THESIS

A STUDY OF THE PERMEABILITY OF CONCRETE

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A Study of the Permeability of Concrete

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INTRODUCTION.

The study of the permeability of concrete has been quite a common form of research work. The results so far have shown that concrete cannot hold water under pressure. In this thesis a concrete that is theoretically considered to be the densest possible has been used. The densest concrete is the strongest and should be the most impervious. Upon this hypothesis we are testing the densest concrete possible for its property of holding water under pressure and if it fails it can be assumed that a concrete without the aid of a water-proofing compound is not water-proof.

To get the densest concrete possible, the gravel was tested by Sieve Analysis and with the help of Taylor and Thompson's Ideal Curve, a proportion of sand, gravel, and cement was determined that would give the densest concrete. It was decided to test four different cements and a composite cement so that average results could be obtained.

The concrete was made into 6" diameter and 2" high discs and tested under heads of 10, 20, 30, 40, 50, and 150 feet.

MATERIALS

Cement. The cements used in these tests were secured from local dealers in Lansing. Four Michigan

cements were used and a composite cement composed of equal parts of the other four was made. Some of the cements used were rock cements and some were marl cements. The cements used were denoted as follows:

A	Burt Cement	(rock)
B	Peninsular Cement	(rock)
C	Michigan Cement	(marl)
D	Wolverine Cement	(marl)
E	Composite Cement	

Burt cement is a very dark almost black cement while Peninsular cement also a rock cement is very light colored. The two marl cements were about the same color being a medium light slate gray.

Sand and gravel. The sand and gravel used in these tests was secured from a pit in the northeastern part of the city of Lansing and was of a very good grade having a good sharp sand mixed with well graded stone. No stone larger than one half inch was used however.

TESTS OF MATERIALS.

1. Specific Gravity Test.

Sixty five grams of each cement was carefully weighed and the volumes of these samples were determined by placing them in bottles containing bensel and noting the change in volume. From the weight and the volume

the specific gravity of each cement was determined. These tests were carried on all at the same time and under the same conditions so that a constant temperature was maintained.

The following results were obtained:

CEMENT	WEIGHT OF CEMENT	VOL. CHANGE	SPECIFIC GRAVITY
A	65 gms.	20.75 c.c.	3.133
B	65 gms.	20.80 c.c.	3.126
C	65 gms.	20.88 c.c.	3.112
D	65 gms.	20.90 c.c.	3.110
E	65 gms.	20.90 c.c.	3.110

The average of cements A, B, C, and D is 3.120 and this compares with the composite Cement E. Standard specifications require that the specific gravity be 3.10. The results obtained above are sufficiently close to standard and the cements are therefore up to standard specific gravity.

2. Boiling Test for Soundness.

Neat cement pats useing 25% water was made of each kind of cement. Two pats of this neat cement were made for each cement on glass plates. These pats were placed in moist air for 24 hours and then in a steam bath for 5 hours following.

When the pats were removed from the steam bath they showed no signs of having raised at the edges or of having cracked on the surface. These tests showed the cements to

be sound.

3. Fineness Test.

Each cement was tested for fineness by placing exactly 50 gms. of the cement on a number 200 screen and shaking for 10 minutes in an automatic shaker. The residue remaining on the screen was carefully weighed and the percent calculated. The following results were obtained:

CEMENT	WEIGHT OF RESIDUE	% OF THE TOTAL WEIGHT
A	9.56	15.12
B	10.77	21.6
C	13.83	27.7
D	6.56	13.1
E	9.61	19.23

Standard specifications for the fineness of cement require that not more than 22% by weight shall remain on the No. 200 screen. (See Hool and Johnson's Handbook page 833). An allowable variation of 1.5% is permitted however but all cements testing within this limit should be reported as 22%. All the cements tested met the standard specifications except cement C and this was very much below standard.

Cement C was heated at a temperature of 212 degrees Fahrenheit for one hour and then retested. The results after heating were no different. Cement C was not rejected however but the tests with it were continued.

4. Normal Consistency Test.

The Vicat test for normal consistency was used. 500 gms. of cement was taken in each case with a measured quantity of water. The cement and water were mixed for one half minute with a trowel and then thoroly mixed and kneaded by hand into a thick paste. The mass was then passed 6 times from hand to hand and then pressed into the large end of a tapered hard rubber ring. The ring was placed on a glass plate and the top of the cement was smoothed off by a single cut with a trowel.

The glass plate and the ring were placed under a rod having a diameter of 1 cm. and weighing 300 gms. The penetration in 30 sec. was determined by a scale graduated in millimeters. For normal consistency the penetration should be 10 mm for 30 sec. The results of the tests on each cement are shown in Table I.

5. Tension and Compression Tests.

Standard briquettes 1 inch thick and with a cross-sectional area of one square inch at the center were made for all tension tests.

Neat Cement. Eight briquettes of neat cement of normal consistency were made for each cement. Three were tested at the end of 7 days, two were tested at the end of 14 days and three were tested at the end of 28 days. The forms containing the test pieces were placed in

TABLE OF NORMAL CONSISTANCY. TABLE I

Cement		Percent Water	Weight of Cement gms.	Penetration	Time sec.
Burt	A	25	500	5 m.m.	30
"	A	27	500	20 m.m.	30
"	A	26	500	18 m.m.	30
"	A	25	500	11 m.m.	30
Peninsular	B	25	500	9.5 m.m.	30
"	B	25	500	11 m.m.	30
Michigan	C	25	500	20 m.m.	30
"	C	25	500	15 m.m.	30
"	C	24.5	500	16.5 m.m.	30
"	C	24	500	12 m.m.	30
"	C	23.5	500	11 m.m.	30
"	C	23.	500	8 m.m.	30
Wolverine	D	25	500	10 m.m.	30
Composite	E	25	500	13 m.m	30
"	E	24.5	500	9 m.m.	30

RESULTS OF COMPRESSION TESTS OF CUBES. TABLE II

Cement	Brkg Load	Ave.	#/sq.in.	Ave #/sq.in.
A	4750		1188.	
A	4875	4567	1219.	1142
A	4075		1019	
B	4450		1113	
B	4250	4500	1063	1125
B	4800		1200	
C	4875		1219	
C	5275	4717	1319	1179
C	4000		1000	
D	6925		1756	
D	5375	6242	1344	1561
D	6425		1606	
E	5775		1444	
E	4875	5333	1219	1333
E	5350		1338	

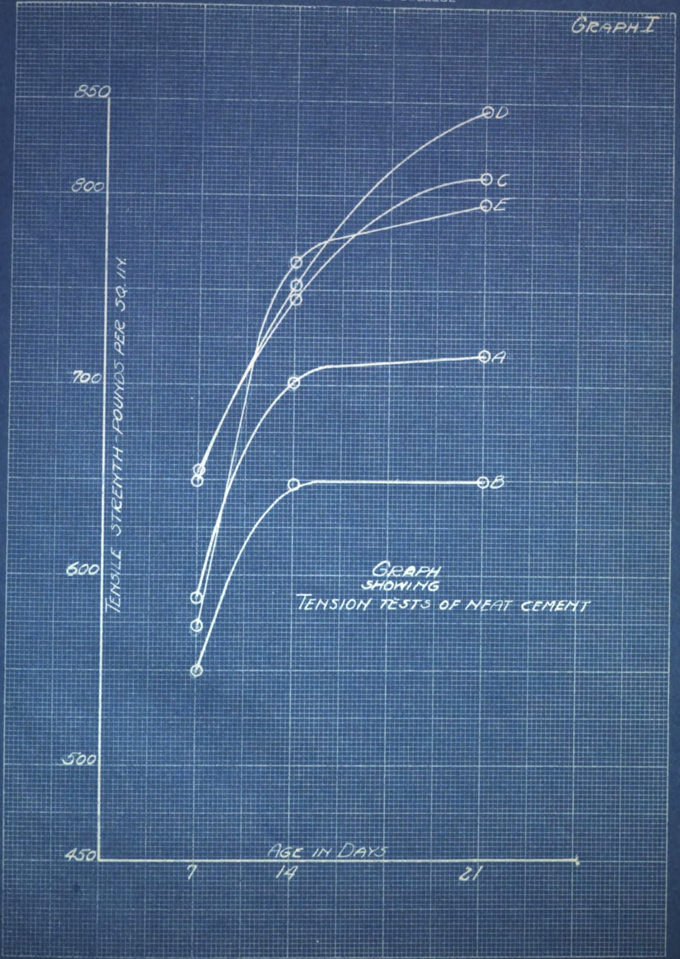
TABLE III

TENSION TEST

FOR

NEAT CEMENT & 1:3 MORTOR FOR 7, 14, & 28 DAYS.

Cement.	Neat Cement Briquettes						1:3 Mortor Briquettes.					
	7 Days		14 Days		28 Days.		7 Days		14 Days		28 Days	
	Load lbs/sq.in		Load lbs/sq.in.		Load lbs/sq.in.		Load lbs/sq.in.		Load lbs/sq.in.		Load lbs/sq.in.	
	Results	Ave.	Results	Ave.	Results	Ave	Results	Ave.	Results	Ave.	Results	Ave.
A	595		680		650		234		320		350	
A	600	590	725	702	655	715	225	220	333	327	385	363
A	575				840		200				357	
B	536		700		615		225		313		388	
B	512	549	595	648	670	643	235	225	302	308	386	389
B	598				643		215				393	
C	650		790		810		260		345		432	
C	536	655	700	745	810	810	218	244	370	357	426	433
C	660				810		253				440	
D	710		830		830		320		337		510	
D	600	649	675	752	865	845	275	295	470	404	465	504
D	638				840		290				537	
E	580		500		830		280		425		490	
E	610	573	700	770	740	795	235	263	382	404	500	493
E	530				815		275				490	


GRAPH I
850
800
700
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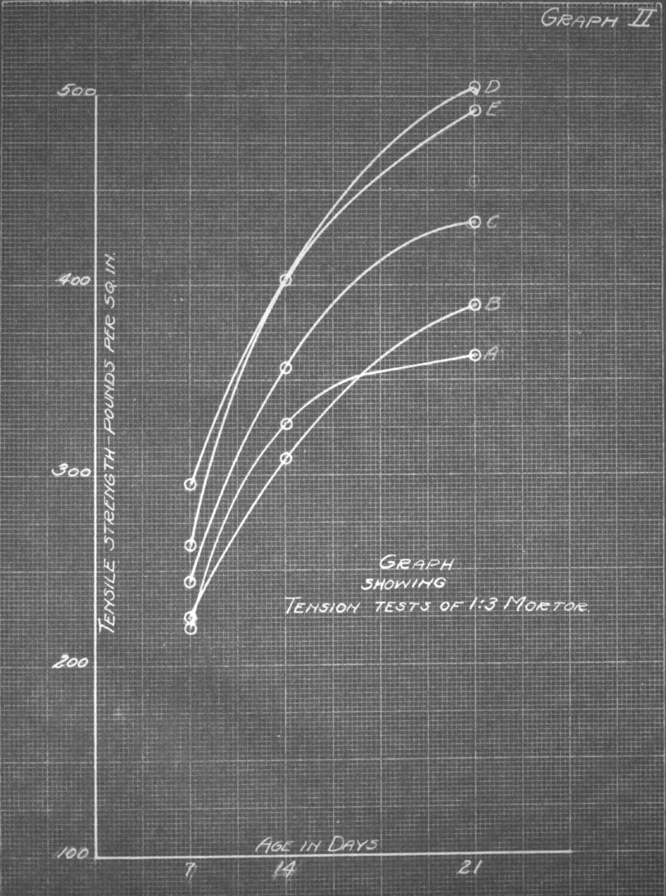
500
450
TENSILE STRENGTH-POUNDS PER SQ. IN.
D
C
E
A
B
GRAPH
SHOWING
TENSION TESTS OF NEAT CEMENT
AGE IN DAYS
7
14
21


GRAPH II
500
400
300
200
100
TENSILE STRENGTH-POUNDS PER SQ. IN.
D
E
C
B
A
GRAPH
SHOWING
TENSION TESTS OF 1:3 MORTOR.
AGE IN DAYS
7
14
21

moist air for 24 hours and then the forms were removed and the briquettes were placed in water at a temperature approximately 70 deg. Fahrenheit until tested.

The results obtained from the tests are tabulated in Table III and comparative curves are shown in Graph I. All the results of these tests were compared with the average results obtained by the Technologic Branch of the United States Geological Survey at the Structural Materials Laboratory at St. Louis, Mo. These results are shown on graphs in Hool and Johnson's Concrete Engineers Handbook pages 217 to 219. The results for neat cement in tension obtained by the U. S. G. S. are as follows:

7 days	655 lbs per sq. in.
14 days	700 " " " "
28 days	780 " " " "

It will be noticed from the table that, for 7 days, all cements used tested below these results except cement C. For 14 days the samples all tested abeve except cement B. The 28 day test showed that the cements C & D and the composite cement E were well above the average while the rock cements A & B were far below the average of the cements tested by the U. S. G. S. The general average of these results is very good however.

Cement mortar 1:3. Eight briquettes of 1:3 cement mortar were made and these tested on 7, 14 and 28 day periods as above with the neat cement. The results are given in Table III and comparative curves shown in Graph II. These briquettes were seasoned as the neat cement briquettes above. The results of these tests were compared with the results obtained with 1:3 cement mortar by the U. S. G. S. which are as follows:

7 days	265	lbs	per	sq.	in.
14 days	315	"	"	"	"
28 days	425	"	"	"	"

Cement D is the only cement that comes above these results for 7 days, the rest fall below. For 14 days cement B falls slightly below the U. S. average but the rest are all well above the standard. The 28 day tests show that the marl cements C & D and the composite cement E are above the U.S.G.S. average while the rock cements A & B are below. These tests bear out the results obtained with the neat cement above and the general average is very good.

Compression tests of 1:3 Cement mortar.

Two inch cubes were made of 1:3 cement mortar and tested at the end of 28 days. Three cubes were made of each cement and the average results taken. The results are tabulated in Table II. All the cubes were placed in moist air for 24 hours and then immersed in water for the rest of the 28 day period until tested. The results of these tests were compared with the U. S. tests at St. Louis.

The cubes tested gave results that showed a unit compressive stress of a little over 1000 lbs per sq. in. while the U. S. samples tested over 4000 lbs per sq. in. at the end of 28 days. We were unable to account for this wide variation unless the cubes should have been embeded in plaster of paris.

Silt Test.

A silt test was made of the fine aggregate. A sample weighing 534.73 gms. was placed on a number 200 screen and a small stream of water was allowed to run on it while the screen was slowly tipped from side to side. The residue was thoroly dried over a gas flame and then reweighed. The resulting weight was 519.77 gms. The difference in weight represented the weight of the silt removed by the water. This was 14.96 gms. and was 2.88% of the original weight.

The Mechanical Analysis of the Aggregate.

In order to obtain the densest concrete possible the sand and stone had to be carefully analized. Only that aggregate which passed thru a 1/2 inch screen was used.

The screens used in this analysis were the 1/2", 1/4", 1/8" and numbers 10, 20, 30, 40, 50, 80, 100, 150, and 200. The samples were taken by quartering stock piles and carefully weighing the entire sample. The screening was done with a mechanical agitator. The residue was weighed and these are the results tabulated in the second column in Tables IV, V and VI. By dividing the results in the second column by the total weight of the sample the percent caught in each screen is obtained and these results are tabulated in column three. The fourth column is a summation of the preceeding percents which shows that if that specific screen was used that percent of the total would remain on the screen. The fifth column gives the results of the fourth column subtracted from 100 or is the amount that passes the screen. The results of each of these samples could have been plotted but they would have been of no use in connection with the Ideal Curve which was used as acriterion.

To plot results the samples were divided into coarse and fine aggregates. The coarse aggregate being that which passed thru a 1/2" screen and remained on a 1/8" screen and the fine aggregate was that which passed the 1/8" screen. Considering the two aggregates separately, curves were plotted from the average results worked out in Table VII and are shown in Graph III.

The ideal curve was plotted from a set of rules determined by William B. Fuller and Sandford E. Thompson. The principles by which the aggregates are proportioned in order to approach the Ideal Curve were developed by Messrs. Taylor and Thompson.

Experiments have shown that where only two aggregates are represented by curves that are to be combined the best results are obtained when the combined curve intersects the Ideal Curve at the 40% line, at K. AB is the sand or fine aggregate curve, CD is the stone or coarse aggregate curve and AKD is the Ideal Curve.

Scaling the ordinates at K, LK was found to be 40% and LG is 95.1%. Then LK:LG::40:95.1 and LG is equal to 42.1%. This means that 42.1% of the dry materials by weight should be sand and cement and 57.9% should be stone or coarse aggregate.

The ordinates on the curve AB were measured at various points and 42.1% of the values taken and plotted thus forming a new curve that approached the Ideal Curve under the fine aggregate curve. Then by useing the right hand scale that is the amount retained in percent and measuring from the top and taking 57.9% of these values and plotting as above the rest of the aggregate curve was obtained. The resulting curve was a very close approximation of the Ideal Curve. Since this was the result that it was desired to obtain these percents used in plotting the curve were used in the proportioning of the aggregate for the concrete for the test pieces.

A good average commercial mix of concrete is a 1:2:4 by volume which is approximately one part cement to

SIEVE ANALYSIS OF AGGREGATE (3 Samples.)

Sample I

Total weight = 755.33 gms. TABLE IV

Screen Nº	Amount Caught		Amount would be retained %	Amount would pass. %	Size of screen opening
	gms.	%			
½"	0	0	0	100.0	0.5"
¼"	198.71	26.30	26.30	73.70	0.25"
⅛"	115.47	15.20	41.58	58.42	0.125"
10	46.25	6.13	47.71	52.29	0.065"
20	58.25	7.70	55.40	44.60	0.032"
30	95.32	12.60	68.00	32.00	0.0198"
40	74.32	10.10	78.10	21.90	0.0150"
50	81.81	10.82	88.82	11.18	0.0110"
80	53.89	7.14	95.96	4.04	0.0069"
100	13.55	1.79	97.75	2.25	0.0056"
150	5.17	0.69	98.44	1.56	0.0041"
200	4.10	0.54	98.98	1.02	0.0029"
Over 200	5.00	0.66	99.74	.26	

Sample II

Total weight = 758.44 gms. TABLE V

Screen Nº	Amount Caught.		Amount would be retained %	Amount would pass. %	Size of screen opening.
	gms.	%			
½"	0	0	0	100.0	0.5"
¼"	215.29	28.40	28.40	71.60	0.25"
⅛"	99.20	13.08	41.08	58.92	0.125"
10	50.92	6.71	47.79	52.21	0.065"
20	60.77	8.00	55.79	44.21	0.032"
30	94.69	12.50	68.20	31.71	0.0198"
40	73.97	9.75	78.04	21.96	0.0150"
50	79.11	10.45	88.49	11.51	0.0110"
80	53.65	7.07	95.56	4.44	0.0069"
100	13.75	1.81	97.37	2.63	0.0058"
150	5.91	0.78	98.15	1.85	0.0041"
200	3.99	0.53	98.68	1.32	0.0029"
Over 200.	5.49	0.72	99.40	.60	

Sample III
Total Weight = 758.44

TABLE VI

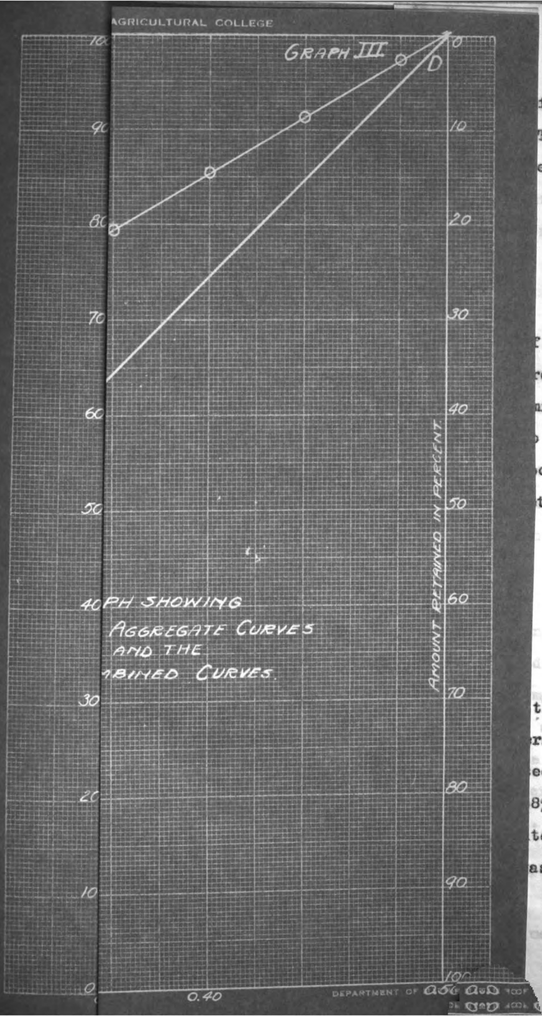
Screen Nº	Amount Caught. gms.	Amount Caught. %	Amount would be retained %	Amount would pass %	Size of screen Opening.
1/2"	0	0	0	100.0	0.5"
1/4"	157.47	21.00	21.00	79.00	0.25"
1/8"	110.85	14.75	35.75	64.25	0.125"
10	55.88	7.44	43.19	56.91	0.065"
20	67.39	8.96	52.15	47.85	0.032"
30	103.92	13.81	65.96	34.04	0.0198"
40	80.70	10.64	76.60	23.40	0.0150"
50	86.05	11.45	88.05	11.95	0.0110"
80	56.44	7.50	95.50	4.50	0.0069"
100	14.69	1.96	97.46	2.55	0.0058"
150	6.00	0.80	98.26	1.75	0.0041"
200	3.86	0.51	98.76	1.24	0.0029"
Over 200	6.01	0.80	99.56	44	

TABLE VII

Data for Ideal Curve (Average of three samples)

Ave. total wt. = 755.27 gms Course Aggre. = 299.0 gms Fine Aggre. = 456.27

Screen Nº	Average Amount Caught. gms.	Average Amount Caught. %	Average Amount would be retained %	Average Amount would pass. %	Size of screen opening.
1/2"	0	0	0	100.0	0.5"
1/4"	190.49	63.70	63.7	36.7	0.25"
1/8"	108.51	36.30	100.0	0	0.125"
1/8"	0	0	0	100.0	0.125"
10	57.02	12.50	12.50	87.50	0.065
20	62.14	13.60	26.10	73.90	0.032
30	97.98	21.45	47.55	52.45	0.0198"
40	76.50	16.78	64.33	35.67	0.0150"
50	82.32	18.00	82.33	17.67	0.0110"
80	54.66	12.00	94.33	5.67	0.0069"
100	14.00	3.07	97.40	2.60	0.0058"
150	5.69	1.25	98.65	1.45	0.0041"
200	3.98	0.87	99.52	.48	0.0029"
Over 200.	5.50	1.21	100.0	0	



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five parts sand and gravel by weight or 16.7% of the total weight of the dry materials should be cement. This percent was used in the proportioning of the concrete for the tests. The sand used was 42.1% minus 16.7% or 25.4%. The coarse aggregate used was 57.9%

The Making of the Test Pieces.

The test pieces were made in the form of discs 6 inches in diameter and 2 inches thick. They were moulded in wrought iron rings which were tapered to permit drawing. By experiment the amount of material to fill two moulds was determined. From the percents determined above in the sieve analysis the weighs to be used were determined and they are as follows:

Cement	755 gms.	-	16.7%
Sand	1200 gms.	-	25.4%
Gravel	2575 gms.	-	57.9%
			100.0%

The materials were thoroly mixed before the water was added. The dry mixture was then formed into a crater and the water added. The average amount of water used in each batch was about 400 cc. which was between 88% and 89%. The materials were gradually worked into the center and then thoroly mixed with a trowel until the mass was of an even consistency.

The moulds were well oiled and oiled papers were placed on the glass plates upon which the discs were moulded. The concrete was added in thin layers and well rammed. When the mould was full it was jarred until water appeared on the top. The surface was then smoothed off by means of a trowel.

Seasoning of Test Pieces.

All discs were placed in vats over water and allowed to remain in this moist air for 24 hours. The wrought iron rings were then removed by jarring the forms. Each disc was marked with its letter and the date on which it was made. They were then placed in damp sand, about one inch of sand being below the concrete and the whole covered by an inch of the damp sand. They were allowed to remain in this condition for the rest of the 28 day period, the temperature remaining fairly constant at about 70 degrees F. The object of the damp sand was to give the discs all the water necessary for a complete hardening and also approach as nearly as possible the subsurface conditions that would be encountered in practice in concrete construction. At the end of the 28 day period the discs were removed from the sand and tested.

Tests of the Specimens.

Percent of water in the discs at the time of testing.

An extra disc was made of composite cement and this disc was made and cured in the same manner as the other discs. At the end of the 28 days the disc was broken and three pieces weighing approximately 100 grams each were secured. These were carefully weighed to the nearest one hundredth of a gram. The pieces were then heated over a gas flame for two hours and then reweighed. The difference in weight was the free or uncombined water in the sample. The percentage was computed in each case and the average of the three samples taken as the percentage of free water in the test specimens at the time of the beginning of the tests. The following are the results obtained:

Sample	Weight before heating	Weight after heating	Difference	% of water
1	92.11	86.07	6.04	6.556
2	94.64	89.11	5.49	5.801
3	88.19	83.09	5.10	5.783
		Average percent	6.05	

Description of the Apparatus.

The water pressure used in these tests was obtained from the pressure tank in the hydraulic laboratory of the College. A two inch pipe line was extended from the tank and T's were placed at intervals of approximately 18 inches. To these were connected the apparatus for holding the test (See Figs. I, II, III, IV and V) discs. The discs were held between cast iron plates

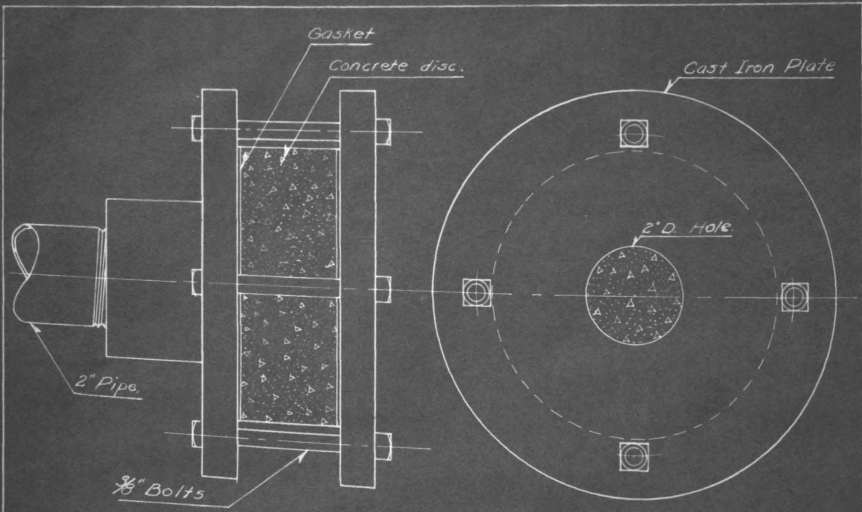
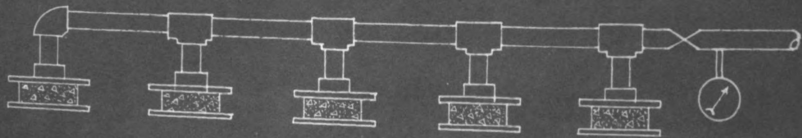
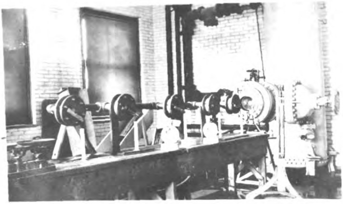


Plate No I Water Pressure Apparatus.

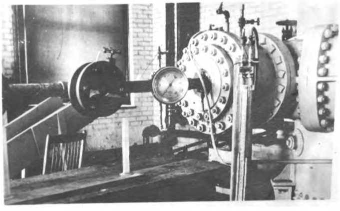


Arrangement of Test Apparatus

PLATE II



Testing Apparatus. Fig. III



Pressure Apparatus. Fig IV

Concrete Discs used in Tests.
Fig. V

clamped together by means of 6-3/8" bolts. Both plates had two inch holes at the center so that the water pressure was applied on an area of 3.14 sq. inches. One plate was threaded and attached to the pipe line. 5 sets of plates were used and 5 discs were tested at the same time. Leaks between the castiron and the concrete were prevented by rubber gaskets.

Pressure Tests on the Specimens.

The first set of discs were tested under a head of 10 feet which is equivalent to a pressure of 4.33 pounds per square inch. This pressure was maintained for a period of four hours. The first difficulty which was encountered was the cracking of the discs due to uneven pressure in clamping the plates together. Those discs that did not crack allowed no water to pass thru them.

These tests were repeated for heads of 20, 30, and 40 feet with the same result. New discs were inserted for each new head. When the 50 ft. head was applied it was decided to allow this to remain for a longer period so the pressure was kept at this head for 4 days or 96 hours. None of the discs allowed any water to pass thru at this pressure in the 4 days.

Direct pressure from the college mains of about 150 ft. head or 64 pounds per sq. in. was next put on the discs. The same discs that had withstood the 50 ft. head were used. This pressure was maintained for 12 hours. All the specimens except the one made with cement C held back the water at this pressure for the entire time of the test. The disc C allowed 2 cc. of water to come thru in the 12 hours. This test was repeated on the following day with the same results.

All the discs were weighed before and after the test to determine the effect of the free water in the discs on the permeability of the concrete. No water came thru the whole discs however and the weight of the discs were from 1 to 6 grams lighter after the test than they were before. This shows that if there was any permeation the evaporation was much faster thus causing the discs to weigh less instead of more. The floor of the laboratory was kept flooded to prevent excessive evaporation. The following are the results of the tests for permeability.

10 ft. head.

Disc	Weight before test	Weight after test	Permeation in 4 hours
A	2359 gms.		Cracked
B	2340 gms.	2336 gms.	Cracked-64 cc.
C	2294 gms.		Cracked
D	2376 gms.		Cracked
E	2427 gms.	2423 gms.	Cracked-9 cc.

20 ft. head

Disc	Weight before test	Weight after test	Permeation in 4 hours
A	2300 gms.		Cracked
B	2381 gms.	2383 gms.	Cracked-65 cc.
C	2345 gms.	2341 gms.	00 cc.
D	2353 gms.		Cracked
E	2330 gms.	2327 gms.	00 cc.

30 ft. head

Disc	Weight before test	Weight after test	Permeation in 4 hours
A	2374 gms.	2370 gms.	00 cc.
B	2342 gms.	2334 gms.	00 cc.
C	2340 gms.	2335 gms.	00 cc.
D	2386 gms.	2380 gms.	00 cc.
E	2391 gms.	2390 gms.	00 cc.

40 ft. head

Disc	Weight before test	Weight after test	Permeation in 4 hours
A	2364 gms.	2360 gms.	Cracked-85 cc.
B	2392 gms.	2387 gms.	Cracked-3 cc.
C	2390 gms.	2383 gms.	Cracked-5 cc.
D	2390 gms.	2384 gms.	00 cc.
E	2306 gms.	2301 gms.	00 cc.

50 ft. head

Disc	Weight before test	Weight after test	Permeation in 4 hours
A	2381 gms.	Not weighed	00 cc.
B	2426 gms.	" "	Cracked
C	2345 gms.	" "	00 cc.
D	2399 gms.	" "	00 cc.
E	2502 gms.	" "	00 cc.

At the end of the four hours the disc B was changed for a new one and the test on the discs at the same pressure was continued for 92 more hours making a total of 96 hours for discs A. C. D. and E. At the end of the 96 hours there was no trace of water coming thru any of the discs.

In order to determine the compressive strength of the concrete discs used, a disc was embedded in Plaster of Paris on the Riehle testing machine in the testing laboratory and a load of 3000 lbs applied for 30 min. to permit a set. The pressure was then continued up to the full capacity of the machine or 100,000 lbs. with no signs of failure in the concrete. This is equivalent to a pressure of 3540 lbs. per sq. in. which is very high for commercial concrete.

CONCLUSIONS

From the tests preformed it is to be concluded that water-proof concrete is a practical possibility if the proper care is exercised in the selection and grading of the materials and in placing the concrete. The proportions used in the making of the test pieces were theoretical and were obtained by the use of Taylor and Thompson's rules in connection with the Ideal Curve as outlined above. However it is entirely possible to analyse and grade stock gravel in the field and with the proper supervision and care in the mixing, the laboratory conditions can be very closely duplicated. With concrete made in this way there is every reason to believe that it would be water-proof for any heads under which it would be necessary to use it, even up to 150 ft.

The slight permeation thru the concrete made with the cement C can probably be accounted for by the coarseness of the cement. It will be observed that this cement was very far below standard in the test on it for fineness.

That such a method of proportioning concrete is entirely possible is clearly proven by the fact that large construction companies have followed it, not as a means of making a water-proof concrete, but as an economical measure in the making of strong dense concrete.

APPENDIX I

The following is a list of the books, articles and papers covering work on concrete from which much valuable information was obtained in the preparation of this thesis.

1. Professional Memoirs Vol. 7
   Percolation and upward pressure of water on
   concrete dams.

2. Standard Specifications and Tests for Portland
   Cement of the American Society for Testing
   Materials.

3. Proportioning of Concrete Mixtures.
   Portland Cement Association.

4. Concrete Engineers Handbook.
   Hool and Johnson.

5. Reenforced Concrete Vol. I
   G. A. Hool.

6. Effect of Vibration, Jigging, and Pressure on
   Fresh Concrete.
   Duff A. Abrams.

7. Masony Construction.
   I. O. Baker.

APPENDIX II

The following is a copy of the outline of the plan for the work on this thesis submitted previous to the beginning of the work.

Outline of Work.

1. Materials

    1. Four different cements are to be used and a mixture of equal parts of the four cements forming a composite cement, making a test of five cement mixtures.

    2. Gravel to be a good grade of sharp bank gravel.

    3. Water to be tap water from the college mains.

II. Mixtures

    1. All mixtures of concrete are to be determined by a sieve analysis of the gravel used.

    2. An analysis is to be made of the sand passing the one eighth inch screen and also of the stone passing the one half inch screen and remaining on the one eighth inch screen.

III. Tests.

    1. Concrete
        a. Two discs are to be tested at each head for each mixture. Tests to be made at the end of 28 days. (This part revised).

        b. Tension briquettes for tests at the end of 7, 14 and 28 days are to be made.

        c. Compression cubes will be made for tests of each mixture at the end of 28 days.

    2. Heads.
        Heads from 10 to 50 ft. in increments of 10 ft. will be used in making the tests. (Later this was changed to include 150 ft.)