per bag of cement.

SERIES 14.—Proportions, by weight, 1 part Portland cement to 3 parts sand, fluid consistency, hand tamped, cured by sprinkling for a period of at least 12 days. Greater part of settling of material in molds took place during the first hour, after which the molds were refilled with some of the same material tamped and troweled. An average of 8 tile was obtained per bag of cement.

SERIES 15.—Proportions, by weight, 1 part sand-cement to 3 parts sand, fluid consistency, hand tamped, cured by sprinkling with water for a period of at least 10 days. Molds refilled with same material, tamped and troweled, after settling had taken place. These tile required very careful handling when the molds were removed on the day after molding to avoid breakage. An average of 7.4 tile was obtained per bag of cement.

SERIES 16.—Proportions, by weight, 1 part Northwestern States Portland cement to 4 parts sand, plastic consistency, machine-made, cured in steam. This series, which was taken from the stock pile of the Armstrong Cement Works, represents the regular commercial output of this factory. No especial care was used in selection, except to throw aside tile which were cracked or had jammed ends. The exact age of this series is uncertain, but the tile are probably at least six months older than those of the preceding series.

The machine-made tile varied in weight from 23 to 25.25 pounds, averaging 24 pounds; the semiwet hand-tamped tile varied in weight from 42.25 to 45 pounds, averaging about 43.2 pounds; tile in series 15, sand-cement, averaged about 41.5 pounds.

The difference in appearance of the surfaces of the different series is shown in Figs. 11 to 14. The appearance varies with the richness of the mixture as well as the method of molding. Of the machine-made series, 9 and 10, the richest, are lightest in color with more of a glazed appearance while the leaner mixtures are darker in color and have more of a sandy, roughened appearance. In the handmade series, No. 15 is nearly white with a "chalky" appearance, due to the use of sand cement. In series 2, 14, and 15 the handmade tile of quaking and fluid consistency have rather smooth surfaces with numerous small and shallow indentations due

to air pockets on the walls of the molds. The plastic mixtures of the handmade tile series 1, 3, and 6 have rough surfaces as a rule, and in a few cases irregular and insufficient tamping was indicated by the appearance of circumferential rings of porous appearing concrete.

Throughout this work no departure from the regular processes in use at this plant were made except that the proportions were varied and all the materials were weighed to insure uniformity. No specially chosen aggregates were used, the sand being that used in the factory for the manufacture of all kinds of cement products and the cement being purchased under bids with the requirement that it was to pass the United States Government specification for Portland cement. Although some of the mixtures contain more cement than those in ordinary commercial use, and it is not practicable to make a handmade tile which can compete in price with the usual machine-made tile, any well equipped and managed factory using good materials should be able to turn out a product which is as good in every respect as has been provided for this investigation.

2. 1914 REPLACEMENT TILE

The tile supplied to replace those tested during the year 1914 were manufactured and donated by the Universal Portland Cement Co., and were designated by the series numbers 17 and 18. These tile were 12 inches in length, of 8 inches inside diameter, with a wall thickness of 0.8 inch.

All concrete was machine mixed, sufficient water being added that the mixture would just hold its shape when piled with a shovel and would not splash out of the molds when agitated. The sheet-metal molds were filled with an excess of material in a funnel attached to the top of the form. The mold was then placed upon the jigging-machine platform and the machine operated for a period of 30 seconds. The drop of this platform was $\frac{13}{32}$ inch, while the platform made 120 complete trips through this space per minute.

Two sizes of aggregate were used, a sand of good quality passing the ¼-inch screen and a gravel passing a ½-inch round opening and retained on a No. 8 sieve. The sample of cement used in the manufacture of these series was lost in transit, and the results shown in Table 4 were obtained on a sample of the same brand of cement which was submitted six months later. The proportions used were as follows:

SERIES 17.—One sack of cement to 1½ cubic feet of sand.

SERIES 18.—One sack of cement to 2 cubic feet of a mixture of fine and coarse aggregates, which were mixed in the proportion of 2 parts sand to 3 parts ¼-inch to ½-inch gravel.

The tile were removed from the molds on the following day and then piled in one corner of the laboratory and covered with sand which was kept constantly wet.

The surface of these tile had much the same appearance of that of the tile of series 2, 14, and 15, since they were made of a quaking consistency.

After these tile had cured for a period of at least one month they were crated in wooden crates holding six tile each and shipped to the various projects and later installed in the place of those removed for test.

TESTS OF MATERIALS USED IN MANUFACTURING REPLACEMENT TILE, 1914

TABLE 4

Results of Tests of Universal Portland Cement

Sample	Specific gravity	Fineness		Time of setting		Soundness		
		100-mesh	200-mesh	Initial	Final	Air	Water	Steam
		Per cent	Per cent	h. m.	h. m.			
1	3.09	97.2	78.9	1 20	5 15	Sound.	Sound.	Sound

Chemical Analysis

	Per cent
SiO_2	19.84
Fe_2O_3	1.30
Al_2O_3	7.30
CaO	62.90
MgO	2.30
SO_3	1.42
Loss	2.83
Insoluble	.32

Tensile Strength

[Average of three briquettes]

7-day mortar	7-day neat	28-day mortar	28-day neat
214	527	281	664

TABLE 5

Results of Tests of Sand

[Average of three test pieces (pounds per square inch)]

	7 days	28 days
Tensile strength:		
Proportion 1:3 by weight	310	434
Compressive strength:		
Proportion 1:1½, 2-inch cubes	3545	5863
Proportion 1:2, 2-inch cubes	2732	5440
Proportion 1:2 (2 parts sand, 3 parts gravel), 2-inch cubes	3725	5675

Granular Analyses

Sand passing sieve No.—	Per cent
100	1.99
50	14.39
40	21.21
30	33.31
20	48.01
14	55.78
10	66.73
8	76.63
Retained on No. 8	23.37

Gravel: All material passed the ½-inch screen and was retained on the No. 8 sieve.

3. 1915 REPLACEMENT TILE

The 1915 replacement tile were made at the factory of the Utah Concrete Pipe Co., Salt Lake City, Utah, during the month of July, 1915, under the supervision of a representative of the Office of Public Roads and Rural Engineering, Department of Agriculture. After aging for one month, the tile were crated and shipped to various points for installation.

These tile were numbered as series 19 and 20. The materials used, the methods employed, and the proportions and consistencies of the mortars were the same in the two series, the only variable being the duration of steam treatment. The tile of series 19 were cured for 48 hours in steam, the same as the regular product of the factory, while those of series 20 were held in the steam curing chamber for a period of 96 hours.

These tile, which were 12 inches long, 8 inches inside diameter, with a wall thickness varying from ¾ inch to 1⅛ inches were made on an Atlas tile machine. The tile are molded between an outer metal jacket, lined with No. 26 gauge metal, and a rotating packing head, the material being fed into the mold through the hollow

shaft of the packing head and compacted by two steel tampers controlled by spring clamps which allow the tamper to move upward as the mold is filled. The mortar was made of as wet a consistency as would allow the immediate removal of the forms.

The desired quantities of sand and gravel were first proportioned in a measuring hopper and then introduced into a batch mixer of the screw type and the cement and water added. After the mixing was completed the mass was dropped into the boot of a bucket elevator, by which it was conveyed to the tile machine.

After molding, the tile were placed in the curing chamber and exposed to a moist warm atmosphere with a temperature of about 99° F for the required period. While in the curing chamber the tile were sprinkled four times daily.

The materials used were "Red Devil" brand Portland cement, manufactured by the Union Portland Cement Co., Devils Slide, Utah, and a mixture of graded sand ranging up to pea gravel with a clean gravel passing the ¼-inch mesh screen, the amounts being 2 bags (188 pounds) cement, 278 pounds of sand, and 263 pounds of gravel. The resulting proportions of cement to total aggregates were 1:2.9 by weight or 1:2.5 by volume. Water was obtained from the Salt Lake City water supply.

Tests of cement and aggregates used in the manufacture of the 1915 replacement tile are shown in Tables 6 and 7.

TESTS OF MATERIALS USED IN MANUFACTURING REPLACEMENT TILE, 1915

TABLE 6

Results of Tests of Red Devil Portland Cement

Sample	Specific gravity	Fineness		Time of setting		Soundness		
		100-mesh	200-mesh	Initial	Final	Air	Water	Steam
		Per cent	Per cent	h. m.	h. m.			
1	3.09	97.2	79.9	4 10	7 50	Sound	Sound	Sound

Chemical Analysis

	Per cent
SiO_2	22.68
Fe_2O_3	2.15
Al_2O_3	6.51
CaO	61.40
MgO	2.92
SO_3	1.40
Loss	2.70
Insoluble residue	.29

TABLE 6—Continued

Tensile Strength

[Average of three briquettes.]

7-day mortar [a]	7-day neat [b]	28-day mortar	28-day neat
167	585	316	664

[a] 10.3 per cent mixing water used. [b] 23.0 per cent mixing water used.

The tests included in Table 7 were made upon a sample of the sand and gravel aggregate as mixed at the factory for the manufacture of the tile.

TABLE 7

Results of Tests of Sand

[Red Devil cement used, see Table 6.]

Tensile Strength

[All results average of three briquettes.]

	7 days	28 days
Proportions:		
1 cement, 3 sand as received	237	382
1 cement, 3 sand washed	201	354

Compressive Strength

[All results average of three 2-inch cubes (pounds per square inch.)]

	7 days	28 days
Proportions:		
1 cement, 1½ sand	3700	5153
1 cement, 2 sand	3446	4912
1 cement, 3 sand	2327	3544
1 cement, 3 standard Ottawa sand	1284	2023

Granular Analysis of Aggregate

Material passing sieve No.—	Per cent
100	2.9
65	5.6
48	9.0
35	13.4
28	18.1
20	22.1
14	25.1
10	29.0
8	38.6
6	56.6
4	81.7
3	98.5
½-inch	99.7

4. 1916 REPLACEMENT TILE

No experimental tile were secured to replace those removed from the drains for testing in 1916. At each project whatever type of tile could be obtained locally on the market was installed.

At Columbia, Mo.; Crookston, Minn.; Garland, Wyo.; Fort Shaw, Mont.; Sunnyside, Wash.; and Roswell, N. Mex., clay drain tile and sewer pipe were installed. In a number of cases it was impossible to obtain 8-inch tile, so 6-inch tile were substituted. At Yuma, Ariz., and Huntington, Utah, wood box drains were used to replace the tile tested.

At Montrose, Colo., the locally made unglazed drain tile were used, while at Grand Junction, Colo., a similar type, made at Delta, Colo., was installed. These tile will permit observations to be made upon the durability of commercial unvitrified and unglazed clay tile in highly alkaline soils when buried below the frost line.

IV. INSTALLATION OF DRAINTILE, SERIES OF 1913

1. SHIPMENT

Shipments of the tile from the factory at Armstrong, Iowa, were made early in October, 1913. A carload (about 780 tile) was shipped to each project, each shipment consisting of 50 tile of each series, with the exception of series 5 and 15, of which 45 and 36, respectively, were sent. The tile were piled with their walls parallel to the car sides, beginning at either end, and tiered three and four high, depending upon the length of the car. This arrangement was continued up to within 3 feet of the doorway, where the number of layers was reduced to two and then one. The doorway space was occupied by several rows one tile high, placed so as to block the lower layer in the two ends. To reduce the breakage, a thin layer of straw was spread over the floor and between the layers. The cars arrived at their destination showing little evidence of the tile having been thrown out of place while in transit, although no framing whatever was used to keep them in position. Breakage was due almost entirely to wedging of tile in the lower layers. This wedging action was probably aided by the "giving" of the car sides while in motion. In some cases no record of breakage was kept at the time of unloading, so that the following figures include the loss in unloading and hauling of the tile at destination.

The length of wagon haul and the total breakage is recorded in the following table:

Location	Wagon haul	Loss	Location	Wagon haul	Loss
	Miles			Miles	
Garland	3.5	3	Grand Junction	2.0	9
Fort Shaw	1.0	3	Montrose	12.0	22
Huntington	24.0	18	Columbia	1.5	22
Sunnyside	1.0	8	Crookston	0.5	6
Yuma	2.0	18	Ames	0.08	3
Roswell	5.0	4			

A total of 116 tile were broken out of over 8500 shipped, an average railway haul of about 1300 miles and a wagon haul of over 4.5 miles. The average loss by breakage is 1.3 per cent.

2. PLACING

The tile were placed in such an order that sections containing two tile of each series could be removed at yearly intervals without disturbing the remainder of the line. Ten such sections, 32 feet long, were placed at one end of the line, and then all the tile remaining of each series were placed end to end in groups, commencing with series 1. This grouping is shown in Fig. 15. At Garland, Fort Shaw, Sunnyside, Yuma, and Roswell the "A" sections were placed at the upper end of the drain and the "B" sections at the outlet end. At the other points this arrangement of sections was reversed.

(*a*) **Garland, Wyo.**—The drain was placed about 3½ miles southeast of Garland in a low section where alkali stood in layers an inch or more in thickness on the ground. Several concrete turnouts located near by in unused ditches were entirely disintegrated. As shown in Fig. 16, the lower end of the drain runs through a sandy soil and the upper end through coarse gravel, the grades being 0.022 and 0.010, respectively. The outlet is in an open ditch, which has a grade of 0.002. Since the outlet end for a distance of 200 feet lies above the frost line, a back fill was made, giving a minimum covering of 4 feet.

The tile were laid in cradles made of 2 by 4 inch side pieces and 1 by 4 inch cross pieces, on which the tile rested. Manholes were placed at stations 3 + 50 and 5 + 50, at an angle point and change of grade. At the time the tile were placed the groundwater plane was at the surface of the ground for the entire distance.

Photographs were taken during the placing of the tile, which are shown in Figs. 17 and 18. The total fall in the line is 11 feet. Only three tile were broken or missing at Garland, the number being unusually low considering the length of the haul.

(*b*) **Fort Shaw, Mont.**—At Fort Shaw a location for the tile line was found just above an alkali lake, where the tile would also be of some service in draining an upper swamp which had ruined several farm units. The surface of the ground surrounding the lake and the site of the drain was incrusted with alkali one-eighth to one-fourth inch in thickness. Wooden silt boxes were placed at the upper end at station 6+00, where an angle was made. As the greater portion of the drain was located above the frost line, the refill was made to a depth of 4 feet wherever the cut was less than this amount. A portion of the line passed through hard cemented gravel, which gave considerable trouble in digging. The upper 400 feet of the line was given a grade of 0.021 and the lower 200 feet a grade of 0.004, the outlet being into an open ditch which emptied into the alkali lake 200 feet below the tile line. Three tile were broken in this shipment. Figs. 19, 20, and 21 show the location of this drain.

(*c*) **Huntington, Utah.**—At Huntington the tile drain was installed on private land about 1 mile south of town. Wooden box drains, without bottoms, had been placed in this ground about eight years before, and as these boxes were filled and badly off grade, it was decided to replace them with cement tile.

As shown in Fig. 22 the line of the old wooden drain was not closely followed, but an offset was made and the old line paralleled. The trench varied in depth from 4½ to 6 feet, passing through a soil uniform in color and appearance, and acting much like quicksand in the bottom, due to the excess of water. The digging was very easy, requiring no picks or spades but only round-pointed long-handled shovels. The drain was laid with a fall of approximately 1 foot per 100 feet. In the portion of the trench which followed the old box drains the tile were supported on boards 1 inch by 6 inches by 12 feet on account of the soft bottom. Figs. 23 and 24 show the conditions near the site of the drain.

On account of rains preceding the installation of the experimental tile, the white surface of this and the surrounding land was not so apparent, but in spots large white patches could be seen. Land to the west and slightly higher than that on which the tile were placed was very wet, and sandstone boulders lying on the

surface were badly cracked and disintegrated, apparently due to the crystallization of the alkali in their pores.

As Huntington is located about 23 miles from the railroad, it was necessary to haul the tile from Price, Utah. The number of tile broken was 18, confined mostly to the handling on the railroad, as only 4 tile were broken in the 24-mile haul from Price.

(*d*) **Sunnyside, Wash.**—At Sunnyside the tile were installed on private land about 1 mile from town. The trench at the lower end was about 6 feet deep and at the upper end 4½ feet deep. At the lower end the soil was very sandy. The water table was low at the time the tile were placed. A uniform grade of 0.002 was used. There was a loss of eight tile in this shipment. The location of this drain is shown in Fig. 25. Figs. 26 and 27 show the conditions at this point.

(*e*) **Yuma, Ariz.**—The installation at Yuma was made in the southeast corner of the experiment farm of the United States Department of Agriculture on the Yuma Indian Reservation. The drain follows the line of an old slough and is exposed to concentrated alkali water. The wagon haul to this point was about 2 miles, and the total number of tile lost, including railroad breakage, was 18. Fig. 28 shows the location of this drain. Figs. 29 and 30 show the installation of the drain.

(*f*) **Roswell, N. Mex.**—The installation at Roswell was made on private land 4 miles east and 1½ miles north of Roswell on the northeast quarter of sec. 25, T. 10 S., R. 24 E., New Mexico principal meridian. (Fig. 31.)

The outlet of the line was placed in the wooden manhole of a drain which had been previously constructed and extended northeast in a straight line with a uniform rise of 0.1 foot per 100 feet. The depth averaged about 6.5 feet, with the exception that the upper 150 feet had a depth of about 5.5 feet. During the installation the ground water stood about 4 feet above grade, causing the sides of the trench to cave unless well braced. A wooden manhole was placed at the end of the tenth "A" section, and an observation well at the upper end of the line. Three tile were found broken in the car and one was broken in hauling to the drain site, so that the breakage was approximately one-half of 1 per cent. Fig. 32 shows the work in progress at Roswell.

(*g*) **Grand Junction, Colo.**—The tile at Grand Junction were placed on a 10-acre tract of land included in the McKinney experimental farm, one-fourth mile south of the old United States Indian school just east of the city. (See Fig. 33.) The land of

which this tract is a part is being improved under the supervision of Drainage Investigations, Department of Agriculture. This land had previously been irrigated and cultivated, but was later abandoned on account of the concentration of alkali on the surface and in the upper part of the soil. At the time the experimental tile were placed the surface was entirely covered with a thick white coating of alkali salts, as shown in the accompanying photographs. (See Figs. 34 and 35.)

The trench was excavated to a depth of 5½ to 6½ feet, the lower portion being very wet and mucky, requiring heavy sheeting and bracing, which interfered greatly with the work of excavation and made progress very slow. (See Fig. 36.) The tile were laid on a grade of 0.3 foot per 100 feet.

The drain empties into a large wood silt basin which is a part of the system of drains of an adjacent 10-acre tract. Although the line is straight without bends, another basin was placed at the end of the tenth "A" section and also one at the upper end to aid in observing the working of the drain.

The total breakage in this shipment was nine tile, four being found broken while unloading the car.

(*h*) **Montrose, Colo.**—The point selected for placing the tile was about 12 miles from Montrose on "seep" land near milepost No. 6 and below the level of the South Canal on the Uncompahgre project of the United States Reclamation Service. The soil consists of adobe and shale. This shale becomes very hard when dry and is difficult to excavate. The upper end of the tile line was entirely through shale. The amount of water flowing in the bottom of the trench was small, being as great near the upper end as at the outlet, indicating that most of the seepage occurs through the shale. Seepage was small in amount because the canal had been emptied previous to the excavation of the ditch for the experimental drain, but during the summer months the seepage should be considerably increased, as the change from concrete-lined to the unlined canal, whose maximum capacity is 1300 second-feet, is made opposite the upper end of the tile line.

The breakage of tile at this point was the maximum, 22 tile being damaged in the railroad and wagon haul. A 12-foot wooden box was placed at the outlet and wooden silt boxes at the two angles, at stations 2+60 and 5+35. From stations 1+92 to 2+42 and 2+75 to 3+07 the tile were laid on boards in the bottom of the trench. The location of this drain is shown in Figs. 37, 38, and 39.

(*i*) **Columbia, Mo.**—The experimental drain at Columbia was placed on land belonging to and being farmed by the University of Missouri Agricultural School, about one-half mile south of the campus. The line which has a total fall of about 24 feet, follows the line of a small channel which has been cut by surface water. The depth of the tile below the surface is small, as shown in Figs. 40 and 41, but it is sufficient to protect the line from frost action. The upper 12 or 15 inches is black soil and rather easy to dig, with the exception of a short length through the ridge at station 2+00, where some rocks were found. The soil was moist, but no stream of water was developed during the trenching. A wooden-box outlet was placed in the lower end where the earth covering was shallow.

The total breakage in the shipment of tile to this point was 22.

(*j*) **Crookston, Minn.**—The tile shipped to Crookston were installed in a 40-acre tract of pasture land, which is part of the land belonging to the "Northwest Agricultural School" of the University of Minnesota, which is located about 1½ miles north of Crookston. This region is very flat and has very little natural surface drainage, being made up mainly of small ridges and depressions varying only a few feet in elevation. The flatness of the country, of which this farm is one of the lowest areas, is shown by the results of a topographical survey, which indicates that in the 476 acres included in this farm the greatest difference in elevation is about 2 feet.

The soil is mainly a clayey loam, the upper few inches being black, the lower sections yellow, but of about the same composition. The black soil appears to be deeper in the depressions. Scattered deposits of alkali salts can be found in the elevations. At the time the trench was dug the soil was quite moist and sticky and was removed from the spade with difficulty. The lower foot was harder and drier and even more difficult to dig.

As shown in Fig. 42, the tile were placed quite shallow, with a uniform fall of 0.8 foot in the length of 800 feet. A wooden box emptying into an open ditch was placed at the outlet. (See Fig. 43.) There was no flow of water at the time the tile were installed. The total breakage in tile in this shipment amounts to six, of which three were broken in being hauled to the ditch.

(*k*) **Ames, Iowa.**—A car containing 48 tile of each series, excepting series 15, of which there were only 42, was shipped to the campus of Iowa State College, Ames, Iowa, for storage. These tile

were piled on wooden strips so as to keep them above the surface of the ground. A more careful account was made of the breakage here than had been made of the previous shipments. Although no packing of any kind was used and the tile were piled to a height varying from four high at the ends to two high at the doorway of the car, only three tile were broken. When the car was opened, the tile were found arranged just as placed at the time of loading. The breakage was confined to the lower layers near the car sides, indicating that the damage was due to the wedging of the tile, caused by movement of the car sides.

3. INSTALLATION OF REPLACEMENT TILE

The 1914 and 1915 replacement tile, description and methods of manufacture of which are given on pages 26 to 30, were shipped from the factories to the various projects in crates containing six tile each. The tile were uncrated and placed in the drain at the time those of the 1913 installation were removed for test. Each year the replacement tile have included two series, and they were placed in sections of four, containing two tile of each series, for convenience in removal for test at later periods.

V. CHEMICAL ANALYSES OF ALKALIES, SOILS, AND WATERS REMOVED FROM DRAINS

The various methods of expressing the results of water analyses have been the subject of more or less discussion, and in this paper an effort is made to so express these results that they will convey the desired information in the most direct manner. It is extremely difficult to explain the exact meaning of some of the terms used so that they will be understood by one who has a limited knowledge of chemistry, but it is believed that the following explanation, while not complete, will render the terms used more intelligible and furnish the requisite information.

In Tables 10 to 12 in the third column, the amount of concentration of the soluble solids present in the water or soil examined is expressed as a percentage of the total sample. The amounts of the various constituents of the solids as determined by analyses are shown in the following columns of these tables as percentages of the total soluble solids and not in parts per million.

To make clear the method followed in transposing the results of chemical analyses to the form used in this paper so that other analyses may be put into the same form, an example is given. A

sample of water analyzed gave the following results in parts per million:

Sodium, Na	2988
Calcium, Ca	423
Magnesium, Mg	150
Chlorine, Cl	383
Sulfate, SO_4	7030
Carbonate, CO_3	222
	11 196

The total soluble solids or the concentration is 11 196 parts per million, or, expressed as a percentage, 1.12 per cent.

The above analysis is computed to percentage composition of the soluble solids by dividing the amount of each constituent by the sum of the constituents (11 196), which gives:

	Per cent
Na	26.69
Ca	3.78
Mg	1.34
Sum of bases	31.81
Cl	3.42
SO_4	62.79
CO_3	1.98
Sum of acids	68.19
	100.00

In order to present the amounts of the constituents in a manner that permits of rapid comparison of the salts in the waters, soils, and alkalies, a series of diagrams are used. Inspection of Figs. 44 to 46 shows at a glance the relative concentration of any water or soil by the vertical scale of the diagram, and the comparative composition of its salts can be quickly judged by the relative horizontal length of the various divisions of a diagram, the upper half showing the metals or bases in solution and the lower half the acids with which the bases combine to form the salts. It is not known exactly how these salts are combined. Therefore it is not correct to calculate theoretical combinations and state definitely that the elements found in the water are so combined.

The figures given in these diagrams are different from those tabulated under the analyses of waters and soils for the reason that in order to make a comparison between the acids and bases present they must be reduced to a common basis.

The sum of the acids and bases in the analysis given above are, respectively, 68.19 and 31.81 per cent, but in the diagrams the two sums reduced to a common basis are made equal, i. e., 50

per cent each. To do this it is necessary to reduce the quantity of each constituent present to a common base for comparison.

Since hydrogen is ordinarily used as the basis for chemical comparisons and computations, the analyses have been reduced to their so-called hydrogen equivalents, or the amount of hydrogen that is chemically equal to each constituent has been determined and these values reduced to 100 per cent. Hydrogen equivalents are also called "reacting values" and are so designated in this report.

The hydrogen equivalent or reacting value of any chemical expression (ion, atom, molecule) is derived by multiplying the weight of the substance found by analyses by its valence and dividing this product by its ionic weight (atomic weight or the sum of the atomic weights of its component elements). The value obtained by dividing the valence by the ionic weight is called the "reaction coefficient" and has been calculated in the following table for convenience in later computations.

TABLE 8

Table of Ionic Weights, Valence, and Reaction Coefficients of the Acids and Bases

	Symbol	Ionic weight	Valence	Reaction coefficient
Sodium	Na	23.00	1	0.0435
Potassium	K	39.10	1	.0256
Calcium	Ca	40.07	2	.0499
Magnesium	Mg	24.32	2	.0823
Sulfate	SO_4	96.06	2	.0208
Chlorine	Cl	35.46	1	.0282
Carbonate	CO_3	60.00	2	.0337
Nitrate	NO_3	62.00	1	.0161

The reacting values obtained by multiplying the weight in milligrams of the acid and bases as given in the example on page 38 by the respective "reaction coefficient" given in Table 8, are as follows:

Analyses in parts per million	Reaction coefficient	Hydrogen equivalent or "reacting value"
2988 Na	Multiplied by 0.0435	130.00
423 Ca	Multiplied by .0499	21.10
150 Mg	Multiplied by .0823	12.38
383 Cl	Multiplied by .0282	10.80
7030 SO_4	Multiplied by .0208	146.10
222 CO_3	Multiplied by .0337	7.48
		327.86

The "percentage reacting values" obtained by multiplying each value by 100 and dividing by the sum 327.86 are given below.

	Percentage reacting values
Na	39.65
Ca	6.42
Mg	3.78
Sum of bases	49.85
Cl	3.29
SO_4	44.58
CO_3	2.28
Sum of acids	50.15
	100.00

In the results given above for the "percentage reacting values" it is seen that the sum of the percentages of the bases exceeds that of the acids by 0.30 per cent. Such differences as this are due to slight errors in chemical analysis, undetermined constituents, etc., and are to be expected in greater or less degree depending upon the characteristics of the water or soil. For convenience, the values shown in Figs. 44 to 46 have been adjusted so that the bases equal the acids, i. e., each is made 50 per cent of the total, the errors so introduced being negligible.

Taking the above analysis as an example, the bases and acids have been adjusted as follows:

Adjusted percentage reacting values

$$Na=39.65+\frac{39.65\times.15}{49.85}=39.65+0.12=39.77$$

$$Ca=6.42+\frac{6.42\times.15}{49.85}=6.42+0.02=6.44$$

$$Mg=3.78+\frac{3.78\times.15}{49.85}=3.78+0.01=3.79$$

$$\overline{}\ 50.00$$

$$Cl=3.29-\frac{3.29\times.15}{50.15}=3.29-0.01=3.28$$

$$SO_4=44.58-\frac{44.58\times.15}{50.15}=44.58-0.13=44.45$$

$$CO_3=2.28-\frac{2.28\times.15}{50.15}=2.28-0.01=2.27$$

$$\overline{}\ 50.00$$

A diagram of the results of analysis of this water is shown in Fig. 47.

Approximately the same results as shown above may be obtained by multiplying each of the values for percentage com-

position by the respective reaction coefficient and dividing each value so obtained by the sum of all values and multiplying by 100.

The method of obtaining percentage reacting value when the acids and bases are given in percentage composition, as in Tables 10 to 12, is shown below.

Symbol	Per cent composition	Product of per cent composition by the reaction coefficient	Percentage reacting value	Adjusted per cent reacting value
Na	26.69	1.1610	39.63	39.78
Ca	3.78	.1886	6.44	6.46
Mg	1.34	.1102	3.75	3.76
			49.82	
Cl	3.42	.0964	3.28	3.27
SO_4	62.80	1.3050	44.64	44.48
CO_3	1.98	.0667	2.26	2.25
		2.9279	50.18	
			100.00	

The results shown in Figs. 44 to 46 are directly comparable and show at a glance the differences in composition of the water, soils, and alkalies, since they result from reduction to a common base, one unit of any metal or acid being equivalent to one unit of any other metal or acid.

For the convenience of the reader in transposing other analyses to the form of reacting values a table of conversion values is given below.

Table of Atomic Weights and Equivalents

	Atomic weights (1916)
Ca	40.07
Mg	24.32
Na	23.00
K	39.10
C	12.005
S	32.06
N	14.01
O	16.00
Cl	35.46
H	1.008

In case the analysis is given in parts per 100 000 or grains per United States gallon, reduce the given analysis to parts per million

by multiplying (1) parts per 100 000 by 10 or (2) grains per United States gallon by 17.1.

To convert analyses expressed as anhydrides to analyses expressed as ions multiply the values given for the anhydrides by:

Anhydrides		Ions	
CaO	to	Ca	multiply by 0.714
MgO	to	Mg	multiply by .603
Na_2O	to	Na	multiply by .742
K_2O	to	K	multiply by .829
CO_2	to	CO_3	multiply by 1.364
SO_3	to	SO_4	multiply by 1.200
N_2O_5	to	NO_3	multiply by 1.148
Cl	to	Cl	multiply by 1.000
HCO_3	to	CO_3	multiply by .492

Reaction Coefficient for Ions

$$Ca = \frac{2}{40.07} = 0.0499$$

$$Mg = \frac{2}{24.32} = .0822$$

$$Na = \frac{1}{23.00} = .0435$$

$$K = \frac{1}{39.10} = .0256$$

$$CO_3 = \frac{2}{60} = .0333$$

$$SO_4 = \frac{2}{96.06} = .0208$$

$$NO_3 = \frac{1}{62.01} = .0161$$

$$Cl = \frac{1}{35.46} = .0282$$

Reacting values are obtained by multiplying amount of a given constituent (in ions) expressed in parts per million by its reaction coefficient.

Factors for Converting Analyses Expressed in Hypothetical Combinations (in Parts Per Million) to Reacting Values

	Carbonate CO_3	Bicarbonate HCO_3	Chloride Cl	Sulfate SO_4	Nitrate NO_3
Ca	0.0200	0.0123	0.0180	0.0147	0.0122
Mg	.0237	.0137	.0210	.0182	.0135
Na	.0189	.0119	.0171	.0141	.0177
K	.0145	.0100	.0134	.0115	.0099

For example, following is given the analysis of a drainage water in the form of hypothetical combinations:

Hypothetical combinations:	Parts per million
Sodium nitrate ($NaNO_3$)	120
Sodium chloride ($NaCl$)	6167
Sodium sulfate (Na_2SO_4)	1884
Magnesium sulfate ($MgSO_4$)	3085
Calcium sulfate ($CaSO_4$)	1257
Calcium carbonate ($CaCO_3$)	22
Calcium bicarbonate [($Ca(HCO_3)_2$]	543

Multiplying each of the above values by the proper factor from the above table gives—

	Reacting values							
	Na	Ca	Mg	Cl	SO_4	CO_3	NO_3	HCO_3
120 parts $NaNO_3$ gives	1.46	.....	.....	.....	.....	.....	1.46	.....
6167 parts NaCl gives	1029.0	.....	.....	1029	.....	.....	.....	.....
1884 parts Na_2SO_4 gives	265.7	.....	.....	.....	265.7	.....	.....	.....
3085 parts $MgSO_4$ gives	.....	.....	562.0	.....	562.0	.....	.....	.....
1257 parts $CaSO_4$ gives	.....	184.8	.....	.....	184.8	.....	.....	.....
22 parts $CaCO_3$ gives	.....	.44	.....	.....	.....	0.44	.....	.....
543 parts $Ca(HCO_3)_2$ gives	.....	6.73	.....	.....	.....	.....	.....	6.73
Sum	1296.16	191.97	562.00	1029.0	1012.5	.44	1.46	6.73

The percentage reacting values are then obtained by dividing each of the above by the sum of all.

TABLE 9

Analyses of Alkalies from Surface of Ground at Sites of Drains, Fall of 1913

Location	Composition of soluble solids in per cent					
	Na	K	Ca	Mg	Cl	SO_4
Garland, Wyo	30.8	0.5	0.6	0.1	Trace.	68.0
Fort Shaw, Mont	26.2	.2	2.3	1.1	1.1	69.1
Sunnyside, Wash	23.9	.2	.6	.6	10.0	64.7
Yuma, Ariz	24.7	.5	7.1	.....	52.6	15.1
Roswell, N. Mex	10.8	2.3	16.8	4.9	22.0	43.2
Montrose, Colo	9.4	.....	2.1	26.7	Trace.	61.8
Grand Junction, Colo	28.1	.....	.7	6.6	17.1	47.5
Huntington, Utah	27.6	.6	2.4	2.5	.1	66.8

TABLE 10

Analyses of Soils at Level of Cement Tile Drains, Fall of 1913 and Fall of 1914

Location	Year[a]	Percentage water-soluble solids in soil	Composition of soluble solids, in per cent					
			Na	Ca	Mg	Cl	SO_4	CO_3
Garland, Wyo	1913	0.80	8.4	24.2	.....	0.9	66.5	.....
	1914	.21	31.4	5.6	2.3	2.4	47.8	10.5
Fort Shaw, Mont	1913	3.61	14.9	13.1	1.2	.6	69.6	.6
	1914	.09	27.8	5.7	5.8	.....	31.6	29.0
Sunnyside, Wash	1913	.40	21.4	6.0	3.0	5.2	64.4	.....
	1914	.47	27.5	4.5	3.2	5.5	55.8	3.5
Yuma, Ariz	1913	.12	18.4	13.5	7.2	10.0	18.8	32.1
	1914	.11	32.0	1.9	4.3	22.4	24.3	15.1
Roswell, N. Mex	1913	.19	27.1	9.4	.9	11.5	29.0	22.1
	1914	.36	20.4	12.0	2.1	12.8	49.8	2.9
Montrose, Colo	1913	.93	10.6	16.2	3.5	1.9	67.8	.....
	1914	.53	5.5	21.8	4.0	.....	66.5	2.2
	1914[b]	1.09	9.3	15.0	5.1	1.3	68.3	1.0
Grand Junction, Colo	1913	.78	20.8	9.7	2.7	16.1	50.7	.....
	1914[c]	1.06	11.6	15.0	4.1	5.4	63.1	.8
	1914[d]	1.00	15.1	12.0	3.4	9.4	58.7	1.4
Huntington, Utah	1913	1.01	2.6	26.2	2.2	.3	68.7	.....
	1914	.65	11.6	16.4	2.6	1.3	66.3	1.8

[a] All samples taken in fall of year.
[b] Under tile 6-b.
[c] Under tile 3-b.
[d] Under tile 16-b.

TABLE 11

Analyses of Seepage Waters Flowing Through Cement Tile Drains, Fall of 1913 to Fall of 1916, Inclusive

[Samples from outlets of drain unless otherwise noted.]

Location and year	Per cent soluble solids in water	Composition of soluble solids in per cent						
		Na	Ca	Mg	Cl	SO_4	CO_3	NO_3
Garland, Wyo.:								
Fall, 1913	0.49	26.4	3.9	1.9	3.0	59.9	4.9	.....
Spring, 1914 [a]	.34	20.8	7.4	3.1	4.4	59.2	5.1	.....
Spring, 1914	.34	21.2	7.1	3.0	4.1	59.0	5.6	.....
Fall, 1914	.32	19.5	7.0	3.0	4.1	61.0	5.4	.....
Spring, 1915	.31	20.8	6.7	3.3	3.7	61.5	4.0	.....
Fall, 1915	.29	20.6	7.5	3.3	3.3	59.0	6.3	.....
Spring, 1916	.29	21.6	6.7	3.2	3.2	59.1	6.2	.....
Fall, 1916	.28	22.3	6.3	2.8	3.3	58.4	6.9	.....
Fort Shaw, Mont.:								
Fall, 1913	.54	27.8	4.0	4.9	2.2	54.8	6.3	.....
Fall, 1913 [a]	.23	20.8	4.5	6.5	2.2	46.8	19.2	.....
Spring, 1914 [a]	.13	20.2	5.8	6.4	2.6	43.5	21.5	.....
Spring, 1914	.14	21.7	4.9	5.8	2.5	46.3	18.8	.....
Fall, 1914	.15	21.4	6.1	6.5	.....	44.0	22.0	.....
Spring, 1915	.13	23.5	2.6	6.0	1.5	50.5	15.9	.....
Fall, 1915	.14	21.2	6.2	5.4	1.0	48.3	17.9	.....
Spring, 1916	.16	21.0	4.7	5.9	2.1	50.8	15.5	.....
Fall, 1916	.15	22.2	4.8	5.6	1.7	48.9	16.9	.....
Sunnyside, Wash.:								
Fall, 1913	.58	17.9	8.7	4.0	7.2	57.9	4.3	.....
Spring, 1914 [a]	.29	18.4	8.9	4.9	13.0	43.6	11.2	.....
Spring, 1914	.43	17.1	19.1	4.6	7.2	55.8	6.2	.....
Fall, 1914 [a]	.38	15.7	9.7	4.8	6.0	57.0	6.8	.....
Fall, 1914	.43	17.6	8.3	4.4	6.3	58.0	5.4	.....
Spring, 1915	.37	17.6	9.3	4.4	7.1	56.6	5.0	.....
Spring, 1916	.30	17.3	9.4	4.6	6.9	56.1	5.7	.....
Fall, 1916	.29	18.9	8.7	4.1	6.4	55.6	6.3	.....
Yuma, Ariz.:								
Fall, 1913	.08	17.0	13.1	5.4	22.9	15.1	26.5	.....
Spring, 1914 [a]	.08	15.5	13.3	4.5	18.6	19.3	26.8	.....
Spring, 1914	.07	17.7	14.0	4.2	20.2	17.9	26.0	.....
Fall, 1914 [a]	.10	16.6	13.8	5.4	23.2	20.7	20.3	.....
Fall, 1914	.46	22.6	7.6	4.4	42.2	14.7	8.5	.....
Spring, 1915	.08	17.8	14.8	4.5	18.8	23.9	20.2	.....
Fall, 1915	.13	21.6	11.3	4.5	18.9	19.3	24.4	.....
Spring, 1916	.09	17.8	13.3	4.0	21.8	29.1	14.0	.....
Fall, 1916	.19	24.2	8.0	3.9	14.5	23.5	25.9	.....
Roswell, N. Mex.:								
Fall, 1913	.50	15.0	15.2	2.5	24.4	38.6	4.3	.....
Fall, 1913 [a]	.49	19.0	11.5	3.0	29.6	33.6	3.3	.....
Fall, 1914 [a]	.44	19.8	11.9	3.0	36.3	25.8	3.2	.....
Fall, 1914	.46	18.5	12.5	2.9	33.7	29.5	2.9	.....
Spring, 1915	.42	19.1	12.0	2.7	32.9	31.8	2.5	.....
Fall, 1915	.47	18.5	12.6	2.8	36.4	27.3	2.4	.....
Spring, 1916	.42	19.3	12.2	2.5	31.9	32.0	2.1	.....

[a] Sample taken from upper end of drain.

TABLE 11—Continued

Location and year	Per cent soluble solids in water	Composition of soluble solids in per cent						
		Na	Ca	Mg	Cl	SO_4	CO_3	NO_3
Montrose, Colo.:								
Fall, 1913	1.00	8.8	4.9	11.8	0.5	69.9	4.1	.....
Spring, 1914 [a]	.59	8.2	8.6	9.7	.4	69.3	3.8	.....
Spring, 1914	.57	8.5	8.9	9.4	.5	69.1	3.6	.....
Fall, 1914 [a]	.42	4.4	13.0	9.0	.2	70.4	3.0	.....
Fall, 1914	.42	4.5	12.8	8.8	.3	70.7	2.9	.....
Spring, 1915	.33	4.7	17.6	6.3	2.1	66.4	2.9	.....
Fall, 1915	.65	6.5	8.7	10.8	.4	70.9	2.7	.....
Spring, 1916	.25	4.6	16.4	6.0	.5	69.5	3.0	.....
Fall, 1916	.24	3.2	15.6	8.6	.5	68.7	3.4	.....
Grand Junction, Colo.:								
Fall, 1913	1.10	22.0	5.4	4.7	26.4	40.9	.6	.....
Spring, 1914 [a]	.99	20.2	5.9	5.0	21.1	39.7	1.1	7.2
Spring, 1914	.86	17.2	6.9	6.0	19.0	43.7	1.9	5.3
Fall, 1914 [a]	.82	18.9	7.7	6.0	19.0	46.2	2.2	.....
Fall, 1914	.86	20.2	7.0	5.7	19.9	45.3	2.1	.....
Spring, 1915	.69	21.3	5.6	3.9	18.0	40.1	4.3	6.8
Fall, 1915	.75	17.6	7.4	6.4	18.8	48.1	1.7	.....
Spring, 1916	.88	18.3	7.4	5.9	16.3	42.4	2.0	7.7
Fall, 1916	.82	18.7	6.2	6.5	17.9	44.9	2.0	3.8
Irrigation water:								
Fall, 1913	.07	19.1	10.8	3.7	23.8	28.7	13.9	.....
Huntington, Utah:								
Fall, 1913	.25	10.8	15.6	4.1	2.1	57.7	9.7	.....
Spring, 1914 [a]	.49	15.1	9.1	5.4	2.5	62.6	5.3	.....
Spring, 1914 [b]	1.17	22.7	3.7	3.9	2.1	63.3	2.3	.....
Fall, 1914	.24	11.5	15.1	4.0	2.0	59.5	7.9	.....
Fall, 1914 [c]	1.23	23.6	3.4	3.0	1.1	66.9	2.0	.....
Spring, 1915 [b]	1.05	21.0	3.7	4.2	2.3	66.9	1.9	.....
Fall, 1915	.25	12.0	13.8	4.2	1.3	63.3	5.4	.....
Spring, 1916 [b]	.85	23.5	4.0	3.2	1.2	65.6	2.5	.....
Fall, 1916	.28	13.9	13.0	3.6	1.8	60.4	7.3	.....
Fall, 1916 [c]	1.18	24.6	3.5	2.7	.1	67.1	1.9	.....

[a] Sample taken from upper end of drain.
[b] Mixture of water from experimental drain and from central drain.
[c] Entire sample from central drain.

TABLE 12

Average Composition of Seepage Waters Flowing Through Cement Tile Drain, Fall of 1913 to Fall of 1916, Inclusive

[See Tables 11]

Location	Soluble solids in water		Composition of soluble solids					
			Na		Ca		Mg	
	Parts per million	Per cent	Parts per million	Per cent	Parts per million	Per cent	Parts per million	Per cent
Garland, Wyo	3324	0.33	735	22.1	208	6.3	95	2.8
Fort Shaw, Mont	2016	.20	486	24.1	92	4.6	111	5.5
Sunnyside, Wash	4019	.40	711	17.7	356	8.8	173	4.3
Yuma, Ariz	1071	.11	212	19.8	128	11.9	48	4.5
Roswell, N. Mex	4564	.46	822	18.0	590	12.9	125	2.7
Montrose, Colo	4952	.50	332	6.7	497	10.1	479	9.6
Grand Junction, Colo.[a]	8489	.85	648	19.5	556	6.6	470	5.6
Huntington, Utah	3011	.30	393	13.1	381	12.6	133	4.4

Location	Composition of soluble solids					
	Cl		SO_4		CO_3	
	Parts per million	Per cent	Parts per million	Per cent	Parts per million	Per cent
Garland, Wyo	117	3.5	1986	59.8	183	5.5
Fort Shaw, Mont	35	1.7	1022	50.7	270	13.4
Sunnyside, Wash	277	6.9	2284	56.9	218	5.4
Yuma, Ariz	206	19.2	232	21.7	245	22.9
Roswell, N. Mex	1453	31.8	1444	31.7	130	2.9
Montrose, Colo	30	.6	3449	69.7	165	3.3
Grand Junction, Colo.[a]	1684	19.8	3702	43.6	148	1.7
Huntington, Utah	62	2.0	1835	61.0	207	6.9

[a] NO_3: Parts per million=274; per cent=3.2.

91217°—17——4

TABLE 13

Average of Analyses (Percentage Reacting Values) of All Waters Flowing Through Cement Tile Drains, Fall of 1913 to Fall of 1916, Inclusive

[For results in percentage composition form, see Table 12.]

Location	Per cent soluble solids in water	Percentage reacting values						
		Na	Ca	Mg	Cl	SO_4	CO_3	NO_3
Garland, Wyo	0.33	32.0	10.3	7.7	3.2	40.6	6.2	.....
Fort Shaw, Mont	.20	30.6	6.6	12.8	1.6	34.2	14.2	.....
Sunnyside, Wash	.40	24.7	14.0	11.3	6.1	38.1	5.8	.....
Yuma, Ariz	.11	23.5	16.3	10.2	15.4	12.9	21.7	.....
Roswell, N. Mex	.46	23.9	19.4	6.7	27.1	20.0	2.9	.....
Montrose, Colo	.50	9.2	15.8	25.0	.5	46.0	3.5	.....
Grand Junction, Colo	.85	25.9	10.1	14.0	17.7	28.7	1.9	1.7
Huntington, Utah	.30	18.3	20.1	11.6	1.8	40.8	7.4	.....

VI. METHOD OF TESTING TILE

The first physical tests of the tile were made in 1914, about one year after the tile were placed. A representative of the Bureau visited all projects, where two tile of each type were removed from each drain and tested immediately upon removal.

A small portable machine was designed which could be transported to the site of the drains. This machine, with all accessories and trunk for carrying, weighed 170 pounds. The machine is of 4800-pound capacity, of the three-edge bearing type, and consists essentially of a steel angle-iron frame supporting a hydraulic press which is operated by a hand lever through a worm gear and screw for applying the load. The load is recorded on a hydraulic gauge which can be read to 5 pounds.

The tile were uncovered and taken from the ditch one or two at a time, cleaned, measured, and tested immediately. Notes were made on the length and thickness of the tile at each end, also its condition if in any way abnormal. The tile were placed in the machine in the same relative position as found in the ditch, care being taken to obtain a uniform bearing on all edges and to operate the hand lever at as uniform a rate as possible. The load was applied at the rate of about 1500 pounds per minute.

In 1915 and 1916 the tile were tested in the same manner as in 1914. A second hydraulic tile-testing machine with a cast aluminum frame was constructed in the Bureau's instrument

shop and used in testing tile on several of the projects. This machine, which will take tile up to 30 inches in length, is shown in Fig. 48. Its capacity is 4800 pounds.

VII. RESULTS OF CRUSHING TESTS OF TILE

The results of all tests of the tile up to and including three years' exposure in alkali soils are given in Table 14. To determine the approximate loads which these tile would have withstood in the trench, the results given should be multiplied by the constant 1.50, which is the factor recommended by the American Society for Testing Materials. The results, as a whole, are quite uniform and compare favorably with other tests of drain tile. Occasionally results of tests of similar tile differ by 30 or 40 per cent, but usually they agree within a few per cent. It should be borne in mind that these tile are exposed to abnormal conditions, which may cause a variation in results of tests of apparently similar tile only a few feet apart in the same ditch.

A summary of the results of crushing tests grouped according to exposure is given in Table 15. In Figs. 49 to 53 the averages of all tile of the same series are shown in separate groups.

TABLE 14

Individual Results of Crushing Tests of Experimental Cement Draintile, 1914, 1915, and 1916

[Total breaking load in pounds]

NOTE.—Footnotes at end of table. See page 53.

Description of tile: Proportion; consistency; wall thickness; method of molding	Series No.	Exposure to atmosphere				Exposure to fresh water							
		Ames, Iowa				Columbia, Mo.				Crookston, Minn.			
				1916				1916[b]				1916	
		[a]1914	[a]1915	Wet	Dry	1914	1915	Sec. 3	Sec. 4	1914	1915	Sec. 3	Sec. 4
1 to 2½; plastic; 1½ inches; hand tamped	1a	2825	[c]2790	3100	4100	2705	[c]2740	2635	2830	2580	[c]3600	3400	3570
		2895	[c]2700	3265	4260								
	1b	3195	[c]2890	3060	3195	2670	[c]3040	2645	2515	2760	[c]2900	3345	3205
1 to 2½; quaking; 1½ inches; hand tamped	2a	2425	[c]3210	2595	2960	2600	[g]3070	2445	2685	2750	[g]2910	3600	3195
		2895	[c]2710	2055	3860								
	2b	2660	[c]3580	2505	3650	2385	[g]3280	2445	2830	3085	[g]3340	3165	3400
1 to 2; plastic; 1½ inches; hand tamped	3a	2395	[c]2340	2960	4040	[c]2480	[c]3550	2345	1995	2770	[c]3100	3185	3380
		2130	[c]2250	2810	2910								
	3b	1900	[c]2400	2625	3090	2690	[c]3450	2005	3050	3230	[c]3100	3450	3175
1 to 2; plastic; 1½ inches; hand tamped; cement grout coat	4a	1955	[c]2560	2715	2665	2725	[c]2230	2545	2415	2395	[c]2940	3175	2870
		2045	[c]1740	2565	3195								
	4b	2950	[c]2350	2950	3205	2615	[c]3340	2545	2565	2950	[c]2330	3480	2850
1 to 2; plastic; 1½ inches; hand tamped; tar coat	5a	2905	[c]2540	2345	2820	[c]2140	[c]3080	2415	2870	2180	[c]2570	2635	2585
		3220	[c]2510	2345	2790								
	5b	3105	[c]3310	2395	3365	2555	[c]2440	2890	2505	2590	[c]2600	2820	2675
1 to 2; plastic; 1½ inches; hand tamped; 10 per cent ferrous sulfate	6a	2140	[c]2340	2065	2810	[c]2535	[c]2140	2830	2135	2885	[c]3340	3060	3430
		3150	[c]2470	2185	2735								
	6b	2320	[c]2270	2075	2840	2750	[c]2390	2015	2345	2525	[c]2780	3365	2990
1 to 3; fluid; 1½ inches; hand tamped	14a	2030	[c]2070	1565	3060	2555	[g]2070	2525	1965	2780	[g]2670	2735	3080
		2670	[c]2960	2535	2920								
	14b	2275	[c]2120	2145	3420	2340	[g]3080	2735	2465	2750	[g]2470	3245	3400
1 to 3; sand cement; fluid; 1½ inches; hand tamped	15a	1275	[c]1520	1435	1885	1615	[g]1660	1595	1675	1320	[g]1270	1755	2035
		2045	1150	1565	1795								
	15b	1530	1200	800	1615	1515	[g]1140	1635	1605	1770	[g]1490	1250	1815
1 to 3; plastic; ⅞ inch; machine made	7a	1265	1230	1335	1495	1210	[c]1360	1200	1575	1515	[c]1220	1250	1575
		1165	890	1385	1365								
	7b	1385	1310	1335	1795	1145	[c]1190	.....	1220	1415	[c]1240	1475	1285
1 to 4; plastic; ⅞ inch; machine made	8a	940	870	1100	1325	1075	[c]1030	870	990	950	[c]1090	1060	1080
		860	800	1140	1295								
	8b	1035	870	1020	1485	970	[c]1280	970	1010	1045	[c] 880	1050	1240
1 to 1½; plastic; ⅞ inch; machine made	9a	1570	[c]840	1835	2175	1530	[c]1950	1425	1635	1660	[c]1470	1635	1945
		1485	1260	1545	2135								
	9b	1945	1290	1475	2185	1705	[c]1700	1475	1515	1505	[c]1800	1945	1615
1 to 1½; plastic; ⅞ inch; machine made	10a	1540	1050	1505	2085	1695	[c]1570	1515	1455	1770	[c]1400	1645	1070
		1310	780	1595	1975								
	10b	1440	880	1415	1795	1870	[c]1670	1210	1395	1855	[c]1250	1595	1875
1 to 3; plastic; ⅞ inch; machine made	11a	1255	990	1060	1795	1200	[c]1280	1435	1275	1275	[c]1540	1505	1495
		1120	1190	1230	1555								
	11b	1360	1020	1315	1635	1200	[c]1320	1255	1515	1440	[c]1010	1325	1595
1 to 4; plastic; ⅞ inch; machine made	12a	1100	[c]820	1080	1255	1145	[c]1170	1200	1000	920	[c]1240	1150	1305
		1130	[c]920	945	980								
	12b	1055	980	1045	1130	1200	[c]1080	1000	1070	1155	[c]1400	1070	1335
1 to 2½; plastic; ⅞ inch; machine made	13a	1385	1250	1265	1765	1460	[c]1600	1395	1455	1470	[c]1870	1545	1525
		1185	1280	1615	1875								
	13b	1450	[c]990	1535	1605	1485	[c]1230	1220	1415	1405	[c]1330	1365	1250
1 to 4; plastic; ⅞ inch; machine made	16a	1185	960	1285	1695	1000	[c]990	1220	1100	1000	[g] 940	1070	1375
		1100	1180	1100	1755								
	16b	1350	1010	1180	1535	1155	[c]1430	1375	1365	880	[c]1060	940	1150
1 to 1½; quaking; ⅞ inch; jigging machine	17a	....	1060	1555	1585	.....	[g]1570	1305	1240	.....	[g]1200	1375	1555
		....	1160	1495	2035								
	17b	.....	1480	1375	1625	.....	[c]1380	1220	1180	.....	[g]1440	1585	1250
1 to 2; quaking; ⅞ inch; jigging machine	18a	....	990	1245	1625	.....	[g]1410	1140	1285	.....	[g]1330	1515	1675
		....	1090	1240	2165								
	18b	.....	1030	1240	1875	.....	[g]1280	1030	1130	.....	1260	1645	1515
1 to 2½; plastic; ⅞ inch; machine made	19a	....	.....	1395	2035	.....	.....	1355	1385	.....	.....	1605	1445
		....	.....	1395	1945								
	19b	.....	.....	1485	1905	.....	.....	1355	1140	.....	.....	1475	1585
1 to 2½; plastic; ⅞ inch; machine made	20a	....	.....	1535	1975	.....	.....	1375	1305	.....	.....	1645	1795
		....	.....	1645	2035								
	20b	.....	.....	1385	1815	.....	.....	1210	1395	.....	.....	1315	1595

TABLE 14—Continued

Description of tile: Proportion; consistency; wall thickness; method of molding	Series No.	Exposure to alkali water											
		Garland, Wyo.				Fort Shaw, Mont.				Sunnyside, Wash.			
		1914	1915	1916 Sec. 3	1916 Sec. 4	1914	1915	1916 Sec. 3	1916 Sec. 4	1914	1915	1916 Sec. 3	1916 Sec. 4
1 to 2½; plastic; 1½ inches; hand tamped	1a	c3390	c2815	d3100	d2890	2780	c2990	c2255	d2605	c2645	c3080	d2655	d2565
	1b	c3175	c1960	d2750	d2970	2470	c3030	c3010	d2970	c2460	d2065	d2840	d2565
1 to 2½; quaking; 1½ inches; hand tamped	2a	g3030	c2830	c2715	c3200	2490	2850	g3345	c3435	g3005	c2890	g3140	3500
	2b	g2885	2690	c3305	c3040	2570	c2535	g3355	c3275	g3285	c2920	3265	3190
1 to 2; plastic; 1½ inches; hand tamped	3a	l1945	c1690	d2295	d2505	2680	c2600	d2645	d2435	c2570	d3190	d2800	d3040
	3b	l3365	c1585	d2165	d2635	2525	3760	d2225	d2335	c1980	d2550	d2255	c2055
1 to 2; plastic; 1½ inches; hand tamped; cement grout coat	4a	c2680	c1880	c2165	d2415	1825	2170	c2575	d2385	c2320	d2460	d2845	d2940
	4b	c2750	c3065	c2575	d2675	2350	2590	c2565	d2265	c2840	d3000	d2375	d2165
1 to b; plastic; 1½ inches; hand tamped; tar coat	5a	c2645	c2960	c1965	c2535	1900	c2890	d2055	c3070	c2415	d2475	c2890	d2495
	5b	c2750	1750	d2595	d2025	3105	c2720	c2255	d2735	c2660	d2790	c3010	c2445
1 to 2; plastic; 1½ inches; hand tamped; 10 per cent ferrous sulfate	6a	c2340	c1825	d2845	d2535	l2545	2400	d2515	d2225	c2350	d2170	d2465	d2465
	6b	c1910	c2890	d1975	d2935	l2715	2180	d2105	d1655	c1910	d2830	d2790	d2615
1 to 3; fluid; 1½ inches; hand tamped	14a	g2770	c2450	c2675	c2645	2670	2780	c2625	c2145	c2360	2640	2790	3190
	14b	g2435	c2640	c2605	c2770	2995	2275	g2695	g2930	c2635	2830	3355	2890
1 to 3; sand cement; fluid; 1½ inches; hand tamped	15a	c1595	c1365	c1645	c1665	1385	1385	c1315	c1615	c1375	c1710	g1655	(j)
	15b	c1375	c1245	c1815	c1770	1680	1505	c1815	c1565	c1375	d1545	g1905	g1865
1 to 3; plastic; ⅞ inch; machine made	7a	c1200	c1045	c1265	d950	1185	1365	c1405	c1200	c900	d1365	c1715	c1495
	7b	c1605	c1455	c1090	d1000	1310	1265	c1565	c1250	c1320	d1195	c1365	c1365
1 to 4; plastic; ⅞ inch; machine made	8a	c770	c760	d970	d520	1185	770	c1010	d690	c980	d 970	d 835	d 960
	8b	c820	c720	d910	d950	910	705	c1100	d850	c990	d1055	d1120	d1020
1 to 1½; plastic; ⅞ inch; machine made	9a	g1570	c1295	c1200	c1645	1625	c1205	c1735	c1665	c1870	d1170	c1895	c1405
	9b	c1440	c1775	c1675	c1575	1485	c1145	c1645	c1745	c1585	d1475	c1735	c1965
1 to 1½; plastic; ⅞ inch; machine made	10a	c1145	c1815	c1535	c1220	1550	c1620	c1595	c1745	c1640	d1405	c1895	c1545
	10b	c1090	c1405	c1625	c1565	1515	c1065	c1475	c1415	c1750	d1650	c1465	c1695
1 to 3; plastic; ⅞ inch; machine made	11a	c1255	c1345	c1355	c1425	1495	1245	c1275	c1565	c1110	d1145	c1505	c1645
	11b	c1275	c1545	d1145	c1250	1360	1395	c1355	c1475	c1595	d1085	c1605	c1335
1 to 4; plastic; ⅞ inch; machine made	12a	c570	c870	e, f0	c540	1045	1125	d1240	d825	c1035	d1255	d1125	c1080
	12b	c730	c855	d510	d820	980	1345	d920	c1020	c1035	d980	d1225	c1050
1 to 2½; plastic; ⅞ inch; machine made	13a	c1285	c1295	c1615	c1595	1045	1205	c1605	c1285	c1625	d1720	c1895	d1180
	13b	c1000	c1345	c1595	c1115	1375	1455	c1484	c1475	c1265	d1765	c1555	c1595
1 to 4; plastic; ⅞ inch; machine made	16a	c660	c830	d510	d850	1020	d915	d1335	c940	c1055	d830	e, f0	e, f0
	16b	c720	c830	c1220	e, f0	940	850	d850	d950	c950	d880	d930	d1110
1 to 1½; quaking; ⅞ inch; jigging machine	17a	.....	1345	c1485	c1345	.....	c1345	g1465	g1605	.....	c1455	1575	1695
	17b	.....	1270	c1505	c1565	.....	c1585	g1465	g1355	.....	c1465	1745	g1345
1 to 2; quaking; ⅞ inch; jigging machine	18a	.....	1475	c1395	c1220	.....	c1155	g1425	.....	.....	c1590	1365	g1385
	18b	.....	1045	c1535	c1385	.....	c1435	g1595	.....	.....	c1240	1425	1505
1 to 2½; plastic; ⅞ inch; machine made	19a	.....	.....	c1645	c1545	.....	.....	c1415	g1515	.....	.....	g1345	1640
	19b	.....	.....	c1605	c1545	.....	.....	g1405	g1895	.....	.....	g1545	g1335
1 to 2½; plastic; ⅞ inch; machine made	20a	.....	.....	c1505	c1665	.....	.....	g1615	g1595	.....	.....	1735	g1345
	20b	.....	.....	c1725	c1485	.....	.....	g1695	g1565	.....	.....	1735	g1665

TABLE 14—Continued

Description of tile: Proportion; consistency; wall thickness; method of molding	Series No.	Exposure to alkali water—Continued											
		Yuma, Ariz.				Roswell, N. Mex.				Montrose, Colo.			
		1914	1915	1916		1914	1915	1916		1914	1915	1916	
				Sec. 3	Sec. 4			Sec. 3	Sec. 4			Sec. 3	Sec. 4
1 to 2½; plastic; 1½ inches; hand tamped	1a	c2570	c2660	d2770	d2820	c2385	c2880	d2595	d2515	c2870	d2940	d3170	d2075
	1b	c3420	c2620	c3245	d2790	c3050	c2390	d2810	d3195	c2715	d3070	d3745	d2685
1 to 2½; quaking; 1½ inches; hand tamped	2a	g2860	g2800	g3185	g2970	g3590	g3310	3500	3225	g3075	c3140	3450	3135
	2b	g3120	g3030	3185	g3115	g2690	g2710	3195	3470	g3030	g3270	g3550	g3010
1 to 2; plastic; 1½ inches; hand tamped	3a	c2350	c2830	d2770	d2195	c2840	d2370	d2635	d3450	c2200	d2550	d2860	e560
	3b	c2160	c2190	d2535	d2605	c2490	c2340	d3375	d2860	c2360	d2040	e1845	e1805
1 to 2; plastic; 1½ inches; hand tamped; cement grout coat	4a	c2500	c2610	c2275	c2655	c2645	c2220	c3090	c3195	c2940	d3070	d3095	d2715
	4b	c2375	c2190	d2295	c2565	c2425	c2570	d2445	c2890	c3500	d2400	d2920	d2285
1 to 2; plastic; 1½ inches; hand tamped; tar coat	5a	c2075	c3000	c2870	c3345	c2470	c2540	c2505	c2890	c3150	c1800	d2960	c3390
	5b	c2350	c2940	c2655	d2635	c3230	c2200	c3500	d2725	c3150	c2530	c2950	c3010
1 to 2; plastic; 1½ inches; hand tamped; 10 per cent ferrous sulfate	6a	c1910	c2420	c2005	c2970	c2985	c2230	d2465	d2645	c2245	d1880	d3080	e1605
	6b	c2340	c2920	c2225	c2840	c2010	c2440	g3530	d2295	c2795	d2270	e1795	d2705
1 to 3; fluid; 1½ inches; hand tamped	14a	g2535	g3130	g3275	g2940	g2750	g2550	g2810	2990	g2705	c2660	g3375	g3205
	14b	g2660	g3040	g2525	g2810	g2525	g2320	g2695	g2820	g2905	c2740	i3480	g2990
1 to 3; sand cement; fluid; 1½ inches; hand tamped	15a	c1715	c2000	d1305	c1335	c1750	c1520	c1745	c2095	k1220	k1190	e1495	e1875
	15b	c1550	c1395	d780	d1130	c1470	c1190	d1665	c1635	c1220	k1420	e655	e705
1 to 3; plastic; ⅞ inch; machine made	7a	c1505	c1300	c1565	g1645	c1175	c980	c1425	c1475	c1405	d1110	c1515	c1475
	7b	c1255	c1515	c1675	c1375	c1470	c670	d1295	d1110	c1340	d970	c1735	d1130
1 to 4; plastic; ⅞ inch; machine made	8a	c1055	c1115	c1140	d1000	c980	c910	d1250	d1080	c1000	d1490	d1335	e300
	8b	c1090	c1125	c1080	d1250	c1100	c1010	d1220	d1100	c960	d810	d1160	e350
1 to 1½; plastic; ⅞ inch; machine made	9a	c1715	c1375	c1695	c1835	g1450	c1710	c1945	c1645	c1910	d1640	c2025	d1475
	9b	c1650	g1775	c1745	c1305	c1660	c1570	c1765	g2005	c1495	d1520	d1190	c1535
1 to 1½; plastic; ⅞ inch; machine made	10a	c1640	c1575	c1815	c1495	g1605	c940	d1415	c1715	c1630	c1720	c1545	c960
	10b	c1980	c1495	c1595	c1705	c1185	c1180	c1775	c1605	c1055	d1610	c2035	c1325
1 to 3; plastic; ⅞ inch; machine made	11a	c1340	c1375	c1180	c1275	c1495	c1010	d1635	c1545	c1265	d1050	c1425	d1160
	11b	c1395	c1650	c1475	c1465	c1375	c1080	d1435	d1345	c1130	d1520	c1505	c1305
1 to 4; plastic; ⅞ inch; machine made	12a	c910	c1115	c1180	c1080	c1255	c1170	d940	d1090	c1000	d1090	d1050	e, f0
	12b	c1055	c1175	c1190	d1110	c880	c1070	d1465	d1230	c1000	d1320	d1040	e, f0
1 to 2½; plastic; ⅞ inch; machine made	13a	c1185	c1435	c1255	c1575	c1790	.....	c1615	c1915	c1395	c830	c1815	e, f0
	13b	c1200	c1485	c1435	c1415	c1120	c1330	c1365	d1445	c1595	c1170	d1295	d880
1 to 4; plastic; ⅞ inch; machine made	16a	c1000	c1245	d1295	d1345	c1145	c880	d1100	d1265	c490	e770	e775	e, f0
	16b	c1100	c1015	d1200	d1130	c1010	c850	d900	d1080	c1065	d910	e, f0	d1180
1 to 1½; quaking; ⅞ inch; jigging machine	17a	.....	g1535	g1435	g1565	.....	.....	h1465	.....	.....	g1250	h1325	.....
	17b	.....	g1525	g1505	g1465	.....	g1260	h970	.....	.....	g1390	h1150	.....
1 to 2; quaking; ⅞ inch; jigging machine	18a	.....	c1315	g1275	g1260	.....	g1260	g1695	.....	.....	c480	h1050	.....
	18b	.....	c1295	g1465	g1525	.....	g1120	g1265	.....	.....	c1380	h1435	.....
1 to 2½; plastic; ⅞ inch; machine made	19a	.....	.....	g1485	g1575	.....	.....	g1895	.....	.....	.....	g1995	.....
	19b	.....	.....	g1435	g1625	.....	.....	g1635	.....	.....	.....	g1725	.....
1 to 2½; plastic; ⅞ inch; machine made	20a	.....	.....	g1365	g1775	.....	.....	g1545	.....	.....	.....	g1805	.....
	20b	.....	.....	g1755	g1495	.....	.....	g1595	.....	.....	.....	g1645	.....

TABLE 14—Continued

Description of tile: Proportion; consistency; wall thickness; method of molding	Series No.	Exposure to alkali water—Continued							
		Grand Junction, Colo.				Huntington, Utah.			
		1914	1915	1916 Sec. 3	1916 Sec. 4	1914	1915	1916 Sec. 3	1916 Sec. 4
1 to 2½; plastic; 1½ inches; hand tamped	1a	c2590	d2550	e, f0	d3030	e2435	d3050	d3265	d3225
	1b	c2670	d2780	d2125	e1835	c2105	d2560	d2910	d3850
1 to 2½; quaking; 1½ inches; hand tamped	2a	g2815	g3500	3295	g3590	g3330	g3270	g3315	3550
	2b	g2975	g3390	g3110	g3100	g3580	g3380	g3225	3950
1 to 2; plastic; 1½ inches; hand tamped	3a	c2885	e910	e2295	d2970	c1530	d2590	d2820	e1645
	3b	c1375	e1660	e1395	e, f0	c1825	d2280	d2800	c2165
1 to 2; plastic; 1½ inches; hand tamped; cement grout coat	4a	c2130	d2020	d2940	c3335	c3465	d2980	d2860	d2545
	4b	c2555	d2400	d2760	d2145	c2985	d2340	d2720	d3020
1 to 2; plastic; 1½ inches; hand tamped; tar coat	5a	c2055	d1110	d2615	d2545	c2770	d2670	d2940	d2325
	5b	c2115	d1580	c3060	d3030	c2645	d2230	c3150	d2645
1 to 2; plastic; 1½ inches; hand tamped; 10 per cent ferrous sulfate	6a	c2045	d910	d2465	d2315	e1485	d1520	d2085	e1250
	6b	c2960	e500	e2415	d2215	e1440	d2040	d2525	e1955
1 to 3; fluid; 1½ inches; hand tamped	14a	g2265	g2570	h2225	g3275	g2770	g3180	g2970	g2735
	14b	g3175	g2910	g3100	g2810	g2905	g3190	g2665	g3240
1 to 3; sand cement; fluid; 1½ inches; hand tamped	15a	k1625	e1310	d1585	d1815	c1725	d1340	d1375	c1865
	15b	k1855	e880	d1775	c1795	c2105	d1510	d1545	d2045
1 to 3; plastic; ⅞ inch; machine made	7a	c1295	c1150	c1555	c1365	c1570	d1510	c1445	d1265
	7b	c1220	d880	c1495	c1455	c1505	d1470	c1495	d1275
1 to 4; plastic; ⅞ inch; machine made	8a	c840	d760	d970	d1240	c1075	d910	d990	d1150
	8b	c910	d540	d980	e, f0	c1120	d1110	d1120	d1090
1 to 1½; plastic; ⅞ inch; machine made	9a	c1175	c1210	c1675	g1855	c1920	g1860	c1905	c1845
	9b	c1495	g1360	c1585	1825	c1945	d1280	c1925	g1765
1 to 1½; plastic; ⅞ inch; machine made	10a	c1295	g1310	d1615	d1445	c1570	g1690	c1715	d1465
	10b	c1310	d1150	d1140	c1515	c1955	c1910	c1545	d1505
1 to 3; plastic; ⅞ inch; machine made	11a	c1310	d920	d1295	c1565	c1695	c1640	c1365	d1405
	11b	c1340	d1190	d1040	c1535	c1450	c1590	c1365	d1495
1 to 4; plastic; ⅞ inch; machine made	12a	c1035	d870	d1220	d1220	c1185	d950	d1020	d725
	12b	c1265	d890	d910	d1020	c1090	d1100	d1180	d910
1 to 2½; plastic; ⅞ inch; machine made	13a	c1440	d1070	d1240	d1140	c1680	c1710	c1405	d1265
	13b	c1065	g1590	d1040	d1415	c1295	c1590	c1695	d1020
1 to 4; plastic; ⅞ inch; machine made	16a	e760	d1070	d1130	e840	e840	d1400	d1210	e490
	16b	e, f0	d1130	e, f0	e, f0	c1075	d1400	c1495	d1030
1 to 1½; quaking; ⅞ inch; jigging machine	17a	.....	c1140	g1525	.....	.....	c1720	g1595	.....
	17b	.....	g1490	c1445	.....	.....	c1660	g1795	.....
1 to 2; quaking; ⅞ inch; jigging machine	18a	.....	g1440	g1250	.....	.....	g1930	c1220	.....
	18b	.....	g1350	g1545	.....	.....	c1440	g1415	.....
1 to 2½; plastic; ⅞ inch; machine made	19a	.....	.....	g1655	.....	.....	.....	1775	.....
	19b	.....	.....	g1595	.....	.....	.....	g1805	.....
1 to 2½; plastic; ⅞ inch; machine made	20a	.....	.....	g1575	.....	.....	.....	g1615	.....
	20b	.....	.....	d1355	.....	.....	.....	g1485	.....

[a] Tested both years following heavy rains to which tile were exposed.
[b] Disintegration in evidence on all tile of series 1 to 16 except series 5. See page 62.
[c] Saturated; entire surface of one or more fractured surfaces wet.
[d] Moisture and some alkali apparent in fractured surfaces. No cracking, swelling, or disintegration apparent.
[e] Saturated; large amount of alkali; cracked; disintegrated.
[f] Swollen; cracked; broken in removal from drain. Considered as "0" strength in averages of Table 15.
[g] Damp, wet spots in fractured surfaces.
[h] Alkali action on outer bottom surface; penetrated less than one-fourth of an inch; no alkali in walls.
[i] Alkali deposit in one end.
[j] Accidentally broken.
[k] Saturated; mortar softened at end.
[l] Saturated; crusty white deposit on outer wall; did not penetrate.

TABLE 15

Average Results of Crushing Tests of Experimental Cement Draintile

[Results in 1914 and 1915 are generally average of 2 tests; in 1916, average of 4 tests.]

Proportion / Consistency / Method of molding / Wall thickness / Special treatment	1 to 2½ Plastic Hand tamped 1½ inches			1 to 2½ Quaking Hand tamped 1½ inches			1 to 2 Plastic Hand tamped 1½ inches			1 to 2 Plastic Hand tamped 1½ inches Dipped in grout			1 to 2 Plastic Hand tamped 1½ inches Dipped in tar			1 to 2 Plastic Hand tamped 1½ inches 10 per cent ferrous sulfate			1 to 3 Fluid Hand tamped 1½ inches		
Exposure and location	1			2			3			4			5			6			14		
	1914	1915	1916	1914	1915	1916	1914	1915	1916	1914	1915	1916	1914	1915	1916	1914	1915	1916	1914	1915	1916
Exposed to atmosphere:																					
Ames,[a] Iowa, average	2970	2795	3500	2660	3170	2940	2170	2330	3075	2315	2220	2885	3075	2790	2675	2535	2360	2450	2325	2380	2610
Dry	.....	.....	3850	.....	.....	3490	.....	.....	3350	.....	.....	3020	.....	.....	2990	.....	.....	2795	.....	.....	3135
Saturated	.....	.....	3140	.....	.....	2385	.....	.....	2800	.....	.....	2745	.....	.....	2360	.....	.....	2110	.....	.....	2080
Exposed to fresh water:																					
Columbia, Mo	2680	2890	2680	2490	3175	2600	2585	3505	2350	2670	2785	2520	2345	2760	2670	2640	2265	2330	2447	2575	2420
Crookston, Minn	2670	3250	3380	2915	3125	3340	3000	3100	3300	2670	2635	3095	2385	2585	2680	2705	3050	3210	2765	2570	3115
Grand average	2680	3070	3030	2705	3150	2970	2790	3305	2825	2670	2710	2810	2365	2675	2675	2675	2660	2770	2606	2575	2770
Maximum individual	2760	3600	3570	3085	3340	3600	3230	3550	3450	2950	3340	3480	2590	3080	2890	2885	3340	3430	2780	3080	3400
Minimum individual	2580	2740	2615	2385	2910	2445	2480	3100	1995	2395	2230	2415	2140	2440	2415	2525	2140	2015	2340	2070	1965

Exposed to alkali water:																					
Garland, Wyo	3280	2390	2930	2955	2760	3065	2655	1640	2400	2715	2470	2460	2695	2355	2280	2125	2360	2570	2600	2545	2675
Fort Shaw, Mont	2625	3005	2710	2530	2695	3350	2600	3180	2410	2085	2380	2450	2500	2805	2530	2630	2290	2125	2830	2530	2600
Sunnyside, Wash	2550	2570	2655	3145	2905	3275	2275	2870	2540	2580	2730	2580	2535	2635	2710	3130	2500	2585	2495	2735	3055
Yuma, Ariz	2995	2640	2905	2990	2915	3115	2255	2510	2525	2435	2400	2450	2210	2970	2875	2125	2670	2510	2595	3085	2890
Roswell, N. Mex	2715	2635	2780	3140	3010	3350	2665	2355	3080	2535	2395	2905	2850	2370	2905	2495	2335	2490	2735	2435	2830
Montrose, Colo	2795	3005	2915	3050	3205	3285	2280	2295	1770	3220	2735	2755	3150	2165	3080	2520	2075	2295	2805	2700	3260
Grand Junction, Colo	2630	2665	1750	2895	3445	3275	2130	1285	1665	2340	2210	2795	2085	1345	2810	2500	705	2350	2720	2735	2850
Huntington, Utah	2270	2805	3340	3455	3325	3510	1675	2435	2360	3225	2660	2785	2705	2450	2765	1460	1780	1955	2835	3185	2900
Grand average	2735	2715	2750	3020	3030	3280	2315	2320	2345	2645	2500	2650	2595	2385	2745	2250	2090	2360	2705	2745	2880
Maximum individual	3420	3080	3850	3590	3500	3950	3365	3760	3450	3230	3070	3335	3230	3000	3500	2985	2920	3530	3175	3190	3480
Minimum individual	2105	1960	0	2490	2535	2715	1375	1585	0	1900	1880	2165	1900	1110	1965	1440	500	1605	2265	2275	2145

TABLE 15—Continued

Proportion	1 to 3, sand cement			1 to 3			1 to 4			1 to 1½			1 to 1½			1 to 3			1 to 4		
Consistency	Fluid			Plastic			Plastic			Plastic			Plastic			Plastic			Plastic		
Method of molding	Hand tamped			Machine made			Machine made			Machine made			Machine made			Machine made			Machine made		
Wall thickness	1½ inches			⅞ inch			⅞ inch			⅞ inch			⅞ inch			⅞ inch			⅞ inch		
Special treatment																					
	15			7			8			9			10			11			12		
Exposure and location	1914	1915	1916	1914	1915	1916	1914	1915	1916	1914	1915	1916	1914	1915	1916	1914	1915	1916	1914	1915	1916
Exposed to atmosphere:																					
Ames,[a] Iowa, average	1615	1290	1660	1270	1145	1450	945	850	1230	1665	1130	1890	1430	905	1730	1245	1065	1430	1095	905	1075
Dry	.....	.....	1765	.....	.....	1550	.....	.....	1370	.....	.....	2165	.....	.....	1950	.....	.....	1660	.....	.....	1120
Saturated	.....	.....	1500	.....	.....	1350	.....	.....	1085	.....	.....	1620	.....	.....	1505	.....	.....	1200	.....	.....	1225
Exposed to fresh water:																					
Columbia, Mo	1565	1400	1625	1175	1275	1330	1020	1155	960	1615	1825	1510	1780	1620	1395	1200	1300	1370	1170	1125	1070
Crookston, Minn	1545	1380	1715	1465	1230	1395	995	985	1110	1580	1635	1785	1815	1325	1545	1355	1275	1480	1035	1320	1215
Grand average	1555	1390	1670	1320	1255	1360	1010	1070	1035	1600	1730	1650	1795	1475	1470	1278	1290	1425	1104	1220	1140
Maximum individual	1770	1660	2035	1515	1360	1575	1075	1280	1240	1705	1950	1945	1870	1680	1875	1440	1540	1595	1200	1400	1335
Minimum individual	1320	1140	1250	1145	1190	1200	950	880	870	1505	1470	1425	1695	1250	1070	1200	1010	1255	920	1280	1000

Exposed to alkali water:																					
Garland, Wyo	1485	1305	1725	1400	1250	1075	795	740	840	1505	1535	1525	1115	1610	1485	1265	1445	1295	650	865	470
Fort Shaw, Mont	1530	1445	1580	1245	1315	1355	1045	740	910	1555	1175	1700	1530	1340	1560	1425	1320	1420	1010	1235	1000
Sunnyside, Wash	1375	1625	1810	1110	1280	1485	985	1015	985	1725	1320	1760	1695	1530	1650	1350	1115	1520	1035	1120	1120
Yuma, Ariz	1630	1700	1140	1380	1410	1565	1070	1120	1120	1680	1575	1645	1810	1535	1650	1365	1515	1350	985	1145	1140
Roswell, N. Mex	1610	1355	1785	1320	825	1325	1040	960	1160	1555	1640	1890	1395	1060	1630	1435	1045	1490	1065	1120	1180
Montrose, Colo	1220	1305	1180	1370	1040	1465	980	1150	785	1700	1580	1555	1340	1665	1465	1195	1285	1350	1000	1205	520
Grand Junction, Colo	1740	1095	1740	1255	1015	1470	875	650	800	1335	1285	1735	1300	1230	1430	1325	1055	1360	1150	880	1090
Huntington, Utah	1915	1425	1680	1535	1490	1370	1095	1010	1090	1930	1570	1860	1760	1800	1560	1572	1615	1410	1135	1025	960
Grand average	1565	1405	1580	1330	1205	1390	985	925	960	1625	1460	1710	1495	1470	1555	1370	1300	1400	1005	1075	935
Maximum individual	2105	2000	2095	1605	1515	1715	1185	1490	1335	1945	1860	2025	1980	1910	2035	1695	1650	1645	1265	1345	1465
Minimum individual	1220	1190	655	900	670	950	770	705	0	1175	1145	1190	1055	940	960	1110	920	1040	570	870	0

TABLE 15—Continued

Proportion / Consistency / Method of molding / Wall thickness / Special treatment	1 to 2½ Plastic Machine made ⅞ inch			1 to 4 Plastic Machine made ⅞ inch			1 to 1½ Quaking Machine made ⅞ inch Jigging machine			1 to 2 Quaking Machine made ⅞ inch Jigging machine			1 to 2½ Plastic Machine made ⅞ inch			1 to 2½ Plastic Machine made ⅞ inch			Grand average, series 1 to 16, inclusive		Grand average, all series		
	13			16			17			18			19			20							
Exposure and location	1914	1915	1916	1914	1915	1916	1914	1915	1916	1914	1915	1916	1914	1915	1916	1914	1915	1916	1915	1916	1914	1915	1916
Exposed to atmosphere:																							
Ames,[a] Iowa, average	1340	1175	1610	1210	1050	1425	.....	1235	1610	.....	1035	1565	.....	.....	1695	.....	.....	1750	1728	2100	1865	1655	2015
Dry	.....	.....	1750	.....	.....	1660	.....	.....	1750	.....	.....	1890	.....	.....	1960	.....	.....	1940	.....	2350	.....	.....	.....
Saturated	.....	.....	1470	.....	.....	1190	.....	.....	1475	.....	.....	1240	.....	.....	1425	.....	.....	1520	.....	1820	.....	.....	.....
Exposed to fresh water:																							
Columbia, Mo	1470	1415	1370	1075	1210	1265	.....	1475	1235	.....	1345	1145	.....	.....	1310	.....	.....	1320	1990	1840	1870	1950	1725
Crookston, Minn	1435	1600	1420	940	1000	1135	.....	1320	1440	.....	1295	1590	.....	.....	1530	.....	.....	1590	2005	2180	1955	1930	2055
Grand average	1455	1510	1395	1010	1105	1200	.....	1400	1340	.....	1320	1370	.....	.....	1420	.....	.....	1455	.....	.....	.....	.....	.....
Maximum individual	1485	1870	1545	1155	1430	1375	.....	1570	1585	.....	1410	1675	.....	.....	1605	.....	.....	1795	.....	.....	.....	.....	.....
Minimum individual	1405	1230	1220	880	940	940	.....	1200	1180	.....	1260	1030	.....	.....	1140	.....	.....	1210	.....	.....	.....	.....	.....

Exposed to alkali water:																							
Garland, Wyo	1140	1320	1480	690	830	645	.....	1310	1475	.....	1260	1385	.....	.....	1585	.....	.....	1595	1713	1805	1820	1665	1750
Fort Shaw, Mont	1210	1330	1460	980	880	1020	.....	1465	1470	.....	1295	1510	.....	.....	1560	.....	.....	1620	1855	1885	1835	1800	1820
Sunnyside, Wash	1445	1740	1555	1002	850	510	.....	1460	1590	.....	1415	1420	.....	.....	1490	.....	.....	1620	1910	1985	1840	1860	1895
Yuma, Ariz	1190	1460	1420	1050	1130	1240	.....	1530	1490	.....	1305	1350	.....	.....	1530	.....	.....	1600	1985	1970	1860	1925	1875
Roswell, N. Mex	1455	1330	1585	1077	865	1085	.....	1260	1220	.....	1190	1480	.....	.....	1765	.....	.....	1570	1725	2090	1945	1700	1975
Montrose, Colo	1495	1000	1000	777	840	490	.....	1320	1240	.....	1430	1240	.....	.....	1860	.....	.....	1725	1825	1825	1930	1780	1760
Grand Junction, Colo	1250	1330	1210	760	1100	490	.....	1315	1485	.....	1395	1400	.....	.....	1620	.....	.....	1465	1535	1800	1770	1515	1740
Huntington, Utah	1485	1650	1345	957	1400	1055	.....	1690	1695	.....	1685	1320	.....	.....	1790	.....	.....	1550	1980	1935	1940	1945	1915
Grand average	1335	1395	1380	912	985	815	.....	1420	1460	.....	1370	1390	.....	.....	1655	.....	.....	1593	.....	.....	.....	.....	.....
Maximum individual	1790	1765	1915	1145	1400	1495	.....	1720	1795	.....	1590	1695	.....	.....	1995	.....	.....	1805	.....	.....	.....	.....	.....
Minimum individual	1000	830	0	490	770	0	.....	1140	970	.....	1045	1050	.....	.....	1335	.....	.....	1345	.....	.....	.....	.....	.....

[a] In 1916 three tile were tested after air drying and three after 24 hours' immersion in water. See text, p. 62.

It should be emphasized that the breaking tests alone should not be taken as an index of the resistance of the tile to alkali action, as some of those which had a normal or slightly reduced strength showed evidences of alkali action by softened edges, cracked surfaces, or deposits of white alkali salts in the walls of the tile, as indicated in the footnotes in Table 14. Where such action has been noted, it is possible that another year or two of exposure may cause the failure of tile similarly affected, although this need not necessarily result.

The variations in results of the same mixtures at the same or several points may also be due in part to the nonhomogeneity of the material, due in most part to nonuniform or insufficient "packing" in the machine or "tamping" by hand. With the same materials the two factors which enter into the strength of the product are "richness" or proportion of cement and the fabrication or process of manufacture. Richness of mixture alone will not insure a product of good quality. The low-strength results obtained in a number of cases of the richer mixtures can be explained by poor tamping, especially in the handmade tile, in whose broken surfaces rings of untamped material were apparent. Even though extra care is taken in the tamping, there is certain to be some variation in density which will affect the strength.

The absorption of moisture by the walls of the tile of the various series was noticeable at the different projects. The apparent amount of absorption varied with the amount of water present in the soils at the various points, and it was found that some of the series would be apparently saturated where the ground was barely moist while other series were apparently only slightly damp, even where the drain was filled with mud and water. Of the handmade tile and under the worst conditions, those made in the proportion 1 to 2½, quaking consistency (series 2), were, with very few exceptions, found to be slightly damp, as indicated by the appearance of the fractured surfaces. This difference is not alone due to the variation in the proportions of the cement, since series 3, 4, 5, and 6, the richest mixtures used, were nearly always found partially or completely saturated. The term saturated is indefinite and inexact, since the condition was determined only by observation, but was used to indicate a dark spongy appearance of the fractured surface common to water-soaked concrete. The tile of series 14 (1 to 3, fluid consistency), next to those of series 2 (1 to 2½, quaking consistency), showed the smallest amount of absorption, while the tar-coated tile of series 5 (1 to 2, plastic consistency) and the

tile of series 6 (1 to 2, plastic consistency), containing the ferrous sulfate, were usually found to show the greatest absorption. We have no explanation to offer for the saturation of the tile of series 5 and 6.

Series 17 (1 to 1.5) and 18 (1 to 2) when tested in 1915 and 1916 had absorbed very little water and can be ranked with series 2 and 14 with respect to low absorption.

The absorption of the machine-made tile appeared to vary as the amount of cement contained in them. The tile of series 9 and 10 (both proportion, 1 to 1½) were usually found apparently dry or only partially saturated with a few wet spots in the fractured surfaces, while the tile of series 8, 12, and 16 (all proportion, 1 to 4), the leanest mixture, were always found saturated. Some low-strength results obtained may be partially due to higher porosity, which caused the tile to be saturated with water when tested. This condition would also tend to increase the danger of failure due to alkali action at a later period.

In 1916 two sections, totaling 80 tile, were tested at each project, except at Roswell, Montrose, Grand Junction, and Huntington, where only two each of the replacement tile (series 17 to 20) were removed. Although the grand averages of all the tile of each individual series are generally higher in 1916 than in 1915, and in some cases higher than in 1914, many individual tiles showed partial or complete failure at several of the projects. At none of the projects were the tile found collapsed when the drain was opened, but many tile were so cracked or swollen or otherwise weakened by the alkali that they were broken in removal. This was especially true where the drains were carrying considerable water.

As in previous inspections, the tile of lean proportions and those with the more porous walls were most seriously and generally affected. However, alkali action was visible in at least one tile of each series except series 2 (1 to 2½ mixture, quaking consistency, hand made, wall thickness 1½ inches), which to date have shown no effect of alkali action or reduction in strength which might be attributed to such action. Reference is made to alkali action on the better-quality tile of other series in the discussion which follows:

Following is a discussion of the results of particular interest in each locality. All tile appeared to be in normal condition unless otherwise stated.

Ames, Iowa.—In addition to the usual crushing tests, absorption tests were made on the tile of each series. About four weeks previous to testing, six tiles of each series were weighed and stored in the laboratory at room temperature. Nine days later all tiles were again weighed, thereby furnishing air-dried weights to be used in calculating absorption. Three tiles of each series were then placed in water, and the amount of absorption was determined after 24 hours' immersion. The saturated tiles were replaced in the water until crushing tests were made. As shown in Table 14, three tiles of each series were tested in a saturated condition and three in a dry condition. The results of the absorption and crushing tests are also shown in Table 16 together with the percentage decrease in strength due to saturation with water. It is not possible to compare the strength results of either the saturated or dry tile of 1916 with those of the previous years because of the variations in moisture content, the tests in 1914 and 1915 being made following heavy rains to which the tile were exposed, the degree of saturation varying due to difference in exposure. Fig. 54 gives in diagrammatic form the results of strength tests of the tile when dry and when saturated, together with the percentage of absorption of each type of tile.

Comparison of the amount of absorption of the different series of tile with the results obtained for these tile exposed to severe alkali conditions on the different projects shows that the tile having the lower absorption are the more durable.

Columbia, Mo.—The grand average of all the results at Columbia are lower in 1916 than in either 1914 or 1915. An exceptional condition has arisen at this project, presumably caused by some local action, in that the tile of series 1 to 16, excepting series 5 (tar coated), showed evidences of disintegration (see Fig. 55) on the lower outer surface, indicated by the apparent dissolving away of cement, leaving the sand grains coated with a brown stain. The action was in every case confined to the outer one-eighth 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 a slight surface action, which was visible only when carefully inspected.

That the conditions at Columbia are abnormal is shown by the fact that cement draintile has been in successful use for years in

the humid region. An investigation is now being made to discover the cause of this trouble.

TABLE 16

Results of Absorption and Crushing Tests of Experimental Cement Draintile

[Stored outside three years previous to test. All results average of three tests.]

Series No.	Proportion; consistency; type of tile	Absorption in 24 hours [a]		Average crushing strength, pounds		Per cent decrease in strength due to saturation
		Average per cent	Range	Dry	Saturated	
1	1:2.5; plastic; hand tamped	2.3	0.4	3850	3140	18.4
2	1:2.5; quaking; hand tamped	1.8	1.4	3490	2385	31.7
3	1:2; plastic; hand tamped	4.2	.5	3350	2800	16.4
4	1:2; plastic; hand tamped, grouted	3.9	.7	3020	2745	9.1
5	1:2; plastic; hand tamped, tar coat	1.9	.3	2990	2360	21.0
6	1:2; plastic; hand tamped, 10 per cent ferrous sulfate	5.4	.7	2795	2110	24.6
14	1:3; fluid; hand tamped	3.8	3.2	3135	2080	33.6
15	1:3; fluid; hand tamped, sand cement	7.2	1.2	1765	1500	15.0
7	1:3; plastic; machine made	2.3	.4	1550	1350	12.9
8	1:4; plastic; machine made	3.1	.3	1370	1085	20.8
9	1:1.5; plastic; machine made	1.5	.2	2165	1620	25.2
10	1:1.5; plastic; machine made	1.5	.8	1950	1505	22.8
11	1:3; plastic; machine made	2.3	.3	1660	1200	27.7
12	1:4; plastic; machine made	3.0	.1	1120	1025	8.5
13	1:2.5; plastic; machine made	2.0	.7	1750	1470	16.0
16	1:4; plastic; machine made	2.4	.4	1660	1190	28.3
17	1:1.5; quaking; hand made	.9	.0	1750	1475	15.7
18	1:2; quaking; hand made	1.5	.4	1890	1240	34.4
19	1:2.5; plastic; machine made	2.2	.4	1960	1425	27.1
20	1:2.5; plastic; machine made	2.1	.5	1940	1520	21.6

[a] Tile removed from outdoors and stored under cover for 9 days, after which air-dry weight was determined, and tile were immersed for 24 hours. These tile were not oven dried.

CROOKSTON, MINN.—The grand average for all tile in 1916 shows an increase of nearly 200 pounds over those of the previous years. All tile, with the exception of those of series 8, 12, and 13, show higher average crushing strengths than the year previous. No disintegrating action such as occurred at Columbia, Mo., was observed on any of the tile at Crookston.

GARLAND, WYO.—The grand average for 1916 is about 100 pounds lower than for the years 1914 and 1915. Alkali salts were visible in the fractured walls of one or more tile of series 1, 3, 4, 5, 6, 7, 8, 11, 12, and 16 after the crushing tests were made. Series 8, 12, and 16 (the 1:4 proportions) were most seriously affected, and one each of series 12 and 16 were so weakened that they were broken in removal from the trench.

FORT SHAW, MONT.—The grand average strength of all tile in 1916 is about the same as that obtained for the two previous years. Alkali salts were found in the fractured surfaces of one or more tile of series 1, 3, 4, 5, 6, 8, 12, and 16. Series 2 shows a marked increase over all previous results. Series 6 (proportion 1:2, plastic consistency, ferrous sulfate in mixing water) has shown a constant falling off in strength since the first tests were made in 1914. Series 9 and 10 (both proportions 1:1.5, plastic consistency) show marked increases over the 1915 results, which were considerably below those of 1914.

SUNNYSIDE, WASH.—The grand average result of the crushing tests in 1916 is slightly higher than for the two previous years. Alkali salts were found in the fractured surfaces of one or more tile of series 1, 3, 4, 5, 6, 15, 8, 12, 13, and 16. One tile of series 3 was swollen and cracked, while two of series 16 were so badly affected that they were broken in removal.

YUMA, ARIZ.—The grand average crushing strength in 1916 is slightly lower than in 1915. Alkali salts were found in the fractured surfaces of one or more of the tile of series 1, 3, 4, 5, 15, 8, 12, and 16. Series 15 showed a marked decrease in strength as compared with previous results. The ground-water table has been above the tile line since the summer of 1914, previous to making the first year's tests.

ROSWELL, N. MEX.—The grand average of all results in 1916 is about 300 pounds higher than in 1915. Alkali salts were found in the fractured surfaces of one or more tile of all series except 2, 9, 14, 18, 19, and 20. Reference only to the strength values obtained would in several cases give no indication of the presence of the quantities of salts which were visible in the concrete. The two tile of series 17 were affected on the bottom surface in contact with the bottom of the trench. (See Fig. 56.) On tile of series 17 the salts were not distributed through the wall, but appeared to affect only the surface to a depth of probably one-eighth inch. The average results for series 3 and 5 (1:2 proportion, plastic consistency, hand tamped), 7 and 11 (1:3 proportion, plastic consistency, machine made), and 10 (1:1.5, plastic, machine made), which in 1915 showed large reductions, were equal to or in excess of those obtained in 1914.

MONTROSE, COLO.—The grand average of all results in 1916 is about the same as for 1915, but more individual failures were found than in the tests of that year. Alkali salts were found in

the fractured surfaces of one or more tile of all series except 2, 10, 17, 18, 19, and 20. A ring of alkali salts was found in one tile of series 14 one-half inch from one end. This localizing of salts may be due to a seam produced during manufacture. (See text, p. 25.) All tile of series 17 and 18 were affected on the surface in contact with the bottom of the trench in the same manner as the tile of series 17 at Roswell. (See Fig. 56.) Several tile of series 3 and 6 were swollen and cracked. Tile of series 12, 13, and 16 were so badly disintegrated by alkali salts that they were broken during removal from the trench. Series 4, 5, and 6 (1:2, plastic, hand tamped) and 13 (1:2.5 plastic, machine made), which showed a large falling off in strength in 1915, showed no further loss in strength in 1916, and series 5 gave results equal to those obtained in 1914.

Grand Junction, Colo.—The grand average of all results in 1916 was about the same as in 1914 and over 200 pounds higher than that of 1915. Alkali salts were found in the fractured surfaces of one or more tile of all series except 2, 7, 9, 14, 17, 18, and 19. One or more tile of series 1, 3, 8, and 16 were so seriously affected by alkali salts that they were broken in removal from the trench. The salts found in the tile of series 20 were distributed through the wall of the tile. One tile of series 14 was affected on the outer surface at one end in contact with the bottom of the trench, but the alkali was not distributed through the wall. In 1915 the tile of series 6 (proportion 1:2, plastic, ferrous sulfate in mixing water) had an average strength of 705 pounds, one tile being swollen and cracked. The tile of series 16 were badly affected by alkali in 1914 (see Fig. 57), both being swollen and cracked. The disintegration of some of the tile removed in 1916 is shown in Fig. 58.

Huntington, Utah.—The grand average of all results in 1916 is slightly lower than those of the years 1914 and 1915. Alkali salts were found in the fractured surfaces of one or more tile of all series except 2, 9, 14, 17, 18, 19, and 20. Tile of series 3, 6, and 16 were swollen and cracked. Large quantities of salts were apparent in the walls of tile of series 3 and 6 (proportion 1:2, plastic, ferrous sulfate in tile of series 6) when tested in 1914.

VIII. MANUFACTURE AND INSTALLATION OF CONCRETE

Throughout the work all materials were weighed to insure uniformity and accuracy in proportioning and all blocks were carefully molded so as to secure a dense mass with smooth surfaces. Samples of all cements, aggregates, mixing waters, as well as soils, alkalies, and seepage waters, were secured for tests and analyses, results of which are shown on pages 81 to 87. Detailed descriptions of the methods employed are given below.

1. DENVER, COLO.

The "A" specimens, as described on page 15, were manufactured under the supervision of a representative of the Bureau of Standards during August, 1915, at Denver, Colo., in the laboratory and with the cooperation of the United States Reclamation Service, located in the new Federal building. The materials used were Iola Portland cement, manufactured by the Iola Portland Cement Co., Iola, Kans.; natural cement, manufactured by a company in the Middle West; sand cement, from the Elephant Butte Mill of the United States Reclamation Service, Elephant Butte, N. Mex.; sand and gravel from the pit of the Tramway Co., Denver, Colo.; and water from the Denver city supply. Tests of the cements and aggregates are shown in Tables 25 to 32.

Material for all blocks was mixed by hand in batches sufficiently large to just fill one block form and two 6-inch cube molds. The weight per cubic foot of the sand and gravel was determined and the volume proportions were reduced to a weight basis in order to secure accuracy. The weight of a cubic foot of cement was assumed to be 100 pounds.

The following method was used in mixing. The weighed sand was dumped and spread evenly over the bottom of a large mortar box and the weighed cement spread out over the sand. This material was then mixed with a mortar hoe until it became a uniform color, again spread out, and the weighed gravel added, after which the mass was turned twice with a shovel. A crater was then formed, water poured in, and the whole mass turned until of a uniform appearance. The concrete was then shoveled into the wooden form, which had been previously well oiled, at the rate of three shovels full at a time, between which intervals the mass in the form was cut through and spaded by means of a large bricklayer's trowel. Two vertical three-eighths inch square plain steel reinforcing rods were forced in just before completion

of the molding, as specified on page 14, the iron handle placed, and an aluminum marker cast flush in the top. After four days the forms were removed, and the blocks were then sprinkled for three additional days. The compacting of the material in the forms was further aided by shaking the forms and by tapping the sides with a hammer after filling was completed.

In addition to the large group of specimens which were molded in planed wooden forms, 12 each were molded in rough wooden forms, and in forms which were lined with sheet-metal plates. The rough wooden forms showed marks of the circular saw, and the same were very apparent in the cast concrete. The sheet-metal plates were accurately cut to size so that a metal surface was in contact with the concrete at all points. The result was a very smooth surface, which was in marked contrast with the rough surfaces resulting from the use of the unplaned lumber. The lumber used in the forms was very dry, which caused some trouble, due to the absorption of water by the wood and the resultant swelling. This action occurred before the concrete had attained final set, and the bond between the wood and the concrete was sufficient to form a plane of weakness which later resulted in the corner shelling off. This trouble was later entirely avoided by thoroughly soaking the forms in water just previous to filling them.

The natural-cement blocks which were made at Denver were so fragile that all were broken in removing the forms, although the forms remained in place longer than the specified four days. The blocks made of sand-cement concrete were slow in gaining strength, and the corners were slightly damaged in several cases in removing the forms.

In Fig. 59 is shown a plan view of a block which indicates the position of the rods, the handle, and the aluminum marking plate. In describing the condition of the blocks later, reference is made to corners, such as 2, 3, and to surfaces, as 1–2, 2–3. The corners have been numbered clockwise, beginning below and to the right of the number plate.

In Table 17 is given a complete list of the blocks made at Denver and the project to which each was shipped. After curing for a period of one month the blocks were crated and shipped to the various projects by freight. The dates of installation are given under section "(*c*) Installation" at each of the various projects.

TABLE 17 [a]

Portland-Cement and Sand-Cement Concrete Blocks Molded at Denver, 1915

[Proportions by volume]

PORTLAND-CEMENT CONCRETE BLOCKS

Block No.	1:1.5:3		Block No.	1:2.5:5	
	Type of form	Installation		Type of form	Installation
1	Smooth wood	Belle Fourche, S. Dak., project.	32	Smooth wood	Belle Fourche, S. Dak., project.
2	do	Do.	33	do	Do.
3	Metal lined	Do.	34	Rough wood	Do.
4	do	Do.	35	do	Do.
5	Rough wood	Do.	36	Metal lined	Do.
6	do	Do.	37	do	Do.
7	Smooth wood	Shoshone, Wyo., project.	38	Smooth wood	Shoshone, Wyo., project.
8	do	Do.	39	do	Do.
9	Metal lined	Do.	40	Rough wood	Do.
10	do	Do.	41	do	Do.
11	Rough wood	Do.	42	Metal lined	Do.
12	do	Do.	43	do	Do.
13	Smooth wood	Grand Valley, Colo., project.	44	Smooth wood	Grand Valley, Colo., project.
14	do	Do.	45	do	Do.
15	Metal lined	Do.	46	Rough wood	Do.
16	do	Do.	47	do	Do.
17	Rough wood	Do.	48	Metal lined	Do.
18	do	Do.	49	do	Do.
19	Smooth wood	Sun River, Mont., project.	50	Smooth wood	Sun River, Mont., project.
20	do	Do.	51	do	Do.
21	do	Yakima, Wash., project.	52	do	Yakima, Wash., project.
22	do	Do.	53	do	Do.
23	do	Rio Grande, N. Mex., project.	54	do	Rio Grande, N. Mex., project.
24	do	Do.	55	do	Do.
25	do	Uncompahgre, Colo., project.	56	do	Uncompahgre, Colo., project.
26	do	Do.	57	do	Do.
27	do	Truckee-Carson, Nev., project.	58	do	Truckee-Carson, Nev., project.
28	do	Do.	59	do	Do.
29	do	Held for reference.	60	do	Held for reference.
30	Metal lined	Do.	61	Rough wood	Do.
31	Rough wood	Do.	62	Metal Lined	Do.

SAND-CEMENT CONCRETE BLOCKS

63	Smooth wood	Grand Valley, Colo., project.	65	Smooth wood	Grand Valley, Colo., project.
64	do	Do.	66	do	Do.
71	do	Held for reference.			

[a] All natural-cement blocks were too badly damaged to be shipped.

2. BELLE FOURCHE PROJECT

"B" SPECIMENS

GRAVEL AND SAND.—The aggregate used in 1915 in manufacturing the blocks was obtained from a gravel bank 1½ miles east of Fruitdale, S. Dak., on the Belle Fourche River. This material was hauled to the work and screened. Gravel and sand from the same bank have been used in the construction of a number of concrete structures in the western portion of the project and also for making the blocks with which the upstream face of the dam is lined.

In 1916 the same materials were used, except that both the sand and gravel were thoroughly washed before being used.

CEMENT.—The cement used in 1915 was Lehigh brand Portland cement which had been in stock for about a year. The material was rather lumpy and was screened before being used.

In 1916 Iola brand Portland cement was used in making the blocks.

WATER.—Mixing water in 1915 and 1916 was taken from the north canal just below the dam.

"C" SPECIMENS

The same materials were used for the "C" specimens, quantities of each being hauled to the site of installation for the purpose.

"B" SPECIMENS, 1915

The series of "B" blocks were molded in the yard of the old United States Reclamation headquarters at Orman, just below the north end of the Belle Fourche Dam. Weights per cubic foot of aggregates were determined and volume measure reduced to weight measure to insure accuracy in proportioning. All materials were weighed on a small platform scale. The sand and cement were spread on a large steel plate, thoroughly mixed, and the stone was added and distributed through the mass by shoveling. Water was then added and the mixing completed. The wooden forms were well soaked in water and then oiled just previous to being filled. Each batch was made sufficiently large to fill one block form and to make two 6-inch cubes. Sufficient water was used to bring the mass to a mushy consistency. A bricklayer's trowel was used to spade the material, which was added at the rate of three shovels full at a time. The tops of the blocks were covered with wet sacks to reduce evaporation and to prevent possibility of freezing at night. Forms were removed and the blocks were placed at the specified time.

In 1916 two "B" type blocks were molded, in smooth wood forms, in the general manner described above using washed aggregates, and installed after 28 days.

"C" SPECIMENS, 1915

All materials and tools were hauled to the site of installation and the "C" blocks were prepared in the same manner as were the "B" blocks, except that pits were dug 1 foot in depth, in which the forms were placed just previous to filling. Reference blocks 221 and 224 (see Table 18) were molded on the surface and not exposed to the seepage waters during fabrication. After the specified time forms were removed from the blocks, molded in the pits, and the soil refilled about them.

Following is a tabulation of the blocks installed on the Belle Fourche project in 1915:

TABLE 18

[Proportions by volume]

Block No.	1:1.5:3			Block No.	1:2.5:5		
	Type of form	Molded	Installed		Type of form	Molded	Installed
[a] 1	Smooth wood	Sept. 10	Sept. 21.	[a] 32	Smooth wood	Aug. 7	Sept. 21.
[a] 2	do	do	Do.	[a] 33	do	do	Do.
[a] 3	Metal lined	do	Do.	[a] 34	Rough wood	do	Do.
[a] 4	do	do	Do.	[a] 35	do	do	Do.
[a] 5	Rough wood	do	Do.	[a] 36	Metal lined	do	Do.
[a] 6	do	do	Do.	[a] 37	do	do	Do.
[b] 119	Smooth wood	Sept. 21	After 28 days.	[b] 122	Smooth wood	Sept. 21	After 28 days.
[b] 120	do	do	Do.	[b] 123	do	do	Do.
[b] 121	do	do	Reference.	[b] 124	do	do	Reference.
[c] 219	Molded in place; smooth wood forms.	Sept. 22	Sept. 22.	[c] 222	Molded in place; smooth wood forms.	Sept. 22	Sept. 22.
[c,d] 220	do	do	Do.	[c,d] 223	do	do	Do.
[c] 221	do	do	Reference.	[c] 224	do	do	Reference.

[a] "A" series. [c] "C" series.
[b] "B" series. [d] Remolded Oct. 11, 1915, on account of defects in original blocks.

NOTE.—The following defects were noted in the "A" specimens before installation: Block 1, corner 4 rough and piece broken off near top. Block 2, small patch on corner 4; portions of corners 1 and 2 have a shelly appearance. Block 3, good condition. Block 4, lower corners 3 and 4 broken off. Block 5, stones show in lower corners 2 and 3. Block 6, few large sand particles show in corner 3; piece broken out of corner 4, 6 inches below top. Block 32, small piece broken out of corner 1, 12 inches above bottom; corner 3 appears shelly. Block 33, poor surface appearance; large shell off corners 2, 3, and 4; bottom corner 1 broken off. Block 34, rough surfaces. Block 35, lower corner 2 broken off. Block 36, corner 3 rough for distance of 6 inches above bottom. Block 37, corner 2 rough, with some stones showing.

The blocks were installed in low seeped ground just below the north canal and about one-half mile east of the dam. The ground was fairly level and covered with a short coarse grass. The soil was very wet, with an inch or more of water standing over the surface in spots. Before placing the "A" series blocks made in Denver, small defects such as broken corners and edges were noted and photographs taken. Pits about 1 foot in depth were dug and the blocks set in place and the wet earth thrown about them.

In 1916 the following blocks were molded and installed on the Belle Fourche project:

[Proportions by volume 1:1½:3]

Block No.	Type of mold	Molded	Installed
[a] 301	Smooth wood	Sept. 5	After 28 days.
[b] 302	do	do	Do.

[a] Consistency, fluid. [b] Consistency, midway between mushy and fluid.

3. SHOSHONE PROJECT

"B" SPECIMENS

GRAVEL.—Gravel was taken from a spoil bank near the canal in front of the main office of the United States Reclamation Service at Powell, Wyo. Dust and fine material were removed by screening on a one-half inch screen. Pieces larger than 3 inches were picked out by hand.

SAND.—Obtained from the bottom of a small canal about 1 mile east of Powell.

WATER.—Taken from well which supplies camp with water.

"C" SPECIMENS

GRAVEL.—Taken from a site adjoining Ralston Reservoir.

SAND.—From some locality.

CEMENT.—Same as for "B" specimens.

WATER.—From the Ralston Reservoir.

"B" SPECIMENS, 1915

The "B" blocks were made in the yard at the United States Reclamation Service headquarters at Powell, Wyo. The methods used in mixing and molding were similar to those used on the Belle Fourche project.

"C" SPECIMENS, 1915

These blocks were molded in the same manner as the "B" specimens except that the forms were placed on a cradle in the

alkali slough. Some alkali water seeped into the forms before the concrete was placed, which made the mix watery in the bottom of the forms. These blocks were not sprinkled at any time, but were covered immediately after molding to reduce evaporation.

All blocks (see Table 19) were installed in the outlet of a slough below a culvert leading from the Ralston Reservoir on the Shoshone, Wyo., project of the United States Reclamation Service. Pits about 1 foot in depth were dug and the "A" blocks were installed at the time the "C" blocks were made.

Following is a tabulation of the blocks installed on the Shoshone project in 1915:

TABLE 19

[Proportions by volume]

Block No.	1:1.5:3			Block No.	1:2.5:5		
	Type of form	Molded	Installed		Type of form	Molded	Installed
[a] 7	Smooth wood	Aug. 10	Sept. 18	[a] 38	Smooth wood	Aug. 9	Sept. 18
[a] 8	do	do	Do.	[a] 39	do	do	Do.
[a] 9	Metal lined	do	Do.	[a] 40	Rough wood	do	Do.
[a] 10	do	do	Do.	[a] 41	do	do	Do.
[a] 11	Rough wood	do	Do.	[a] 42	Metal lined	do	Do.
[a] 12	do	do	Do.	[a] 43	do	do	Do.
[b] 103	Smooth wood	Sept. 17	After 28 days.	[b] 101	Smooth wood	Sept. 17	After 28 days.
[b] 104	do	do	Do.	[b] 102	do	do	Do.
[c] 201	do	Sept. 18	Molded in place.	[c] 203	do	Sept. 18	Molded in place.
[c] 202	do	do	Do.	[c] 204	do	do	Do.

[a] "A" series. [b] "B" series. [c] "C" series.

4. SUN RIVER PROJECT

"B" SPECIMENS

Gravel and Sand.—Pit-run gravel was obtained on the south bank of the Sun River about one-half mile west of the United States Reclamation Service headquarters at Fort Shaw, Mont. The material was passed through a 2.5-inch screen, and that retained on the No. 4 sieve was classed as gravel and that passing as sand. This material is used in making small structures, such as turnouts, gates, etc., on the Fort Shaw unit.

Cement.—The cement used was Red Devil brand Portland cement from stock.

Mixing Water.—From tap of the Indian School headquarters supply, into which it is pumped from the Sun River.

"C" SPECIMENS

The same materials were used in the "C" specimens except that mixing water was obtained from an irrigation ditch adjoining the site where the specimens were installed.

"B" SPECIMENS

The "B" blocks were made at the headquarters of the Reclamation Service at the old Indian school, Fort Shaw, Mont. All concrete was hand mixed, using the same method as on the Belle Fourche project. The materials were weighed, and each batch was made large enough to mold one block and two 6-inch cubes.

"C" SPECIMENS

The four "C" specimens were molded at the site of installation in the general manner described for the "C" blocks on the Belle Fourche project. As noted under "Materials," these blocks differed from the "B" series only in the mixing water used and in exposure to alkali water immediately after molding.

All blocks (see Table 20) were installed in seeped ground at the east end of farm unit E, section 6, township 20 north, range 1 west. The blocks installed near Fort Shaw in 1915 are shown in Fig. 60 and detailed in the following tabulation:

TABLE 20

[All blocks were molded in smooth wood forms. Proportions by volume]

Block No.	1:1.5:3		Block No.	1:2.5:5	
	Molded	Installed		Molded	Installed
[a] 19	Aug. 10	Sept. 22.	[a] 50	Aug. 9	Sept. 22.
[a] 20	...do.....	Do.	[a] 51	do.	Do.
[b] 107	Sept. 22	After 28 days.	[b] 109	Sept. 22	After 28 days.
[b] 108	...do.....	Do.	[b] 110	...do.....	Do.
[c] 207	In place	Sept. 22.	[c] 209	In place	Sept. 22.
[c] 208	...do.....	Do.	[c] 210	...do.....	Do.

[a] "A" series [b] "B" series [c] "C" series

NOTE.—The following defects were noted in the "A" series blocks previous to placing: Block 19, lower corner 1 broken off vertically for a distance of 1½ inches. Block 20, patch 6 inches long on corner 4, 3 inches below top. Block 50, lower corner 3 shelled off 1½ inches vertically; piece 2 inches long broken out of corner 4 about 15 inches below top. Block 51, bottom edge of face 1–2 chipped off for distance of 4 inches near corner 2; also small piece cracked off lower edge of face 2–3; piece 4 inches long broken out of corner 2, 2 inches below top.

5. YAKIMA (SUNNYSIDE) PROJECT, WASH.

No blocks were made at Sunnyside by the Bureau of Standards representative, as a set of four blocks conforming to the "B" series specifications was made prior to his arrival. These "B"

blocks were made under the supervision of an engineer of the Reclamation Service, and the following information is taken from his report.

Aggregate was taken from a supply on hand for use in construction of the power house and miscellaneous structures in connection with the Outlook irrigation district. The pit-run material was passed over a one-fourth-inch screen and separated into divisions of sand and gravel. Lehigh brand Portland cement was used. Mixing water was taken from the Sunnyside Canal.

All materials were measured in a carefully calibrated measuring box and mixed by hand. Six blocks were molded and the four most free from defects were installed.

The "A" blocks from Denver and the "B" blocks made on the project (Table 21) were installed on the east side of a small isolated pond situated south of the Oregon-Washington Railroad & Navigation Co. tracks in the west half of the northwest quarter of the southwest quarter of section 7, near Sunnyside, Wash.

Following is a tabulated list of the blocks installed near Sunnyside in 1915.

TABLE 21

[All blocks molded in smooth wood forms. Proportions by volume]

Block No.	1:1.5:3		Block No.	1:2.5:5	
	Molded	Installed		Molded	Installed
a 21	Aug. 10	Oct. 26.	a 52	Aug. 9	Oct. 26.
a 22	...do.....	Do.	a 53	...do.....	Do.
b 3S	Sept. 20	Do.	b 1S	Sept. 20	Do.
b 4S	...do.....	Do.	b 2S	...do.....	Do.

a "A" series. b "B" series.

NOTE.—Following is a list of defects noted in the blocks before installation: Block 21, small piece broken off lower corner 2. Block 22, small piece broken off lower corner 2. Block 52, small pieces broken off of lower corners 2 and 3; small patch on corner 1, 1 inch below top. Block 53, lower corner 3 broken off; small piece out 11 inches below top on corner 2. Block 1S, lower corner 2 broken off; small piece broken off corner 1, 1 inch below top. Block 2S, defect in corner 1, 12 inches below top. Block 3S, small defects 7 inches and 11 inches below top in corner 4 and 6 inches below top in corner 3; lower corner 1 broken off; number of small defects on corner 2. Block 4S, top corner 2 broken off; lower edge of 1-2 and lower corners 2 and 3 shelled off to within 10 inches of the top.

6. TRUCKEE-CARSON PROJECT, NEV.

"B" SPECIMENS

GRAVEL.—Gravel was secured from near the Lahonton Dam and was similar to that used in the construction of the dam.

SAND.—Sand was secured from a pit at the Fallon City pumping station.

CEMENT.—Golden Gate Portland cement from stock was used.

MIXING WATER.—Water was pumped from a cistern at the old United States Reclamation Service headquarters, 1 mile from Fallon.

"C" SPECIMENS

All materials were the same as were used in the manufacture of the "B" blocks.

"B" SPECIMENS

The "B" blocks were made in the yard at the old Reclamation Service headquarters, about 1 mile west of Fallon, Nev. Materials were mixed on a large mixing board in a manner similar to that used on the Belle Fourche project, the cement and sand being mixed dry, the gravel added, and the mass remixed and then given a final mixing after the addition of water. After molding the blocks were covered with wet bags to reduce evaporation.

"C" SPECIMENS

Materials and tools for use in the molding of the "C" specimens were hauled to the site of installation and the blocks were molded with the forms in place in the soil, the methods of molding being the same as for the "B" blocks.

All blocks (Table 22) were placed in a bend of the drainage ditch at the southeast corner of the United States Department of Agriculture experiment farm, which is south of Fallon, Nev. The blocks were placed in a curved line near the water's edge. At the time the blocks were installed there was a considerable flow of seepage water in the ditch. Fig. 61 shows the blocks after installation.

Following is a tabulation of the blocks installed near Fallon, Nev., in 1915:

TABLE 22

[All blocks were molded in smooth wood forms. Proportions by volume]

Block No.	1:1.5:3		Block No.	1:2.5:5	
	Molded	Installed		Molded	Installed
[a] 27	Aug. 11	Oct. 9.	[a] 58	Aug. 11	Oct. 9.
[a] 28	...do.....	Do.	[a] 59	...do.....	Do.
[b] 137	Oct. 8	After 28 days.	[b] 140	Oct. 8	After 28 days.
[b] 138	...do.....	Do.	[b] 141	...do.....	Do.
[b] 139	...do.....	Reference.	[b] 142	...do.....	Reference.
[c] 237	Oct. 9	In place.	[c] 240	Oct. 9	In place.
[c] 238	...do.....	Do.	[c] 241	...do.....	Do.

[a] "A" series. [b] "B" series. [c] "C" series.

7. RIO GRANDE PROJECT

"B" SPECIMENS

GRAVEL AND SAND.—Pit-run material was screened at the pit on a one-fourth-inch rotary screen. This material was at that time being used in the construction of the Mesilla Diversion Dam across the Rio Grande River near Mesilla Park, N. Mex.

CEMENT.—El Toro brand Portland cement from the stock being used in the construction of the Mesilla Diversion Dam was used.

MIXING WATER.—Water was secured from the Rio Grande.

"C" SPECIMENS

The same cement and aggregate was hauled to the site of installation and used in the manufacture of the "C" specimens.

WATER.—Mixing water was obtained from a pool in the canal near the site. There was no flow in the canal at the time, but water from the river had passed through a few days previous.

"B" SPECIMENS

Concrete was mixed in a one-half cubic yard Koehring batch mixer. Enough material was weighed out for each batch to mold all the blocks and cubes desired of each proportion. The blocks were molded in the same manner as described at the Belle Fourche project.

"C" SPECIMENS

Concrete for the "C" blocks was mixed by hand at the site of installation. Large batches were prepared, enough material being mixed in each batch for all the blocks of that proportion. The method of mixing was similar to that used on the Belle Fourche project and Truckee-Carson project, the cement and sand being first mixed before the addition of the gravel.

All blocks (Table 23) were installed in a borrow pit on the lower side of the large irrigation canal about 200 yards east of Mesquite, N. Mex. The particular spot selected lies between two deeper pits which contained water at the time the blocks were installed. The site was dry on the surface but was covered with a thick coating of white salts. The canal had just been completed and had carried water for a few days, after which the flow was stopped, so that the alkali conditions just below the canal may be expected to become worse for sometime after the canal is put into service.

Following is a tabulation of the blocks installed on the Rio Grande project near Mesquite, N. Mex., during 1915:

TABLE 23

[All blocks were molded in smooth wood forms. Proportions by volume]

Block No.	1:1.5:3		Block No.	1:2.5:5	
	Molded	Installed		Molded	Installed
[a] 23	Aug. 11	Oct. 23.	[a] 54	Aug. 12	Aug. 23.
[a] 24	...do.....	Do.	[a] 55	...do.....	Do.
[b] 143	Oct. 23	After 28 days.	[b] 146	Oct. 22	After 28 days.
[b] 144	...do.....	Do.	[b] 147	...do.....	Do.
[b] 145	...do.....	Reference.	[b] 148	...do.....	Reference.
[c] 243	...do.....	In place.	[c] 246	...do.....	In place.
[c] 244	...do.....	Do.	[c] 247	...do.....	Do.
[c] 245	...do.....	Reference.	[c] 248	...do.....	Reference.

[a] "A" series. [b] "B" series. [c] "C" series.

NOTE.—The following defects were noted in the "A" series blocks before installation: Block 23, corners rough, with corner 4 somewhat shelly at bottom. Block 24, rough surfaces on upper portion of block due to air pockets. Block 54, corners are rough with some sand grains showing. Block 55, corner 1 rough; small patch on corner 3; small section of corner 3 shelly; many air pockets in surfaces 4-1 and 3-4.

8. UNCOMPAHGRE VALLEY PROJECT, COLO.

"B" SPECIMENS

SAND AND GRAVEL.—Gravel previously dredged from the river channel at the head gate of the Montrose and Delta Canal was passed over a screen with openings slightly larger than one-fourth inch.

CEMENT.—Iola brand Portland cement from stock was used in most of the blocks. Ideal brand Portland cement was used in the blocks noted later.

MIXING WATER.—Water was obtained from the Montrose and Delta Canal just below the head gate.

"C" SPECIMENS

The above materials were also used in the "C" blocks, except that mixing water was obtained from the South Canal near milepost 5.

"B" AND "C" SPECIMENS

Batches of materials sufficient for one block and two cubes were mixed by shovel in a large mortar box, all quantities being weighed. The "B" series blocks were molded near the gravel supply at the head gate of the Montrose and Delta Canal and allowed to remain there until curing was completed. Material for the "C" blocks was hauled to the site where the concrete was mixed and molded.

The blocks (Table 24) were installed in a borrow pit in seeped ground about 8 miles south of Montrose, Colo., on the lower side of the South Canal near milepost 5 and just 1 mile above the tile drain which was placed on this project in 1913. During the summer there is considerable water standing in the pit, which will insure the blocks being wet at least a portion of the year. Following is a tabulation of the blocks installed on the Uncompahgre project in 1915:

TABLE 24

[All blocks were molded in smooth wood forms. Proportions by volume]

Block No.	1:1.5:3		Block No.	1:2.5:5	
	Molded	Installed		Molded	Installed
[a] 25	Aug. 11	Sept. 30.	[a] 56	Aug. 12	Sept. 30.
[a] 26	...do.....	Do.	[a] 57	...do.....	Do.
[b,c] 125	Sept. 29	After 28 days.	[b] 128	Sept. 29	After 28 days.
[b] 126	...do.....	Do.	[b] 129	...do.....	Do.
[b,c] 127	...do.....	Reference.	[b] 130	...do.....	Reference.
[d] 225	Sept. 30	In place.	[d] 228	Sept. 30	In place.
[d] 226	...do.....	Do.	[d] 229	...do.....	Do.
[d] 227	...do.....	Reference.	[d] 230	...do.....	Reference.

[a] "A" series.
[b] "B" series.
[c] Ideal brand Portland cement used.
[d] "C" series.

NOTE.—The following defects were noted in the "A" series blocks before installation: Block 25, small piece broken out of corner 3, 1 inch above bottom; sand grains show in corners. Block 26, good condition. Block 56, corner 2 rough; corner 3 had small pieces broken out at top and bottom. Block 57, corners rough; air pockets in side 2–1.

9. GRAND VALLEY PROJECT, COLO.

"B" SPECIMENS

SAND AND GRAVEL.—In 1915 river gravel containing rather fine sand and gravel up to 3 inches was separated on the one-fourth-inch screen.

In 1916 sand and gravel of the same appearance was used in molding the blocks. This material was taken from a storage supply of about 3000 yards.

CEMENT.—Iola brand cement obtained from the stock house at the diversion dam was used in the blocks in 1915 and 1916.

MIXING WATER.—Water from the Grand River was obtained from the Price irrigation ditch for the 1915 blocks. In 1916 water was obtained from the main canal of the Grand Valley project.

FORMS.—Made of 2-inch creosoted lumber.

"C" SPECIMENS

In 1915 the same materials were used for both the "B" and "C" specimens.

NATURAL-CEMENT SPECIMENS

All material was the same as the above except that natural cement from a mill in the middle west, the same as was used at Denver, was used in these blocks.

In 1915 concrete was mixed by shovels in a large mortar box, the material being weighed in batches sufficient to mold one block and two cubes. A mushy consistency was used. Since the "B" and "C" specimens were in every way similar, except for exposure to the alkali immediately after molding, two reference specimens were omitted. The natural-cement blocks were molded on the bank above ground, similar to those of the "B" series.

Following is a tabulation of the blocks installed on the Grand Valley project near Clifton, Colo., in 1915.

TABLE 25

[Proportions by volume]

Block No.	1:1.5:3			Block No.	1:2.5:5		
	Type of form	Molded	Installed		Type of form	Molded	Installed
[a] 13	Smooth wood	Aug. 11	Oct. 4.	[a] 44	Smooth wood	Aug. 12	Oct. 4.
[a] 14	do	do	Do.	[a] 45	do	do	Do.
[a] 15	Metal lined	do	Do.	[a] 46	Rough wood	Aug. 13	Do.
[a] 16	do	do	Do.	[a] 47	do	do	Do.
[a] 17	Rough wood	do	Do.	[a] 48	Metal lined	Aug. 9	Do.
[a] 18	do	do	Do.	[a] 49	do	do	Do.
[b] 63	Smooth wood	Aug. 12	Do.	[b] 65	Smooth wood	Aug. 13	Do.
[b] 64	do	do	Do.	[b] 66	do	do	Do.
[c] 131	do	Oct. 4	Nov. 16.	[c] 134	do	Oct. 4	Nov. 16.
[c] 132	do	do	Do.	[c] 135	do	do	Do.
[c] 133	do	do	Reference.	[c] 136	do	do	Reference.
[d] 67	do	do	Nov. 16.	[d] 69	do	do	([e])
[d] 68	do	do	Do.	[d] 70	do	do	([f])
[g] 231	do	do	In place.	[g] 234	do	do	In place.
[g] 232	do	do	Do.	[g] 235	do	do	Do.

[a] "A" series (Portland cement).
[b] "A" series (sand cement).
[c] "B" series (Portland cement).
[d] "B" series (natural cement).
[e] Broken in two pieces in removing form Oct. 8, 1915. Piece held for reference sample.
[f] Fell to pieces Nov. 16, 1915, when carried by handle.
[g] "C" series (Portland cement).

NOTE.—The following defects were noted in the "A" series blocks before installation: Block 13, two small pieces broken out of corner 2. Block 14, good condition. Block 15, good condition; bottom edges rough. Block 16, good condition; bottom edges rough. Block 17, good condition. Block 18, good condition. Block 44, corner 3 rough with some stones showing; lower corner 4 broken off. Block 45, bottom corners rough with stones showing. Block 46, corners rough. Block 47, some stones show in lower corners. Block 48, good condition. Block 49, good condition. Block 63, good condition. Block 64, corner 3 shelly; patch in surface 2–3 badly hair cracked; corner 1 rough near top. Block 65, corners 1, 2, and 4 rough with small pieces broken out; bottom corners broken off; many stones show. Block 66, not sufficient water used in molding; very porous, rough appearance in lower section.

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In 1916 the blocks were molded in the same manner as in 1915 except that the materials were measured rather than weighed. A mushy consistency was used.

The blocks (Table 25) were installed on the Grand Valley project in a borrow pit just below the new main canal, 1 mile northwest of Clifton, Colo. A few days previous to placing the blocks in 1915 water had been turned into the canal for the first time, and seepage through the shale had brought large quantities of alkali salts to the surface of the ground on the lower side of the canal. The surface of the site was rather dry and covered with a heavy deposit of white salts, but the earth below the surface was moist. Later, after installation of the blocks had been completed, water was again turned into the canal and the blocks were surrounded with several inches of seepage water.

In 1916 the following blocks were installed on the Grand Valley project.

[Creosoted smooth wood molds were used. Proportion by volume]

Block No.	1:1.5:3		Block No.	1:2.5:5	
	Molded	Installed		Molded	Installed
[a] 303	Oct. 23	After 28 days.	305	Oct. 23	After 28 days.
304	...do.....	Do.	306	...do.....	Do.

[a] Consistency slightly drier than mushy.

IX. PHYSICAL AND CHEMICAL TESTS OF CEMENTS AND AGGREGATES USED IN THE CONCRETES

Samples of contents and aggregates were taken from materials used in the manufacture of concrete blocks on each project and shipped to the Bureau for test.

Complete physical and chemical tests were made on all samples of cement and tensile and compressive strength tests were made of all sands, using the same brand of cement with all. In a like manner absorption tests were made. The results of these various tests are given in the following tables.

In Table 26 is given a list of the cements used in the concrete-block investigation during 1915, which will serve to identify the results of tests in Tables 27 and 28.

In Table 27 will be found the results of chemical analyses of all the cements. The high results given for "loss" for several of the cements is probably due to age of the cement and the considerable time which elapsed between sampling and testing. The cements

used on the various projects were taken usually from the storage warehouses and had been in stock for varying periods, as long as a year in the case of cement No. 104. The samples were shipped to the Bureau in cloth bags containing about 8 pounds each and were not tested until about six months after arrival in the laboratory.

The physical tests of the same cements are shown in Table 28. The low values obtained in some cements for specific gravity and tensile strength may be at least partially explained by the above statement of length of storage.

A complete list of the sands and gravels, together with the projects on which they were used, is given in Table 29.

In table 30 are shown the granular analyses of the sands used in the manufacture of the concrete blocks. The samples each weighed about 100 pounds, from which the required portion was taken for the sieving tests. On most of the projects the aggregate was obtained in the form of pit-run material and screened through approximately one-quarter-inch mesh screens before using in concrete.

The granular analyses of the gravels are given in Table 31.

In Table 32 are shown the results of tensile and compressive tests made in the laboratory, using the various sands combined with the same brand of cement, with results of the same cement with standard Ottawa sand for comparison. All results shown are the average of three test pieces of either 20-inch cubes or briquettes made of one part cement and three parts sand.

The results of absorption tests of mortars made of the various sands are shown in Table 33.

TABLE 26

List of Cements Used in Concrete-Block Investigation, 1915

Cement No.	Brand	Where used	Cement No.	Brand	Where used
101	Iola	Denver, Colo.	107	El Toro (Portland)	Rio Grande, N. Mex.-Tex.
102	Natural cement	Grand Valley, Colo.			
103	Elephant Butte sand cement.	Denver, Colo.	108	do	Do.
			109	Ideal (Portland)	Uncompahgre Valley, Colo.
104	Lehigh (Portland)	Belle Fourche, S. Dak.[a]			
105	Red Devil (Portland).	Sun River, Mont.	110	Iola (Portland)	Grand Valley, Colo.
			111	Tidewater (Portland).	Bureau of Standards, Washington, D. C.[b]
106	Golden Gate (Portland).	Truckee-Carson, Nev.			

[a] In storage one year. [b] In tests of sands from projects.

TABLE 27

Chemical Analyses of Cements Used in Concrete-Block Investigation, 1915

Cement No.[a]	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Loss	Insoluble residue
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
101	20.22	3.77	6.35	60.10	2.28	1.46	4.67	0.06
102	19.56	3.60	4.36	44.60	12.00	1.53	7.40	7.20
103	13.26	1.95	4.85	33.90	1.04	.87	3.50	40.88
104	21.42	2.47	6.93	59.90	2.68	1.41	3.88	.11
105	22.86	1.70	6.04	61.60	1.24	1.24	4.03	.50
106	21.28	2.85	6.89	61.20	1.04	1.39	3.99	.18
107	22.76	3.00	6.26	63.00	1.64	1.17	1.51	.08
108	22.88	3.02	6.14	62.00	1.68	2.14	2.04	.31
109	21.10	3.85	5.85	63.20	2.40	1.55	2.81	.15
110	20.80	3.87	6.73	61.00	2.16	1.57	2.73	.05
111	.....	.....	.....	.....	2.16	1.59	1.71	.14

[a] See Table 26 for brand and project where used.

TABLE 28

Physical Tests of Cements Used in Concrete Investigation, 1915

Cement No.	Specific gravity	Fineness passing sieves		Soundness	Time setting		Water	Tensile strength (average of 3 briquettes)				
								Neat		Water	Sand	
		100 mesh	200 mesh		Initial	Final		7 days	28 days		7 days	28 days
		Per ct.	Per ct.		h. m.	h. m.	Per ct.			Per ct.		
101	3.10	95.3	81.0	O. K.	2 22	7 42	26.0	484	656	10.8	317	352
102	3.05	86.8	79.0	O. K.	3 11	7 41	40.0	60	194	13.3	55	84
103	2.85	98.2	85.9	O. K.	3 38	7 48	22.0	258	431	10.2	96	189
104	3.10	92.1	78.1	O. K.	3 37	7 52	25.0	539	654	10.7	208	364
105	3.08	95.8	84.5	O. K.	2 15	7 35	24.5	520	621	10.5	188	302
106	3.08	96.8	84.6	O. K.	2 48	7 48	23.0	617	834	10.3	245	395
107	3.19	94.6	79.7	O. K.	2 54	7 19	23.0	774	860	10.3	274	303
108	3.18	94.6	80.5	O. K.	3 51	7 21	22.0	763	855	10.2	259	393
109	3.16	94.9	80.0	O. K.	3 35	7 45	24.0	600	908	10.5	228	373
110	3.15	95.1	80.3	O. K.	4 00	7 30	23.0	775	965	10.3	252	425
111	3.22	95.2	78.6	O. K.	4 20	8 05	22.0	610	809	10.2	243	303

TABLE 29

List of Aggregates Used in Concrete Blocks and in Laboratory Tests

Sample No.	Weight per cubic foot	Aggregate	From—	Sample No.	Weight per cubic foot	Aggregate	From—
	Pounds	1915			Pounds	1915	
200	.....	Sand, standard Ottawa.	Used in laboratory tests.	206	87	Sand.....	Rio Grande, N. Mex.-Tex.
201	85	Sand.....	Belle Fourche, S. Dak.	305	103	Gravel.....	Do.
301	100	Gravel.....	Do.	207	77	Sand.....	Uncompahgre Valley, Colo.
401	.....	Pit-run gravel.	Do.	306	103	Gravel.....	Do.
202	85	Sand.....	Shoshore, Wyo. ("B" blocks).	402	.....	Pit-run gravel.	Do.
203	107	.....do.....	Shoshone, Wyo. ("C" blocks).	208	90	Sand.....	Grand Valley, Colo.
302	105	Gravel.....	Shoshone, Wyo.	307	106	Gravel.....	Do.
204	90	Sand.....	Sun River, Mont.	209	97	Sand.....	Denver, Colo.
303	104	Gravel.....	Do.	308	105	Gravel.....	Do.
205	81	Sand.....	Truckee - Carson, Nev.			1916	
304	93	Gravel.....	Do.	210	81	Sand.....	Belle Fourche, S. Dak.
				211	102	.....do.....	Grand Valley, Colo.

TABLE 30

Granular Analyses of Sands Used in Concrete Investigation

Mesh No.....		3	4	6	8	10	14	20	28	35	48	65	100
Opening, inch.....		0.263	0.185	0.131	0.093	0.065	0.046	0.0328	0.0232	0.0164	0.0116	0.0082	0.0058
Project	Aggregate No.	Per cent passing sieves											
1915													
Belle Fourche, S. Dak.....	201	100.0	100.0	100.0	100.0	98.9	95.8	89.8	78.8	64.6	43.5	27.1	13.6
.....do.....	[a]401	100.0	95.5	87.4	80.9	74.7	68.8	61.1	51.0	41.0	28.6	18.9	9.6
Shoshone, Wyo....	202	100.0	100.0	99.9	99.2	98.1	96.4	90.6	72.3	39.3	13.1	5.4	1.5
.....do.....	203	99.8	97.9	91.6	83.8	76.8	71.6	65.6	55.7	43.5	28.1	18.1	10.0
Sun River, Mont.	204	100.0	99.5	94.7	87.8	80.0	72.8	64.1	51.4	34.4	18.0	10.7	5.7
Truckee - Carson, Nev.....	205	99.5	98.7	98.1	96.1	91.1	83.5	70.1	50.6	32.6	18.9	12.4	5.5
Rio Grande, N. Mex.-Tex.....	206	99.1	96.7	86.3	78.0	71.2	66.2	61.1	52.7	37.0	18.4	8.9	3.4
Uncompahgre Valley, Colo.....	207	100.0	98.7	94.5	90.8	87.9	85.8	83.3	77.6	67.1	45.0	26.9	13.4
.....do.....	[a]402	100.0	93.5	85.4	79.5	75.3	72.5	69.2	63.5	53.0	33.5	18.2	8.1
Grand Valley, Colo.	208	100.0	96.5	92.5	89.7	87.2	85.0	81.4	70.4	50.4	32.2	21.8	12.6
Denver, Colo.....	209	100.0	99.5	92.8	79.6	63.5	51.7	40.1	29.1	20.1	11.3	6.0	3.2
1916													
Belle Fourche, S. Dak.....	210	100.0	99.3	97.0	92.3	85.6	78.8	69.7	58.2	46.2	30.4	21.0	10.5
Grand Valley, Colo.	211	90.7	84.6	79.6	76.2	73.0	70.6	68.0	61.4	47.8	34.0	21.8	11.0

[a] Portion of pit-run gravel below one-fourth inch in size, separated in the laboratory from pit-run material.

TABLE 31

Mechanical Analyses of Gravels Used in Concrete Investigation

Project	Aggregate No.	Screen openings in inches					
		2	1½	1	¾	½	¼
		Per cent passing screens					
1915							
Belle Fourche, S. Dak	301	97.75	90.50	66.50	55.00	40.00	20.00
Do	401	86.12	80.98	75.60	69.60	62.23	51.23
Shoshone, Wyo	302	100.00	100.00	65.00	42.50	22.50	2.50
Sun River, Mont	303	100.00	93.40	78.50	66.00	39.20	8.47
Truckee-Carson, Nev	304	87.50	76.75	53.75	42.75	22.25	6.25
Rio Grande, N. Mex.-Tex	305	88.25	67.00	42.75	28.50	11.50	0.00
Uncompahgre Valley, Colo	306	94.00	83.75	63.75	45.75	25.75	2.25
Do	402	99.13	97.02	85.75	78.50	65.50	50.00
Grand Valley, Colo	307	85.19	63.19	30.57	16.07	4.57	0.39
Denver, Colo	308	100.00	100.00	90.00	69.75	43.75	7.37

TABLE 32

Tensile and Compressive Strength Results of Mortars Made From Sands Used in Concrete Investigation

[Compression-test pieces, 2-inch cubes. Proportions, 1 part cement No. 111 [a] to 3 parts sand. All results average of three tests]

Project	Aggregate No.	Per cent water	Tensile strength (pounds per square inch)		Compressive strength (pounds per square inch)	
			7 days	28 days	7 days	28 days
1915						
Ottawa sand	200	10.2	213	267	1491	2142
Belle Fourche, S. Dak	201	16.0	202	282	1375	2316
Shoshone, Wyo	202	13.5	183	228	1002	1756
Do	203	13.0	233	363	1630	2610
Sun River, Mont	204	13.0	318	400	2120	3900
Truckee-Carson, Nev	205	13.0	213	280	1342	2720
Rio Grande, N. Mex.-Tex	206	13.0	238	340	1780	2690
Uncompahgre Valley, Colo	207	15.0	217	348	981	1796
Grand Valley, Colo	208	14.0	193	320	1345	2030
Denver, Colo	209	12.0	238	288	1730	3740
1916 [a]						
Belle Fourche, S. Dak	210	11.5	288	420	2278	3333
Grand Valley, Colo	211	13.0	298	393	1975	2750
Ottawa sand	212	10.2	255	362	1930	2866

[a] Another lot of cement of the same brand was used in 1916.

TABLE 33

Absorption Tests of Mortars Made from Sands, Concrete-Block Investigation

[Proportions, 1 part cement, 3 parts sand. Test pieces, 2-inch cubes. Average of three tests]

Project	Aggregate No.	Average percentage absorption	Project	Aggregate No.	Average percentage absorption
1915			Rio Grande, N.-Mex.-Tex.	206	9.3
Standard sand	200	7.3	Uncompahgre Valley, Colo.	207	13.0
Belle Fourche, S. Dak.	201	13.4	Grand Valley, Colo.	208	11.3
Shoshone, Wyo.	202	10.4	Denver, Colo.	209	8.3
Do.	203	9.9	1916		
Sun River, Mont.	204	10.0	Belle Fourche, S. Dak.	[a] 210	9.6
Truckee-Carson, Nev.	205	9.7	Grand Valley, Colo.	211	11.7

[a] The sand was similar to 201 except that it was thoroughly washed before using in molding the 1916 blocks on the Belle Fourche project.

X. CHEMICAL ANALYSES OF ALKALIES, SOILS, AND WATERS MADE IN CONNECTION WITH THE CONCRETE INVESTIGATION

Analyses of mixing waters used in the manufacture of the 1915 concrete blocks are shown in Table 34.

TABLE 34

Analyses of Mixing Waters Used in the Manufacture of Concrete Blocks, Fall of 1915

Project	Block series	Source	Percentage soluble solids in water	Composition of soluble solids in per cent					
				Na	Ca	Mg	Cl	SO_4	CO_3
Belle Fourche, S. Dak.	B+C	Belle Fourche Lake.	0.08	4.1	19.4	5.5	0.6	61.3	9.1
Shoshone, Wyo.	C	Ralston Reservoir.	.04	9.1	26.4	.....	1.8	29.1	33.6
Sun River, Mont.	C	Irrigation ditch	.05	15.1	11.7	5.2	14.1	35.7	18.2
Yakima (Sunnyside), Wash.	B	Sunnyside Canal	.05	3.8	19.7	7.8	5.7	36.6	26.4
Truckee-Carson, Nev.	B+C	Cistern	.11	12.5	19.2	3.5	14.5	31.1	19.2
Rio Grande, N. Mex.-Tex.	B	Rio Grande	.04	13.6	15.2	3.9	12.6	36.8	17.9
Do.	C	Canal	.05	14.8	14.6	3.4	9.6	43.1	14.5
Uncompahgre Valley, Colo.	B	M. and D. Canal	.03	2.9	21.8	6.0	1.7	46.8	20.8
Do.	C	South Canal	.01	3.0	22.0	8.3	3.8	22.0	40.9
Grand Valley, Colo.	B+C	Price ditch	.09	24.4	10.8	.....	15.9	43.0	5.9

In Table 35 are shown the results of chemical analyses of alkalies taken from the surface of the ground at the sites of installation of the concrete blocks manufactured in 1915.

The results of analyses of soils taken at a depth of about 1 foot below the surface of the ground at the sites of installation are given in Table 36.

Analyses of seepage waters from the surface on or near the sites are shown in Table 37.

TABLE 35

Analyses of Alkalies from Surface of Ground at Sites of Concrete Blocks, Fall of 1915

Project	Composition of soluble solids in per cent					
	Na	Ca	Mg	Cl	SO_4	CO_3
Belle Fourche, S. Dak	16.8	2.1	8.6	0.5	71.6	0.4
Sun River, Mont	23.9	2.2	3.9	.8	69.0	.2
Yakima (Sunnyside), Wash	34.9	.2	.....	7.0	49.9	8.0
Truckee-Carson, Nev., No. 1	38.7	.1	.....	9.6	30.6	21.0
Truckee-Carson, Nev., No. 2	36.4	.1	.....	10.8	40.8	11.9
Rio Grande, N. Mex.-Tex	29.7	2.8	.1	4.6	62.6	.2
Grand Valley, Colo	28.7	2.1	1.5	.8	66.8	.1

TABLE 36

Analyses of Soils from Sites of Concrete Blocks, Fall of 1915

Project	Percentage water-soluble solids in soil	Composition of soluble solids in per cent					
		Na	Ca	Mg	Cl	SO_4	CO_3
Belle Fourche, S. Dak	1.93	13.2	10.9	5.1	0.8	64.9	5.1
Sun River, Mont	1.52	9.1	19.2	1.6	1.4	68.4	.3
Yakima (Sunnyside), Wash	.23	13.4	14.9	4.0	.3	61.6	5.8
Rio Grande, N. Mex.-Tex	.55	21.7	10.6	.6	5.1	61.2	.8
Uncompahgre Valley, Colo	2.39	17.0	11.4	2.5	.7	67.5	.9
Grand Valley, Colo	7.46	8.5	18.3	1.8	1.3	68.2	1.8

TABLE 37

Analyses of Seepage Water from Sites of Concrete Blocks, Fall 1915 to Fall 1916, Inclusive

Project and year	Percentage soluble solids in water	Composition of soluble solids in per cent					
		Na	Ca	Mg	Cl	SO_4	CO_3
Belle Fourche, S. Dak.:							
Fall, 1915	1.46	17.4	2.3	8.1	0.6	70.1	1.3
Spring, 1916	.93	16.4	5.8	6.8	.1	66.8	4.2
Fall, 1916	1.36	17.0	2.8	8.2	.5	69.3	2.2
Shoshone, Wyo.:							
Fall, 1915	.81	29.4	1.3	1.2	3.6	60.2	4.3
Spring, 1916	.70	28.2	2.3	1.6	3.5	59.7	4.6
Fall, 1916	.67	29.1	2.6	1.6	4.1	56.6	6.0
Sun River, Mont.:							
Fall, 1915	.40	24.1	1.4	3.9	2.1	67.8	.7
Spring, 1916	.95	22.2	3.9	3.6	1.8	67.4	1.1
Fall, 1916	2.45	23.7	1.6	4.5	1.5	67.9	.8
Yakima, Wash.:							
Fall, 1915	.22	14.8	9.2	6.5	9.3	55.9	4.3
Spring, 1916	.22	21.1	4.3	5.2	6.7	60.2	2.5
Fall, 1916	.23	18.9	4.2	6.2	9.4	57.1	4.2
Fall, 1916 [a]	.19	35.2	.3	.4	5.0	44.3	14.8
Truckee-Carson, Nev.:							
Fall, 1915	.13	34.3	1.6	1.1	10.1	35.3	17.6
Spring, 1916	.13	34.2	1.3	.5	9.8	33.9	20.3
Fall, 1916	.12	34.4	1.7	.4	11.0	34.8	17.7
Rio Grande, N. Mex.-Tex.:							
Fall, 1916	.86	30.5	3.4	.5	22.2	42.6	.8
Spring, 1916	3.02	31.0	2.3	.8	15.8	49.6	.5
Fall, 1916	2.64	30.7	2.5	1.2	26.1	38.9	.6
Uncompahgre Valley, Colo.:							
Fall, 1915	1.61	20.2	2.5	5.4	.8	69.8	1.3
Spring, 1916	1.08	20.7	4.2	5.0	.7	67.4	2.0
Fall, 1916	1.78	19.6	3.3	5.9	.7	69.9	.6
Grand Valley, Colo.:							
Spring, 1916	2.51	27.3	1.9	2.7	2.1	65.5	.5
Fall, 1916 [b]	.32	20.6	9.6	1.0	.8	66.6	1.4

[a] Seepage water from new site for blocks above new lake level. Other samples taken from lake.
[b] Taken from depression in ground. Probably is surface water, as no seepage water could be obtained by making deep excavation near by.

XI. CONDITION OF CONCRETE—RESULTS OF INSPECTION IN SEPTEMBER-OCTOBER, 1916

An inspection of the concrete blocks installed in 1915 was made in September and October, 1916, at which time the following conditions were noted:

Concrete blocks made of selected aggregates in the proportion by volume 1:1.5:3 and 1:2.5:5 ("A" series blocks molded at Denver) were unaffected except on the Sun River and Grand Valley

projects. The two blocks of the proportion 1:2.5:5 on the Sun River project showed slight scaling and pitting on the surfaces for a height of 2 inches above the ground line. Two blocks of the same proportion made in steel-lined molds and exposed on the Grand Valley project were also slightly scaled and pitted for a height of 6 inches above the ground line.

Concrete blocks made of local aggregates on each project in the proportions of 1:1.5:3 and 1:2.5:5, molded at a convenient place on the project and cured for one month before being placed in the alkali soil ("B" series), as described on pages 69 to 80, were affected as follows:

Belle Fourche, S. Dak., Project.—All blocks proportions 1:1.5:3 and 1:2.5:5 were partially disintegrated at and above the ground line.

Sun River, Mont., Project.—Two blocks, proportion 1:2.5:5, were surface scaled and pitted for a height of 2 inches.

Rio Grande, N. Mex.-Tex., Project.—All blocks of this series, proportions 1:1.5:3 and 1:2.5:5, were slightly scaled and pitted just above the ground line.

Uncompahgre Valley, Colo., Project.—The blocks of both proportions were slightly scaled and pitted up to within 2 inches of the tops.

Grand Valley, Colo., Project.—The surfaces of the blocks of the leaner mixture 1:2.5:5 were disintegrated to a depth of one-half inch just above the ground line.

All blocks of this series installed on the Shoshone, Yakima, and Truckee-Carson projects were apparently unaffected.

Concrete blocks made with the same local aggregates and in the same proportions, 1:1.5:3 and 1:2.5:5, similar to the above blocks except that they were molded in place in the alkali soil ("C" series blocks), as described on pages 69 to 80, were affected as follows:

Belle Fourche, S. Dak., Project.—The two blocks of the proportion 1:1.5:3 were slightly scaled and pitted just above the ground line. The blocks of the 1:2.5:5 proportion were disintegrated for a depth of 2 inches at the ground line. The concrete was soft at the ground surface.

Shoshone, Wyo., Project.—One block of the proportion 1:1.5:3 was slightly scaled and pitted. Both blocks of the 1:2.5:5 were in the same condition.

SUN RIVER, MONT., PROJECT.—The two 1:2.5:5 proportion blocks were slightly scaled on one surface just above the ground line.

UNCOMPAHGRE VALLEY, COLO., PROJECT.—The two 1:2.5:5-proportion blocks were scaled and pitted to within 2 inches of the top of the blocks.

The blocks of this series were unaffected on the Truckee-Carson and Grand Valley projects.

XII. SUMMARY OF RESULTS

1. CONCRETE

After one year's exposure none of the 1:1.5:3-proportion blocks molded at Denver with selected aggregates (series "A") have shown signs of disintegration on any of the projects. The 1:2.5:5-proportion blocks have also been unaffected, with the exception of those installed on the Sun River and Grand Valley projects.

It is noticeable that the "C" series blocks, 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 soil after 28 days of curing, on the Belle Fourche, S. Dak.; Sun River, Mont.; Rio Grande, N. Mex.-Tex.; Uncompahgre Valley, Colo.; and Grand Valley, Colo., projects. On the Shoshone, Wyo., project the "C" series blocks were very slightly affected, while the "B" series blocks were in perfect condition.

Blocks made of sand-cement concrete molded at Denver were installed on the Grand Valley, Colo., project. The two 1:1.5:3-proportion blocks were scaled and pitted for a distance of 6 inches above the ground surface, while one block of the proportion 1:2.5:5 was disintegrated to a depth of 1 inch. The second 1:2.5:5-proportion sand-cement block, made of such a dry consistency that rough surfaces and corners resulted in molding, was unaffected by the alkali.

Natural-cement blocks, of the proportion of 1:1.5:3, were molded on the Grand Valley project in a manner similar to the "B" series blocks. These blocks were entirely disintegrated three months after being installed.

2. DRAINTILE

Reference to Table 38 shows the disintegrating effect of alkali on the experimental tile varied directly with the concentration of salts in the waters. Attention is called to the fact that all of these

waters contained over 21 per cent (12.5 per cent reacting value) of sulfates.

The disintegrating effect seems to be directly proportional to the total quantity of sulfate and magnesium.

The tile exposed to waters containing the larger percentages of carbonates have shown less indication of disintegration. However, these waters having the higher content of carbonates also have the lower concentration of salts, so that it can not be stated definitely that the presence of the carbonates are a factor.

The concentration of salts in the soil is not necessarily an indication of the concentration of salts in the seepage water, as shown by reference to Figs. 45 and 46, although the character of the salts are similar.

TABLE 38[a]

Drain-Tile Investigation—Projects Grouped According to the Percentage Reacting Values of the Various Bases and Acids, Percentage Concentration, Average Results of Crushing Tests, and Number of Series Affected by Alkali

	Per cent sodium	Per cent calcium	Per cent magnesium	Per cent chlorine	Per cent sulphate	Per cent carbonate	Per cent concentration
Garland, Wyo	32.0	H...20.1	M...25.0	R....27.1	M...46.0	Y....21.7	G. J.0.85
Fort Shaw, Mont	30.6	R....19.4	G. J.14.0	G. J.17.7	H...40.8	F. S.14.2	M...0.50
Grand Junction, Colo.	25.9	Y....16.3	F. S.12.8	Y....15.4	G...40.6	H... 7.4	R....0.46
Sunnyside, Wash	24.7	M...15.8	H...11.6	S.... 6.1	S....38.1	G... 6.2	S....0.40
Roswell, N. Mex	23.9	S....14.0	S....11.3	G... 3.2	F. S.34.2	S.... 5.8	G...0.33
Yuma, Ariz	23.5	G...10.3	Y....10.2	H... 1.8	G. J.28.7	M... 3.5	H...0.30
Huntington, Utah	18.3	G. J.10.1	G... 7.7	F. S. 1.6	R....20.0	R.... 2.9	F. S.0.20
Montrose, Colo	9.2	F. S. 6.6	R.... 6.7	M... 0.5	Y....12.9	G. J. 1.9	Y....0.11

	Grand average[b]				Number of series out of 20 affected by alkali, all years
	1914	1915	1916	1914–16	
Grand Junction, Colo	1770	G. J.1535	G. J.1800	G. J.1700	M...17
Garland, Wyo	1820	G...1715	G...1805	G...1780	G. J.16
Fort Shaw, Mont	1835	R....1725	M...1825	M...1860	R....14
Sunnyside, Wash	1840	M...1825	F. S.1885	F. S.1860	H...14
Yuma, Ariz	1860	F. S.1855	H...1935	S....1910	S....14
Montrose, Colo	1930	S....1910	Y....1970	R....1920	G...10
Huntington, Utah	1940	H...1980	S....1985	Y....1940	F. S. 8
Roswell, N. Mex	1945	Y....1985	R....2090	H...1950	Y.... 8

[a] Reacting values taken from Table 13, "Average of analyses of all waters flowing through cement tile drains, fall of 1913 to fall of 1916, inclusive." Results of strength tests taken from Table 15.

[b] Average crushing strength of series 1 to 16, inclusive.

The results of the crushing tests of tile made at Ames in 1916, together with the results of the absorption tests, are especially worthy of notice, since they show that the effect of absorbed water in the walls is to materially weaken cement tile. This reduction in strength of from 10 to 30 per cent probably accounts for many of the varying results obtained in the field, since the walls of the tile as removed from the drains contained varying amounts of water when tested. Even though all of the tile of any one series were of the same density and homogeneity, the condition of exposure alone would account for many large strength variations.

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 mix—machine made. Series 8, 12, and 16 (proportions 1:4); 7 and 11 (1:3); 9 and 10 (1:1.5); 19 and 20 (1:2.5 replacement tile).

(*b*) Plastic mix—hand made. Series 1 (1:2.5); 3, 4, 5, and 6 (1:2).

(*c*) Quaking mix—hand made. Series 2 (1:2.5); 17 (2:1.5); and 18 (1:2).

(*d*) Fluid mix—hand made. 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 experimental drains where exposed to alkali waters, and at five of the eight projects swelling, cracking, and partial disintegration has 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 swelling and cracking were observed. None of these tile are made of mixtures leaner than 1 part Portland cement to 2½ 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 beneficial effects have resulted from the addition and the use of ferrous sulfate in the mixing water of series 6 or by a coating of neat cement grout (series 4) or coating of tar (series 5). All tile of these three 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 1.5 parts sand) and 18 (1 part cement to 2 parts sand) were made on a jigging device. No salts have been found in any 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 surface. 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 2.5 parts sand, quaking consistency) are the only tile which have to date shown no disintegration nor alkali salts in the pores at any of the projects where exposed to alkali water.

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 in the pores, and in numerous cases have shown a softening of the surface at several of the projects, which action was first noticed at Montrose in 1914, when the first year's tests were made. Series 14, most nearly comparable with series 2 (group (*c*)), 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 constituent in the soil or water. The variation in the average results for each series during the past three years is less than the variation obtained at Ames in 1916 for the dry and saturated tile.

While many of the individual tile in fresh water at Columbia, Mo., showed an increase in strength over the previous year's results, the outer lower surfaces of all tile excepting series 17 to 20, which has been exposed only two years and one year, respectively, and series 5, which were tar-coated, were affected as stated on page 62. The cause and the rapidity of this action is unknown, but it is most marked on the tile of the leanest mixtures.

XIII. CONCLUSIONS

1. CONCRETE

No definite conclusions can yet be drawn as to the ultimate resistance of concrete to the action of alkali in the soils and waters on the projects. However, the complete failures found at the Belle Fourche project, where local materials were used, together with the action which has commenced on the surfaces of many of the blocks on other projects, indicate that materials of good quality and proper workmanship are of greatest importance.

The surface action noted on blocks at several of the projects was not confined to those made of local materials, but was also apparent on some of the blocks made of selected aggregates ("A" series molded at Denver). Whether or not this surface action on the best-quality concrete blocks is progressive will be apparent after a longer period of exposure. Concrete which is to be placed in alkali soils should be made of selected and tested materials, so proportioned as to produce a dense concrete. As small an amount of mixing water should be used as will allow the mass to be properly placed. Unless these precautions are taken the resistance of the concrete to alkali action will be reduced.

2. DRAINTILE

The following conclusions may be drawn for the use of cement drain tile exposed to soils or waters containing alkali salts in quantities of 0.1 per cent or more:

1. The use of cement tile in soils containing alkali salts in large quantities is experimental.

2. Porous tile due to the use of lean mixtures or relatively dry consistencies are subject to disintegration.

3. Some dense tile are under certain conditions subject to surface disintegration.

4. Disintegration is manifested by physical disruption caused by the expansion resulting from the crystallization of salts in the pores and by softening, resulting from chemical action of the solutions with the constituents of the cement.

5. While results obtained will not permit of a definite statement as to the relative effect of the various constituents of the salts, indications are that the greater the quantity of sulfate and magnesium present and the greater the total concentration of salts the greater will be the disintegrating effect.

6. Tile made by the process commonly used, which allows the removal of forms immediately after casting, are subject to disintegration where exposed to soils or waters containing one-tenth per cent or more alkali salts similar in composition to those encountered in this investigation.

7. The hand-tamped tile of plastic consistency as made in this investigation are not equal in quality to machine-made tile of the same mixture, and they do not resist alkali action as well.

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

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

10. The tar coating as used is not effective in preventing the absorption of alkali salts from the soil.

11. The cement-grout coating is not effective in preventing the absorption of alkali salts from the soil.

12. No advantage is found in introducing ferrous sulfate into the cement mixture.

If cement draintile are to be used in alkali soils or waters containing 0.1 per cent or more of salts similar in composition to those encountered in this investigation, they should be made of good quality aggregate in proportions of not less than 1 part Portland cement to 3 parts aggregate. The consistency should preferably be quaking, which has proved the most resistent of all mixtures used. (See description of tile series 2.) This is wetter than that generally used in commercial tile plants and will probably require the retention of the tile in the molds for several hours, unless some means are found to hasten the hardening of the cement.

WASHINGTON, January 25, 1917.

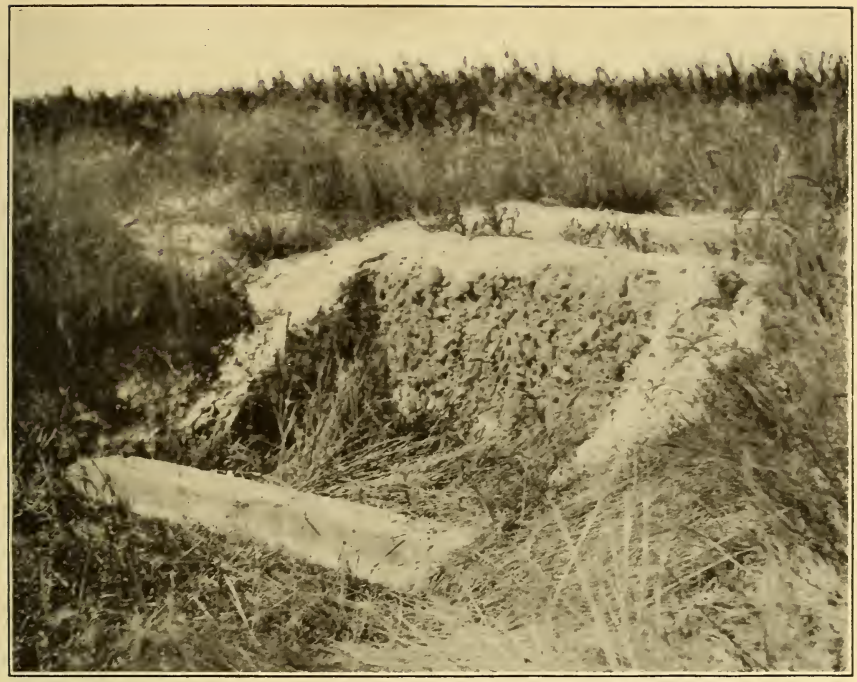

FIG. 1.—*Concrete "turnout" in alkali soil on abandoned irrigation lateral, showing the complete disintegration of one portion of the structure, with a premolded beam partially immersed in alkali seepage water. The beam showed no signs of disintegration five years after installation. Three years later disintegration was evident at the ends of the beam where in contact with the soil. The remainder of the beam was apparently sound*

FIG. 2.—*Concrete gate culvert in alkali soil on irrigation canal. Note complete disintegration of concrete in foreground while upper end is perfectly sound. White deposit of alkali is visible on the left above the surface of the water*

FIG. 3.—*Concrete wing wall of culvert in alkali soil under irrigation canal. Damage attributed to alkali due to appearance of alkali on eroded surface. Initial erosion probably due to impact of large bowlders brought down by flood water*

FIG. 4.—*Concrete culvert in alkali soil under railway roadbed. Small mass of concrete in foreground remaining from an earlier structure is completely disintegrated. Present structure shows no effect of alkali action although it is considerably cracked from settlement*

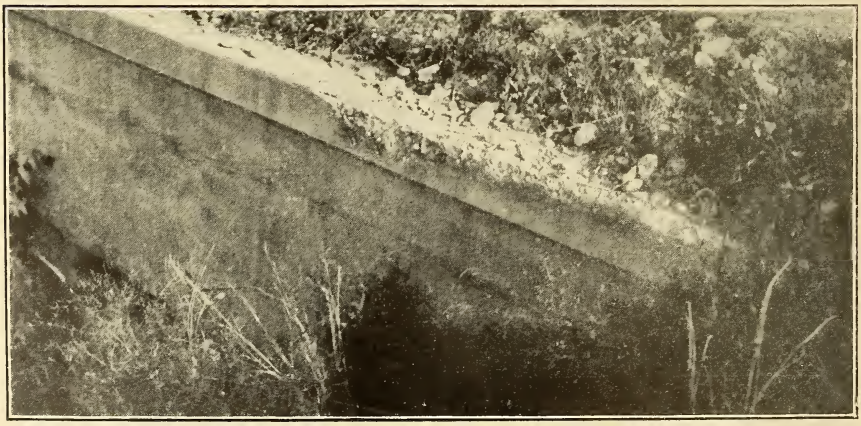

FIG. 5.—*Concrete retaining wall in alkali soil. Alkali salts are visible in the surrounding soil. There is no disintegration of concrete in lower section just above water level, where it usually occurs. Disintegrated coping is probably due to use of excess of water in concrete at time of placing*

FIG. 6.—*Combination batch mixer and pug mill. Materials are thoroughly mixed dry in cylindrical steel drum, then dropped into hopper above pug mill into which the dry mixture flows in a small continuous stream. Water is added through a perforated pipe as the materials are forced through the horizontal trough by the rotating blades*

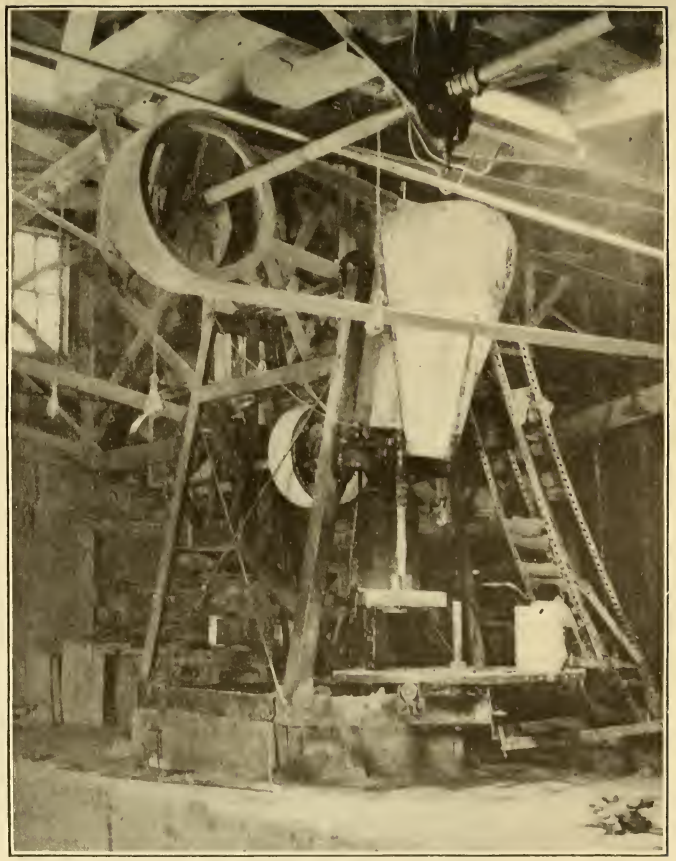

FIG. 7.—*Schenck cement tile machine. When the packer head on the vertical rotating shaft is in its lowest position cement mortar is automatically dumped into the mold by a bucket elevator and the material is packed against the wall of the mold by the rotating packer head as it is withdrawn vertically*

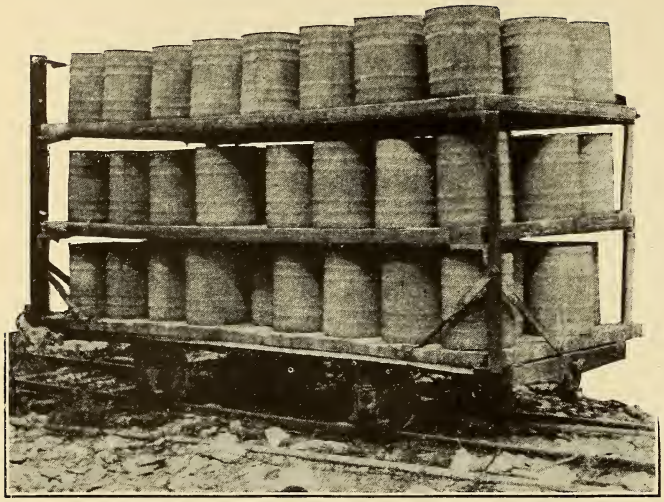

FIG. 8.—*Machine-molded cement tile, showing method of handling drain tile in a modern tile factory with 3-decked cars. The tile shown are of series 10, which have just been drawn from the steam curing chamber*

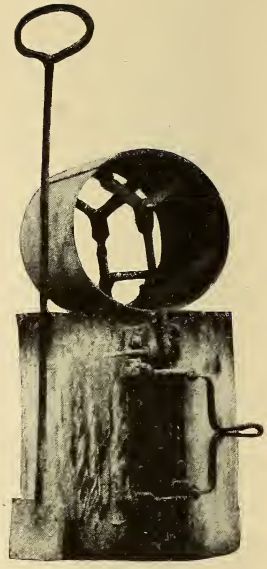

FIG. 9.—*Mold for 8-inch handmade cement tile. Sheet-metal mold consisting of outer jacket and collapsible inner core. Tamping iron used in molding tile is also shown*

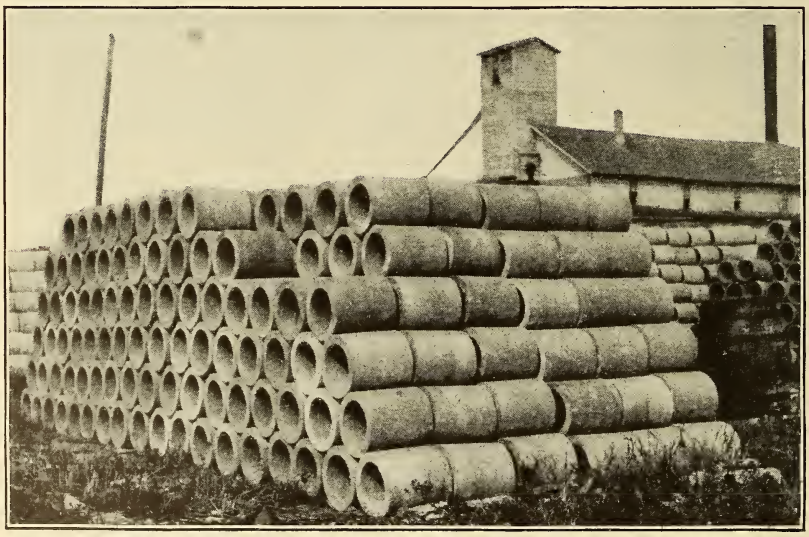

FIG. 10.—*Handmade cement tile stored in yard at factory after completion of curing period. The tile in foreground are a complete set of series 1 ready for shipment*

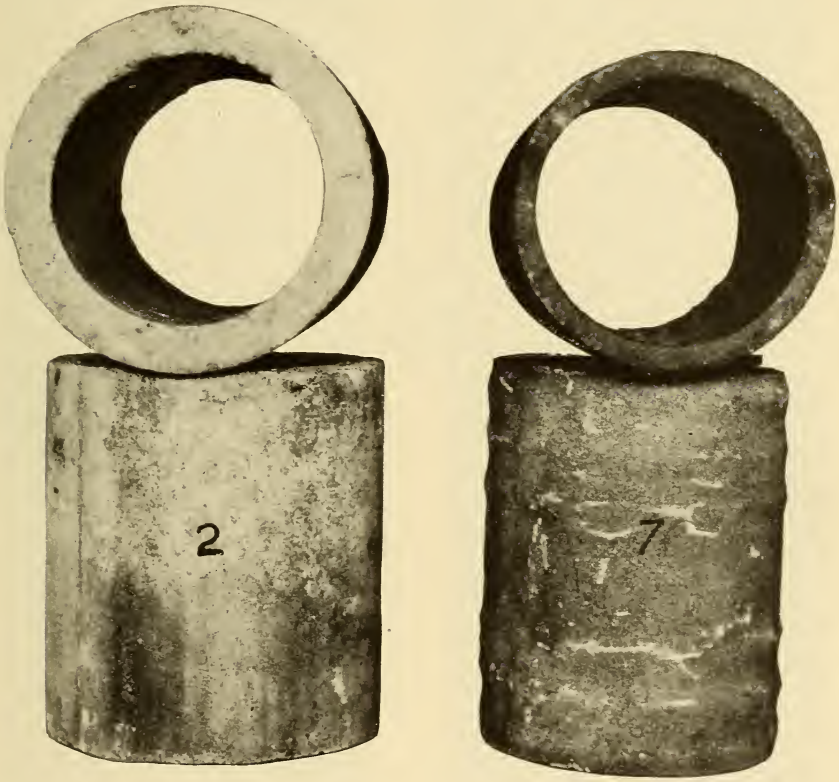

FIG. 11.—*Handmade tile of series 2, made of a quaking consistency mortar, and machine-made tile of series 7, made of plastic consistency mortar, showing the texture of the surface and relative size of the two types*

FIG. 12.—*Appearance of machine-made tile of rich and lean mixtures. Tile marked 10 is composed of one part cement to one and one-half parts sand; tile 7, one part cement to three parts sand; and tile 12 and 16 are one part cement to four parts of sand, all made by the same process excepting 12, which was cured by sprinkling instead of exposing in steam*

FIG. 13.—*Appearance of handmade tile of different consistencies. Tile marked 1 was made of plastic consistency; 2 of quaking consistency, and 14 of fluid consistency. Tile 1 and 2 are composed of one part cement to two and one-half parts of sand; tile 14 of one part cement to three parts sand*

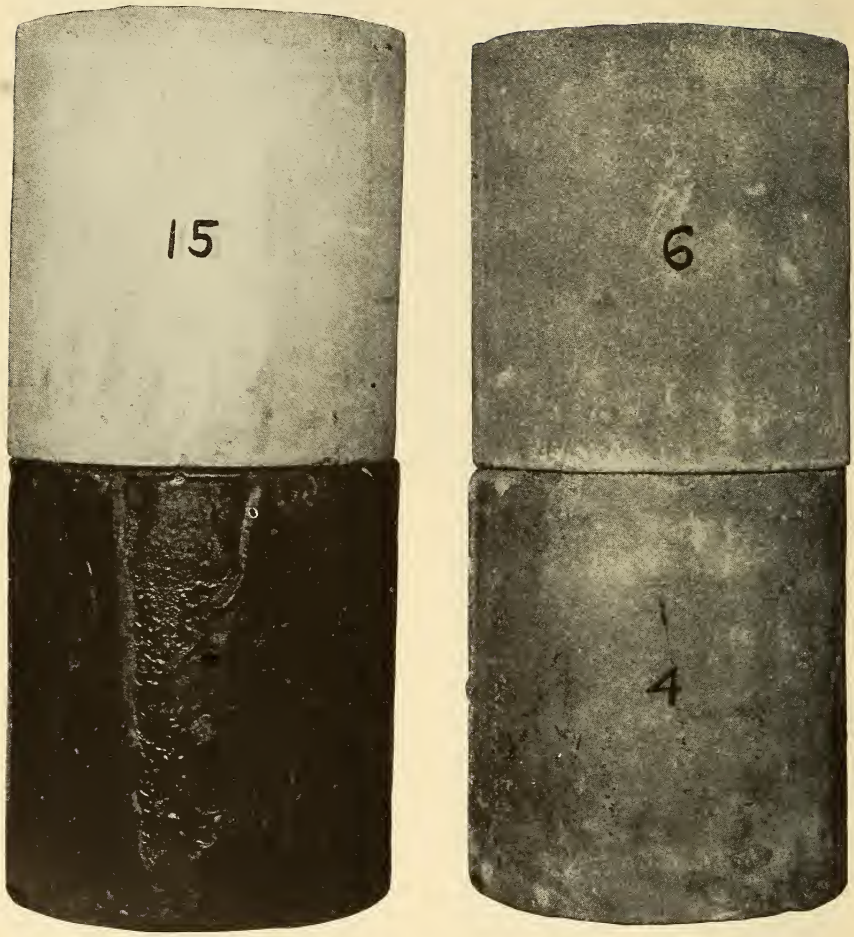

FIG. 14.—*Appearance of special and treated tile. Tile of series 4, 5, and 6 were all made by the same process. No. 4 was dipped in cement grout, 5 in hot tar, and 6 was treated by adding ferrous sulphate to the water used in mixing. Tile of series 15 were made of one part sand-cement to three parts of sand mixed to a fluid consistency*

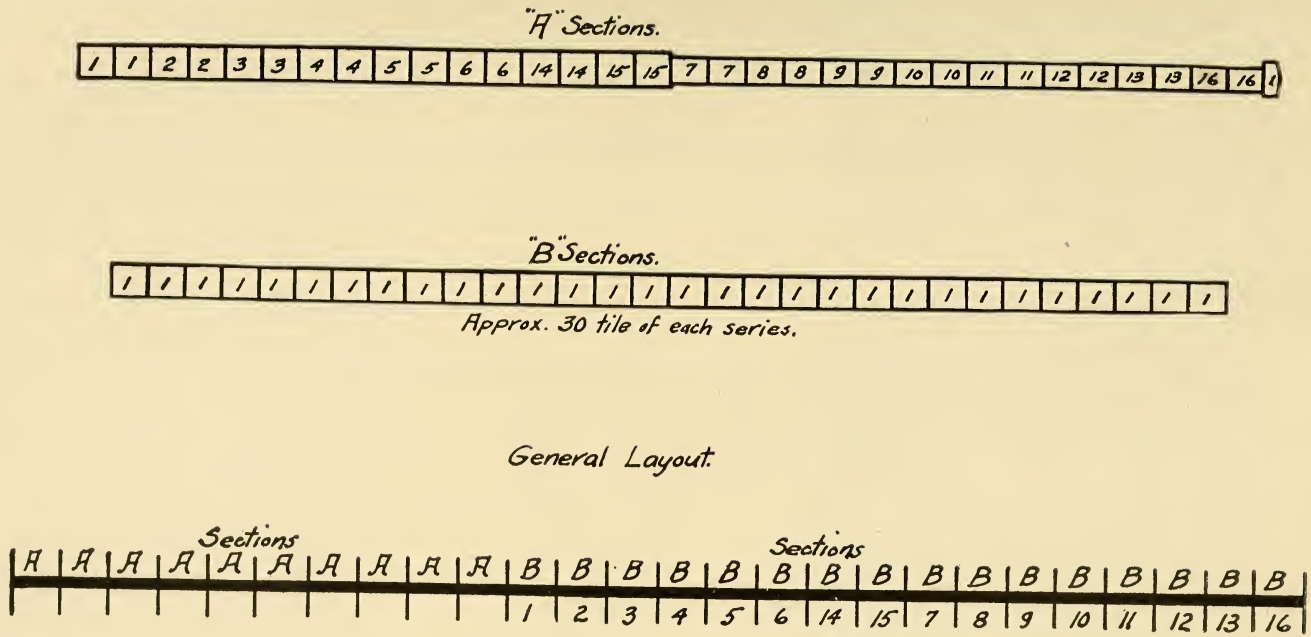

FIG. 15.—*Arrangement of drain tile. The "A" sections contain two tile of each series and were thus arranged for convenience in removal for testing. There are 10 "A" sections followed by "B" sections each of which is composed of all the remaining tile of one type*

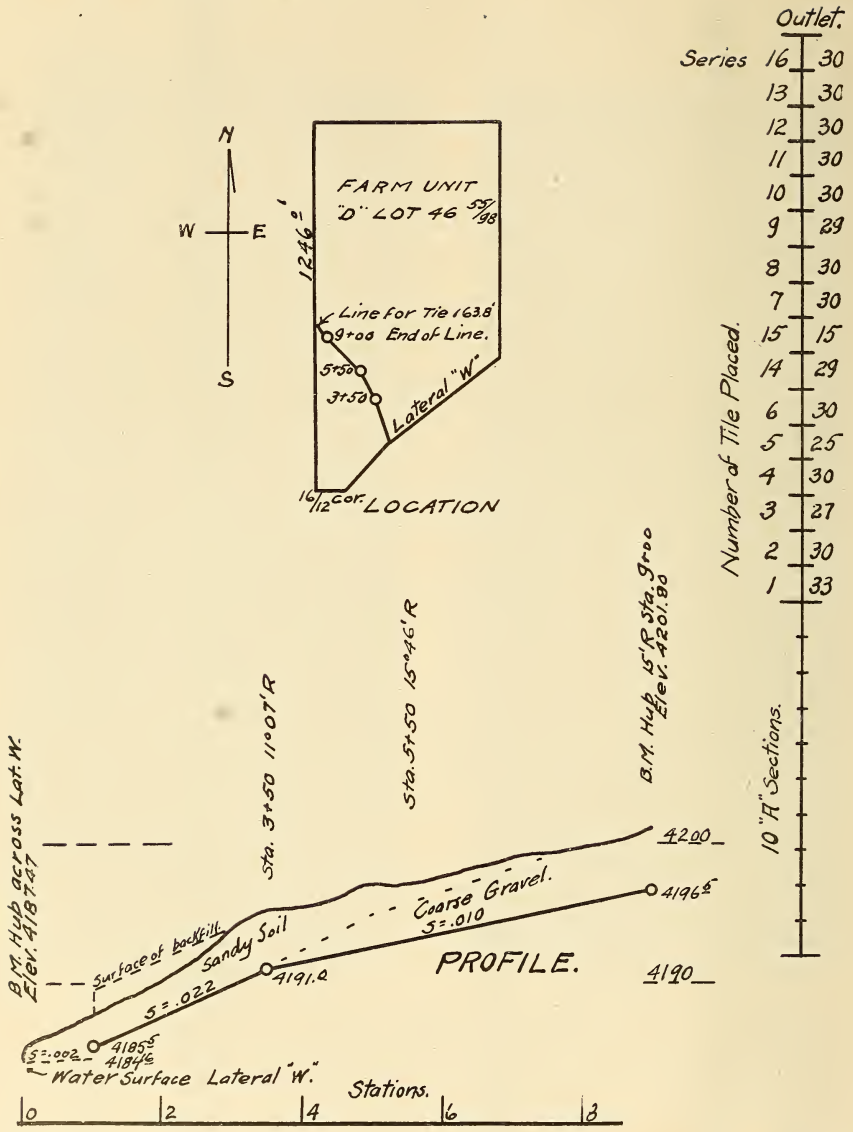

FIG. 16.—*Showing location, plan, profile, and arrangement of experimental drain tile at Garland, Wyo.*

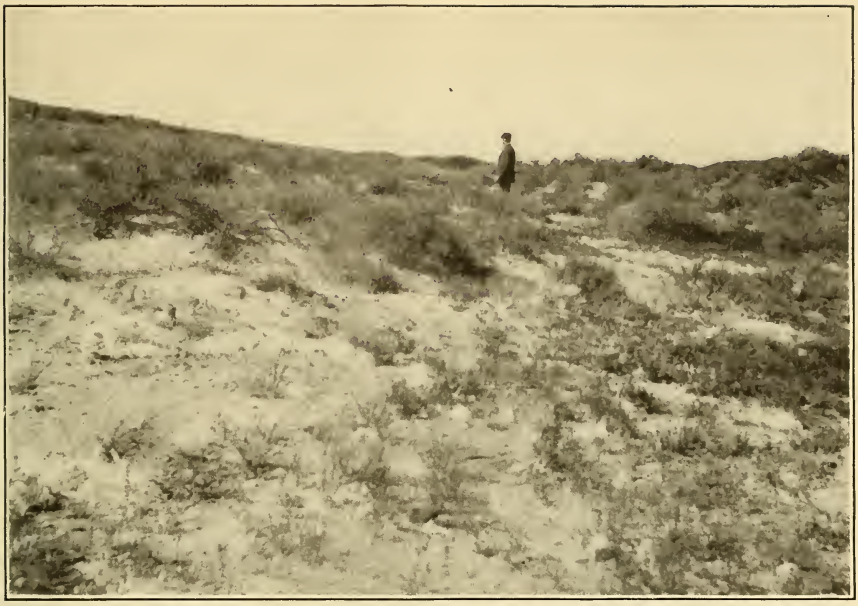

FIG. 17.—*Site of experimental drain, lower end, at Garland, Wyo., showing heavy incrustations of alkali on surface and character of the vegetation. This site is usually swampy from seepage water, and the alkali concentration may be considered as bad as any to be found in the State*

FIG. 18.—*View of opened ditch at silt basin experimental drain at Garland, Wyo., showing the gravel soil and seepage water in the trench above the grade of the drain; also the wooden cradles shown on the left upon which the tile were placed*

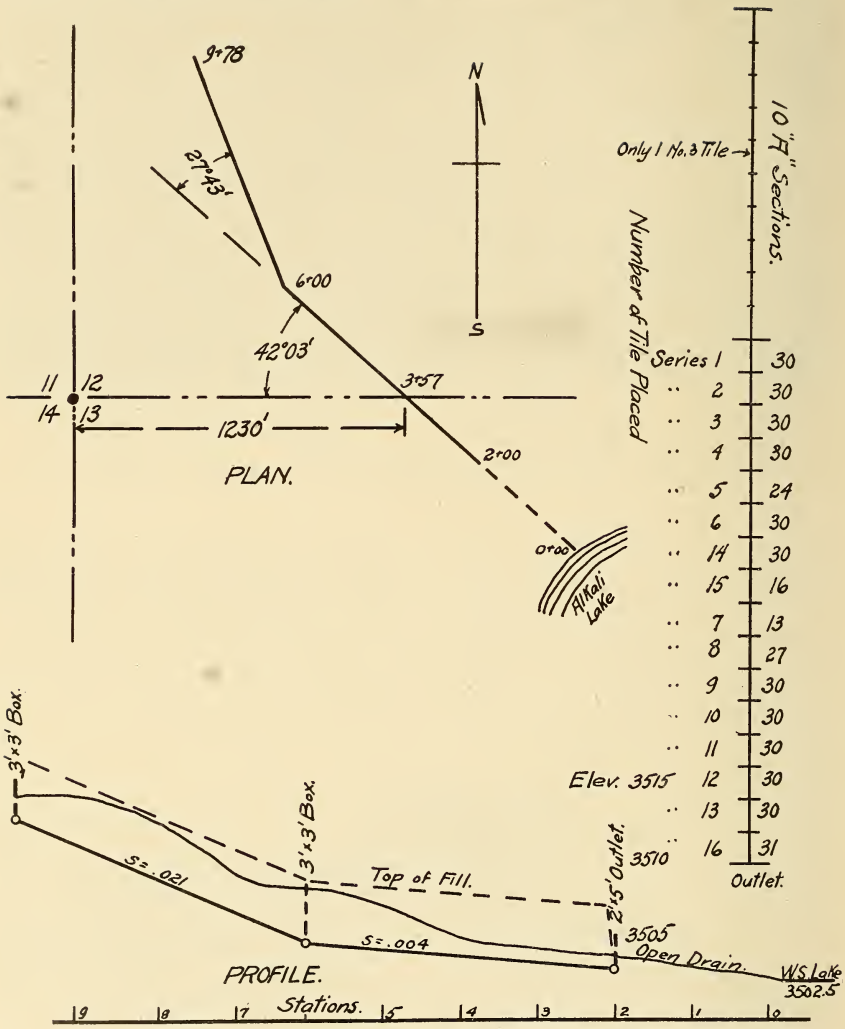

FIG. 19.—*Showing location, plan, profile, and arrangement of experimental drain tile at Fort Shaw, Mont.*

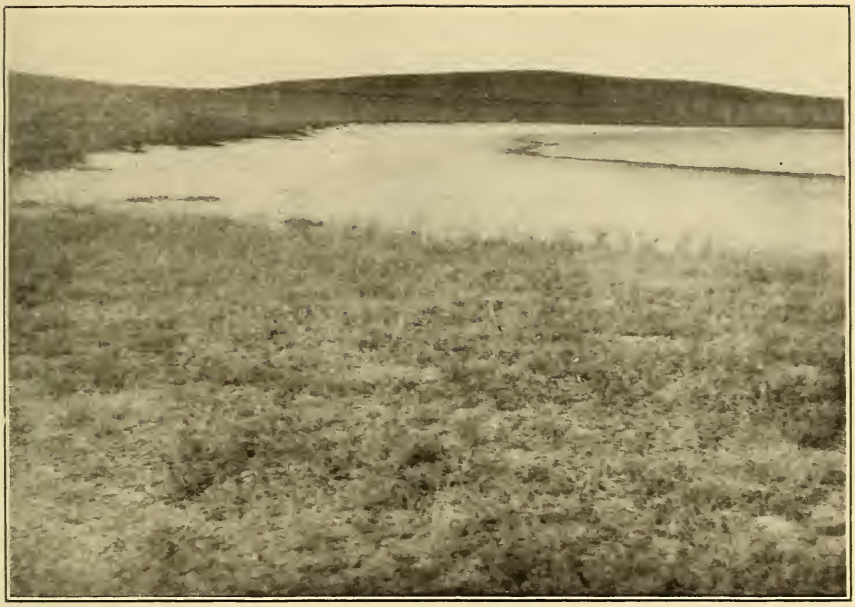

FIG. 20.—*Alkali Lake at lower end of experimental drain at Fort Shaw, Mont., showing the heavy alkali deposits surrounding the lake*

FIG. 21.—*Site of experimental drain at Fort Shaw, Mont., looking toward lower end, showing the partially excavated trench and alkaline seepage water collecting in the bottom; also alkali weed covering the site*

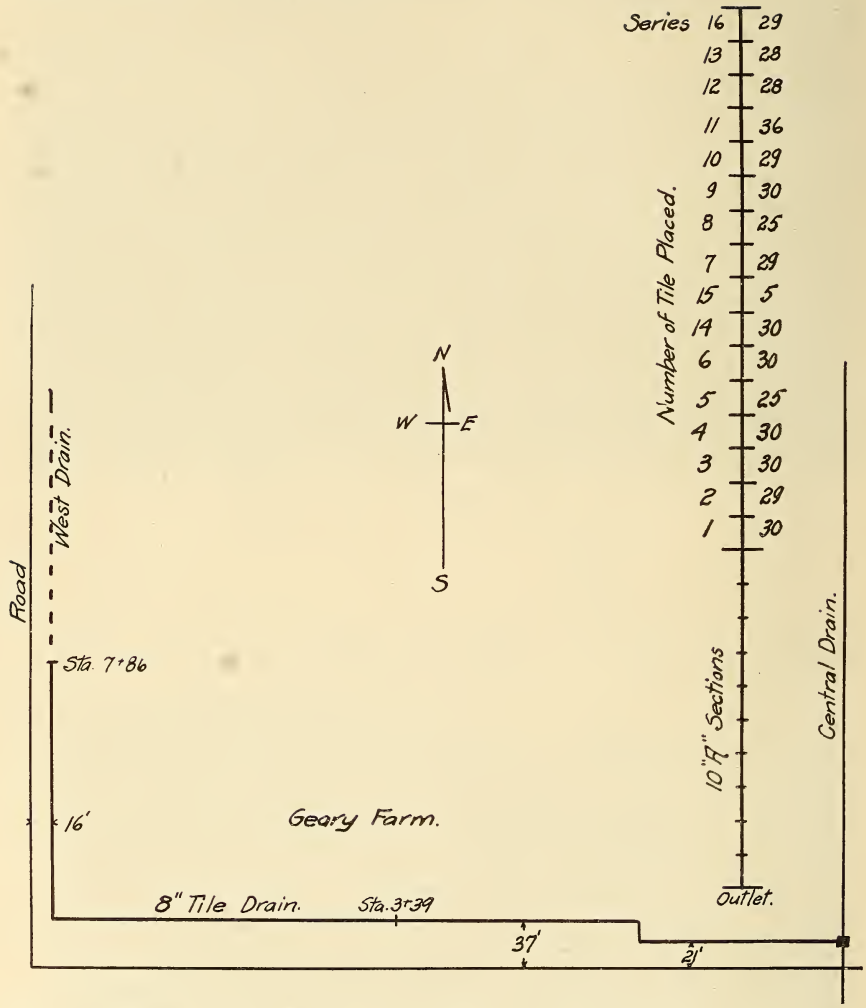

FIG. 22.—*Showing location, plan, and arrangement of experimental drain tile at Huntington, Utah*

FIG. 23.—*Opened ditch for experimental drain at Huntington, Utah, showing the character of the soil, lack of vegetation due to alkali salts, and the approximate depth of excavation*

FIG. 24.—*Bank of waste ditch, showing heavy white incrustation of alkali salts at Huntington, Utah. The concentration of alkali salts in this locality is probably as great as will be found in the State*

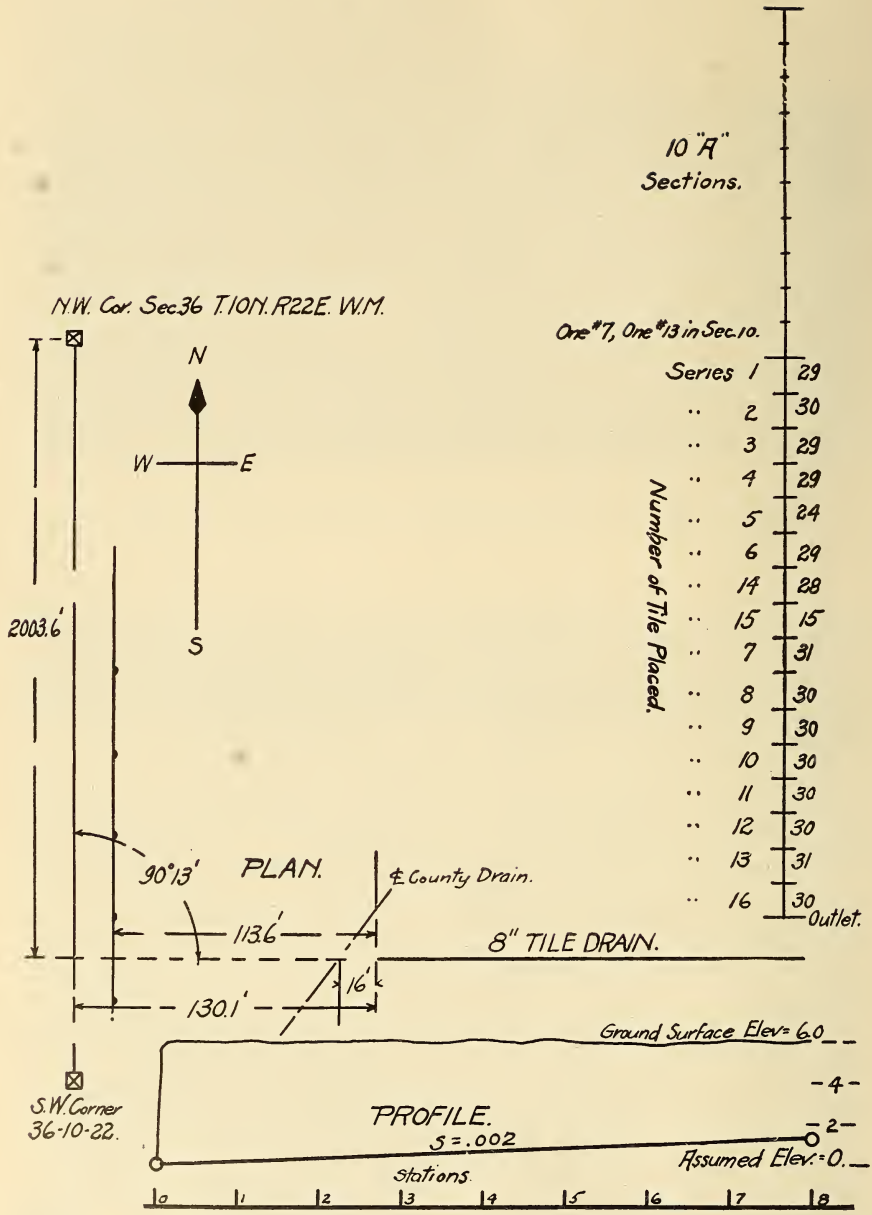

FIG. 25.—*Showing location, plan, profile, and arrangement of experimental drain tile at Sunnyside, Wash.*

FIG. 26.—*Opening lower end of ditch for experimental drain at Sunnyside, Wash., showing partially excavated trench. Note amount of vegetation as compared with that in Fig. 27*

FIG. 27.—*Upper end of site of experimental drain at Sunnyside, Wash., showing lack of vegetation and heavy alkali crust on surface of ground. The salts appear much more concentrated on the surface at the upper end than at the lower end. While there are scattered deposits of salts on the surface over the site, conditions do not appear as bad as upon some of the other projects*

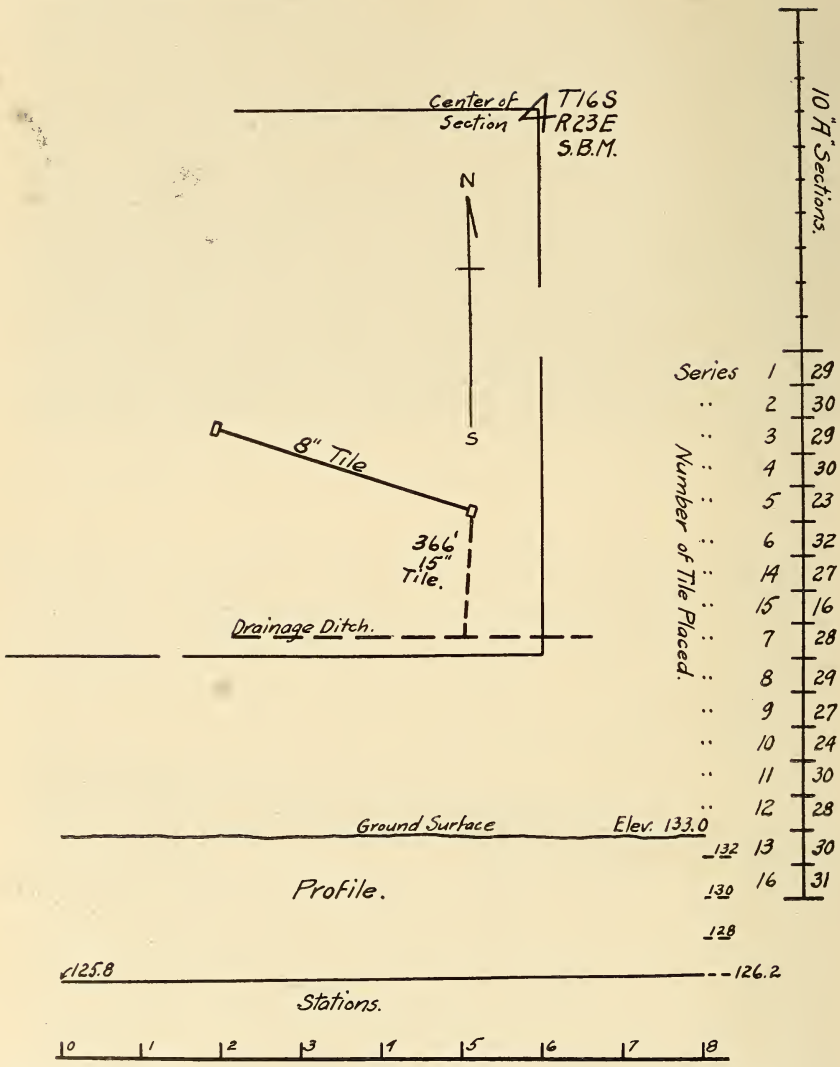

FIG. 28.—*Showing location, plan, profile, and arrangement of experimental drain tile at Yuma, Ariz.*

FIG. 29.—*View from upper end of opened ditch for experimental drain at Yuma, Ariz., showing tile laid along the ditch ready for placing. There is only little alkali salt visible on the surface at this site, and conditions do not appear to be as severe as on many of the other projects*

FIG. 30.—*View of opened ditch at Yuma, Ariz., showing heavy flow of seepage water in the bottom; also the method of placing the tile*

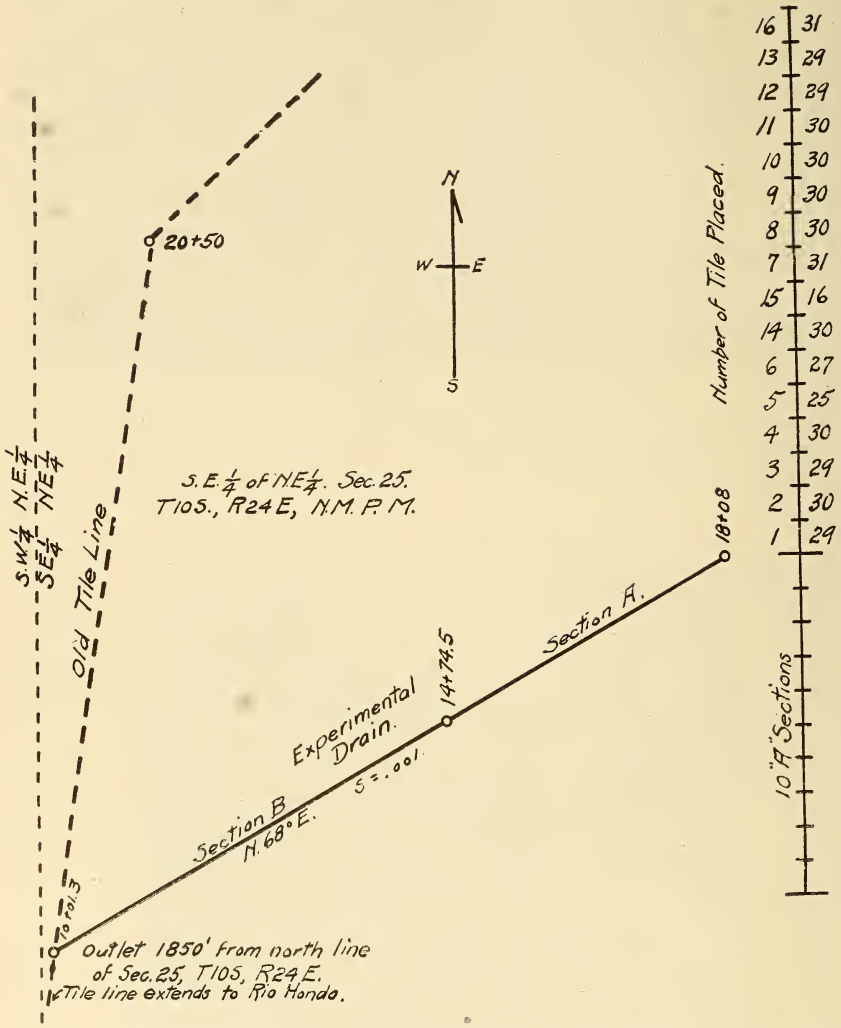

FIG. 31.—*Showing location, plan, and arrangement of experimental drain tile at Roswell, N. Mex.*

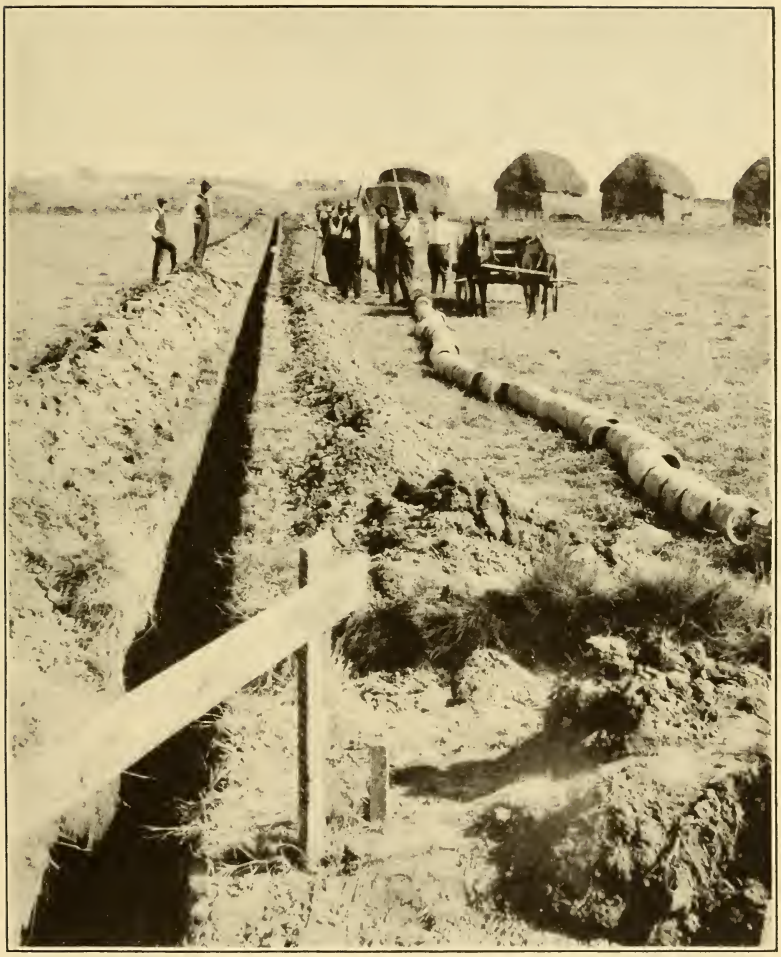

FIG. 32.—*View from lower end of opened ditch for experimental drain at Roswell, N. Mex., showing tile strewn ready for placing. Note the entire trench is partly excavated and banks are vertical. The concentration of salts is not as great at this project as at some of the others*

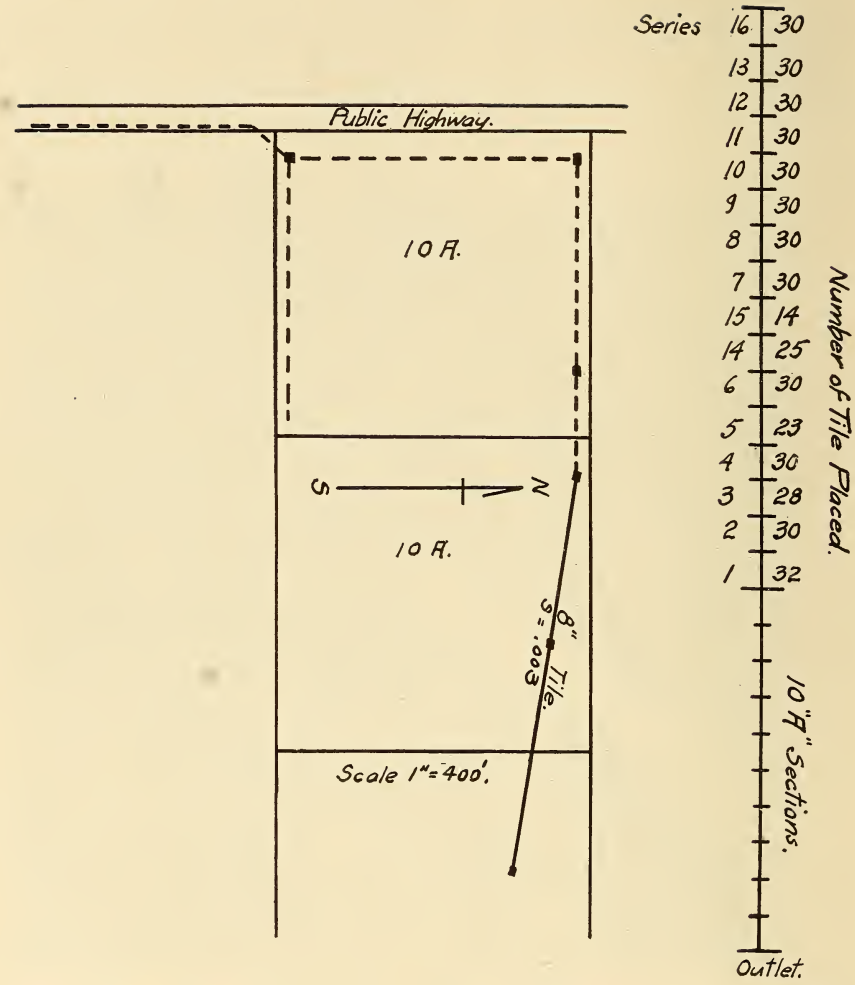

FIG. 33.—*Showing location, plan, and arrangement of experimental drain tile at Grand Junction, Colo.*

FIG. 34.—*View of site of experimental drain at Grand Junction, Colo., showing extremely heavy concentration of alkali salts on the surface of the ground. There is practically no vegetation other than alkali weed. Observe the salts are more concentrated on the high spots*

FIG. 35.—*Site of experimental drain at Grand Junction, Colo., showing heavy alkali deposit. The tile have been strewn ready for placing. Note lack of vegetation*

FIG. 36.—*Opened ditch for experimental drain at Grand Junction, Colo., showing the difficulties encountered in placing the tile. Observe the caving banks and timber bracing required*

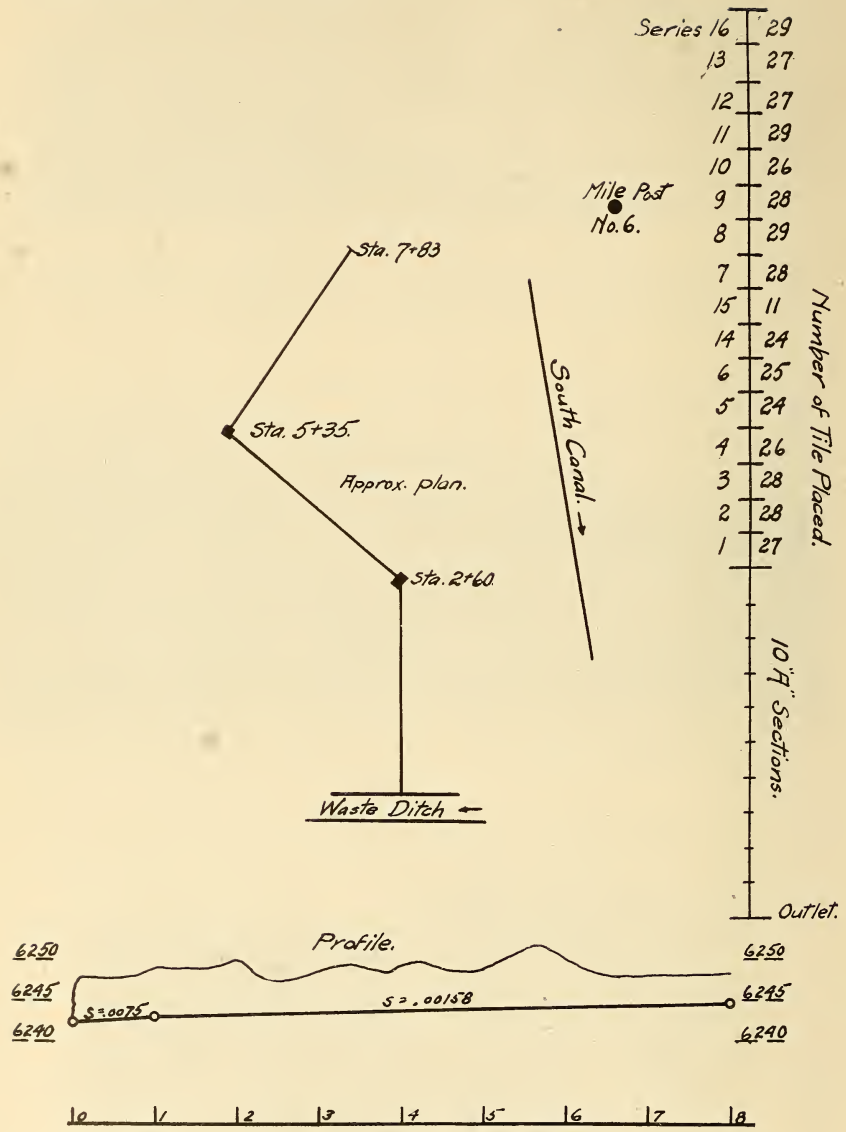

FIG. 37.—*Showing location, plan, profile, and arrangement of experimental drain tile at Montrose, Colo.*

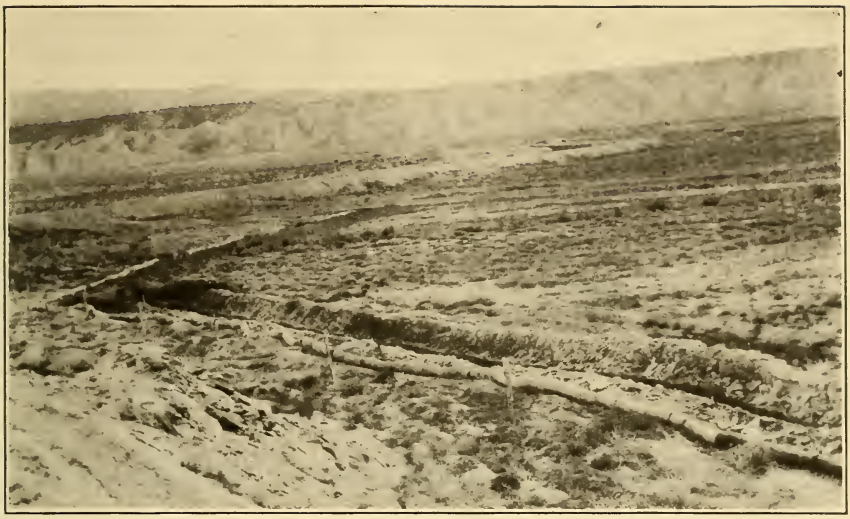

FIG. 38.—*View from upper end of site of experimental drain at Montrose, Colo., showing the opened ditch and the distribution of the tiles just previous to placing. Observe hard shale excavated at upper end to the right in picture*

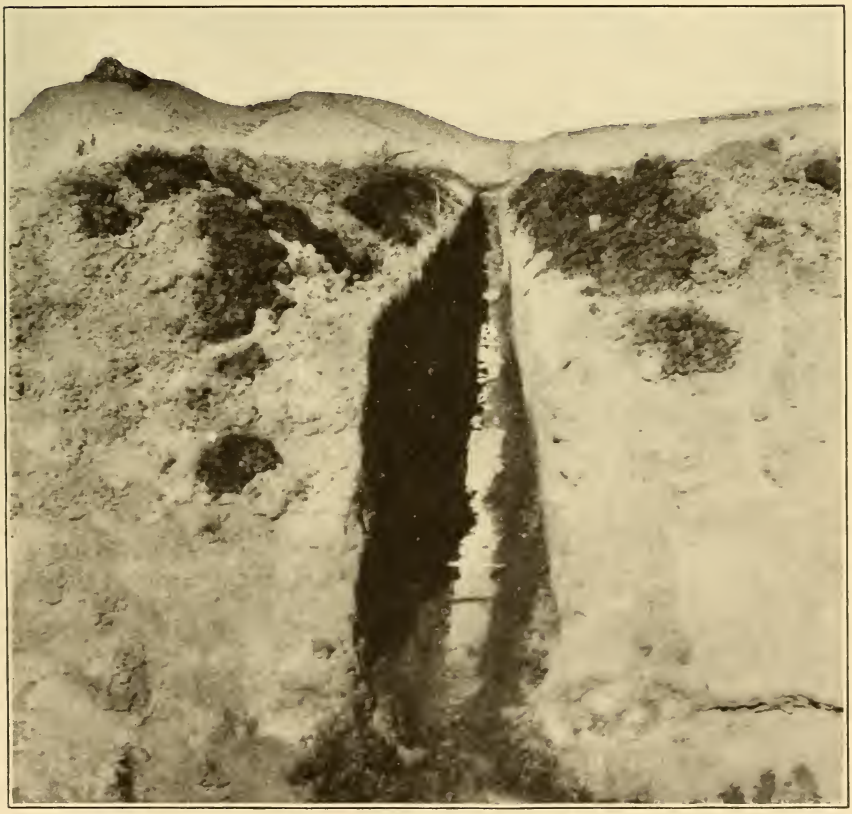

FIG. 39.—*Lower end of opened ditch for experimental drain at Montrose, Colo., showing depth of completed trench, flow of seepage water, and alkali salts on surface of soil where partially dried in the foreground*

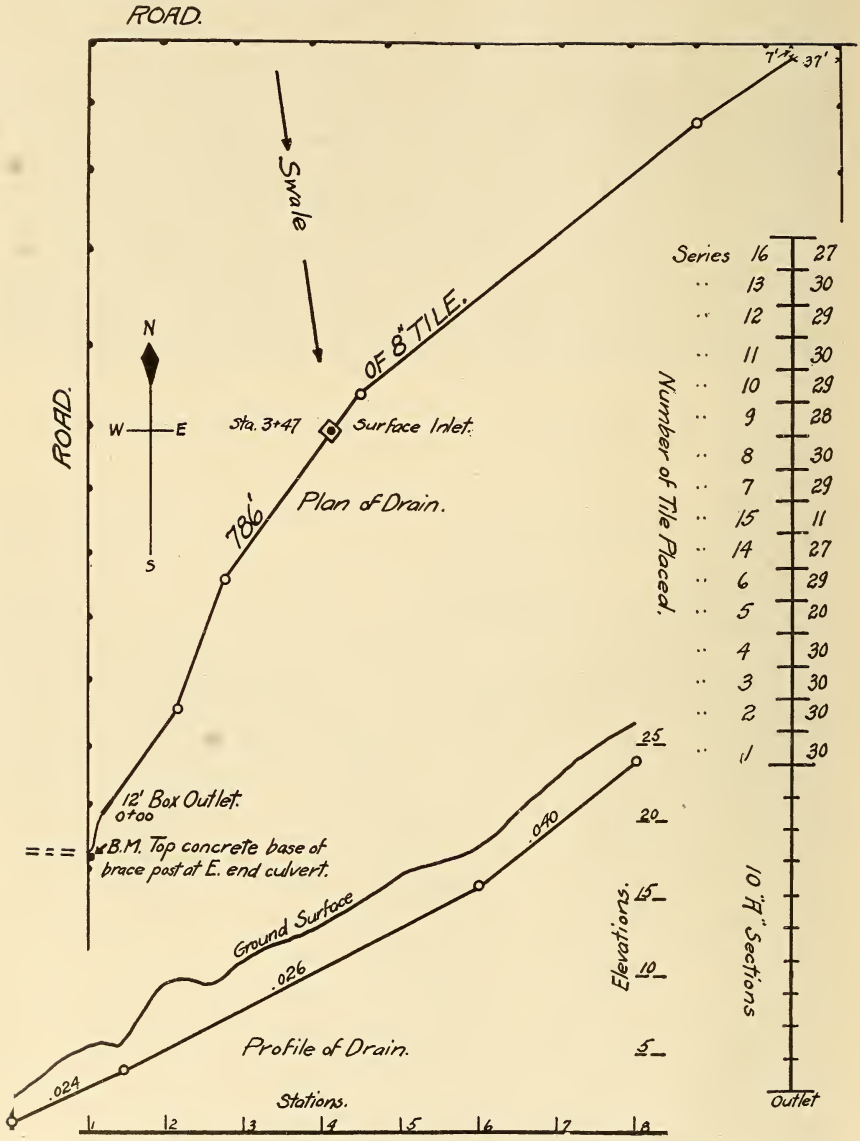

FIG. 40.—*Showing location, plan, profile, and arrangement of experimental drain tile at Columbia, Mo.*

FIG. 41.—*Lower end of experimental drain, Columbia, Mo., showing shallow installation of tile necessary on account of high outlet*

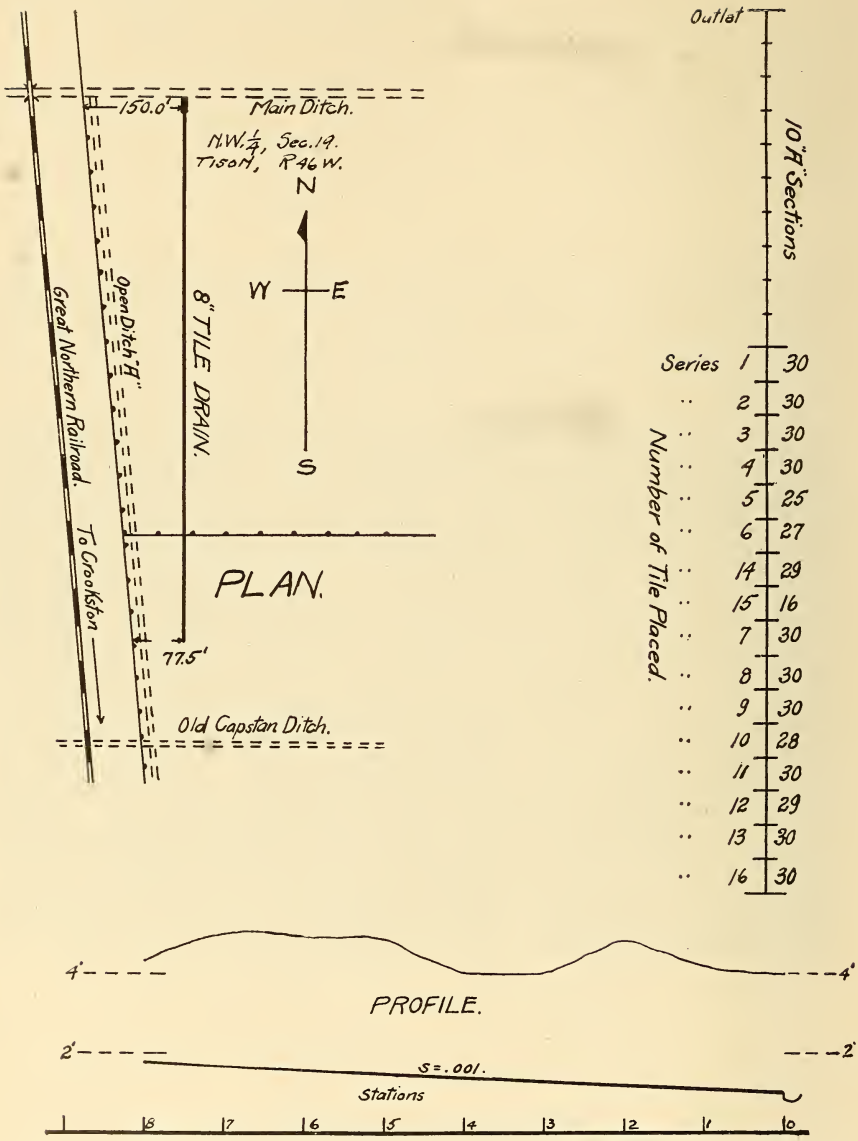

FIG. 42.—*Showing location, plan, profile, and arrangement of experimental drain tile at Crookston, Minn.*

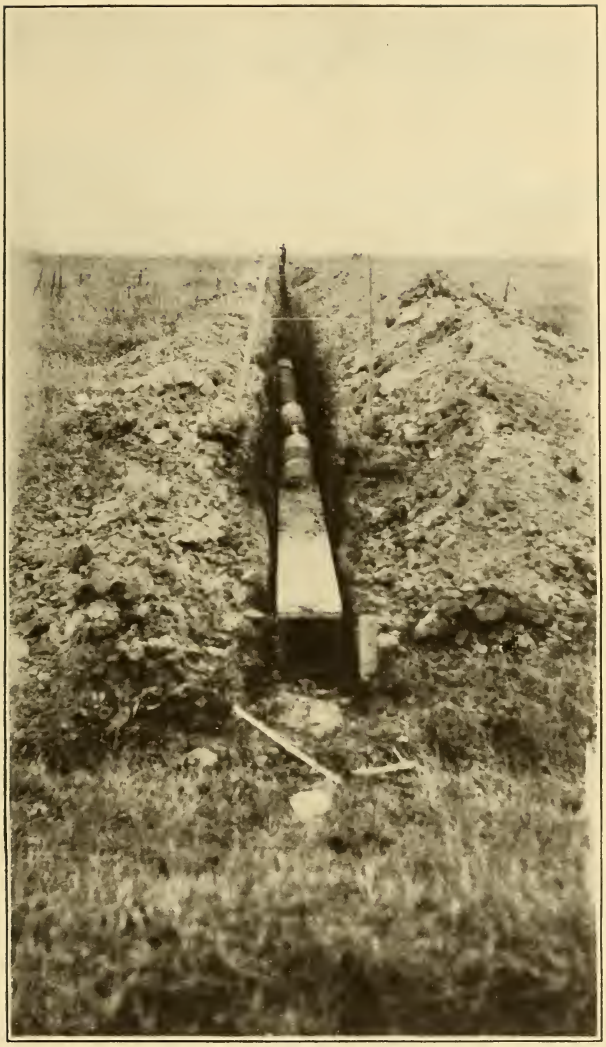

FIG. 43.—*Lower end of experimental drain at Crookston, Minn., showing shallow installation of tile with box at outlet to prevent tile being washed out*

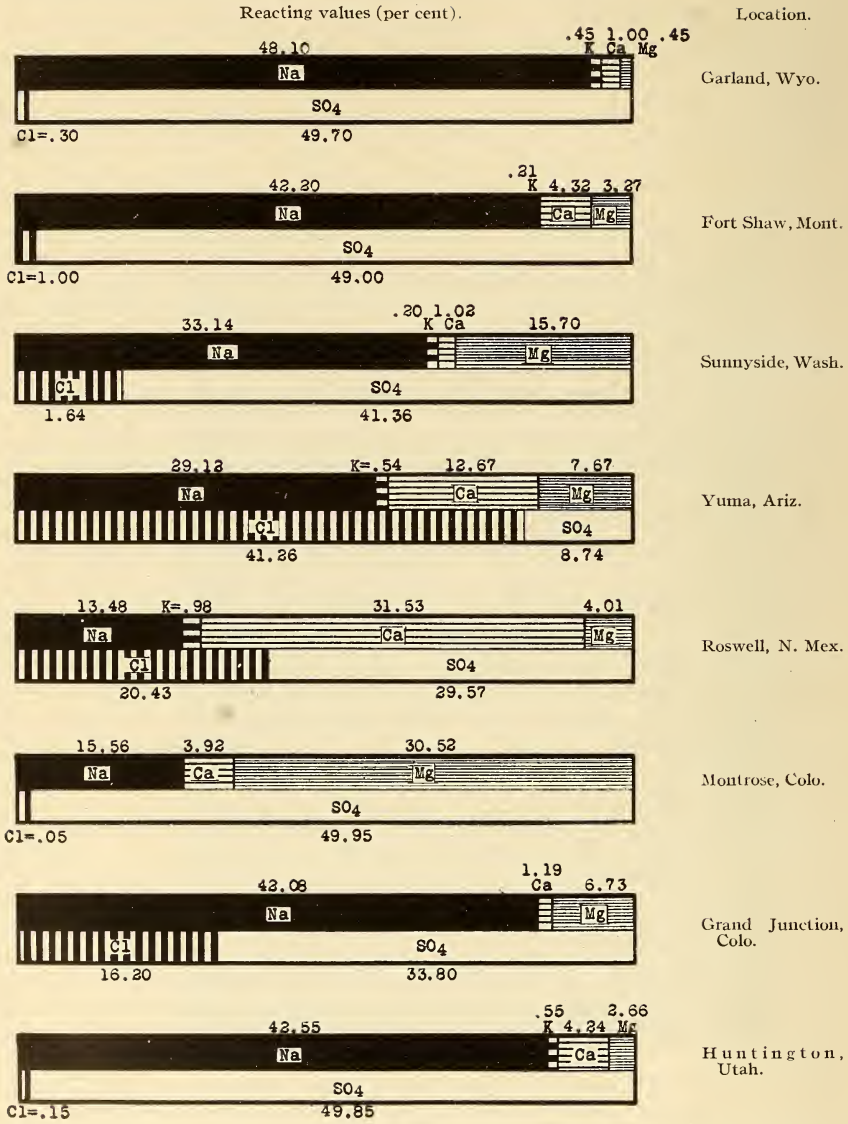

FIG. 44.—*Chemical analyses of alkali salts from surface of ground at site of experimental cement tile drains (1913). (Results given in Table 9)*

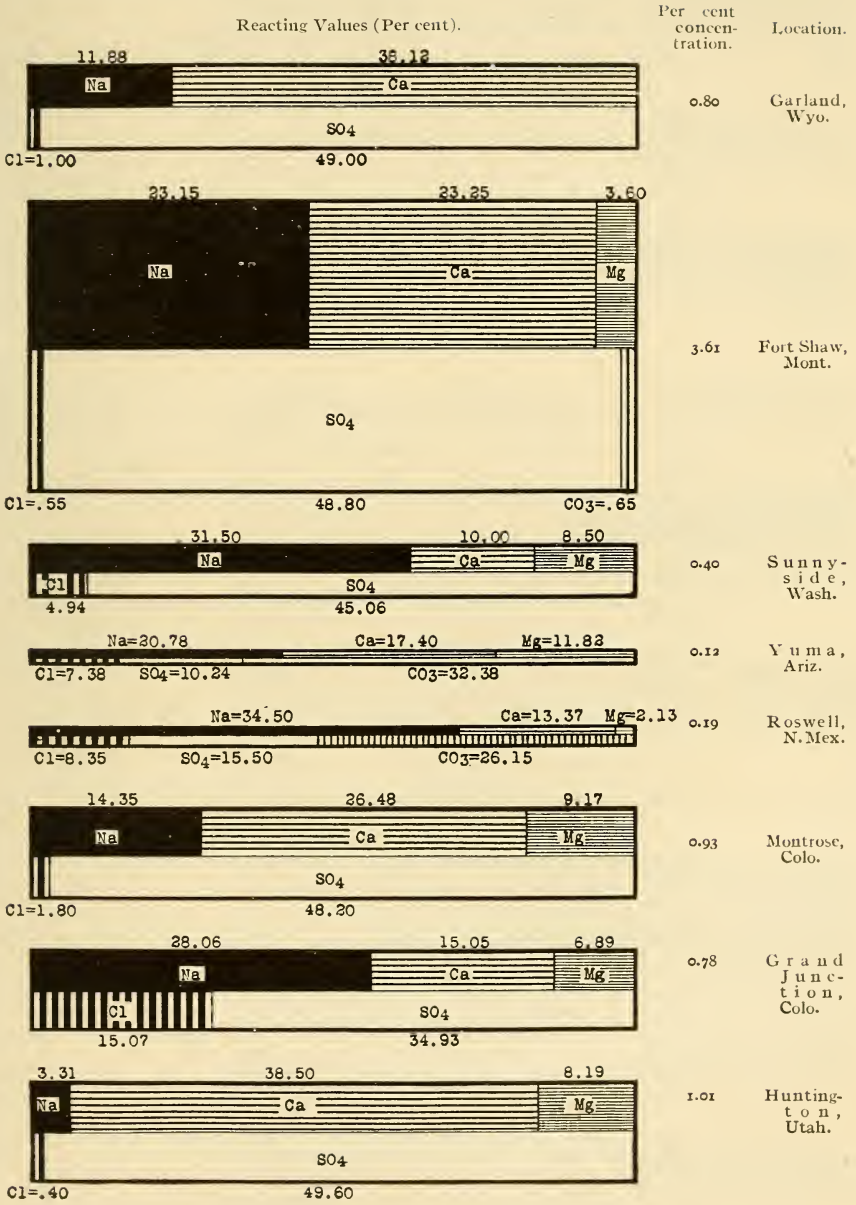

FIG. 45.—*Chemical analyses of soils at level of experimental tile drains (1913). (Results given in Table 10)*

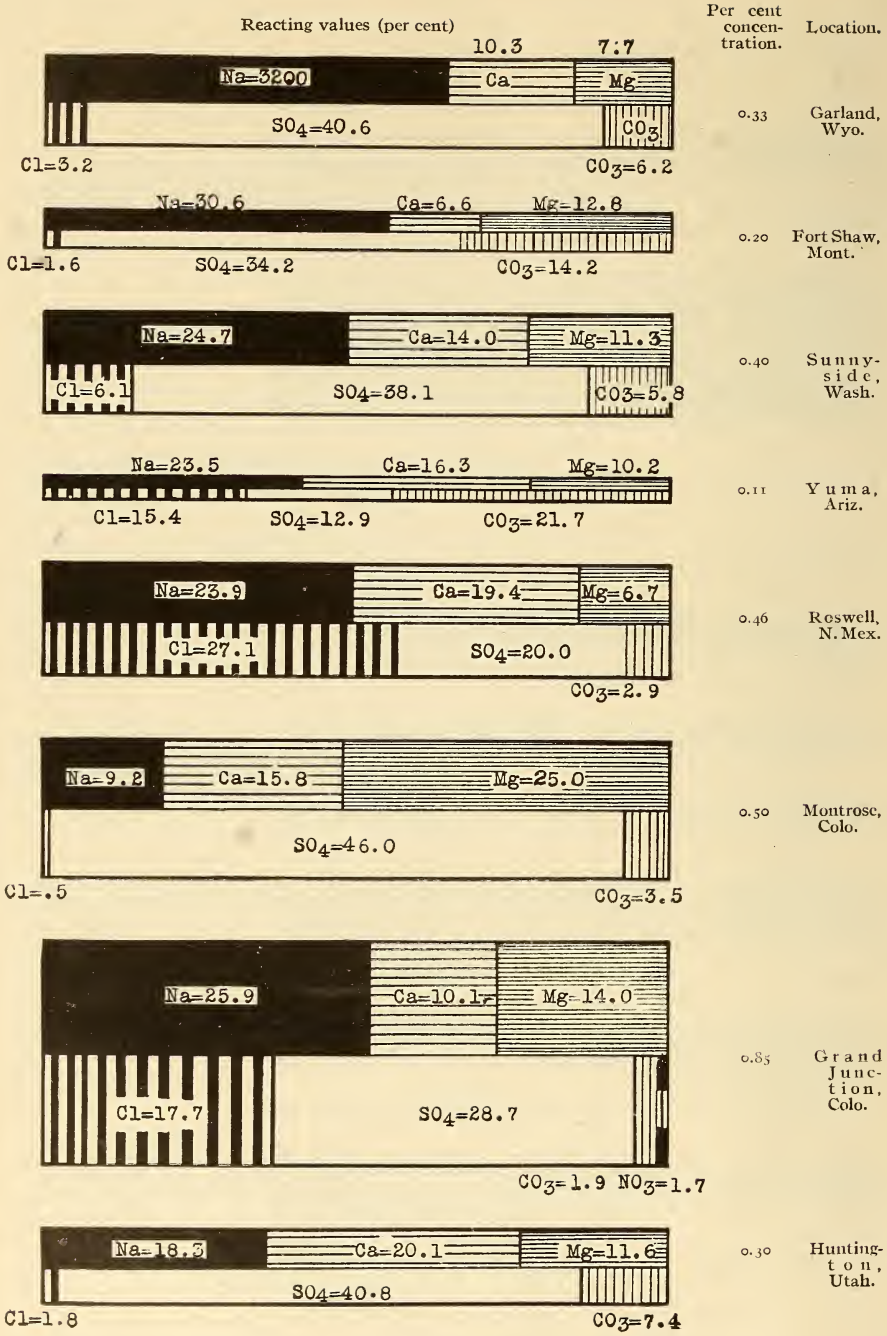

FIG. 46.—*Analyses of seepage waters (percentage reacting values) flowing through cement tile drains, fall of 1913 to fall of 1916, inclusive*

[See Table 13]

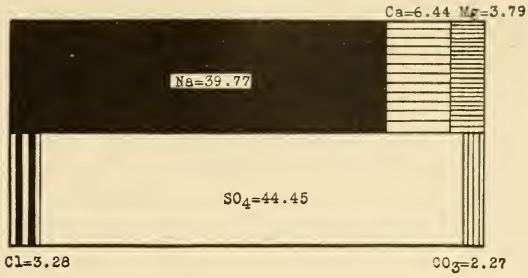

FIG. 47.—*Analysis of water (percentage reacting values), in diagrammatic form, to accompany method of calculation of reacting values*

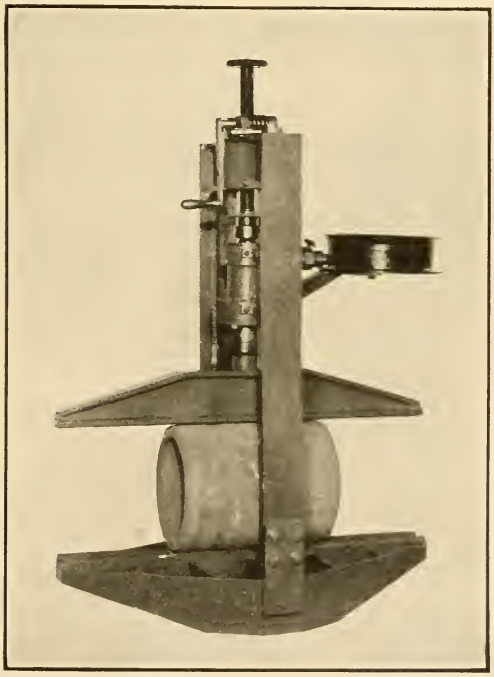

FIG. 48.—*Portable tile-testing machine of the three-edge bearing type used in testing experimental tile at the site of the drain. The pressure which is applied to the tile through the worm gear and screw is measured by the hydraulic gauge attached to the ram. All parts excepting the gears and gauge are made of cast aluminum*

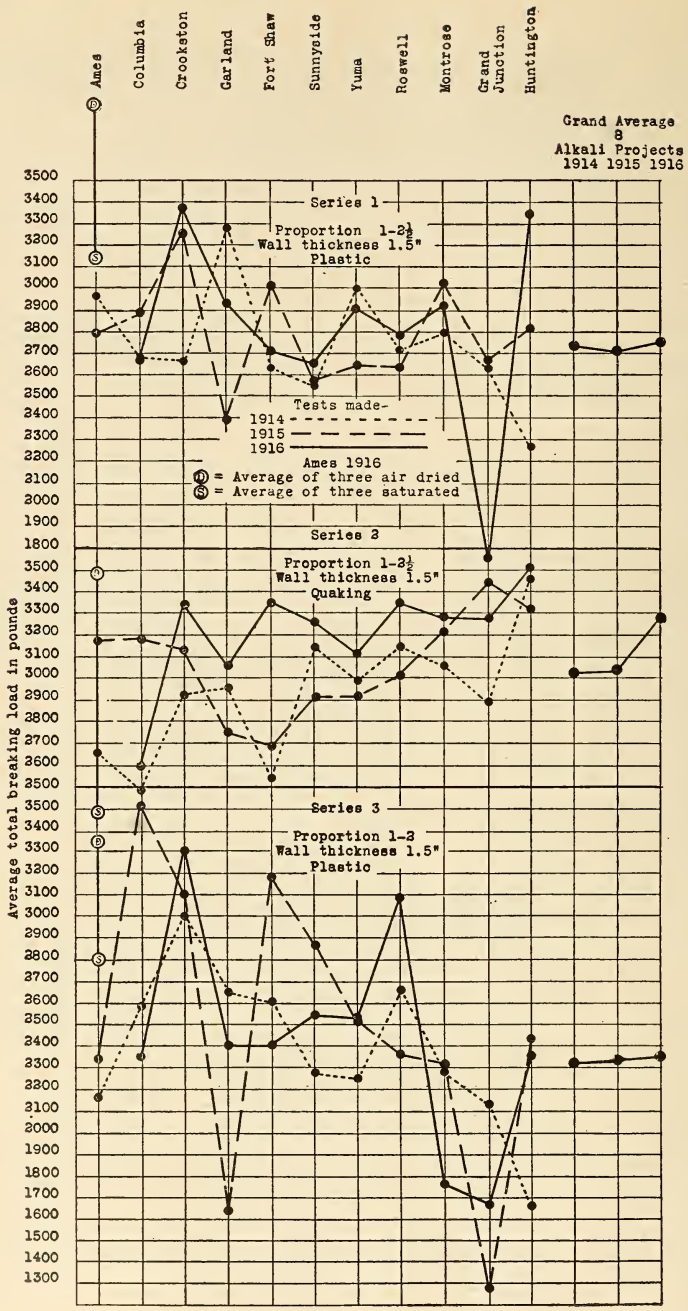

FIG. 49.—*Average results of tests of experimental cement drain tile*

[See Table 15]

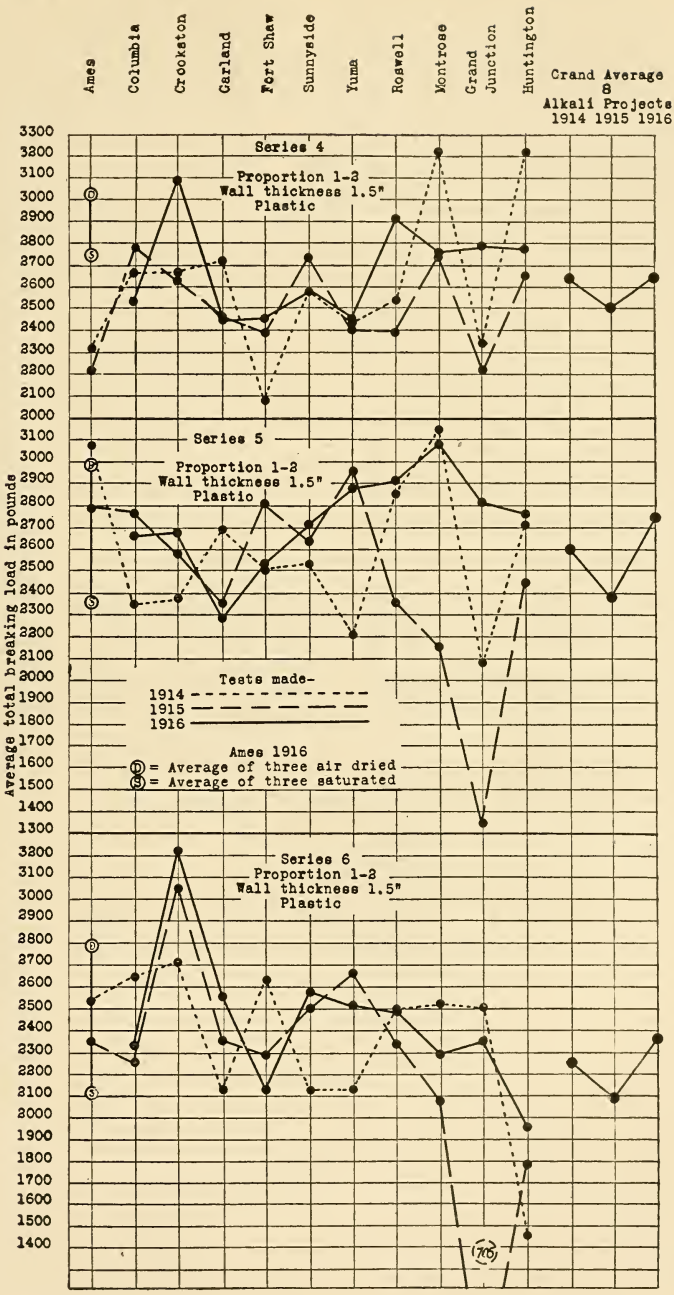

FIG. 50.—*Average results of tests of experimental cement drain tile*

[See Table 15]

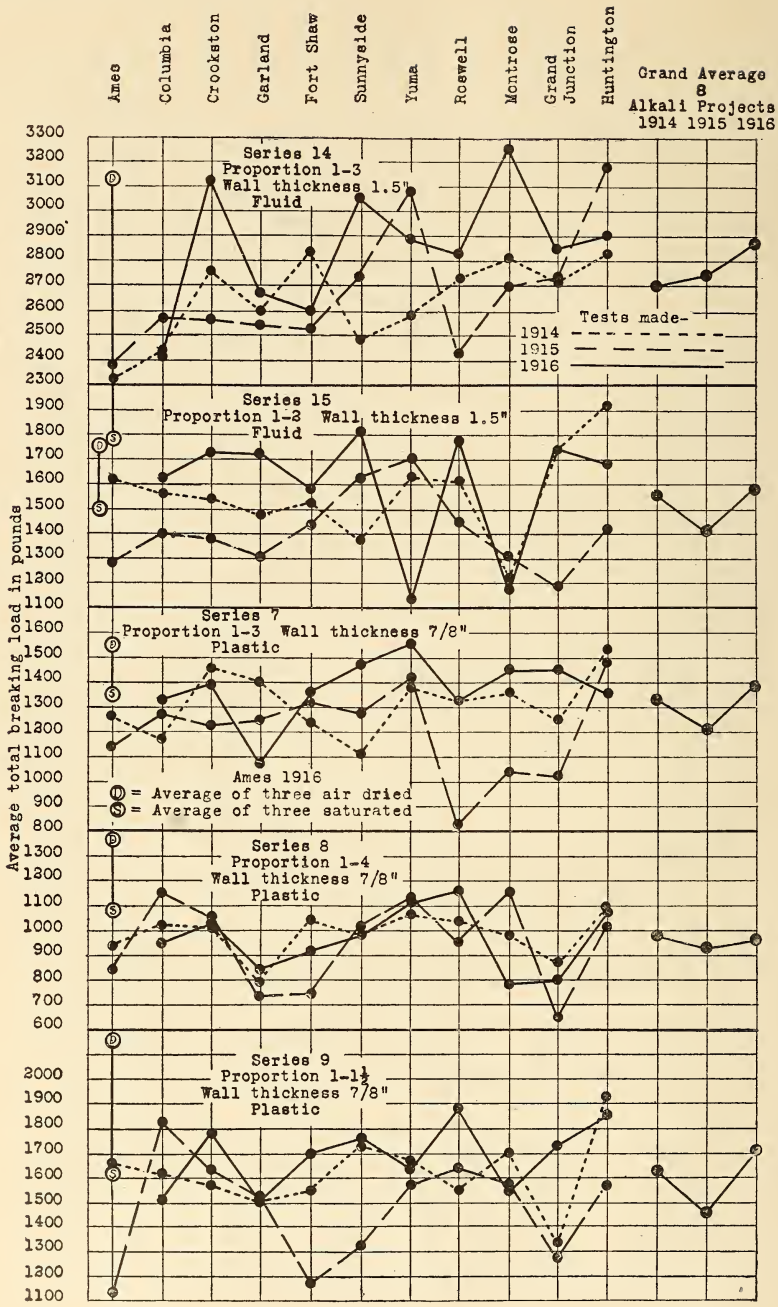

FIG. 51.—*Average results of tests of experimental cement drain tile*

[See Table 15]

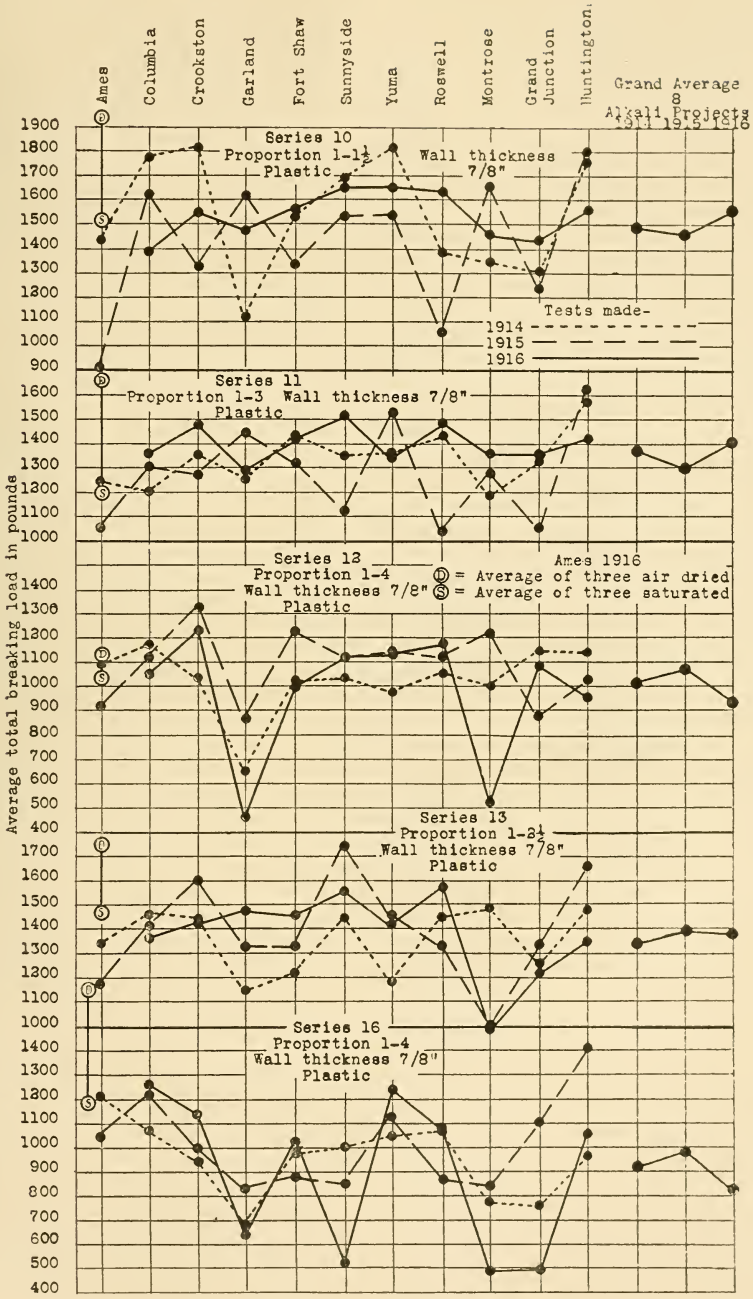

FIG. 52.—*Average results of tests of experimental cement drain tile*

[See Table 15]

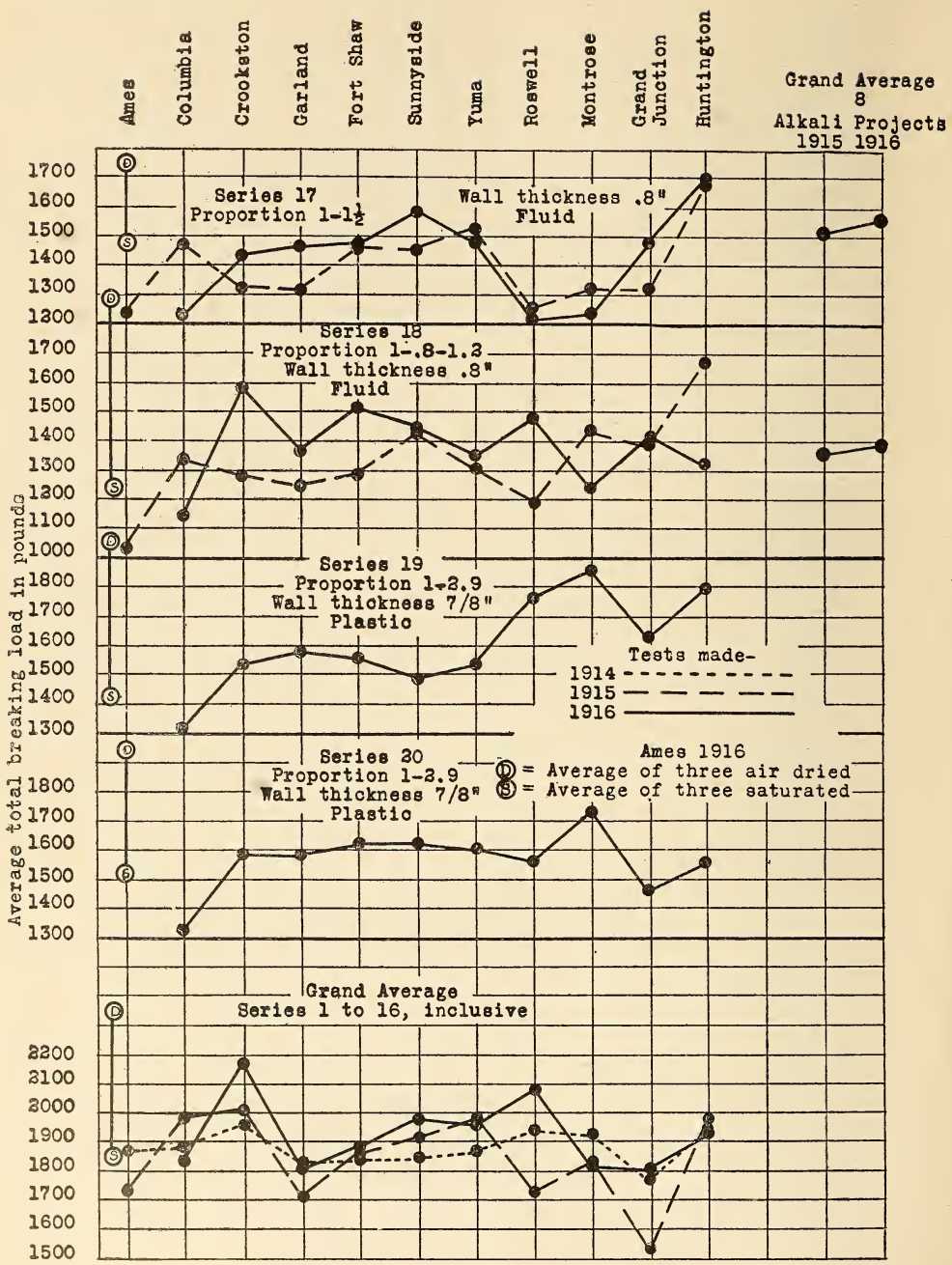

FIG. 53.—*Average results of tests of experimental cement drain tile*

[See Table 15]

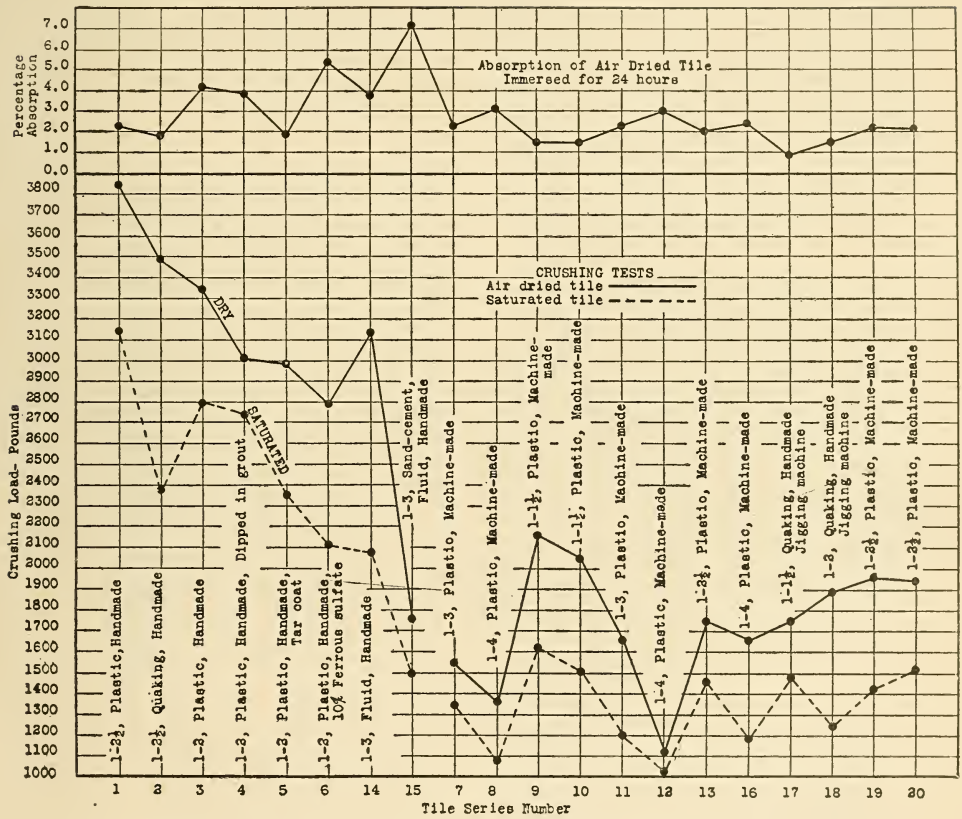

FIG. 54.—*Results of absorption tests of dry and saturated cement drain tile, with percentage of absorption of saturated tile. All results are the average of three tests. The tile of series 1 to 16 were approximately 3 years old, 17 and 18 were 2 years old, 19 and 20 were one year old*

FIG. 55.—*Surface disintegration of tile removed from drain at Columbia, Mo., in 1916 after three years exposure*

(*a*) Uninjured surface of a tile which has never been exposed in a drain; (*b*) series 8, proportion 1-4, machine made; (*c*) series 9, proportion 1-1½, machine made; (*d*) series 8; (*e*) series 3, proportions 1-2, quaking consistency, hand tamped. The lower right-hand surface is unaffected.

L2 L1-2½

FIG. 56.—*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. 57.—*Swollen and cracked tile of series 16 after one year's exposure at Grand Junction, Colo. The interior surface is cracked similarly to the exterior*

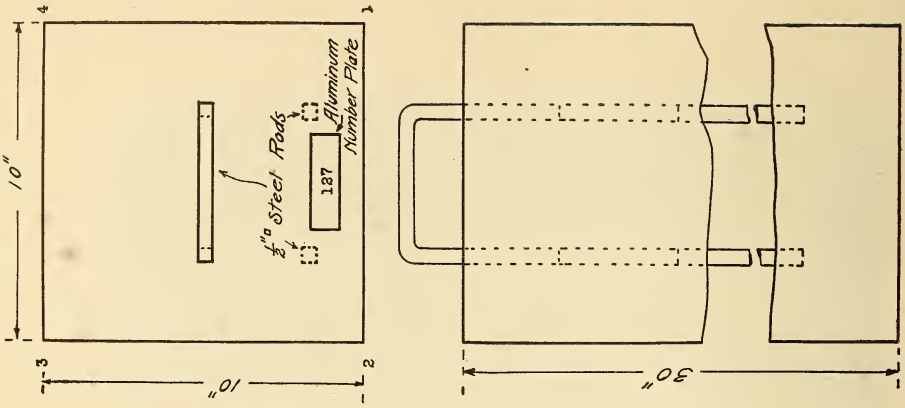

FIG. 59.—*Type of concrete block installed on the projects in 1915 and 1916*

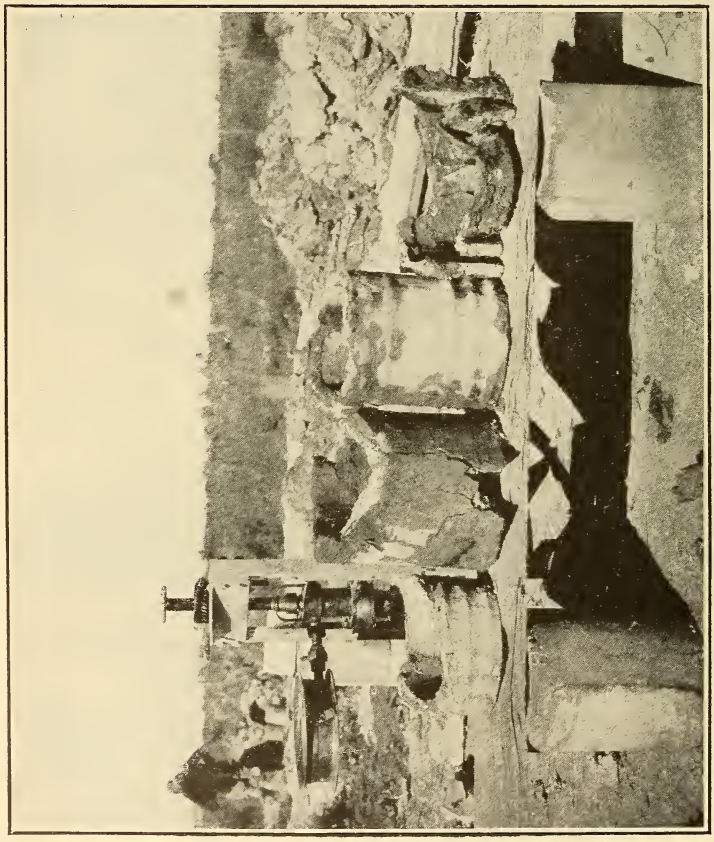

FIG. 58.—*Group of disintegrated tile removed from the drain at Grand Junction, Colo., in 1916. From left to right the series represented are 16 (1–4, plastic consistency), 3 (1–2 plastic consistency), 16, and 16*

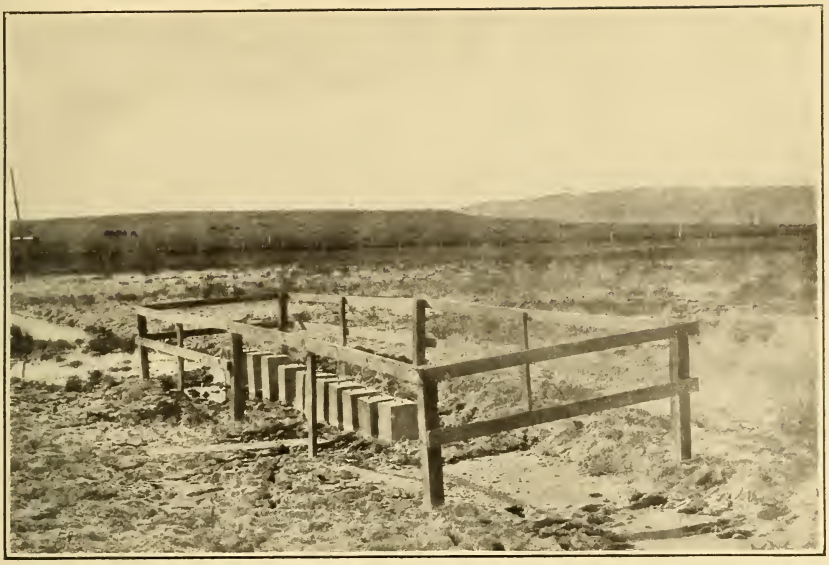

FIG. 60.—*Concrete blocks in place in seeped ground on the Sun River project, 1916. Note the alkali crust on surface of ground. Some disintegration was noted.* (*See page 73.*)

FIG. 61.—*Concrete blocks in place in drainage ditch on the Truckee-Carson project. Note the large incrustations of alkali salts on the surfaces. The concrete is apparently unaffected*