INTRODUCTION

The effect of hydrated lime on the tensile and compressive strength of mortar and concrete has long been a source of argument between The Portland Cement Association and the National Lime Association.

In a letter submitted by The Portland Cement Association they quote the following items taken from a paper entitled "Effect of Hydrated Lime and Other Powdered Admixtures in Concrete" by Professor Duff A. Abrams of the Structural Material Research Laboratory.

(1) "In general the addition of powdered materials reduced the strength of concrete approximately in proportion to the quantity of admixture. Some exceptions are noted below.

(2) "In usual concrete mixtures, each 1% hydrated lime (in terms of the volume of cement) reduced the compressive strength 0.5%; 1% by weight of cement reduced the strength 1.2%. The reduction in strength caused by replacing cement with an equal value of hydrated lime was about 1.75 times that caused by adding hydrated lime.

(3) "High calcium and high magnesium limes produced the same effect.

(6) "Rich concrete mixes showed a greater loss in strength due to powdered admixtures than the leaner ones. Lean mixes (1:9 to 1:6) and in those with aggregates graded too coarse for the quantity of cement used, the strength

was little affected or slightly increased by admixtures up to 50%.

(7) "The wetter mixes showed a greater loss in strength than the dry, due to the addition of hydrated lime.

(8) "The effect of admixtures was in general independent of the age of the cement.

(10) "Hydrated lime and other powdered admixtures used in these tests slightly increased the workability of the leaner mixes (1:9 and 1:6) as measured by the slump test. Ordinary mixes (1:5 and 1:4 were little affected; richer mixes (1:3 and 1:2) were made less plastic.

(13) "Hydrated lime had little effect on the absorption of dry concrete, increased the evaporation of water from wet concrete and produced no beneficial effect on the strength of concrete stored in air."

Also the following is a copy of the statement, (submitted to the author by letter) of T. H. Hart, Manager of Construction, Department of the Lime Association.

"Hydrated lime is used in concrete for the purpose of making it work smooth, fat and buttery. It produces an effect which no amount of water can produce, and permits the use of a dryer batch than would otherwise be possible. This leads directly to greater strength, (if the water is carefully controlled) and at the same time gives a better flow thru the mixer, better discharge from the mixer, flow in chutes and hoppers, better flow around reinforcement and complicated forms; smoother white surfaces, less segregation, etc. A long train of advantages are inter-related. These have never been measured mathematically. In most of the tests, the water has not been properly controlled and investigators have reported a reduction in strength which was not really caused by the lime itself, but by the water which they added (quite unnecessarily) with the lime."

Mr. Hart makes several statements that conflict with those of Professor Abram. Mr. Hart says, ' Hydrated lime is used in concrete for the purpose of making it work smooth, fat and buttery. It produces an effect which no amount of water can produce and permits the use of a dryer batch than would otherwise be possible." Professor Abram contradicts the above when he states that, "Hydrated lime and other powdered admixtures used in these tests slightly increased the workability of the leaner mixes (1:9 and 1:6) as measured by the slump test. Ordinary mixes (1:5 and 1:4) were little affected; richer mixes (1:3 and 1:2) were made less plastic.'

Mr. Hart also claims that when a proper amount of water is used the addition of hydrated lime will cause a stronger concrete while Professor Abram states that,'In general the addition of powdered materials reduced the strength of concrete approximately in proportion to the quantity of admixtures.' Also, 'The wetter mixes showed a greater loss in strength than the dry, due to the addition of hydrated lime.' Professor Abram's only statement in favor of lime is that it increases the evaporation of water from wet concrete.

Some one must be in error and therefore it seems to be the policy of one association or the other to make incorrect statements for simply commercial reasons. A consideration of the above quotations and discrepancies observed in other general sources of information lead to the idea of running a series of tests on hydrated lime and mortar for which were made a large number of standard briquets and 2 inch cubes for tension and compression tests respectively. The tests were run by laboratory methods which will be described as the different tests are taken up later.

The idea conveyed by Mr. Hart in his letter has been followed as nearly as possible in eliminating plasticity as a variable from the tests and to study the effect of hydrated lime on the strength of mortar. The normal consistancy was determined for each test so that plasticity was kept constant.

A neat cement mix; 1:2 mortar and 1:3 mortar were severally made up into three groups of briquets and cubes. The percentage of lime was varied from 0% to 30% by a stepped variation of 5% and was tested at the end of 7, 14 and 28 days respectively.

MATERIALS.

Cement. Burt cement which is of the rock variety was secured from a local dealer in Lansing for use in the tests.

Lime. A commercial hydrated lime manufactured by the Ohio Hydrate & Supply Company was secured from the same dealer as was the cement.

Sand. The sand was secured from gravel taken from a pile in the cement laboratory and screened through a 1/8" sieve.

TESTS OF MATERIALS.

1. 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 thoroughly 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.

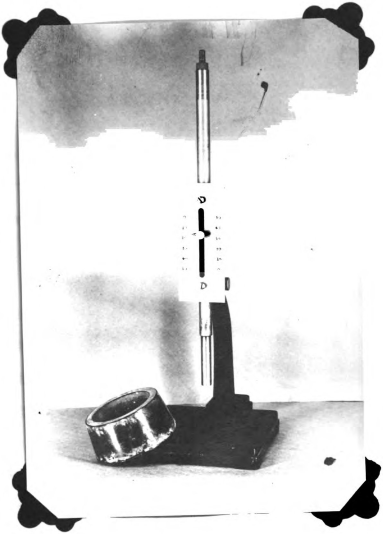
The glass plate and the ring were placed under a rod having a diameter of 1 cm. and weighing 300 gms. The penetration in 30 seconds was determined by a scale graduated in millimeters. For normal consistency the penetration should be 10 mm. for 30 sec. The results of the tests are shown in Table 7.

It not being possible to determine the normal consistency of a mortar with the Vicat method a 1:3 mix of cement and Ottawa sand was mixed to the proper normal consistency, the proper values being taken from a table on Page 838 in Hool and Johnson's Concrete Engineers' Handbook. All the 1:2 mortar and 1:3 mortar mixes were tried out with different quantities of water until the consistency appeared to be like that of the sample made up of the proper consistency. The values determined are given in Table 7.

TABLE NO. VII.

Table of Normal Consistency.

Per Cent of Lime		Neat Cement. Per Cent of Water	Neat Cement. Penetration	1:2 Mix	1:3 Mix
0%		25 %	9 Mm.		
		25-1/2	8		
		26	16		
		26-1/2	13		
		26-1/2	8		
		27	11-1/2		
		27	9		
	Av.	26.2	10.6		
	Use	26		12.5%	11. %
5		27 %	8 mm.		
		27-1/2	10		
	Use	27-1/2		12.5%	11.3%
10		28-1/4%	8 mm.		
		28-3/4	13.		
	Use	28-1/2		13.4%	11.6%
15		29 %	7 mm.		
		29-1/2	12		
		29-1/2	11		
	Use	29-1/2		13.85%	11.9%
20		30 %	7 mm.		
		30.6	14 mm.		
	Use	30.3		14.3%	12.2%
25		31 %	11 mm.		
		31	9		
	Use	31		14.75%	12.5%
30		30 %	5 mm.		
		32	9		
		33	13		
	Use	32		15.2%	12.8%



Vicat apparatus

2. Tension Tests.

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

Neat Cement. Twelve briquets of neat cement of normal consistency were made for each mix of 0%, 5%, 10%, etc., to 30%. Four were tested at the end of 7 days, four at the end of 14 days and four at the end of 28 days. The forms containing the test pieces were placed in moist air for 24 hours and then the forms were removed and the briquets were placed in water at a temperature of approximately 70° F until tested.

The results obtained from the tests are tabulated in Table I and comparative curves are shown in Diagram I. All the results of these tests will be summed up and compared with the other tests in the conclusions. The diagram shows that the briquets were stronger on the 28th day than on the 14th day and stronger on the 14th day than on the 7th day. If an average curve was drawn for each day's test it would be approximately parallel with the other ones. This graph bears out what Professor Abram says, 'In general the addition of powdered materials reduced the strength of concrete approximately in proportion to the quantity of admixture'. The diagram gives average results.

1:2 Mortar Mix. The same number of text pieces with the same variation of lime were made up for this test, as in the Neat Cement. The pieces were tested on 7, 14 and 28 day periods as was the Neat Cement. The results are given in Table II and comparative graphs shown in Diagram II.

Table No. 1

BRIQUETS

NEAT CEMENT MIX.

		7 Day	14 Day	28 Day
1A		705	720	710
0% of Lime		470	700	850
		450	790	810
		685	725	845
	Ave.	577.5	734	804
1B		565	640	660
5% of Lime		425	660	650
		575	520	755
		515	540	845
	Ave.	520	590	716
1C		475	610	670
10% of Lime		380	510	660
		460	495	695
		440	635	690
	Ave.	501	562.5	681
1D		400	480	550
15% of Lime		345	570	650
		425	560	650
		415	540	450
	Ave.	396	537.5	575
1E		330	410	530
20% of Lime		365	480	520
		380	480	580
		375	470	540
	Ave.	362.5	460	542.5
1F		280	430	520
25% of Lime		310	420	525
		365	440	585
		350	500	480
	Ave.	326	447.5	527.5
1G		325	410	520
30% of Lime		335	440	570
		340	440	530
		345	440	495
	Ave.	336	432.5	529

Note: Averages are given in pounds per square inch.

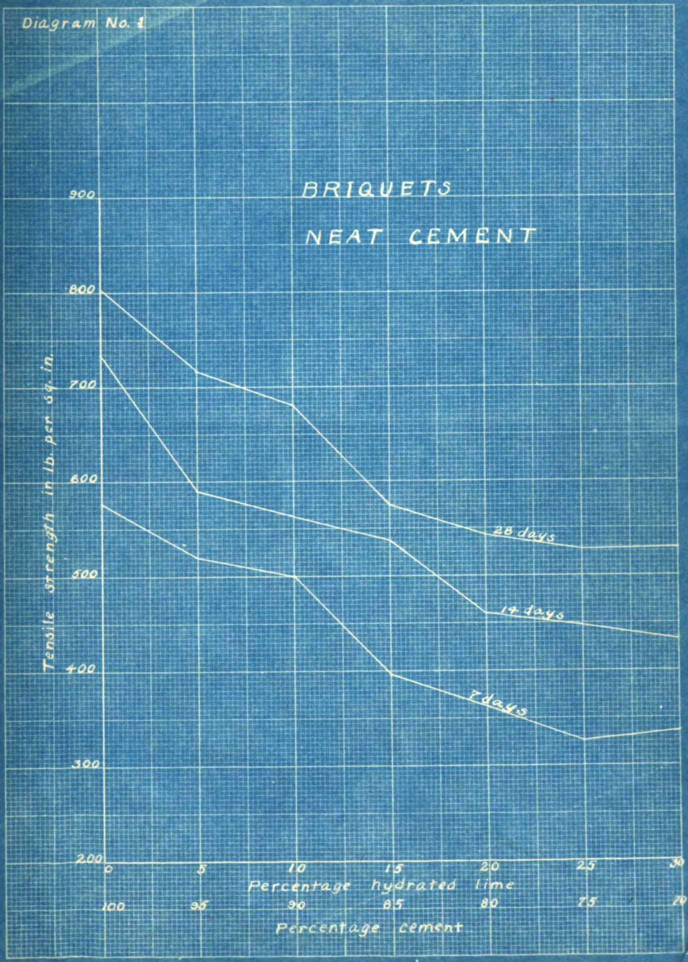


Diagram No. 1
BRIQUETS
NEAT CEMENT
Tensile strength in lb. per sq. in.
900
800
700
600
500
400
300
200
28 days
14 days
7 days
0
5
10
15
20
25
30
Percentage hydrated lime
100
95
90
85
80
75
70
Percentage cement

Table No. 2

BRIQUETS

1 : 2 - Mix.

		7 Day	14 Day	28 Day
2A		475	510	550
0% of Lime		380	590	545
		460	480	540
		440	515	490
	Ave.	439	524	531
2B		370	410	490
5% of Lime		440	380	505
		415	420	420
		330	430	440
	Ave.	389	410	464
2C		310	415	425
10% of Lime		335	435	470
		340	360	420
		330	430	435
	Ave.	329	410	437.5
2D		330	330	410
15% of Lime		280	340	405
		330	355	400
		300	345	405
	Ave.	310	342.5	405
2E		210	300	360
20% of Lime		250	285	370
		215	330	350
		210	310	350
	Ave.	221	306	357.5
2F		250	270	370
25% of Lime		240	315	330
		260	280	335
		250	285	330
	Ave.	250	287.5	341
2G		210	225	285
30% of Lime		200	250	300
		200	250	310
		220	255	270
	Ave.	207.5	237.5	291

Note: Averages are given in pounds per square inch.

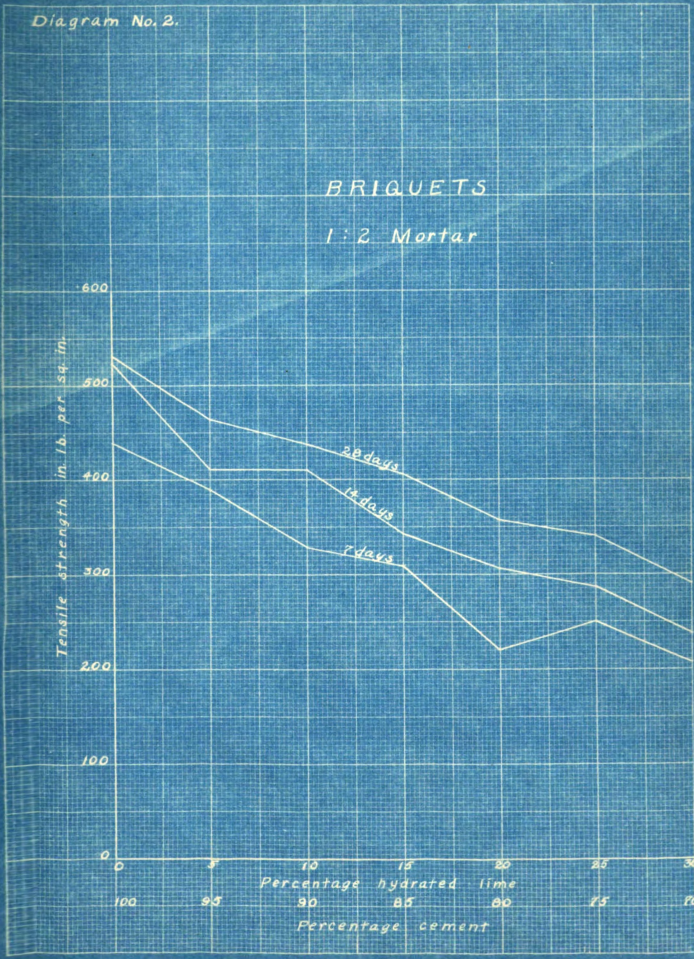


Diagram No. 2.
BRIQUETS
1:2 Mortar
Tensile strength in lb. per sq. in.
600
500
400
300
200
100
0
28 days
14 days
7 days
0
5
10
15
20
25
30
Percentage hydrated lime
100
95
90
85
80
75
70
Percentage cement

Table No. 3

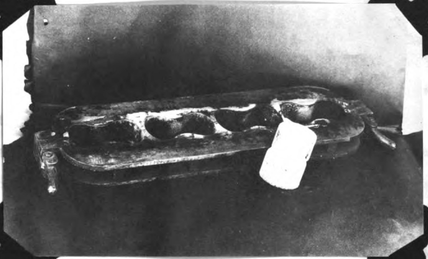
BRIQUETS

1 : 3 - MIX.

		7 Day	14 Day	28 Day
3A 0% of Lime		360	405	410
		315	375	435
		330	450	410
		355	415	420
	Ave.	340	411	419
3B 5% of Lime		270	325	405
		235	315	370
		295	320	395
		290	305	360
	Ave.	272.5	316	382.5
3C 10% of Lime		230	275	350
		240	285	375
		260	340	350
		260	290	355
	Ave.	247.5	297.5	357.5
3D 15% of Lime		220	240	305
		220	275	335
		130	250	275
		210	290	270
	Ave.	195	264	296
3E 20% of Lime		260	255	280
		220	260	290
		200	245	290
		160	270	285
	Ave.	210	257.5	286
3F 25% of Lime		190	285	275
		190	220	260
		160	185	290
		210	250	240
	Ave.	187.5	235	266
3G 30% of Lime		170	190	215
		190	210	225
		170	205	250
		170	210	210
	Ave.	175	204	225

Note: Averages are given in pounds per square inch.


Diagram No. 3
BRIQUETS
1:3 Mortar
Tensile strength in lb. per sq. in.
600
500
400
300
200
100
0
28 days
14 days
7 days
0
5
10
15
20
25
30
Percentage hydrated lime
100
95
90
85
80
75
70
Percentage cement



Briquet mold and briquet

Briquet testing machine

All that was said about the neat cement tests applies to this test. There are a few variations in the diagram as for instance: The 5% point on the 14th day shows a low test; while the 10% point on the 14th day shows a high test. The variations on the tensile tests have been charged up to the personal equation, because the variations have not held constant for the 7, 14 and 28 day graphs.

1:3 Mortar Mix. The same number of test pieces with the same variation of lime were made for this test as in the neat cement and 1:2 mortar mix. These briquets were seasoned as were the neat cement and 1:2 mortar mix. The average results are summed up in the Conclusions. The results are given in Table III and comparative graphs shown on Diagram III. What was said of the neat cement mix and 1:2 mortar mix applies to the 1:3 mortar mix, as shown by the graph.

In all the tensile tests the graph proves what Professor Abram has said and what was quoted in his paper as Item I.

COMPRESSION TESTS.

Two-inch cubes were made of neat cement 1:2 and 1:3 mortar with a cross sectional area of four square inches, for compressive tests. All blocks were set up in plaster of paris before being broken to eliminate uneven surfaces.

<u>Neat Cement</u>. Twelve cubes of neat cement of normal consistency were made for each mix;- 0%, 5%, 10%, etc., to 30%. Four were tested at the end of 7 days, four at the

end of 14 days and four at the end of 28 days. The blocks were seasoned the same as the briquets.

The results are tabulated in Table IV and comparative graphs are shown in Diagram IV. The graph shows a decided difference between the tests of the cubes and those of the briquets. The test of the 7 day cubes is very similar to that of the 7th day briquets and also the 14th day. The 28 day are stronger than the 14 day test pieces at 0% and 5%. Then the 28 day dropped below the 14 day; rose above at 15%; went below to 20% and continued so to 30%. The graphs show that in rich mixtures after a certain age the mortar begins to lose strength. The only way that it can be accounted for is that on drying, the lime sets up forces that cause very small cracks invisible to the naked eye and as a result of the small cracks, the strength is reduced. This is one of Professor Abram's theories. This graph not only shows that age decreases the strength, but that Professor Abrams first item is checked again.

1:2 Mortar Mix. The same number of cubes with the same variation of lime were made for this test as were for the neat cement. These cubes were seasoned the same as the other ones.

The results are given in Table V and comparative graphs shown in Diagram V. The 5% tests of the 14th day is the same as 5% tests for the 28th day which shows that age decreases the strength and again the 28th day, 10% tests fall below the 14th day 10%. From here on the graph is similar

Table No. 4

CUBES - 2 in.

NEAT CEMENT -- COMPRESSIVE STRENGTH

		7 Day	14 Day	28 Day
1A 0% of Lime		22140 25760 21000 19690	25905 25940 27135 26725	Over - 31000
	Ave.	5537	6607	8000
1B 5% of Lime		18130 16890 17415 14460	19620 24200 23230 22110	27145 31000 24680 27600
	Ave.	4181	5573	6964
1C 10% of Lime		12080 13515 16055 12960	24140 18500 19775 20400	21020 18510 17055 21885
	Ave.	3413	5176	4905
1D 15% of Lime		13240 14630 15520 14680	20495 16225 21670 23070	18090 23340 23390 24440
	Ave.	3630	5091	5579
1E 20% of Lime		11920 13750 13720 13160	21850 22200 21715 20750	20990 21860 18600 19330
	Ave.	3284	5407	5049
1F 25% of Lime		13310 11270 13380 12840	13690 18900 20040 14710	16590 19460 13300 14465
	Ave.	3175	4210	3988
1G 30% of Lime		9510 10460 10590 9840	13725 16260 15020 14210	12760 15425 15060 13230
	Ave.	2525	3701	3530

Note: Averages are given in pounds per square inch.

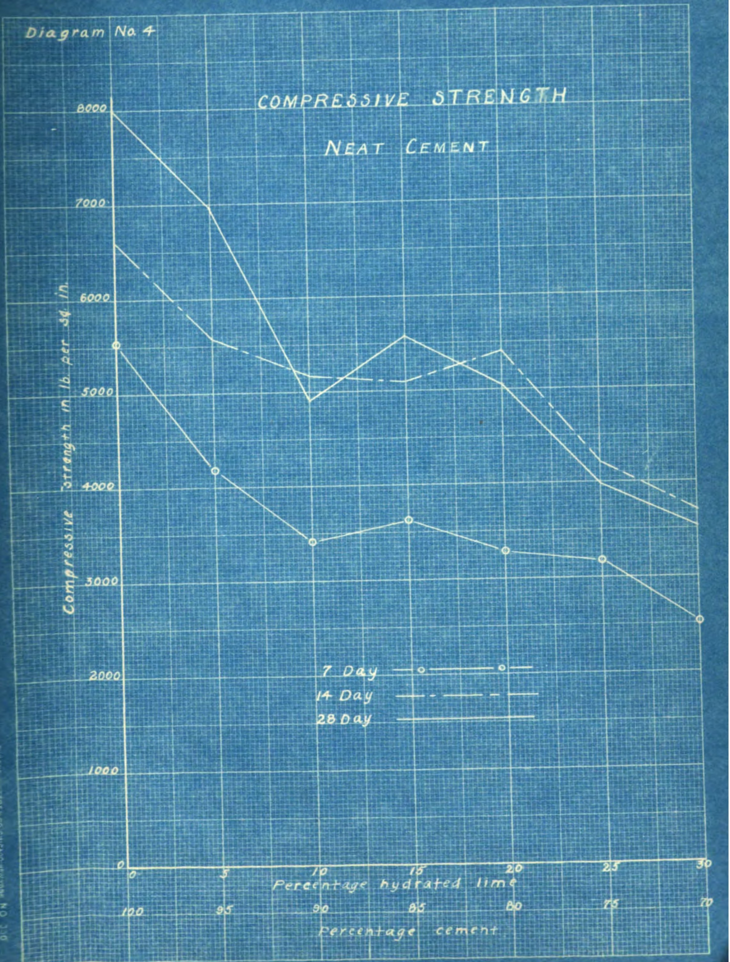


Diagram No. 4
COMPRESSIVE STRENGTH
NEAT CEMENT
Compressive strength in lb. per sq. in.
8000
7000
6000
5000
4000
3000
2000
1000
0
7 Day
14 Day
28 Day
0
5
10
15
20
25
30
Percentage hydrated lime
100
95
90
85
80
75
70
Percentage cement

Table No. 5

CUBES - 2 in.

[illegible] 2 MIX -- COMPRESSIVE STRENGTH

		7 Day	14 Day	28 Day
2A 0% of Lime		12075	12525	16720
		8000	10925	15695
		9800	10460	17630
		9850	12150	16900
	Ave.	2483	2879	4184
2B 50% of Lime		10370	13805	12380
		9550	12210	14105
		10190	11595	12270
		10840	15200	14105
	Ave.	2560	3301	3304
2C 10% of Lime		8430	10640	9110
		8710	9545	10550
		8340	10895	10525
		9920	11290	11060
	Ave.	2213	2648	2578
2D 15% of Lime		8725	9815	12370
		7885	9545	10940
		9000	9555	11005
		8000	11535	11745
	Ave.	2101	2526	2879
2E 20% of Lime		7770	7750	10310
		7250	8130	10555
		7370	8725	10460
		7000	8360	10865
	Ave.	1837	2060	2637
2F 25% of Lime		6310	7525	10280
		6750	7700	9590
		6530	8000	9200
		6435	7155	10380
	A ve.	1627	1899	2467
2G 30% of Lime		5415	5575	8615
		5540	6095	8960
		6120	5525	9050
		5850	5525	7710
	Ave.	1433	1420	2146

Note: Averages are given in pounds per square inch

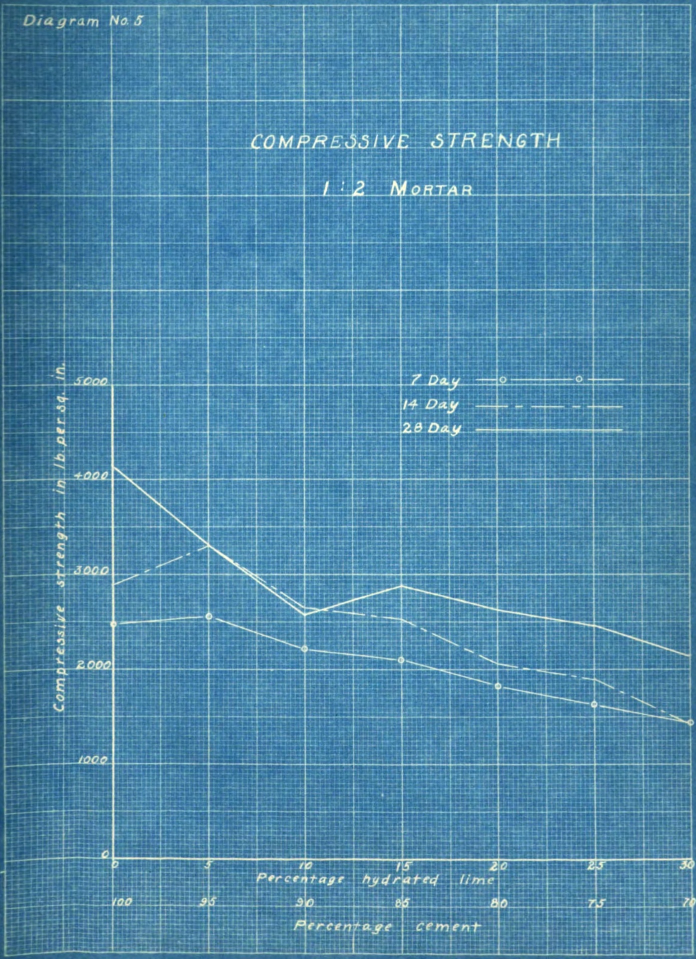


Diagram No. 5
COMPRESSIVE STRENGTH
1:2 MORTAR
7 Day
14 Day
28 Day
Compressive strength in lb. per sq. in.
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
Percentage hydrated lime
100
95
90
85
80
75
70
Percentage cement

Table No. 6

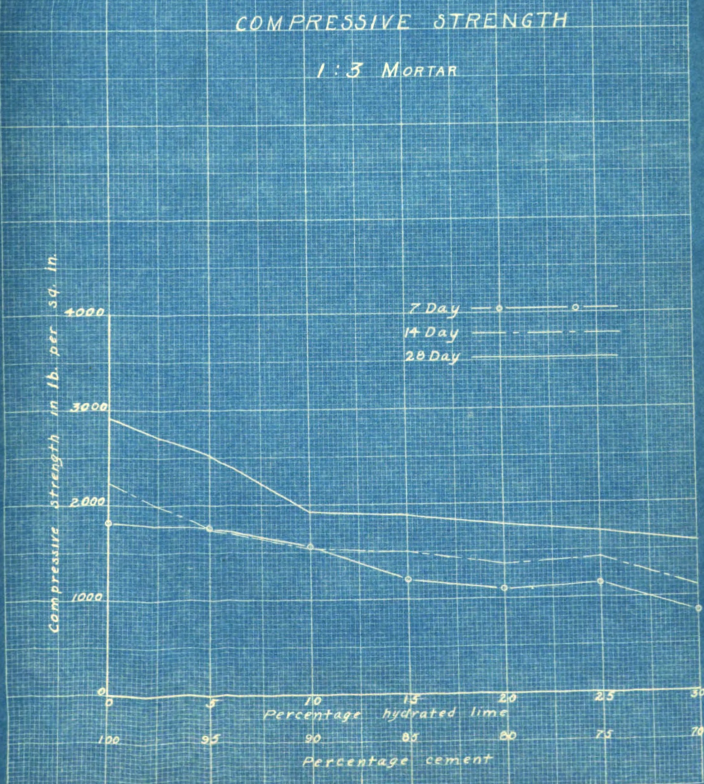
CUBES - 2 in.

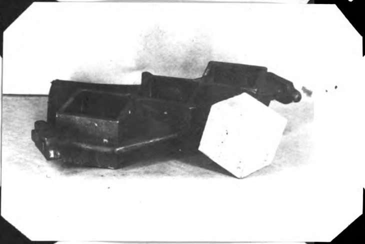
1 : 3 MIX -- COMPRESSIVE STRENGTH

		7 Day	14 Day	28 Day
3A 0% of Lime		6350	9860	13205
		7630	9550	9750
		7060	7500	10740
		8020	8750	12910
	Ave.	1816	2229	2913
3B 5% of Lime		7440	6015	11025
		6855	7950	9000
		6800	7335	9960
		7180	6710	10445
	Ave.	1767	1751	2527
3C 10% of Lime		6410	4710	7705
		6180	6540	7285
		5760	6670	7640
		6510	6725	8205
	Ave.	1554	1540	1927
3D 15% of Lime		4685	5575	7900
		4870	6560	7350
		5480	5525	6810
		4345	6380	8040
	Ave.	1211	1503	1881
3E 20% of Lime		4510	5015	7295
		4100	6140	7370
		4285	5785	6365
		4860	4840	7520
	Ave.	1110	1361	1784
3F 25% of Lime		4550	6495	6075
		4225	5035	7315
		4600	5605	7030
		5025	5755	6805
	Ave.	1150	1431	1702
3G 30% of Lime		3400	4475	5740
		3200	4070	6335
		3670	4410	5980
		3240	4835	7285
	Ave.	844	1112	1584

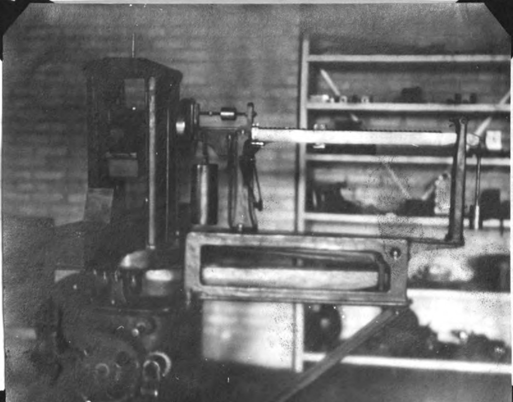
Note: Averages are given in pounds per square inch.

Diagram No. 6


COMPRESSIVE STRENGTH
1:3 MORTAR
7 Day
14 Day
28 Day
Compressive strength in lb. per sq. in.
4000
3000
2000
1000
0
0
5
10
15
20
25
30
Percentage hydrated lime
100
95
90
85
80
75
70
Percentage cement



Cube mold and cube



Cube testing machine

to that of the briquets. The variation may be due more to the personal equation.

1:3 Mortar Mix. The same number of cubes with the same variations were used in this test as in the other tests. The cubes were seasoned as were all the other cubes.

The results are given in Table VI and comparative graphs shown in Diagram VI. This graph shows that the age is not effective as far as this test goes. This still further proves Professor Abram's first item in his paper. There is a slight variation in the 5% and 10% cubes at 7 and 14 days, but this is due to the personal equation.

CONCLUSIONS.

From the tests preformed it seems proper to conclude that under no condition does rich mixtures of mortar (neat cement, 1:2 and 1:3) with lime increase the tensile and compressive strength, but bears out the statement of Professor Abram's in which he says, 'In general the addition of powdered materials reduced the strength of concrete approximately in proportion to the quantity of admixtures.'

There may often be places where the value of lime for producing color, etc., will out-weigh the importance of high strength, but under ordinary conditions lime should be left out of concrete.

Finally, the investigation outlined herewith plainly indicates that Mr. Hart's statements are in error. Possibly he has been led to extravagant claims by the enthusiasm of advertising campaign, a not uncommon occurrence in business.

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. Concrete Engineers Handbook.
   Hool and Johnson.

2. Effect of Hydrated Lime on Portland-Cement Mortars.
   Henry S. Spackman.

3. The Effect of Hydrated Lime on Portland-Cement Mortars.
   Professor Harry Gardner.

4. Letter - Portland Cement Association.
   J. E. Freeman.

5. Letter - National Lime Association.
   F. H. Hart.

6. Letter - Lewis Institute.
   Professor Duff A. Abrams.

APPENDIX II.

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

Subject: The effect of hydrated lime on the tensile and compressive strength of mortar.

Proportions: Neat, 2:1 and 3:1

Percentages (by weight) of lime: 0 - 5 - 10 - 15 20 - 25 - 30.

Age: 7, 14 and 28 days.

Number: 21 kinds x 3 different ages x 4 for each test = 252 briquets.

Number of cubes: The same as for briquets - 252.