Sect. V.—BRIEF OBSERVATIONS ON COMMON MORTARS, HYDRAULIC MORTARS, AND CONCRETES,

WITH SOME EXPERIMENTS MADE THEREWITH AT FORT ADAMS, NEWPORT HARBOUR, R. I. FROM 1825 TO 1838.

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CHAPTER XXIII.

On Lime, Hydraulic Cement, Sand, Mortar making, Strength of Mortars and Grout.

During the progress of operations under my direction in the construction of Fort Adams, in Newport Harbour, Rhode Island, many experiments were made with mortars exposed in the air; giving, in some cases, results quite interesting. The results are too limited in number and restricted in variety, to justify the deduction of general principles; still they afford some hints that may be deemed worthy of being followed up.

The following tables contain these results in a very condensed form; but before giving the tables, it is proper to make some observations on the materials employed—the manner of using them, and the modes adopted of trying the relative strengths of the essays.

Lime.—Three kinds of lime were used, namely:

1st. "*Smithfield Lime.*"—From Smithfield, R. I. about fifteen miles from Providence. This is a very fat lime—slaking with great violence, when properly burned, and affording a large bulk of slaked lime.

2d. "*Thomastown Lime.*"—From Thomastown (Maine.) This is also a fat lime, at least so far as it has been tried at Fort Adams: but it is probable that some of the many varieties—including those of the neighbouring towns of Lincolnville, and Camden, may prove to be hydraulic. The richer varieties slake promptly, giving a large bulk of slaked lime.

3d. *Fort Adams Lime.* This is made from a ledge of whitish transition limestone found within the domain of the Fort. The stone is very fine grained and compact, exceedingly difficult to break, and crossed in all directions by three veins of whitish quartz. The ledge is a bed, or large nodule, in graywacke-slate. After calcination it yields, by sluggish slaking, a lime decidedly hydraulic. A little of this lime, after being slaked, was made into a cake of stiff hydrate; the excess of water being absorbed by bibulous paper: the cake was placed in the bottom of a tumbler and covered immediately with water. In about $7\frac{1}{2}$ days, a wire $\frac{1}{23}$ of an inch in diameter, loaded to weigh 1 lb., made no impression on this hydrate.

Three modes of slaking the lime were tried in these experiments, namely:

1st. *Slaking by Sprinkling.*—In this mode, water, in quantity sufficient to slake the lime to dry powder, but not enough to afford moist powder, was sprinkled upon the lime. The lime was not made into mortar until it had become cold.

2nd. *Slaking by Drowning.*—In this mode, water enough was given, in the first place, to reduce the lime to a cream of such consistency as to afford mortar of proper "*temper*" for common use without any further addition of water, provided the mortar was made up immediately. If the making the mortar was delayed, a further supply of water became necessary.

3d. *Air-slaking.*—In this mode, lime, reduced to pieces about the size of a walnut, was left in the air to slake spontaneously.

These were the processes by which the lime used in the experiments was slaked: but by neither of these, nor by any modification recommended by others, or that we, ourselves, could devise, were we able to free the hydrate from an infinity of small particles of lime, that being imperfectly, or not at all, slaked in the first instance, it was almost impossible, by any amount of labour afterward, to break down and mix with the rest. The mortar mill, hereafter described, reduced these refractory particles better than any of the ordinary modes of acting upon lime; but not sufficiently, without an unwarrantable amount of labour. All other means having failed, resort was had, at last, for the mortar for the masonry of the Fort, to grinding the dry lime to a very fine powder between millstones. Lime thus ground gives a perfectly homogeneous mortar: and some partial experiments lead to the opinion that the gain in the quantity of lime available for mixtures with sand, will, nearly if not quite, compensate for the expense of grinding. So far as the mortar thus made has been tried, the results were favourable: but the experiments on the quantity and quality of lime thus treated, though they justify confidence, are not, yet, so conclusive as to warrant any positive assertions.

Hydraulic Cement.—Three kinds of hydraulic cement were employed—namely, a kind that will be here designated as *hydraulic cement A*, which was supplied from the State of New York—another kind, called *hydraulic cement B*, supplied from a different manufactory in the same State—and "*Roman (or Parker's) cement,*" imported from England.

The experiments will show a material difference in the respective qualities of these hydraulic cements. According to them, cement A was the best, cement B the next best, and the "Roman cement" the worst; but it must be remarked that the last mentioned had, no doubt, greatly deteriorated, from imbibing moisture during a long voyage, and long keeping in store; while there is reason to suppose that the two first mentioned had been calcined within a few weeks. Between these two, there was also a marked difference; but though the superiority of cement A was probably in part intrinsic, it was, no doubt, in part, to be ascribed to its greater freshness. These cements, therefore, should, in our tables, be compared with themselves under various combinations with other ingredients, rather than with each other.

This is perhaps the best place to mention a very certain and satisfactory mode of testing the hydraulic quality of lime or cement. It is derived from Raucourt's work on mortars.

Of the lime or cement to be tried, a cake of quite stiff hydrate must be made of a size to lie, without touching the sides, in the bottom of a tumbler: any excess of water should be absorbed from the cake by bibulous paper, until it will just support a wire $\frac{1}{12}$ of an inch in diameter loaded to weigh $\frac{1}{4}$ of a pound—this wire should barely make its impression. Noting the hour and minute of the watch, the cake, thus prepared, should be placed in the tumbler, and covered immediately with water. If the specimen be very hydraulic, it will set almost instantly; if not very hydraulic, it may require days, and if but slightly hydraulic, it may require weeks to harden. In order to have some invariable measure of what we call *setting*, we have always used a wire $\frac{1}{24}$ of an inch in diameter, loaded to weigh 1 pound.

With these two simple instruments, and these simple appliances, the comparative hydraulic qualities of limes and cements may be detected infallibly. It may not be strictly accurate to say that those cements which indurate most promptly under water will afford the strongest mortars in the air; although that has, for the greater part, appeared to be the case, in our experiments; still it is highly probable that such cements will be found among the best; it is, at any rate, amongst such that we should look when in search of mortars of superior excellence; and it is undoubtedly true, that when hydraulic qualities exist in lime, although in feeble proportion, the lime is essentially benefited. A simple means of testing hydraulic quality is therefore of value.

Our experience has, however, taught us one important caution in the use of this test; which is, to leave the cement in the water for a day or two, although it may have set in a few minutes. A cement was under trial which, at the expiration of 7 minutes had set so as to bear the small wire with the weight of 1 pound—and at the expiration of 15 minutes, with the weight of 2 pounds. In about two hours, however, it was entirely soft again, having been broken down by the slaking of some free lime that happened to be present, and which had not had time to slake before the hydraulic ingredients had indurated. After about fifteen hours it was taken out of the water, restored to the condition of stiff mortar, and again immersed. It now hardened very slowly, and was six days acquiring the test hardness. Such cements require peculiar treatment. It is evident that there is great hydraulic energy wasted in the first instance of immersion; because the subsequent swelling of the lime, breaks down the indurated mass; and, removing the hydraulic particles beyond the sphere of mutual action, prevents any useful effect from the remaining hydraulic power. The slaking the lime should, therefore, be complete before the cement is immersed. The best mode of slaking this lime has not been ascertained. Perhaps it would be best to sprinkle a little water on cement of this kind, leaving it for a few hours in the state of moist powder—perhaps leaving it exposed to spontaneous slaking for the requisite time—and perhaps throwing on a small quantity of water, in order to slake the lime, and then exposing the cement to heat for a short time, so as to drive off the water absorbed by the hydraulic constituents. This last mode is suggested by the following facts.

Some hydraulic cement A, which had been in a cask more than one year, on first opening the cask, hardened under water in three hours. After two or three days, it required five hours to harden; and after ten days, about nine hours—the cask being kept covered by the head lying loosely upon it. A little of this cement that had been out of the cask for more than a week, on being heated (but not to a red heat) for a few minutes, set under water in three hours. Some of the same cement that had been in the office, enclosed in paper, for about three weeks, required six hours to harden in water, while a little of it, after being kept on a red hot iron plate for about fifteen minutes, hardened in water in 45 minutes.

This power of restoring the energy of deteriorated cements may have many important applications.

Sand.

Several kinds of sand were used in the experiments, namely:

Sand No. 1.—This is the kind habitually used at Fort Adams in stone masonry. It is entirely free from dirt, and the particles, though not very sharp, are angular. Separated mechanically, it was found to consist, in 100 parts, in bulk, of

particles from	$\frac{1}{6}$ to $\frac{1}{12}$ of an inch in diameter			—about	10.00
do.	$\frac{1}{12}$ to $\frac{1}{24}$	do.	do.	do.	5.00
do.	$\frac{1}{24}$ to $\frac{1}{48}$	do.	do.	do.	48.00
do.	$\frac{1}{48}$ to dust			do.	45.00
do.	dust mostly silicious—no dirt			do.	4.50
100 parts in bulk producing				do.	112.50

Sand No. 2.—Is the above sand freed from particles larger than $\frac{1}{12}$ of an inch.

Sand No. 3.—Is the above sand freed from particles larger than $\frac{1}{48}$ of an inch.

Sand No. 4.—Is sand No. 2, pounded very fine after being freed from dust by washing.

Mortar Making.

With a view to a thorough incorporation of the constituents, at a small expense, and in order, at the same time, to break down the refractory particles of lime before mentioned, a mortar mill was constructed at the commencement of the works at Fort Adams in 1825, which has been in operation ever since.

The mill consists of a very heavy wheel about eight feet in diameter (having a tire one foot broad) moving in a circular trough fifteen inches wide at the bottom—the diameter of the circle being about twenty-one feet. The lime is slaked under the wheel, and ground until, with suitable additions of water, it has become a homogeneous paste sufficiently dilute to make mortar of the ordinary consistency. The requisite quantity of sand is then gradually sprinkled in, as the wheel is in motion. The draught is easy to the horse until near the last; when, for a few minutes, as he is giving the last turns, after all the sand has been thrown in, it is rather heavy.

It was found convenient to use three barrels of lime to each batch of mortar.

The three mortar mills of Fort Adams were competent to supply in one day 3077 cubic feet of mortar, at a total expense of $0.087 per cubic foot, viz.

105 casks of lime, at $1.52 per cask,	$ 159.60
2094 bushels of sand, at $0.04 per bushel,	83.76
Carting sand to mill, $0.12 for 20 bushels,	12.56
3 horses and 3 drivers, at $1.50 per day,	4.50
6 labourers, at $1.00 per day,	6.00
1 cooper at $1.00 per day,	1.00
Other small expenses say	0 58
Total cost of 3077 cubic feet of mortar	$ 268.00

or $0.087 per cubic foot. It appears that the expense of *making* the mortar was $12.08, being about $\frac{1}{3}$ of a cent for a cubic foot.

The proportions in the above mortar are about 1 of lime in paste to $2\frac{1}{2}$ of sand—should the proportion of lime be greater, the mortar will, of course, cost more.

The above statement refers to mortar made without addition of any hydraulic substance. But such mortars are now never used at Fort Adams. Hydraulic cement, or burnt clay, or brick dust, or some other similar matter is added to every kind of mortar made at the work, in proportions varying with the purpose to which the mortar is to be applied. The poorest mortar we make contains 1 barrel of hydraulic cement to 3 barrels of unslaked lime and about 15 barrels of sand; the cement being added before the sand, and while the lime is being reduced under the wheel.

All the mortars used in the experiments in the tables, were made by hand with the trowel, with such exceptions, only, as are noticed.

Trials of the Strength of Mortars.

The strength of mortars as regards tenacity, was determined by measuring the force required to separate bricks that, having been joined by the mortar, had been left, for the desired length of time, in some place safe from frost or accident.

The bricks were joined in pairs, being crossed at right angles thus,

so that, supposing each brick to be 4 inches wide, the surface of contact would be 16 square inches. The real surface, or surface of effectual contact, was, in every case, found by actual measurement. The mortar joint separating the bricks was made about $\frac{3}{8}$ of an inch thick: and, in order that this mortar should in all cases be equally consolidated, each pair of bricks was submitted to the pressure of 600 lbs. for 5 minutes, immediately after being joined.

An idea of the mode of separating the bricks may be got from fig. 9, Pl. II, where *a* and *b* represent two strong half-staples fastened to the floor: under these the ends of the lower brick are passed, while the ends of the upper brick are embraced by the piece of iron *c*, *c*, suspended from the steelyard *d*. The force needed to separate the bricks, is applied by pouring sand, at a uniform rate, into the bucket *e*. The weight of the sand and bucket, the mark on the beam where the weight was applied, and the weight of the *poise*, enable us to ascertain the force necessary to tear the bricks asunder. In the tables, the force required to separate the bricks is reduced to the proportional force required to tear up a surface of one square inch: so that if there were 16 square inches of actual contact, and the force used in separating the bricks was 1000 pounds, the table would represent the tenacity of the mortar by $62\frac{1}{2}$lbs.—equal to $\frac{1000}{16}$.

The hardness of the mortars was determined by ascertaining the weight, applied on a circular plane surface of 0.16 of an inch in diameter, (or .02008 of an inch area,) which the mortar would support. This mode of trial is represented in fig. 10, Pl. II. The circular surface at the extremity *a*, presses upon mortar still adhering to one of the bricks. The arms of the lever *b*, are of equal length, so that the upward force at *c* is equal to the pressure at *a*. The force is applied by means of a steelyard and sand, as in the preceding case.

The experiments were generally made with several pairs of bricks, and a mean was taken of the results; unless it had obviously been subjected to some accident or disturbance, being made to contribute to the mean. Very few results were rejected. There could be only as many trials of *tenacity*, in each particular experiment, as there were pairs of bricks. But for *hardness*, it was often possible to make a considerable number of distinct trials on the same surface of mortar: on the other hand, it would sometimes happen that the surface would be left too ragged and uneven for this trial: and in several instances this test seemed to be entirely inapplicable—the mortar beginning to yield with light weights, and continuing to yield more and more as the weight was increased, the whole effect being a gradual crumbling. In a great majority of cases, however, the effects were sufficiently decided to leave no doubt as to the moment when the power prevailed over the resistance—and sufficiently consistent to afford useful comparisons.

The method, just described, of trying the strength of mortars, was adopted in the Fort Adams experiments, on account of the facility of application. There was, in the first instance, no purpose of extending the experiments beyond what was deemed indispensable to a proper choice, and judicious application of materials, in the construction of a work of some magnitude, then being begun. One series of experiments, however, involved another and another, until the series became extended and the experiments too numerous and valuable, not to make it desirable that subsequent ones should be comparable with them, and, consequently, the same mode of test was continued.

It is probable that the method followed by Genl. Treussart, of making rectangular prisms of mortar, and subjecting them to fracture by weights suspended from the middle, is the best mode. It, at any rate, has the advantage of allowing mortars made in different places, and at distant times to be compared. This mode was adopted in some of the later trials at Fort Adams.

The following table exhibits the mean results of all the experiments made from 1825 to 1832; comprising seven series. The time of exposure of the 1st series was 5 months; of the 2nd. series, 10 months; of the 3rd, 10 months; of the 4th, 5 months; of the 5th, 10 months; of the 6th, 25 months; and of the 7th, 11months. In the 1st series, there were 2 pairs of bricks to each experiment; in the 2nd, 3 pairs; in the 3rd, 3 pairs; in the 4th, 1 pair; in the 5th, 4 pairs; in the 6th, 2 pairs; and in 7th, 3 pairs.

The first column prefixes a number to each kind of mortar, for convenient reference; the 2nd column expresses the nature, or composition of the mortar; the 3rd column, whether the bricks were *wet* or *dry* when joined together; the 4th, the number of series of which the results are a mean as to *tenacity*; the 5th, the *tenacity*, as expressed by the number of pounds required to tear open a joint of one inch square; the 6th, the number of series of which the results are a mean as to *hardness;* and the 7th, the number of pounds required to force into the mortar a circular plane surface of 0.16 of an inch in diameter.

Table No. LXV.

No.	Nature and Composition of the mortar.	Bricks wet or dry.	Tenacity. Number of series affording the mean.	Tenacity. Mean tenacity.	Hardness. Number of series affording the mean.	Hardness. Mean hardness.	Remarks.
1	New York Hydraulic cement B, alone .	W	1	32.6			
2	do. do. do. A, alone . .	W	5	56.2	4	1053	
3	Roman cement (Parker's English) alone .	W	1	18.5	1	260	
4	do. (do.) alone	D	1	22.6	1	412	
5	Lime alone	W	1	10.5	1	98	
6	Hydraulic cement A in powder . 1; Sand No 3 .50	W	1	61.9	1	1055	
7	Cement A do. 1; Sand the same 1	W	6	40.3	5	993	
8	Cement A do. 1; Sand the same 1.50	W	5	33.1	4	918	
9	Cement A do. 1; Sand the same 1.50	D	2	30.4	1	765	
10	Hydraulic cement A in powder . 1; Sand No. 3 . 2	W	3	17.5	3	670	
11	Cement A do 1; Sand the same 3	W	3	19.8	2	367	
12	Cement A do. 1; Lime slaked to powder .50; Sand the same 1.50	W	2	29.6	3	573	
13	Cement A do. 1; Lime the same .50; Sand No. 2 2	W	4	20.1	3	509	
14	Cement A do. 1; Lime the same 1; Sand No. 2. 2	W	4	28.3	3	778	
15	Cement A do. 1; Lime the same 2; Sand No. 2 4	W	4	17.1	3	545	
16	Cement A do. 1; Lime the same 2; Sand No. 2 6	W	4	16.2	3	267	
17	Cement A do. 1; Lime in paste, .50; Sand No. 2 1.50	W	1	44.4	1	765	
18	Cement A 1; Lime in paste .50; Sand No. 2 1.50	D	1	54.7	1	915	
19	Cement B do. 1; Sand No. 3 1	W	2	18.9			
20	Cement B do. 1; Sand No. 2 1.50	W	1	23.4			
21	Cement B do. 1; Sand No. 2. 2	W	2	14.7			

Table No. LXV—Continued.

No.	Nature and Composition of the mortar.		Bricks wet or dry.	Tenacity. Number of series affording the mean.	Tenacity. Mean tenacity.	Hardness. Number of series affording the mean	Hardness. Mean hardness.	Remarks.
22	Cement B do.	1	W	2	17.5			
	Lime in powder slaked	.50						
	Sand No. 2	2						
23	Cement B do.	1	W	2	19.1			
	Lime the same	1						
	Sand No. 2	2						
24	Hydraulic cement B in powder	1	W	2	18.1			
	Lime slaked in powder	2						
	Sand No. 2	4						
25	Cement B	1	W	2	15.0			
	Lime the same	2						
	Sand No. 2	6						
26	Roman cement	1	W	1	19.2	1	397	
	Sand No. 2	.50						
27	Roman cement	1	W	1	16.8	1	309	
	Sand No. 2	1						
28	Roman cement	1	W	1	13.3	1	286	
	Sand No. 2	1.50						
29	Roman cement	1	W	1	26.7	1	471	
	Lime in paste	0.50						
	Sand No. 2	1.50						
30	Roman cement	1	D	1	29.1	1	787	
	Lime in paste	0.50						
	Sand No. 2	1.50						
31	Lime in powder	1	W	3	12.3	1	159	
	Sand No. 3	3.50						
32	Lime in powder	1	W	1	5.6	1	107	
	Sand No. 3	6						
33	Lime in paste	1	W	1	14.3	1	208	
	Sand No. 3	.50						
34	Lime in paste	1	W	3	15.4	2	275	
	Sand No. 3	1.50						
35	Lime in paste	1	W	4	12.8	2	146	Made with a hoe.
	Sand No. 3	3						
36	Lime in paste	1	W	6	14.3	3	202	Made in mortar mill.
	Sand No. 3	2.50 *a* 3						
37	Lime in paste	1	D	5	14.9	4	254	do. do.
	Sand No. 3	2.50 *a* 3						
38	Lime in paste	1	W	1	13.7	1	217	do. do.
	Sand No. 1	2.50 *a* 3						
39	Lime in paste	1	D	1	16.2	1	200	do. do.
	Sand No. 1	2.50 *a* 3						
40	Lime in paste	1	W	1	33.8	1	242	Lime different.
	Sand No. 1	2						
41	Lime in paste	1	D	1	26.6	1	231	(Lime different.)
	Sand No. 1	2						

Observations on the Experiments of Table No. LXV.

1st. Generally, within the limits of the experiments, *a mortar made of lime and sand, or of hydraulic cement and sand, or of hydraulic cement, lime and sand—whether it was cement A, or cement B, or Roman cement, was the stronger, as the quantity of sand was the less.* In 24 comparisons, 3 exceptions.

In 13 comparisons of *tenacity*, 2 exceptions.

In 11 comparisons of *hardness*, 1 exception.

2nd. *It appears that with cement A, or cement B, any addition of sand weakens the mortar.* In all the cement experiments, except one, composed of Roman cement 1—sand ½ (No. 26,) the cement alone, was stronger than when mixed with sand in any proportion whatever. Cement A (No. 6,) would seem to be another exception, but it is not; the strength of cement A, alone, as given in No. 2, is the average of five results with different specimens of cement, some of which were of inferior quality; while the result given in No. 6 is of one trial only, and that of a cement proving to be the best used; the particular result of No. 2 which corresponds with No. 6—that is to say, which was afforded by the same specimen of cement, gave for *tenacity* 74.7 lbs. and for *hardness* 1063 lbs., while No. 6 shows a *tenacity* of 61.9 lbs. and a hardness of 1055 lbs.

3rd. *It appears that when cement mortars are not required to be the strongest that can be made—a little lime may be added, without great loss of tenacity, and, of course, with a saving of expense.*

4th. *Mortar made in the mortar-mill was superior to mortar made by being mixed, in the common mode, with the hoe.*

5th. *When the bricks were dry and the mortar more fluid than usual, the mortar was better, both as to* TENACITY *and* HARDNESS—*in five cases out of seven, than when the bricks, being wet, were put together with mortar of common consistence.*

In the next table there is a comparison of the three kinds of lime—of the three modes of slaking, of various proportions of sand—of the effect of wet and of dry bricks on the mortar, &c.

In most cases six pairs of bricks were put together at the same time, and of the same materials; of which three pairs were separated after about 6 months, and the remainder after the lapse of 4 years and 5 months.

Table No. LXVI.

Showing the tenacity and hardness of mortars variously composed after exposure in the air.

No.	Nature and composition of the mortar.	Bricks wet.				Bricks dry.				Remarks.
		Tenacity per square inch.		Hardness.		Tenacity. per square inch.		Hardness.		
		After 6 months.	After 4 years and 5 months.	After 6 months.	After 4 years and 5 months.	After 6 months.	After 4 years and 5 months.	After 6 months	After 4 years and 5 months	
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1	*Paste of Smithfield lime slaked by* DROWNING 1; Sand No. 2 1	20.4	42.8	119	220					There are two kinds of Fort Adams lime in the table. The first, A, was imperfectly calcined: the second B, was thoroughly burned.
2	Lime the same 1; Sand No. 2 2	15.2	18.8	130	297					
3	Lime the same 1; Sand No. 2 3	12.6	16.6	182	232					
4	Lime the same 1; Sand No. 2 4	13.2	16.4	85	203					
5	*Paste of Thomastown lime slaked by* DROWNING 1; Sand No. 2 1	11.3	38.3	216	300		40.3		355	
6	Lime the same 1; Sand No. 2 2	17.1	38.3	123	273		39.1		310	
7	*Paste of Thomastown lime, slaked by* DROWNING 1; Sand No. 2 3	24.7	27.6	265	240		38.0		220	
8	Lime the same 1; Sand No. 2 4	15.1	21.7	214	210		35.4		203	
9	*Paste of Fort Adams lime* A *slaked by* DROWNING 1; Sand No. 2 1	13.4	21.9	105	273		34.0		186	
10	Lime the same 1; Sand No. 2 2	9.9	18.8	68	175		22.5		110	
11	Lime the same 1; Sand No. 2 3	12.6	22.7	75	93		22.8		187	
12	Lime the same 1; Sand No. 2 4	9.6	11.5	92	93		21.4		102	
13	*Paste of Thomastown lime, slaked by* SPRINKLING 1; Sand No. 2 1	26.8	49.1	259	798		40.6		787	
14	Lime the same 1; Sand No. 2 2	26.4	35.6	225	666		57.3		370?	
15	Lime the same 1; Sand No. 2 3	26.3	37.0	285	392		26.2		625	
16	Lime the same 1; Sand No 2 4	25.2	31.0	289	313		38.0		347	
17	*Paste of Fort Adams lime* B *slaked by* SPRINKLING 1; Sand No. 2 1	32.9	47.8	446	900		56.7		620	

Table No. LXVI. Continued.

No.	Nature and Composition of the mortar.	Bricks wet. Tenacity per square inch. After 6 months.	Bricks wet. Tenacity per square inch. After 4 years and 5 months.	Bricks wet. Hardness. After 6 months.	Bricks wet. Hardness. After 4 years and 5 months.	Bricks dry. Tenacity per square inch. After 6 months.	Bricks dry. Tenacity per square inch. After 4 years and 5 months.	Bricks dry. Hardness. After 6 months.	Bricks dry. Hardness. After 5 years and 5 months.	Remarks.
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
18	Lime the same 1 Sand No. 2 2	33.1	54.5	228	600		52.4		507	
19	Lime the same 1 Sand No. 2 3	28.9	43.1	221	327		51.8		266	
20	Lime the same 1 Sand No. 2 4	23.5	30.4	254	258		52.6		233	
21	*Paste of Smithfield lime* AIR SLAKED 1 Sand No. 2 1		22.4		126					
22	Lime the same 1 Sand No. 2 2		9.9		85					
23	*Paste of Thomastown lime* AIR SLAKED 1 Sand No. 2 1				37[illegible]					
24	Lime the same 1 Sand No. 2 2		6.0		20[illegible]					
25	*Paste of Fort Adams lime* B AIR SLAKED 1 Sand No. 2 1		29.2		664					
26	Lime the same 1 Sand No. 2 2		21.6		281					
27	*Paste of Fort Adams lime* B *slaked by* DROWNING 1 Brick dust 0.40 Sand No. 2 1.40	16.3		104						
28	Lime the same 1 Dust of burnt clay .50 Sand No. 2 .50	17.5		168						
29	*Paste of Thomastown lime slaked by* SPRINKLING 1 Brick dust 2	35.0		360						
30	*Paste of Thomastown lime slaked by* DROWNING, measured before slaking 1 Sand No. 2 5	12.2	18.5	102	263		22.5		192	
31	Lime the same* 1 Cement A .33 Sand No. 2 5.50	15.4	23.1	165	192		42.6		230	
32	*Paste of Fort Adams lime* B *slaked by* DROWNING, measured before slaking 1 Sand No. 2 5	25.7	48.8	130	650		17.8		652	
33	Lime the same* 1 Cement A .33 Sand No. 2 5.50	22.7	46.7	194	849		46.2		303	
34	Cement A in powder 1 Sand No. 2 1.50	63.3	72.4		1508	467	88.4		1659	

*Equal, lime 1 Cement 0.33 Sand 5.00
do. 50
Lime 1 Cement 0.33 Sand 5.50

Observations on the experiments of Table No. LXVI.

1st. *Within the limits of the experiments, whatever was the mode of slaking, or the kind of lime, the mortar was the stronger as the quantity of sand was less.*

The lime being measured in paste, the proportions were 1 of lime to 1 of sand; 1 of lime to 2 of sand; 1 to 3, and 1 to 4 of sand.

In all the corresponding trials of the table,

1 lime in paste, to 1 sand, gave the strongest mortar in 35 cases of tenacity, and in 13 cases of hardness.

1 lime in paste, to 2 sand, gave the strongest mortar in 3 cases of tenacity, and in 1 case of hardness.

1 lime in paste, to 3 sand, gave the strongest mortar in 2 cases of tenacity, and in 2 cases of hardness.

1 lime in paste, to 4 sand, gave the strongest mortar in 0 cases of tenacity, and in 1 case of hardness.

2d. *Slaking by* DROWNING, *or using a large quantity of water in the process of slaking, affords weaker mortar than slaking by* SPRINKLING.

In 24 corresponding cases of the table—The quantity and quality of the materials being alike: and there being no other difference than in the modes of slaking the lime.*

Lime slaked by SPRINKLING, gave the best mortar in 22 cases of tenacity, and in 24 cases of hardness.

Lime slaked by DROWNING, gave the best mortar in 2 cases of tenacity, and in 0 case of hardness.

The average strength in all the 24 cases in which the lime was slaked by *drowning* was, as to tenacity, 23.79 lbs., and as to hardness, 187.00 lbs.

While the average strength in all the 24 cases in which the lime was slaked by *sprinkling* was, as to tenacity, 38.63 lbs., and as to hardness 417.33 lbs.

The relative tenacity then is as 1 to 1.62; and the relative hardness as 1 to 2.23.

3d. *The experiments with air* SLAKED LIME, *were too few to be decisive—but the results were unfavourable to that mode of slaking.*

Average strength of the mortar made of *air-slaked* lime as to tenacity 20.80 lbs., and as to hardness 202.18 lbs.

Average strength of the corresponding mortars made of lime slaked by *drowning*, as to tenacity 27.10 lbs., and as to hardness 207.50 lbs.

Average strength of the corresponding mortars made of lime slaked by *sprinkling*, as to tenacity 46.70 lbs., and as to hardness 533.83 lbs.

4th. *The mortars were very materially stronger at the end of* 4 *years and* 5 *months, than at the end of the first half year.*

Of the 26 mortars which enter into this comparison, the average strength at the end of 6 months was, as to tenacity, 22.54 lbs., and as to hardness 166.33 lbs., and at the end of 4 years and 5 months it was, as to tenacity, 35.45 lbs., and as to hardness 367.37 lbs.

The relative tenacities being as 1 to 1.57, and hardness as 1 to 1.97 lbs.

5th. *Brick dust, or the dust of burnt clay, improves the quality of mortars both as to tenacity and hardness.*

6th. *Hydraulic cement added, even in small quantities, to mortars, improves their quality sensibly.*

* Except in their being two different burnings of Fort Adams lime

7th. *The tenacity of mortars seems to have been increased by using dry bricks, and making the mortar a little more fluid than usual. But the hardness of the mortars was rather the greatest when* WET BRICKS *were used.*

In 21 corresponding instances, *wet bricks* and mortar of common consistency gave the best results, as to tenacity, in 5 instances; and, as to hardness, in 12 instances. *Dry brick* and mortar more fluid, gave the best results as to tenacity in 16 instances; and as to hardness, in 9 instances.

Table No. LXVII.

Trials in December, 1836, of mortars made in December, 1835. The results show the weights in pounds required to break prisms of mortar 2 inches square, 6 inches long and 4 inches in the clear between the supports.

				Lime from the same barrel.							Lime slaked with water enough to make a thin paste—and made into mortar after 12 hours.		Lime from the same barrel.			
No. of the comparison.	Sand No. 2.	Lime { slaked to powder with 1-3 of its bulk of water, measured in paste.	Cement A, cask No. 1, measured in paste.	Mortars made with the least possible quantity of water	Mortars made rather thin.	Mortars made with equal parts of water and bitter-water.	Mortars made with bitter-water alone.	Mortars made of cement A, cask No. 2, which required much more time to set under water than cask No. 1.	Mortar made of calcined clay instead of cement A, cask No. 1.	Mortar made of sand No. 4, instead of sand No. 2.	Stone Lime.	Shell Lime	Lime slaked with ¼ its bulk of water, after being kept sealed hermetically in a jar 3 months.	Lime slaked to cream at first, and kept in that state in a keg under ground for 3 months.	Lime allowed to slake spontaneously for 3 months.	Lime slaked to powder with 1-3 its bulk of water and kept dry in a tight keg for 3 months.
1	1		½	497	370	323										
2	1		¾	562	502											
3	1		1	655	525	703	206									
4	1		1¼	782	516											
5	1		1½	707	721	1125	483									
6	1		1¾	783	712											
7	1		2	844	694	984	452									
8	1	1	¼		117			103	115	197						
9	1	⅓	½		351		220									
10	1	1	½		155			164	178	211						
11	1	1	¾		337			173	155	412						
12	1	½	1		469		295									
13	1	1	1		426			178	206	328						
14	1	1	1¼		328			305	187	469						
15	1	1	1½		295		295	267	206	426						
16	1	1	1¾		337			305	206	351						
17	1	1	2					548		511						
18	1	1	3		417		454	455								
19	1	1	4		389		455	520		806						
20	1	1	5		492		548	530		633						
21	1	1	6		576		553	649		862						
22	1	1									206	141	401	286	253	286
23	2	1									155	129	412	225	244	
24	3	1									122	173	356	160	159	244
	4	1									131	89	286	169	150	220

Observations on Table No. LXVII.

It results from this table, and from the tables from which it has been abridged, 1st. *That in mortars of cement and sand (no lime) the strength is generally greater as the quantity of sand is less.* In 33 comparisons, 12 exceptions.

2nd. *That in mortars of sand, cement and lime—the lime remaining the same in quantity, the mortars were stronger as the quantity of sand was less in proportion to the cement.* In 57 comparisons, 10 exceptions.

3rd. *That in mortars of cement, sand and lime—the quantities of cement and sand being the same—the mortars were stronger as the quantities of lime were less.* In 52 comparisons, 15 exceptions.

4th. *That mortars made of cement and sand were materially stronger when the least possible quantity of water was used, than when the mortars were made thin.* In 14 cases, 1 exception.

5th. *That mortars made of cement and sand with the least possible quantity of water, were stronger when kept in a damp place, than when kept in a dry one.* In 7 comparisons, 1 exception. The experiments did not prove this to be true with reference to mortars made thin. These results were afforded by the experiments but are not included in the above table.

6th. *That in mixtures of lime and sand in various proportions, the mortar was generally stronger as the lime was slaked with less water.*

The average strength of several trials with 0.30 of water being represented by 80—with .40 of water, it was 98—with .60 of water, it was 72—with .80 of water, it was 60, and with 1.00 of water, it was 57. These results were afforded by the experiments, though not included in the table.

7th. *That mortars of lime and sand are materially improved by the addition of calcined clay, but not so much as by the addition of cement A.*

8th. *That sand freed from dust by washing and then pounded fine, gives much better mortars, than a sand composed of particles of every size from dust (no dirt) up to grains $\frac{1}{12}$ of an inch diameter.* In 21 comparisons, 2 exceptions.

9th. Many experiments were made to ascertain whether of two cements of the same manufactory, the difference being, probably, only difference of age, that cement which sets the quickest under water will give the strongest mortars in the air after a considerable lapse of time. The results leave the matter in doubt. The quick cement sometimes giving stronger mortars, and sometimes weaker.

10th. Of lime kept for three months after being slaked, before being made into mortar—the lime slaked into powder by sprinkling one-third of its bulk of water, gave the strongest mortar—represented by 250 lbs.; the lime slaked into cream gave the next strongest mortar—represented by 210 lbs., and the lime slake spontaneously during three months, the weakest mortar, represented by 202 lbs. All these mortars being much inferior to that made of the same lime which had been carefully preserved from slaking by being sealed hermetically in a jar—this last mortar being represented by 364 lbs. It must be remarked here that this result is very extraordinary for fat lime and sand; and it is probable this particular barrel of lime was somewhat hydraulic.

11th. Mortars of cement and sand in which bitter-water alone was mixed (Bitter-water being the mother water after the separation of muriate of soda from sea water,) were weaker than those in which water, or a mixture of equal parts of water and bitter-water, was used. But a mixture of equal parts of water and bitter-water gave much better mortar than water alone—the strongest composition we had, being cement $1\frac{1}{2}$, sand 1, and equal parts of water and bitter-water. In 8 comparisons, 2 exceptions.

The trials that afforded the two exceptions were with mortars containing a smaller proportion of cement than the six others. These facts seem to show that the addition of bitter-water, within certain limits, improves the cement, but that beyond these limits it is injurious; and that where the proportions of cement are great, an increased addition of bitter-water may be advantageous. These particular experiments were made in consequence of finding that the addition of a little bitter-water hastened the setting of cement A when immersed.

12th. *Mortars of cement and sand are injured by any addition of lime whatever, within the range of the experiments; that is to say from sand* 1, *lime* $\frac{1}{8}$, *and cement* $\frac{1}{2}$; *to sand* 1, *lime* 1, *and cement* 2. No exceptions in 67 comparisons.

13th. *Stone-lime, in the proportions tried, gives better mortar than shell-lime, as* 153 *to* 133: but some previous trials had afforded results slightly the best with shell-lime.

Table No. LXVIII.

Trials made in June, 1836, *of mortars made in September,* 1835.

The results show the weights, in pounds, required to separate each inch square of surface of bricks joined by mortars. The object is to compare grout with mortar.

No.	Sand No. 2.	Lime slaked to powder and measured in paste.	Cement A.		Mortar.	Grout.
1	2	1		Lime and cement the same.	30.12	17.19
2	2	1	$\frac{1}{8}$		33.33	17.84
3	2	1	$\frac{1}{4}$		31.35	15.13
4	2	1	$\frac{1}{2}$		32.14	25.14
5	2	1	$\frac{3}{4}$		41.06	21.42
6	2	1	1		39.64	34.68
7	2	1		Lime and cement the same.	22.94	23.08
8	2	1	$\frac{1}{8}$		23.38	14.22
9	2	1	$\frac{1}{4}$		27.07	12.67
10	2	1	$\frac{1}{2}$		29.93	16.96
11	2	1	$\frac{3}{4}$		33.79	22.71
12	2	1	1		36.69	19.75

Observations on Table No. LXVIII.

In order to compare the strength of grout with that of mortar, bricks were joined (as before described) with the mortar given in the table—there being four pairs to each kind of mortar. To obtain similar joints of grout, bricks were supported on their ends and edges, in a box large enough to contain all, in such a way as to admit the proper quantity of grout to flow in between each pair. The box was not disturbed until the grout had become quite stiff, when it was first laid on one side, and then taken to pieces. The excess of grout was carefully cleared away from the bricks, which were removed without injury to any of the pairs, and put away by the side of the bricks joined with mortar.

It will be seen that, in every case but one, the grout was much inferior to the mortar. The average strength of all the mortars in the table is 31.78, and the average strength of all the grouts is 20.06

Changes of bulk on slaking lime—making mortar, grout, &c.

A great many measurements were made of the changes of bulk in the operations of slaking lime, making mortars, &c., and the results, as might be expected, varied with the qualities of the lime. The following condensation of the results may be useful.

			trials.	varying from
1 lime and	$\frac{1}{3}$ water	made, as a mean, 2.25 of powder.	27	1.56 to 2.97
1 do.	$\frac{2}{3}$ do.	do. 1.74 do.	4	1.55 to 1.83
1 do.	$\frac{3}{4}$ do.	do. 1.81 do.	4	1.63 to 1.95
1 do.	1 do.	do. 2.06 do.	4	1.77 to 2.39
1 do.	2.54 do.	do. 2.68 of thin paste. Slaked by drowning.	3	2.50 to 2.82
1 do.	1.70 do.	do. 1.98 do. Slaked by sprinkling.	6	1.73 to 2.36

Lime in powder.	Water.			
1	0.40	made, as a mean, 0.66 thick paste.	2	0.65 to 0.67
1	0.50	do. do. 0.76 thinner paste.	19	0.67 to 0.94

1 lime air-slaked gave, as a mean, 1.84 powder 3 1.37 to 2.41

1 of air slaked lime in powder and 0.50 water made, as a mean, 0.75 thin paste, 2 trials varying from .70 to .80.

1 of lime (quick) pounded to powder, made 0.90 of powder, 1 trial.

1 of lime slaked to powder, kept dry for 3 months, still measured 1.00, 1 trial.

Sand.	thin paste.	cement.		mortar.	trials.	varying from.
1	52	00	made, as a mean,	1.17	13	1.06 to 1.21
1	58	0.125	do.	1.25	23	1.70 to 1.50
1	55	0.25	do.	1.37	3	1.29 to 1.54
1	61	0.35	do.	1.43	3	1.38 to 1.57
1	72	0.50	do.	1.60	2	1.50 to 1.70
1	1.00	0.125	do.	1.78	1	
1	1.00	0.25	do.	1.85	1	
1	1.00	0.50	do.	2.18	1	
1	1.10	0.75	do.	2.14	1	
1	1.40	0.25	do.	2.20	1	
1	1.28	1.00	do.	2.36	1	
1	1.00		do.	1·71	1	
1	2.00		do.	2.14	1	

1	50	00	do.	0.32	water,	made	1.27	grout.
1	50	0.062	do.	0.45	do.	do.	1.50	do.
1	50	0.125	do.	46	do.	do.	1.55	do.
1	50	.25	do.	51	do.	do.	1.66	do.
1	50	.375	do.	52	do.	do.	1.78	do.
1	50	.50	do.	61	do.	do.	1.88	do.

202	of mortar with	87	of water	made	290	of grout.
213	do.	87	do.	do.	305	do.
430	do.	180	do.	do.	604	do.
467	do.	201	do.	do.	660	do.
430	do.	180	do.	do.	620	do.
495	do.	176	do.	do.	664	do.
553	do.	180	do.	do.	711	do.

CHAPTER XXIV.

Observations and experiments on Concrete, &c.

It was ascertained, by careful measurement, that the void spaces, in 1 bulk of sand No. 1, taken from the middle of the heap, amounted to 0.33: the cementing paste, whatever it may be, should not be less therefore, than one-third the bulk of this sand. Taking one bulk of cement A, measured in powder from the cask, and a little compacted by striking the sides of the vessel, water was added till the consistence was proper for mortar: 0.35 of water was required to do this, and the bulk of the stiff cement paste was 0.625. To obtain, at this rate, an amount of cement paste equal to the voids (0.33) in the sand, will require, therefore, 0.528 cement in powder, and 0.185 of water, or

Dry sand,	1.000	making a bulk of 1.000 of mortar.
Cement in powder,	.528	
Water,	.185	

It is by no means certain that a mortar composed on this principle will be the most tenacious that can be made—on the contrary our experiments indicate that the mortar would be stronger with a smaller proportion of sand; but possessing the minimum quantity of cementing constituent, which is by far the most expensive ingredient, it affords the cheapest admissible mortar, made of cement and sand; and as it was probable, that it would shrink very little on drying, it was tried as a *pointing* for exposed joints, and also as *stucco*, and it answered very well for both purposes—becoming very hard, and never showing the slightest crack. An excess of cement, and a very *slight excess of water*, above the stated proportions, should be allowed for imperfect manipulation, because the proportions suppose every void to be accurately filled.

Extending the application of this principle to concrete—experiment showed that one bulk of stone fragments (nearly uniform in size, and weighing about 4 oz. each) contains 0.482 of void space. To convert this bulk of stones into concrete, we, in strictness, need use no more mortar than will fill this void space; and to compose this mortar we need use no more cement than is necessary to occupy, in the state of paste, the voids in 0.482 of sand. This concrete would therefore be composed as follows:

Stone fragments about 4 oz. each,	1.000	making a bulk of 1.000 of concrete.
Sand No. 1 . .	.482	
Cement in powder, .	.255	
Water, . .	.089	

Obtaining thus a cubic yard of concrete by the use of one-fourth of a cubic yard of cement in powder, (about one and a half bbls.)

But the above fragments were of nearly equal size, and of a form approaching the spherical: affording more void space than if they had been more angular, and had varied in size from about six oz. to less than one oz. such as would commonly be used. We have found that clean gravel, quite uniform in the size of the pebbles, which were about half an inch in average diameter, afforded voids to the amount of 0.39. And Mr. Mary, a French Engineer, used pebbles, probably mixed of coarse and fine, of which the voids were 0.37. The above allowance of 0.482 for void space is therefore quite large.

In all cases of the composition of concrete, the quantities expressed above, should be ascertained by actual measurement of the particular cement, sand and fragments, or pebbles, that are to be used. No better mode of measuring the void spaces, will be found, probably, than measuring the quantity of water that can be poured into a vessel already filled with stone fragments, pebbles, or sand, as the case may be.

Although the hydraulic property of cement will be the cause, in all cases of its use in concrete, it may happen that the cement at hand is more energetic than is actually necessary, and that the concrete would fully accomplish the object in view, even if it should be two or three weeks in becoming hard and impervious to water. Under such circumstances lime may take the place of part of the cement, with great economy. The lime may be added either in the state of powder that has been slaked some time, or in the state of paste: but in either case, the previous slaking must be complete.

The mortar is to be made first, and then the pebbles, or broken stones, may be mixed therewith by turning them over several times with the shovel.

When it is to be deposited under water, it is still a disputed point whether the concrete, prepared as above, should be used immediately, or be left in heaps to stiffen to such a degree as to require the use of pickaxes to break down the heaps: but, in works out of water, there can hardly be a case in which it will not be best to place it at once in its allotted space, where it should be compacted by ramming till none of the stone fragments project above the common surface. One or two trials will show how much mortar over and above the strict proportion is necessary in each case.

In circumstances where ramming cannot be applied, as when depositing concrete in deep water, the concrete should be more yielding and plastic —containing a larger proportion of mortar, and the mortar should be rammed before being deposited, in order thoroughly to imbed the larger constituents.

In many situations where concrete may be resorted to with great advantage, the economy need not stop at the above proportions. This substance may be rammed between, and upon, stones of considerable size—the only indispensable precaution being, to make sure that the stones are perfectly clean, are well imbeded in the concrete, and are far enough apart to permit the full action of the rammer between them.

The following case occurred at Fort Adams in October, 1836.

The proportions adopted were, *fragments of granite*, of

nearly uniform size, and about 5 oz. each,	1.000	Bulk of concrete, a little more than 1.000.
Sand No. 1 . .	0.500	
Cement A, in powder, . -	0.280	
Water rather more than .	0.100	

Experiment gave 16.683 as the number of cubic feet of concrete made by 1 barrel of cement—187 barrels were consumed which afforded 115.52 cubic yards of concrete. There were also used, 11.29 struck Winchester bushels of sand, and 22.58 struck Winchester bushels of granite fragments.

187 barrels of cement at $2.45	$ 458.15
1129 struck bushels of sand at $.0.37	41.77
2258 do. granite fragments at $0.04	90.32
Carried over,	$ 590.24

Brought over,	$ 590.24

There were 151 days labour, applied to making mortar—making concrete—depositing the concrete in its proper place, ramming it into a compact mass, and doing all other work required in the operation.

151 days at $ 0.92.	138.92
Supervision	10.00
Cost of 115.52 cubic yards,	$ 739.16

Cost of one cubic yard $ 6.40

Springs of water flowed over this work continually; and were allowed to cover each day's work. The next morning the concrete was always found hard and perfectly set.

Had we dispensed with one half of the cement used, and used in lieu thereof, as much paste of lime, as the cement dispensed with would have furnished of paste of cement, the cost would have been materially reduced, and the work have been still very hydraulic, and very strong. In that case, the bulk would not have been altered, but would have been as before, 115.52 cubic yards. We should have used 93½ bbls. of cement less than we did: and, as cement, in passing to the state of paste, diminishes in bulk in the proportion of 1 to .625, we should have used $93.5 \times .625$ equal to 58.43 barrels of paste of lime. Saving, thereby, the difference between the cost of 93.5 barrels of cement and 58.43 barrels of paste of lime.

93.5 barrels of cement at $ 2.45	$ 229.07
58.43 do. of paste of lime at $ 0.60	36.06
Amount saved	$193.01

$ 739.16, less $ 193.01, equal $ 546.15; the cost of 115.52 cub. yards.
Cost of one cubic yard $ 4.73.

Another Instance.

Proportions—Clean gravel,	1.000	Bulk of concrete about 1.15
Sand No. 1,	.530	
Cement A, in powder,	.430	
Water about,	.140	

This was rammed into a mould of the capacity of 13.786 cubic feet.

Cement A,	4.35	struck bushels at	$ 0.59	cost $ 2.57
Sand No. 1, washed	5.44	do.	" 0.04	.22
Gravel	10.00	do.	" 0.04	.40
Cost of all the labour,				1.03
Total cost of 13.786 cubic feet,				$ 4.22

Being $ 0.306 per cubic foot, or $ 8.26 per cubic yard.

This became very hard, and is a very good substitute for stone, in certain applications.

Another Instance.

Proportions—Clean gravel,	1.000
Sand No. 1,	.625
Cement A, in powder,	.333
Water, about	.125

This was rammed into a mould of the capacity of 7.812 cubic feet; and the whole cost was $ 2.15, being $ 0.276 per cubic foot, or $ 7.45 per cubic yard.

This became a hard mass, but the concrete was rather too incoherent to make the best factitious stone.

Another case.

In this instance, a box containing 7.812 cubic feet was filled, first, with pieces of a stone of slaty structure—laying the pieces on their beds; a grout was then poured in, until all the interstices were filled. The composition of grout was as follows.

Washed sand No. 1,	1.000
Cement A in powder,	1.000
Water,	.910

The whole cost was $2.40—being $0.31 per cubic foot—or $8.37 per cubic yard.

This mass became hard, but was not so strong as those made of mortar instead of grout.

Numerous objects have, at different times, been moulded at Fort Adams, with analogous compositions, and always with success. Sometimes concrete was used, the entire mass being rammed into the mould: at other times the mortar without the fragments was used *as mortar*; bricks, or fragments of stones, being laid therein, in successive strata, until the mould was filled. Shafts of columns—the Doric echinus, abacus, &c., thus formed many years ago, resist the climate well, although less perfect than we should now be able to produce.

All our experiments concur in showing that much sand weakens cement mortar essentially; at least when exposed to the air. The improvement to be applied to the foregoing proportions should consist therefore, if the expense be no objection, in increasing the quantity of cement—taking care to keep the quantity of water as low as possible, in order to retain the shrinkage of the indurated mass at a minimum. It is surprising how much water may be driven out of an incoherent and apparently half-dry heap of cement-mortar, by hard ramming: and it is still more surprising, after the exact quantity necessary to saturation has been supplied, how small a quantity of water will suffice to convert a dry and powdery heap, if well worked, into a thin paste. Cements vary in their capacity for water: hence the dose of water is a matter that must be established by experiment in each case. The true quantity for concrete, and moulded objects in air, is that which, with hard ramming, affords a stiff paste, with a *little* free water on the surface: a state to which it can be brought with difficulty under the trowel or under the shovel. More water than this is attended with the double disadvantage of lessening the density of the mortar when dry, and of causing cracks by the shrinkage. If the quantity of water be thus regulated, the quantity of cement may be increased at pleasure, but the expense will increase rapidly with every addition of cement. In the first concrete above, the bulk of the dry cement is about one half the bulk of the sand, and the expense per cubic yard is $6.40; make the dry cement to equal the sand in bulk, and the expense per cubic yard will be about $10.00, all other proportions remaining, as they ought, the same.

In the preceding proportions it has been supposed that the concrete was to be used in the air, and that nothing would prevent the free use of the rammer. But if the concrete is to be deposited under water beyond the reach of this instrument, there should be a change of the proportions; and the quantity of mortar should be so increased that the fragments will be certain to be severally imbedded therein from their own weight, the gentle operation of the rake and other leveling instruments, and the pressure of the superincumbent concrete. Attention must be paid to the constituents of the mortar, in reference to hydraulic energy, also, especially in running water: this mortar must not only be very hard after a time—it must become hard speedily; and to attain this end, the materials at command may demand proportions quite different from those required to fill the voids in the sand.

The following instances are derived from the practice of the French.

M. Mary, Engineer des Ponts et Chausseés, states that he ascertained the voids between the stones to be .37 of the whole bulk—that filling .90 parts of a box with stones, .10 parts+(.37×.90=.33)=.43 parts of mortar would be required, in theory, to fill the box: but he found that the box was more than full, showing that some of the mortar designed to occupy the voids did not reach them, from imperfect manipulation. Instead of .90 parts, he then filled .87 parts of the box with stones, which required that the mortar should amount to .13+ (.37×.87=.32) =.45 parts of mortar; and this he found filled the box very exactly. He also found that the transportation of the concrete, in wheelbarrows, from the mortar bed to the place where it was to be deposited, produced agitation enough to settle all the stones to their places, and bring the excess of mortar to the top. M. Mary is not aware that so large a proportion of stones had been employed any where else than at Pont-de-Remy, at Abbeville, and at the upper dam of Saint Valery; but at these places, no disadvantage resulted from the quantity, and the concrete was impervious to water. The mortar mixed with these stones was composed of 0.22 parts of feebly hydraulic lime measured in paste—0.225 of sand—and 0.225 of brick, or tile, dust ("*cement.*") The proportions of this concrete were therefore, as follows:

	Stones,	.87	Total bulk 1.000
	Sand,	.225	
	Brick, or tile dust,	.225	
	Feebly hydraulic lime in paste	.22	
	Water,		
Or—	Stones,	1.000	1.15
	Sand,	.259	
	Brick or tile dust,	.259	
	Feebly hydraulic lime in paste,	.253	
	Water,		

At the lock of Haningue the cube of concretes was composed as follows:

Pebbles,	.69	Bulk 1.00
Sand,	.40	
Hydraulic lime in paste,	.22	
Water,		

As to this case M. Mary observes that it is probable the pebbles were a mixture of coarse and fine gravel; because, with these quantities, in order to make up the cube of 1.00, the void spaces could amount to only about .09. This would be about 13 per cent. only of the measure of the pebbles, instead of 37, found by M. Mary, himself, in the case stated above. Expressing, as in the other cases, the proportions used at this lock, in parts of the measure of pebbles—it would stand thus,

Pebbles,	1.00	Bulk 1.45
Sand,	.58	
Hydraulic lime in paste,	.32	

To found the pier of the suspension bridge communicating between la Grève and l'île de la Cité, at Paris, a concrete was used which was much more hydraulic than those just mentioned. It was thus composed:

Fragments of Buhrstone,	1.00	Resulting bulk 1.50
Sand,	.50	
Factitious puzzolana of M. St. Leger,	.25	
do. hydraulic lime do. (unslaked)	.25	
	2.00	

This concrete was placed in a bed eight feet thick, which, owing to a flood in the Seine, was about six weeks in being deposited. Masonry was begun upon it in eight days after its completion, and in six weeks it had the whole pier to support; and before the concrete was four months and a half old it sustained the weight of the pier of the bridge, and of the proof load, without the least appearance of subsidence.

At the Saint Martin canal, where great quantities of concrete were used, the proportions were:

Pebbles,	1.00	Bulk 1.63
Sand,	1.00	
Hydraulic lime	.33	

In another case, these proportions were used, viz:

Siliceous pebbles,	1.00	Bulk 1.34
Tile dust and brick dust,	.28	
Fat lime made from chalk used at the moment of slaking—measured as quicklime,	.56	
Water, more or less,	.53	

Another case.

Rounded gravel about the size of a hazle-nut,	1.000	Bulk 1.15
Mortar, . .	0.500	

The mortar being composed of brick-dust,	1.00
Slaked lime, in powder,	1.00
Sea-sand,	1.00

After three months immersion in salt water, this concrete sustained a pressure on one end of the mass of 260,000 pounds per square foot of surface without impression. On being broken up, it showed that the gravel was well imbedded in mortar. The void space in the gravel was found to measure 0.35.

Another.

The aqueduct of Guétin, which conducts the Loire canal across the Allier, is composed of 18 arches of 53½ feet span, and of 17 piers of 9.84 feet in thickness. Immediately at one end of the aqueduct are three connected locks, whereof the mass forms the left buttress of the bridge.

The right buttress and its wing-walls, the 17 piers, and the three connected locks, are built on a general "*radier*" or platform, 1594 feet long, 57.42 feet wide, and 5.41 feet thick; on the upper and lower sides of the platform are two guard walls 6.56 feet thick, and 14.76 feet deep—these walls, like the rest of the platform, rising to within 1.64 feet of the level of the water in the river in its lowest state.

The whole of the guard walls, as well as the lower layer of the platform for a thickness of 3.28 feet, were formed of concrete deposited in the water. The concrete used amounted to near 22,000 cubic yards.

The operation of depositing the concrete was confined to the 4 or 5 months between the spring and autumn floods; and at the end of the second season it supported the superstructure above described.

The following is the composition of the concrete:

Stone fragments,	1.000		
Mortar,	1.000		
		The mortar was composed of sand,	1.50
		Hydraulic lime measured in powder,	1.00
		Artificial puzzolana of M. St. Leger,	0.50

And the puzzolana was formed by calcining, at a heat not great, a mixture of four parts of earthy clay measured in paste, and one part of fat lime measured in the same way—the mixed pastes being formed into small prisms, dried in the sun, calcined and pulverised.

In order to obtain some evidence of the actual strength of concrete, and to compare several varieties of compositions, the experiments contained in the following table were made at Fort Adams: some prefatory remarks are necessary in relation to them.

The *cement* was obtained by taking several casks of hydraulic cement A, of nearly equal energy—emptying them into one heap on the floor, and after mixing the contents intimately, returning the cement into the casks, and heading them all tightly, until they were severally wanted. As the casks were opened, in succession, for use, the quality of the mixture was tried with the test wire, and was found to be very uniform—about half an hour being required for the setting. This cement had been on hand about four months.

The *lime* used was Fort Adams' unground lime. It was slaked to powder by the affusion of one-third its bulk of water, and allowed to stand several days. As it was about to be used, it was reduced to paste and passed through a hand paint-mill, by which it was made very fine. It should be borne in mind that this lime is slightly hydraulic.

The *sand* used was sand No. 1

The larger constituents of the concrete were of four kinds, viz: 1st. *granite fragments,* angular, average weight of each 4 oz.; 2d, *brick fragments,* angular, average weight 4 oz.; 3d. *stone-gravel,* made up of rounded pebbles from ½ to ¾ of an inch in diameter; and, 4th. *brick gravel,* composed of angular fragments of bricks from ½ to 1 inch in their greatest dimensions. All were perfectly free from dirt, and were drenched with water before mixing them with the mortar.

The measure of the void spaces in the granite and brick fragments was .48; and of the stone gravel and brick gravel, .39.

One set of experiments was made by using, in each case, a measure of mortar equal to the measure of void space—and another set, by using two such measures of mortar.

The mortar was made witn as small a quantity of water as possible. On this account, the mixture of the constituents was probably somewhat imperfect; and to this may, in part, be attributed the irregularities observable in the results. The concrete, before ramming, was quite incoherent, especially when only one measure of mortar was used. It was, in every case, consolidated by ramming into boxes that afforded rectangular prisms of concrete 12 inches by 6 inches by 6 inches.

The prisms were made in December 1836, and being kept in a damp place, safe from frost and accident, were broken in June, July, and August following. In breaking the prisms the two edges of the supports were 9 inches apart, leaving $1\frac{1}{2}$ inch resting at each end: weights were applied, by adding about 60 lbs. at a time, to a scale-pan suspended from a knife edge which bore on the middle of the prism.

Table LXIX.

Trials made in June, July and August, 1837, of the strength of concretes made in December 1836. The results show the weight in pounds required to break prisms of concrete 12 inches by 6 inches by 6 inches—the distance between the supports being 9 inches.

No.	Composition of the Concrete.	Mortar No. 1. Cement A. 1.00, Sand No. 1. 0, Lime 0	Mortar No. 2. Cement A. 1.00, Sand No. 1. .50, Lime 0	Mortar No. 3. Cement A. 1.00, Sand No. 1. .50, Lime .25	Mortar No. 4. Cement A. 1.00, Sand No. 1. 1.00, Lime 0	Mortar No. 5. Cement A. 1.00, Sand No. 1 1.00, Lime .25	Mortar No. 6. Cement A. 1.00, Sand No. 1. 1.50, Lime 0	Mortar No. 7. Cement A. 1.00, Sand No. 1 1.50, Lime .25	Mortar No. 8. Cement A. 1.00, Sand No. 1. 2.00, Lime 0	Mortar No. 9. Cement A. 1.00, Sand No. 1. 2.00, Lime .25
1	Granite fragments, with 1 measure of mortar	4973	4142	2778	3989	2721	2045	2056	lost	1574
2	do. with 2 do.	4068	4983	5064	4088	5366	1547	3537	1643	1972
3	Brick fragments, with 1 measure of mortar	3242	2117		4127	3254	1788	2136	1567	3649
4	do. with 2 do.	2805	5047	2826	4232	1178	3655	3856	2320	4803
5	Stone gravel, with 1 measure of mortar	1097	1049	1240	1256	1066				
6	do. with 2 do.	2347	4247	2655	1295	3351				
7	Brick gravel with 1 measure of mortar	5437	6183	3088	lost	4726				
8	do. with 2 do.	6025	5712	5480	3142	2699				
9	Stone fragments, grouted,	3278	1846	2012	1158	1178				
10	Brick fragments, grouted,	1634	2305	2869	2726	2770				

Observations on the experiments given in the above table.

It is to be regretted that such discrepancies are to be noted in the table. They are ascribable, in the first place, as suggested above, to the difficulty of bringing the mixture always to the same condition as regards the dissemination of the ingredients, when worked in so dry a state; but, probably, chiefly to the difficulty of filling the moulds always with equal accuracy, and ramming every part with equal force, when using so incoherent a mortar, united with so large a proportion of very coarse ingredients.

Notwithstanding these discrepancies, however, several deductions may be fairly drawn from the table, which, if confirmed by future trials, will be useful.

1st. *When the mortar was made of cement, sand, and lime, or of cement and sand without lime, the concrete was the stronger as the sand was less in quantity* In 50 comparisons 19 exceptions. *But there may be* 0.50 *of sand and* 0.25 *of lime without sensible deterioration; and as much as* 1.00 *of sand and* 0.25 *of lime, without great loss of strength.*

2d. *A mortar of cement and sand does not seem to be improved by the addition of lime, while the bulk of sand is only equal to, or is less than, the bulk of cement; but as the quantity of sand is further increased, the mortar appears to be more and more benefitted by the addition of a small quantity of lime.*

3d. *Two measures of mortar, in concrete, are better than one measure; that is to say, a quantity of mortar equal to the bulk of the void space does not give as strong a concrete as twice that quantity of mortar.* In 30 comparisons, 7 exceptions. Nevertheless, the strongest example was with one measure of mortar, and it is not unlikely that the deficiency of strength in the other cases resulted from the difficulty of causing all the voids to be accurately filled, when the mortar was a minimum, and the space into which it was forced so small. It is not improbable that the voids may be perfectly occupied, even with one measure of mortar, when the mass of concrete is large enough to permit the full effect of the rammer.

4th. The results of the experiments recommend the several compositions of the table, in the following order, namely:

1.	Brick gravel,	with 2	measures of mortar,	No. 8.
2.	do.	with 1	do.	7.
3.	Brick fragments,	with 2	do.	4.
4.	Granite fragments,	with 2	do.	2.
5.	do.	with 1	do.	1.
6.	Brick fragments,	with 1	do.	3.
7.	Stone gravel,	with 2	do.	6.
8.	Brick fragments, grouted			10.
9.	Stone fragments, grouted			9.
10.	Stone gravel,	with 1	measure of mortar	5.

5th. *It appears that the best material to mix with mortar to form concrete, is quite small, angular, fragments of bricks: and that the worst is small, rounded, stone-gravel.*

6th. *Grout, poured amongst stone, or brick fragments, gave concretes inferior to all, but one, of those obtained from mortars.*

A piece of sound and strong *red sand-stone*, 12 inches by 4 inches by 4 inches, required a weight of 3673 pounds to break it—there being 9 inches between the supports. According to the formula $P = R.\frac{ab^2}{c}$,* prisms of

* In this formula P is the weight causing fracture, c the distance between the supports, a the breadth, and b the depth of the prisms.

this stone of the size of our prisms of concrete, would require the weight of 12,396 lbs. to break them; whence it appears that the strongest prism under trial, was, after eight months exposure, half as strong as this sand stone.

CHAPTER XXV.

Some recent experiments with Mortars made of Lime and Sand.

There will be presented, in conclusion, some experiments, made very recently at Fort Adams, with lime mortars without cement; they were instituted in reference to the best proportions of lime and sand, and also to a comparison of coarse and fine sand, and salt and fresh water.

In making these, a cask of fresh Smithfield lime, of the best quality, was taken, and the lumps broken into pieces of about the size of a pigeon's egg. These being carefully screened, in order to get rid of all dust and fine lime, and carefully intermixed, in order to obtain uniformity of quality throughout, were slaked by the affusion of water to the amount of one third the bulk of lime. When cold, the slaked lime was returned to the barrel, which was carefully headed and put in a dry place; and on all occasions of withdrawing a portion of this lime for use, the cask was carefully re-headed.

The sands used were those described in page 4, as sand No. 1, sand No. 2, sand No. 3, and sand No. 4.

In making the mortars, just enough water was added to the slaked lime taken from the cask, to make a stiff paste. This paste being passed through a hand paint mill, which ground it very fine, was mixed, by careful manipulation, with the due proportions of sand. Much care was bestowed upon the operation of filling the prism-moulds with mortar; and each prism was submitted to a pressure of 600 lbs. for a few minutes, that is to say while the succeeding prism was being formed.

About one week was consumed in preparing the prisms—namely, from the 7th to the 15th of May, 1838. And they were broken on the 1st of July, 1838, making the average duration of the experiment, 50 days.

Three prisms were made of each composition. But, on the principle that there are several causes which tend to make a prism weaker than it should be, and few or none that tend to make it stronger, only the maximum result of eaoh experiment is given in the following table.

It may, however, be well to state that precisely the same inferences are deduceable, if the mean of the results be taken instead of the maximum.

Table No. LXX.

Trials made on the 1st of July, 1838 of the strength of the mortars made between the 7th and 15th of May, 1838 (50 days.) The results show the weights, in pounds, required to break prisms of mortar 6 inches long, by 2 inches by 2 inches: the distance between the supports being 4 inches, and the power acting midway between the supports.

Composition of the mortars.	Sand No. 1.—Lime. Fresh water.	Sand No. 2.—Lime. Fresh water.	Sand No. 3.—Lime. Fresh water.	Sand No. 4.—Lime. Fresh water.	Sand No. 1.—Lime. Salt water.	Sand No. 3.—Lime. Salt water.
Lime in stiff paste 1—Sand 0	262½					
do. 1 do. ¼	224	220½	248½	353½	192½	234½
do. 1 do. ½	213½	234½	234¼	241½	210	199½
do. 1 do. 1	248½	220½	227½	234½	178½	178½
do. 1 do. 2	164½	199½	161	178½	140	178½
do. 1 do. 3	157½	189	185½	157½	119	119
do. 1 do. 4	126	227½?	157½	136½	101½	154

Observations on the experiments of table No. LXX.

1st. Within the limits of the experiments, the mortar was the stronger as the quantity of sand was the less—in 96 comparisons, 12 exceptions.

2nd. Although the above inference is derived from the whole range of the table, still, when the quantity of sand was less than the quantity of lime, the weakening effect of the sand on the mortar was not very sensible. And it would seem from table No. LXV. that from one-fourth to one-half of sand may be slightly beneficial.

3rd. It appears that coarse sand, or, rather, sand composed of coarse and fine particles, (sands No. 1 and 2,) is a little inferior to sand that is all fine (sands No. 3 and 4;) in 36 comparisons, 16 exceptions; and also that sand reduced by pounding to a fine powder (No. 4,) afforded some of the best results of the table. It is to be regretted that no experiments were instituted in order to compare sand all coarse, with sand all fine.

4th. It appears that the mortars made with salt water—that is to say, the water of the ocean, was decidedly weaker than those made with fresh water; 1 exception in 12 comparisons. The aggregate strength of all the prisms made of coarse sand and salt water was 2674 lbs.; while the aggregate strength of the corresponding prisms of coarse sand and fresh water was 3174 lbs. And the aggregate strength of all the prisms of fine sand and salt water was 2800lbs. while the aggregate strength of the corresponding prism of fine sand and fresh water was 3346 lbs.

DESCRIPTION OF THE PLATES.

PLATE I.

Fig. 1. *a, a,* Prism of mortar under trial.
b, b, Iron stirrups, supporting the prism.
c, c, Iron collar, embracing the prism.
d, d, Iron link, to which the ropes of the scale-pan are fastened.
e, e, check, against which the collar rests when on the middle of the prism.
f, f, Timber, to which the stirrups are attached.
g, Scale pan, in which the weights to break the prism are put.
Fig. 2. *h,* Interior of the furnace.
i, Door of the furnace.
k, k, Chimney
l, Register.
m, m, Arches, under the hearth, in which the fuel is placed.
n, n, Conduits, to lead the flame and a current of air into the furnace.
Fig. 3. *o,* Plan of lime kiln.
p, p, Nut of the kiln.
q, q, Steps descending to the doors of the kiln.
r, Steps, up which the materials are carried to the top of the kiln.
s, s, Doors of the kiln.
t, t, Portions of spherical arches leading to the doors of the kiln.

PLATE II.

Figs. 4, 5, 6, 7 and 8, represent Mr. Petot's "*curves of energy*" of fat lime, hydraulic lime—plaster-cements—calcareous puzzolanas, and clay.
Fig. 9. *a, b,* Half staples, driven into the floor.
f, g, A pair of bricks united by mortar.
c, c, Iron piece, embracing the ends of the upper brick, and suspended from the steelyard.
d, Steelyard.
e, Bucket, into which sand flowed from the trough.
h, Trough.
i, Floor.
Fig. 10. *a, b, c,* Iron lever, with a steel point at *a* to impress the mortar *f,* on the brick *g.*
d, Steelyard, connected with the lever *a, b, c,* at *c.*
e, Iron rod, from which the steelyard is suspended.
h, h, Uprights, supporting the rod *e.*
i, Uprights of iron, supporting the fulcrum of the lever *a, b, c.*

FINIS.

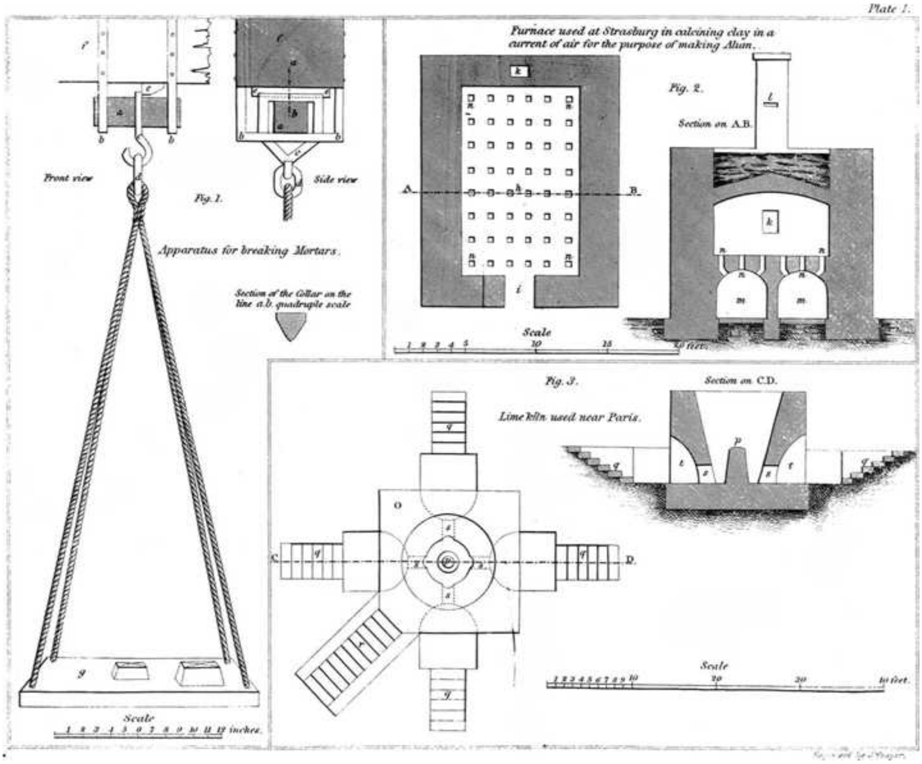
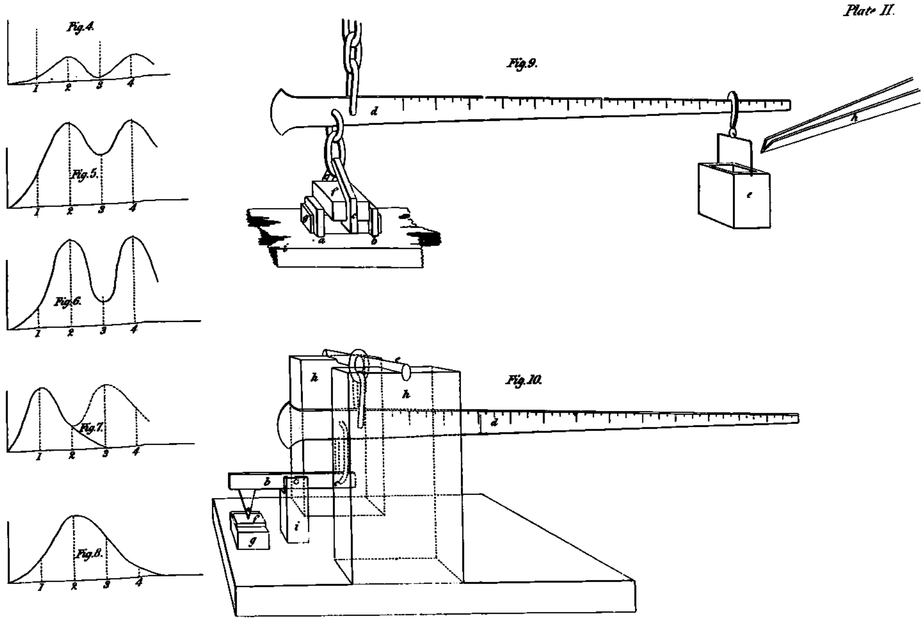

Front view
Fig. 1.
Side view
Apparatus for breaking Mortars.
Section of the Collar on the line a.b. quadruple scale
Scale
inches.
Furnace used at Strasburg in calcining clay in a current of air for the purpose of making Alum.
Fig. 2.
Section on A.B.
Scale
feet.
Fig. 3.
Section on C.D.
Lime kiln used near Paris.
Scale
feet.

Plate II.



ERRATA.

PAGE.

8. Line 29 from top—for *Berard*, read *Brard*.
26. Table 4, last column—for 22 lbs, read —22 lbs.
33. Table 8, No. 3—for 1 day required to harden in water, read 1½ day.
35. 8th line from bottom—for *pharmacitur* read *pharmacien*.
37. Table 9, last column, 2 lines from bottom—for 197 lbs., read 187 lbs.
42. Line 6 from top—for *one-fifth*, read *one and a half grammes*.
44. Table 10, No. 5—for 1 day, read 15 days.
" " No. 10—for 24 days, read 25 days.
45. Line 3 from top—erase the ; after the word lime.
49. Table No. 11, No. 2—for 3-10 of pipe clay, read 2-10.
" Line 5 from bottom—for 1-10 read 2-10.
57. Table No. 14, 8th column—for 96 read 396.
" " " for 3*d* read *d*.
" " 11th " for 86 read 385.
61. Line 14 from top—insert the word *the*, before the word *three*.
" Line 4 from bottom—for *table* read *tables*.
" Bottom line—insert the word *good*, before *resistance*.
65. Line 3rd from bottom—erase *up*.
66. Last line in the note—for 194 lbs., read 191 lbs.
76. Table No. 22, No. 12—for *dust of clay No*. 9, read *dust of clay No*. 8.
77. Line 20 from bottom—for *Haquenau*, read *Haguenau*.
78. Table No. 23, No. 9—for *same clay with* 1-6 *do*., read *same clay with* 1-4 *do*.
" " " 6, in last column but one—for 15, read 25.
80. Table No. 24, Nos. 15 and 16—for *Kilbsheim clay*, read *Kolbsheim clay*.
84. Line 13 from top—for *vigorously*, read *rigorously*.
85. Line 15 from bottom—for *the bad mortar*, read *the last mortar*.
90. Line 15 from top—for *are as follows*, read *cost as follows*.
91. Line 12 from top—for *preparation*, read *proportion*.
101. Table No. 28, No. 15, last column—for 405, read 385.
105. Line 24 from bottom—for *attach*, read *attacks*.
107. Line 20 from top—insert the word *dissolved*, after the word *had*.
" Line 6 from bottom—for *nearly*, read *merely*.
109. Line 17 from top—insert the word *always* after the word *not*.
110. Line 2 from top for *thorough*, read *thoroughly*.
" In the table, last column—for 0.3500, read 0.3300.
112. Line 2 from top—for *lamelleo*, read *lamelles*.
122. Line 6 from top—for *poured*, read *formed*.
129. Line 10 from top—for *mortars*, read *matters*.
" Line 11 " " "
" Line 17 " for *difficult*, read *different*.
133. Line 13 from bottom—for *le mortar que*, read *le mortier qui*.
134. Line 9 from top—for *that the lower*, read *the lower*.
136. No. 3 of table 32—for 1 *of lime and* 1 *of sand*, read 1 *of lime and* 2 *of sand*.
137. Table No. 33, No. 1—for 50 lbs., read 55 lbs.
" " When 22 lbs. occurs in the table, it should be preceded by the negative sign.
138. Line 6 from bottom—for *Table No*. VI, read *Series No*. 6.
139. Table No. 34, last column—for 10, read —22.
142. Table No. 35, No. 4—for 262 lbs, read 242 lbs.
143. Line 21 from top—for *shows*, read *shew*.
146. Line 2 from bottom—for *Article* XIII., read *Chapter* XIII.
" Bottom line—for *Article*, read *Chapter*.
147. Top line—for *Article*, read *Chapter*.
149. Line 16 from top—for XXVII, read XXXVII.
156. Line 7 from bottom—insert the word *in* after the word *cement*. and erase the comma.
157. Line 2 from top—for *should*, read *would*.

PAGE.	
160.	Line 18 from bottom—for *pieces*, read *piers*.
"	Line 17 " do do
161.	Line 9 from bottom—for *least*, read *last*.
164.	Line 12 from top—substitute for *or*, the words *such as*.
"	Line 16 " substitute for *wrong*, the word *advantageous*.
168.	Line 7 " for *amelioracion*, read *amelioration*.
"	Line 7 " for *work*, read *works*,
177.	Line 22 from bottom—for *trass*, read *copper*.
180.	Table 48, last line—for *calcined*, read *melted*.
"	Line 4 from bottom, and in every other case where the word occurs—for *plas tic cements*, read *plaster-cements*.
184.	Line 27 from bottom—insert the words *stone of the*, before the word *Pouilly*.
189.	Table 51, 3d column—for 54, read 51. 4th column, for 51, read 54.
190.	Line 5 from top—for *cases*, read *causes*.
"	Table 52, 7 line from top—for *one-half of quartzose sand*, read *one of quartze sand*, and in the last column, for 12.31, read 13.31.
"	Line 10 from bottom—for *Biard*, read *Brard*.
198.	Line 16 from bottom—for 76.00, read 74.00.
211.	Line 9 from top—for *that of* 1·5 *of clay*, read *as much as* 1·5 *of clay*.
213.	Line 16 from top—for *Rine de Geir*, read *Rive-de-Gile*.
219.	Table 57, column 3—for *clay from Bidoreau*, read *clay from Bedouan*.
222.	" 60, column 4—for 0.159, read 0.059.
"	" " 5—for 0.019, read 0.059.
223.	Table 61, column last—for 19, read 79.
225.	Table 63, No. 17—for *minerals*, read *mineral*.
226.	Table 64, No. 10—for 09.4, read 59.4.
"	" No. 53—for 293.8, read 239.8.
227.	Bottom line—for *three*, read *thin*.
229.	Line 16 from bottom—for *instance*, read *instants*.
232.	Line 10 from top—insert the words *each result*, before the word *unless*.
233.	No. 19—for *Sand, No.* 3, read *Sand, No.* 2.
239.	No. 9, 3d column—for $\frac{1}{3}$, read $\frac{1}{8}$,
242.	Line 25 from bottom—for 1.70, read 1.10.
244.	Line 8 from bottom—for 11.29, read 1129.
"	" 7 " for 22.58, read 2258.
"	" 4 " for $0.37, read $0.037.
247.	Line 16 from bottom—for *Haningue* read *Huningue*.