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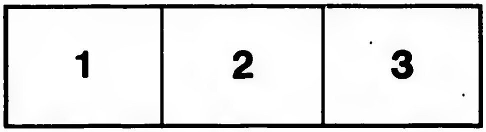
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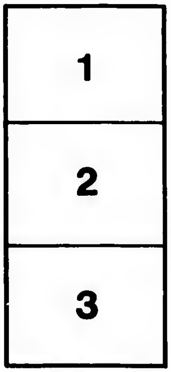
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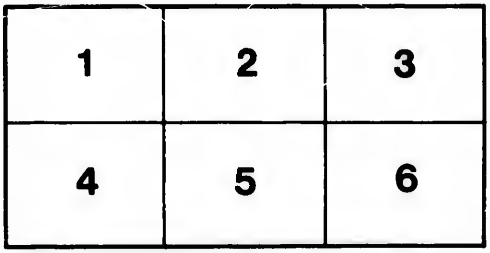
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Canadian Society of Civil Engineers.

INCORPORATED 1887.

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CEMENT TESTING.

By Cecil B. Smith, Ma. E., A.M. Can. Soc.C.E.

This subject has so often been written on, and is being so continually and persistently investigated, that it forms, as it were, an inexhaustible mine.

But this very feature shows how very important and yet how little understood it is, for, when investigators continue to disagree, the presumption is, that there is either a lack of agreement as to the basis on which the investigations are made, or else a failure, up to the present, to solve all the intricate mazes of the problem, or indeed a combination of the two.

To illustrate the first point, a tabular synopsis (Table I) is presented, giving the present standard tests in use, in various countries, according to the latest obtainable information. The variations, in many cases, are too great to be reconciled, in others trifling; but it is evidently difficult to compare results obtained in different countries, and a hopeless task to ever bring them to a uniform standard. What it behooves us, as Canadian Engineers, to do is to take such sensible and immediate action on the subject as will commend itself to the good graces of all of us, if possible, or, if not, of a great majority of those who test the manufactured article.

However, before proposing a mode of conducting such tests as will (according to the author's experience) be of practical utility to practical men, the following Table (Table II) is presented to the Society, as embodying results which have been obtained during the last two sessions, in making ordinary commercial, private and student tests (chiefly commercial and private).

Many results have been discarded as being inaccurate, and only those are recorded here which are believed to be very close to the truth much closer than is ordinarily obtained.

These results have been classified according to country of manufacture, and somewhat on a scale of increasing tensile strength.

Let us consider the various qualities given in their tabular order.

(*a*) *Specific Gravity.*

The average of Canadian Portlands = 3·11

The average of English Portlands = 3·10

The average of Belgian Portlands = 3·055

The average of all Portlands (16) = 3·09.

It would seem advisable, therefore, to specify a minimum for Portlands of 3·10.

The samples were not dried or prepared in any way; if they were dried for 15 minutes, according to English practice, it is probable they would go somewhat higher.

It will be noticed that the only two Portlands (?) whose specific gravity was low (Belgians Nos. 16 and 17) were both poor cements, one, No. 16, sets slowly, and the briquettes made for 4 week tests, and immersed in water after 24 hours, were found sloughed down in the tanks, and had evidently run and set over again! They would not give any test to speak of. Evidently the hydraulic property, in 24 hours, was not

TABLE I.—STANDARD CEMENT TESTS.—*Continued.*

Kind of sand used.	How put in Moulds.	Rate of loading in tensile tests.	Time in air before immersions.	No. of tests used for Averages.	Time of Mixing.	Wearing Qualities.	Adhesive Qualities.
Standard crushed quartz to all pass No. 20 sieve all caught on No. 30 sieve.	10 lbs. per sq. in. steady pressure.	200 lbs. per minute.	24 hrs.	Not stated, probably 5	1 min. for quick setting, 2 minutes for slow setting, mechanical mixer.		
ditto	10 lbs. on briquette for 5 min., or shaken in moulds or beaten with trowel for 1 min.	400 lbs. per minute.	24 hrs.	5	1 minute or more, mechanical mixer.		Mr. Mann 1 week 57, 1 mo. 78, 3 mos. 98 } ground glass. Fineness has great effect.
ditto	Pressed in with trowel without ramming.	ditto	24 hrs.	5 Smallest section only.	1 minute or more, hand or mechanical mixing.		
Standard crushed quartz, ½ to pass 20, caught on 30. ½ to pass 30, caught on 38 sieves.	Bohmes' apparatus, 150 blows with trip hammer weighing 4.4 lbs.	13 lbs. per minute.	24 hrs.	10	1 minute for quick setting, 3 min for slow setting cements.	1 to 1 and 2 to 1 give higher results than neat or 3 to 1 tough, at 7 days as at 20 days.	Advised to be still reported on and investigat'd, to be made on ground glass.
Crushed Cherbourg quartz pass No. 20 caught on No. 30 sieves.	Filled in and tamped with rammer weighing 7 oz. till water stands on surface.	Not specified.	24 hrs. then in sea water of 59° to 64° F.	6 Mean of 3 highest taken.	5 minutes by hand on a slab, temp. of air 59° to 64° F.		
				10 Mean of 6 highest taken.			

nough to hold them together, while the other one (No. 17) failed in the blowing test. Altogether, it is doubtful whether these cements are Portlands or naturals, although sold as the former, owing to their colour beipo..ura..

10
Mean of 6
highest taken.

1893-1894.

...q. in.

...s	6 mos	t wk.
.	....	......
.	....	......
.	....	30
.	...	49
.	....	43
.	....	106
.	....	......
.	....	.....
.	....	....
.	....	......
.	....	55
.	....	95
.	....	72
9	271	......
.	....	......
.	....	......
.	....	60
.	....	54
.	....	34
.	....	.....
.	....	......
.	....	......
.	....	......
.	....	133
.	....	......
.	....	....
.	....	......
.	....	......
.	....	......

..0 per cent. residue on No. 120 sieve)
high for present facilities for fine grinding; this would let in 3 out of 4 Canadian Portlands tested, 1 out of 10 English Portlands tested, 2 out of 4 Belgian Portlands tested, or in all 6 out of 18 brands. There are signs, however, that the English manufacturers are waking up to finer grinding, and will soon fall into line; there is no reason why educating influences should not bring grinding down much finer still for ordinary brands, but for the present, too much severity would defeat the object in view. (For tests on the effect of fine grinding, see Series I of Experiments.)

nough to hold them together, while the other one (No. 17) failed in the blowing test. Altogether, it is doubtful whether these cements are Portlands or naturals, although sold as the former, owing to their colour being gray.

TABLE II.

CONDENSED TABLE OF CEMENT TEST

Designation of Origin.	No. in Table.	Obtained from.	Specific Gravity.	% water for standard consist'ncy	Residue % on Sieves. No. 20	No. 50	No. 80	No. 120	Blowing test result.	Time of setting in air. Incipient	Full.	Average Tensile Strength in lbs. per sq. in. Neat Cement. 3 dys.	1 wk.	2 wks	3 wks	4 wks	2 mos	3 mos	4 mos	6 mos	1 year	Average Tensile Strength in lbs. pe[r sq. in.] 1 to 1. 1 wk.	2 wks	4 wks	2 mos	3 mos	4 mos	6 mos	1½ to 1. 1 month.	2 to 1. 1 wk.	4 wks	2 mos	3 mos	[illegible]
Canadian N	1	Dealer	3·01	33	0	7·2	12·5	18·3	very good	4°00′	7°45′	78	71	....	....	124	226	....	....	....	....	68	....	102	125	....	....	....	....	....	....	....	....	.
Canadian N	2	Maker	2·96	33⅓	0	2·9	11·7	21·4	good	0°45′	2°45′	99	150	....	....	268	377	448	478	492	....	76	....	115	158	162	137	163	132	...	....	....	....	.
Canadian P	3	Maker	3·12	25½	0	1·1	14·2	31·2	good	5°00′	20°00′	125	210	....	....	356	....	...	....	....	....	....	....	....	....	....	....	...	....	....	....	....	....	.
Canadian P	4	Maker	3·12	26	0	0·8	2·7	6·7	good	0°37′	3°10′	335	388	....	....	525	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	..	.
Canadian P	5	Maker	3·09	25	0	0·6	5·5	13·2	good	1°00′	5°00′	278	399	....	....	459	....	....	.	....	....	....	....	....	....	....	....	....	......	....	....	....	....	.
Canadian P	6	Maker	3·12	24	0	0·9	6·4	13·2	good	4°30′	6°00′	438	588	....	....	671	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	.
Canadian P	6a	Dealer	....	24	0	3·0	13·6	20·7	very good	2°00′	6°30′	312	531	....	....	611	....	....	....	....	...	....	....	....	....	....	....	....	....	....	....	....	....	.
Canadian P	6b	Dealer	....	24	0	2·3	27·0	40·7	fair	......	....	300	307	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	.
Canadian P	6c	Dealer	....	23	0	31·4	52·2	61·2	bad	....	....	253	264	....	...	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	.
English P	7	Dealer	....	33	0	10·5	21·6	....	good	....	....	....	230	....	....	331	....	....	....	....	....	...	....	....	....	....	....	....	....	....	....	....	...	.
English P	8	Dealer	3·09	25	0	14·0	28·4	39·5	good	3°20′	6°30′	160	414	....	....	528	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	......	.
English P	9	Dealer	3·09	26	0	1·4	12·8	22·9	good	13′	2°00′	390	420	....	....	453	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	.
English P	10	Dealer	3·10	23½	0	6·7	19·2	26·5	good	25′	50′	250	386	372	....	552	...	....	....	....	....	232	345	316	....	....	....	....	....	....	....	....	....	.
English P	11	Dealer	3·08	23	0	4·0	14·2	23·1	good	30′	1°00′	336	477	396	....	504	560	637	627	644	....	192	....	204	245	253	257	531	....	151	198	189	196	1
English P	12	Dealer	3·11	24	0	4·2	19·5	28·5	good	25′	3°00′	244	362	....	....	547	....	....	....	....	..	....	....	....	....	....	....	....	....	....	....	....	..	.
English P	13	Dealer	3·13	24½	0	4·5	17·3	26·3	bad	20′	4°00′	335	344	...	....	422	....	....	....	....	...	....	....	....	..	....	....	....	....	....	....	....	....	.
English P	14	Dealer	3·13	24	0	0·25	5·0	12·9	very good	20′	2°30′	....	387	444	....	495	....	....	....	....	....	....	....	....	....	..	....	..	....	....	....	....	....	.
English P	14a	Dealer	3·12	23	0	5·6	20·9	30·5	bad	27′	3°05′	...	343	350	...	469	....	....	....	....	....	....	....	....	....	..	....	....	....	....	....	....	....	.
English P	14b	Dealer	3·05	23	0	5·3	19·7	30·1	some bad	20′	2°30′	304	309	....	....	440	....	....	....	....	....	...	....	....	....	....	....	....	....	....	...	....	...	.
Belgian N	15	Dealer	2·97	30	0	7·7	15·4	19·4	very good	1°00′	2°30′	154	219	....	....	285	....	....	....	....	....	134	....	195	....	....	....	....	......	48	77	....	....	.
Belgian P	16	Dealer	3·03	26½	0	2·2	12·4	20·6	good	5°00′	12°00′	232	332	....	....	Fl'd	....	....	....	....	....	....	....	....	....	......		....	....	....	....	....	....	.
Belgian P	17	Dealer	3·02	26	0	3·1	12·9	20·1	bad	1°10′	5°00′	328	394	....	....	487	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	.
Belgian P	18	Dealer	3·09	27	0	0·3	2·8	9·4	good	1°20′	4°50′	255	360	....	....	492	....	....	....	....	....	....	....	....	....	....	....	....	....	126	207	....	....	.
Belgian P	19	Agent	3·08	25	0	0·9	6·2	15·8	good	2°40′	7°40′	452	536	....	......	525	...	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	..	.
	20	......	......	25	....	....	....	....	....	....	....	....	....	....	....	....	..	....	....	....	533	....	....	....	....	....	....	....	....	....	..	....	....	.
	21	......	......	25	0	4·0	10·8	....	....	....	....	....	....	....	463	....	..	....	....	....	648	....	....	....	....	....	....	....	....	....	....	....	....	.
	22	......	......	......	....	....	....	....	....	....	....	....	152	....	....	485	...	....	....	....	606	....	....	....	....	..	....	....	....	....	....	....	....	.
	23	.....	......	......	....	....	....	....	....	.. ..	....	....	345	450	....	545	....	....	....	....	593	....	....	...	....	....	....	....	......	....	....	....	....	.
Total.......	....	......	......	......	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....		....	....	....	....	....	....	....	....	....	....	....	.

20 per cent. residue on No. 120 Sieve } ... ... too high for present facilities for fine grinding; this would let in 3 out of 4 Canadian Portlands tested, 1 out of 10 English Portlands tested, 2 out of 4 Belgian Portlands tested, or in all 6 out of 18 brands. There are signs, however, that the English manufacturers are waking up to finer grinding, and will soon fall into line; there is no reason why educating influences should not bring grinding down much finer still for ordinary brands, but for the present, too much severity would defeat the object in view. (For tests on the effect of fine grinding, see Series I of Experiments.)

TABLE II.

ED TABLE OF CEMENT TESTS. 1893-1894.

Average Tensile Strength in lbs. per sq. in.															Average Compressive Strength lbs. per sq. in.														Transverse Strength.					No. of Tests.		
	1½ to 1.	2 to 1.						3 to 1.							Neat Cement						1 to 1.			2 to 1.			3 to 1.		Neat 1"x1" broken on 6" centres.					Tensile.	Comp.	Trans.
6 mos.	1 month.	1 wk.	4 wks.	2 mos.	3 mos.	4 mos.	6 mos.	1 wk.	2 wks.	4 wks.	2 mos.	3 mos.	4 mos.	6 mos.	1 wk.	2 wks.	3 wks.	4 wks.	2 mos.	1 year.	1 wk.	4 wks.	2 mos.	1 wk.	4 wks.	2 mos.	1 wk.	wks.	1 wk.	2 weeks.	3 weeks.	4 weeks.	1 year.			
																			1600															27	1	0
163	132														1285			2255			900	1350												100	8	0
								30		72																	205	475						33	3	0
								49		75																	392	412(?)						33	4	0
								43		92					1362			2492											42					30	4	1
								106		126					3025				4975									1025	99					35	7	2
																																		15	0	0
																																		6	0	0
																																		10	0	0
															1502			1720											54			84		10	5	2
								55		136					1967			2650											73			99		30	2	5
								95		115									4500															40	1	0
								72		96												3325												29	1	0
531		151	198	189	196	189	271				104											2826	3200			800						112		105	9	2
																																		44	0	0
																																		14	0	0
								60	79	102																								30	0	0
								54	64	90																								30	0	0
								34																										93	0	0
		48	77												1250			1950						743	953									35	8	0
																																		10	0	0
																																		13	0	0
		126	207																															50	0	0
								133		154					2970			4350									718	900						24	6	0
																				6391													113	12	10	2
																	5310			4826											86			17	3	2
															1200	1555		2566		5066												59		13	9	2
																3000		4400															60(?)	6	2	1
																																		894	83	19

The sand briquettes were lightly tamped with a small iron rammer.—C. B. S.

nough to hold them together, while the other one (No. 17) failed in the blowing test. Altogether, it is doubtful whether these cements are Portlands or naturals, although sold as the former, owing to their colour being gray.

It will be noticed, with satisfaction, that Canadian Portlands stand at the top in specific gravity, judging by the samples tested, which were, however, all received from manufacturers.

The specific gravity of natural cements might be placed at 2·95, although it is not so likely to be under-run, owing to the ease with which this can be obtained.

(*b*) *Water required for standard consistency.*

This is considered, by many, to be very important; but many tests have demonstrated to the writer that what is especially needed is that there shall be sufficient to make good briquettes; to err, say, 1 per cent. in adding water is fatal if too little, while if too much, it does not seem to affect the strength of briquettes at one week, certainly not at 4 weeks. This is contrary to statements often made regarding the increased strength given by a minimum amount of water; but probably what is referred to is an excess of water sufficient to make a thin batter or soup. Undoubtedly such an amount not only makes the briquettes shrink and crack in drying, but will seriously affect the early strength.

A very peculiar effect was met with in two Canadian and one English Portlands. They were evidently fresh, and when mixed with a normal amount of water would work into a good plastic mass, but in about 1 to 2 minutes after the water was added, they would suddenly set, so hard that it was useless to attempt to put them in the moulds.

By increasing the per cent. of water to about 30, a thin batter was made, which could be got into the moulds before this action took place; of course this amount of water made the set very slow, and deadened the indurating action in 1 week tests.

When tests were made, several weeks later, on these cements, this effect had disappeared; perhaps someone connected with the industry can explain the cause of this notion.

(*c*) *Residues or Fineness.*

The variation is enormous, as the following statement shows:—

	Residue on No. 50 Sieve %	Residue on No. 80 Sieve. %	Residue on No. 120 Sieve. %
Coarsest	31·4	52·2	61·2
Finest	0·25	2·7	6·7

The English Portlands are generally very coarse, as will be seen, and the selected Canadian ones fine.

It is not putting it too severely to say that specifying a certain residue on No. 50 Sieve is a direct premium on coarse grinding, and so, in fact, are neat tensile tests.

For instance, English brands No. 10, No. 11, No. 12, No. 13 and Nos. 14 A. 14 B. are all evidently ground to pass a specification of 5 per cent. residue on No. 50 Sieve, and are all very coarse when sifted on finer ones, thus plainly showing the failure of the specification to obtain as good a product as possible.

The author would urge the severest requirements for fineness.

Various papers read and the statements of manufacturers themselves go to show that the increased cost is very slight, not more than 10c per bbl. between ordinary and fine grinding.

10 per cent. residue on No. 80 Sieve }
20 per cent. residue on No. 120 Sieve } as maximums are not too high for present facilities for fine grinding; this would let in 3 out of 4 Canadian Portlands tested, 1 out of 10 English Portlands tested, 2 out of 4 Belgian Portlands tested, or in all 6 out of 18 brands. There are signs, however, that the English manufacturers are waking up to finer grinding, and will soon fall into line; there is no reason why educating influences should not bring grinding down much finer still for ordinary brands, but for the present, too much severity would defeat the object in view. (For tests on the effect of fine grinding, see Series I of Experiments.)

(*d*) The time of incipient and final set, as found by Gilmore's needles, does not seem to affect the strength, except for very short tests. When the slow settings are generally stronger, good cements may be either the one or the other; but ordinarily, unless for tidal work, a slow setting one has the desirable feature of allowing masons to mix and use good sized batches of mortar, without constant tempering, which is the practice with quick setting ones, much to their own hurt.

(*e*) The blowing test advised by Faija, has detected a "blowey" tendency in seevral instances; but much late evidence seem to throw some discredit on blowing tests, whether made with hot or boiling water, on the ground that manufacturers can, by the addition of sulphate of lime, cause the cement to be so slow setting and set so strongly as to resist the blowing tendency of so much as 3 per cent. of free lime added after the cement had been burnt. If this is a fact, chemical analysis will need to be resorted to more frequently, to detect this dangerous adulteration which is fatal in sea-water and bad in any case, as the great strength which it gives to cements at early dates is apt to decrease at longer periods. Belgian No. 19 cement tested gave higher results at 1 week than at 4 weeks; this looks a little suspicious.

Cements have been tested usually neat; the Germans have reached the stage of 3 to 1 mixtures as the deciding test, and this would seem to be the only rational way of testing a cement, *i.e.*, in the same condition as it is used.

The difficulty, however—and it is a very serious one—has been to get anything like uniform results in sand tests. The variation in putting the mortar in the moulds has been so much more than the variation in the cementing value of the cement that the tests were valueless, so that most testers have clung to neat tests as being simple and a fair index of cementing qualities. That this view is in fault, and misleading, every tester will admit, and it is only partly avoiding the difficulty to specify a certain fineness, strength and specific gravity in combination, and even thenthe results are not definite, as each cement is different in value. However, for those who have facilities for testing cement, neat only,—and these will probably be in the majority for some time to come—it would seem that 350 lbs. at 1 week neat and 450 lbs. at 4 weeks neat are easily obtained, and quite enough to specify, 11 brands tested would give this much strengh and stand the blowing test, and of these there are 6 brands fine enough for 10 p.c. residue on 80 sieve and 20 p.c. residue on 120 sieve, with a specific gravity varying from 308 to 313, while the six brands which are not strong enough are also too coarse.

The tests on natural cements are not extensive enough to form a good basis, but it would seem easy to get 100 lbs. neat at 1 week and 200 lbs. neat at 4 weeks, and a fineness the same as for Portlands.

The tests on No. 2 natural and No 11 Portland were carried on for 6 months, and show the natural to be gaining on the Portland, although each has evidently nearly reached a maximum. This would seem to bear out the idea which many people yet have, that, in time, a natural cement not being so brittle will catch up to a Portland long time tests are very much needed on this subject.

Natural cements being underburnt (usually) have very much less combining power with sand; the 1 to 1 natural is not as strong as 2 to 1 Portland, according to tests made last year as per Table II, in which the mixtures were made with 15 p.c. of water for 1 to 1, and 12 p.c. of water for 3 to 1 mixtures, the mortars being lightly tamped into the mould with an iron rammer; the tests made this year, however, by means of a uniform pressure, give much higher results for 1 to 1 naturals, when 20 p.c. of water is used, which would seem to be nearer to the amount used in practice, making a soft plastic mortar. (See pressure tests.)

Natural cement has many uses. It is being passed aside in many quarters,—why? because *if immersed in water* for 1 week or 4 weeks, it will give low tensile tests. That terror of the present day, the testing machine, condemns it.

Now there are many occasions where it would not be wise to use anything but the best Portlands—such as laying mortar in extreme frost, or where great immediate strength is required, or for sub-aqueous work generally, but, on the other hand, no one doubts the *durability* of good natural cement. Works in Europe hundreds of years old, and all the work done in the United States and Canada previous to 30 years ago, are built with such mortars, and stand as witnesses of their lasting qualities.

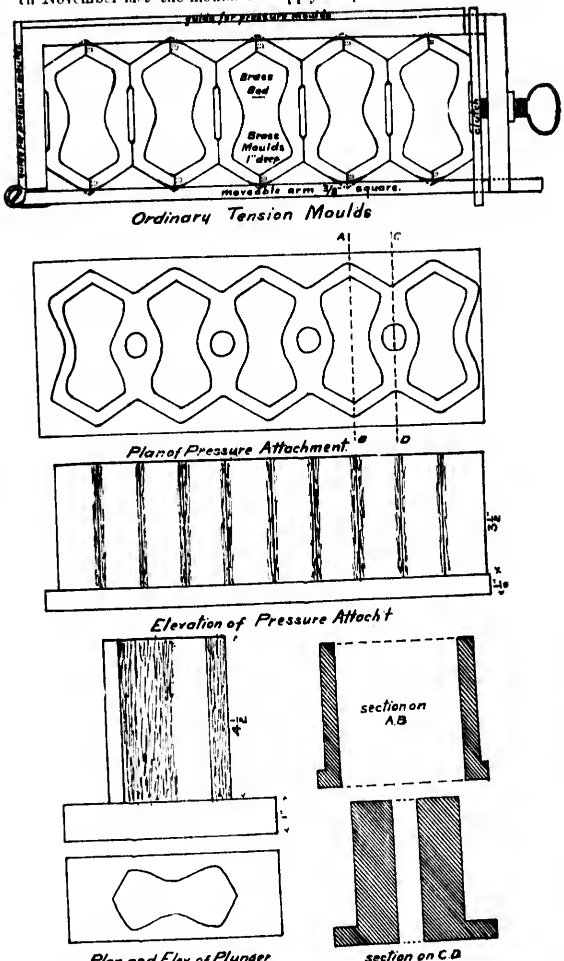
Moreover, tests made on No. 1 natural cement (see Series III frost tests) show that while it cannot be immediately exposed to extreme cold, yet when it is exposed, after it has set, it will resist frost thoroughly, and become stronger than if immersed in water at an ordinary temperature. There are thousands of situations, where natural cement mortar, 1 cement 2 sand, will be found amply strong for the purposes required, in which case it will be found cheaper than Portland mortar, 1 cement 3 sand. Referring ahead to Series III (frost), it will be seen that if mortars are tested in open air, the Portlands are weaker and naturals stronger than if the briquettes had been under water. This is a point of much importance, because if work is to be done which will not usually be submerged, as in damp foundations, abutments on land, culverts, etc., then tests made in open air will give results more favourable to naturals. In so many words our standard tests say: "Let us test all hydraulic cements under water, whether the mortar as used will be so or not, we will be on the safe side." This, as a generality, is doubtless best; but if we consider what a large proportion of cement is used in situations usually not submerged it would seem more rational to test cements under conditions similar to those under which they are to be used, in each case be it in water *or air*.

As before mentioned, all the sand tests given in the Table (Table II) were made by tamping the mortar lightly into the moulds with an iron rammer weighing about ½ lb. and ½ inch square—section.

This has been done in as nearly a uniform manner as possible; about 3 layers were tamped, and then a 4th layer smoothed off with a spatula; every effort was directed toward uniformity in method, and, doubtless, some degree of accuracy was obtained; but it was felt that the best possible would only enable comparisons to be made in this laboratory, it would not enable any to be made with results obtained elsewhere.

The Cement Committee of the Society (of which the writer was made a member, by invitation) advised that tests, should be made under a pressure of 10 lbs. per sq. inch. It was not defined at the time whether this applied to sand tests only or to neat tests also; but the necessity for pressure is not so great in neat tests, because anyone with ordinary skill and practice can make a good neat briquette, and a light pressure will not affect the result much, as will be shown farther on.

In November last the moulds for applying pressure (see drawings),



which were from a design of the writer's, modified by Mr. Withycombe, were completed, and since then several hundred briquettes have been made with them. It would seem a simple matter to mix up mortar, put it under a plunger, and by putting on 10 lbs. per sq. inch, make briquettes; but theory and practice must be fellow-labourers. Now, 12 p.c. of water is considered the correct thing in 3 to 1 mixtures, but with this amount, the mortar would not pack at all in a closed mould under so light a dead pressure, and it is light dead pressure that is wanted; even 20 lbs. per sq. inch was of no greater effect, then 15 p.c. of water was tried, with very little better results.

It was finally concluded to try several series with different percentages of water, and thereby determine the best per cent. for making a good briquette.

TABLE III.

TESTED IN TENSION. PRESSURE SAND TESTS.

Brand	Mixture.	% of water.	Pressure per sq. in.	1 week tests, 1 air, 6 water. lbs. per sq. in. Highest.	Lowest.	Average.	W't when tested in oz.	Weight after 2 days evap'n.	% of evaporation.	Product col. 3 x col. 6.	4 week tests, 1 air, 27 water. lbs. per sq. in. Highest.	Lowest.	Average.	Weig't when tested in oz.	W't after 2 days evapor'n.	% of evaporation.	Product col. 3 x col. 6.
No. 2	1 to 1	15	10	45	23	32½	4·56	3·98	12·63	410·4	71	39	59	4·64	4·01	13·49	795·9
		17½	10	165	106	136	5·26	4·84	7·98	1085·3	282	205	239½	5·32	4·95	7·03	1683·7
		20	10	130	94	117	5·56	5·08	8·62	1008·6	292	239	265½	5·52	5·17	6·34	1683·2
		22½	10	123	106	113½	5·54	4·99	9·88	1121·4	258	200	235	5·49	5·12	6·71	1583·9
No. 2	1 to 1	15	20	47	42	43½	4·79	4·05	15·52	675·1	95	70	84	4·99	4·22	15·40	1293·6
		17½	20	144	111	126½	5·37	4·92	8·38	1060·0	278	160	176½	5·27	4·83	8·35	1473·7
		20	20	157	90	114	5·67	5·13	9·63	1097·8	297	212	264	5·62	5·28	6·12	1615·6
		22½	20	126	110	119	5·54	5·03	9·28	1104·3	295	234	262	5·56	5·21	6·29	1648·0
No. 15	1 to 1	15	10	86	40	62½	4·92	4·42	10·16	653·7	112	98	104	5·04	4·41	12·50	1300·0
		17½	10	60	57	52	5·14	4·60	10·50	546·0	......	......	......	......	......	......	......
		20	10	149	108	133	5·69	5·12	8·46	1125·1	......	......	......	......	......	......	......
		22½	10	129	120	125	5·68	5·19	8·76	1095·1	......	......	......	......	......	......	......
No 15	1 to 1	15	20	49	42	45	4·94	4·18	15·46	695·7	......	......	......	......	......	......	......
		17½	20	184	145	166½	5·62	5·28	6·61	1100·5	......	......	......	......	......	......	......
		20	20	146	114	135½	5·63	5·17	8·20	1111·1	......	......	......	......	......	......	......
		22½	20	130	108	118	5·72	5·25	8·22	970·0	......	......	......	......	......	......	......

TESTED IN TENSION. PRESSURE SAND TESTS—*Continued.*

Brand	Mixture.	% of water.	Pressure per sq. in.	1 week tests, 1 air, 6 water. lbs. per sq. in. Highest.	Lowest.	Average.	W't when tested in oz.	Weight after 2 days evapor'n.	% of evaporation.	Product col. 3 x col. 6.	4 week tests, 1 air, 27 water. lbs. per sq. in. Highest.	Lowest.	Average.	Weig't when tested in oz.	W't after 2 days evapor'n.	% of evaporation.	Product col. 3 x col. 6.
No. 15	3 to 1	15	10	20	14	16½	4·75	4·03	15,21	251·0	35	19	28	4·61	3·88	15·88	411·6
		17½	10	12	5	7	4·59	3·92	14·66	102·4	48	32	40	4·66	4·15	11·03	441·2
		20	10	13	7	11	4·73	4·17	11·79	129·7	23	5	15	4·86	4.21	12·75	191·2
No. 15	3 to 1	15	20	23	9	16	4·64	3·97	14·48	231·7	55	28	38	4·56	4·01	12·15	461·7
		17½	20	7	2	5	......	......	......	......	40	25	33½	4·71	4·23	10·80	361·8
		20	20	17	8	12½	4·85	4·28	11·75	146·9	28	19	24	4·89	4·36	10·80	259·2
No. 9	3 to 1	15	10	25	14	**19**	**4·37**	3·81	12·77	242·6	71	58	**63**	**4·54**	3·89	14·24	897·1
		17½	10	35	18	**27**	**4·49**	4·07	9·35	252·5	106	92	**96**	**4·72**	4·24	10·17	976·3
		20	10	27	20	**23½**	**4·68**	4·08	12·91	303·4	134	101	**120**	**4·65**	4·18	10·14	1218·8
		22½	10	27	22	**24½**	**4·85**	4·23	12·86	315·1	88	74	**79**	**4·70**	4·16	11·49	907·7
		25	10	11	8	**10**	**4·81**	4·13	14·13	141·3	53	33	**46½**	**4·73**	4·11	13·18	612·9
No. 9	3 to 1	15	20	37	33	**34**	**4·66**	4·05	13·22	459·5	86	62	**71½**	**4·69**	4·15	12·22	873·7
		17½	20	33	20	**27½**	**4·53**	4·10	9·54	262·3	124	103	**114½**	**4·75**	4·27	10·15	1162·1
		20	20	29	25	**26½**	**4·8**	4·19	12·78	338·7	143	109	**127**	**4·69**	4·26	9·17	1164·5
		22½	20	25	22	**23**	**4·86**	4·27	12·06	277·4	103	87	**95½**	**4·81**	4·28	11·02	1052·4
		25	20	27	22	**25**	**4·80**	4·18	12·89	321·4	53	44	**49**	**4·70**	4·09	12·94	634·1
No. 10	3 to 1	15	10	37	30	**34½**	**4·70**	4·18	11·07	381·9	59	51	**55½**	**4·72**	4·18	12·27	681·0
		17½	10	43	22	**31½**	**4·67**	4·12	11·69	368·2	87	63	**70**	**4·84**	4·35	10·05	703·5
		20	10	48	32	**37½**	**4·79**	4·24	11·41	427·8	65	62	**63½**	**4·89**	4·32	11·68	741·6
		22½	10	34	27	**30**	**4·95**	4·33	12·45	373·5	50	38	**44½**	**4·88**	4·22	13·48	600·0
		25	10	33	15	**23½**	**4·92**	4·27	13·14	308·7	34	23	**28½**	**4·86**	4·15	12·94	368·8
No. 10	3 to 1	15	20	41	27	**33½**	**4·68**	4·11	12·18	408·0	67	52	**61**	**4·95**	4·40	11·04	673·4
		17½	20	37	16	**27**	**4·65**	4·08	12·13	327·5	88	47	**68**	**4·84**	4·31	10·96	745·3
		20	20	42	31	**35**	**4·82**	4·24	11·96	421·5	84	56	**71**	**4·97**	4·42	11·03	783·1
		22½	20	36	23	**29½**	**4·90**	4·28	12·65	373·1	85	70	**75**	**4·90**	4·35	11·23	842·2
		25	20	33	27	**31**	**5·00**	4·35	13·06	403·0	58	34	**48**	**4·85**	4.27	11·92	572·2

These series (see Table III) ran from 15 p.c. to 25 p.c. of water and were for 10 lbs. and 20 lbs. pressure per sq. in. for 1 week and 4 weeks, and each result tabulated is the average of 5 briquettes, and the whole table the result of 77 experiments, or 385 briquettes.

The result, to the author's mind, is definite, 20 p.c. of water is just sufficient to make a plastic mortar, so that a good briquette can be formed while more water tends to drown the cement and make it weaker at both the 1 week and 4 week tests, although longer tests would probably show a recovery in this respect.

This 20 p.c. applies to 1 to 1 and 3 to 1 mixtures, and will probably be about right for 2 to 1 also, if it is desired to make such tests.

It is conclusive from the table that if any standard test under light pressure is to be adopted for sand tests, 20 p.c. of water must be prescribed as a definite part of the test, and in this way perfect uniformity obtained. It is understood that the sand used is standard sand dry and sharp, a finer or rounder sand would allow less water to be used. This amount of water, while greater than that usually given by authorities whose method of making sand briquettes is by some severe hammering process (*e.g.* German) is still close to the amount used in practice.

What we want, it seems, is, first of all, a uniform method capable of application in any part of the Dominion, after that we want it to approach as nearly as possible to actual usage, and fortunately the two conditions are in harmony with each other; even at the risk of repetition it is worth saying again, that plastic mortar made with 20 p.c. of water is close to practice, and will give regular and accurate tests if put into moulds under light pressure. The amount of this pressure does not seem to be of such great importance, but 20 lbs. per sq. inch gives rather sharper-edged briquettes, with about the same variation in uniformity and the same tensile strength per sq. inch. This is equivalent to 20 feet of masonry, which, of course is more than practice would give; but the tests do not vary to any extent when compared with those made with 10 lbs. per sq. inch. Therefore it is not deemed of sufficient importance to sacrifice good manual results. Therefore, 20 lbs. per sq. inch pressure and 20 p.c. water was adopted about 1 month ago, and the following results obtained (Table IV); this table will be com-

TABLE IV.

CONDENSED SUMMARY OF PRESSURE SAND TESTS.

Put in Moulds with 20 % water, 20 lbs. per sq. in.

1 week tests, 1 air, 6 water.

Brand	Mixture	lbs. per sq. in. Highest.	Lowest.	Average.	Weight when tested.	Weight after 2 days evap'n.	% of evaporation.	Product, col. 3 x col. 6.
No. 1	1 to 1	75	46	**58**	**5·25**	4·55	13·33	773·1
No. 2	1 to 1	157	90	**114**	**5 67**	5·13	9·63	1097 8
No. 15	1 to 1	146	114	**135½**	**5·63**	5·17	8·20	1111·1
No. 15	3 to 1	17	8	**12½**	**4·85**	4·28	11·75	146·9
No. 3	3 to 1	19	8	**13**	**4·74**	4·17	12·06	156·8
No. 9	3 to 1	29	25	**26½**	**4·80**	4·19	12·78	338·7
No. 10	3 to 1	42	31	**35**	**4·82**	4·21	11·96	424·5
No. 8	3 to 1	34	25	**30½**	....	....	......	......
No. 5	3 to 1	15	12	**14**	**4·78**	4·12	13·70	191·8
No. 4	3 to 1	52	30	**39½**	**4·94**	4·37	11·58	457·4
No. 19	3 to 1	77	58	**69½**	**4·79**	4·09	14·61	1015·3
No. 6	3 to 1	83	74	**78**	**4·77**	3·97	16·84	1313·5
No. 11	3 to 1	25	15	**19**	**4·56**	4·13	9·51	180·7
No. 14	3 to 1	15	8	**10½**	**4·69**	....	......	......

4 week tests, 1 air, 27 dys. water.

Brand	Mixture	lbs. per sq. in. Highest.	Lowest.	Average.	Weight when tested.	Weight after 2 days evap'n.	% of evaporation.	Product, col. 3 x col. 6.	REMARKS.
No. 1	1 to 1	102	80	**93**	**5·32**	4·70	11·73	1090·9	Temp. of air, 60° F.
No. 2	1 to 1	297	212	**264**	**5·62**	5·28	6·12	1615·6	" " 60 F.
No. 15	1 to 1	......	......	......	....	....	......	......	" " 61° F.
No. 15	3 to 1	28	19	**24**	**4·89**	4·36	10·80	259·2	" " { 60° F. (1) 69° F. (2)
No. 3	3 to 1	52	37	**47**	**4 48**	3·89	13·20	620·0	" " 63° F.
No. 9	3 to 1	143	109	**127**	**4·69**	4·26	9·17	1164·5	" " { 65 F. (1) 58° F. (2)
No. 10	3 to 1	84	56	**71**	**4·97**	4·42	11·03	783·2	" " { 68° F. (1) 59° F. (2)
No. 8	3 to 1	85	75	**80**	**4·99**	4·41	11·55	924·0	" " 54° F.
No. 5	3 to 1	58	43	**50**	**5·13**	4·36	15·01	750·4	" " 74 F.
No. 4	3 to 1	118	83	**103**	**5·02**	4·49	10·56	1087·7	" " 61 F.
No. 19	3 to 1	143	101	**129**	**4·88**	....	......	......	" " 65 F.
No. 6	3 to 1	......	......	......	....	....	......	......	64 F.
No. 11	3 to 1	46	37	**41½**	**4·85**	4·18	13·90	576·8	" " 48 F.
No. 14	3 to 1	36	24	**30**	**4·88**	4·16	14·76	442·8	" " 53° F.

pleted in a few months, when it is intended to complete this paper by additional results on pressure, frost and pier tests.

Whether the future will bring sand tests to greater uniformity than this remains to be seen; but it is believed that, in this way, the sand combining qualities of cements can be compared with accuracy with one another, and in future such will be the method adopted in the cement laboratory at McGill, subject to the modifications of our cement committee.

It is earnestly to be desired that a code of tests be formulated at once, and all members urged to test under this code. Let all cements stand or fall under it. In the contest it is believed that Canadian cements can be as good as the best; but to do this, there must be reform on some sides, so that tests made from outputs will show a greater regularity, and cause the cement to commend itself to the consumers of the article.

COMPRESSIVE TESTS.

These are doubtless more valuable than tensile ones, in the sense that we use mortar usually, in compression. There are several reasons, however, why such tests are not really needed:—

(1) Because the strong machinery needed would not be generally available;

(2) Because the compressive strength, after all, varies quite regularly with the tensile, being 5 to 6 times as great at 1 week or 4 weeks, and gradually increasing to 9 to 10 times as great at a year, because by this time the cement is becoming brittle and has attained its maximum tensile strength. This is more particularly true of Portland cements, as naturals do not get so brittle;

(3) Because the compressive strength of cement mortar is so great that we need seldom concern ourselves with it, but should rather know the adhesive and tensile strengths should they ever be called into play, and, moreover, the strength of mortar in thin joints is much greater than in cubes. Tests on cubes always go higher for small cubes than for large ones. (See also Series (IV*a*) tests of mortar joints in brick piers.)

TRANSVERSE TESTS

Have often been advocated, and the machinery needed may be quite simple; but there are two objections which would preclude there being any great value in such tests:—

(1) Because the co-efficients of rupture in transverse testing are known to be at fault in not really indicating the tensile strength of the outer layer or fibre; this could possibly be avoided by determining certain corrections as a thesis paper to the *Engineering News* pointed out;

(2) The main objection is that a flaw of a very slight amount may be objectionable in such tests if situated near the tension face. Any cement tester knows that bubbles will occur. They may be very minute, or if of any size may be deducted in tensile tests, while in transverse tests, who could determine the correction to be made? Also tests made show that if tested upside down from position moulded, the results are higher than when tested as moulded. Altogether, this method of testing does not seem to commend itself to general use.

To conclude the subject of ordinary testing for commercial purposes, and with the addition of chemical analysis where available for scientific ones also, the following seems to be a good basis to work on, that 4 tests should be made in combination:—

(1) Specific gravity 3.10 for Portlands 2.95 for naturals.

(2) Blowing test. In the absence of really final knowledge on the subject to continue to specify pats in steam at 115°F. for four hours, in water at 115°F. for twenty hours, at which time if the pats are stuck tight to the ground glass, the cement may be considered safe, while if it has loosened from the plate but has not yet cracked or warped, it may

be immersed again for 24 hours at 115°F., or else placed in water of ordinary temperature for 4 weeks, after which, if no further signs have developed, the cemet may be considered safe.

(3) Fineness:—

10 p.c. residue on No. 80 sieve } as maximum.
and 20 p.c. " " " 120 "

(4) Tensile strength:—

		Portland.	Naturals
Minimum neat	3 days	250	75
" "	1 week	350	100
" "	4 weeks	450	200

1 to 1 and 3 to 1 sand tests with 20 p.c. water, and 20 lbs. per sq. inch pressure to be determined by tests made and results furnished within the next year.

SERIES I.

SPECIAL TESTS.

On the effect of fine grinding:—

(*a*) 2 oz. cement passing No. 120 sieve.........Cement
2 oz. " caught on No. 120 sieve }
2 oz. " " " No. 80 sieve } ...... Sand
2 oz. sand }
tested at 4 weeks gave 165 lbs., while
2 oz. cement passing No. 120 Sieve.........Cement
6 oz. sand.. Sand
gave 121 lbs. tested at the same age.

Thus, if in the first instance we consider all but the finest as sand, then our result is only 35 per cent. higher than the 2nd mixture, showing of how little value the coarser particles were.

(*b*) No. 8 English Portland (very coarse) gave in ordinary test 414 lbs. 1 week neat, 528 lbs. 4 weeks neat; but when all the particles caught on No. 80 sieve were rejected, the results were 393 lbs. in 1 week, 484 lbs. in 4 weeks, demonstrating the well-known fact that neat tests of Portlands operate against fine grinding, and therefore should be considered only in connection fineness and specific gravity.

	1 to 1.		2 to 1.		3 to 1.	
	Ordinary.	Fine on 120 Sieve.	Ordinary.	Fine on 120 Sieve.	Ordinary.	Fine on 120 Sieve.
No. 2 Natural 1 week 20 % water 20 lbs. pressure.	114	190	....	....	....	....
No. 2 " 4 " 15 % " tamped........	98	65	....	....	....	....
No. 2 " 4 " 15 % " "	145	123	....	....	....	....
No. 15 " 1 " 20 % " 20 lbs. pressure.	166	229	....	....	....	....
No. 15 " 4 " 14 % " tamped........	....	....	77	125	....	....
Brand A " 4 " 20 % " "	31	39	....	....	....	....
No. 3 Portl'd 4 " 12 % " "	....	....	....	....	72	121
No. 3 " 4 " 20 % " 20 lbs. pressure.	....	....	....	....	47	100
No. 9 " 4 " 20 % " 20 " "	....	....	....	....	49	109
No. 5 " 4 " 12 % " tamped........	....	....	....	....	82	102
No. 6 " 4 " 12 % " "	....	....	....	....	126	188

(c) Equal portions (same brand) of residues on No. 50 and No. 80 sieve were mixed with $22\frac{1}{2}$ per cent. water, and gave 262 lbs. in 1 week and 324 lbs. in 4 weeks, which is very surprising, and can only be accounted for on the ground that the dust of cement clinging on to the coarse particles was sufficient to hold them together, or else that the mechanical action of mixing the mortar broke up many coarse particles into finer ones.

(d) To show the superior value of fine cement in sand mixtures, the following results have been obtained :—

These results should be a convincing argument to users of Portland cement, that fine grinding is worth paying for, because the finer the same cement the greater its sand-carrying value is.

The only partial exception in the above results is No. 2 natural. This is either erratic, being, however, duplicated, or if not, is easily accounted for. An underburnt cement is easily ground, and therefore is not apt to be *well* ground ; very easy grinding will make it fine enough, and the better burnt particles being a little *better* burnt are therefore harder and escape grinding ; but these particles, not being very hard, are probably bruised up in mixing, and form the best part of the cementing substance ; therefore, when these are sifted out, the underburnt fine particle has not as great a cementing value as the mixture would have unsifted. On the other hand, the coarse particles in Portland cement are much harder, and are always a detriment in a sand mixture.

SERIES II.

HOT WATER TESTS.

(a) No. 1. Natural cement neat, 2 months old, gave when tested the following results :—

(1) Water at temperature 52°F., 226 lbs. average.
(2) " " " 122°F., 250 lbs. average.

(b) No. 1. Natural cement 1 to 1, 2 months old, gave when tested the following results :—

(1) Water at temperature 47°F., 125 lbs. average.
(2) " " " 118°F., 129 lbs. average.

(c) No. 4 Portland, neat, 1 month old, gave when tested the following results :—

(1) Water at temperature 65°F., 533 lbs. average.
(2) " " " 118°F., 616 lbs. average.
(3) " " " 186°F., 556 lbs. average.

(d) No. 4 Portland, 3 to 1, 1 month old, gave when tested the foling results :—

(1) Water at temperature 66°F., 81 lbs. average.
(2) " " " 183°F., 81 lbs. average.

These tests, which are very uniform, indicate that for either natural or Portland cements tested neat or with sand, there is a slight gain in strength, by using hot water in mixing.

The *advantage* being that for exposure to frost the cement will set quicker and resist the frost action better, by referring ahead to frost tests, it will be seen that cements exposed at about same temperature (natural cement only tested with hot water in frost) gave much higher results when mixed with hot water, being in ratio, 94 to 0 for neat cement No. 1 Natural and 117 to 44 for 1 to 1 cement No. 1 Natural.

SERIES III.

FROST OR EXPOSURE TESTS.

This series consisted of various investigations into the strength of mortars when mixed with different conditions of water and under different exposures, reference being particularly made to frost. All tests were made in quadruplicate :—

The 1st set was submerged, after 24 hours, in water of laboratory tanks ;

The 2nd set was kept on damp boards in a closed tank for the whole period, and never allowed to dry out ;

The 3rd set was allowed to set in the laboratory, and then exposed to the severe frost and left in open air for the whole period;

The 4th set were exposed in from 8 to 10 minutes to the severe frost, and left there for the whole period, except to take them out of the moulds when they were set or frozen.

TABLE V.

FROST OR EXPOSURE TESTS.

SERIES III.

Mixture.	Age.	Tensile Strength. Water test. (1)	Tensile Strength. Damp air test. (2)	Tensile Strength. Exposure after sett'g. (3)	Tensile Strength. Exp're before sett'g. (4)	Compressive Strength. 1	Compressive Strength. 2	Compressive Strength. 3	Compressive Strength. 4	Dates of Exposure.	Temp. of Exposure for 3.	Temp. of Exposure for 4.	Time from mixing till exposure.	Natural time of set.	No. of tests.	Remarks.
No. 11. Portland Neat.	2 mos.	602	471	282	334					Dec. 6th to Feb. 6th.	+23°F.	+22°F.	30′ (3) 12′ (4)	25′	16	
1 to 1.	"	377	276	194	233	3200	1780	1600	1900	Dec. 11th to Feb. 11th.	+5.°F.	+3½°F.	40′ (3) 8′ (4)	35′	20	
2 to 1.	"	168	150	105	111	800	720	660	410	Dec. 12th to Feb. 12th.	−½ F.	0°F.	40′ (3) 10′ (4)	37′	21	
3 to 1.	"	104	86	92	97	300	520	230	300	Dec. 13th to Feb. 13th.	−5°F.	−6°F.	1°27′(3) 10′ (4)	1° 25′	21	Nos. 3 and 4 showed irregular and injured fractures.
No. 1. Natural Neat.	"	226	221	349	0	1600	1500	2300	1390	Jan. 12th to Mar. 12th.	+2° F.	45 F.	4°15′ (3) 11′ (4)	4 15′	24	No. 4 tension completely blown in fragments.
1 to 1.	"	125	229	187	14			0	800	Feb. 5th to April 5th.	18 F.	+5/10 F.	8° 0′ (3) 10′ (4)	8 00′	22	Some of No. tension injured an No. 3 compression.
Neat.	"	250	281	159	94	2800	2000	3300	1300	Feb. 13th to April 13th.	+13 F.	+5° F.	6° 0′ (3) 10′ (4)	6° 0′	24	Mixed with water at temp. 122° F.
1 to 1.	"	129	170	80	117					Feb. 14th to April 14th	+9° F.	0 F.	3° 0′ (3) 8′ (4)	2 50′	20	Mixed with water at temp. 118° F.
Neat.	1 m	155	278	217	249					Feb. 26th to Mar. 26th.	+17 F.	+7½ F.	7° 0′ (3) 9′ (4)	7 0′	20	Mixed with 2 % brine.

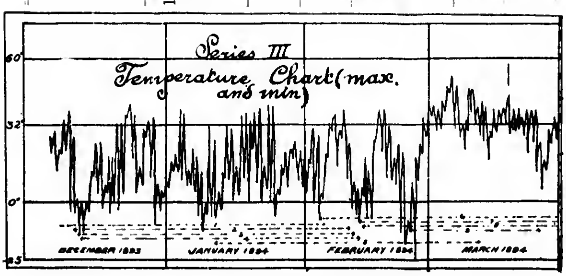


Table V is here given, showing the results obtained, and accompanying it is a temperature chart showing the weather to which these mixtures were exposed during their whole period.

It will be noticed that these tests were purposely made in cold snaps so as to make the tests as severe as possible.

It would appear improbable that mortar immediately exposed to severe frost would become stronger than that allowed to set in a warm atmosphere, but the results of all the Portland cement tests, both in tension and compression (with one exception) assert it; and also that those allowed to set in the laboratory, and then exposed continually, are the weakest of all the 4 conditions treated of—this would go far to dispute the advisability of covering up mortar laid in frosty weather.

The next deduction from the Portland cement tests is that laboratory tests made with briquettes submerged give higher results than can be expected in open air work, and therefore that engineers should add this to the various other degenerating contingencies, such as bad mixing, dirty sand, etc. A deduction not much evidenced in the Table is that it is not safe to lay Portland cement mortar below 0° F. because the 3rd and 4th series of 3 to 1 Portland exposed at —6° F. gave ocular evidence that their structure was injured, and the test-pieces broke most irregularly, while the other exposures at about 0° F. gave no evidence of any injury at all. Coming to the natural cement mortar in the 5th and 6th lines, we find much different results. The first one is decisive, and is that this particular cement mortar cannot be laid in zero weather. The first set were all blown to pieces (except the cube), which surprisingly stood 1390 lbs., while the 2nd set, although not quite blown to pieces, all showed extreme injury.

The most peculiar result is that this same cement, neat, if given a few hours to set in the temperate air, will on exposure to the frost attain a strength highest of the 4 conditions; this is quite remarkable, that while the Portland cement was strongest when submerged, the Natural cement was stronger in damp air and strongest in frost.

Indeed, the Portland cement, in air, for 1 to 1 mixtures, was very little stronger than the 1 to 1 natural.

All of the natural cement specimens exposed to frost showed a disintegrated layer on the outside about $\frac{1}{8}''$ thick; underneath this the structure was quite sound, and doubtless much of the variations in tests is due not so much to a weakening through the whole mass as to a reduced sections' area.

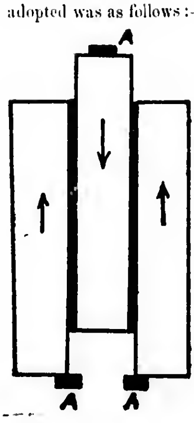
The last series made with 2 per cent. brine in mild weather for 1 month (exposed at $+7\frac{1}{2}°$ F) showed that salt increased the strength, making them as strong as others were at 2 months, when mixed with fresh water, and also again emphasised the advantage to this natural cement of open air tests.

It would seem that either hot water or salt are therefore very strengthening in their effect. Much additional data on this subject is hoped for in Part II of this paper.

SERIES IV.

SHEARING TESTS.

This series of experiments was carried out with a view of obtaining more information on the shearing strength of mortar. The method adopted was as follows:—



Three bricks placed, as shown in sketch, were cemented together, and tested at the end of one month. It was found that by placing pieces of soft wood at A.A.A., an action as nearly as possible a shear was obtained, and gave very satisfactory results, the pressure being practically concentrated along the two mortar joints. No side pressure was applied, because the desire was to obtain minimum results where friction was not assisting.

The combined effect of adhesions and friction can easily be computed if the adhesion and super-imposed load are known.

The results are divided into lime mortar, natural cement mortar and Portland cement mortar, also into $\frac{1}{4}''$ and $\frac{1}{2}''$ joints, also into flat, common, unkeyed bricks and pressed Laprairie brick keyed on one side. (1) The lime mortar was mixed 1 lime to 3 of standard quartz sand, by weight; (2) natural cement mortar was mixed, 1 of No. 2 natural cement to 1½ standard sand; (3) Portland cement mortar was mixed, 1 of No. 5 Portland cement to 3 standard sand. (See exhibits of bricks with mortar attached.) The test-pieces were chiefly allowed to stand in the laboratory at a temperature of 55° to 65°F., but one set of natural cement mortar and two of Portland cemen mortar were duplicated by immersing in water for 29 days, after setting in air 24 hours before submersion.

These results point out many interesting facts: (*a*) the first fact noticeable is that the results are independent of the *thickness* of joint; this is true of lime and cement mortars. (*b*) The next one is not evidenced to any extent in the Table, but was quite apparent in the testing, viz., that the adhesion of the mortar to the brick was greatest when the mortar was put on very soft, and least when the mortar was dry. This will largely uphold the use of soft mortars by masons, albeit their reason is a purely selfish one, the mortar being easy to handle, The tensile tests of cements made *very* soft are lower than when the mixture has the minimum amount of water for standard consistency. But for adhesive tests the case is evidently the reverse. It may be here mentioned that in these tests all bricks were thoroughly soaked with water before the joints were laid. (*c*) Coming now to the tests on lime mortar, the shears were through the mortar, except in the 4th experiment, and therefore they are quite independent of the key of the pressed brick on the surface of adhesion. This would point out the fact that keyed brick are superfluous in lime mortar joints, and the shearing strength per sq. inch averages about 10½ lbs. per sq. inch The tensile strength of the same mixture at the same age was 30 lbs. per sq. inch and the compressive strength 102 lbs. per sq. inch. (*d*) The natural cement mortar showed distinctly that its adhesive strength was not as great as its shearing strength, which is the reverse of the lime mortar tests. It also showed that the keyed brick aided in some unknown way, for the results on them are 3 times as great as with the common flat brick. Of course this may have been, and probably was partly due to the different surface of adhesion. In 5 tests out of 21 made on the natural cement mortar, the mortar sheared through, and the average of these 5 was 97 lbs. per sq. inch, which gives the shearing strength proper, while the average adhesive strength of the 13 tests in air which came loose from the bricks was 26 lbs. per sq. inch in common brick, 48 lbs. per sq. inch on Laprairie pressed brick, and 38 lbs. per sq. inch on Laprairie pressed brick for three tests submerged in water for the whole period.

This would show that the adhesive strength is nearly twice as great on pressed brick as common brick, and that submersion in water had a rather harmful effect than otherwise, on the adhesive strength, and was certainly of no benefit.

The tensile strength of the same mortar at the same age was 132 lbs. per sq. inch; the compressive strength was not obtained, but would have been about 1000 lbs. per sq. inch. The hints to be taken from these tests are that pressed brick keyed on both sides will give much higher results than flat common bricks, and would probably place the shearing strength of such joints at 100 lbs. per sq. in., and make it largely independent of the consistency of the mortar. Also that the shearing strength is very much higher in proportion to the tensile strength than was the lime mortar shearing strength to its tensile strength, but about the same proportion to its compressive strength, *i.e.*, 10 to 1.

It becoming evident that the thickness of joint had no appreciable effect, the Portland cement mortar tests were made all ¼" thick. The results are surprisingly low. The adhesion on the common brick is about the same for air drying or submersion in water, and is slightly less than ½ that of natural cement mortar tests of 1½ to 1. This is a significant fact, for while a neat tensile test of No. 2 natural cement 4 weeks old is 268 lbs., the No. 5 Portland is 459 lbs. for the same age, and a 3 to 1 No. 5 Portland is 82 lbs. for same age. See Table of general Laboratory results.) Thus while any test of this cement would show that a 3 to 1 mixture of the latter would be nearly equal to a 1½ to 1 test on the former, yet in their adhesive properties to common brick the heavily dosed sand mixture was only half as strong as the natural cement mortar with a smaller dose of sand; we might easily have expected this, but the main point is, is it taken account of in considering the comparative values of these mixtures, that the adhesive strength of a Portland cement mortar heavily dosed with sand is low as compared with a weaker but richer mixture of natural cement mortar? The shearing of Portland mortar shows that the adhesion to pressed brick is greater than to common brick, but not in such proportion as in natural cements, being $1\frac{1}{2}$ or 2 to 1 in place of 3 to 1 in the latter. But here again comes out the advantage given to Portland cements by testing them under water, the submerged specimens are stronger than open air ones while in natural cements the reverse is the case.

Table VI is here given summarising the results obtained:

TABLE VI.

TABLE OF SHEARING TESTS, OR MORTAR ADHESION TO BRICK SURFACES (in shear)

SERIES IV.

Kind of Mortar.		Joint.	Brick.	No. of tests.	How indurated.	Shear in lbs. per sq. in. Average.	Least.	Greatest	Remarks.
Lime 1.	Sand 3.	¾"	A	5	in air	9·7	8·4	11·9	All sheared through the mortar.
"	"	½"	A	4	"	12·1	6·1	19·8	" " "
"	"	¼"	B	5	"	12·0	9·1	15·5	" " "
"	"	½"	B	5	"	8·0	5·5	11·0	All came away from brick (mortar dry).
No. 2. Natural Cement	1 Sand $1\frac{1}{2}$	¼"	A	5	"	22·3	8·0	32·1	" " "
"	"	½"	A	5	"	29·0	24·0	33·0	" " "
"	"	¼"	B	5	"	75·0	25·0	118·6	2 came away from brick, 3 sheared.
"	"	½"	B	3	"	85·0	43·0	118·0	1 " " " 2 "
"	"	½"	B	3	in water	38·0	34·0	42·0	All came away from brick.
No. 5. Portl'd Cement	1 Sand 3	¼"	A	3	in air	10·6	10·2	11·6	" " "
"	"	¼"	A	3	in water	13·0	10·2	16·4	" " " The brick which was on top in the original laying, always sheared 1st and at a less load than that of lower one, which, of course, set under twice as much load or pressure.
"	"	¼"	B	3	in air	16·5	9·2	24·2	" " "
"	"	¼"	B	3	in water	27·1	20·2	36·9	" " "

A. common, flat, unkeyed, salmon brick.
B. Laprairie pressed brick, key on one side.

SERIES IV. (*A*)

THE STRENGTH OF MORTAR IN COMPRESSION IN BRICK MASONRY.

All engineers realise that the strength of mortar is much less, tested in cubes, than in thin layers, but just what proportion they bear to one another is not very well known. The following experiments have been made with a view of obtaining this information.

TABLE VII.

MORTAR JOINTS IN COMMON BUILDING-BRICK PIERS.

Composition of Mortar.	Age of Test.	Thickness of Joints.	Dimensions of Brick Pier.	% of water in mortar.	Loads in lbs per sq. inch. 1st signs of failure in mortar.	1st signs of failure in brick.	Bricks failing rapidly.	Maximum load	Compression per foot under a total load of 5,000	20,000	35,000
No. 1. 1 Lime. 5 Building sand.	1 week.	$\frac{3}{16}$"	7.80" x 7.85". 16.57" high. 6 bricks. 61.2 sq. in. area.	37 (?)	245	327	980	1,143	.015"	.08"	.13"
No. 2. 1 Lime. 5 Building sand.	3 weeks.	$\frac{3}{16}$"	8.0" x 8.0". 11.16" high. 4 bricks. 64.0 sq. inches.	37	469	563	1,406	1,553	.007"	.043"	.075"
No. 3. 1 Lime. 5 Building sand.	3 weeks.	$\frac{3}{16}$"	7.9" x 7.9". 24.50" high. 9 bricks. 62.4 sq. inches.	37	400	689	897	1,282	.005"	.055"	.094"
No. 4. 1 Lime. 3 Lab'tory sand.	1 week.	$\frac{1}{4}$"	7.75" x 7.85". 11.42" high. 4 bricks. 60.84 sq. inches.	34	287	575	....	1,117	.032"	.133"	.158"
No 5. 1 of No. 2 Natural cement. 1½ Lab'tory sand	1 week.	$\frac{1}{8}$"	7.80" x 7.90". 11.15" high. 4 bricks. 62.01 sq. inches.	22½	968	1,190	1,403	1,984	.009"	.027"	.054"
No. 6. 1 of No. 5 Portland cement. 3 Lab'tory sand.	1 week.	$\frac{1}{4}$"	8.00" x 7.95". 11.30" high. 4 bricks. 63.60 sq. inches area.	20	755	959	1,305	1,564	.007"	.007"	.019"

At the same time that these tests were made, mortar was also made into test-pieces, and tested at the same age. We are thus enabled to form an idea of the relative strengths of mortar in thin joints and in cubes, and also to form an intelligent opinion of the comparative strengths of lime mortar, natural cement mortar and Portland cement mortar. The mortars of the 4th, 5th and 6th tests are identical with the mortars of the *shearing* tests, and show the same clear superiority of the natural cement 1½ to 1 over the Portland cement 3 to 1 when used in this manner. The following table summarises the results obtained :—

TABLE VIII.

	Strength of Mortar per sq. in. In joints.	In cubes	In tens'n.	Loads released at 17,500 lbs., set observed per lineal foot.	
(1)	245	40	17	....	1 week old, mortar, 1 lime, 5 sand.
(2)	469	57	20	.01"	3 " " " 1 " 5 "
(3)	400	57	20	.03"	3 " " " 1 " 5 "
(4)	287	21	....	.08"	1 " " " 1 " 3 "
(5)	968	250	....	....	1 " " " 1 Natural Cement 1½ sand.
(6)	755	341	43	.00	1 " " " 1 Portland " 3 "

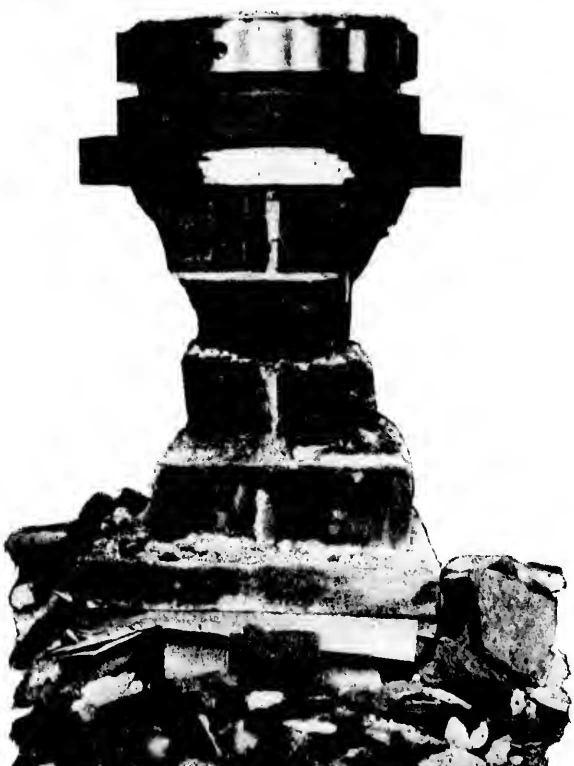
Roughly speaking, the lime mortar at 1 week 5 to 1 is 6 times as strong; the lime mortar at 1 week 3 to 1 is 14 times as strong; the natural cement mortar at 1 week 1½ to 1 is 4 times as strong; the Portland cement mortar at 1 week 3 to 1 is twice as strong, as the same mortar tested in cubes, at the same age.

Referring to the amount of compression in Table VII, it will be seen that the amount of compression per foot is much less according as this ratio is less—*i.e.*, the less yielding the mortar the nearer does the strength in cubes approach to the strength in joints; this is to be expected—because the more yielding substances will be at a much greater disadvantage when unsupported at the sides than if enclosed in a thin masonry joint.

In the 2nd, 3rd, 4th and 6th tests——— at 17,500 lbs., the load was released, and the permanent set observed was as given in the 5th column of the preceding table.

It seems probable from this, therefore, that the lime mortars must have yielded to an injurious extent before there were any external signs. But whether this was the case or not, it is impossible to say, because the compression was quite uniform up to and in many cases much past the points of evident failure.

It seems fair to suppose that 1 week and 3 weeks are about the minimum and average times which would elapse before the maximum load might be put on a brick wall, and when it is remembered that these joints were less than ½" thick. The amount of compression in a high brick wall under a load of 80 or 90 lbs. per sq. inch is seen to be very great, and under a load of 300 to 400 lbs. per sq. inch, a brick wall 50 ft. high in lime mortar would not only fail, but compress from 2 to 6 inches in doing so—the compression practically all taking place in the mortar as in the unyielding Portland cement mortar, the compression is seen to be very small.



The second part of this paper will contain tests made on piers built with pressed brick, in which the mortar has had longer time to harden, and interesting results are looked for.

The brick in this case was as mentioned in Table VII, common building brick. The photograph given illustrates the method of testing and the interesting manner of failure of 5th test, in which the lines of least resistance are clearly defined.

SERIES V.

EVAPORATION AND CRUSHING TESTS AND EVAPORATION AND TENSILE TESTS.

(*a*) *Evaporation and crushing tests.*

This series had for its first intention, information on the comparative and actual amount of evaporation of moisture from different mortars made with different cements, but it soon developed into an endeavour to obtain some relation between crushing strength and evaporation. Any law on the matter, if there is any general law, will of course take years to demonstrate; but enough has been done to show that any investigations on this subject will be fruitful of results. The method of procedure was as follows:—Mixtures were kept in damp air 30 days, then immersed 2 days in water of ordinary temperature, then taken out and

TABLE IX.

EVAPORATION AND CRUSHING TESTS.

No. 11—Portland.

SERIES V.

Mixture.	Evap. % in 2 days.	Crushing strength per sq. in.	Product.	Max. wt. of 2" Cube.	$\left(\frac{2}{\sqrt[3]{wt.}}\right)$	Product. / column 6.
				oz.		
Neat.	1.48	3925	5809	10.43	22.16	262.1
1 to 1	3.41	2211	7539	10.12	21.71	347.3
2 to 1	6.20	1031	6492	9.39	20.66	314.2
3 to 1	10.39	544	5652	9.14	20.30	278.4
4 to 1	11.49	431	4952	8.92	19.97	247.9

No. 10—Portland.

Mixture.	Evap. % in 2 days.	Crushing strength per sq. in	Product.	wt.		
Neat.	0.97	4367	4231	9.84	21.31	199.0
1 to 1	2.20	3062	6736	10.23	21.87	308.0
2 to 1	5.59	1079	6032	9.13	20.72	291.1
3 to 1	8.61	*940	8093	9.15	20.31	398.4
4 to 1	11.68	504	5886	8.86	19.87	296.2

* One day older than others.

No. 3—Portland.

Mixture.	Evap. % in 2 days.	Crushing strength per sq. in.	Product.	wt.		
Neat.	4.65	1863	8662	10.00	21.62	100.7
1 to 1	4.10	1875	7687	10.12	21.71	354.1
2 to 1	5.67	1417	8034	9.60	20.97	383.1
3 to 1	8.11	687	5572	8.95	20.01	276.2
4 to 1	12.56	412	5176	8.88	19.90	260.0

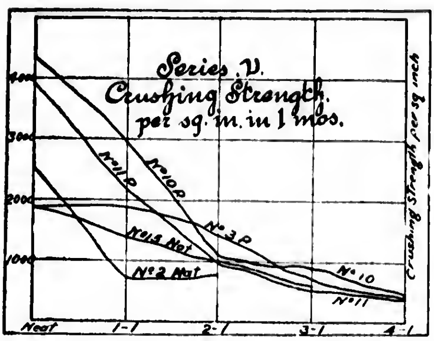
No. 15—Natural.

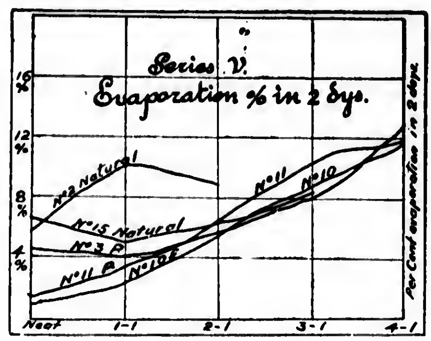
Mixture.	Evap. % in 2 days.	Crushing strength per sq. in.	Product.	wt.		
Neat.	6.76	1888	12762	9.40	20.67	617.4
1 to 1	5.08	1437	7300	9.65	21.02	347.3
2 to 1	6.12	988	6046	9.32	20.57	293.9
3 to 1	8.34	575	4796	9.05	20.16	237.9

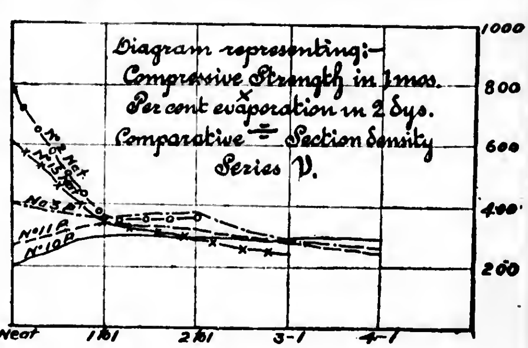
No. 2—Natural.

Mixture.	Evap % in 2 days.	Crushing strength per sq. in.	Product.	wt.		
Neat.	5.93	2575	15729	9.43	2072	758.7
1 to 1	10.32	703	7254	9.06	2016	359.9
2 to 1	8.93	810	7233	9.28	2057	352.6

weighed; they were then kept in the warm dry air of the laboratory at a temperature of about 65° F., exactly 2 days, when they were again weighed and immediately crushed. The experiments recorded in Table IX were all made on 2″ cubes, and 2 days was established, because it was found that at that time the evaporation was practically complete. Other experiments (not recorded) made on 3″ cubes gave less evaporation per cent. and also less strength; attached to this are 3 dragrams: the first two show strength and evaporation in different mixtures and with 5 brands of cement. The third diagram is the product of the other two, and is quite worthy of inspection, because it would appear from it that it would be possible to estimate fairly accurately, without actually crushing a specimen, what load it would bear.





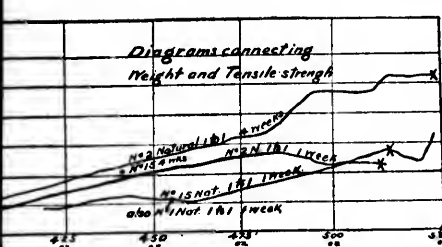


Reference to the table and diagrams will show that the evaporation increases and the strength diminishes with the increase of sand in the mixture. This is, of course, almost self-evident, but the striking difference in the amount of evaporation for different cements neat is unaccountable. This difference disappears as the admixture of sand increases, and we are led, therefore, to conclude that there is something inherent in the cement itself, which aids it more or less in holding particles of water in suspension. The natural cements show high evaporation neat, so also does the No. 3 Portland, which has a high specific gravity (see general tables), and the cubes of which weighed more than those of the No. 10, which evaporated least; we cannot account for it on the ground of Portland and natural, but one thing is evident, that that same quality which enables it to hold water in suspension also aids it in holding particles of sand together, but not particles of itself. The third diagram showing the convergence of lines on the 1 to 1 mixture is very striking. The *product* of the *crushing strength of a* 1 *to* 1 *mixture* and the *evaporation per cent.* under conditions named is practically CONSTANT. This is for one condition only, namely, 32 days, with access of water and 2 days drying. This means in plain words that we may possibly be able to test with a balance instead of a crushing machine.

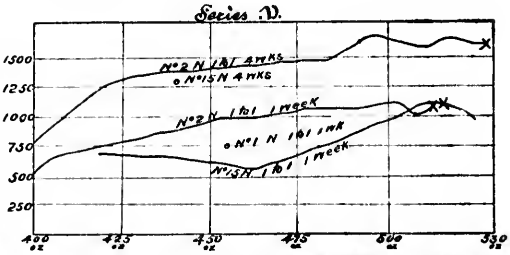
It is probable that the microscope would reveal a decided difference of structure in various cements. It is, of course, well known that the underburnt natural cements have softer, rounder and more easily pulverised grains than that produced by the highly burnt clinker of the Portland. It is possible, therefore, that the evaporation qualities of a neat cement would indicate more closely than anything else the degree of burning practised, independent of the fineness. It will be noticed, by Table II, that the residues on sieves afford no clue to the density of the mixture and no guide to determine beforehand the evaporation. Neither does the weight of the specimens vary at all regularly either with the crushing strength or evaporation.

It would seem that the coarse, angular laboratory sand had its interstices just about filled up with a 1 to 1 mixture, and the strength of the mixture depended directly on the amount of evaporation, in an inverse ratio. The— —Evaporation diagram No. 4 is the same as No. 3, except that this product is referred to a uniform section density (*i. e.*) $(\sqrt[3]{weight})^2$; the diagram is practically the same, showing that the variation in weight of test pieces made practically no difference in the results, *i.e.*, the per cent. of evaporation determines the strength in 1 to 1 mixtures, but is no criterion in neat ones.

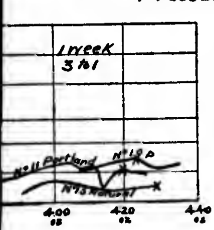
(*b*) *Evaporation and tension tests.*

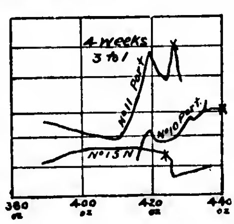


Series D.

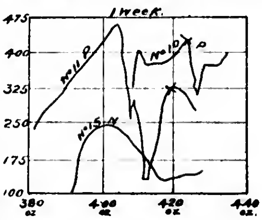


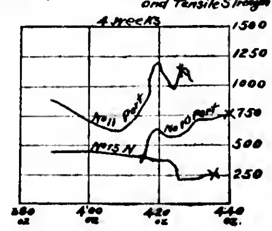
Pressure Tests.

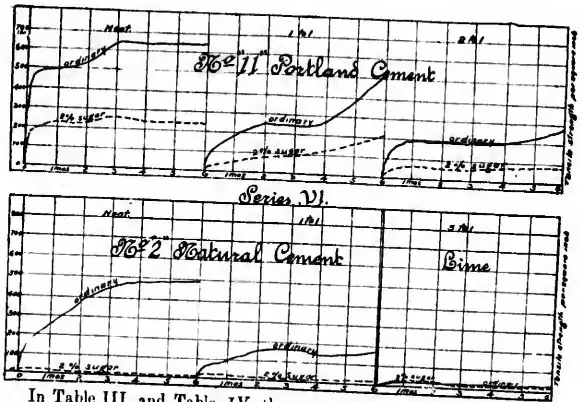




Diagrams connecting Weight with product of :- Evaporation and Tensile Strength







In Table III. and Table IV. the per cent. of evaporation in 2 days is again given, and diagrams are plotted showing the relation between the tensile strength and the weight of the dried briquettes in the pressure tests, and also other diagrams showing the product of tensile strength and evaporation plotted on a base of weights of briquettes.

The × marks in the diagrams show the positions of tests made with 20 lbs. pressure and 20 p. c. of water, and they are seen to stand at prominent and usually maximum points on the diagrams, proving that this is the best point to select of all the tests made.

It will be seen in these diagrams as in those of crushing tests, that in 1 to 1 mixtures the variation of evaporation and strength combined is not very great, but not so close as in the former tests.

The 3 to 1 tests are very erratic, as might have been expected with different per cents. of water and different amounts of pressure. It is evident that each cement has distinctive qualities of its own, because with the same weight of briquette the strengths vary, and this brings up the important point that in sand tests the strength ought to be referred to some basis of weight of briquette, because a slight variation in weight seems, from Table IV, to affect the strength very much. It would not take much evidence to determine the average weight, and all tests could be reduced to this by multiplying by $(\sqrt[3]{weight})^2$ which would change the section density to a standard.

SERIES VI.

SUGAR TESTS.

Sucrate of lime is soluble in water, and it was chiefly a matter of interest to see the effect of sugar on cements in weakening them, because it has been asserted by several writers that the reverse is the case; one investigator several years ago showed by tests that from ½ to 1 p. c. of sugar would in 4 to 6 months give a gain in strength.

Sugar, in these tests, 2 p. c. of the amount of cement (by weight), was used, and the diagrams attached sufficiently indicate the results In the Portland cement the strength ranges closely at 50 p. c. of the ordinary strength as far as 6 months, while with the natural cements, the sugar effect was overpowering. After one week's immersion the briquettes showed signs of cracking, and as time went on became completely checked, and expanded so much as to give practically no tests. This is further evidenced (see exhibit of briquettes) by the upper surface, which was protected by a coating of iron deposited from Montreal water, being intact, while the checking was greatest on the bottom where the water had free access.

The lime mixtures, kept in open air, showed encouraging results for 2 months, and seemed to prove that the use of sugar, in lime, as practised in India, was beneficial; but the 3, 4 and 6 months' tests disprove it. Altogether, it seems evident that this much or more sugar would be damaging in its effects on any kind of mortar in any situation, and it is extremely doubtful whether any sugar whatever would have other than a weakening effect.

In concluding this paper, the author cannot but help feeling that he is, as it were, dipping just on the surface of a vast subject, and that the more one finds out, the larger the unknown fields beyond appear.

In any efforts that have been made, the frequent manual aid and more frequent sound practical advice Mr. J. G. Kerry have been of much service, and here is the place to acknowledge it.

The endeavour has been to find out anything of practical use to the Engineering profession; and if any points raised here will fulfill this desire, the object of this paper will be, in the main, accomplished.

In conclusion the author cannot but acknowledge the opportunity given by the Engineering Equipment of McGill University. In carrying out the various tests recorded, every facility has been offered not only for student instruction but for private research, and whenever anything is needed that is not possessed, Professor Bovey, the Dean of Engineering, is always ready to have the want filled, if possible. In this way many things not feasible in ordinary cases are practicable, and it is hoped that, in due time, other results of value to the profession may be determined and presented to the Society.