

INVESTIGATIONS OF PORTLAND CEMENT MORTARS

A THESIS

Submitted as partial fulfillment of the requirements
for the degree of Master of Science in Civil Engineering

By

L. V. Clark Deichler

Georgia School of Technology

June 1, 1936.

Approved by:

not D

47 _____

Special Committee on Approval.

42237

TABLE OF CONTENTS

	PAGE
INTRODUCTION -----	1
PORTLAND CEMENT MORTARS IN GENERAL -----	2
PORTLAND CEMENT -----	3
LIME -----	5
SAND -----	6
WATER -----	8
MAKING MORTAR -----	9
THE EFFECT OF LIME IN CEMENT MORTAR -----	19
CALCIUM CHLORIDE IN PORTLAND CEMENT MORTAR -----	22
EFFLORESCENCE -----	23
FREEZING -----	24

INTRODUCTION

In the last fifty years there have been made many improvements in the field of masonry construction. I doubt, however, if any single advancement has been as important as the relatively recent use of Portland cement in masonry mortars. By its use, a builder is able to reduce wall thickness, build smaller piers and columns, increase the height of his walls, and erect surprisingly light arches. Furthermore, not only is the resulting masonry structure lighter and stronger than could have been obtained formerly by the use of clay or lime mortars, but a more enduring type of construction is obtained.

With the advantages of Portland cement mortars over lime mortars so numerous and so valuable, it would seem that information about such mortars would be readily accessible to any engineer or builder. Unfortunately, such is not the case. There is, for some unknown reason, a horrible lack of printed information available about this subject. The entire purpose of this paper is to attempt to disseminate the information now available about the use of Portland cement mortars, discard that portion of it that is unsound, add to it some laboratory investigations of my own, and classify the whole in such a way as to make clear the use of this important material of construction.

PORTLAND CEMENT MORTARS IN GENERAL

I would like to first approach the subject of Portland cement mortars by defining the subject. Portland cement mortar, primarily, is an intimate mixture of sand, Portland cement, sometimes lime, and water.

The purpose of Portland cement in the mortar is to **unite** the sand particles together; its action in the mortar, upon hydration, may well be compared to the use of glue to "stick" together many small particles of sand and to fill up the spaces or voids between these same particles.

The use of lime in the mortar is primarily to make the mortar work easier off the mason's trowel. What effect results from the employment of lime in Portland cement mortar will be traced later in this paper.

The use of water in the mortar is:

1. To hydrate the cement, and lime, and thus form a binding material which will unite the otherwise non-cohering particles of sand.
2. To flux both the dissolved and the undissolved cementing substances, over the surfaces of the sand grains, rendering possible extensive and close adhesion by carrying these substances into the surface irregularities of the particles, where they are absorbed as the water is later absorbed or evaporated.
3. To act as a lubricant between the sand particles so that the mortar may be spread in place with a trowel.
5. To itself occupy space in the mass.

Before proceeding further with the discussion of this intimate mixture of substances, I believe it well if the various materials that enter into the mixture are examined separately.

PORTLAND CEMENT

Portland cement is made by finely pulverizing the clinker produced by burning a definite mixture of silicious, argillaceous, and calcareous materials to a point above where they begin to fuse or melt. The percentages of the principal components range about as follows:

SiO_2	-	19% to 25%
Al_2O_3	-	5% to 9%
Fe_2O_3	-	2% to 4%
CaO	-	60% to 64%
MgO	-	1% to 2.5%

There are also present small amounts of K_2O , Na_2O and SO_3 . The specific gravity of Portland cements range from 3.1 to 3.2.

Microscopical examinations of Portland cement clinker, and of all the substances considered likely to be formed in manufacture, show Portland cement to be made up largely of the three compounds $3 \text{CaO} \cdot \text{SiO}_2$, $2 \text{CaO} \cdot \text{SiO}_2$, and $3 \text{CaO} \cdot \text{Al}_2\text{O}_3$. The tri-calcium silicate appears the best cementing compound and it is probable that the higher its percentage the better the cement. The small amounts of Fe_2O_3 , MgO , alkalies, etc. have but little effect on the three major compounds but their presence aids materially in manufacture by promoting the combination of CaO with Al_2O_3 and SiO_2 .

A perfectly burned cement clinker consists of about 36% of tri-calcium silicate, $3 \text{CaO} \cdot \text{SiO}_2$; 33% of di-calcium silicate, $2 \text{CaO} \cdot \text{SiO}_2$; 21% of tri-calcium aluminate, $3 \text{CaO} \cdot \text{Al}_2\text{O}_3$; and 10% of minor constituents. The principal cementing compound, tri-calcium silicate, $3 \text{CaO} \cdot \text{SiO}_2$, is the last constituent to form completely in Portland cement manufacture, and this compound is formed by the combination of CaO with $2 \text{CaO} \cdot \text{SiO}_2$. When cement clinker is not perfectly burned there is evidently less $3 \text{CaO} \cdot \text{SiO}_2$ formed and more $2 \text{CaO} \cdot \text{SiO}_2$. There is also a certain percentage of free lime (CaO) present, the amount depending upon the degree of burning.

The setting and hardening of Portland cement is caused principally by hydration in the order named, of the three major constituents: $3 \text{CaO} \cdot \text{Al}_2\text{O}_3$, $3 \text{CaO} \cdot \text{SiO}_2$ and $2 \text{CaO} \cdot \text{SiO}_2$. When water is added to Portland cement, these constituents form first amorphous and later both crystalline and amorphous hydrated materials, which act much as does ordinary glue; except that since they are of mineral origin and largely insoluble, hardening progresses even under water.

Of these hydration products, the compound tri-calcium aluminate ($3 \text{CaO} \cdot \text{Al}_2\text{O}_3$) when mixed with water, sets and hardens very quickly; tri-calcium silicate ($3 \text{CaO} \cdot \text{SiO}_2$) sets and hardens somewhat less rapidly; and di-calcium silicate ($2 \text{CaO} \cdot \text{SiO}_2$) reacts slowly. Hardening occurs only after a lapse of a long period of time. The initial set of the cement is due undoubtedly to the hydration of $3 \text{CaO} \cdot \text{Al}_2\text{O}_3$, the early hardness and cohesive strength do to this hydration and to that of the $3 \text{CaO} \cdot \text{SiO}_2$;

while the gradual increase in strength is due to the further hydration of these two compounds together with the hydration of the $2 \text{ CaO} \cdot \text{SiO}_2$.

The compound $3 \text{ CaO} \cdot \text{SiO}_2$ appears to be the best cementing constituent of this group, as it is the only one of the three which, when mixed with water, will set and harden within a reasonable time to form a mass which is comparable in hardness and strength to Portland cement. Although $5 \text{ CaO} \cdot \text{Al}_2\text{O}_3$ sets, and hardens rapidly, it is rather soluble in water and is not particularly durable or strong. The compound $2 \text{ CaO} \cdot \text{SiO}_2$, however, requires too long a time to harden to be in itself a valuable cementing material.

Portland cement, to be suitable for mortar, should be the same high grade cement that would be specified for use in Portland-cement concrete. In the appendix of this paper will be found the "Standard Specifications and Tests for Portland Cement", as adopted by the American Society for Testing Materials.

LIME

Common lime is manufactured by burning limestone (CaCO_3) at a temperature of about 900°C . until its carbon dioxide (CO_2) is driven off as gas. The residue is common lime (CaO), known commercially as "quicklime." On addition of water this product slakes with evolution of heat and much increase in volume.

In even the purest limestone there are some impurities present. Generally a part of the lime is found to be replaced by a certain percentage of magnesia (MgO); clay also is present to some extent. (Clay is composed chiefly of silica (SiO_2) and Alumina (Al_2O_3), and usually contains some iron oxide (Fe_2O_3). In the manufacture of quicklime, magnesia acts in much the same manner and may be considered the equivalent of lime, which makes it possible to use limestone which is high in magnesia. Quicklimes are divided into four main types according to the relative content of calcium oxide (CaO) and magnesium oxide (MgO). These are:

1. High-calcium; quicklime containing 90% or over of calcium oxide.
2. Calcium; quicklime containing not less than 85% or more than 90% of calcium oxide.
3. Magnesium; quicklime containing between 10 and 25% of magnesium oxide.
4. Dolomitic; quicklime containing over 25% of magnesium oxide.

Hydrated lime is quicklime that has been slaked at the place of manufacture. Its market form is that of a dry powder, and it requires only the addition of water on a job to be turned into lime paste.

The hardening of lime paste is due mainly to crystallization, but in addition some of the water in the hydroxide is gradually replaced by carbon dioxide from the atmosphere, causing a part of the hydroxide to revert to the original calcium carbonate.

SAND

In as much as almost the only fine aggregate ever used in mortar is sand which has resulted from the disintegration of rocks through the natural geological process of "weathering", only this type of aggregate will be discussed. The process of disintegration which breaks down rocks into small particles is physical in its nature. Any sands which have undergone a chemical process (decomposition) in their formation, must generally be looked upon with some caution. Silt and clay are generally the result of such decomposition, and such chemical change has altered the original character of the material, usually to its detriment.

Since coarse sands are of a size to retain and partake of the nature and properties of the parent rock, the structure of at least large particles should be identical with the structures of such rocks.

Because of its hardness and resistance to chemical agents, quartz or silica is the commonest mineral in sand. Other minerals such as feldspar, mica, etc., though originally present, because of their lesser resistance, have been more readily decomposed by the action of the elements; and by reason of their complete disintegration with resultant fine state of subdivision, have been removed by wind and water. Quartz crystals, therefore, remain as the most evident survivors of the parent rock.

In order that a mortar attain satisfactory strength upon hardening, it is necessary that the cementing materials of that mortar (cement and lime) coat the surface of the grains of sand and fill the voids between them. For the sake alone of coating the grains, it would seem very evident that a coarse sand would require less cementing material than a fine sand. This is true but the resulting mortar is apt to be quite porous, due to a lack of material sufficient to fill the voids between the particles. Such a mortar is also difficult to work off a trowel, due to its inability to slide without a grating scratching action. If, on the other hand, an all fine sand is employed for the mortar, although the voids are smaller and easier filled, the surface area to be coated is so large that an uneconomical amount of cementing material must be used. Thus, the only satisfactory mortar sand is a sand fairly well graded from coarse to fine.

The presence of organic matter in the sand such as: tannic acid, colloidal sewage, manure, decayed vegetable matter, etc. is in all cases to be regarded as harmful. No engineer would accept a sand containing these objectionable impurities in a sand to be used for concrete - unfortunately mortar sands have not been examined so carefully in the past. It is important that a mortar sand be carefully selected as would a sand for concrete. Fortunately, most of those impurities can be washed out of the sand with little expense.

The effect of a small amount of either clay or silt in mortar sands is at times beneficial to the mortar. However, in as much as either of these impurities can cause injury to the mortar by coating the sand particles or by "balling up" when wetted and so remaining as lumps in the

mortar, I am inclined to believe that it is always safer to secure sand free from them.

A mortar sand should be selected carefully as would be a concrete sand; and on any job of consequence when the sand is so selected, there will be a resulting savings in cement and lime in the masonry work, that will more than make up the slight expense of sand tests in conjunction with this selection. Moreover, the resulting mortar will be stronger and more easily worked by the massus.

The logical procedure in the selection of a sand for mortar work would be:

1. To determine its granulometric analysis by screening.
2. Determine its cleanness by washing, or by chemical tests.
3. To determine its actual strength value in mortar by test.

WATER

Water, a chemical mixture of oxygen and hydrogen, plays a very important part in the making of the mortar. Generally, to be suitable for mortar use, it should be free from oil, acids, alkalies, or vegetable matter. A good mortar water should be of a quality fit for drinking purposes.

MORTAR MAKING

In practice, almost all mortar is hand mixed in a wooden or steel mortar box. Generally, any local sand is selected for the mortar, regardless of its suitability. The mortar is mixed by common labor, of such proportions as seem to suit the masons or mason foreman. Seldom is any attempt made to secure uniform proportions of the constituents of the mix; and seldom are any two batches mixed exactly the same. Any mortar remaining after the day's work is usually covered with sand and a little water, to be reworked (retempered) into the first batch of the next day. All of this procedure, which is admitted to be common throughout the entire building industry, tends to defeat any advantage which might be gained by the use of Portland cement in the mortar. Instead of obtaining a mortar of high uniform strength, which the very nature of the materials decrees should be secured, generally a mortar of low, varying strength is produced; a mortar which many times is inferior to the plain lime mortar employed for many hundreds of years.

The sheer fact that Portland cement has been used in making the mortar seems to satisfy both architect and owner and the ignorant employment of a high grade material continues on.

Without continuing further with the unintelligent use of Portland cement mortar - the facts of which are known generally to the building industry - let us rather review the making of mortar, from the time the materials are bought, tracing each step of its history to the point of finally leaving it to fulfill its purpose of bonding together masonry in a wall or pier.

In the construction of any building of consequence, containing considerable work, I believe that money will always be saved if careful laboratory tests are run on a mortar sand that is being considered for use. I feel that probably the most economical sand to be used will have a fineness modulus within the limits of 2.8 and 3.5. As soon as a sand has been found to be clean, sharp and suitably graded, it will be wise to determine the proportions of that sand with lime, cement and water that will produce a mortar sufficiently strong to meet the loading requirements of the contemplated building and still be as economical of material as possible. Normally, any cement mortar that will show a compressive strength of 2000#/Sq" (or better) at 28 days will be suitable for laying up masonry work of the highest quality. In as much as the ultimate compressive strength of the best hard brick seldom exceeds 2000#/Sq", it may be reasonably deduced that to lay brick in a mortar stronger than the brick itself is to waste expensive mortar materials (cement and lime) fruitlessly. Thus, having beforehand decided what ultimate strength is to be desired from the mortar, the laboratory problem is the selection of the mix which will produce a mortar of required strength and in making it demand the least amount of lime and cement to be used.

As the first step towards such an end, I would recommend making standard briquettes of the selected sand and the brand of Portland cement that will be used in the actual construction; it is quite important that the tests are run on mortars made with the cement that will be used on the job because many times entirely different results will be obtained with various cements and the same sand. At times one brand of cement will act with a sand, or possibly certain impurities in the sand, and the lime quite differently than will another brand, although both are of equally as high quality.

Practically any good sand, mixed with Portland cement in the ratio of one part of cement to three parts of sand (1:3), by weight, will withstand a tensile stress of nearly 300#/Sq" at 28 days, (1 day moist air, 27 days dry air). Converting tensile strength into compressive strength, this would indicate a mortar good for 3000#/Sq" compressive stress at 28 days.* Thus, I would advise making no briquettes of a higher proportion of cement to sand than 1:3. Furthermore, as already outlined previously, any mortar stronger than 2000#/Sq" (compression) will probably exceed in strength the materials that it is bonding together and this extra strength is wasted. I would, therefore, make a set of briquettes (three to a set) for each of the different mix proportions: 1:3, 1:3 $\frac{1}{2}$, 1:3 $\frac{1}{4}$, 1:3 $\frac{3}{4}$, 1:4. Time allowing, these briquettes should be broken at the end of twenty-eight days, and the breaking strength of each briquette carefully noted. If the briquettes were made carefully no one should vary much more than 15% in strength from the others in its same mix.**

The average tensile strength of these mixes should then be derived and a curve plotted of these values, using tensile strength in #/Sq" for the ordinate and the mixes for the abscissa (I choose to start from the ordinate with the richest mix and secure thus a descending curve). Within the limits of such a curve, any desired mortar strength may be selected to be used on the job, by the process of simple interpolation between values. Thus it may be found that a real mix of 1:3 $\frac{5}{8}$ will produce a mortar suitable for a particular job. Realizing that without these tests a 1:3 (standard mix) would probably have been used, already there has been realized a definite cement saving that may be considerable if the job calls for much masonry construction. However, only the first portion of our ultimate cement saving has been made at this point. Now to go further.

A second series of briquettes should now be made, starting with the mix (1:3 $\frac{5}{8}$) that has been selected as suitable, the first three of the 1:3 $\frac{5}{8}$ mix, the second, of a mix in which 5% (by weight) of the cement

*I realize that many authorities dislike making a definite ratio between tensile strength and compressive strength. I feel, however, that for the purpose of determining mortar mixes, in view of the fact that tensile strength tests can be made so much more easily and so much more rapidly than can compressive strength tests, it is perfectly allowable to multiply the ultimate tensile stress that the mortar will sustain by the factor of "10" to cement into compressive strength. My entire endeavor throughout this paper is to attempt to improve the use of a material entirely within practical limits.

**If it is found to be impossible to have these tests run over so long a period of time, briquettes may be broken at seven days and a very close approximation of the 28 day strength will be reached if the 7 day strength is multiplied by the constant of 1.5.

has been replaced by 5% (by weight) of hydrated lime, the third of a mix in which 10% (by weight) of the cement has been replaced by 10% (by weight) of hydrated lime, etc., or designating the amount of the hydrated lime by the decimal between the cement and the sand quantities, the new mixes will be - 1:3 5/8 (original), .95:.05:3 5/8, .90:.10:3 5/8, .85:.15:3 5/8, .80:.20:3 5/8 and .75:.25:3 5/8. This series of six sets of briquettes should be stored the same as the first series, and broken in the same fashion at 28 days. Now, as will be later discussed under the heading of "The Effects of Hydrated Lime on Portland Cement Mortar", somewhere in this series of replacements of cement with lime will be attained a tensile strength as high or higher than was attained with the straight 1:3 5/8 mortar; and at the same time will be also attained a mortar which will be more workable and easier flowing than that mortar which contained no lime; this is naturally the final mortar mix which we desire. Having carefully recorded the breaking strength of this series of briquettes, average the values in each group as before and plot a new curve with these values using $\#/Sq$ as the ordinate and % lime as the abscissa. Then, the percentage of lime to be used in the mix will be that point on the curve, furthest from the "Y" axis, the ordinate of which is of equal value with the ordinate of the mix made of 100% cement and 0% lime. Thus, our final mix may be that of .82:.18:3 5/8; and once again, a considerable savings in cement has been realized because 18% of the weight of the cement in the 1:3 5/8 mix has been replaced with a considerably cheaper material, hydrated lime.

Now - let me trace through this procedure on an actual sand and determine what savings, if any, can be made by following this method.

CONDITIONS - Sand, Common Creek sand of fair quality.

Cement, standard brand of Portland cement.

Lime, standard brand of hydrated lime, dolomitic in nature.

Water, good quality.

Mix, Architect's specifications called for a 1:3 cement mortar with not exceeding 10% (not specified to be either by weight or by volume) - Architect agreed to allow the mortar mix to be designed for the materials used and would allow a 2000 $\#/Sq$ mortar to be used regardless of the proportions of the mix.

1. Standard Colormetric test for organic matter was run on the sand which showed a color of $\# 2\frac{1}{2}$ - suitable.

2. Screen test run on sand showed the sand to have a fineness modulus of 3.04 - suitable.

Sample 200 gms.

Screen Size	Sample Coarser in grams	Sample Coarser in percent.
1½ inch	0	0
¾ inch	0	0
⅜ inch	0	0
#4 mesh	0	0
#8 mesh	2.03	1.02
#14 mesh	12.46	6.23
#28 mesh	53.31	26.65
#48 mesh	143.93	71.97
#100 mesh	195.99	97.99
Beyond	200.01	<u>100.00</u> 303.86
	F.F. = $\frac{303.86}{100}$	= 3.04

3. Five sets of briquettes were carefully prepared (three briquettes to a set) utilizing the following mixes - all mixes by weight:

1:3, 1:3½, 1:3¾, 1:3 3/4 2, 1:4.

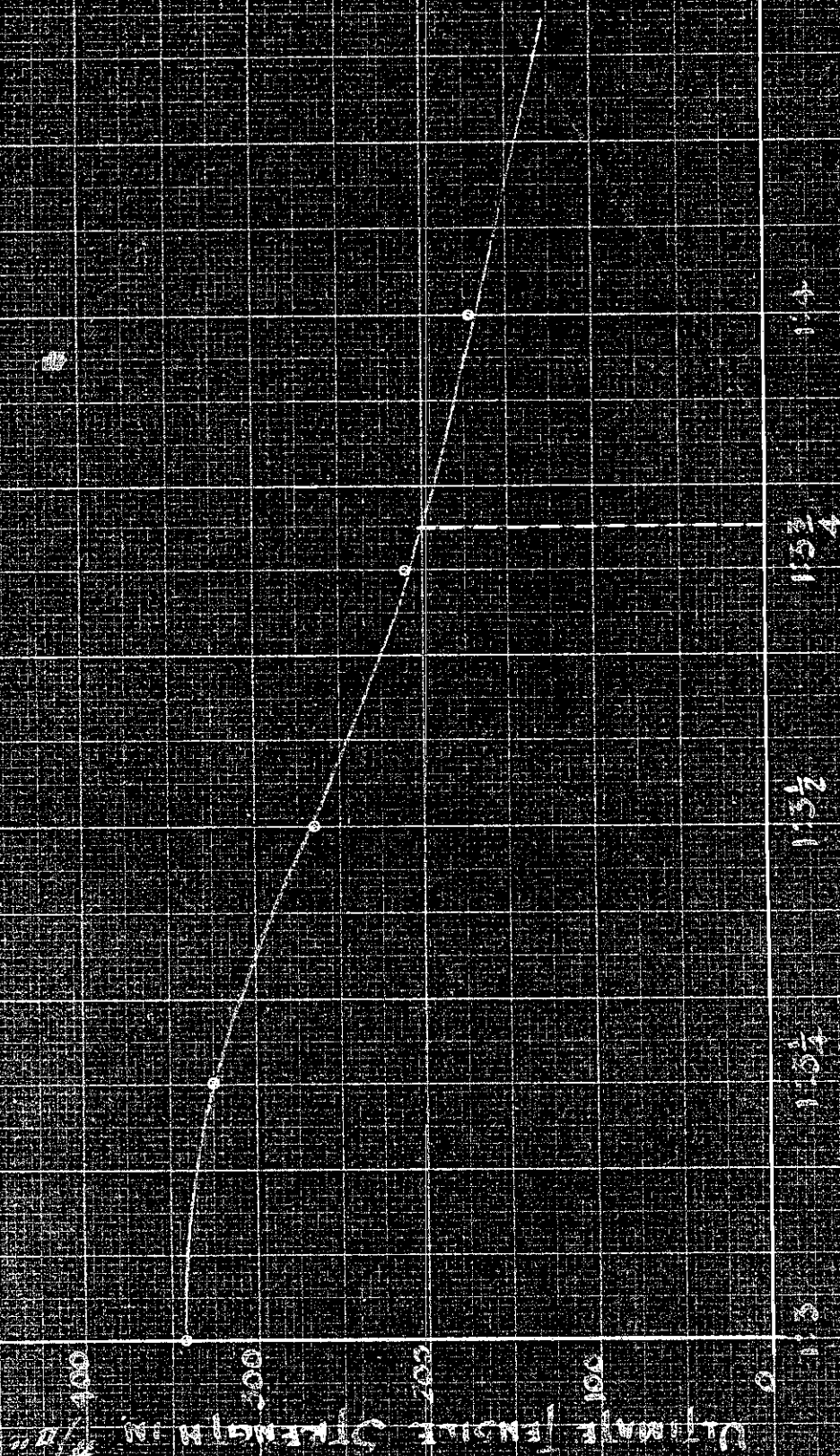
These briquettes were stored one day in moist air and twenty-seven days in dry air. Broken at 28 days, they showed the following results:*

Number	Mix	Tensile Strength 28 days in #/Sq"	Average in #/Sq"
1		335	
2	1:3	355	347
3		350	
4		320	
5	1:3 $\frac{1}{4}$	340	325
6		315	
7		280	
8	1:3 $\frac{1}{2}$	265	265
9		250	
10		210	
11	1:3 $\frac{3}{4}$	200	210
12		220	
13		175	
14	1:4	180	172
15		160	

4. These tensile strengths averaged, allowed the "Strength - Mix" curve to be constructed as shown on page 14. From this curve, it

*I realize that normal laboratory procedure calls for briquettes to be stored one day in moist air and twenty-seven days in water. I do not feel, however, that a storage of twenty-seven days in water represents conditions similar to those which will be actually experienced by mortar in actual construction and, therefore, have cured my briquettes in dry air in order to approximate actual field conditions. Without doubt, all of the briquettes examined would have shown far more strength if cured in water rather than air. They would, however, have represented much less of an indication of what strength the actual mortar on the job was to attain.

TENSILE STRESS-MIX CURVE



DEQUELET MIXES

may be seen that the actual mix needed to produce a tensile stress of 200#/Sq" is slightly weaker than one of cement to three and three quarters parts of sand. Thus, a mix of 1:3 3/4 will produce a mortar sufficiently strong for our purpose.

5. Next, as outlined previously, the selected mix of 1:3 3/4 was taken as a starting mix, and one set of briquettes made from it; then five other sets of briquettes in which, increasing in units of 5% by weight, the Portland cement was replaced with hydrated lime. Those briquettes of 1:3 3/4, .95:.05:3 3/4, .90:.10:3 3/4, .85:.15:3 3/4, .80:.20:3 3/4 and .75:.25:3 3/4 mix, were carefully prepared, and cured, as before - one day in moist air and twenty-seven days in dry air. Upon breaking, these briquettes tested as follows:

Number	Mix	Tensile Strength 28 days in #/Sq"	Average in #/Sq"
1		230	
2	1:3 3/4	210	218
3		215	
4		140	
5	.95:.05:3 3/4	135	142
6		150	
7		205	
8	.90:.10:3 3/4	200	208
9		220	
10		175	
11	.85:.15:3 3/4	160	167
12		165	
13		135	
14	.80:.20:3 3/4	140	140
15		145	
16		110	
17	.75:.25:3 3/4	110	105
18		95	

6. These strengths averaged, allowed a "Tensile Strength - Percentage of Lime" curve to be constructed as shown on page 17. From this curve it may be seen that the real mix needed to produce a tensile stress of 200#/Sq" most economically is approximately .88:.12:3 3/4.

- - - - -

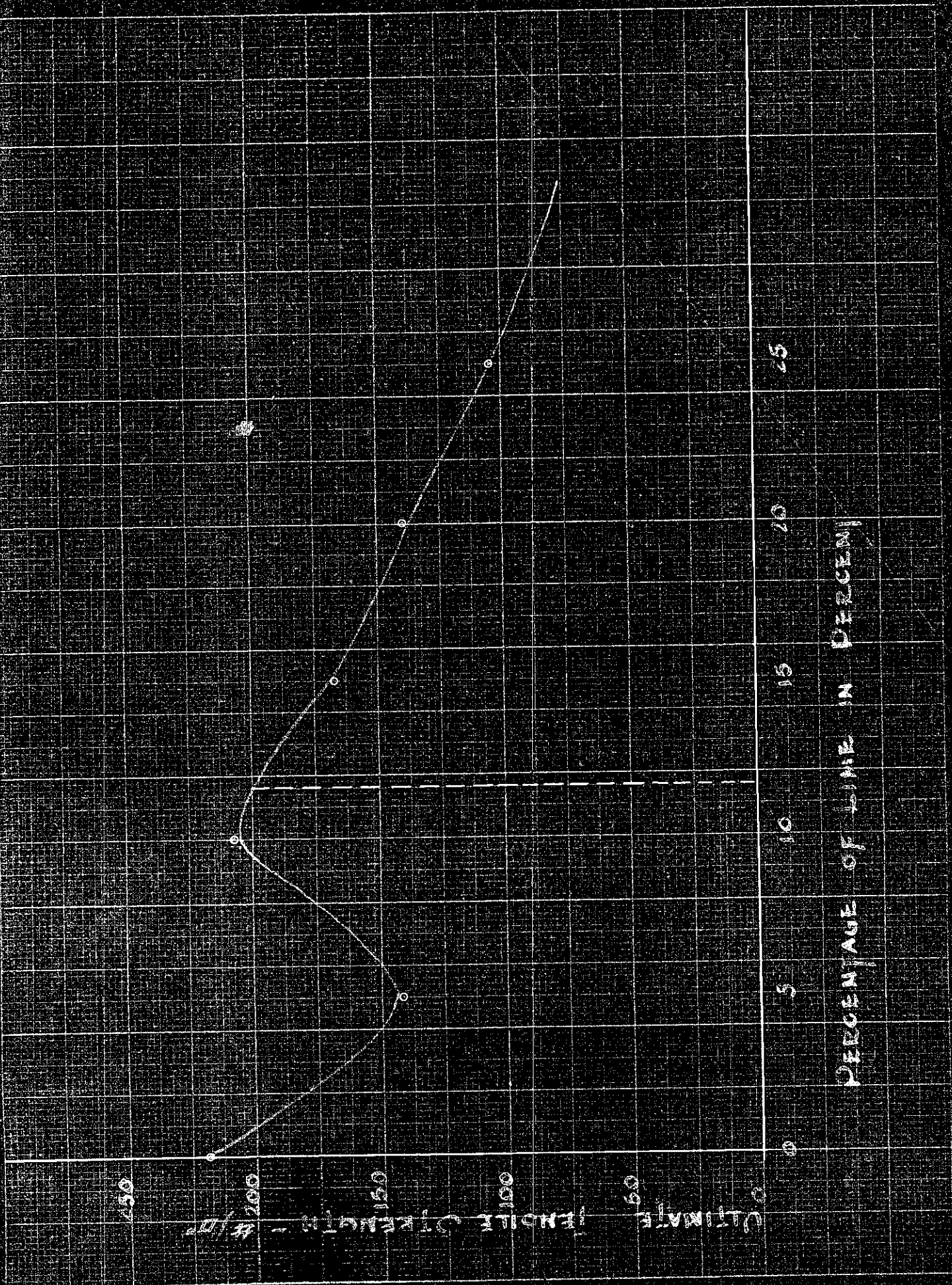
Tracing over the results of these tests it is at once apparent that a savings in cement of 23.1% has been made with a resulting mortar quite sufficiently strong for any practical usage.

Now, having examined the materials and decided upon the proper mix to be used, let us go into the field and actually make this mortar.

As mentioned before, the mortar will be hand mixed in a wooden or steel mortar box. (The mortar box should be thoroughly cleaned each day before using, and if any mortar remains in the box at the end of the day's work, it should be taken out and discarded) In view of the fact that scarcely any two shovels full of sand will be of exactly the same amount, I think it inadvisable to have the mortar maker use a "shovel of sand" as a unit of measure. A wooden measuring box can be made quite rapidly and its use requires little more time and effort than to shovel the sand directly into the mortar box from the pile. Fortunately, most Portland cement is brought in bags and in as much as each batch of mortar will take a full bag, no measuring device will be required for the cement. A small wooden measure should be made for the lime, however, because it will be used in less than bag lots.

After the proper amounts of sand, lime and cement have been dumped into the mortar box, these constituents should be mixed ("cut"), dry, with a mortar hoe until the mixture has assumed one uniform color. It is quite important for proper mixing that this procedure be carefully carried out. Then, a little at a time, water is introduced, the mixture being hoed vigorously at the same time. At the time of making the first batch of mortar on each job, a foreman should stay at the mortar box and regulate the amount of water put into each batch. Thereafter, the number of buckets of water required (about $2\frac{1}{2}$ to $3\frac{1}{2}$) for a proper mix can become a unit of the mix similar to the sand and lime units. Only sufficient water is desired in the mortar to fully hydrate the cement and lime and make the mortar possible to use: the least amount of water that can be used to make the mortar "workable" will be the correct unit of water. This mortar is then ready to be taken from the box in buckets or hods and be used by the masons in laying up the masonry structure.

On almost any job requiring more than four masons, it will be found that the use of two mortar boxes will result in a money savings. By the use of two boxes, one batch of mortar can always be ready to be taken to masons while a new batch is being prepared in the other. The common practice of mixing a batch of mortar in one end of a box while the other end contains part of the last batch is to be looked upon with disfavor. Obviously, some of the unmixed materials from the new batch will always get mixed with the remaining portion of the former batch and the mixing is neither complete nor satisfactory.



Discretion should be exercised just before noonday and just before "quitting" time that no new batch of mortar is mixed up. Over even so short a period as the half an hour that the men are at lunch in the middle of the day, many cements will attain their initial sets and thereafter be worthless for use in any load bearing masonry construction. If cautioned to be careful of the time, even common labor mixing the mortar will seldom have a bucket full of mortar left when the whistle blows. Without proper cautioning, however, about a batch of mortar each day will have to be discarded. The practice of "retempering" a batch of partially set up mortar with new materials is a poor one and should never be adopted. Proper time cautioning a half an hour before a stopping off point will completely do away with even the occasion for "retempering" mortar.

THE EFFECT OF LIME IN CEMENT MORTAR

Normally, the allowable amount of lime that may be used in cement mortars is 10% of the cement content of the mortar, and this 10% is seldom specified to mean either weight or volume; thus the lime content has wide margins. Furthermore, by most engineers, any amount of lime is supposed to be detrimental to the mortar but this 10% is allowed mainly to satisfy the masons who almost require some little lime in order to be able to spread the mortar evenly. Thus, lime is oftentimes considered to be a material that is undesirable but which, for the sake of the masons, must be endured: this, however, is not the case.

Laboratory tests have definitely proven that lime, in correct proportions, in the mortar mix has a directly beneficial rather than a detrimental effect upon cement mortars. If used correctly, the resulting cement mortar is much stronger, cures better, works easier and may be made cheaper than it would if no lime was used.

The high degree of workability or plasticity that lime introduces into cement mortars is almost universally admitted. Lime makes the mortar work easily off a trowel, and produces a uniform mortar bed for the masonry to be laid on. One certain proof that lime in cement mortar is highly beneficial and even necessary for workability is the fact that masons on a job will always complain of a mix too lean in it.

I feel that the lime content in mortar aids mortar greatly by retaining a portion of the water in the mixture until after complete hydration of the cement has taken place. Without lime, particularly in hot weather, masonry materials, and especially brick, absorb water from mortar too rapidly. Thus, a too quick "drying out" process takes place without complete hydration of the cement having taken place. It is true that many of the better sets of building specifications call for wetting down brick before laying in hot weather in order to overcome this too quick absorption, but this is practically never carried out in the field. A wetted brick is hard to handle and seems to tear, and wear out rapidly the skin on mason's hands; thus, although ideal in theory, it is seldom, if ever, practical to lay wet brick. Again the lime content in cement mortar is quite necessary.

My own laboratory experiments, made upon many mortar sands, have conclusively proven that an addition of the correct amount of lime to the mix of a Portland cement mortar will in every case produce a stronger mortar, by at least 10%, than would be otherwise produced. Normally, a percentage of lime to cement between 12% and 15% by weight will produce this stronger mortar. A composite "Breaking Strength - Percentage of Lime by Weight" curve may be inspected on

page 21. This curve is the result of plotting the results of tests run on eight different sands - as may be seen, the average high strength in the mortars appears when approximately 12% lime was added to the mix. Thus, as already pointed out under "Mortar Making", and in view of the fact that seldom will this increased strength be needed, the Portland cement content of the mortar may be reduced, lime substituted and a mortar produced both sufficiently strong for all purposes and economical in cost.

The proper amount of lime required for a mortar seems to be directly dependent upon the sand used; both upon its fineness, and possibly upon the chemical nature of some of the impurities it contains. The only method of determining the correct amount of lime required for a particular sand probably is to break a series of briquettes which contain varying amounts of lime and from them construct a curve similar to that shown on page 21. The maximum value of the lime may easily be picked from such a curve.

The addition of lime to the mortar seems to have a harmful effect on the mortar's strength both when too much and too little lime are added. Why it is that a very small amount of lime (4% or 5% by weight) should weaken a cement mortar while a larger amount of lime (12% or 13% by weight) should strengthen it seems to have no answer at present. As best I can discover, no reason for this action has yet been presented to the profession and I am of the opinion that only a chemist will be able to tell us finally. Still, a study of a "lime curve" for a sand contemplated in being used on a job will not only be interesting but will produce, for not exceeding several hours simple laboratory work, sufficient data to allow any superintendent or engineer to design a mortar mix both strong and economical. I would advise the construction of such a curve for the sand to be used on any job of consequence, because in this way, savings as high as 22% of the amount of the Portland cement can be realized.

BREAKING STRENGTH - POUNDS / IN² - SECTION - 28 DAYS

40

35

30

25

20

15

10

5

0

40

35

30

25

20

15

10

5

0

% LIME BY WEIGHT

FINENESS MODULUS 304 to 306

1:3 PORTLAND CEMENT MORTARS WITH VARYING AMOUNTS OF LIME

BREAKING STRENGTH - POUNDS / IN² - SECTION - 28 DAYS

40

35

30

25

20

15

10

5

0

40

35

30

25

20

15

10

5

0

% LIME BY WEIGHT

FINENESS MODULUS 304 to 306

1:3 PORTLAND CEMENT MORTARS WITH VARYING AMOUNTS OF LIME

CALCIUM CHLORIDE IN PORTLAND CEMENT MORTAR

The effect of a very weak solution of calcium chloride in a Portland cement mortar seems to be to retard slightly the initial setting of the cement. A very weak solution may also render sound a cement containing free lime by facilitating the hydration of the lime.

EFFLORESCENCE

The white efflorescent disfiguration so common on masonry walls, and particularly brick walls, is due to certain soluble salts present in either the brick or the mortar and sometimes in both. The most frequent cause of such efflorescence is a soluble salt, sulphate of magnesia, which when present is carried out to the face of the wall by the rain. I know of no remedy that will overcome this unsightliness quite as effectively as coating the walls with a good transparent waterproofing compound (of which the market affords several) after the white soluble salts have been removed by scrubbing with a weak solution of muriatic acid.

FREEZING

Fortunately, little consideration of mortars freezing must ever be taken. It is nearly impossible to lay brick at any time the weather is cold, for the reason that no mason can work when his hands must be protected from extreme weather by gloves. There are times, however, in both the late Fall and early Spring when the temperature will drop below freezing at nightfall, although the daytime is quite warm enough for men to work. The precaution at such times should be taken to stop the masonry work slightly earlier in the afternoon than normally would be done in order that all of the mortar may have reached at least its initial set before the temperature falls below freezing. Mortar which is exposed to low temperatures, too quickly, will naturally freeze and loses much of its strength upon subsequent setting. Mortar used just before nightfall at such times will oftentimes freeze on the surface only. Even though such freezing is almost always on only the exposed surface of the mortar and destroys little of its actual strength, a thin outer layer if frozen will scale and result in unsightly joints.

APPENDIX
STANDARD SPECIFICATIONS AND TESTS
FOR
PORTLAND CEMENT *

These specifications are the result of several years' work of a special committee representing a United States Government Departmental Committee, the Board of Direction of the American Society of Civil Engineers, and Committee C-1 on Cement of the American Society for Testing Materials in cooperation with Committee C-1.

SPECIFICATIONS

1. Definition.- Portland cement is the product obtained by finely pulverizing clinker produced by calcining to incipient fusion, an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

I. Chemical Properties

2. Chemical Limits.- The following limits shall not be exceeded:

Loss on ignition, %	4.00
Insoluble residue, %	0.85
Sulphuric anhydride (SO ₂), %	2.00
Magnesia (MgO), %	5.00

II. Physical Properties

3. Specific Gravity.- The specific gravity of cement shall be not less than 3.10 (3.07 for white Portland cement). Should the test of cement as received fall below this requirement a second test may be made upon an ignited sample. The specific gravity test will not be made unless specifically ordered.

4. Fineness.- The residue on a standard No. 200 sieve shall not exceed 22% by weight.

5. Soundness.- A pat of neat cement shall remain firm and hard, and show no signs of distortion, cracking, checking, or disintegration in the steam test for soundness.

* These specifications and tests were adopted by letter ballot of the American Society for Testing Materials on Sept. 1, 1916, and became effective Jan. 1, 1917.

6. Time of Setting.- The cement shall not develop initial set in less than 45 min. when the Vicat needle is used or 60 min. when the Gillmore needle is used. Final set shall be attained within 10 hr.

7. Tensile Strength.- The average tensile strength in pounds per square inch of not less than three standard mortar briquettes (see Sec. 51) composed of 1 part cement and 3 parts standard sand, by weight, shall be equal to or higher than the following:

Age at test, days	Storage of briquettes	Tensile strength, lb. per sq. in.
7	1 day in moist air, 6 days in water	200
28	1 day in moist air, 27 days in water	300

8. The average tensile strength of standard mortar at 28 days shall be higher than the strength at 7 days.

III. Packages, Marking and Storage

9. Packages and Marking.- The cement shall be delivered in suitable bags or barrels with the brand and name of the manufacturer plainly marked thereon, unless shipped in bulk. A bag shall contain 94lb. net. A barrel shall contain 376 lb. net.

10. Storage.- The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building which will protect the cement from dampness.

IV. Inspection

11. Inspection.- Every facility shall be provided the purchaser for careful sampling and inspection at either the mill or at the site of the work, as may be specified by the purchaser. At least 10 days from the time of sampling shall be allowed for the completion of the 7-day test, and at least 31 days shall be allowed for the completion of the 28-day test. The cement shall be tested in accordance with the methods hereinafter prescribed. The 28-day test shall be waived only when specifically so ordered.

V. Rejection

12. Rejection.- The cement may be rejected if it fails to meet any of the requirements of these specifications.

13. Cement shall not be rejected on account of failure to meet the fineness requirement if upon retest after drying at 100°C. for 1 hr. it meets this requirement.

14. Cement failing to meet the test for soundness in steam may be accepted if it passes a retest using a new sample at any time within 28 days thereafter.

15. Packages varying more than 5% from the specified weight may be rejected: and if the average weight of packages in any shipment, as shown by weighing 50 packages taken at random, is less than that specified, the entire shipment may be rejected.

TESTS

VI. Sampling

16. Number of Samples.- Tests may be made on individual or composite samples as may be ordered. Each test sample should weigh at least 8 lb.

17. (a) Individual Sample.- If sampled in cars one test sample shall be taken from each 50 bbl. or fraction thereof. If sampled in bins one sample shall be taken from each 100 bbl.

(b) Composite Sample.- If sampled in cars one sample shall be taken from one sack in each 40 sacks (or 1 bbl. in each 10 bbl.) and combined to form one test sample. If sampled in bins or warehouses one test sample shall represent not more than 200 bbl.

18. Method of Sampling.- Cement may be sampled at the mill by any of the following methods that may be practicable, as ordered:

(a) From the Conveyor Delivering to the Bin.- At least 8 lb. of cement shall be taken from approximately each 100 bbl. passing over the conveyor.

(b) From Filled Bins by Means of Proper Sampling Tubes.- Tubes inserted vertically may be used for sampling cement to a maximum depth of 10 ft. Tubes inserted horizontally may be used where the construction of the bin permits. Samples shall be taken from points well distributed over the face of the bin.

(c) From Filled Bins at Points of Discharge.- Sufficient cement shall be drawn from the discharge openings to obtain samples representative of the cement contained in the bin, as determined by the appearance at the discharge openings of indicators placed on the surface of the cement directly above these openings before drawing of the cement is started.

19. Treatment of Sample.- Samples preferably shall be shipped and stored in air-tight containers. Samples shall be passed through a sieve having 20 meshes per linear inch in order to thoroughly mix the sample, break up lumps and remove foreign materials.

VII. Chemical Analysis

Loss on Ignition

20. Method.- One gram of cement shall be heated in a weighed

covered platinum crucible, of 20 to 25-c.c. capacity, as follows, using either method (a) or (b) as ordered:

(a) The crucible shall be placed in a hole in an asbestos board, clamped horizontally so that about three-fifths of the crucible projects below, and blasted at a full red heat for 15 min. with an inclined flame; the loss in weight shall be checked by a second blasting for 5 min. Care shall be taken to wipe off particles of asbestos that may adhere to the crucible when withdrawn from the hole in the board. Greater neatness and shortening of the time of heating are secured by making a hole to fit the crucible in a circular disc of sheet platinum and placing this disc over a somewhat larger hole in an asbestos board.

(b) The crucible shall be placed in a muffle at any temperature between 900 and 1000°C. for 15 min. and the loss in weight shall be checked by a second heating for 5 min.

21. Permissible Variation.- A permissible variation of 0.25 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 4%.

Insoluble Residue

22. Method.- To a 1-gram sample of cement shall be added 10 c.c. of water and 5 c.c. of concentrated hydrochloric acid; the liquid shall be warmed until effervescence ceases. The solution shall be diluted to 50 c.c. and digested on a steam bath or hot plate until it is evident that decomposition of the cement is complete. The residue shall be filtered, washed with cold water, and the filter paper and contents digested in about 30 c.c. of a 5% solution of sodium carbonate, the liquid being held at a temperature just short of boiling for 15 min. The remaining residue shall be filtered, washed with cold water, then with a few drops of hot hydrochloric acid, 1:9, and finally with hot water, and then ignited at a red heat and weighed as the insoluble residue.

23. Permissible Variation.- A permissible variation of 0.15 will be allowed, and all results in excess of the specific limit but within this permissible variation shall be reported as 0.85%.

Sulphuric Anhydride

24. Method.- One gram of the cement shall be dissolved in 5 c.c. of concentrated hydrochloric acid diluted with 5 c.c. of water, with gentle warming; when solution is complete 40 c.c. of water shall be added, the solution filtered, and the residue washed thoroughly with water. The solution shall be diluted to 250 c.c., heated to boiling and 10 c.c. of a hot 10% solution of barium chloride shall be added slowly, drop by drop, from a pipette and the boiling continued until the precipitate is well formed. The solution shall be digested on the steam bath until the precipitate has settled. The precipitate shall be filtered, washed, and the paper and contents placed in a weighed platinum crucible and the paper slowly charred and consumed without flaming. The barium sulphate shall then be ignited and weighed. The weight obtained multiplied by 34.3 gives the percentage of

sulphuric anhydride. The acid filtrate obtained in the determination of the insoluble residue may be used for the estimation of sulphuric anhydride instead of using a separate sample.

25. Permissible Variation.- A permissible variation of 0.10 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 2.00%.

Magnesia

26. Method.- To 0.5 gram of the cement in an evaporating dish shall be added 10 c.c. of water to prevent lumping and then 10 c.c. of concentrated hydrochloric acid. The liquid shall be gently heated and agitated until attack is complete. The solution shall then be evaporated to complete dryness on a steam or water bath. To hasten dehydration the residue may be heated to 150 or even 200°C. for $\frac{1}{2}$ to 1 hr. The residue shall be treated with 10 c.c. of concentrated hydrochloric acid diluted with an equal amount of water. The dish shall be covered and the solution digested for 10 min. on a steam bath or water bath. The diluted solution shall be filtered and the separated silica washed thoroughly with water.* Five cubic centimeters of concentrated hydrochloric acid and sufficient bromine water to precipitate any manganese which may be present, shall be added to the filtrate (about 250 c.c.). This shall be made alkaline with ammonium hydroxide, boiled until there is but a faint odor of ammonia, and the precipitated iron and aluminum hydroxides, after settling, shall be washed with hot water, once by decantation and slightly on the filter. Setting aside the filtrate, the precipitate shall be transferred by a jet of hot water to the precipitating vessel and dissolved in 10 c.c. of hot hydrochloric acid. The paper shall be extracted with acid, the solution and washings being added to the main solution. The aluminum and iron shall then be reprecipitated at boiling heat by ammonium hydroxide and bromine water in a volume of about 100 c.c., and the second precipitate shall be collected and washed on the filter used in the first instance if this is still intact. To the combined filtrates from the hydroxides of iron and aluminum, reduced in volume if need be, 1 c.c. of ammonium hydroxide shall be added, the solution brought to boiling, 25 c.c. of a saturated solution of boiling ammonium oxalate added, and the boiling continued until the precipitated calcium oxalate has assumed a well-defined granular form. The precipitate after 1 hr. shall be filtered and washed, then with the filter shall be placed wet in a platinum crucible, and the paper burned off over a small flame of a Bunsen burner; after ignition it shall be redissolved in hydrochloric acid and the solution diluted to 100 c.c. Ammonia shall be added in slight excess, and the liquid boiled. The lime shall then be reprecipitated by ammonium oxalate, allowed to stand until settled, filtered and washed. The combined filtrates from the calcium precipitates shall be acidified with hydrochloric acid, concentrated on the steam bath to about 150 c.c., and made slightly alkaline with ammonium hydroxide, boiled and filtered (to remove a little aluminum and iron and perhaps calcium). When cool, 10 c.c. of saturated solution of

*Since this procedure does not involve the determination of silica, a second evaporation is unnecessary.

sodium-ammonium-hydrogen phosphate shall be added with constant stirring. When the crystallin ammonium-magnesium orthophosphate has formed, ammonia shall be added in moderate excess. The solution shall be set aside for several hours in a cool place, filtered and washed with water containing 2.5% of NH₃. The precipitate shall be dissolved in a small quantity of hot hydrochloric acid, the solution diluted to about 100 c.c., 1 c.c. of a saturated solution of sodium-ammonium-hydrogen phosphate added, and ammonia drop by drop, with constant stirring, until the precipitate is again formed as described and the ammonia is in moderate excess. The precipitate shall then be allowed to stand about 2 hr., filtered and washed as before. The paper and contents shall be placed in a weighed platinum crucible, the paper slowly charred, and the resulting carbon carefully burned off. The precipitate shall then be ignited to constant weight over a Meker burner, or a blast not strong enough to soften or melt the pyrophosphate. The weight of magnesium pyrophosphate obtained multiplied by 72.5 gives the percentage of magnesia. The precipitate so obtained always contains some calcium and usually small quantities of iron, aluminum, and manganese as phosphates.

27. Permissible Variation.- A permissible variation of 0.4 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 5.00%.

VIII. Determination of Specific Gravity

28. Apparatus.- The determination of specific gravity shall be made with a standardized Le Chatelier apparatus which conforms to the requirements illustrated in Fig. 1. This apparatus is standardized by the United States Bureau of Standards. Kerosene free from water, or benzine not lighter than 62°Be., shall be used in making this determination.

29. Method.- The flask shall be filled with either of these liquids to a point on the stem between zero and 1 c.c. and 64 grams of cement, of the same temperature as the liquid, shall be slowly introduced, taking care that the cement does not adhere to the inside of the flask above the liquid and to free the cement from air by rolling the flask in an inclined position. After all the cement is introduced, the level of the liquid will rise to some division of the graduated neck; the difference between readings is the volume displaced by 64 grams of the cement.

The specific gravity shall then be obtained from the formula:

$$\text{Specific gravity} = \frac{\text{Weight of cement (grams)}}{\text{Displaced volume (c.c.)}}$$

30. The flask, during the operation, shall be kept immersed in water, in order to avoid variations in the temperature of the liquid in the flask, which shall not exceed 0.5°C. The results of repeated tests should agree within 0.01.

31. The determination of specific gravity shall be made on the cement as received; if it falls below 3.10, a second determination shall be made after igniting the sample as described in Sect. 20.

IX. Determination of Fineness

32. Apparatus.- Wire cloth for standard sieves for cement shall be woven (not twilled) from brass, bronze, or other suitable wire, and mounted without distortion on frames not less than $1\frac{1}{2}$ in. below the top of the frame. The sieve frames shall be circular, approximately 8 in. in diameter, and may be provided with a pan and cover.

33. A standard No. 200 sieve is one having nominally an 0.0029-in. opening and 200 wires per inch standardized by the U. S. Bureau of Standards, and conforming to the following requirements:

The No. 200 sieve should have 200 wires per inch, and the number of wires in any whole inch shall not be outside the limits of 192 to 208. No opening between adjacent parallel wires shall be more than 0.0050 in. in width. The diameter of the wire should be 0.0021 in. and the average diameter shall not be outside the limits 0.0019 to 0.0023 in. The value of the sieve as determined by sieving tests made in conformity with the standard specification for these tests on a standardized cement which gives a residue of 25 to 20% on the No. 200 sieve, or on other similarly graded material, shall not show a variation of more than 1.5% above or below the standards maintained at the Bureau of Standards.

34. Method.- The test shall be made with 50 grams of cement. The sieve shall be thoroughly clean and dry. The cement shall be placed on the No. 200 sieve, with pan and cover attached, if desired, and shall be held in one hand in a slightly inclined position so that the sample will be well distributed over the sieve, at the same time gently striking the side about 150 times per minute against the palm of the other hand on the up stroke. The sieve shall be turned every 25 strokes about one-sixth of a revolution in the same direction. The operation shall continue until not more than 0.05 gram passes through in 1 min. of continuous sieving. The fineness shall be determined from the weight of the residue on the sieve expressed as a percentage of the weight of the original sample.

35. Mechanical sieving devices may be used, but the cement shall not be rejected if it meets the fineness requirement when tested by the hand method described in Sect. 34.

35. Permissible Variation.- A permissible variation of 1 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 22%.

X. Mixing Cement Pastes and Mortars

37. Method.- The quantity of dry material to be mixed at one time shall not exceed 1000 grams nor be less than 500 grams. The proportions of cement or cement and sand shall be stated by weight in grams of the dry materials; the quantity of water shall be expressed in cubic centimeters (1 c.c. of water = 1 gram). The dry materials shall be weighed, placed upon a non-absorbent surface, thoroughly mixed dry if sand

is used, and a crater formed in the center, into which the proper percentage of clean water shall be poured; the material on the outer edge shall be turned into the crater by the aid of a trowel. After an interval of $\frac{1}{2}$ min. for the absorption of the water the operation shall be completed by continuous, vigorous mixing, squeezing and kneading with the hands for at least 1 min.*

38. The temperature of the room and the mixing water shall be maintained as nearly as practicable at 21°C. (70°F.).

XI. Normal Consistency

39. Apparatus. The Vicat apparatus consists of a frame A (Fig. 2) bearing a movable rod B, weighing 300 grams, one end C being 1 cm. in diameter for a distance of 6 cm., the other having a removable needle D, 1 mm. in diameter, 6 cm. long. The rod is reversible, and can be held in any desired position by a screw E, and has midway between the ends a mark F which moves under a scale (graduated to millimeters) attached to the frame A. The paste is held in a conical, hard-rubber ring G, 7 cm. in diameter at the base, 4 cm. high, resting on a glass plate H about 10 cm. square.

40. Method.- In making the determination, 500 grams of cement, with a measured quantity of water, shall be kneaded into a paste, as described in Sect. 37, and quickly formed into a ball with the hands, completing the operation by tossing it six times from one hand to the other, maintained about 6 in. apart; the ball resting in the palm of one hand shall be pressed into the larger end of the rubber ring held in the other hand, completely filling the ring with paste; the excess at the larger end shall then be removed by a single movement of the palm of the hand; the ring shall then be placed on its larger end on a glass plate and the excess paste at the smaller end sliced off at the top of the ring by a single oblique stroke of a trowel held at a slight angle with the top of the ring. During these operations care shall be taken not to compress the paste. The paste confined in the ring, resting on the plate, shall be placed under the rod, the larger end of which shall be brought in contact with the surface of the paste; the scale shall be then read, and the rod quickly released. The paste shall be of normal consistency when the rod settles to a point 10 mm. below the original surface in $\frac{1}{2}$ min. after being released. The apparatus shall be free from all vibrations during the test. Trial pastes shall be made with varying percentages of water until the normal consistency is obtained. The amount of water required shall be expressed in percentage by weight of the dry cement.

* In order to secure uniformity in the results of tests for the time of setting and tensile strength the manner of mixing above described should be carefully followed. At least one minute is necessary to obtain the desired plasticity which is not appreciably affected by continuing the mixing for several minutes. The exact time necessary is dependent upon the personal equation of the operator. The error in mixing should be on the side of over mixing. During the operation of mixing, the hands should be protected by rubber gloves.

41. The consistency of standard mortar shall depend on the amount of water required to produce a paste of normal consistency from the same sample of cement. Having determined the normal consistency of the sample, the consistency of standard mortar made from the same sample shall be as indicated in Table I, the values being in percentage of the combined dry weights of the cement and standard sand.

Table I. -- Percentage of Water for Standard Mortars

Percentage of water for neat cement paste of normal consistency	Percentage of water for one cement, three standard Ottawa sand	Percentage of water for neat cement paste of normal consistency	Percentage of water for one cement, three standard Ottawa sand
15	9.0	23	10.3
16	9.2	24	10.5
17	9.3	25	10.7
18	9.5	26	10.8
19	9.7	27	11.0
20	9.8	28	11.2
21	10.0	29	11.3
22	10.2	30	11.5

XII. Determination of Soundness*

42. Apparatus.- A steam apparatus, which can be maintained at a temperature between 98 and 100°C., or one similar to that shown in Fig. 3, is recommended. The capacity of this apparatus may be increased by using a rack for holding the pats in a vertical or inclined position.

* Unsoundness is usually manifested by change in volume which causes distortion, cracking, checking or disintegration.

Pats improperly made or exposed to drying may develop what are known as shrinkage cracks within the first 24 hours and are not an indication of unsoundness. These conditions are illustrated in Fig. 4.

The failure of the pats to remain on the glass or the cracking of the glass to which the pats are attached does not necessarily indicate unsoundness.

43. Method.- A pat from cement paste of normal consistency about 3 in. in diameter, $\frac{1}{8}$ in. thick at the center, and tapering to a thin edge, shall be made on clean glass plates about 4 in. square, and stored in moist air for 24 hr. In molding the pat, the cement paste shall first be flattened on the glass and the pat then formed by drawing the trowel from the outer edge toward the center.

44. The pat shall then be placed in an atmosphere of steam at a temperature between 98 and 100°C. upon a suitable support 1 in. above boiling water for 5 hr.

45. Should the pat leave the plate, distortion may be detected best with a straight-edge applied to the surface which was in contact with the plate.

XIII. Determination of Time of Setting

46. The following are alternate methods, either of which may be used as ordered:

47. Vicat Apparatus.- The time of setting shall be determined with the Vicat apparatus described in Sect. 39 (see Fig. 2).

48. Vicat Method.- A paste of normal consistency shall be molded in the hard-rubber ring G as described in Sect. 40, and placed under the rod B, the smaller end of which shall then be carefully brought into contact with the surface of the paste, and the rod quickly released. The initial set shall be said to have occurred when the needle ceases to pass a point 5 mm. above the glass plate in $\frac{1}{2}$ min. after being released; and the final set, when the needle does not sink visibly into the paste. The test pieces shall be kept in moist air during the test. This may be accomplished by placing them on a rack over water contained in a pan and covered by a damp cloth, kept from contact with them by means of a wire screen; or they may be stored in a moist closet. Care shall be taken to keep the needle clean, as the collection of cement on the sides of the needle retards the penetration, while cement on the point may increase the penetration. The time of setting is affected not only by the percentage and temperature of the water used and the amount of kneading the paste receives, but by the temperature and humidity of the air, and its determination is therefore only approximate.

49. Gillmore Needles.- The time of setting shall be determined by the Gillmore needles. The Gillmore needles should preferably be mounted as shown in Fig. 5b.

50. Gillmore Method.- The time of setting shall be determined as follows: A pat of neat cement paste about 3 in. in diameter and $\frac{1}{8}$ in. in thickness with a flat top Fig. 5a, mixed to a normal consistency, shall be kept in moist air at a temperature maintained as nearly as practicable at 21°C. (70°F.). The cement shall be considered to have acquired its initial set when the pat will bear, without appreciable indentation, the Gillmore needle $\frac{1}{12}$ in. in diameter, loaded to weigh $\frac{1}{4}$ lb. The final set has been acquired when the pat will bear without appreciable indenta-

tion, the Gillmore needle 1/24 in. in diameter, loaded to weigh 1 lb. In making the test, the needles shall be held in a vertical position, and applied lightly to the surface of the pat.

XIV. Tension Tests

51. Form of Test Piece.- The form of test piece shown in Fig. 6 shall be used. The molds shall be made of non-corroding metal and have sufficient material in the sides to prevent spreading during molding. Gang molds when used shall be of the type shown in Fig. 7. Molds shall be wiped with an oily cloth before using.

52. Standard Sand.- The sand to be used shall be natural sand from Ottawa, Ill., screened to pass a No. 20 sieve and retained on a No. 30 sieve. This sand may be obtained from the Ottawa Silica Co., at a cost of 2 cts. per lb., f.o.b. cars, Ottawa, Ill.

53. This sand, having passed the No. 20 sieve, shall be considered standard when not more than 5 grains pass the No. 30 sieve after 1 min. continuous sieving of a 500-grain sample.

54. The sieves shall conform to the following specifications:

The No. 20 sieve shall have between 19.5 and 20.5 wires per whole inch of the warp wires and between 19 and 21 wires per whole inch of the shoot wires. The diameter of the wire should be 0.0165 in. and the average diameter shall not be outside the limits of 0.0160 and 0.0170 in.

The No. 30 Sieve shall have between 29.5 and 30.5 wires per whole inch of the warp wires and between 28.5 and 31.5 wires per whole inch of the shoot wires. The diameter of the wire should be 0.0110 in. and the average diameter shall not be outside the limits 0.0105 to 0.0115 in.

55. Molding.- Immediately after mixing, the standard mortar shall be placed in the molds, pressed in firmly with the thumbs and smoothed off with a trowel without ramming. Additional mortar shall be heaped above the mold and smoothed off with a trowel; the trowel shall be drawn over the mold in such a manner as to exert a moderate pressure on the material. The mold shall then be turned over and the operation of heaping, thumbing and smoothing off repeated.

56. Testing.- Tests shall be made with any standard machine. The briquettes shall be tested as soon as they are removed from the water. The bearing surfaces of the clips and briquettes shall be free from grains of sand or dirt. The briquettes shall be carefully centered and the load applied continuously at the rate of 600 lb. per min.

57. Testing machines should be frequently calibrated in order to determine their accuracy.

58. Faulty Briquettes.- Briquettes that are manifestly faulty, or which give strengths differing more than 15% from the average value of

all test pieces made from the same sample and broken at the same period, shall not be considered in determining the tensile strength.

XV. Storage of Test Pieces.

59. Apparatus.- The moist closet may consist of a soap-stone, slate or concrete box, or a wooden box lined with metal. If a wooden box is used, the interior should be covered with felt or broad wicking kept wet. The bottom of the moist closet should be covered with water. The interior of the closet should be provided with non-absorbent shelves on which to place the test pieces, the shelves being so arranged that they may be withdrawn readily.

60. Methods.- Unless otherwise specified, all test pieces, immediately after molding, shall be placed in the moist closet for from 20 to 24 hr.

61. The briquettes shall be kept in molds on glass plates in the moist closet for at least 20 hr. After 24 hr. in moist air the briquettes shall be immersed in clean water in storage tanks of non-corroding material.

62. The air and water shall be maintained as nearly as practicable at a temperature of 21°C. (70°F.).

BIBLIOGRAPHY

The Encyclopaedia Britannica

- - - -

Handbook of Building Construction

Hool & Johnson

- - - -

The Civil Engineer's Pocket-Book

Trautwine

- - - -

Kidder's Architects and Builders Pocket Book

Kidder-Wolan

- - - -

"Stucco Investigations at the Bureau of Standards
with Recommendations for Portland Cement Stucco."

U. S. Bureau of Standards

- - - -

Portland Cement Mortar

U. S. Bureau of Standards

(Klein and Phillips)

- - - -

Concrete Engineer's Handbook

Hool & Johnson

- - - -

Paper presented before the Amer. Con. Institute Feb. 1916

G. A. Rankin

- - - -