General Treussart ESSAYS ON HYDRAULIC AND COMMON MORTARS AND ON LIME-BURNING. TRANSLATED FROM THE FRENCH OF GEN.TREUSSART BY M. PETOT, AND M.COURTOIS.

WITH BRIEF OBSERVATIONS OF COMMON MORTARS, HYDRAULIC MORTARS, AND CONCRETES,
AND AN ACCOUNT OF SOME EXPERIMENTS MADE THEREWITH AT FORT ADAMS, NEWPORT HARBOR, R. L, FROM 1825 TO 1838. BY J. G. TOTTEN, LT.COL. OF ENGINEERS, AND BREVET COL. U.S.ARMY.

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ON HYDRAULIC AND COMMON MORTARS.

Sect. 1.— ON MORTARS PLACED UNDER WATER.

CHAPTER I.

On Lime.— Actual state of our knowledge of this substance.

Lime has been employed from time immemorial. Mixed with sand, or certain other substances, it forms what is called mortar. Although the solidity and durability of masonry depends on the goodness of mortar; still, few experiments have been made with lime; **and the manner of making mortar has almost always been given up to workmen.** It is only within about fifty years that a few scientific men have attended to this important subject.

Comparing the mortars of the ancients, and especially of the Romans, with those of modern times, it was perceived that the old mortars were much better than ours; and the means have, consequently, been sought of imitating them. Several constructors have thought they had discovered the secret of making Roman mortars: others, on the contrary, have thought that **the Romans had no particular process, but that, of all their constructions, those only which were made of good lime had survived to our day. We shall see that my experiments tend to confirm this latter opinion.** Lime used in building, is obtained by the calcination of calcareous stones, which occur abundantly on the surface of the globe. Marbles, certain building stones, chalk, calcareous alabaster, and shells, are employed in making lime. The effect of calcination is to drive off the water and the carbonic acid which are combined with the lime. The water and the first portions of carbonic acid pass off easily; but it requires an intense, and long continued heat to dispel the remainder of the acid. Lime, as used in constructions, contains, almost always, a considerable quantity of carbonic acid.

When the stone submitted to calcination is white marble, pure lime is obtained, provided the calcination be carried far enough. According to an analysis which I made of white marble, this substance contained, in 100 parts, as follows: lime 64; carbonic acid 33; water 3.

Lime obtained by calcination possesses the following properties. It has a great avidity for water, imbibes it from the air, and has its bulk enlarged thereby. If a certain quantity of water be thrown on lime recently calcined, it heats highly, breaks in pieces with noise, and a part of the water is evaporated by the heat produced….

It is rare that lime derived from white marble is used in the arts; that which is commonly employed, and which is derived from ordinary lime stone, almost always contains oxide of iron, and sometimes a certain quantity of sand, aluminae, magnesia, oxide of manganese, &c. Some of these substances combine with the lime by calcination: and the lime thus acquires properties which it had not before, and of which I shall speak in the sequel.

If we take lime derived from white marble, or from common limestone, and reduce it as it comes from the kiln, to a paste with water, and if we place this paste in water, or in humid earth, it will remain soft forever. **The same result will be obtained, if lime be mixed with common sand and the resulting mortar be placed in similar situations**.

It is a common practice to deluge lime, fresh from the kiln, with a large quantity of water, and run it into large basins, where it is allowed to remain in the condition of soft paste. Alberti says (book II., chap. XI.) he has "seen lime, in an old ditch, that had been abandoned about 500 years, as was conjectured from several manifest indications; which was still so moist, well tempered, and ripe, that not honey or the marrow of animals could be more so." There is another kind of lime which possesses a singular property: if it be slaked as it comes from the kiln, as above, and be then placed in the state of paste, in water, or in moist earth, it will harden more or less promptly, according to the substances it contains. The same result is obtained if the lime, being mixed with sand, is made into mortar and placed in similar situations. If this lime be slaked and run into vats, as is done with common lime, it will become hard after a little time, and it will then be impossible to make use of it.

On slaking lime, fresh from the kiln, with enough water to reduce it to paste, it is found to augment considerably in bulk; this augmentation is such that one volume of quick lime will sometimes yield more than three volumes, measured in the condition of thick paste. **When lime which has the property of hardening in water is slaked in the same manner, it affords a much smaller volume than common lime.** Sometimes one volume of this lime, measured before slaking, will give, when slaked to thick paste, scarcely an equal bulk. For a long time, those limes which had the property of hardening in water were called meagre limes, and those which had not this property were called fat limes. These denominations were affixed because the first kind increased but little in bulk when made into paste, while the other give a considerable augmentation of volume; and because fat limes formed, with the same quantity of sand, **a mortar much fatter or more unctuous than meagre lime**. But the designation "meagre lime" is altogether improper to indicate limes which enjoy the property of hardening in water; because there are limes which augment their volume very little, on being made into paste, and at the same time possess no hydraulic property. Belidor gave the name of beton to lime which had the quality of hardening in water; but many engineers continued to call it meagre lime. The denomination of beton is not suitable; and, in this sense, is not now in use. The following are the terms now employed. In England, the name of aquatic lime has been given to lime which indurates in water; in Germany it is called lime for the water; Mr. Vicat, Engineer of roads and bridges, has proposed the name of hydraulic lime, and this denomination, which is a very good one, has been generally adopted. I shall therefore call that lime which swells considerably in slaking, fat lime, that which swells but little and does not harden in water, meagre lime, and that which possesses the property of hardening in water, hydraulic lime. Fat lime is often called common lime, also. The term quick lime is applied to all unslaked limes whether fat lime, meagre lime, or hydraulic lime. Although meagre lime and hydraulic lime may have been calcined exactly to the proper degree, still they are slower to slake, and give out less heat than jut lime. When fat lime has been too much burned, it, also, becomes slow to slake; while, if properly burned, it begins to slake the instant water is thrown on. Experiments, to be given in the sequel, will show that iron, in the state of red oxide, causes fat lime to slake sluggishly.

(Discussion about what impurity caused hydraulic set – for a long time, manganese thought to be the cause.)

… On the other hand we find in the Bibliotheque Britannique of 1776, vol. Ill, page 202, that Smeaton, the English Engineer, who built the Edystone Light-house, in 1757, attributed this property to clay…

… Mr. Saussure, in his Voyage des Alpes, says that the property possessed by certain limes of hardening in water is due solely to silex and alumine (that is to say, to clay) combined in certain proportions.

(Discussion of Vicat's experiments in making artificial hydraulic lime using air lime and clay fired together (the lime for the second time))…

Such is the process indicated by Mr. Vicat. But this engineer did not content himself with experiments on a small scale: **a manufactory was established near Paris by his means, where artificial hydraulic lime is made in large quantities; he moreover exerted himself to extend the use of hydraulic mortar every where, and he succeeded.**

P6… In terminating this reference to works on hydraulic mortars, which have appeared up to this time, I must introduce a fact, entirely new, announced by Mr. Girard de Caudemberg, engineer of roads and bridges, in a notice published by him in 1827. He states that the proprietors of mills on the river Isle, in the department of Gironde, discovered by accident, a kind of fossil sand to which they gave the name of arene, which has the singular property, without any preparation, of forming, with fat lime, a mortar that hardens under water, and has great durability. I shall have occasion to return to this important fact, and to report what Mr. Girard says, as well as to state the principal experiments which have been made with this substance, in other places where it has been found.

CHAPTER II. On slaking Lime; manner of making Mortar; observations on Hydrate of Lime.

There are three modes of slaking lime. The first consists in throwing on the lime, as it comes from the kiln, enough water to reduce it to thin paste. This process is the one generally employed with fat lime. Too much water is added, almost always — that is to say, as much as is required to make it a thin cream. In this state it is run into vats; after some time it thickens, and it is then covered with a layer of sand or earth to preserve it from contact of the air, which would soon convert the upper portion into a carbonate.

It is a common opinion that the longer the lime has been kept in this state, the better it is. My experiments will show that **this is not true**, at least not always true: since **some fat lime that I had experimented with, which had been lying in this condition, gave, in the air, when the mortar was composed of lime and sand only, very bad results.** The thickening of the lime in the vats is due to the escape of water by filtration, by evaporation, and also to a third cause: for this thickening which is quite prompt, occurs equally when the vats are constructed in moist ground, and when the season is rainy. This third cause appears to me to be this: that the lime, having a strong affinity for water, solidifies the first portions very promptly, but requires a considerable time to saturate itself completely. These portions of the lime which have been too much or too little burned are, besides, slow to slake, I made the following experiment to satisfy myself on this point.

I took a portion of lime that had been lying wet in a vat for four years, it was quite thick, I added a little water to bring it to the consistence of syrup, and placed it in a stoneware vessel. I took an equal portion of fat lime, slaked fresh from the kiln, reducing this also to the consistence of syrup, and placing it in a similar vessel. After a short time, this last had become very thick, while the former retained its consistence of syrup; 1 then added water to restore the consistence first given. The thickening again occurred, but more slowly than at first.

The second method of slaking consists in plunging quick-lime into water for a few seconds. It is withdrawn before the commencement of ebullition; slakes with the water it has absorbed, **and falls to powder**. It is preserved in a **dry place.** The operation is performed with baskets into which the lime, broken to the size of an egg, is put.

Mr. de Lafaye, in 1777, proposed this mode of slaking lime, as a secret recovered from the Romans; it made much noise at the time, but experience has not realized the great results anticipated.

The third process consists in leaving the quick-lime exposed to the air. Its strong affinity for water causes it to attract the greater part of that which is in the surrounding air. Lime, thus exposed, slakes slowly without giving out much heat, and falls at last to powder. This mode of slaking is called air-slaking, or spontaneous slaking. It is employed, more or less, in several countries. It is spoken of in several works on constructions, and is generally condemned. Mr. Vicat, however, appears to give it the preference, for, at page 20 of his memoir, he says: "Such are the three modes of slaking lime: the first is generally used; the second has hardly been tried, except as an experiment at certain works; the third is proscribed, and represented, in all the treatises on construction, as depriving the lime of all energy, to such a degree that those portions which have fallen to powder in the air, are considered as lost.

We shall not now speak of the processes of Rondelet, Fleuret, and others, because they do not differ much from those described. We shall see, further on, that, as regards spontaneous slaking, these proscriptions of authors who, believing everything, repeat without examination the errors of those who preceded them, are founded on false observations and are deserving only of mistrust. **Mr. Vicat has announced that a mortar made of sand, and fat lime which was air-slaked, resisted perfectly at the end of ten years, the test indicated by Mr. Berard for frost-proof stones;** he says on this subject "a hint, this, to those who have written and spoken so much against air-slaking, and in opposition to the opinion which I have had to maintain singly, unable to invoke to my aid any experiments but my own."

The results I have obtained are far from water it absorbs, in a certain number of seconds, a quantity sufficient to reduce it well to powder. **We shall have then a like result by throwing the same quantity of water on the lime, and avoid the inconveniences attending the plunging into water.**

Since 1817, this process has been employed at Strasburg, where considerable masses of lime were operated on. A small building was erected near the works, into which the hydraulic lime, not allowed to arrive too fast from the kiln, was put, to be protected from the weather; the building was boarded on the sides and top, and, in case of rain, covered with a tarpaulin. By the side of this lime-house, a larger shed was constructed, the top only being boarded; a plank floor, on which the mortar was mixed, was laid under this shed. There was a measure, without a bottom, which contained about 10 cubic feet, each dimension of the box being about 2.20 feet, this was placed on the floor and filled with lime; which being done, the same measure was used **for the sand, which was placed around the lime, without covering it:** with large tin watering pots of known capacity, water, **equal in bulk to about one-quarter the bulk of the lime, was thrown on:** the workmen knew they were to empty the watering pots but a given number of times; and the lime being all in sight they saw that they should throw the greater quantities on those parts of the heap where lay the largest lumps of lime. **As soon as the slaking became energetic, the lime was left to itself until the vapours had ceased; it was then turned a little with a shovel, or a rod was thrust in, and if any lumps were found still entire, either for the want of water, or because they were too much burned, a little water was poured on these lumps. A regular form was then given to the heap, and the surface being slightly pressed with the back of the shovel, the lime was covered with the sand that had been placed around it. This process was completed towards evening — as many heaps being prepared as it was presumed would be required during the whole of the ensuing day. By thus leaving the lime, over night, in heaps, the slaking is complete; portions which have too much water impart it to those which have too little, and the water becomes thus uniformly diffused through the heap.**

In the morning the sand and lime of each heap were mixed together, and passed twice under the rab (rabot) before adding any water: in this way, if there were any stones, or pieces of lime imperfectly slaked, they were easily found and rejected. Water was then added in sufficient quantity to bring the whole to the state of very soft paste; because in this dilute state the mortar is, with less labour, mixed more perfectly.

Experiments which follow will show that it is an error to insist that mortar should be mixed with 'the sweat of the labourers' brows:' it is enough if the sand be well mixed with the lime; and this mixture is better effected, and in a much more economical manner, when the mortar is in a state rather thin, than when it is thick; another reason for making it rather thin is, that it often becomes stiffer than it ought to be, before it is used, in consequence of the lime preserving, as before stated, for a considerable time, the **property of solidifying water.**

When the lime has been properly burned, the operation just described gives a homogeneous mortar not at all granular, and not exhibiting a multitude of little white specks, which are particles of lime that have been badly slaked.

At Strasburg the precaution was always taken of **making up only one or two heaps of mortar at a time; so that it should not have too much time to dry before being used, and that the masons might find it in the state of paste, in the heaps in which it was deposited after being well worked**. In making the mortar only as it is needed, there is, besides, the advantage of avoiding the labour of remixing, in the frequent case of the being prepared as it was presumed would be required during the whole of the ensuing day by thus leaving the lime, over night, in heaps, in which it was deposited after being well worked.

In making the mortar only as it is needed, there is, besides, the advantage of avoiding the labour of remixing….

A circular trench, having the two sides sloping, is built of masonry; the section of the trench is a trapezoid 2 feet wide at bottom, 3 feet 4 inches wide at top, and 1 foot 4 inches deep; the inner circle of the trench is 9 feet 4 inches in diameter; at the centre there is a mass of masonry, in which is fixed a vertical axis, of wood, 6 feet 8 inches long, and 8 inches square, and which is bedded in the masonry about 5 feet; the top of this axis is formed into a cylinder 5 inches in diameter, and 6 inches high; around which is fitted a collar of cast-iron, carrying laterally two horizontal trunions 3 ½ inches in diameter, and 480 inches long; a piece of wood, 26 feet 8 inches long, is notched at its middle upon the collar of the vertical axis. (Instead of one piece of wood, two might be taken, each 13 feet 4 inches long, by strongly securing, with iron, their junction with the vertical axis.) This piece is placed horizontally, and is about 13 inches square in the middle, lessening towards the ends, so as to serve as an axletree to two vertical wheels with broad felloes — 6 feet diameter of wheel, and 6 inches breadth of felloe. These two wheels rest in the circular trench in such a way that the one touches the exterior and the other the interior slope of the trench. A horse is attached to each extremity of the horizontal bar, and their united efforts cause the wheels to revolve in the trench; behind each wheel, attached to the horizontal bar, by means of a hinge, is a scraper of wood armed with iron, these follow the movement of the wheels, scraping the two sides of the trench so as to throw the mortar under the wheels. These scrapers of which the lower end is within two inches of the bottom of the trench, are attached by hinges in order that they may rise over any obstacle. Mortar is made in this machine in the following manner. **A cubic metre (35.34 cubic feet) of lime in the state of paste is thrown into the trench, and the horses are started; a little water is added if necessary, and when the paste has become quite liquid and homogenous, the proper quantity of sand is thrown in by the shovel, without arresting the movement; in about 20 or 25 minutes the mortar is made.** With this machine **12 batches of 3 cubic metres each (12 x 3 x 35.34 equals 1272:24 cubic feet) may be made in 10 hours labour**; the requisite agents being 4 labourers, 2 horses and their driver, and 1 superintending mason. The expense of making a cubic metre or mortar, amounts in Paris to about 80.10; this is a considerable saving over the common mode of making mortar. It is desirable therefore that frequent use be made of this machine, in places where there are important constructions. The description just given is extracted from the devis-modele of the corps of Engineers, and was prepared by Lt. Col. Bergere of the Engineers. It is stated above that at Strasburg, lime which was to be made into mortar, was slaked to dry powder, and left in that state for twelve hours at least before giving it the quantity of water necessary to convert it into paste. I made the following experiments with limes in the environs of Strasburg, to ascertain the volume obtained in powder and in paste, when the proper quantities of water are used to produce those slates.

. TABLE I. Designation of the lime of which the volume is taken as unity. Lime of white marble Fat lime of Strasburg Yellow lime of Obernai Blue do. do. Brunstat lime Ville lime Altkirch lime Verdt lime Metz lime Boulogne pebbles Volume of water| used to bring it] first, to a state off dry powder. 1 I ! f Volume produced of dry powder. Volume of water| used, in all, to. bring to state of] paste. 21 si 4 2-1 1 » 1 6 J T 0 2 3 l| 1 Volume produced in state of n n 3

All the limes in the above table, were used fresh from the kiln. I reduced them to powder in a mortar, sifted them, and used, for quantity, about one quart. Thus, for example, I took a measure of quick lime of white marble, and throwing upon it half a measure of water, I obtained 2 ½ measures of lime slaked to powder, which I measured after it was cold.

The quality of the mortar is superior to that made by the common process; and it is well to remark, that the time during which the mortar is made is precisely that in which the labourers repose: it is therefore their interest lo let the machine go as long as possible, and consequently to render the mortar more perfect, so that the supervision will be directed chiefly to the proportions of the mixture. This note is extracted from the devis-modele du corps du Genie, p. 71. — Tr.

Quantity of lime obtained in powder is given in the third column. I was obliged to throw upon this lime in powder, one measure and one-tenth of water in addition to reduce it to paste. Adding this last quantity of water to the half measure used in the first instance, the total is 1 A measures of water, absorbed by the lime, in being reduced to paste: this is shown in the fourth column. The fifth column shows that I obtained 1|- measure of lime in paste. I followed the same process for all the limes of the above table, producing a uniform consistence of paste, by adding the water little by little. Experience had taught me that these limes were reduced to dry powder by throwing on one-fifth of their bulk of water; and that as much as one-half their bulk might be thrown on without the powders ceasing to be dry: beyond this term, a moist powder would be obtained. The only lime on which I threw less than half its bulk, was that at the bottom of the table, of the Boulogne pebbles; on this I poured but its bulk of water; as this lime forms a moist powder with its bulk of water, I was obliged to restrict myself to one-third. This table shows that these different limes afforded very different volumes of powder with the same quantity of water: that the quantities of water absorbed to produce the state of paste were very different, and, also, that the volumes of paste differed much. Experiments which follow will show that, of the limes in the table, **those are the most hydraulic which absorbed the least water in passing to the state of paste, and which gave the smallest bulk both of powder and of paste.** Those limes, of the table, which are not hydraulic, are those which gave the greatest volumes in powder and in paste. There are in the table two kinds of Obernai lime, one yellow and the other blue; they are of the same limestone, but one more highly calcined than the other. When this lime has been burned just enough, it is of a yellow-fawn colour; when a little more burned, it is of an ashy-gray, and when too much calcined, of a decided blue. It was upon the two extremes of calcination that I made the above experiments, they show that the degree of calcination has a sensible influence on the swelling of this hydraulic lime. As the swelling of lime, shown in the above table, was obtained with quite small quantities, and with pulverized quicklime, I caused experiments to be made at the mortar beds on a large scale, with fat lime and with Obernai lime; these being the two kinds of lime ordinarily used upon the works. The following results were obtained. Fat lime was taken immediately from the kiln, and measured in the boxes in use at the mortar beds; care being taken to break up a portion of the lumps of quick lime into smaller pieces, in order to occupy the interstices between the larger pieces, and to have the measure well filled: water, in quantity sufficient to bring the lime at once to paste of the consistence of mortar, was thrown on without delay, and the quantity of paste thus obtained was measured. Proceeding thus — one measure of quicklime, just from the kiln, required two measures of water to produce the state of paste, and yielded 1.83 of paste, which differs but little from Table No. 1, wherein the produce is 1.75. The same operation was repeated with Obernai lime, after having rejected vitrified pieces, and those which had not been sufficiently calcined: one measure of this lime absorbed 1.30 of water in being reduced to paste, and in this state gave 1.30 of lime.

This differs somewhat from the result in the Table. The difference may be owing to this, that in the experiments of the Table, the lime was pulverized, and was twice slaked; that is to say had two successive applications of water, while in the larger experiment the lime was not broken up, and had water poured on but once. The degree of calcination might, also, have had some influence. Many metallic oxides are susceptible of absorbing and solidifying a certain quantity of water forming compounds which possess peculiar properties. It is to these compounds that the term hydrate has been assigned. It has been seen, above, that lime is a metallic oxide, and that this substance absorbs and solidifies a large quantity of water; but the quantity of water absorbed by lime in forming its hydrate is not exactly known. Berzelius asserts that the hydrates are formed of water and oxides in such proportions that the quantity of oxygen contained in the oxide is equal to the quantity of oxygen contained in the water; but Mr. Thenard does not admit this law: he says that the experiments on which it is founded are not numerous enough, nor sufficiently precise, to allow its definitive admission. It is certain nevertheless, says this celebrated chemist, that amongst the hydrates which have as yet been examined, those which contain the most water, are those, also, of which the oxides contain the most oxygen. According to Berzelius, the hydrate of lime is obtained by throwing upon quick lime the water necessary to reduce it to thin paste (bouille,) and exposing this paste in a silver or platina crucible to the heat of a spirit-of-wine lamp. After having dried the hydrate of lime in this manner, it is weighed, and the quantity of water it has absorbed is known by the augmentation of weight. Berzelius made two experiments, one with 10 grammes of lime and the other with 30 grammes. He found in the first experiment, that the lime had increased in weight 32. 1 per cent., and in the second, 32.5: in this second experiment there was, therefore, an augmentation of four-tenths more than in the first. He attributes this difference to an absorption of carbonic acid, and he admits, as good, only the first experiment, in which 100 parts of pure lime containing 28.16 parts of oxygen, are combined with 32.1 parts of water containing 28.3 parts of oxygen; whence Berzelius concludes that the water absorbed by pure lime contains a quantity of oxygen equal to that contained in the lime. I have repeated the experiment of Berzelius by operating on 20 grammes of pure lime, using, as he did, a spirit-of-wine lamp, and a platina crucible. I was surprised at obtaining an augmentation of only 22.5 per cent. I repeated the experiment several times, successively diminishing the thickness of the wick, and as I did this, the lime retained more and more water. I inferred, therefore, that the hydrate of lime decomposes with a feeble heat; and that, if Berzelius obtained a greater result in the second experiment than in the first, it was not all due to the absorption of carbonic acid, seeing that the operation lasts only a short time; but to this, that heating with an equal flame, two volumes of hydrate of lime, of which one was triple the other, the smaller volume should lose most water by the heat. But there is a fact which proves with how great facility the hydrate of lime abandons a part of its water. **All those who have made mortar of lime newly slaked, have perceived that it becomes very dry in a short time. If, when in this state, it be worked for some time without adding water, it will be brought back nearly to the same moist state it had at first ; and drops of water may be seen on the mortar.** The same result is obtained with lime alone. It follows from this, that simple friction (working) decomposes the hydrate of lime, and that a feeble heat produces the same effect. To know, therefore, the quantity of water which enters into the hydrate of lime, it appears to me that other means of drying should be resorted to than fire. The various kinds of lime are used in constructions, only after having been brought to the condition of hydrate: nothing, therefore, that relates to the properties of this compound, is a matter of indifference. As yet, few experiments have been made to determine the quantity of water that should be given to lime in making mortar. I proposed undertaking several experiments on this point, but time failed me. The matter should be attended to, because, opinions are much divided thereon, for want of exact experiments. The following are the principal properties of hydrate of lime: it is white, pulverulent, and much less caustic than quick lime; it easily abandons to heat the first portion of water, but it requires a high temperature to drive off all the water entering into its composition. This hydrate absorbs carbonic acid; experiments which follow show that it has, also, the property of absorbing oxygen, and that lime sustains important modifications in consequence of this absorption of oxygen. According to the chemists, lime is incapable of absorbing a fresh quantity of oxygen: but according to my observations, there is no doubt that the hydrate of lime absorbs a considerable quantity. I shall give, in the following chapter, experiments which I made on this subject.

Chapter Three

I was employed from 1816 to 1825 at Strasburg, at which place they had made no use of hydraulic lime. I ascertained, however, that such lime was to be found in the neighbourhood. Almost all the hydraulic works connected with the fortifications of the place, having been badly constructed, and dating as far back as Vauban's time, were to be rebuilt. **Twenty-five years' experience had taught me the great superiority of hydraulic mortars in the air as well as in the water — where, indeed, they are indispensable**. I tried, therefore, the hydraulic limes, afforded by the environs of Strasburg, and found them excellent: they were, consequently, used in all the works both in air and water. All the revetments built from port de Pierre to port Royal, having a development of about 1650 yards, were rebuilt or repaired with hydraulic mortar. It was the same with the hydraulic works; they were rebuilt or repaired with the hydraulic lime of the neighbourhood.

An engineer who should use fat lime, even for constructions in the air, when there are hydraulic limes at hand, would be very censurable, because the expense is about the same, and, as regards the strength and durability of masonry, there is a vast difference in favour of the hydraulic mortar. But in countries where no hydraulic lime is to be had, or only that of mediocre quality, what should be done? Shall the engineer adopt the process of Mr. Vicat, which consists in making an artificial hydraulic lime? I answer, emphatically, that I think not; in this case, occurring very often, it is, in my opinion, preferable to make hydraulic mortar by a more direct process which I shall point out.

There are two modes of obtaining hydraulic mortar; the first consists in mixing natural, or artificial, hydraulic lime with sand; the second consists in mixing ordinary fat lime with certain substances such as puzzalona, trass, certain coal-ashes, and brick dust, or tile dust.

...p14 ... At other stations, I had several times made hydraulic mortars of fat lime and brick, or tile, dust. At the great works of Vesel, where I was employed three years, considerable use was made of trass, which was brought from Andernach by the Rhine; and on the experience I had acquired of hydraulic limes, I introduced the use of the Obernai lime in all the constructions of the works of Strasburg, both in and out of water….

P 16 …Before giving my first experiments, I will explain the processes I followed, both in making mortars, and in breaking them in order to determine their tenacity. In my first experiments, I fixed the proportions of my mortars, **by slaking the lime to dry powder with one-fifth of its volume of water, and measuring this lime in powder. Afterwards I measured the lime in paste, in order to approach the mode ordinarily pursued in practice with fat lime**. I shall take care to state in every instance, which of these modes of measurement I followed. When I had united the lime to its proper proportion of sand, or other substance, I mixed them well together, adding water, till the consistence was like honey; and I passed the mortar seven or eight times under the trowel. The mortar being made, I put it in wooden boxes which were six inches long by three inches wide, and three inches deep, leaving them in the air for twelve hours, so that the mortars might be some what stiffened. They were then placed in a cellar, within a large tub filled with water. I examined the mortars from time to time, and noted the number of days required to harden. I called the mortars hard, when, on pressing them strongly with the thumb, no impression was made on the surface. All the mortars were left in the water one year; at the end of which time they were withdrawn, and I scraped off the four sides or faces with the chisel of a stone cutter until nearly half an inch was removed, when they were rubbed upon a stone until they were reduced to parallelopepids of 6 inches long by 2 inches square. By means .of a wooden form which they were made to fit, all were reduced, very exactly, to the same dimensions, and had the four faces well squared. It will be observed that I took off from each side about half an inch, with the view of submitting to rupture only the portion which had not been in contact with water. I ought to notice that in doing this it was often found that the mortars were harder at the surface than in the interior: sometimes the contrary happened. By taking off a portion from each face, I rejected all that, from any cause, had received a different degree of hardness from the interior.

Chapter 4 Artificial hydraulic limes

I stated in the first chapter, that, for a long time, the property possessed by certain limes of hardening in water, was attributed to the presence of oxides of manganese and of iron; several very hydraulic limestones were, however, at last found that contained no oxide of manganese and very little iron. It was observed, at a later period, that almost all hydraulic limestone contained from one to three-tenths of clay. This led to the opinion that when a certain proportion of clay is disseminated in limestone, it combines, by calcination, with the lime, and imparts to it the property of hardening in water. I stated that Mr. Vicat, Engineer of roads and bridges, published, in 1818, an interesting memoir on hydraulic mortars, and that he announced that **by reburning fat lime with a certain quality of clay, he obtained very good hydraulic lime**. I was bound to state, also, that Dr. John, of Berlin, presented to the Society of Sciences of Holland, a memoir on the subject which was crowned in 1818, and published the following year. He gave the analysis of many common, and hydraulic limes, as well as of many ancient mortars, and he showed that the hydraulic property of lime is due to a portion of clay which combines with it by calcination, and he calls this clay the cement of the lime.
The Minister of War sent the memoir of Mr. Vicat to those places where public works were in progress, and directed the experiments announced by this Engineer, to be repeated.

… In the erection of the sluices at Strasburg, we composed the mortar of the Obernai hydraulic lime, sand and trass; but this last substance being dear, I had begun making some essays towards replacing it with cement, when the memoir of Mr. Vicat was sent to me. I caused the experiments given in that work to be repeated, in the first place by an officer of Engineers, who used a clay of which bricks are made in the environs of Strasburg: he obtained no satisfactory result. A second officer was directed to recommence the experiments, and he was not more successful than the first. I repeated them, then, myself, and I took great pains in making the mixture of clay and lime; they were then calcined and I obtained a result, but it was a very feeble one. I then began anew, using other argillaceous earths, richer in clay, (plus grasses) and I got much better results.

(table shows experiments with numerous clays. One hardened under water after 5 days; some after ten; most between 10 and 35 days).

A part of my preceding experiments having been printed in 1824 in a small pamphlet which was sent to the public works, and was inserted in the seventh number of the Memorial de l'Officier du Genie, Mr. Vicat published, in the Bulletin des Sciences, in 1825, and in the Annates des Mines, Vol. X, 3d livraison, page 501, some observations on the results that I had presented. I propose answering the observations of Mr. Vicat, as the more suitable occasions present themselves. This Engineer commences his remarks in the following manner: "In proscribing hydraulic limes, Mr. Treussart rests upon experiments which do- not appear to be conclusive: in the mixtures he made, sometimes he did not employ the clay in suitable proportions, sometimes he used a clay too aluminous, or charged with too great a quantity of oxide of iron, and sometimes he used quartz pounded very fine, as if the degree of fineness obtained by simple trituration could be compared to that of the silex contained in clay." *[Vicat seeking to defend his commercial advantage as a producer of his artificial hydraulic lime?]*

I do not know what induced Mr. Vicat to say that I proscribed hydraulic lime; the following are the expressions which conclude the pamphlet in question. "We see, by what precedes, that the principal idea of the author (Mr. Treussart) is, that **there would be much more advantage in making, directly, mortar with fat lime, and trass, or factitious puzzalona, than in seeking first to make hydraulic lime, and afterward to compose mortars of this lime and common sand."**

… It is now more than twenty-five years since I learned to appreciate the good effects of hydraulic limes, whether for constructions in the air or in water: I have employed them wherever I could procure them: during the nine years that I was at Strasburg, there were built, with hydraulic lime, in the works in water and in air, more than a million of masonry: I have, then, used this lime for a long time, and I think few Engineers have used more; it would be strange, therefore, in me to proscribe it. I was bound to show the precautions that should be taken in using it, so as not to risk making very bad mortar out of very good lime; I was bound to say what my experience had led me to think, namely, that, **in places where good natural hydraulic lime could not be found, it is preferable, as regards the quality of the mortar, and as regards economy, to make hydraulic**

mortar, directly, by using fat lime and factitious trass, in lieu of attempting to make artificial hydraulic lime with which to compose mortars by the addition of common sand: the sequel of my experiments will leave no doubt in this respect.

…. The above experiments of Mr. Vicat were made with hydrate of lime, that it to say, with limes reduced to paste with water. We see that ordinary slaking gave better results than spontaneous slaking; with both fat lime and hydraulic lime. In his table No. XVIII., which contains eight mortars made with diverse hydraulic limes, and sand; **the first five gave greater resistances when the lime was slaked in the ordinary way than when slaked spontaneously**. The mortars made of fat lime and sand, as exhibited in tables Nos. XIX., XX.. and XXL, gave, it is true, better results when these limes were slaked spontaneously: but with hydraulic limes he, himself, obtained results very different, since the mortar No. 5 of table No. XVIII. gave a resistance represented by 4102 when the lime had been slaked by the ordinary process, while it was only 3082, when the lime had slaked spontaneously. The experiments of Mr. Vicat are, therefore, far from causing us to reject the **old saying of masons as to the bad results obtained from air-slaked lime**; and we do not perceive how he could regard this saying as a condemnatory assertion growing out of false observations. This old saying appears to me to be well founded as to the greater number of hydraulic limes.

All that precedes proves that hydraulic limes, whether natural or artificial, lose much of their hydraulic property if not used soon after they are calcined.

CHAPTER V.

On Hydraulic Mortars made of fat lime and trass, or fat lime and puzzalona.

Trass is a substance obtained from the village of Brohl, near Andernach, on the Rhine; this village is situated at the foot of an extinct volcano. Trass is of a grayish colour, much resembling gray clay which has been calcined. I have seen several pieces of trass which were covered with lava. This last substance differs much from trass: the separation is distinct: the lava which covers the trass is of a blackish colour, and its surface is full of asperities and cavities, showing that it has sustained a very high heat, and very rapid cooling: trass seems to have been exposed to a much lower heat.

Puzzalona is likewise a burned clay — deriving its name from the village of Puzzoles, at the foot of Vesuvius; it is found at or near the surface. According to Mr. Sganzin, there are a great many varieties of puzzalona: it is found white, black, yellow, gray, brown, red, and violet.

The Dutch have a great trade in Trass. They get out this substance in masses, and reduce it to a very fine powder, by means of windmills. Much has been sent to France, to the North, and to England; but it seems that the commerce has diminished a little. Some authors call this substance the Terras of Holland.

On the shores of the Mediterranean, much puzzalona, furnished from the environs of Rome and Naples, is used.

… Before becoming acquainted with the excellent qualities of the Obernai hydraulic lime, I caused some of it to be brought to Strasburg, and the first hydraulic works that I constructed at Strasburg were made of mortar composed of fat lime, sand, and trass.

(All fat lime/sand/trass mortars tested by Treussart set under water in between 3 and 5 days).

In comparing the results of table XIII., with those of the preceding tables in which mortars were made of natural or artificial hydraulic lime and sand only, we see that these last hardened much more slowly, and gave much less resistance, than mortars made of fat lime, sand, and trass or puzzolana.

(Takes issue with Vicat having taken issue with him, once more. Challenges the comparability of testing methods of his and Vicat's, particularly resistance tests).

… This manner of slaking fat lime is that which Mr. Vicat prefers: he, in Annales de chimie, Vol. XIX. page 22, publishing as follows: "The assertion of Mr. John relative to lime exposed to the air is in contradiction to recent facts, so presented, and so multiplied, that I am constrained to combat it. It was I who first announced that **fat lime slaked spontaneously *[air-slaked]*, and abandoned for one year to the action of the air, under cover and protected from winds, gives better results, than when employed immediately, according to the common method.** This conclusion is founded on a hundred and fifty experiments, varied in several ways: it results, for example, that the force of ordinary mortar being, in the most favourable case of a series of experiments represented by 1506, that of mortar made of air- slaked lime gave, under the same circumstances 2293."

Mr. Vicat acknowledges that the ideas, commonly received, on this point of the doctrine of mortars, are all in favour of Mr. John, and he says, because of this sentiment, almost general, he presumes Mr. John did not examine the matter. I will remark, touching this point, that Lieut. Col. Bergere of the Engineers, notices, in the last *devis instructive*, and in the account he has given of the work of Mr. Raucour, that several Engineers have thought, in times long gone by, that air-slaking gave better results than the other two processes, and that this mode has been in use, from time immemorial, in Spain, and in a part of Italy. Mr. Bergere says that he used it at Flushing; and that this method is recommended in a letter written in 1764 by Mr. Sienne, an Engineer officer, resident at Graveline. I do not however counsel the process of air-slaking in making hydraulic mortar with fat lime and trass, or other analogous substance; because the mortars made in this way contain a great many white specks which appear to be lime passed to the state of carbonate. We may conceive, in fact, that when lime is left to slake spontaneously, every successive small portion of lime remains for some time exposed to the contact of the air, as the lime falls off in successive layers: there ought, therefore, to be a considerable absorption of carbonic acid: whereas lime slaked to powder with water and formed into heaps, has the surface only exposed to the air.

Besides the experiments of the above table, I have made others of the same kind, by **slaking fat lime into thick paste, and into thin paste** — comparing these results with each other, and with those I got from the same lime slaked to powder.

To make the experiments of the above table, I took fat lime as it came from the kiln, and divided it into three portions: one of these portions we slaked to a thick paste and left in a vessel; another portion was slaked to a thin paste, and, as it thickened, I added a little water so as to keep it in the consistence of sirup; the third portion wa9 slaked to a dry powder with one-fourth of its bulk of water, and put, like the others, in an open vessel. I, immediately, made the mortar in the first column, which may serve as a term of comparison. The others were made, at the periods expressed in the table, of lime slaked in the several modes mentioned. In proportioning the parts, I added, when I made the mortar, a little water to the lime which had been slaked to a thick paste and also to that which had been slaked to powder, so as to bring all to the condition of that slaked to thin paste.

In the first series of the table, **the mortar made immediately gave a result rather weaker than those made afterwards**: the hardening was more prompt in summer than in winter. I left the lime of the second series for six months in a state of clear paste before using it. We see that the results were not so good as those obtained from the thick paste. There are, certainly, several anomalies in the re sults, but, as before remarked, we must look at the whole. The third series was likewise commenced at the end of six months…. If we compare the results obtained in the preceding tables, we shall see that there is a great difference in the effects of mortars made of natural or artificial hydraulic lime and sand, and of these made of fat lime, sand and trass. When the first are made of lime which has for some time slaked to powder, or which has been air- slaked, they generally lose much of their force. There is not the same dis advantage with fat lime: whether the mortars are made as soon as the lime comes from the kiln, or after it has beeq slaked with a little water and left exposed for some time in the air, or after the lime has been air-slaked, good results are always obtained: but we have seen that the best are got by slaking the lime with a little water as soon as it is burned and leaving it exposed for some time to the air in a covered place. Experiments, to be given by and by, will show that I obtained good results, also, by making hydraulic mortars of sand, trass, and fat lime which had been lying wet in basins for four or five years.

We have also seen by comparison of the preceding table, **that mortars made of hydraulic lime, natural or artificial, without trass or puzzalona, did not harden, with sand, until from eight to fifteen days, although giving resistances; while those made of fat lime,**

sand and trass, hardened at the same season of the year, in the space of from four to six days, and, on the average, gave much greater resistances.

Chapter VI

Of Artificial Trass and Puzzalona.

….I made several essays, substituting brick and tile dust for trass. To this end I composed a number of mortars of fat lime and the dust of bricks or tiles taken from all the kilns of the neighbourhood. A part of the mortars were made of brick dust, and a part of tile dust. I obtained many results: — sometimes very good, sometimes indifferent, and sometimes very bad. What struck me much, at first, was, that mortars made of different dusts coming from the same burning gave very different results: notwithstanding that the dusts were of the same burning, were all made of the same clay, were used with the same lime, and that all other circumstances were the same. I saw from this, that great risk was run of making bad mortar, by taking brick or tile dusts without discrimination. I know that the great majority of constructors preferred highly burned dusts, and that, although made of the same clay, they much preferred dust of tiles to that of bricks. To settle my opinion on these two points, and to explain up contradictory results that I had obtained, I made the experiments reported in the follow ing table.

(all at 1:2)

	To harden Underwater	resistance
Fat Lime slaked to powder and measured in powder		
dust of bricks little burned	11 days	330lbs
dust of bricks well-burned	+40 days	180lbs
dust of tiles but little burned	5 days	275lbs
dust of tiles well-burned	+30 days	125lbs

(got somewhat different results with bricks and tiles from another yard)

These opposite results led me to examine the composition of the clays of these two brickyards; and I ascertained that the clay which gave the dust of table No. XVII contained very little carbonate of lime, while that which produced the dust of table No. XVI, contained almost a fifth of its weight of that substance. I repeated the experiment with the clays of several other tile kilns, arid I always obtained this remarkable result, namely, when the clays contained little or no carbonate of lime, gentle burning imparted only mediocre qualities, while strong burning gave them excellent qualities. **When, on the contrary, the clays contained from one to two tenths of carbonate of lime I procured good results only by heating lightly**, and, if I augmented the degree of calcination the quality was impaired; and if the heat had been very great, all hydraulic property was lost.

… It is certain…that the presence of lime in clays has a great influence on the quality of the puzzalona.

… Several Engineers have proclaimed the good results obtained with ashes derived from the combustion of coal in furnaces, or lime kilns; others on the contrary, have denied the effect of this substance.

… The good results of the Tournay ashes* have been known for a long time, and are contested by no one. Having been employed at Lille, in 1815 and 1816, I had an opportunity of knowing the good effects. But when I wished to use, in the same way, the coal ashes at Strasburg, I could not obtain a good result. I made mortars composed of one part of fat lime measured in paste, and two parts of coal ashes: after an immersion of a year, these mortars were as soft as if made of sand….

and on examining different coals and their analyses, I saw that several of them contained quite a quantity of clay, while others contained little or none. But coals are generally burned on a grate: the clay they contain is thus calcined in a current of air; and it is the mixture of this clay with a little iron, constituting the residue, that is used, when we take these ashes: we see, therefore, that it is a real puzzalona that they have been making, for a long time, without knowing it. Should the coal contain no clay, or should the clay be mixed with too much lime; in the first case no result will be got; and in the second, if the calcination has been too high, the ashes will possess but an indifferent quality.

… It is possible that in countries where chalk is abundant it will not cost more to make hydraulic mortar with artificial hydraulic lime and sand, than with fat lime, sand and factitious trass: but in many countries chalk is not to be procured; and then it will be necessary to mix fat lime with clay, and to give a second burning for the mixtures; which will cause embarrassment, and an augmentation of expense. I am convinced that, in such cases, there will generally be economy in making hydraulic mortar at once of fat lime, sand and artificial trass: and besides the relation of the resistance" of these two kinds of mortar, is no important consideration. If we compare the results obtained in all the preceding tables, we shall see that the mortars made of sand and hydraulic lime, whether natural or artificial, afford an aver age resistance hardly amounting to 220 lbs., while it is 352 lbs. for the mortars made of fat lime, sand and natural or artificial trass. To compare the expense justly, therefore, it would be necessary to lessen the preparation of trass, substituting sand, until we arrived at an equal resistance.

I must, besides, observe that **we are much more certain to obtain uniform results with hydraulic mortars, composed of fat lime, sand and factitious trass *[brick or tile dust; certain ashes]*, than with those that can be made of artificial, or natural hydraulic lime, and sand only.**

…. The question, however, is, to know what should be done in a country where there is no hydraulic lime, or where it is of an inferior quality. It is on this point that I differ entirely from Mr. Vicat. This engineer contends that it is best to make factitious hydraulic cement by the process he points out; **while I think there will, in general, be more economy, and better and more uniform results, by making hydraulic mortars at once from fat lime, sand, and artificial trass. It appears to me that the general bearing of the very numerous experiments I have presented, leaves no room to doubt as to this matter. I will add, that, from time immemorial, in countries affording natural hydraulic limes, they have been used with great advantage. Wherever they were not to be had, hydraulic mortars were made, directly, of fat lime and cement.** I have, several times, had occasion to demolish works in water, of which the mortars had been made in this manner. It appears then, that, in fact, I only propose to continue a method long in use, with this difference, that in lieu of using every kind of cement indiscriminately, I give the means of distinguishing the good from the bad, and of making such as will give results equal to those furnished by natural puzzalona or trass.

…. A fragment of each of these bricks (each of a different level of firing) should be separately reduced to a very fine powder, and passed through a very fine wire seive. The finer the dust, the better; in taking it between the fingers no grains should be felt, and it should be soft to the touch. Fat lime which has been reduced to paste for some time, should then be made into mortar with one of these cements — using one part of lime in paste, to two parts of cement. (and placed underwater to observe speed of set, setting having occurred when the sample will resist the hard pressure of the thumb).

… mortars of the hydraulic limes which harden very quickly, did not give great resistances; but those made of cements which have caused fat lime to harden promptly, have always given good mortars. We ought, therefore, to prefer those cements which cause fat lime to harden promptly.

… With brick dust, we may easily obtain mortars which, according to my mode of determining tenacity, will support from 220 lbs. to 330 lbs. before breaking, if composed of equal parts of lime, sand and brick dust. This force is sufficient for gross masonry: but, for important works, such as the floors of locks, foundations of dikes and dams, caps of arches, and for factitious stones, of which I shall speak in the sequel, it is necessary to have cements that will give mortars capable of supporting from 330 lbs. to 440 lbs.

CHAPTER VII.

Various Experiments on Mortars placed under water.

Much importance has been attached .to the manner of slaking lime. Mr. Lafaye published in 1777, a memoir in which he gives, as a secret recovered from the Romans, the mode of slaking lime by plunging it into water for a few seconds, and then withdrawing it to slake and fall to powder in the air. This powdered lime is preserved in a covered place.

Other Engineers have asserted that there is great advantage in stifling lime as it slakes; that is to say, covering it with sand before it begins to slake, in order to retain the vapours liberated during the process.

Mr. Fleuret attributes great efficacy to this vapour, for he says "**This vapour awakens and excites the appetite of the workmen**, whence I conclude that it contains principles proper to the regeneration of lime and consequently to the hardening of mortars."

To make the three experiments above, I took a piece of Obernai lime which I divided into three portions.

The first portion was slaked by throwing on one fifth of its volume of water, leaving the lime at rest in the air for **twelve hours** before making it into the mortar No. 1. The hardening was slow because the experiment was made in November. No. 2 was slaked in the same manner with this difference, that I covered the lime with the sand as soon as I had thrown on the water. This, also, was left to itself for twelve hours before making it into mortar. These two experiments gave, we see, **the same results.**

The third experiment differs from the first in this, that to slake the lime, I plunged it into water for fifty seconds — afterwards treating it in the same manner as No. 1. The result was less by 22 lbs. It is singular that I got the same results, as will be seen further on, by making similar mortars and leaving them in the air, instead of placing them under water. The result, it seems to me, is owing to the lime, immersed for fifty seconds, absorbing too much water, which is hurtful, as the experiments in the following table will show. I purposed repeating the trial, by varying the time during which the lime should be immersed, but I had not an opportunity *[shame]*.

… It often happens that a good deal of mortar is prepared and that bad weather for a day or two prevents the workmen from using it. If it be hydraulic mortar, it becomes hard in the interval of a day, and often of a night, and it would be impossible to use it in that state. By reworking it for a long time, it might be brought to the proper consistence without any addition of water, but this is expensive: it is better to bring it to proper consistence by reworking it for a short time with a little water. **Many Engineers think that mortar is improved by being worked several times a day: they consequently often make mortars several days before hand** — work it well at first, and permitting it to stiffen, bring it again to proper condition by reworking, because, say they, good mortars must be tempered with the sweat of the Labourer: but the sweat of the Labourer costs money, which it is important to save…..

All the mortars made at Strasburg, whether for works in water or air, were made of the consistence of common mortars, and very often, when, from any cause, they had somewhat stiffened, they were worked up anew with a little water, and we always had very good results.

…. Other philosophers, and several engineers, have thought that the solidification of mortars was owing to the lime passing again to the state of carbonate, by absorbing carbonic acid from the air. This opinion cannot, how ever, be sustained; for we know that carbonic acid penetrates only very slowly into the portion of hydrate of lime which is exposed to the air. Very large masses of mortar, plunged into water, will sometimes acquire complete hardness in three or four days, while other mortars containing the

The following, moreover, is a proof that the absorption of carbonic acid has no influence on the induration of mortars, at least in the beginning. I took hydraulic lime and reduced it to the state of hydrate with distilled water, making a rather thick paste, which I placed at the bottom of a phial; I then filled the phial with distilled water and corked it tightly; and when the lime was so much stiffened as not to run, I inverted the bottle, (still corked,) placing the mouth in a vessel full of water. I repeated the experiment with mortar made of hydraulic lime and sand, and with another mortar of fat lime and trass. These three substances hardened as quickly as if they had been put in water which was in contact with the air. Being deprived of all communication with the air, we cannot ascribe the hardening to carbonic acid. The surface of several old mortars exposed to the air has been observed to have passed to the state of carbonate; but only for a small depth, and it requires several centuries to produce even this change. The induration of mortars cannot, therefore, be attributed to the regeneration of carbonate of lime. *[wrong-headed, of course, but explaining the difference between air and hydraulic lime mortars without seeming to know it, quite].*

….. To account for the solidification of mortars in water, it seems to be necessary to divide them into two distinct classes; those composed of hydraulic lime and sand, and those composed of fat lime and puzzalona, or some analagous substance. As to mortars made of hydraulic lime and sand, it is not at all necessary to suppose that there is a chemical combination between those two substances, for we have seen by the first tables that the hydraulic limes, alone, when they are reduced to paste, harden promptly in water without it being necessary to mix any substance with them.

… To explain the hardening of mortars made of hydraulic lime, it is not necessary to suppose that it combines with the sand, since this lime hardens when alone in the water. It remains then to explain why hydraulic lime, itself, should harden in water. I will observe, on this point, that this particular lime is a combination of lime and a certain quantity of argil, by means of calcination; **it is a substance, therefore, altogether different from lime, and it has acquired new properties that the lime had not:** lime dissolves in water, while good hydraulic lime does not.

We know that when we mix, in certain proportions, soda, or potash, which are opaque, and soluble in water, with silex, which is also opaque, and heat the mixture, we obtain a new substance, which is transparent and in soluble in water, and which is called glass. It is not, therefore, astonish ing that lime mixed with a little clay and heated, should produce a new substance that will harden in water, while lime alone will remain soft. **Although we give to this compound the name of hydraulic lime, it ought, in fact, to be regarded as a substance altogether different from lime; it is a new body with new properties.**

As to hydraulic mortars made of fat lime and puzzalona, or other analagous substance, I do not see that the hardening in water can be explained without supposing a combination between the fat lime and the puzzalona; for this lime, put alone in water, or mixed with sand, remains always soft. To prove the truth of this explanation, I made the following experiment: I took a mortar composed of one part of lime made from white marble, and two parts of puzzalona, which mortar had been one year in water. From the centre of this mortar I took a piece which I reduced to very fine powder, putting the powder in a vessel which I then filled with distilled water. But we know that if fat lime be put in water, the water will dissolve of its weight in a few minutes. Nevertheless, after twenty-four hours, the distilled water had no portion of the lime. I satisfied myself, on the other hand, that the lime of the mortar had not passed to the state of carbonate: because, on throwing muriatic acid on the powdered mortar, there was very little effervescence. The lime had not therefore passed to the state of carbonate, and still it would not dissolve in water, which could only proceed from its state of combination with the puzzalona.

The hardening of hydraulic mortars in water may be explained, then, in the following manner: if the mortar be made of hydraulic lime and sand, this last substance appears to be in a passive state; the induration of mortar takes place because hydraulic lime hardens of itself in water — this being a property resulting from the state of combination of a small quantity of clay with the lime. If the proportion of lime be too much forced, a good hydraulic lime will no longer be obtained. A similar effect occurs in making glass: if the quantity of soda or potash be too much forced, the re sult is nearly a deliquescent compound. When hydraulic lime is made of fat lime and puzzalona, the hardening takes place because there is brought about a combination of fat lime and puzzalona in the moist way. In this case — that the combination may work well, it is requisite that the puzzalona be in greater proportion than the lime.

CHAPTER VIII. *Of Sand, and Hydraulic Sand (Arenes.)*

"There exists" says Mr. Girard," in the valley of the river Isle, fossil sands of which the colour varies from reddish brown to yellowish red and even ochre yellow. They are called arenes,* which denomination we shall preserve in this notice, to distinguish them from common sands. **These sands are often used alone, as mortar, in walls of enclosures and of houses; and as they have the property**

of making a paste with water, and as they shrink less than clay, they are very proper for this kind of construction: they represent in this case a pise, which acquires hardness and resists inclemencies. But the proprietors of the mills on the river Isle, in the department Gironde, discovered by accident a quality in the arenes much more important and worthy of serious attention; they use it with common lime more or less fat, to form mortars which set under water and acquire, great hardness."

Mr. Girard says that for want of hydraulic lime, he made several Locks with mortar composed of common lime and arenes. He states that he obtained very good results; and that the following year it was necessary to use the pick to break up the concrete that had been made with these arenes. The examination of the arenes showed Mr. Girard that they were all composed of sand and clay in various proportions. By means of washing and decantation he separated the clay from the sand, and in eight kinds of arenes he found the proportions of clay varied from **ten to seventy per cent.** He ascertained **that those arenes which were meagre, were hydraulic only in a very feeble degree.** The sand of the arenes is sometimes coarse and some times fine: it is occasionally calcareous, but more frequently siliceous or mixed. Some of the arenes are red, others brown, yellow and sometimes white.

Mr. Avril anil Mr. Payen discovered, about the same time, in Bretagne,the properties of puzzalona, in gray wacke, and in **decomposed granite**, though to a degree quite **feeble**. They remarked, besides, that natural puzzalonas acquire a new degree of energy by a slight calcination.

Captain Leblanc of the Engineers, employed at Peronne (noted during demolitions of old military fortifications that the old mortars were very hard)… On examining the mortars which were hard, it was perceived that the sand therein was very fine, and that these mortars, from their aspect, seemed to have been made of the sand of the country, **rejected in the official instructions, because too earthy. (This sand is used in all the constructions of the town.)** Another consideration led to the belief that the sand of the country had been used: for all this masonry appeared to be very carelessly put together; the mortar, badly made, showed every where, lumps as large as a hazle nut, of lime not mixed with sand and still soft;

although all the surrounding mortar was very hard. It was to be presumed that when applying so little care to all parts of the workman ship, the constructors had taken, no greater, as to the choice of sand: and that they used that which was nearest at hand — namely the sand of the country.

The author states that on recommencing labours in 1827, he made six cubes of mortar, of which three were composed of sand recommended in official instructions, and the other three of the clayey sand whereof the good masonry appeared to have been made. One cube of each kind of mortar was left in the air, one put in a humid place, and one in water. It was in this interval, as Capt. LeBlanc states, that the notice of Mr. Girard appeared. What was said in that notice showed that the clayey sand of the neighbourhood of Peronne was a true arene.

The mortar made of common lime and this arene had completely hardened in the water at the expiration of a month; so as to receive no impression when borne upon strongly by the thumb. A mortar made at the same time of the same lime and of the sand recommended officially, and usually employed, remained entirely soft at the end of several months.

By heating the arenes, Capt. LeBlanc ascertained that the hardening took place much more promptly, for the mortars made of the crude arenes required a month to harden, whereas those made of arenes that had been heated, hardened in eight or ten days.

… At Paris they build the walls of houses with plaster, and cellar walls with mortar. I have had occasion to observe latterly, that several of these mortars were made of clayey sand which appeared to me to be a species of arene: it contained a little lime, and some of it is yellow, and some greenish, like that from Ham. I learned that this sand was brought from the neighborhood of the ancient garden of Tivoli, and that it appears to have been employed at Paris for a long time to improve mortars. I made two mortars of these two clayey sands, adopting the same proportions as with the sands from Saint Cyr, and placed them in water. The results were similar to those given by the clayey sands from Saint Cyr. From what has been said, we see that these clayey sands are arenes of little energy: they do not appear to me to be proper for mortars that are to be placed in water; but the hydraulic property they possess, feeble as it is, will give, for works in the air, much better mortar than ordinary sand

…If we mix clay with fat lime, the resulting mortar will take no consistence when put under water. **It is necessary that clays be more or less calcined to become hydraulic**. Mr. Girard seems to think that the arenes have been submitted to the action of fire, and that perhaps they have a volcanic origin; but this second assertion does not seem to be a necessary consequence of the first; all that we may affirm is, that the arenes are clays which have sustained the action of fire. On the other hand, the small rounded stones and pebbles found in some of these deposits, prove that they are, also, alluvial. It is not easy to meet important facts without seeking to account for them, although at the risk of deceiving ourselves.

…The experiments that I shall give in the second section, on mortars made of fat lime and sand, and exposed to the air, will show how important it is to search after good arenes in the environs of our public works; because it is a means of procuring good mortars at a very cheap rate, and because it is the only means of procuring them cheaply, in countries where there are no hydraulic limes.

CHAPTER X. Summary of the First Section. From the facts presented in the foregoing articles, may be deduced the following conclusions.

There are two modes of making hydraulic mortar; first, by making it of lime that is naturally or artificially hydraulic, and of sand; and secondly, by making a mixture of common lime and puzzolana, or of some analagous substance.

In countries where there are good natural hydraulic limes, it is very advantageous to employ them; and in such cases no use should be made of fat lime. In gross masonry, they may be used with sand alone; but when it is required to construct the foundations of sluices, roofs of arches, and other similar works, it is advantageous to add to the mortar, a little hydraulic cement.

In a country where there is no hydraulic lime, in lieu of making it by calcining lime with a little clay, it is more advantageous, and more economical, to make hydraulic mortar by mixing, directly, fat lime with hydraulic cement and sand. The advantage is the greater in countries where there is no chalk, and where it would be necessary to submit the limestone designed to be made hydraulic, to two successive burnings— burning it the second time with a small quantity of clay*

Fat lime becomes hydraulic by being burned to the proper degree with a little crude clay; this result is not obtained if the clay has been previously calcined. Fat lime also gives a good hydraulic mortar, when it is united in the moist way with a mixture of equal parts of puzzolana and sand, and when the proportion of these substances is at least double that of the lime.

Silex, when it is very finely divided and disseminated in lime stone, produces good hydraulic lime, as is proved by the Senonches lime: when fat lime and finely divided silex are burned together, a hydraulic result, though feeble, is obtained. Iron and the oxide of manganese communicate to lime no hydraulic property: iron in the state of brown or red oxide, prevents the lime from heating much in process of slaking. It does not appear that alumina or magnesia, cause lime to become hydraulic; but when these substances are mixed with silex, good results are obtained.

The best process for converting fat lime into hydraulic lime, is to burn it with a small quantity of crude clay; the proportion of 1/5th of clay, seems the most suitable; and it appears that the best clay is that which contains as much silex as alumine. The quality of hydraulic lime is improved by mixing with the clay that is to be burned with the lime, a small quantity of water containing soda; a better result is obtained with potash; but this means would be too embarrassing, and would occasion an excess of expense which might not be in proportion to the advantage, were the operations on a large scale.

Hydraulic lime bears less sand than is commonly thought; there are few of these limes which can be mixed with more than 2 ½ parts of sand, without sensibly diminishing the resistance of the mortars. Fat lime may take a greater quantity of mixed sand and puzzolana to form hydraulic mortar. Puzzolanas, or hydraulic cements, which are energetic, apply equally to hydraulic lime and fat lime. **In mixing hydraulic lime, or fat lime, with sand and puzzolana, or other analagous substance, in equal parts, a better result is often obtained than by mixing these limes with puzzolana alone.** When very hydraulic lime is used, the addition of sand permits a sensible diminution of the quantity of puzzolana, natural or artificial, required to obtain a prompt induration and great resistance. With fat lime there always results a very good mortar, on mixing it, in equal parts, with sand and natural or artificial puzzolana; and if it sometimes happens that a mortar a little superior is obtained with lime and this last substance, without the sand, the advantage is not so great as to compensate for the greater economy of using sand also.

Hydraulic limes are difficult to burn to the proper degree. When they are not sufficiently burned, they slake badly; and the resulting mortar has not all the tenacity it ought to have.

A degree of heat a little greater than it should be, causes, with these limes, a beginning of vitrification; they then slake slowly; the mortar they form loses its force, it swells after having been used, and may occasion considerable injury to the works. Hydraulic limes should be used soon after leaving the kiln; they should not be slaked with much water, like fat limes, nor be left in a state of cream, like them, because, in a very short time they would become very hard, and it would be impossible to make use of them. **Whether slaked with a small quantity of water to reduce them to dry powder, or left to slake in the air, they, in general, very soon lose a part of their hydraulic properties, and finally pass to the state of common limes.** It is likely that this effect is due to the absorption of oxygen by the hydrate. Notwithstanding the precautions that hydraulic limes demand, it is important to employ them whenever natural limes of this sort, of good quality, can be obtained, because they supply a very good mortar at a cheap rate.

We should carefully study the exact point of burning, and should satisfy ourselves, as to whether or not they soon lose their hydraulic property, on exposure to the air, when slaked to dry powder, or when air slaked; without these precautions, we may expose important works to failure, by making very bad mortar out of very good lime. **Common lime has not, like hydraulic lime, the inconvenience of losing a part of its qualities by a degree of heat a little greater than that which is most suitable.** A very violent fire is required to produce this result. **Whether slaked with much water so as to be made into a fluid paste and run into vats, or with a little,**

only, so as to be reduced to dry powder; or if spontaneously slaked in the air; or <u>if used immediately as it comes from the kiln</u>, a good hydraulic mortar is always obtained by mixing fat lime, in equal parts, with sand and natural or artificial puzzolana. By air slaking the result is the least good.

It appears that by slaking in the air, the lime absorbs a considerable quantity of carbonic acid; and the mortar which results is filled with white points, which are particles of carbonate of lime, that cannot be made to disappear, whatever pains may be taken in the mixing process.

…The best mode of slaking hydraulic lime is to sprinkle it, as it comes from the kiln, with about one fourth of its bulk of water.

The best mode of slaking hydraulic lime is to sprinkle it, as it comes from the kiln, with about **one fourth of its bulk** of water. A measure containing about one third of a cubic metre (a cube of about three feet three inches on each side) permits the mixture of the materials that are to compose the mortar, to be easily made. **Before sprinkling the lime, it is to be surrounded with the (aggregates) that are to be mixed with it, and when it is slaked and gives out no more vapours, it is to be covered with these. The lime is left in this state for twelve hours at least, and for eight or ten days at most. The quantity of water necessary to bring the mortar to the ordinary consistence is afterward added.** Care must be taken to make the mortar no faster than it is needed. The heap of lime surrounded by the sand and other materials should be covered from the rain.

With common lime the process will be a little difficult; being slaked as it comes from the kiln, with **one-third of its volume of water**, the lime, in a state of powder, should be put under cover, and left in this state for one or two months. At the end of this period it should be measured in paste and mixed with the sand and cement in due proportion, adding the quantity of water necessary to bring it to the consistence of ordinary mortar. This process is the one which gives the best results; **but if this be inconvenient the lime may be used as it comes from the kiln, or after it has been lying, wet in vats for any length of time.**

Mortar made of ordinary consistence, and even rather thin, is easier to mix thoroughly, and gives better results than when it has been mixed in a stiff state. If it becomes a little dry before being used, there is no objection to working it anew, with the addition of a little water. It might be left from night till morning, to be then passed twice under the rab: the mortar acquires more consistence by moistening it a little. It might be remixed in this way during a couple of days with out losing its force.

… Cement suitable for making a good mortar for heavy masonry, may be made out of ordinary bricks. The dust of tiles, has no advantage over that of bricks, as a cement. The important point is to know the true degree of calcination which the clay requires. Bricks should not be taken indiscriminately from the kiln, but those should be selected which have been found on trial to afford the best hydraulic cement.

…. Amongst mortars composed of hydraulic lime and sand, those which harden most promptly in water do not always give the greatest resistance: but those do, generally, which are composed of fat lime and puzzolana either natural or artificial.

Sect. 3— ON MORTARS IN THE AIR.

CHAPTER XI.

Of Mortars made of Lime, Sand and Puzzolana.

…We cannot admit, then, that carbonic acid penetrates far into the interior of masonry; and it is proved, by multiplied observations, that moisture remains during a very long time in the interior of certain walls.

Dr. John reports, on this subject, that about ten years ago, they demolished the piers of the Tower of St. Peter's, at Berlin; this tower had been built eighty years, and the pillars were twenty seven feet thick; the mortar on the outside was dry and hard, but that in the middle was as fresh as if it had been lately placed there. I can state that in 1822, that the lower part of a bastion at Strasburg, being under repair, the mortar was found to be as fresh as if just laid, and nevertheless, this bastion was erected in 1666; the revetment was only about seven feet thick, but the moisture of the earth resting against it, prevented the lower part from drying. Similar facts are observed in constructions still more ancient.

It results from what has been advanced, that the good quality of the mortars of several ancient structures is not due to the manner of slaking the lime, as Mr. Lafaye supposed (air slaking), nor to the process of making mortar supposed by Mr. Loriot, nor to the time that has elapsed since they were built.

…. It is the opinion of a great many constructors that when common, or fat lime is to be used, it is necessary to have it lie wet in vats or pits for a long time: **it is asserted, that the older it is the better it is.**

… To make these experiments, I took fat lime which had been slaked and lying wet in a pit for five years — a portion of the same having been used in the construction of the theatre of Strasburg. The mortars were all made in the same manner, and broken in the same way as the hydraulic mortars; they were left in the air in a cellar for one year before cutting them down to their ultimate dimensions and submitting them to the test: the proportions of sand varied from two up to three parts of sand for one of lime measured in paste. The resulting mortars had no consistency, and crumbled between the fingers with the greatest ease.

(same tests with lime and trass and lime/sand/trass. The latter had the best resistance).

… These experiments were made at the same time as those of table No. XV, of the first section, and with the same fat lime. I slaked a part as it came from the kiln, giving it only the quantity of water necessary to reduce it to thick paste, and I made therewith the experiments comprised under Nos. 1 and 2. I slaked a part into thin paste, and made with it the experiments under Nos. 3 and 4, and I also slaked a part into dry powder, by giving it a quarter of its volume of water, and with this I made the two series, Nos. 5 and 6. All these experiments comprise the interval of a year, and the several epochs at which they were respectively made are given in the table. The figures of the table give the number of pounds that the mortars sup ported before breaking.

The series of mortar No. 1, is composed of one part fat lime slaked to thick paste, and two parts and a half of sand. We see that **the mortar made immediately, acquired a hardness which is not, in fact, very great, but which is passable**. The mortars made after fifteen days had nearly one half **less consistency**; at the end of two months it had **two thirds less**, and the mortars made after six months had not strength enough to support the weight of the scale pan, &c, which was twenty-two pounds.

…**we cannot but think that slaking fat lime into vats and letting it lie there in a wet state, is a mistaken practice**. The practice may have been induced from the considerable increase of bulk it gives to fat lime; but the trials I have made show it to be a very bad process, at least with the limes I used.

… The series No. 3 differs from the first only in the lime having been slaked to a thin, instead of a thick paste. The lime was left six months before making any mortar with it. We see that the results were the same, that is to say, were equally bad with those of the first series.

… Series No. 5 was made of the same lime, slaked to dry powder. This series was not commenced till six months after the slaking of the lime. The mortars I obtained had no consistency, and crumbled easily between the fingers. The mortars of the first and third series, made at the same period, bad as they were, gave resistance enough to be submitted to fracture.

… The experiments of table No. XXXIV, were made with **lime just from the kiln**. **The mortars were made immediately**, and with a View to ascertain the quantity of sand which this lime would bear.

The results shew that the greatest resistance corresponded to one part of lime measured in paste, and two parts of sand, and that the resistances diminished in pro portion as the sand was increased. No. 4 had so little strength that it was unable to support the weight of the scale pan; and No. 5 crumbled readily between the fingers. The proportion in general use is one part of fat lime measured in paste, to two parts of sand. Some constructors think that more sand is requisite, but the trials in table No. XXXIV, do not at all confirm this opinion. I regret not having begun by putting a smaller pro portion of sand; these experiments should be repeated.

(One conclusion) **lime, whether common or hydraulic, does not bear as much sand as is commonly thought;** but it appears to be able to bear more trass, whether alone or mixed with sand; which may be attributed to the combination that takes place, in the moist way, between the trass or puzzolana, and the lime.

… I made but few experiments with artificial hydraulic limes in the air, but those which I did make, show that they differ in nothing from natural hydraulic limes. They show, also, **that in the air, as well as in water, better mortars are generally obtained with fat lime, sand, and substances analogous to puzzolana, than with hydraulic lime and sand.**

On comparing the above mortars, left in the air, with the same mortars put in water, we are led to the following conclusions: when mortars are made of hydraulic lime and sand, to be used in masonry exposed to the air, **it is of great importance to use the lime soon after it is burned**: otherwise it loses a great portion of its force, as it does under water. **When we are obliged to wait some days before using it, it should be slaked to dry powder, by throwing on a quarter of its** volume **of water, and be immediately covered with the quantity of sand that is proper to mix with it to make mortar.** These kinds of lime should not be left to slake spontaneously, because they require a considerable time to become reduced to powder, and in general, lose a great part of their energy.

… Comparing mortars made of the same constituents, and in the same manner — some having been left in the air, and others put underwater, we see that the latter, in general, have given the greater resistances. Humidity is, therefore, favourable to hydraulic mortars. *[early hydration is essential when used in the air…]*

In the case of masonry made of fat lime, it has always been recommended, if earth was to be laid against it, that it should be left to dry for some time, before backing it with earth; and with the same object it has been directed to wait a year before pointing the work. We see that with hydraulic mortars used in the air, it will be better to act differently. As the masonry rises, it will be best to throw the earth against it. The pointing should be finished at the same time as the masonry, this being the better and more economical mode. During warm weather, the top of the wall should be copiously watered, at the close of the day, and whenever the masons break off during the day. This was always done at Strasburg, and was found to be a good practice.

CHAPTER XIV.

Observations on Mortars exposed to the Air.

It results from the experiments given in chapters XI, XII, and XIII, that in exposing to the air mortars made of sand, and lime which had been laying a long time slaked and wet, I obtained no satisfactory result; while I obtained tolerable results with sand, and the same lime recently slaked.

…I ought not, however, from this to take up a general conclusion, and counsel against slaking and running lime into vats to preserve it…

I do not know for how long a time the method of running lime into vats has been followed. It may have been introduced in consequence of the considerable increase of bulk which it gives. I do not know that it was followed by the ancients. Vitruvius has left a work on architecture, in which he has given many de tails as to the manner the Romans carried on their works.

It appears probable to me… that the Romans used fat lime as they did hydraulic lime, that is to say, immediately after the burning. This is the more likely, as Vitruvius directs, in the process of stucco making, that only lime that had been long slaked should be used. The following are his remarks on this subject. Book VII, chapter II. " Having examined all that appertains to pavements, the manner of making stucco must be explained. The principal matter in this is, that the lime should be slaked for a long time, so that if there should be some particles less burned than the rest, they may, having time thus given them, be as thoroughly slaked, and as easily tempered, as that which was thoroughly calcined: for, in lime which is used as it comes from the kiln, and before it is sufficiently slaked, there is a quantity of minute stones imperfectly burned, which act on the plaster like blisters, because these particles slaking more slowly than the rest of the lime, break the plaster and mar all the polish." It appears to me that **the precaution of slaking the lime a long time before hand, is here recommended as an exception, and that in the mortars intended for masonry, the Romans used all limes soon after they left the kiln.** It is remarkable that the same author directs, in the first passage cited, mixing with the mortar a portion of sifted tile dust, observing that it will much improve the mortar.....

.... if we examine the two tables in page 111, which contain the analyses of several lime stones, we shall see that many limes which are ranked with fat limes contain, nevertheless, small quantities of clay. Although they may not contain enough clay to harden under water, they ought to afford much better mortars in the air than those limes which contain none. Again, hydraulic limestones are often found disseminated amongst the strata of fat limestones. And, lastly, the important observation of Mr. Girard, the hydraulic proportions of arenes explains easily how very good mortars may have been made of fat lime. I will observe, in addition, that the Romans, in all the countries they occupied, executed a great many works, of which , only those made of good mortars survive to the present day. Saint Augustine complains of the manner in which mortars were made in his day: and the same complaints are found in Pliny; who says, chapter XXII, • that which causes the ruin of the greater part of the edifices of this city (Rome) is, that the workmen employ, from fraud, in the construction of the walls, lime which has lost its quality." We see, therefore, that all the Roman mortars were not good.

..... **We are in the habit of composing our mortars of fat lime and sand;** the preceding experiments show that we are wrong: our mortars have, consequently, little durability. We shall not obtain durable masonry in the air, until we make use, therein, of hydraulic mortars. In countries where good natural hydraulic lime is to be had, no other kind should be used tor any purpose whatever. For ordinary masonry, the mortar should, in that case, be made of lime and sand only. In countries where there are no natural hydraulic limes, but where there are arenes, the mortar should be made of fat lime and these arenes: in both these cases the mortars would be cheap. In countries where neither arenes nor hydraulic limes are to be procured, it will be necessary to incur a little additional expense, and make use of fat lime, sand, and hydraulic cement. To combine economy and solidity at the same time as much as possible, the proportions, in cases where there are to be one part of fat lime and two of sand and cement, the mixture may be made as follows, viz: one part of fat lime measured in paste, one and a half of sand, and a half of hydraulic cement; (according to similar proportions made with trass, as shown in table No. XXVII,) we should have, by this means a very good mortar. The proportions of hydraulic cement, stated above, should be used in all common masonry: in works demanding more care, the mortar should be composed of lime, sand, and cement, in equal parts. I have said, that the proportions indicated for common masonry, should augment the expense but little: but were the augmentation more considerable, it is certainly much more economical to incur at once, all the expense necessary to produce a permanent work, than to build at a cost rather less in the first instance, and to be obliged to reconstruct the work entirely, after no great lapse of time. A government should construct for posterity: and **I do not doubt that this end would be attained by making all masonry with hydraulic mortar, in the manner I have pointed out.**

If, in general, no better results are obtained with fat lime, than those obtained by me, the practice of making mortars of fat lime and sand only, should be abandoned. A small quantity of hydraulic cement, or of some substance of similar nature, should always be mixed in the mortar; that is to say, all air-mortars should be hydraulic mortars. The expense will be a little greater it is true, but there will be full compensation in the duration **of the masonry.** There is no economy in putting up cheap masonry which will require to be rebuilt at the end of a few years; and will need costly repairs, annually: it is much better, and really more economical, to encounter, at once, the expense which will secure to the work an indefinite duration, and exemption from all but trivial repairs.