Harris

The Waterproofing of Concrete and Deterioration of Cement with Age —

THE WATERPROOFING OF CONCRETE

AND

DETERIORATION OF CEMENT

WITH AGE

BY

JAMES WALDO HARRIS

B. S., UNIVERSITY OF ILLINOIS, 1886

THESIS

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I HEREBY RECOMMEND THAT THE THESIS PREPARED BY

JAMES WALDO HARRIS

ENTITLED THE WATERPROOFING OF CONCRETE AND DETERIORATION OF CEMENT WITH AGE.

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE PROFESSIONAL DEGREE OF Civil Engineer

F. H. Newell

Head of Department of Civil Engineering

Recommendation concurred in:

A. P. Carman
A. N. Talbot

Committee

THE WATERPROOFING OF CONCRETE

by

James Waldo Harris.

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THE WATERPROOFING OF CONCRETE.

I. INTRODUCTION

1. Preliminary.--The Chicago Surface Lines operate cars through three tunnels under the Chicago River. These are located in La Salle Street, Washington Street, and just north of Van Buren Street, and are known by the names of the streets mentioned.

In 1909-12 an entirely new tunnel was constructed replacing the old one in La Salle Street. The one in Washington Street was reconstructed in 1909-11, all being new except the roof and upper portions of the side walls in the River Section. In 1906-07 the River Section and portions of the approaches of the Van Buren Street Tunnel were reconstructed. In 1915-16 the west end of this tunnel was lowered, the roof and side walls of the River Section were relined with concrete and other portions of the side walls were relined for some distance above track grade.

In all of the tunnels the track grade in the River Section is at Elevation -46 or forty six feet below the assumed level of the Chicago River, and approximately sixty feet below the street level of the city in the vicinity of the tunnels.

In the La Salle Street Tunnel an integral waterproofing was used throughout above track grade. With the exception of the open approaches and the River Section the concrete was placed in ten foot sections. After the completion of the tunnel leaks were

numerous, and these were stopped to a great extent by the method of drilling through or partly through the walls and forcing in grout under 60 to 90 pounds air pressure. At the present time the appearance of water is almost entirely confined to seepage through the vertical joints.

In the Washington Street tunnel no waterproofing was used. Here also after the completion of the tunnel, grouting operations were carried on for the purpose of stopping leaks. There is now much more leakage in this tunnel than in La Salle Street, but there is less now than was observed immediately after the tunnel was reconstructed.

In the Van Buren Street tunnel leaks were numerous previous to the reconstruction in 1915-16. In the work done at that time no waterproofing was used in the sidewalls or roof of the west end of the tunnel, but it was added to the grout which was forced through the walls. It is purely speculative as to the benefit resulting from the waterproofing used in this manner. An integral waterproofing was used in all the concrete lining of the River Section and adjacent side walls, as well as in the grout that was forced through these walls.

2. Purpose and Scope of Investigations.-- Close observation of the above mentioned tunnels since their completion, combined with information as to the details of their construction, has emphasized the necessity of the adoption of such a combination of methods and materials as will increase the possibility of developing a structure that will be watertight when built under the conditions and when subjected to the hydrostatic head that

accompanied the construction of the three tunnels before mentioned.

With a view to obtaining information along this line, certain experiments have been carried on since early in 1916, and the details of the experimental work together with such conclusions as seem to be justified as a result of the work are set forth in the following pages.

The work has involved the making of forty-nine sixteen inch cubes, which are later described in detail. Of these, ten were destroyed during the progress of the work, and ten others, for various reasons, have not been included in all the experimental work, and are not mentioned in the report.

Twenty-nine of the cubes, of various mixtures and involving the use of several different products for the purpose of producing an impermeable concrete, have been described in detail as to construction and as to experiments with regard to their permeability under a constant pressure of twenty seven pounds, and as to the absorption of water by the cubes during certain periods of time.

With each sixteen inch cube and from the same batch of concrete were made three or more six inch cubes for the making of compression tests. These were broken at specified times and the results afford a comparison of the strength of the different concrete mixtures as compared with their permeability.

Table I gives general information as to the twenty-nine cubes above referred to, including the dates on which they were made up and when the pressure was first applied to them.

TABLE 1.

A TABULATION
COVERING INFORMATION RELATIVE TO 16 INCH CUBES
WHICH HAVE BEEN USED IN MAKING TESTS FOR IMPERMEABILITY.

Cube No.	Index Letter	Proportion	Waterproofing used	Made up	Pressure first applied
15	A	1-1.5-3	No	May 5, 1915	May 19, 1916
17	F	1-2-4	Yes	" " "	" " "
18	H	1-2-4	Yes	" " "	" " "
25	B	1-2-4	No	Aug.24, 1916	Sept.25,1916
26	R	1-2-4	Yes	" " "	" " "
27	S	1-2-4	Yes	" " "	" " "
28	F	1-2-4	Yes	" 25 "	" " "
29	P	1-2-4	Yes	" " "	" " "
30	A	1-1.5-3	No	" " "	" " "
31	B	1-2-4	No	Nov.16, 1916	Dec. 18,1916
33	Q	1-2-4	Yes	" " "	" " "
34	A	1-1.5-3	No	" " "	" " "
35	T	1-2-4	Yes	" " "	" " "
36	S	1-2-4	Yes	Dec. 6 "	Jan. 3. 1917
37	B	1-2-4	No	" " "	" " "
38	A	1-1.5-3	No	" " "	" " "
39	B	1-2-4	No	Jan.10, 1917	Feb.14, 1917
40	A	1-1.5-3	No	" " "	" " "
41	R	1-2-4	Yes	" 15, "	" " "
42	T	1-2-4	Yes	" " "	" " "
43	S	1-2-4	Yes	" " "	" " "
51	P	1-2-4	Yes	Feb. 8, "	March 6, "
44	G	1-2-4	Yes	Jan.25, 1917	March 6,1917
45	J	1-2-4	Yes	" " "	" " "
46	K	1-2-4	Yes	" " "	" " "
47	C	1-3-6	No	" 29 "	" " "
48	L	1-3-6	Yes	" 29, "	" " "
49	M	1-3-6	Yes	" " "	" " "
50	N	1-3-6	Yes	Feb. 2, "	" " "

II. TEST PIECES, PLANT AND EQUIPMENT.

3. Test Pieces.--Figure No.1 shows the 16 inch cube which was designed for use in the tests under consideration. Figure No.2 shows the general layout of the cubes and piping system.

The four inch hollow center gives a six inch wall on all sides of the cube. The nine inch flange at the bottom of the four inch pipe was made use of with the object of preventing the water under pressure from following up the sides of the pipe, and its use was attended with satisfactory results in nearly every case.

In this connection it will be noted that the nearest distance from the edge of the flange to the side of the cube is three and one-half inches, making that distance, instead of six inches, which must be considered as the thickness of the wall at that particular point, in event of the bond between the lower side of the flange and the concrete not being sufficient to prevent the water from working to the edge of the flange.

In numerous instances the water did first appear on the middle of the face of the cube opposite the edge of the flange, indicating that the water had traveled around the flange, but as it would also find its way through other portions of the side and also through the bottom of the cube, it is considered that the use of the flange has not diminished the value of the experiment.

The four inch hollow center was obtained by the use of the four inch block shown on the lower portion of Figure 1. This block was cut into nine sections as shown, and the parts were then

Figure 1.

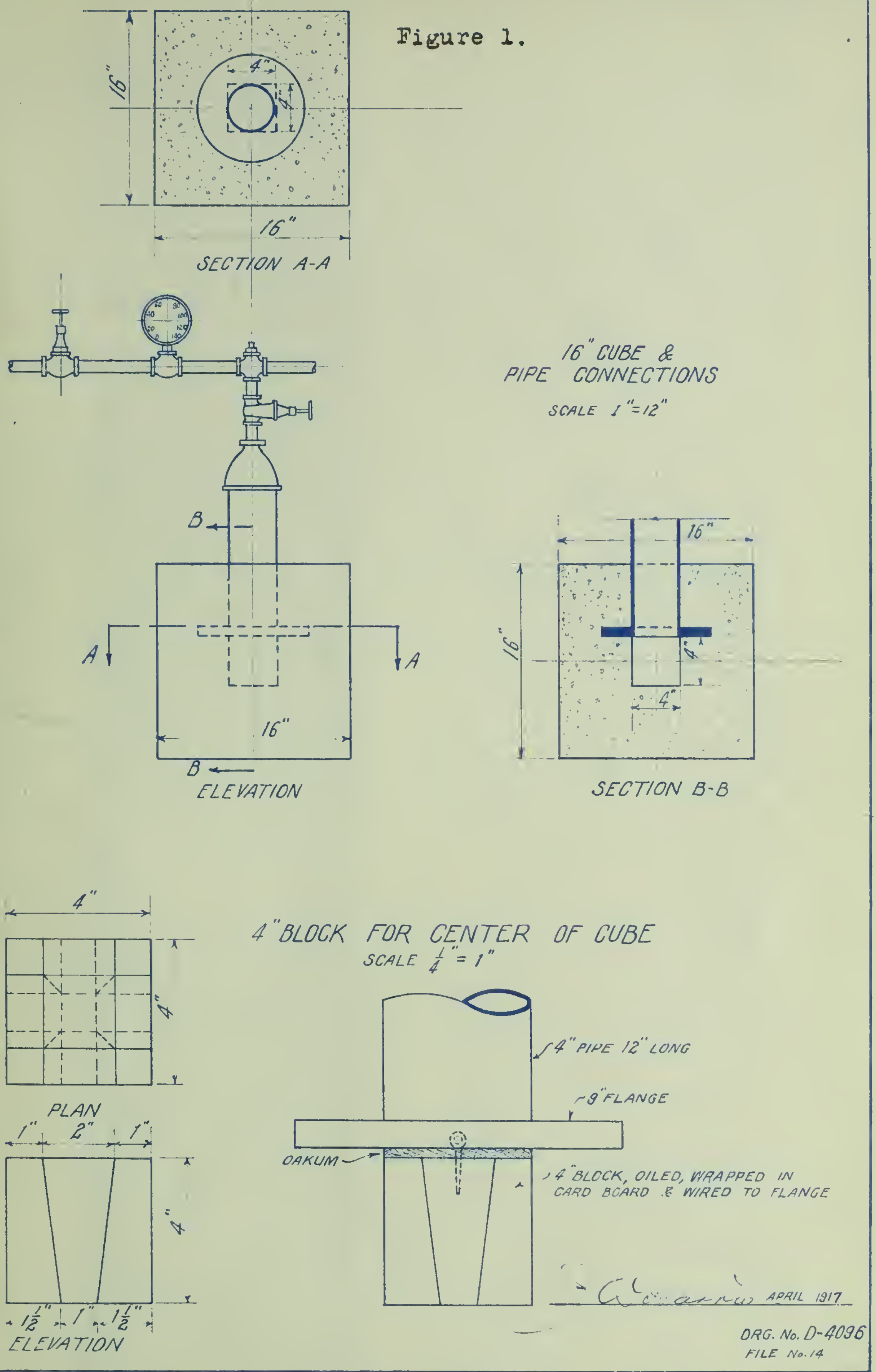
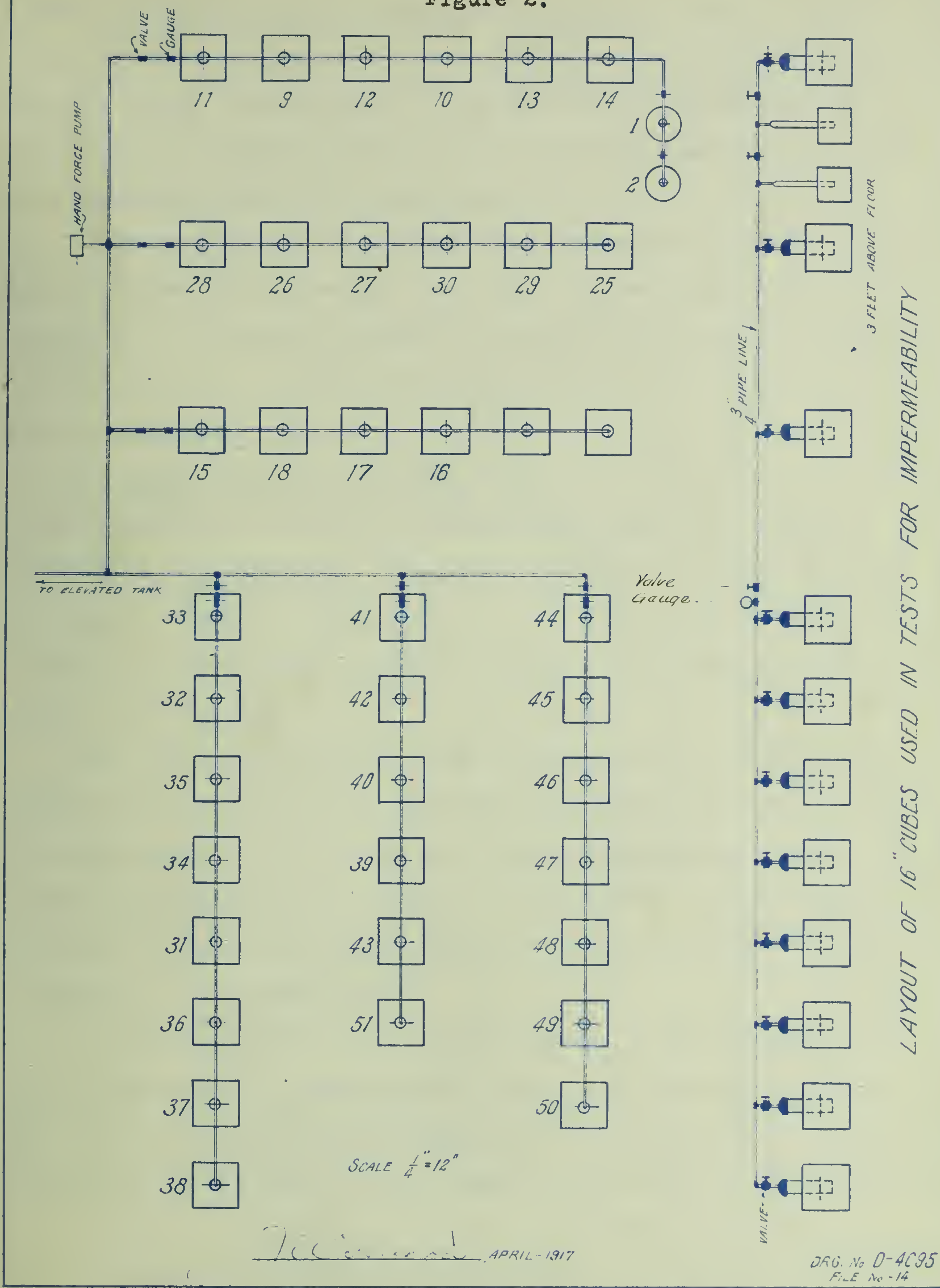

16"
4"
SECTION A-A
16" CUBE &
PIPE CONNECTIONS
SCALE 1"=12"
B
A
ELEVATION
SECTION B-B
4" BLOCK FOR CENTER OF CUBE
SCALE 1/4" = 1"
PLAN
1" 2" 1"
1 1/2" 1" 1 1/2"
4" PIPE 12" LONG
9" FLANGE
OAKUM
4" BLOCK, OILED, WRAPPED IN
CARD BOARD & WIRED TO FLANGE
APRIL 1917
DRG. No. D-4096
FILE No. 14

Figure 2.


VALVE
GAUGE
HAND FORCE PUMP
11
9
12
10
13
14
1
2
28
26
27
30
29
25
15
18
17
16
TO ELEVATED TANK
33
32
35
34
31
36
37
38
41
42
40
39
43
51
44
45
46
47
48
49
50
Valve
Gauge.
3/4" PIPE LINE
3 FEET ABOVE FLOOR
VALVE
LAYOUT OF 16" CUBES USED IN TESTS FOR IMPERMEABILITY
SCALE 1/4"=12"
APRIL-1917
DRG. No D-4C95
FILE No-14

soaked in paraffin oil. They were wrapped in cardboard and wired to the flange with a packing of oakum between the flange and the block. The removal of the block was accomplished by pulling out the center piece, next, the oakum packing, and then the remaining sections of the block.

A gate valve in the upright pipe controlled the water supply for the cube, and the cross connection in the header made it possible, by removing the plug and opening the valve, to insert a graduated stick to measure the depth of water in the cube and four inch pipe.

4. General Layout of Plant.--The cubes were set on a rack three feet above the floor in order to provide for convenient inspection of all sides. They were arranged in groups as shown in Figure 2, and in the pipe line at the head of each group was placed a pressure gauge and a valve for regulating the water supply to the group.

The pipe line connected with the tank furnishing the water supply for the building in which the experiments were carried on, and a pressure of 27 pounds or a head of approximately sixty-two and one-half feet was obtained from this source. A hand pump, by means of which a greater pressure could be obtained, was also connected to the pipe line.

5. Equipment.--This consisted of a 60 ton Ransome hydraulic hand power press for compressive breaks, a Tinius Olsen Machine for tensile breaks, and other smaller accessories required for the testing of cement and for the making up and storing of briquettes.

Forms for the six inch cubes were made of wood with the sides mortised to reduce the chance of warping. These were frequently renewed. The first forms for the 16 inch cubes were made of dressed and matched plank nailed together. Later, a form was developed which was held together by means of four bolts, no nails being used.

III. MATERIALS.

6. Cement.-- Universal Portland Cement was used in all the experimental work described herein.

The proportioning was done according to volume. The cubic feet of stone necessary for the required amount of concrete was determined and the proportionate volume of cement was weighed out at the rate of 94 pounds per cubic foot. This amount, instead of 100 pounds, was used as the weight of one cubic foot, in accordance with the common practice of considering the standard bag of 94 pounds as measuring a cubic foot.

7. Stone and Sand.--One half inch stone, commonly referred to in Chicago as concrete stone was used in all of the cubes made for the waterproofing tests. This was secured from the stock delivered for use in the reconstruction of the Van Buren Street Tunnel, or was ordered directly from the companies furnishing material for that work. Some of it was comparatively clean, and at other times it contained more or less screenings. The stone was used as received.

Torpedo sand was used, and was secured from the work or from

the companies furnishing the sand, as was done with the stone. The weight per cubic foot of stone and sand was determined for each experiment. The material in both cases was dry, or, if it contained any moisture, it was small in amount.

8. Commercial Waterproofing Products.--This term is used in this report in referring to materials which are manufactured and used only for the purpose of producing impervious concrete, as distinguished from other materials, hydrated lime and powdered limestone, the use of which as a waterproofing factor is incidental.

Commercial waterproofing materials, used for the purpose of waterproofing concrete by the integral method, are furnished in liquid, powder, and paste forms. No liquid waterproofing materials have been used in the tests considered in this report.

Waterproofing powders, are, in general, made use of by mixing the powder dry with the cement in some given proportion. This is usually at the rate of two pounds of the powder to one bag of cement, or 12 pounds of powder to the cubic yard of 1-2-4 mix of concrete.

In case it is proposed to make use of this form in any given piece of construction and the mixing of the powder with the cement is to be done by the contractor, it is essential that the mixing be done before the cement is brought to the job. The mixing is usually done by passing the two materials in the proper proportions through a mill. The labor involved in the necessary handling, sacking, weighing, etc. together with the cost, maintenance and operation of the mixing equipment, and the expense of

convenient working and storage facilities, render it important that all the cost details be thoroughly considered before this method is adopted.

A reduced cost is obtained by having the mixing done at the cement mills on special order, or in some cases, the cement with the powder incorporated with it in some stated proportion, can be purchased under a specified brand.

The waterproofing paste is generally considered to have an advantage over the powder. The method of using the paste is to mix it with an equal volume of water and then to combine this mixture with additional volumes of water; the amount varying with different products put out by different manufacturers.

The chief advantages claimed for the paste form is that by incorporating it with the water it is thoroughly and evenly distributed throughout the concrete mass. The amount to be used is sometimes expressed in pounds of paste per cubic yard of concrete, this amount varying greatly with different products and different manufacturers. The more common way of expressing the amount to be used is to state the number of gallons of paste with relation to some definite number of gallons of water. This method is inexact, and in fact is indeterminate, on account of varying ideas as to how much water should be or is being used in any particular piece of concrete construction.

A statement of the number of pounds of paste required for a 1-2-4 mix of concrete is definite and makes it possible for one to figure a cost per cubic yard for the waterproofing factor. A

statement that one gallon of paste should be used to a certain number of gallons of water does not enable one to fix on any definite amount as representing the cost of the waterproofing factor.

Sand is often saturated with water when delivered to a contractor. Stone may contain much or little water. And it is beyond question that there will be less water to be added at the mixer if the stone and sand are saturated than there will be if it is in a dry condition. If the amount of paste to be used is to be expressed in terms relative to the amount of water used, it should be based upon the actual water content of a cubic yard of concrete, and this, if desired, can be ascertained within fairly accurate limits.

In the experiments detailed later in this report, commercial waterproofing products in powder or paste form have been used in cubes 26, 27, 29, 33, 35, 36, 41, 42, 43 and 51.

9. Hydrated Lime.--Much has been said for and against the use of hydrated lime as a means of making concrete impervious to water. Here again misunderstanding has resulted from the use of indefinite terms, and as a result of the lack of definite knowledge of the subject.

There is a great variation in the chemical composition of hydrated limes. Some are high in calcium and others in magnesium content. It is generally assumed that in adding hydrated lime to concrete it acts only as a void filler, thus increasing the density, but there may also be chemical action, and if so, the effect resulting from the use of any particular brand can be determined only by test.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

The amount of hydrated lime to be added when it is intended to make use of it as a means for providing impervious concrete, is usually expressed as some given percentage of the amount of cement used. There is a wide variation as to the percentage recommended by different users.

In the experimental work recorded herein hydrated lime has been used in cubes 17, 18, 28, 44, 45, 49 and 50.

The effect on the compressive strength of concrete resulting from the use of hydrated lime should be taken into consideration.

10. Powdered Limestone.-- This material, to the best of my knowledge, is not rated as a waterproofing agent, but it is here given that distinction because the results following its use in the case of cubes 46 and 48 seem to justify it. It is not intended here to recommend its use as a waterproofing factor, as the experimental work has not been sufficiently extensive to warrant such recommendation.

There would seem to be no question but that in this case use is made of an inert substance which acts only as a void filler, and without any possibility of chemical action upon the other ingredients. In testing for fineness the powdered stone used in the above mentioned cubes, 40 per cent passed the 200 sieve and 73 per cent passed the 100 sieve.

The apparent effect of the addition of this material on the compressive strength of the concrete will attract attention. The results given can be considered only as an indication of possible effects, and further experimental work will be necessary before

any definite conclusion can be reached in regard to this particular point.

Table 2 is a key to the index letters used in connection with the various cubes, and gives details as to kinds and amounts used of the various waterproofing products.

IV. MAKING UP THE CUBES.

11. Regarding Materials.--The concrete was mixed on a large sheet of galvanized iron laid on the floor of the room in which all the experimental work herein described was carried on. The floor was first swept clean. The proportion to be used and the number and size of cubes to be made from one batch of concrete was decided upon, and the number of cubic feet of stone determined, provision being made so that there would be some excess material after all the cubes were made up.

The weight of a cubic foot of stone was ascertained, and the total amount of stone required was weighed out in accordance therewith. The same method was followed with the sand, and the required volume of cement was weighed out at the rate of 94 pounds per cubic foot. The stone was spread out in one pile, and the sand in another with the cement over it. Sand and cement were mixed dry, and the mixture was then spread over the stone and the entire mass was mixed dry. A large pail filled with water was weighed, and after the mixing operation was completed a reweighing gave the exact amount of water used. Care was taken not to lose

TABLE 2.

KEY TO INDEX LETTERS.

INDEX LETTER	CUBE NUMBERS	PROPORTIONS	DESCRIPTION
A	15-30-34-38-40	1-1.5-3	No Waterproofing
B	25-31 37-39	1-2-4	No Waterproofing
C	47	1-3-6	No Waterproofing

		PROPORTIONS	WATERPROOFING USED	AMOUNT LBS.	RATE PER CU.YD. LBS.
F	17-28	1-2-4	5% Hydrated Lime Calcium	2.84	27.
G	44	1-2-4	8% Hydrated Lime Calcium	5.26	45.
H	18	1-2-4	10% Hydrated Lime Magnesium	5.68	54.
J	45	1-2-4	8% Hydrated Lime Magnesium	5.26	45.
K	46	1-2-4	8% Powdered Stone	5.26	45.
L.	48	1-3-6	12% Powdered Stone	5.64	48.
M.	49	1-3-6	12% Hydrated Lime Calcium	5.64	48.
N	50	1-3-6	12% Hydrated Lime Magnesium	5.64	48.
P.	29-51	1-2-4	Toxement-Powder	1.2 & 1.33	11.4
Q	33	1-2-4	Medusa---Powder	1.2	11.4
R	26-41	1-2-4	Ceresit--Paste	1.05 & 1.5	10 & 12.7
S	27-36-43	1-2-4	Trus-Con-Paste	.53 & .69	5 & 6
T	35-42	1-2-4	Medusa---Paste	1.2 & 1.3	11.4

[illegible]

any water by allowing it to run off the galvanized iron. It was desired to obtain a consistency that would correspond closely to what would be proper in actual practice, and this was judged solely by the appearance of the mass.

In event that a paste waterproofing material was to be used, a certain amount was weighedout, mixed with an equal volume of water, and then added to such an amount of water as was judged would be required. In case a waterproofing powder or hydrated lime or powdered stone was to be used, it was weighed out, spread on top of the cement and sand, and the whole mass of dry material was given a few extra turns.

After the cubes were made up all the excess material was swept up, weighed and recorded.

The several pages of Table 3 show the details of the making up of the various cubes in accordance with the above outline.

12. <u>Other Details</u>.--The inside of the wooden forms was given a coat of paraffin oil some hours before the making up of the cubes. The flange and the lower half of the four inch pipe were thoroughly cleaned and given a coat of acid. The four inch block previously referred was fastened to the lower side of the flange, and the reducer was turned on to the top of the four inch pipe. Cleets across the top of the form and close against the pipe under the reducer were so placed as to locate the four inch block exactly in the center of the 16 inch form.

The form was filled with concrete in three lifts, the first being about to the bottom of the four inch block, and the next to

TABLE 3.

RECORD OF MAKING UP OF 16" AND 6" CUBES FOR TESTS OF IMPERMEABILITY AND COMPRESSIVE STRENGTH

Made Up	May 5,'16	May 5, '16	May 5,'16
Index Letter	A	F	H
16" Cubes numbered	15	17	18
6" Cubes. Number made	3	3	3
Proportion	1-1.5-3	1-2-4	1-2-4
Crushed Stone. Cu.Ft.	2.5	2.5	2.5
Torpedo Sand. " "	1.25	1.25	1.25
Cement. " "	.625	.625	.833
" Lbs.			78.3
Waterproofing.used. Lbs.	None	2.84	5.68

Details are not available as to exact weights of stone, sand and water used in making up the above cubes.

T A B L E 3. Continued.

RECORD OF MAKING UP OF 16" AND 6" CUBES FOR TESTS OF IMPERMEABILITY AND COMPRESSIVE STRENGTH

Made Up	Aug.24,'16	Aug.24,'16	Aug.24,'16
Index Letter	B	R	S
16" Cubes numbered	25	26	27
6" Cubes. Number made	3	3	3
Proportion	1-2-4	1-2-4	1-2-4
Concrete. Cu.Yds.	.103	.105	.108
Crushed Stone. Cu.Ft.	2.5	2.5	2.5
" " Lbs.per Cu.Ft.	82.5	82.5	82.5
" " Lbs. used	206.25	206.25	206.25
Torpedo Sand. Cu.Ft.	1.25	1.25	1.25
" " Lbs.per Cu.Ft.	106	106	106
" " Lbs. used	132.5	132.5	132.5
Cement. Cu.Ft.	.625	.625	.625
" Lbs. used	58.75	58.75	58.75
Waterproofing. Lbs. used	None	1.05	.53
Water. Lbs. used	40	36	36
" Per Cent used	10.6	9.03	9.04
Water. Lbs.per Cu.Yd.	388.	343.	333.
" Gals." " "	46.5	41.1	40.0
Surplus Material. Lbs.	18	28	39

Per Cent of water used shows its relation in weight to the total weight of other materials used.

T A B L E 3. Continued

RECORD OF MAKING UP OF 16" AND 6" CUBES FOR TESTS OF IMPERMEABILITY AND COMPRESSIVE STRENGTH

Made Up	Aug.25,'16	Aug.25,'16	Aug.25,'16
Index Letter	F	P	A
16" Cubes numbered	28	29	30
6" Cubes. Number made	3	3	3
Proportion	1-2-4	1-2-4	1-1.5-3
Concrete. Cu.Yds.	.104	.107	.11
Crushed Stone. Cu.Ft.	2.5	2.5	2.5
" " Lbs.per Cu.Ft.	82.5	82.5	82.5
" " Lbs. used	206.25	206.25	206.25
Torpedo Sand. Cu.Ft.	1.25	1.25	1.25
" " Lbs.per Cu.Ft.	106	106	110
" " Lbs. used	132.5	132.5	137.5
Cement. Cu.Ft.	.625	.625	.833
" Lbs. used	58.75	58.75	78.30
Waterproofing. Lbs. used	2.84	1.2	None
Water. Lbs. used	36	36	38
" Per Cent used	8.99	9.03	9
Water. Lbs.per Cu.Yd.	346.	336.	345.
" Gals.per " "	41.5	40.3	41.3
Surplus Material. Lbs.	23	35	51

T A B L E 3. Continued

RECORD OF MAKING UP OF 16" AND 6" CUBES FOR TESTS OF IMPERMEABILITY AND COMPRESSIVE STRENGTH

Made Up	Nov.16,'16	Nov.16,'16	Nov.16,'16
Index Letter	B	Q	A
16" Cubes numbered	31	33	34
6" Cubes. Number made	3	3	3
Proportion.	1-2-4	1-2-4	1-1.5-3
Concrete. Cu.Yds.	.104	.107	.111
Crushed Stone. Cu.Ft.	2.5	2.5	2.5
" " Lbs.per Cu.Ft.	84.	84.	84.
" " Lbs. used.	210	210	210
Torpedo Sand. Cu.Ft.	1.25	1.25	1.25
" " Lbs.per Cu.Ft.	104.2	104.25	104.25
" " Lbs. used	130.25	130.31	130.31
Cement. Cu.Ft.	.625	.625	.833
" Lbs. used.	58.75	58.75	78.30
Waterproofing. Lbs. used	None	1.2	None
Water. Lbs. used	41.	42.	43.75
" Per Cent used	10.2	10.49	10.45
Water. Lbs. per Cu.Yd.	394.	392.	394.
" Gals. " " "	47.2	47.1	47.2
Surplus Material. Lbs.	23.	34.5	52.

TABLE 3. Continued.

RECORD OF MAKING UP OF 16" AND 6" CUBES FOR TESTS OF IMPERMEABILITY AND COMPRESSIVE STRENGTH

Made Up	Nov.16,'16	Dec.6,'16	Dec.6,'16
Index Letter	T	S	B
16" Cubes numbered	35	36	37
6" Cubes. Number made	3	7	7
Proportion	1-2-4	1-2-4	1-2-4
Concrete. Cu.Yds.	.107	.12	.118
Crushed Stone. Cu.Ft.	2.5	2.88	2.88
" " Lbs.per Cu.Ft.	84	84	84
" " Lbs. used	210	241.92	241.92
Torpedo Sand. Cu.Ft.	1.25	1.44	1.44
" " Lbs.per Cu.Ft.	104.25	103	103
" " Lbs. used	130.31	148.32	148.32
Cement. Cu.Ft.	.625	.72	.72
" Lbs. used	58.75	67.68	67.68
Waterproofing. Lbs. used	1.2	.69	None
Water. Lbs. used	42	46.5	47
" Per Cent used	10.49	10.11	10.26
Water. Lbs. per Cu.Yd.	392	387	398
" Gals. per Cu.Yd.	47.0	46.0	47.8
Surplus Material. Lbs.	35	13.75	6

T A B L E 3. Continued

RECORD OF MAKING UP OF 16" AND 6" CUBES FOR TESTS OF IMPERMEABILITY AND COMPRESSIVE STRENGTH

Made Up	Dec.6,'16	Jan.10,'17	Jan.10,'17
Index Letter	A	B	A
16" Cubes numbered	38	39	40
6" Cubes. Number made	7	6	7
Proportion	1-1.5-3	1-2-4	1-1.5-3
Concrete. Cu.Yds.	.117	.116	.121
Crushed Stone. Cu.Ft.	2.88	2.8	2.8
" " Lbs.per Cu.Ft.	84	84	84
" " Lbs. used	241.92	235.2	235.2
Torpedo Sand. Cu.Ft.	1.44	1.4	1.4
" " Lbs. per Cu.Ft.	107	100.5	100.5
" " Lbs. used	154.08	140.70	140.70
Cement. Cu.Ft.	.96	.7	.93
" Lbs. used	90.25	65.8	87.5
Waterproofing. Lbs. Used	None	None	None
Water. Lbs. used	50	45	47.5
" Per Cent used	10.28	10.18	10.25
Water. Lbs. per Cu.Yd.	427	388	393
" Fals. " " "	51.2	46.5	47.1
Surplus Material. Lbs.	None	14	17

T A B L E 3. Continued

RECORD OF MAKING UP OF 16" AND 6" CUBES FOR TESTS OF IMPERMEABILITY AND COMPRESSIVE STRENGTH

Made Up	Jan.15,'17	Jan.15,'17	Jan.15,'17
Index Letter	R	T	S
16" Cubes numbered	41	42	43
6" Cubes. Number made	6	6	6
Proportion	1-2-4	1-2-4	1-2-4
Concrete. Cu.Yds.	.117	.118	.116
Crushed Stone. Cu.Ft.	2.8	2.8	2.8
" " Lbs.per Cu.Ft.	84	84	84
" " Lbs. used	235.2	235.2	235.2
Torpedo Sand. Cu.Ft.	1.4	1.4	1.4
" " Lbs.per Cu.Ft.	100.5	100.5	100.5
" " Lbs. used	140.70	140.70	140.70
Cement. Cu.Ft.	.7	.7	.7
" Lbs. used	65.8	65.8	65.8
Waterproofing. Lbs. used	1.5	1.3	.69
Water. Lbs. used	45.0	50.0	45.0
" Per Cent used	10.15	11.29	10.17
Water. Lbs. per Cu.Yd.	385	424	388
" Gals. " " "	46.2	50.8	46.5
Surplus Material. Lbs.	19	24	16

T A B L E 3. Continued

RECORD OF MAKING UP OF 16" AND 6" CUBES FOR TESTS OF IMPERMEABILITY AND COMPRESSIVE STRENGTH

Made Up	Jan.25,'17	Jan.25,'17	Jan.25,'17
Index Letter	G	J	K
16" Cubes numbered	44	45	46
6" Cubes. Number made	6	6	6
Proportion	1-2-4	1-2-4	1-2-4
Concrete. Cu.Yds.	.117	.117	.115
Crushed Stone. Cu.Ft.	2.8	2.8	2.8
" " Lbs.per Cu.Ft.	85	85	85
" " Lbs. used	238.0	238.0	238.0
Torpedo Sand. Cu.Ft.	1.4	1.4	1.4
" " Lbs.per Cu.Ft.	100.0	100.0	100.0
" " Lbs. used	140.0	140.0	140.0
Cement. Cu.Ft.	.7	.7	.7
" Lbs. used	65.8	65.8	65.8
Waterproofing. Lbs. used	5.26	5.26	5.26
Water. Lbs. used	45.0	45.5	43.5
" Per Cent used	10.02	10.13	9.69
Water. Lbs. per Cu.Yd.	385	389	378
" Gals. " " "	46.2	46.6	45.3
Surplus Material. Lbs.	19	21	13

T A B L E 3. Continued.

RECORD OF MAKING UP OF 16" AND 6" CUBES FOR TESTS OF IMPERMEABILITY AND COMPRESSIVE STRENGTH

Made Up	Jan.29,'17	Jan.29,'17	Feb.2,'17
Index Letter	C	L	M
16" Cubes numbered	47	48	49
6" Cubes. Number made	6	6	6
Proportion	1-3-6	1-3-6	1-3-6
Concrete. Cu.Yds.	.115	.116	.118
Crushed Stone. Cu.Ft.	3.0	3.0	3.0
" " Lbs. per Cu.Ft.	85.0	85.0	84.0
" " Lbs. used	255.0	255.0	252.0
Torpedo Sand. Cu.Ft.	1.5	1.5	1.5
" " Lbs. per Cu.Ft.	100.0	100.0	100.0
" " Lbs. used	150.0	150.0	150.0
Cement. Cu.Ft.	.5	.5	.5
" Lbs. used	47.0	47.0	47.0
Waterproofing. Lbs. used	None	5.64	5.64
Water. Lbs. used	42.0	40.0	41.0
" Per Cent used	9.29	8.74	9.02
Water. Lbs. per Cu.Yd.	365	345	348
" Gals. " " "	43.8	41.4	41.7
Surplus Material. Lbs.	10.0	14.0	23.

T A B L E 3. Continued.

RECORD OF MAKING UP OF 16" AND 6" CUBES FOR TESTS OF IMPERMEABILITY AND COMPRESSIVE STRENGTH

Made Up	Feb.2,'17	Feb.8,'17
Index Letter	N	P
16" Cubes numbered	50	51
6" Cubes. Number made	6	6
Proportion	1-3-6	1-2-4
Concrete. Cu.Yds.	.116	.116
Crushed Stone. Cu.Ft.	3.0	2.8
" " Lbs.per Cu.Ft.	84.0	84.0
" " Lbs. used	252.0	235.2
Torpedo Sand. Cu.Ft.	1.5	1.4
" " Lbs. per Cu.Ft.	100.0	100.0
" " Lbs. used	150.0	140.0
Cement. Cu.Ft.	.5	.7
" Lbs. used	47.0	65.8
Waterproofing. Lbs. used	5.64	1.33
Water. Lbs. used	39.5	44
" Per Cent used	8.69	9.94
Water. Lbs. per Cu.Yd.	341.	379
" Gals. " " "	40.9	45.5
Surplus Material. Lbs.	17.	18.5

the top of the flange. As the concrete for each lift was placed it was thoroughly tamped and troweled around the side of the form. The forms for the 6 inch cubes were filled in two lifts. More effort was exerted in the tamping and spading than would be used in a larger operation, and it is probable that the extra labor produced more favorable results than would be secured by the use of exactly the same materials under less favorable conditions. Every effort was made to do all the work in connection with all the cubes in an equally thorough manner, in order to obtain results that would be comparative so far as the various cubes are concerned.

13. Removal from Forms.--Twenty four hours after the 16 inch forms were filled, the reducer was taken off, the four inch block was removed, and the bolts holding the form together were loosened. Usually the forms were not removed from the 16 inch cubes for another twenty four hours. The 6 inch cubes were removed about twenty four hours after being made.

14. Six Inch Cubes.--It will be noticed that with each 16 inch cube, up to and including No.35, three six inch cubes were made. These were placed on the floor in the room where they were made and allowed to dry out, no further attention being paid to them until they were broken, one each at the age of 7 days, 28 days and 3 months.

Beginning with No. 36, the number of six inch cubes was increased, and of these, three were allowed to dry out as before and the remaining three or four, after being removed from the

forms, were kept wet by sprinkling several times a day until they were seven days old. The tests showing the compressive strength of these cubes and a comparison of the strength of the "dry" with the "wet" groups will be shown later in this report.

15. Water Content.--Beginning with cube No.25, particular attention was paid to weighing and recording, the weight of everything entering into the make-up of the cubes.

Table 4 shows the percentage of water used in the various experiments, and reduces the percentages given to pounds and gallons per cubic yard of concrete. It also shows the calculated number of cubic feet of dry material per cubic yard of concrete, and the number of pounds of water per cubic foot of dry material.

Emphasis is given to this feature of the work because of the general difficulty of obtaining from engineers or contractors exact information as to the amount of water used per cubic yard of concrete. When figures are given the amount is usually underestimated.

It is to be borne in mind that the figures given in Table 4 are based on hand mixing. A less amount would probably have given a similar consistency if the mixing were done by machine.

The concrete as it was mixed might be described as of a "mushy" consistency in the case of nearly all of the cubes. The most decided exception to this, so far as appearance was concerned, was in the cases of 48, 49 and 50. The concrete making up these cubes was much drier in appearance than that in the case of No.47. In the latter case, a slight amount of tamping was all that was

TABLE 4.

DETAILS RELATIVE TO
AMOUNT OF WATER USED
PER CUBIC YARD OF CONCRETE
AND PER CUBIC FOOT OF DRY MATERIALS

Cube No.	Proportion	Per Cent of Water used	Amount of water per Cubic Yard of Concrete Lbs.	Gal.	Dry Material per Cu.Yd.of Concrete Cu.Ft.	Water per Cu.Ft. of dry Material Lbs.
47	1-3-6	9.29	365	43.8	43.48	8.39
48	1-3-6	8.74	345	41.4	43.10	8.00
49	1-3-6	9.02	348	41.7	42.37	8.21
50	1-3-6	8.69	341	40.9	43.10	7.91
	Average	8.93	350	41.9	43.01	8.12
25	1-2-4	10.60	388	46.5	42.47	9.14
26	1-2-4	9.03	343	41.1	41.65	8.23
27	1-2-4	9.04	333	40.0	40.51	8.22
28	1-2-4	8.99	346	41.5	42.07	8.22
29	1-2-4	9.03	336	40.3	40.89	8.22
31	1-2-4	10.20	394	47.2	42.07	9.37
33	1-2-4	10.49	392	47.1	40.89	9.59
35	1-2-4	10.49	392	47.0	40.89	9.59
36	1-2-4	10.11	387	46.0	42.00	9.21
37	1-2-4	10.26	398	47.8	42.71	9.32
39	1-2-4	10.18	388	46.5	42.24	9.18
41	1-2-4	10.15	385	46.2	41.88	9.19
42	1-2-4	11.29	424	50.8	41.52	10.21
43	1-2-4	10.17	388	46.5	42.24	9.18
44	1-2-4	10.02	385	46.2	41.88	9.19
45	1-2-4	10.13	389	46.6	41.88	9.29
46	1-2-4	9.69	378	45.3	42.61	8.87
51	1-2-4	9.94	379	45.5	42.24	8.97
	Average	9.99	379	45.5	41.81	8.51
30	1-1.5-3	9.0	345	41.3	41.66	8.28
34	1-1.5-3	10.45	394	47.2	41.29	9.54
38	1-1.5-3	10.28	427	51.2	45.13	9.46
40	1-1.5-3	10.25	393	47.1	42.40	9.27
	Average	10.00	390	46.7	42.62	9.14

Per Cent of water used shows its relation in weight to the total weight of other materials used.

[illegible]

required, and the cube was made up in about the average time used for the cubes of 1-2-4 mix.

Each one of the above three cubes required from two to three times the amount of work that was necessary in the case of 47, but the tamping and spading were continued until a jelly like consistency was obtained.

In making up these four 1-3-6 cubes it was not expected to produce an impervious concrete. They were made up principally for the purpose of comparison with other proportions. The results, so far as both the 16 inch and the 6 inch cubes are concerned are somewhat surprising, and undoubtedly can be used as a demonstration of results that it is possible to obtain by intelligent workmanship.

In connection with the question of water content, it is to be noted particularly that the change from one consistency to another, as from "plastic" to "quaking", to "mushy", to "fluid", represents actually a very slight increase in percentage, and the amount of water required to produce the various consistencies is dependent upon the amount of cement used, the absorptive qualities of the aggregate, and also upon the manner of mixing and the length of time the mixing is carried on.

V. CONDUCTING A TEST.

16. The Pressure Test.--Reference is here made to a test conducted March 6, 1917, as shown in the various pages of Table 5.

T A B L E 5.

TEST MADE MARCH 6, 1917.

Cube Number	15		17		18	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
Cubes & Pipe Line. filled with water.	9.35 A.M.		9.35 A.M.		9.35 A.M.	
10 lbs. pressure						
20 " "						
27 " "	9.35		9.35		9.35	
Water Shows		Wetted Surface. Sq.In.		Wetted Surface. Sq.In.		Wetted Surface Sq.In.
Top			9.55	9	9.55	40
Bottom						
N.Side						
E. "					12.05	25
S. "					11.20	30
W. "					11.10	30
Pressure off	4.00 P.M.		4.00 P.M.		4.00 P.M.	
Total Wetted Surface. Sq.In.				9		125

ABSORPTION AS SHOWN BY DECREASE IN DEPTH OF WATER IN 4" PIPE

	Depth In.	Depth In.	Depth In.
March 7, 1917	17	17.25	17.25
" 8, "	17	17.25	16.625
" 9, "	17	17.25	15.875
" 10, "	16.875	17.125	15.
" 11, "	16.875	17.125	14.375
" 12, "	16.875	17.	13.375
" 13, "	16.875	17.	13.25
" 14, "	16.875	17.	12.625
" 15, "	16.75	16.875	12.
" 16, "	16.75	16.75	11.5
" 17, "	16.75	16.625	11.
March 7 to 17 Loss in depth.In.	.25	.625	6.25
March 7 to 27 Loss in depth.In.	.625	1.25	11.00
March 7 to April 6 Loss in depth.In.	.875	1.75	13.25

TABLE 5. Continued.

TEST MADE MARCH 6, 1917.

Cube Number	25		26		27	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
Cubes & Pipe Line. filled with water.	9.40 A.M.		9.40 A.M.		9.40 A.M.	
10 lbs.pressure						
20 " "						
27 " "	9.40		9.40		9.40	
Water Shows		Wetted Surface Sq.In.		Wetted Surface Sq.In.		Wetted Surface Sq.In.
Top					9.55	10
Bottom	11.10	50.			9.55	60
N. Side	12.00	30.			10.25	60
E. "	10.50	40.			10.50	15
S. "	11.30	60.			11.03	25
W. "	11.15	60.			11.03	50
Pressure off	4.00 P.M.		4.00 P.M.		4.00 P.M.	
Total Wetted Surface. Sq.In.		240.				220

ABSORPTION AS SHOWN BY DECREASE IN DEPTH OF WATER IN 4" PIPE

	Depth In.	Depth In.	Depth In.
March 7, 1917	17.	17.5	17.75
" 8, "	16.625	17.375	17.75
" 9, "	16.0	17.125	17.75
" 10, "	15.375	17.	17.625
" 11, "	14.875	16.875	17.375
" 12, "	14.375	16.875	17.125
" 13, "	13.875	16.750	17.0
" 14, "	13.25	16.625	16.75
" 15, "	12.75	16.625	16.625
" 16, "	12.375	16.50	16.375
" 17, "	11.875	16.375	16.125
March 7 to 17 Loss in depth.In.	5.125	1.125	1.625
March 7 to 27 Loss in depth.In.	9.375	1.875	4.00
March 7 to April 6 Loss in depth.In.	13.00	2.50	6.00

TABLE 5. Continued.

TEST MADE MARCH 6, 1917.

Cube Number	28		29		30	
	A.M. or P.M.		A.M. or P.M.		A.M. or P.M.	
Cubes & Pipe Line filled with water	9.40 A.M.		9.40 A.M.		9.40 A.M.	
10 lbs. pressure						
20 " "						
27 " "	9.40		9.40		9.40	
Water Shows		Wetted Surface Sq.In.		Wetted Surface Sq.In.		Wetted Surface Sq.In.
Top			10.45	40.		
Bottom						
N. Side						
E. "						
S. "						
W. "			12.50	5.		
Pressure off	4.00 P.M.		4.00 P.M.		4.00 P.M.	
Total Wetted Surface. Sq.In.		0		45.		0

ABSORPTION AS SHOWN BY DECREASE IN DEPTH OF WATER IN 4" PIPE

	Depth In.	Depth In.	Depth In.
March 7, 1917	18.	17.	17.375
" 8, "	17.875	16.5	17.375
" 9, "	17.75	15.75	17.375
" 10, "	17.50	15.	17.375
" 11, "	17.25	14.25	17.25
" 12, "	16.875	13.625	17.25
" 13, "	16.75	13.	17.125
" 14, "	16.625	12.5	17.125
" 15, "	16.375	12.	17.125
" 16, "	16.25	11.5	17.
" 17, "	16.0	11.125	17.
March 7 to 17 Loss in depth. In.	2.00	5.875	.375
March 7 to 27 Loss in depth. In.	3.75	9.875	.75
March 7 to April 6 Loss in depth. In.	5.25	13.00	1.375

TABLE 5. Continued.

TEST MADE MARCH 6, 1917

Cube Number	31		33		34	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
Cubes & Pipe Line. filled with water.	9.30 A.M.		9.30 A.M.		9.30 A.M.	
10 lbs.pressure	10.05		10.05		10.05	
20 " "						
27 " "	10.15		10.15		10.15	
Water Shows		Wetted Surface. Sq.In.		Wetted Surface. Sq.In.		Wetted Surface Sq.In.
Top	10.30	40.	10.25	25.		
Bottom	10.50	140.	10.35	140.		
N.Side	12.50	110.	10.45	140.		
E. "	11.50	130.	10.55	130.		
S. "	12.00	90.	11.08	110.		
W. "	11.30	110.	11.10	100.		
Pressure off	3.15 P.M.		2.00 P.M.		4.00 P.M.	
Total Wetted Surface. Sq.In.		620.		645.		0

ABSORPTION AS SHOWN BY DECREASE IN DEPTH OF WATER IN 4" PIPE

	Depth In.	Depth In.	Depth In.
March 7, 1917	17.5	17.5	17
" 8, "	15.75	16.625	17
" 9, "	14.	15.5	17.
" 10, "	12.25	14.5	17.
" 11, "	10.625	13.75	16.875
" 12, "	9.25	12.75	16.875
" 13, "	8.	12.	16.75
" 14, "	6.75	11.25	16.75
" 15, "	5.375	10.5	16.625
" 16, "	4.	10.	16.50
" 17, "		9.25	16.375
March 7 to 17 Loss in depth.In.	13.5	8.25	.625
March 7 to 27 Loss in depth.In.		13.5	1.5
March 7 to April 6 Loss in depth.In.			2.25

[illegible]

TABLE 5. Continued.

TEST MADE MARCH 6, 1917

Cube Number	35		36		37	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
Cubes & Pipe Line. filled with water.	9.30 A.M.		9.30 A.M.		9.30 A.M.	
10 lbs. pressure	10.05		10.05		10.05	
20 " "						
27 " "	10.15		10.15		10.15	
Water Shows		Wetted Surface. Sq.In.		Wetted Surface. Sq.In.		Wetted Surface Sq.In.
Top	11.15	30			10.10	50
Bottom	11.15	70	11.02	80	11.55	120
N.Side	11.55	50	11.45	120	10.20	130
E. "	10.40	130	10.50	150	11.05	150
S. "	11.00	70	11.07	85	11.00	100
W. "	11.30	60	11.30	60	10.50	190
Pressure off	1.45 P.M.		4.00 P.M.		3.40 P.M.	
Total Wetted Surface.Sq.In.		410		495		740

ABSORPTION AS SHOWN BY DECREASE IN DEPTH OF WATER IN 4" PIPE

	Depth In.	Depth In.	Depth In.
March 7, 1917	18	17.75	17.25
" 8, "	16.5	17.25	16.875
" 9, "	15.5	16.875	15.75
" 10, "	14.125	16.25	15.
" 11, "	13.125	15.75	14.125
" 12, "	12.25	15.25	13.125
" 13, "	11.625	14.875	12.625
" 14, "	10.875	14.50	11.875
" 15, "	10.125	14.	11.
" 16, "	9.5	13.5	10.375
" 17, "	9.	13.	9.50
March 7 to 17 Loss in depth.In.	9.00	4.75	7.75
March 7 to 27 Loss in depth.In.	14.0	8.5	13.25
March 7 to April 6 Loss in depth.In.		11.75	

[illegible]

[illegible]

[illegible]

TABLE 5. Continued.

TEST MADE MARCH 6, 1917

Cube Number	38		39		40	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
Cubes & Pipe Line. filled with water.	9.30 A.M.		9.20 A.M.		9.20 A.M.	
10 lbs.pressure	10.05		9.52		9.52	
20 " "						
27 " "	10.15		10.16		10.16	
Water Shows		Wetted Surface. Sq.In.		Wetted Surface. Sq.In.		Wetted Surface Sq.In.
Top	11.00	10	10.01	25	10.02	25
Bottom	11.00	60	10.50	100		
N.Side	1.45	20	11.00	100	11.02	10
E. "	12.05	25	10.50	120		
S. "	10.45	40	12.15	50	3.20	2
W. "	11.30	30	11.00	70	1.40	10
Pressure off	4.00 P.M.		4.00 P.M.		4.00 P.M.	
Total Wetted Surface.Sq.In.		185		465		47

ABSORPTION AS SHOWN BY DECREASE IN DEPTH OF WATER IN 4" PIPE

	Depth In.	Depth In.	Depth In.
March 7, 1917	18	17.25	17.5
" 8, "	17.875	16.875	17.375
" 9, "	17.75	16.375	17.25
" 10, "	17.5	15.875	17.
" 11, "	17.25	15.50	16.875
" 12, "	17.	15.125	16.625
" 13, "	16.75	14.875	16.5
" 14, "	16.625	14.50	16.375
" 15, "	16.375	14.125	16.375
" 16, "	16.25	13.75	16.125
" 17, "	16.125	13.50	16.
March 7 to 17 Loss in depth.In.	1.875	3.75	1.5
March 7 to 27 Loss in depth.In.	3.625	6.00	2.0
March 7 to April 6 Loss in depth.In.	5.00	7.75	2.5

TABLE 5. Continued

TEST MADE MARCH 6, 1917

Cube Number	41		42		43	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
Cubes & Pipe Line filled with water	9.20 A.M.		9.20 A.M.		9.20 A.M.	
10 lbs. pressure	9.52		9.52		9.52	
20 " "						
27 " "	10.16		10.16		10.16	
Water Shows		Wetted Surface Sq.In.		Wetted Surface Sq.In.		Wetted Surface Sq.In.
Top	9.54	40	11.00	40	9.53	10
Bottom	10.20	60	11.30	60	10.20	190
N.Side	10.16	125	11.02	40	10.20	120
E. "	10.13	180	10.16	90	10.30	150
S. "	10.20	130	10.25	50	10.35	140
W. "	10.16	125	11.30	60	10.46	100
Pressure off	12.00 P.M.		4.00 P.M.		12.45 P.M.	
Total Wetted Surface.Sq.In.		660		340		710

ABSORPTION AS SHOWN BY DECREASE IN DEPTH OF WATER IN 4" PIPE

	Depth In.	Depth In.	Depth In.
March 7, 1917	17.25	17.	17.
" 8, "	16.75	16.375	16.375
" 9, "	16.125	15.75	15.625
" 10, "	15.125	15.	15.
" 11, "	14.5	14.375	14.25
" 12, "	13.75	13.875	13.375
" 13, "	13.375	13.25	13.
" 14, "	12.75	12.75	12.375
" 15, "	12.	12.25	11.75
" 16, "	11.375	11.75	11.25
" 17, "	10.75	11.25	10.75
March 7 to 17 Loss in depth.In.	6.5	5.75	6.25
March 7 to 27 Loss in depth.In.	11.25	9.75	10.75
March 7 to April 6 Loss in depth.In.	13.25	13.00	13.00

TABLE 5. Continued.

TEST MADE MARCH 6, 1917

Cube Number	44		45		46	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
Cubes & Pipe Line. filled with water.	9.09 A.M.		9.09 A.M.		9.09 A.M.	
10 lbs. pressure	9.47		9.47		9.47	
20 " "	10.27		10.27		10.27	
27 " "	10.47		10.47		10.47	
Water Shows		Wetted Surface. Sq.In.		Wetted Surface. Sq.In.		Wetted Surface Sq.In.
Top	10.35	3				
Bottom	11.15	10			12.00	20
N.Side	1.45	10				
E. "	2.00	15				
S. "	2.25	2			3.15	1
W. "	11.50	20			2.30	4
Pressure off	4.00 P.M.		4.00 P.M.		4.00 P.M.	
Total Wetted Surface. Sq.In.		60				25

ABSORPTION AS SHOWN BY DECREASE IN DEPTH OF WATER IN 4" PIPE

	Depth In.	Depth In.	Depth In.
March 7, 1917	17.5	17.	17.
" 8, "	17.125	17.	16.875
" 9, "	16.875	16.875	16.75
" 10, "	16.50	16.625	16.625
" 11, "	16.25	16.50	16.625
" 12, "	15.875	16.375	16.375
" 13, "	15.625	16.25	16.25
" 14, "	15.375	16.	16.125
" 15, "	15.125	15.875	16.
" 16, "	15.	15.75	16.
" 17, "	14.75	15.625	15.875
March 7 to 17 Loss in depth.In.	2.75	1.375	1.125
March 7 to 27 Loss in depth.In.	4.25	2.125	1.75
March 7 to April 6 Loss in depth.In.	5.375	2.75	2.375

TABLE 5. Continued.

TEST MADE MARCH 6, 1917

Cube Number	47		48		49	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
Cubes & Pipe Line filled with water.	9.09 A.M.		9.09 A.M.		9.09 A.M.	
10 lbs.pressure	9.47		9.47		9.47	
20 " "	10.27		10.27		10.27	
27 " "	10.47		10.47		10.47	
Water Shows		Wetted Surface Sq.In.		Wetted Surface Sq.In.		Wetted Surface Sq.In.
Top	9.09	50	9.09	40	10.10	20
Bottom	9.12	130	9.09	150	11.30	100
N.Side	10.10	165	10.30	125	11.30	110
E. "	10.15	110	11.50	10	10.45	110
S. "	9.50	130	9.10	90	10.47	75
W. "	9.55	150	10.50	100	11.30	130
Pressure off	11.00 A.M.		12.05 P.M.		4.00 P.M.	
Total Wetted Surface. Sq.In.		735		515		545

ABSORPTION AS SHOWN BY DECREASE IN DEPTH OF WATER IN 4" PIPE

	Depth In.	Depth In.	Depth In.
March 7, 1917	17.5	17.75	17.75
" 8, "	15.75	16.375	17.25
" 9, "	13.5	15.	16.75
" 10, "	11.375	13.625	16.25
" 11, "	9.5	12.625	15.75
" 12, "	7.875	11.50	15.25
" 13, "	6.5	10.625	14.75
" 14, "	5.	9.75	14.375
" 15, "	4.	8.875	14.
" 16, "		8.125	13.625
" 17, "		7.375	13.25
March 7 to 17 Loss in depth.In.	13.5	10.375	4.5
March 7 to 27 Loss in depth.In.		13.75	7.0
March 7 to April 6 Loss in depth.In.			8.625

TABLE 5. Continued

TEST MADE MARCH 6, 1917

Cube Number	50		51	
	A.M.or P.M.		A.M.or P.M.	
Cubes & Pipe Line filled with water	9.09 A.M.		9.20 A.M.	
10 lbs.pressure	9.47		9.52	
20 " "	10.27			
27 " "	10.47		10.16	
Water Shows		Wetted Surface Sq.In.		Wetted Surface Sq.In.
Top			9.53	40
Bottom	9.10	125	9.53	150
N.Side	9.50	75	9.58	175
E. "			10.00	125
S. "			9.57	170
W. "			10.10	100
Pressure off	11.15 A.M.		12.10 P.M.	
Total Wetted Surface.Sq.In.		200		760

ABSORPTION AS SHOWN BY DECREASE IN DEPTH OF WATER IN 4" PIPE

	Depth In.	Depth In.
March 7, 1917	17.5	17.
" 8, "	14.125	15.5
" 9, "	9.375	14.25
" 10, "	5.75	13.25
" 11, "	4.	12.125
" 12, "		11.125
" 13, "		10.375
" 14, "		9.50
" 15, "		8.75
" 16, "		8.125
" 17, "		7.375
March 7 to 17 Loss in depth.In.	13.5	9.625
March 7 to 27 Loss in depth.In.		13.00
March 7 to April 6 Loss in depth.In.		

Cubes 44 to 50 (See Figure 2) had not previously been under test. A plug in the cross above cube 50 was loosened sufficiently to allow the air to escape. The valve in the header near 44 was opened and when cube 50 was filled, the plug was tightened and the valve near 44 was closed before any pressure was put on the line. The other groups were handled in a similar manner, except that with some that had been under test previously, the pressure was put on all the cubes in the group as soon as the pipe line was filled with water.

In the case of the group first mentioned, the pipe line was filled up at 9.09 A.M. and ten pounds pressure was turned on at 9.47. At 10.27 another ten pounds was turned on, and at 10.47 A.M. the line was given the full pressure of twenty seven pounds. Details as to this and the other groups are shown in Table 5.

The time of appearance of water on the face of a cube was noted, and if excessive leakage occurred in any cube the valve above that particular cube was closed and the area of wetted surface of each face of the cube was measured and recorded. At some specific time the pressure was shut off from all the other cubes, and the wetted area of each cube ascertained at the time of shutting off the pressure.

On April 24, a test similar to the above was made on the same groups of cubes, and similar details are recorded in Table 6.

While this test was under way, the pressure was shut off for about two hours in the middle of the day, and, while the work was carried through, it was considered that a fair comparison could

TABLE 6.

TEST MADE APRIL 24, 1917

Cube Number	15		17		18	
Water in Cube at start--Inches	15.75		14.25		1.375	
	A.M. or P.M.		A.M. or P.M.		A.M. or P.M.	
27 lbs. pressure	9.20 A.M.		9.20 A.M.		9.20 A.M.	
Water Shows		Wetted Surface Sq. In.		Wetted Surface Sq. In.		Wetted Surface Sq. In.
Top			9.25	15	10.10	50
Bottom						
N. Side						
E. "					3.10	3
S. "					3.00	3
W. "						
Pressure off	4.00 P.M.___		4.00 P.M.___		4.00 P.M.___	
Total Wetted Surface. Sq. In.		0		15		56

Cube Number	25		26		27	
Water in Cube at start--Inches	Dry		14.0		8.625	
	A.M. or P.M.		A.M. or P.M.		A.M. or P.M.	
27 lbs. pressure	9.50 A.M.		9.50 A.M.		9.50 A.M.	
Water Shows		Wetted Surface Sq. In.		Wetted Surface Sq. In.		Wetted Surface Sq. In.
Top					9.52	25
Bottom	3.00	25			10.15	80
N. Side	2.30	10			10.25	30
E. "	12.45	80			11.22	20
S. "	2.30	25			12.30	25
W. "	12.45	36			12.30	40
Pressure off	4.00 P.M.__		4.00 P.M.__		4.00 P.M.__	
Total Wetted Surface. Sq. In.		176		0		220

TABLE 6. Continued

TEST MADE APRIL 24,1917

Cube Number	28		29		30	
Water in cube at start--Inches	10.5		0.5		15.25	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
27 lbs.pressure	9.50 A.M.		9.50 A.M.		9.50 A.M.	
Water Shows		Wetted Surface. Sq.In.		Wetted Surface. Sq.In.		Wetted Surface Sq.In.
Top			10.30	12		
Bottom			10.50	80		
N.Side			2.45	8		
E. "			12.30	40		
S. "			2.45	10		
W. "			11.00	10		
Pressure off	4.00 P.M.		4.00 P.M.		4.00 P.M.	
Total Wetted Surface. Sq.In.		0		160		0

Cube Number	31		33		34	
Water in cube at start--Inches	Dry		Dry		13.5	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
27 lbs. pressure	9.45 A.M.		9.45 A.M.		9.45 A.M.	
Water Shows		Wetted Surface. Sq.In.		Wetted Surface. Sq.In.		Wetted Surface Sq.In.
Top	11.35	12	1.30	25		
Bottom	2.00	80	2.30	15		
N.Side			3.30	4		
E. "						
S. "						
W. "	2.15	10				
Pressure off	4.15 P.M.		4.15 P.M.		4.15 P.M.	
Total Wetted Surface. Sq.In.		102		44		0

T A B L E 6. Continued.

TEST MADE APRIL 24, 1917

Cube Number	35		36		37	
Water in cube at start--Inches	Dry		2.25		Dry	
	A.M. or P.M.		A.M. or P.M.		A.M. or P.M.	
27 lbs. pressure	9.45 A.M.		9.45 A.M.		9.45 A.M.	
Water Shows		Wetted Surface Sq. In.		Wetted Surface Sq. In.		Wetted Surface Sq. In.
Top	10.00	25			2.00	4
Bottom	2.20	15	11.40	25	2.15	45
N. Side	2.00	60	2.00	60		
E. "	10.30	120	10.25	110		
S. "	11.15	30	10.45	75		
W. "	3.00	8	2.00	10	2.00	35
Pressure off	4.15 P.M.		4.15 P.M.		4.15 P.M.	
Total Wetted Surface. Sq. In.		258		280		84

Cube Number	38		39		40	
Water in cube at start--Inches	11.0		6.875		14.25	
	A.M. or P.M.		A.M. or P.M.		A.M. or P.M.	
27 lbs. pressure	9.45 A.M.		9.30 A.M.		9.30 A.M.	
Water Shows		Wetted Surface Sq. In.		Wetted Surface Sq. In.		Wetted Surface Sq. In.
Top			9.36	30	9.37	20
Bottom	10.20	30	10.50	80		
N. Side			12.30	15	10.20	25
E. "			2.00	15		
S. "	10.00	40			3.30	2
W. "	3.20	5	11.00	20		
Pressure off	4.15 P.M.		4.30 P.M.		4.30 P.M.	
Total Wetted Surface. Sq. In.		75		160		47

TABLE 6. Continued

TEST MADE APRIL 24,1917

Cube Number	41		42		43	
Water in cube at start--Inches	0.5		0.875		0.25	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
27 lbs. pressure	9.30 A.M.		9.30 A.M.		9.30 A.M.	
Water Shows		Wetted Surface Sq.In.		Wetted Surface Sq.In.		Wetted Surface Sq.In.
Top	10.20	15	2.00	2	9.35	10
Bottom	10.00	30	3.30	5	9.42	160
N.Side	10.25	50	11.50	8	9.55	100
E. "	9.35	156	11.10	15	9.50	120
S. "	9.45	100	11.00	4	10.10	120
W. "	11.00	60			10.50	100
Pressure off	4.30 P.M.		4.30 P.M.		4.30 P.M.	
Total Wetted Surface. Sq.In.		411		34		610

Cube Number	44		45		46	
Water in cube at start--Inches	10.75		13.0		13.5	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
27 lbs. pressure	9.15 A.M.		9.15 A.M.		9.15 A.M.	
Water Shows		Wetted Surface Sq.In.		Wetted Surface Sq.In.		Wetted Surface Sq.In.
Top	2.00	8			9.40	10
Bottom	9.30	25			9.40	80
N. Side	3.45	1				
E. "						
S. "					2.00	30
W. "	2.00	10			11.55	40
Pressure off	4.30 P.M.		4.30 P.M.		4.30 P.M.	
Total Wetted Surface. Sq.In.		44		0		160

TABLE 6. Continued

TEST MADE APRIL 24,1917

Cube Number	47		48		49	
Water in cube at start--Inches	Dry		Dry		7.25	
	A.M.or P.M.		A.M.or P.M.		A.M.or P.M.	
27 lbs. pressure	9.15 A.M.		9.15 A.M.		9.15 A.M.	
Water Shows		Wetted Surface. Sq.In.		Wetted Surface. Sq.In.		Wetted Surface Sq.In.
Top	9.17	20	9.17	10	2.00	15
Bottom	9.18	190	9.15	150	9.40	140
N.Side	9.25	160	9.25	60	2.00	50
E. "	9.35	28			11.10	60
S. "	9.25	80	9.16	20	2.00	25
W. "	9.20	90	9.45	6	3.15	6
Pressure off	10.00 A.M.		10.00 A.M.		4.30 P.M.	
Total Wetted Surface. Sq.In.		568		246		296

Cube Number	50		51	
Water in cube at start--Inches	Dry		Dry	
	A.M.or P.M.		A.M.or P.M.	
27 lbs. pressure	9.15 A.M.		9.30 A.M.	
Water Shows		Wetted Surface. Sq. In.		Wetted Surface. Sq.In.
Top			9.45	15
Bottom	9.15	150	9.35	150
N.Side	9.15	25	10.25	90
E. "			10.40	50
S. "			10.05	100
W. "	9.20	4	10.50	80
Pressure off	9.45 A.M.		4.30 P.M.	
Total Wetted Surface. Sq.In.		179		485

not be made between the results obtained at this time with those of March 6. Accordingly, on April 30, another test was conducted, particular pains being taken to have the hours of application of pressure correspond with those of the test made on March 6.

The details of this test are not included in this report but Table 7 shows a summary of the three tests.

17. Absorption Test.--On the day following the test of March 6, the plug was removed from the top of the cross above each cube, and such an amount of water was added to or drawn off from each cube as gave a depth of not to exceed eighteen inches above the bottom of the four inch hollow center. The actual depth was recorded and daily thereafter for ten days the depth was again measured and recorded. The loss of water in the four inch pipe for any observed time represented the absorption by the cube through eighty square inches, the area of the bottom and five sides of the four inch center. It was desired to keep the area of absorption a constant, and the record was accordingly closed when the water reached a depth of four inches in any particular cube.

On the lower portion of the various pages of Table 5 is shown the daily measurements of the depth of water in the various cubes and also the total decrease in the depth of the water in the four inch pipe for the ten days from March 7 to March 17. Here is also shown the total decrease in depth, representing loss of water in the pipe by absorption, for twenty and thirty day periods, the record being continuous from March 7.

TABLE 7.

A COMPARISON OF PRESSURE TESTS
SHOWING THE TOTAL AREA OF WETTED SURFACE OF EACH CUBE AFTER BEING SUBJECTED TO 27 POUNDS PRESSURE

Total Area of Cube, 1523 Square Inches.

	March 6,1917			April 24,1917			April 30,1917		
Cube No.	Pressure Applied Hrs.	Wetted Surface Sq.In.	Rank	Pressure Applied Hrs.	Wetted Surface Sq.In.	Rank	Pressure Applied Hrs.	Wetted Surface Sq.In.	Rank
15	6.42	0	1	4.67	0	1	6.42	0	1
17	6.42	9	2	4.67	15	2	6.42	4	2
18	6.42	125	3	4.67	56	3	6.42	148	3
25	6.33	240	4	4.17	176	3	6.33	151	6
26	6.33	0	1	4.17	0	1	6.33	8	3
27	6.33	220	3	4.17	220	4	6.33	145	5
28	6.33	0	1	4.17	0	1	6.33	1	2
29	6.33	45	2	4.17	160	2	6.33	78	4
30	6.33	0	1	4.17	0	1	6.33	0	1
31	5.17	620	5	4.50	102	5	5.92	906	7
33	3.92	645	6	4.50	44	2	5.92	380	5
34	5.92	0	1	4.50	0	1	5.92	0	1
35	3.67	410	3	4.50	258	6	5.92	456	6
36	5.92	495	4	4.50	280	7	5.92	266	3
37	5.60	740	7	4.50	84	4	5.92	316	4
38	5.92	185	2	4.50	75	3	5.92	151	2
39	6.17	465	3	5.00	160	3	6.17	323	3
40	6.17	47	1	5.00	47	2	6.17	112	2
41	2.17	660	4	5.00	411	4	6.17	379	4
42	6.17	340	2	5.00	34	1	6.17	15	1
43	2.92	710	5	5.00	610	6	6.17	820	5
51	2.33	760	6	5.00	485	5	6.17	853	6
44	6.00	60	3	5.25	44	2	6.00	58	2
45	6.00	0	1	5.25	0	1	6.00	0	1
46	6.00	25	2	5.25	160	3	6.00	232	4
47	1.00	735	7	0.75	568	7	3.25	1186	7
48	2.08	515	5	0.75	245	5	4.80	944	6
49	6.00	545	6	7.25	296	6	6.00	700	5
50	1.25	200	4	0.50	179	4	1.00	188	3

The details for the three ten day periods are shown in Tables 8, 9 and 10, and they are summarized in Table 11, which shows the absorption by each cube for each ten day period reduced to cubic inches per day of 24 hours, and also showing the rank or relative position of the cubes in each group, as regards the amount of daily absorption.

18. Discussion of Tests.--The above is a record with reference to the same cube of tests conducted under distinctly contrasting conditions. Table 7 is a record of visible results due to pressure from a sixty two and one half foot head, continued for a certain length of time and exerted on eighty square inches of the interior of a cube with a six inch thickness of wall on all sides of the cube.

It will be noted that four of the cubes came through the three tests each with a clean sheet. These are examples of concrete that has proved to be impervious for the length of time and under the pressure as recorded. Other cubes show, as a result of the test on April 30, a condition that is an improvement over that shown on March 6. It will also be noted that this improvement is shown even with the pressure longer continued in the later test than in the earlier one.

It is believed that the record shown of wetted surface of the various cubes renders it possible for a fair comparison to be made between them except in the case of No.50. In this case, voids existed on a small portion of one face and the water came freely through this particular spot, causing the early shutting off of the water, but with only a small portion of the cube being

TABLE 8.

RECORD OF ABSORPTION OF WATER BY VARIOUS CUBES FOR TEN DAY PERIOD FROM MARCH 7 TO MARCH 17, 1917.

The amount absorbed is measured by the decrease in depth of water in the four inch pipe.

Cube No.	Proportion	Water proofed	Time Days	Loss of water Depth Inches	Loss of water Volume Cu.In.	Absorption per day Cu. In.	Rank
15	1-1.5-3	No	10	.25	3.14	.31	1
17	1-2-4	Yes	10	.625	7.85	.78	2
18	1-2-4	Yes	10	6.25	78.54	7.85	3
25	1-2-4	No	10	5.125	64.40	6.44	5
26	1-2-4	Yes	10	1.125	14.14	1.41	2
27	1-2-4	Yes	10	1.625	20.42	2.04	3
28	1-2-4	Yes	10	2.0	25.13	2.53	4
29	1-2-4	Yes	10	5.875	73.83	7.38	6
30	1-1.5-3	No	10	.375	4.72	.47	1
31	1-2-4	No	9	13.50	169.64	18.85	7
33	1-2-4	Yes	10	8.25	103.67	10.37	5
34	1-1.5-3	No	10	.625	7.85	.78	1
35	1-2-4	Yes	10	9.00	113.09	11.31	6
36	1-2-4	Yes	10	4.75	59.68	5.97	3
37	1-2-4	No	10	7.75	97.38	9.74	4
38	1-1.5-3	No.	10	1.875	23.56	2.36	2
39	1-2-4	No	10	3.75	47.12	4.71	2
40	1-1.5-3	No	10	1.50	18.85	1.89	1
41	1-2-4	Yes	10	6.50	81.68	8.17	5
42	1-2-4	Yes	10	5.75	72.25	7.23	3
43	1-2-4	Yes	10	6.25	78.54	7.85	4
51	1-2-4	Yes	10	9.625	20.95	12.10	6
44	1-2-4	Yes	10	2.75	34.55	3.45	3
45	1-2-4	Yes	10	1.375	17.28	1.75	2
46	1-2-4	Yes	10	1.125	14.14	1.41	1
47	1-3-6	No	8.83	13.5	169.64	19.20	6
48	1-3-6	Yes	10	10.375	130.37	13.04	5
49	1-3-6	Yes	10	4.50	56.55	5.65	4
50	1-3-6	Yes	3.5	13.5	169.64	48.46	7

[illegible]

TABLE 9.

RECORD OF ABSORPTION OF WATER BY VARIOUS CUBES FOR TWENTY DAY PERIOD FROM MARCH 7 TO MARCH 27, 1917.

The amount absorbed is measured by the decrease in depth of water in the four inch pipe

Cube No.	Proportion	Water proofed	Time Days	Loss of water Depth Inches	Loss of water Volume Cu. In.	Absorption per day Cu. In.	Rank
15	1-1.5-3	No	20	.625	7.85	.39	1
17	1-2-4	Yes	20	1.25	15.71	.79	2
18	1-2-4	Yes	20	11.00	138.23	6.91	3
25	1-2-4	No	20	9.375	117.81	5.89	5
26	1-2-4	Yes	20	1.875	23.56	1.18	2
27	1-2-4	Yes	20	4.00	50.26	2.51	4
28	1-2-4	Yes	20	3.75	47.12	2.36	3
29	1-2-4	Yes	20	9.875	124.09	6.20	6
30	1-1.5-3	No	20	.75	9.44	.47	1
31	1-2-4	No	9.0	13.5	169.64	18.85	7
33	1-2-4	Yes	18.75	13.5	169.64	9.05	6
34	1-1.5-3	No	20	1.5	18.85	.94	1
35	1-2-4	Yes	20	14.0	175.92	8.80	5
36	1-2-4	Yes	20	8.5	109.95	5.50	3
37	1-2-4	No	19.5	13.25	166.50	8.54	4
38	1-1.5-3	No	20	3.625	46.55	2.28	2
39	1-2-4	No	20	6.00	75.40	3.77	2
40	1-1.5-3	No	20	2.00	25.13	1.26	1
41	1-2-4	Yes	20	11.25	141.37	7.07	5
42	1-2-4	Yes	20	9.75	122.51	6.12	3
43	1-2-4	Yes	20	10.75	135.08	6.75	4
51	1-2-4	Yes	16.25	13.00	163.36	8.17	6
44	1-2-4	Yes	20	4.25	53.40	2.67	3
45	1-2-4	Yes	20	2.125	26.71	1.33	2
46	1-2-4	Yes	20	1.75	21.98	1.10	1
47	1-3-6	No	8.83	13.50	169.64	19.20	6
48	1-3-6	Yes	15.75	13.75	172.78	10.97	5
49	1-3-6	Yes	20	7.00	87.96	4.40	4
50	1-3-6	Yes	3.5	13.50	169.64	48.46	7

[illegible]

T A B L E 10:

RECORD OF ABSORPTION OF WATER BY VARIOUS CUBES FOR THIRTY DAY PERIOD FROM MARCH 7 TO APRIL 6, 1917.

The amount absorbed is measured by the decrease in depth of water in the four inch pipe

Cube No.	Proportion	Water proofed	Time Days	Loss of water Depth Inches	Loss of water Volume Cu.In.	Absorption per day Cu. In.	Rank
15	1-1.5-3	No	30	.875	9.42	.31	1
17	1-2-4	Yes	30	1.75	21.88	.71	2
18	1-2-4	Yes	25.75	13.25	166.50	6.46	3
25	1-2-4	No	30	13.00	163.36	5.44	5
26	1-2-4	Yes	30	2.5	31.41	1.05	2
27	1-2-4	Yes	30	6.0	75.40	2.51	4
28	1-2-4	Yes	30	5.25	68.97	2.30	3
29	1-2-4	Yes	29.25	13.0	163.36	5.59	6
30	1-1.5-3	No	30	1.375	17.28	.57	1
31	1-2-4	No	9	13.50	169.64	18.85	7
33	1-2-4	Yes	18.75	13.50	169.64	9.05	6
34	1-1.5-3	No	30	2.25	28.27	.94	1
35	1-2-4	Yes	20	14.00	175.92	8.80	5
36	1-2-4	Yes	30	11.75	147.64	4.92	3
37	1-2-4	No	19.5	13.25	166.50	8.54	4
38	1-1.5-3	No	30	5.00	62.80	2.09	2
39	1-2-4	No	30	7.75	97.38	3.24	2
40	1-1.5-3	No	30	2.50	31.41	1.05	1
41	1-2-4	Yes	25.5	13.25	166.50	6.53	5
42	1-2-4	Yes	30	13.0	163.36	5.44	3
43	1-2-4	Yes	27	13.0	163.36	6.05	4
51	1-2-4	Yes	16.25	13.0	163.36	8.17	6
44	1-2-4	Yes	30	5.375	67.54	2.25	3
45	1-2-4	Yes	30	2.75	34.55	1.15	2
46	1-2-4	Yes	30	2.375	29.84	1.00	1
47	1-3-6	No	8.83	13.50	169.64	19.20	6
48	1-3-6	Yes	15.75	13.75	172.78	10.97	5
49	1-3-6	Yes	30	8.625	103.38	3.61	4
50	1-3-6	Yes	3.5	13.50	169.64	48.46	7

TABLE 11.

SUMMARY OF ABSORPTION RECORDS

FOR TEN, TWENTY, AND THIRTY DAY PERIODS

March 7 to March 17, 1917
March 7 to March 27, 1917
March 7 to April 6, 1917

Cube No.	Time Days	Absorption per day Cu. In.	Rank	Time Days	Absorption per day Cu. In.	Rank	Time Days	Absorption per day Cu. In.	Rank
15	10	.31	1	20	.39	1	30	.31	1
17	10	.78	2	20	.79	2	30	.71	2
18	10	7.85	3	20	6.91	3	25.75	6.46	3
25	10	6.44	5	20	5.89	5	30	5.44	5
26	10	1.41	2	20	1.18	2	30	1.05	2
27	10	2.04	3	20	2.51	4	30	2.51	4
28	10	2.53	4	20	2.36	3	30	2.30	3
29	10	7.38	6	20	6.20	6	29.25	5.59	6
30	10	.47	1	20	.47	1	30	.57	1
31	9	18.85	7	9	18.85	7	9	18.85	7
33	10	10.37	5	18.75	9.05	6	18.75	9.05	6
34	10	.78	1	20	.94	1	30	.94	1
35	10	11.31	6	20	8.80	5	20	8.80	5
36	10	5.97	3	20	5.50	3	30	4.92	3
37	10	9.74	4	19.5	8.54	4	19.5	8.54	4
38	10	2.36	2	20	2.28	2	30	2.09	2
39	10	4.71	2	20	3.77	2	30	3.24	2
40	10	1.89	1	20	1.26	1	30	1.05	1
41	10	8.17	5	20	7.07	5	25.5	6.53	5
42	10	7.23	3	20	6.12	3	30	5.44	3
43	10	7.85	4	20	6.75	4	27	6.05	4
51	10	12.10	6	16.25	8.17	6	16.25	8.17	6
44	10	3.45	3	20	2.67	3	30	2.25	3
45	10	1.75	2	20	1.33	2	30	1.15	2
46	10	1.41	1	20	1.10	1	30	1.00	1
47	8.83	19.20	6	8.83	19.20	6	8.83	19.20	6
48	10	13.04	5	15.75	10.97	5	15.75	10.97	5
49	10	5.65	4	20	4.40	4	30	3.61	4
50	3.5	48.46	7	3.5	48.46	7	3.5	48.46	7

wet on the outside.

The record of absorption tests summarized in Table 11 and detailed statements in the three preceding tables shows the absorption by each cube in cubic inches per day for a stated number of days under a head indicated by the depth of water in the four inch pipe, a head not exceeding 18 inches in any case, and with the same absorbing area of eighty square inches.

The question as to possible loss of some of the water by evaporation cannot enter, as the plugs in the crosses were in place at all times except when measurements were being taken.

On comparing the results shown in Tables 7 and 11, it will be noted that there is a close correspondence in the relative position of the various cubes of the different groups. In this connection, however, reference should also be made to Table 12, which is a further record of absorption for the eight day period from May 2 to May 10, and following the pressure test of April 30.

Inspection of this table together with the results shown in Table 11 directs particular attention to the fact that a few cubes rank first, both in the pressure and absorption tests, and it also shows that on account of changes in the relative positions of other cubes from time to time that caution must be observed in drawing conclusions as to the relative efficiency of materials used for the purpose of providing an impervious concrete.

19. Decrease in Permeability with Age.--In the case of a few cubes records have been kept which render it possible to make comparison as to the average amount of absorption by various

TABLE 12.

RECORD OF ABSORPTION OF WATER BY VARIOUS CUBES
FOR THE EIGHT DAY PERIOD FROM MAY 2 TO MAY 10, 1917.

The amount absorbed is measured by the decrease in depth of water in the four inch pipe.

Cube No.	Depth of water in cube and pipe May 2	May 10	Loss in Inches	Absorption Total Cu.In.	Per Day Cu.In.	Rank
15	17	16.875	.125	1.67	.21	1
17	17	16.75	.25	3.14	.39	2
18	17.5	16.125	1.375	17.27	2.16	3
25	17.	14.375	2.625	32.99	4.12	5
26	17.5	17.	.5	6.28	.78	2
27	17.	15.625	1.375	17.27	2.16	4
28	17.25	16.25	1.0	12.57	1.57	3
29	17.125	12.875	4.25	53.42	6.68	6
30	17.375	17.125	.25	3.14	.39	1
31	17.5	7.75	9.75	122.53	15.32	6
33	17.	13.625	3.375	42.45	5.31	5
34	17.375	17.	.375	4.72	.59	1
35	17.375	14.625	2.75	34.56	4.32	4
36	17.	15.	2.0	25.14	3.14	3
37	17.5	14.125	3.375	42.45	5.31	5
38	17.	16.	1.0	12.57	1.57	2
39	17.25	15.5	1.75	21.98	2.75	4
40	17.375	16.25	1.125	14.14	1.77	1
41	17.5	16.25	1.25	15.70	1.96	2
42	17.25	15.75	1.5	18.85	2.36	3
43	17.375	15.375	2.0	25.14	3.14	5
51	17.5	13.	4.5	56.56	7.07	6
44	17.375	16.5	.875	10.99	1.37	3
45	17.375	17.	.375	4.72	.59	1
46	17.125	16.5	.625	7.86	.98	2
47	17.375	9.125	8.25	103.66	12.96	7
48	17.	11.875	5.125	64.5	8.06	6
49	17.	13.875	3.125	39.37	4.92	4
50	17.25	12.375	4.875	61.25	7.78	5

[illegible]

cubes at times several weeks apart. Such a record is shown in Table 13, and the most noticeable feature here is that with each cube the amount of absorption is lessened as the age of the cube increases. That is undeniably true. Why it is true is a subject for discussion which must be based principally on theories.

It is generally assumed and stated that concrete through which water may find its way after it is first built will later "tighten up" as a result of having the voids in the back face of the wall filled with silt by the action of the water pressing against the wall. There may on occasion be some action of this kind which will tend to decrease the flow of water through the concrete, but it would be difficult to prove such to be the case. On the other hand, it is certain that the decrease in permeability shown in the various cubes in Table 13 takes place with no possibility of silt entering the cubes under test.

The improvement in the condition of the cubes might be claimed as being due to chemical action. Undoubtedly this has its part in the process, but such a claim, if made, would have little value unless it is capable of demonstration as to what the chemical action is. If it is posible to obtain definite information along this line, it would seem that it would tend to simplify the whole process in connection with the attempt to produce an impervious concrete, and also render it possible to work with more certainty of obtaining definite results.

When it is stated that a given material is colloidal in nature, reference is made to the theory adopted for the explan-

T A B L E 13

INDICATING DECREASE IN PERMEABILITY OF CONCRETE WITH INCREASE IN AGE, AS SHOWN BY DECREASE IN ABSORPTION DURING OBSERVED PERIODS OF TIME

Cube	Time	Absorption per day		Time	Absorption per day		Time	Absorption per day	
No.	Days	Cu.In.	Rank	Days	Cu.In.	Rank	Days	Cu.In.	Rank
	2 weeks old			45 weeks old			53 weeks old		
15	3	2.1	1	10	.31	1	8	.21	1
17	3	27.2	2	10	.78	2	8	.39	2
18	3	60.7	3	10	7.85	3	8	2.16	3
	4 weeks old			17 weeks old			25 weeks old		
31	3	49.41	3	9	18.85	4	8	15.32	4
33	4	40.84	2	10	10.37	2	8	5.31	3
34	7	6.28	1	10	.78	1	8	.59	1
35	2	65.97	4	10	11.31	3	8	4.32	2
	4 weeks old			14 weeks old			22 weeks old		
36	7	12.57	2	10	5.97	2	8	3.14	2
37	7	21.54	3	10	9.74	3	8	5.31	3
38	7	10.77	1	10	2.36	1	8	1.57	1
	5 weeks old			9 weeks old			17 weeks old		
39	7	8.08	2	10	4.71	2	8	2.75	4
40	7	2.70	1	10	1.89	1	8	1.77	1
41	7	20.19	4	10	8.17	5	8	1.96	2
42	7	15.25	3	10	7.23	3	8	2.36	3
43	7	24.23	5	10	7.85	4	8	3.14	5

[illegible]

ation of the effect resulting from the use of a material which fills the voids in the concrete mass and by such means, together with the expansion of the colloidal substance, renders it impermeable. In order to be effective the colloidal constituent must develop with the application of water to the concrete, and a necessary consequence, in order to constitute it an effective waterproofing agent, must be that the development shall be retained, whether the concrete continues in a wet condition or whether it becomes thoroughly dried out.

It would also seem to be essential that the colloidal development and the pressure of water should bear such relation to each other that the colloids will not be broken down as a result of the pressure. In order to develop this theory as a practical proposition, the colloidal constituent should bear a definite relation to the concrete mass, and it should also be in definite relation to the hydrostatic pressure to which the concrete will be subjected. This is a subject for practical experiment in combination with theory.

In this connection attention is called to the two cylinders No.1 and 2 shown on Figure 2. They were made in October 1915, No.1 being of plain concrete and No.2 was waterproofed. The end of the two inch pipe was six inches from the bottom of the cylinder. Pressure was first applied to these cylinders by means of the hand force pump in May 1916. At that time, under sixty pounds pressure water showed on the sides of No.1 but not on No.2. About four months later, twenty seven and one half pounds pressure was applied continuously to both cubes for seventy two hours,

[illegible]

[illegible]

[illegible]

[illegible]

neither cube showing any leakage.

Also please note the showing made by cubes 26 and 28 under the pressure tests shown in Table 7. When the pressure was first applied to these cubes in September 1916, the water showed on all sides of both cubes. No record was kept at the time, but water stains indicate that from thirty to forty per cent of each cube was wet.

VI. COMPRESSIVE STRENGTH OF SIX INCH CUBES.

20. Compressive Tests.--The making up, treating and handling of the six inch cubes made in connection with the sixteen inch cubes have been described earlier in this report.

Table 14 is a record of the breaks of the various cubes, grouped according to proportions and also with reference to composition, as concerns the addition to the concrete mixture of the various products used in the waterproofing tests. The averages shown in Table 14 are summarized in Table 15.

It would probably be unwise to elaborate on the results here shown. The number of pounds per square inch shown in any compressive test is made up of many variables, and before the results given can be accepted as correctly representing the strength of the cubes in question, the details in regard to the make up and the making up, to the treating, handling, storing and breaking of the cubes should be known, and the breaks should be sufficient in number to induce confidence in the correctness of the figure

TABLE 14

COMPRESSIVE STRENGTH OF 6 INCH CUBES IN POUNDS PER SQUARE INCH

The 6 inch cubes represented by the breaks shown below were made from the same batch of concrete that was used in making up the 16 inch cube shown in the first column

Proportion 1-1.5-3 Not Waterproofed.

16" Cube No.	Allowed to dry out 7 days	28 days	3 months	Kept wet until 7 days old 7 days	28 days	3 months
15	2250	2667	3334			
30	2389	3055	3555			
34	2111	2667	2611			
38	2278	3000	3167	2139	2972	3538
40	2667	3222	____	2500	3979	____
Average	2339	2922	3167	2319	3475	3538

Proportion 1-2-4. Not Waterproofed

16" Cube No.	Allowed to dry out 7 days	28 days	3 months	Kept wet until 7 days old 7 days	28 days	3 months
25	1556	1805	2111			
31	1500	1889	2000			
37	1889	2361	2361	1750	2847	3389
39	1750	2055	2111	1944	3250	____
Average	1674	2027	2146	1847	3048	3389

Proportion 1-2-4. With Hydrated Lime

16" Cube No.	Allowed to dry out 7 days	28 days	3 months	Kept wet until 7 days old 7 days	28 days	3 months
17	1750	1944	2833			
18	1528	2194	2500			
28	2055	2889	3200			
44	2250	2778	2861	2278	3389	3556
45	2000	2389	2556	2000	3389	3556
Average	1917	2439	2794	2139	3389	3556

[illegible]

[illegible]

[illegible]

[illegible]

T A B L E 14. Continued

Proportion 1-2-4. Waterproofed

16" Cube No.	Allowed to dry out: 7 days	28 days	3 months	Kept wet until 7 days old: 7 days	28 days	3 months
26	1667	1834	2278			
27	1555	1833	2222			
29	1500	1972	2333			
33	1305	1722	1833			
35	1111	1500	1778			
36	1639	2055	2305	1639	2444	3056
41	1583	1890	1805	1610	2772	2556
42		1472	1611	1222	2250	2222
43	1528	1944	1750	1639	2611	2833
51	1305	1639	1611	2000	3000	3244
Average	1466	1786	1953	1622	2615	2782

Proportion 1-2-4. With Powdered Limestone

46	2500	3000	2889	2278	3605	3556

Proportion 1-3-6. Not Waterproofed

47	1944	2111	1944	1722	3000	3056

Proportion 1-3-6. With Hydrated Lime

49	1444	1611	1582	1804	3278	3444
50	1555	1861	1917	1944	3111	3556
Average	1500	1736	1750	1874	3194	3500

Proportion 1-3-6. With Powdered Limestone

48	2000	2222	2333	1972	3167	2972

TABLE 15.

SUMMARY
OF COMPRESSIVE TESTS OF 6 INCH CUBES.
Figures given represent pounds per square inch

Allowed to dry out			Kept wet until 7 days old		
7 days	28 days	3 months	7 days	28 days	3 months
Proportion 1-1.5-3. Not Waterproofed					
2339	2922	3167	2319	3475	3538
Proportion 1-2-4. Not Waterproofed					
1674	2027	2146	1847	3048	3389
Proportion 1-2-4. With Hydrated Lime					
1917	2439	2794	2139	3389	3556
Proportion 1-2-4. Waterproofed					
1466	1786	1953	1622	2615	2782
Proportion 1-2-4. With Powdered Limestone					
2500	3000	2889	2278	3605	3556
Proportion 1-3-6. Not Waterproofed					
1944	2111	1944	1722	3000	3056
Proportion 1-3-6. With Hydrated Lime					
1500	1736	1750	1874	3194	3500
Proportion 1-3-6. With Powdered Limestone					
2000	2222	2333	1972	3167	2972

representing the average.

Certain details in regard to the make up of the cubes under test are given in Table 3 and the accompanying test. It may further be stated that the sand and stone used was received in several different lots. It was so also with the cement. Tensile tests were made of all cement used, but in some cases, particularly during the early part of the work, these tests were made several weeks in advance of the actual use of the cement.

All of the work in connection with the making up of briquettes and cubes was performed by the Chemist of the Chicago Surface Lines, John Kearney, and his brother James. One made the neat and the other the sand briquettes. They worked together in the mixing, and all the tamping and spading in making up all the cubes was performed by the first mentioned. Throughout, the intent was to approximate uniformity, so far as the workmanship factor was concerned, in order to give more value to any comparison that might be made of one cube with another.

As has been stated the forms were of wood. Each form was made for three cubes, the partition pieces being mortised into the sides. In cases where a less strength is shown for a three months than for a twenty eight day break it may possibly be due to some slight imperfection resulting from the form used. Plaster of Paris was not used to face the cubes.

The room in which the cubes were stored and in which all the work was done was dry and warm at all times, during the progress of the work.

21. <u>Breaks of 1-2-4 Cubes</u>.--Full consideration should be

given to the above when inspection is made of three groups of results of 1-2-4 proportion classified under "Not Waterproofed", "With Hydrated Lime", and "Waterproofed" in Table 15. If these results, in which it appears that the addition of hydrated lime increases, and that of commercial waterproofing preparations decreases the compressive strength of concrete, are confirmatory of results obtained by others in similar experiments with the same materials, the tabulation is of value to that extent.

The breaks obtained in the case of the 1-2-4 cubes in which powdered limestone was used are remarkably high in comparison with the breaks of other cubes of the same mix. There is no question as to these results having been obtained, but as one batch only of this particular combination was made up, it may stand questioned as to the amount of increase in strength that may result from the increase of powdered stone until further experimental work develops more complete information. The question as to the strength of this combination with increase in age should receive particular attention.

22. Breaks of 1-3-6 Cubes.--Here also the value of the results shown is minimized by reason of the small number of experiments performed. Also the results obtained are greater than would ordinarily be expected, especially as compared with the 1-2-4 cubes, but, as previously explained, this is without question due to the low percentage of water used and to the workmanship employed in making up the cubes.

These results are of particular interest in showing the strength that it is possible to develop from a lean mix of con-

crete. It must also be emphasized that the labor involved in getting results similar to what is here shown is greater than will warrant any idea of getting the same results for the amount of money ordinarily representing the price of 1-3-6 concrete.

Assume that a situation exists in which a large amount of heavy foundation is to be constructed in a limited time, and for any reason, it is impossible to procure sufficient cement to build the structure of a 1-2-4 mix, it may still be possible to build it of a 1-3-6 mixture and to have it of a strength approximating what the richer mix would develop. This would be done by using water sufficient to produce a "quaking, or approaching a "quaking" consistency, depositing it in thin layers, and, by persistent tamping and spading of the material as placed, reducing the whole mass to a homogeneous, jelly like mass.

This is simply a reversion to first principles, such as accompanied the details of concrete construction in earlier days, but which have been largely abandoned as a result of close figuring of costs, and in solving the more important question of dumping into the forms the greatest possible yardage in a given space of time.

23. Breaks of 1-1.5-3 Cubes.--These cubes show an increase in strength over those of the plain 1-2-4 cubes, such as seems to be proportionate to the cement content of the two mixtures.

24. Use of Water on Fresh Concrete.--It is a common provision in specifications covering concrete construction that, after the removal of the forms, the concrete shall be kept wet by frequent sprinklings for a given number of days. This prov-

ision is ignored more frequently than it is enforced. That the failure to enforce it results in an absolute loss of strength in the structure is indicated in results shown in the last three columns of Tables 14 and 15. There is no chance for an argument as to these results. The "dry" cubes and the "wet" ones were made from the same batch of concrete. They were stored in the same room within a few feet of each other, and from the time they were made until they were broken, were given the same treatment except in one particular. The "wet" ones when taken from the forms were placed on a piece of burlap, the tops and sides being exposed, and were sprinkled with water three or four times a day until they were seven days old.

The work involved was slight, the resulting benefit was so great it would seem that the ppovision for sprinkling should be included in specifications and the provision enforced.

Again referring to Table 15, it will be seen that the wet 28 day and 3 month cubes of 1-1.5-3 mix show an increase in strength over the dry cubes of 18.9 and 11.7 per cent respectively.

A similar calculation in regard to the totals of the four 1-2-4 groups shows an increase in strength of 36.8 and 35.8 per cent.

A similar calculation for the 1-3-6 cubes shows an increase in strength of 54.2 and 58.1 per cent.

This is of interest so far as these experiments are concerned. If these results should be confirmed by further tests, the information would be of value as showing the necessity of

sprinkling in order to develop the strength of the leaner mixtures.

25. Removal of Forms-- In connection with the preceding, reference is also made to the question as to the proper length of time which should elapse before the removal of forms after concrete is placed. Here the question of the time required for the final set of the particular cement in use should be considered. Some brands of cement are slower setting than others. Cement that is old is slower than when it is fresh. Further, consider that forms are built to hold the concrete placed therein when it is in a wet condition, and they do not ordinarily take any pressure outside of that received from the contained concrete.

When the concrete has hardened sufficiently to permit the removal of the forms without injury to the face of the concrete, the best results, so far as the strength of the structure is concerned, will be obtained by removing the forms and keeping the concrete continuously wet for some specified length of time, which probably should be not less than seven days.

VII. TESTS, COSTS. CONCLUSIONS.

26. Tests in General--It is probable that failures in concrete construction could be avoided, and certainly more satisfactory results could be obtained during the entire progress of any given piece of work, by the proper carrying out of a comprehensive system of tests.

This should involve not only the testing of the cement when it leaves the mill, but also its retesting if several months

should elapse before it is used, especially if storage conditions are such that there is any possibility of deterioration having occurred.

It should include compression tests from time to time, particular effort being made to make the tests cover the combinations of aggregates and cement and water content such as actually goes into the forms.

If the use of a waterproofing compound is considered it should be tested by some appropriate method, and use should be made of the aggregates and cement used in the work. If hydrated lime is made use of, it is probable that the best results will be attained by confining its use to one particular brand.

27. Costs.-- This subject is considered particularly in reference to the cost attached to any proposed method of producing an impermeable concrete by means of the addition of waterproofing compounds or other materials as compared with the cost of the plain concrete.

So far as the actual cost attaching to the use of any particular brand of waterproofing is concerned, no definite figures can be given. There is a great difference in the cost of the different products, and the amount recommended for use varies with the product and with the manufacturer.

If it is proposed to use a commercial waterproofing product in powder form, the cost is based upon the price per pound for the number of pounds recommended per cubic yard plus the cost of mixing and the extra handling of the cement with which it is mixed.

Cement may be bought with the waterproofing powder already incorporated with it, in which case the cost is easily compared with the same cement untreated. If a waterproofed brand is used, frequent testing of the treated and untreated cement would be advisable.

Waterproofing of the paste form may be bought and used at the rate of some specified number of pounds per cubic yard of concrete, but if it is to be used in accordance with the directions which are given the most prominence by the manufacturers, it would be necessary to have definite understanding regarding the amount to be used in proportion to the water content of a cubic yard of concrete, and, in such case, it should be agreed as to the number of gallons of water representing the water content. The cost of the required amount on this basis, together with the extra labor cost involved in handling and mixing the material, would represent the extra cost due to the waterproofing component.

If hydrated lime is to be used, it is in some certain percentage of the cement content, the percentage varying with the mix. The required amount is thrown into the mixer with the other ingredients. The cost of this material delivered at the job, plus the cost of any extra labor required for storage and handling, would represent the additional cost involved in the use of this product.

Table 16 shows approximate prices for materials entering into and making up the cost of a cubic yard of concrete of different mixtures. They represent the net cost of materials delivered at the job in Chicago, and are approximately correct for the

TABLE 16.

APPROXIMATE PRICES OF MATERIALS IN A CUBIC YARD OF CONCRETE OF VARIOUS PROPORTIONS. YEARS 1915--1916--1917

1915

Proportion	Material	Unit	Quantity	@	Cost	Cost per Cu.Yd.	Difference
	Cement	Brl.	2.00	$1.20	$2.40	$	$
1-1.5-3	Sand	Cu.Yd.	.42	1.65	.69		
	Stone	" "	.84	1.55	1.30	4.39	
	Cement	Brl.	1.57	1.20	1.88		
1-2-4	Sand	Cu.Yd.	.44	1.65	.73		
	Stone	" "	.88	1.55	1.36	3.97	.42
	Cement	Brl.	1.11	1.20	1.33		
1-3-6	Sand	Cu.Yd.	.47	1.65	.78		
	Stone	" "	.94	1.55	1.46	3.57	.42

1916

Proportion	Material	Unit	Quantity	@	Cost	Cost per Cu.Yd.	Difference
	Cement	Brl.	2.00	1.45	2.90		
1-1.5-3	Sand	Cu.Yd.	.42	1.45	.61		
	Stone	" "	.84	1.45	1.22	4.75	
	Cement	Brl.	1.57	1.45	2.28		
1-2-4	Sand	Cu.Yd.	.44	1.45	.64		
	Stone	" "	.88	1.45	1.28	4.20	.53
	Cement	Brl.	1.11	1.45	1.61		
1-3-6	Sand	Cu.Yd.	.47	1.45	.69		
	Stone	" "	.94	1.45	1.36	3.66	.54

1917

Proportion	Material	Unit	Quantity	@	Cost	Cost per Cu.Yd.	Difference
	Cement	Brl.	2.00	2.00	4.00		
1-1.5-3	Sand	Cu.Yd.	.42	2.00	.84		
	Stone	" "	.84	2.00	1.68	6.52	
	Cement	Brl.	1.57	2.00	3.14		
1-2-4	Sand	Cu.Yd.	.44	2.00	.88		
	Stone	" "	.88	2.00	1.76	5.78	.74
	Cement	Brl.	1.11	2.00	2.22		
1-3-6	Sand	Cu.Yd.	.47	2.00	.94		
	Stone	" "	.94	2.00	1.88	5.04	.74

[illegible]

years 1915 and 1916. The prices given for 1917 may be considered as fairly representing the price situation about March 15. The difference in cost between the different mixtures is shown.

A similar tabulation of prices and costs made at any time, together with a correctly estimated cost involved in the waterproofing by any method of a cubic yard of 1-2-4 concrete will make comparison easy, so far as cost is concerned, as between a plain 1-2-4 mix, a waterproofed 1-2-4 mix, and a 1-1.5-3 plain mix. The difference in the strength of the concrete made from the various mixtures should also be taken into consideration.

28. Conclusions-- It has been the purpose in this investigation to secure information which might be of value in connection with the effort to secure an impermeable concrete structure when built under conditions similar to those described in the introduction to this report.

The problem of producing an impermeable concrete does not apply to the construction of the foundations of such a structure, but, in view of the results obtained in making tests of compressive strength as shown herein, it would seem proper to build them of 1-3-6 concrete, as is usually done, securing an increase in the compressive strength of the concrete by the addition of hydrated lime or, possibly, of powdered limestone.

That portion of the structure above the foundation consists of a shell, to which, upon completion, the word "waterproof" should apply in fact. The term "waterproof" as commonly applied to concrete work, and, in fact, as the word appears in this report, is loosely used, and often indicates nothing more than

that some certain material has been added to the concrete in the making for the purpose of producing an impermeable mass, but the effect of the use of such material is not necessarily the result implied by the use of the wood "waterproof" in connection with the material or process adopted

Waterproofing compounds may be used and satisfactory results obtained in the construction of a structure subject to a ten foot head of water, and the same material or process prove a total failure in a structure subjected to the pressure resulting from a fifty or sixty foot head.

It may be possible under some circumstances to produce an impermeable concrete with a plain 1-2-4 mix but experience advises to the contrary under conditions such as are assumed above. If it were possible to accomplish it, the cost would be out of all proportion to the results obtained.

It is possible to obtain an impermeable concrete with a 1-2-4 mix by the method of incorporating with the concrete waterproofing compounds, sold as such, or other materials, serving as such; but the use of such compounds or materials should be subject to test and demonstration as to the producing of results under the same head or pressure as that to which the structure will be subjected. It is possible also, that the time element will be called into service before satisfactory results are obtained.

The records herein contained show in detail the results of two tests on each of the various cubes referred to throughout the report. The "absorption" test, under which the bottom of

the four inch hollow center has been under a head of from four to eighteen inches, shows that in every cube there is under way a continuous process of absorption which is greater or less in amount according to the peculiarities attending the make up of each cube.

It is to be particularly noted, however, that, in the case of no cube, has there been any indication on the outer surface of the cube that the process of absorption is going on.

The "pressure" test, under which the cubes have been under a head of sixty-two and one-half feet, forced the water through the walls of the cubes,(a few only excepted), the degree of saturation as shown by the wet surface of the cube, increasing with the time during which the pressure was applied.

In view of the results obtained under the eighteen inch and under the sixty-two foot head, the conclusion must be that, in the case of each cube, at some distance above the eighteen inch column there is a point at which water will be forced through the walls of the cube; and for heights less than that distance, that particular cube may be considered impermeable, and for heights greater than that distance, it may be considered permeable,-and the permeability or the impermeability will be governed, not only by the waterproofing material used and by the head of water, but also by the cement content, by the consistency of the mix, and,probably to the greatest extent, by the workmanship employed in making up the cube.

It is useless to expect satisfactory results in concrete construction with any given mixture or with any combination

of materials unless all the details in connection with the work are properly carried out. Proper attention must be given to the proportioning of materials, to the work at the mixer, to the building of forms, and to the work inside the forms, including the spading of the concrete along the back as well as along the front face.

Assuming that these and other details are correctly carried out, it is evident from the records of these experiments that, in comparison with all the other mixtures and preparations, the best results may be expected from the use of a 1-1.5-3 mixture without the addition of any other material. In the results are considered impermeability, appearance of the finished work, strength, and cost; and in view of the increased strength resulting from the use of the richer mix, it would seem an entirely reasonable supposition that a section less in area could be developed with a 1-1.5-3 mix than would be required by the use of the customary 1-2-4.

DETERIORATION OF CEMENT WITH AGE

1. INTRODUCTION

1. Preliminary.-- As a part of work described in the preceding article, there were made up between July 25 and July 31, 1916, six sixteen inch cubes, numbered 19 to 24 inclusive. With each of these were made three six inch cubes for use in compression tests. These were allowed to dry out when taken out of the molds and were broken at the age of 7 days, 28 days and 3 months, the results being as follows.

Table 1.

Cube No.	Made up	Water-proofing used	Compression Strength in pounds per square inch. 7 Days	28 Days	3 Mos.
19	July 25, 1916	Yes	1250	1556	1667
20	" 26, "	Yes	1000	1167	1222
21	" 26, "	Yes	1000	1388	1334
22	" 27, "	No	1196	1556	1250
23	" 28, "	No	1000	1393	1333
24	" 31, "	Yes	556	667	720

It will be noted that the increase in strength with age is but slight in any of the cubes and that with three of them the strength at three months is less than at twenty-eight days; though this may or may not have special significance.

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[illegible]

[illegible]

[illegible]

The sixteen inch cubes were first put under pressure when twenty eight days old, and all leaked badly with the application of the first few pounds of pressure. The stone and sand used in these cubes was similar to that which had been used in previous experiments and the cement was some that had been in stock several months, but it is not known exactly how long.

Consideration of the poor results as shown by the compression breaks, and also with respect to the larger cubes under pressure seemed to lead to the conculsion that the poor showing made in both cases was due to the cement used. A fresh lot of cement was obtained, and on August 24 and 25, six more cubes, numbered 25 to 30 inclusive, were made up.

The results obtained in connection with the new lot of cubes both as to compressive strength and as to impermeability were such an improvement over those obtained in connection with the previous experiments that it was decided to carry on some tests with a view to determine, if possible, if there is a noticeable deterioration in cement with age; the test to consist of the making up, on the first day of each month, of a certain number of briquettes and six inch cubes from materials which would be practically identical one month with another, and the breaking of the test pieces at specified times.

The work done is herein described in detail.

Table 2.

RECORD OF MAKE UP OF 6" CUBES USED IN COMPRESSIVE TESTS

See following pages for details in connection with these experiments

Made Up	Sept.1,16	Oct.2-16	Nov.1-16	Dec.1-16	Jan.2-17	Jan.31-17
6" Cubes. Number made	12	12	13	12	12	12
Proportion	1-2-4	1-2-4	1-2-4	1-2-4	1-2-4	1-2-4
Concrete Cu. Yds.	.0632	.0632	.0606	.0615	.0589	.0585
Crushed Stone. Cu.Ft.	1.5	1.5	1.5	1.5	1.44	1.44
" " Lbs.per CU.Ft.	89.0	86.0	84.0	84.0	83.0	82.0
" " " used	133.5	129.0	126.0	126.0	119.5	118.1
Torpedo Sand. Cu.Ft.	.75	.75	.75	.75	.72	.72
" " Lbs.per Cu.Ft.	111.75	111.0	108.0	109.0	109.0	109.0
" " " used	83.75	83.25	81.0	81.75	78.48	78.48
Cement. Cu.Ft.	.375	.375	.375	.375	.36	.36
" Lbs.used	35.25	35.25	35.25	35.25	33.84	33.84
Water. Lbs.used	23.0	23.0	22.0	21.75	21.0	20.0
" Per Cent	9.11	9.29	9.08	9.0	9.06	8.68
" Lbs.per Cu.Yd.	366.0	366.0	363.0	354.0	357.0	342.0
" Gals." " "	43.9	43.9	43.5	42.5	42.8	41.0
Surplus Material. Lbs.	33.0	33.0	2.0	26.0	14.0	13.0
Dry Material per Cu.Yd. of Concrete. Cu.Ft.	41.53	41.53	43.31	42.68	42.78	43.08
Water per Cu.Ft. of Dry Material. Lbs.	8.81	8.81	8.38	8.30	8.35	7.94

11. MATERIALS AND TEST PIECES.

2. Cement, Sand and Stone.--Four sacks of Universal Cement were obtained and were emptied into one pile. The whole amount was thoroughly mixed and resacked.

Six sacks of Torpedo Sand were run over a one quarter inch screen and all that failed to pass the screen was rejected. The sand that did pass the screen was thoroughly mixed and resacked.

Six sacks of one half inch and six sacks of one inch crushed limestone were passed over a one quarter inch screen and all that passed through the screen was rejected. The stone that did not pass through formed an aggregate graded from one quarter inch to one inch, and this also was thoroughly mixed and resacked.

The sacks of stone, sand and cement were piled on the floor, clear of the wall, in the room where all the experimental work in connection with this and the waterproofing tests were carried on. The room has been dry and warm at all times while the work has been under way.

3. Test Pieces.-- In making up the six inch cubes, the same method was followed as is described in the preceding article. Table 2 shows the details in reference to the cubes made up on September 1, 1916, and on or near the first day of the five following months.

It will be noticed in referring to Table 2, that the water content was gradually reduced as the experimental work was carried on.

While the reduction in actual amount or percentage used was slight, it was sufficient, in the case of the last lot shown, to be

noticeable in the drier consistency of the mix and in the increased labor caused thereby in making up the cubes.

On the same day with the making of the cubes, were made up lots of neat cement and sand mortar briquettes. Standard Ottawa Sand was used in the latter.

III. TENSILE AND COMPRESSIVE TESTS

4. Tensile Tests.--Table 3 shows breaks of neat cement briquettes of various ages from one day to thirteen weeks. Table 4 shows breaks of sand mortar briquettes made at certain specified times.

In both cases, three breaks were made and the average of these is shown. At the bottom of each table is also shown the average for the first three and for the second three months.

Figure 1 is a graphical representation of the average of the breaks at the specified times for the first month, for the first three months, for the second three months, and for the last or sixth month.

It will be noticed that there is indicated a gradual decrease in the tensile strength of both the neat cement and the sand mortar briquettes during the six months test, the record of which is shown in the above tables 3 and 4.

It seems to be shown by these records that it is advisable to make more than three breaks in making tensile tests. An occasional high break, as is shown in the 28 day column of No. 319, or a low one as is seen in the 1 day column of No.323 or a bunching of high or low breaks, which may at any time occur,

Table 3.

TENSILE TESTS OF NEAT CEMENT IN POUNDS PER SQUARE INCH

The cement used in these briquettes is a part of the lot used in making up the 6 inch cubes and the sand mortar briquettes shown on adjoining pages

Neat Cement Briquettes

Made Up	No.	1 Day	3 Days	7 Days	14 Days	28 Days	8 weeks	13 weeks
September 1, 1916	303	385	565	675	735	725	790	650
		405	540	690	715	815	805	800
		370	480	645	740	775	765	765
Average 1st month		387	528	670	730	772	787	738
October 2, 1916	307	315	495	650	695	730	775	780
		300	520	665	685	690	805	740
		280	520	530	705	820	750	825
Average 2nd month		298	512	615	695	747	777	782
November 1, 1916	311	345	460	590	650	705	690	540
		400	535	595	575	675	690	580
		270	535	680	580	600	695	620
Average 3d month		338	510	622	602	660	692	580
December 1, 1916	315	330	520	715	655	655	665	675
		355	535	700	560	755	690	690
		310	430	540	585	730	725	735
Average 4th month		332	495	652	600	713	693	700
January 2, 1917	319	430	530	645	690	900	695	755
		400	420	655	690	800	845	735
		380	615	575	720	710	775	805
Average 5th month		403	522	625	700	803	772	765
January 31, 1917	323	270	445	575	630	790	750	665
		360	490	515	635	605	855	770
		215	420	555	605	605	633	780
Average 6th month		282	452	548	623	667	747	738
Average 1st three months		341	517	636	676	726	752	700
Average 2nd three months		339	490	608	641	728	737	734

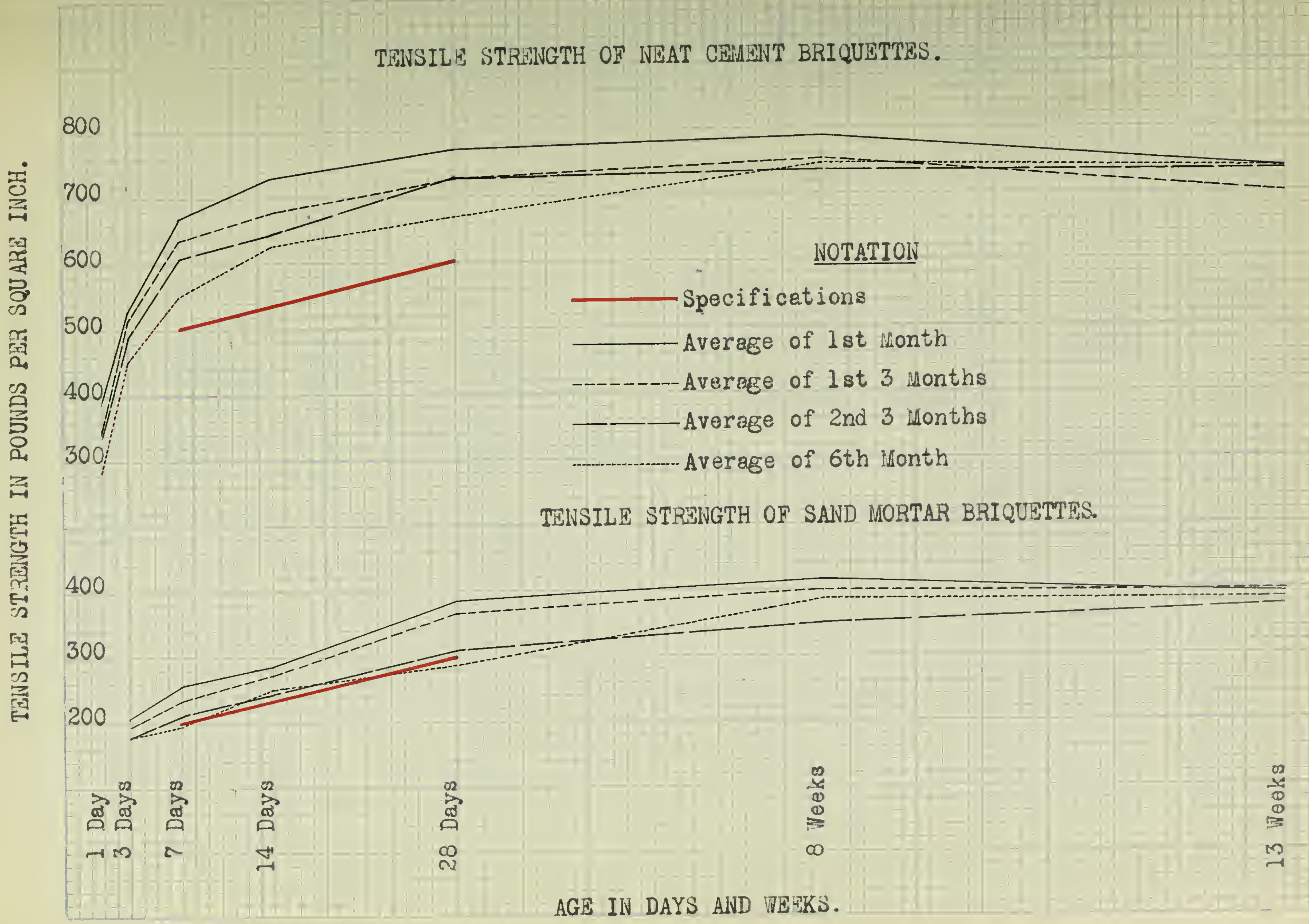
Table 4.

TENSILE TESTS OF SAND MORTAR BRIQUETTES IN POUNDS PER SQUARE INCH

The cement used in these briquettes is a part of the lot used in making up the 6 inch cubes and the neat cement briquettes shown on adjoining pages

		1 Cement to 3 Standard Ottawa Sand					
Made up	No.	3 Days	7 Days	14 Days	28 Days	8 Weeks	13 Weeks
September 1,1916	304	240	245	275	400	415	395
		190	260	285	405	405	365
		180	265	290	345	425	420
Average 1st month		203	257	283	383	415	393
October 2,1916	308	210	210	240	350	375	415
		160	210	230	275	385	415
		200	215	225	350	375	375
Average 2nd month		190	212	232	325	378	402
November 1,1916	312	195	230	275	370	460	420
		215	230	280	360	390	425
		180	230	340	435	360	355
Average 3d month		197	230	298	388	403	400
December 1,1916	316	185	225	245	310	295	340
		150	250	270	295	345	340
		140	200	210	365	320	360
Average 4th month		158	225	242	323	320	347
January 2,1917	320	205	200	220	305	340	395
		195	225	255	310	375	390
		200	225	230	335	310	390
Average 5th month		200	217	235	317	342	392
January 31,1917	324	175	180	250	260	395	375
		180	195	235	290	380	385
		175	200	250	300	375	385
Average 6th month		177	192	245	283	383	382
Average 1st three months		197	233	271	365	399	398
Average 2nd three months		178	211	241	308	348	374

Figure I.


TENSILE STRENGTH OF NEAT CEMENT BRIQUETTES.
TENSILE STRENGTH OF SAND MORTAR BRIQUETTES.
NOTATION
Specifications
Average of 1st Month
Average of 1st 3 Months
Average of 2nd 3 Months
Average of 6th Month
TENSILE STRENGTH IN POUNDS PER SQUARE INCH.
800
700
600
500
400
300
400
300
200
1 Day
3 Days
7 Days
14 Days
28 Days
8 Weeks
13 Weeks
AGE IN DAYS AND WEEKS.

may cause the drawing of wrong conclusions as to the condition of a lot of cement, which would be obviated by a greater number of breaks.

5. Compressive Tests.-- The cubes for the compressive test when made up were stored and treated in a manner similar to that described in the preceding article. Half of them were allowed to dry out when taken from the forms and the others were kept wet until they were seven days old.

The results of the breaks are shown in Table 5. A greater compressive strength is here shown than in Table 15 of the preceding article for 1-2-4 cubes "not waterproofed". It is probable that this may be largely attributed to the graded aggregate desecribed in the second part of this article.

It is worthy of note that in making up the cubes on September 1, the concrete was tamped in the mould. With the making up of the lots on October 2 and November 1, no tamping was done, all the compacting of the concrete being accomplished by the use of a small trowel. All of the remaining lots were tamped, a two by four being used, and the concrete was thoroughly spaded next to the form.

The increase in the strength of the "Wet" cubes, due to the seven days sprinkling, is noticeable.

It is also to be noted that for the six months here shown there is no corresponding decrease in compressive strength such as is indicated in the tensile tests of both neat and sand briquettes shown in Tables 3 and 4.

6. Retesting of Old Sample Lots.--In July 1915, fifteen

Table 5.

COMPRESSIVE TESTS OF 6 INCH CUBES IN POUNDS PER SQUARE INCH

Date	Allowed to dry out				Kept wet until 7 days old			
Made up	No.	7 Days	28 Days	3 mos.	No.	7 Days	28 Days	3 months
September 1, 1916	302	2278	2888	3000	301	2111	3389	
		2389	2833	3277		2055	3444	4244
Average		2333	2860	3138		2083	3416	4244
October 2, 1916	306	2166	2500	3027	305	2055	3500	3450
		2000	2611	3083		2222	3555	3833
Average		2083	2555	3055		2138	3527	3641
November 1, 1916	310	2000	2500	3111	309	1944	3333	3683
		2055	3055	2944		2055	3055	3472
Average		2027	2777	3027		2000	3194	3577
December 1, 1916	314	2444	3111	2867	313	2555	3666	4661
		2555	3222	2950		2500	3716	4611
Average		2500	3166	2908		2527	3691	4636
January 2, 1917	318	2666	3055	3389	317	2611	3583	4033
		2500	3055	3111		2361		
Average		2583	3055	3250		2486	3583	4033
January 31, 1917	322	2527	3111	3555	321	2500	4411	5054
		2722	3277	3611		2611	4093	4562
Average		2624	3194	3583		2555	4252	4808
Average of all		2358	2934	3160		2298	3610	4156

hundred barrels of cement were placed in warehouse for use in the reconstruction of the Van Buren Street Tunnel. August 4th and 5th the fifteen hundred barrels were sampled resulting in thirty-seven composite samples to be used in making up briquettes. Each composite sample was made up from twenty samples as taken.

The neat and sand briquettes were made up from the 37 samples during the following week. The briquettes were broken at specified times, the average result of the 37 samples being as follows.

Table 6.

Briquettes made up in August 1915.

	Tensile Strength in pounds per square inch		
	1 Day	7 Days	28 Days
Neat Cement	356	633	746
One Cement to Three Sand		234	357

In April 1916, near the close of the work of reconstruction of the tunnel, samples were taken from another lot of cement in warehouse, the results being in close agreement with those shown in Table 6.

The composite samples were contained in small canvas sacks and weighed from two and one half to three pounds each. They were kept in a rack in a corner of the large room where all the testing and experimental work was done. The room was heated by steam. In the same corner with the samples were open pans containing the briquettes stored in water.

In January 1917, neat and sand briquettes and six inch

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

cubes were made up from the old August 1915 samples above referred to. Other briquettes and cubes were made up from the April 1916 samples.

The result of the tensile tests are shown in Table 7 under Index Letters A and C respectively. It will be noted that in each case both neat and sand briquettes are under the strength called for by the standard specifications at seven and twenty eight days, but there is a decided increase in strength at eight weeks and thirteen weeks.

7. Comparative Tensile Tests.--During January 1917, other tests were made as follows:

Samples were taken from bags of cement that had been stored since December 1915 in the room in which the experimental work was done. Neat and sand briquettes were made therefrom and the results of the breaks are shown under Index Letter B. Table 7.

Samples were taken from cement which had been stored in an outside warehouse since July 1916. The house was not heated and was more or less open to the weather though sufficient moisture had not entered to cause perceptible hardening of the cement. The breaks of briquettes made from this cement is shown under Index Letter D. Table 7.

In the above two tests it will be noted that only the neat cement of December 1915, Index Letter B. reaches the required strength at twenty eight days, but that both the neats and both the sands have passed well beyond that strength at eight weeks and at thirteen weeks.

The briquettes shown under Index Letters E. F. and G. were

Table 7.

TENSILE TESTS OF NEAT CEMENT BRIQUETTES

Figures shown below represent average of three breaks.

Index Letter	Cement Received		Briquettes Made up	Tensile strength in pounds per square inch 1 Day	3 Days	7 Days	14 Days	28 Days	8 Wks.	13 Wks.
A	August	1915	Jan.5, 1917	257	363	448	617	587	775	787
B	December	1915	Jan.22,1917	223	380	525	550	638	700	698
C	April	1916	Jan.8, 1917	227	363	480	590	538	617	682
D	July	1916	Jan.19,1917	317	452	453	480	583	613	685
E	October	1916	Jan.10,1917	323	468	562	742	673	742	778
F	December	1916	Jan.9, 1917	328	490	627	702	645	682	653
G	January	1917	Jan.24,1917	388	470	562	690	718	565	798

TENSILE TESTS OF SAND MORTAR BRIQUETTES

One Portland Cement to three Standard Ottawa Sand

Index Letter	Cement Received		Briquettes Made up	1 Day	3 Days	7 Days	14 Days	28 Days	8 Wks.	13 Wks.
A	August	1915	Jan.5, 1917		132	183	253	275	347	365
B	December	1915	Jan.22,1917		147	202	257	265	345	395
C	April	1916	Jan.8, 1917		118	160	233	270	248	358
D	July	1916	Jan.19,1917		160	205	213	248	325	412
E	October	1916	Jan.10,1917		203	215	248	308	345	363
F	December	1916	Jan.9, 1917		185	258	290	362	428	355
G	January	1917	Jan.24,1917		188	228	287	373	358	403

Table 8.

COMPRESSIVE TESTS OF SIX INCH CUBES

Proportion 1-2-4

Figures given represent strength in pounds per square inch.

Cement used is that shown in tensile tests on adjoining page under corresponding index letters

Index Letters	Cement Received	Cubes Made up	Allowed to dry out 7 Days	28 Days	3 Mos.	Kept Wet until 7 Days old 7 Days	28 Days	3 Mos.
A	August 1915	Dec.28,1916	944	1250	1083	796	1917	2019
B	December 1915	Jan.19,1917	2153	2680	2764	1874	3111	2837
C	April 1916	Dec.28,1916	1111	1509	1260	963	1926	2102
D	July 1916	Jan.19,1917	1680	2152	1958	1653	2694	3333
F	December 1916	Jan. 2,1917	2167	2676	2796	2185	3417	3154

A. C, and F. are average of 3 breaks
B. and D. are average of 2 breaks.

made from cement received at and kept in the experimental room. In all these cases the cement is well over the requirements at seven days and at twenty eight days; and its strength at thirteen weeks is approximately the same as the other samples.

8. Compressive Tests.--When the cement was procured for making up the above described briquettes, enough was included for a number of six inch cubes. These were made up in December 1916, and January 1917, as shown in Table 8.

It will be noted here that the cubes made from the August 1915, and the April 1916 cement are remarkably low in compressive strength as compared with the other cubes included in the test.

It is also of note that those from the December 1915 and the December 1916 cement are almost identical in strength so far as the "Dry" cubes are concerned and that there is but little difference in the "Wet" ones.

Both the "Wet" and the "Dry" cubes made from the July 1916 cement approximate closely to the average strength of the 1-2-4 "not waterproofed" cubes shown in Table 15 in the preceding article, regardless of the poor showing made by the same cement when tested for tensile strength.

9. Discussion of the Preceding.--In discussing the results of the tensile and compressive tests above described it is probable that first consideration should be given to the storage conditions in connection with each lot of cement.

As stated, the August 1915 and the April 1916 cement, Index Letters A and C, has been kept in small canvas sacks in a dry room since the samples were taken. If hydration of the particles

existed, it might occur from moisture in the air due to the presence in the room of the open pans of water. If hydration did occur, it existed without having caused hardening of the cement to any appreciable extent at the time the briquettes were made up.

The storage conditions connected with the cement from which were made up the briquettes and cubes shown under Index Letters B,D.E.F.and G. have already been given in detail.

The testing of cement is usually done within a comparatively short time after it is turned out by the mill. At such time it is practically certain to be well beyond the strength required by standard specifications.

If it goes into a warehouse and is properly piled and protected from moisture it will undoubtedly be a matter of several months before it will show deterioration.

Retesting of cement should be the practice in case of any great lapse of time occurring, as of several months,-between its shipment from the mill and its going into the work.

IV. CONCLUSION

10. General Comments.--The question as to the quality of cement, involving the decision as to whether or not a given lot shall be used in a given job, is determined by the strength shown in the breaking of seven day and twenty eight day briquettes.

The record of tests shown in the preceding pages demonstrates that cement under certain conditions will decrease in tensile

strength with the lapse of time. This decrease may be sufficient to cause its rejection if judgment is based entirely upon the strength of the briquettes at the age of seven days and twenty eight days.

A continuation of the tests may show that in a few days or possibly a few weeks beyond the twenty eight day period, the cement will be equally strong with another lot which did pass inspection according to specifications.

It may be possible to show that the cement which will not pass specification requirements of tensile strength at twenty eight days will make an equal showing in compressive strength with cement which will do so.

The experiments emphasize the importance of carrying on a proper system of tensile and compressive tests in connection with concrete construction.

The facts being known through such a system of tests as to the conditions of any particular lot of cement, the question as to whether it may properly be used in any given piece of construction may be settled according to the judgment of the engineer, or owner.