the authors in Fig. 57, page 151, from tables presented by Mr. Humphrey.

To transform these mechanical analysis curves to Feret's granulometric composition, we may draw on the diagram, ordinates corresponding to the sizes of sieves used by him, namely, No. 5, No. 15, and No. 46. (See p. 143.) From inspection of the curve it is evident that the granulometric composition of the gravel sand is g = 0.56, m = 0.35, f = 0.09, and of the river sand is g = 0.00, m = 0.89, f = 0.11. Plotting these granulometric compositions as *C* and *D* on Feret's triangle, Fig. 55, and interpolating between contours, we find the relative compressive strengths of mortars made from the two sands to be, after one year in fresh water, about as 1775 is to 2550, or as 1 : 1.44, while Mr. Humphrey's ratio of tensile strength for the two mortars at the age of one year is as 304 is to 470, or as 1 : 1.53. These ratios are remarkably similar when the differences in conditions are considered.

Numerous tests have been made in America* in proof of the general law that coarse sands are stronger than fine. Many experimenters have seemed to reach the result that coarse sand is stronger than mixed sand. In certain cases this is undoubtedly true, because of mixing the different sizes in wrong proportions, or because the mortar of coarse sand contains so large a proportion of cement that the voids are completely filled and the addition of fine sand decreases, instead of increasing, the density. Mortar, for example, as rich as 1 : 2 (*i.e.*, one part cement to two parts sand) of coarse sand is as strong as, and often stronger than, mortar of similar proportions made of almost any mixed sands, but with leaner mortars, a small admixture of from 10% to 25% of fine sand improves it. Natural sand, which in appearance is very coarse, almost invariably has a small percentage of very fine particles which, with the fine grains of cement, may assist, in the leaner mixture, in producing a dense mortar. The mechanical analysis curves of sand shown in Fig. 72, on page 200, are an illustration of the fine matter contained in all bank sands.

EFFECT OF QUANTITY OF WATER UPON THE STRENGTH OF MORTARS

Fine sands require in gaging a larger percentage of water than coarse sands, in order to produce a mortar of the same consistency. This, as discussed on page 147, exerts an indirect influence upon the strength.

The influence of different percentages of water upon the same cement and aggregate is largely physical, although a deficiency may affect the permanent strength of a mortar, while an excess may for reasons given on page 271 injure the cement by dissolving a portion of it.

*E. S. Wheeler in Report Chief of Engineers, U. S. A., 1895, p. 3013, A. S. Cooper in Journal Franklin Institute, Vol. CXL, p. 326, Ira O. Baker in Journal Western Society of Engineers, Vol. I, p. 73

The effect of different proportions of water upon the ultimate strength (as suggested on p. 142) depends chiefly upon the density of the resulting mortar; the consistency which produces with a given weight of the same materials, the smallest volume, after setting, of Portland cement paste or mortar, gives the highest strength. Dry mixed mortars usually test higher than wet, — especially at short periods, as they set and harden more rapidly, — because they can be more densely compacted, but more uniform results in practice as well as in experiment, can be attained with plastic mixtures.

Tests by Mr. E. S. Larned,* a portion of which are shown in the table on page 154, illustrate the practical effect of different proportions of water upon the strength of neat cement pastes at various periods. It is noticeable that although the Natural cement mixed very wet finally attains a high strength, its very low strength up to 28 days shows the inadvisability of mixing Natural cement with an excess of water.

SAND VS. BROKEN STONE SCREENINGS

The relative strength of mortars made from sand and from screenings of broken stone or crusher dust has occasioned much discussion and dispute. It is probably dependent chiefly upon the relative density of the different mortars. Usually, a mortar from screenings will show higher tests, while occasionally mortar from sand will be superior, because of the difference in size or of the relative sizes of the particles or grains composing the two materials.

In some cases the form of the grain† and the mineralogic composition‡ may exert a certain influence, although tests show that these are usually of inferior importance to the mechanical or granulometric composition of the sand or screenings. It is possible that the fine dust or impalpable powder in certain stone may chemically react upon the cement.

On the other hand, screenings from a soft stone like slate, shale or soft limestone, may contain so much dust as to produce a poor mortar or concrete, for the same reason that a very fine sand results in a weak mortar.

*Proceedings American Society for Testing Materials, Vol. III, 1903, p. 401.

†Baumaterialienkunde, V Jahrgang (1900), p. 21, and Annales des Ponts et Chaussées, 1892, II, p. 124.

‡Mr. P. Alexandre found calcareous sands to give relatively high strength, and Mr. Feret obtained similar high results with marble.

Table Showing Strength of Cements Mixed Neat with Different Proportions of Water.

BY EDWARD S. LARNED. (*See p.* 153.)

Cement brand	Water per cent	Sieve test residue on			Wire minutes		Tensile strength					
		No. 50	No. 100	No. 180	Light	Heavy	24 hours	7 days	28 days	3 months	6 months	12 months
Portland A	13											
	14											
	15	0.15	5.4	21.2	12	207	371	655	875	941	720	787
	16	..	..	..	29	297	303	750	973	1008	735	816
	18	..	..	..	80	355	260	649	773	831	645	748
	20	..	..	..	142	402	233	500	693	716	621	676
	22	..	..	..	268	473	184	546	635	658	601	589
	24	..	..	..	327	912	167	539	649	644	629	755
Portland B	13	0.1	7.0	18.0	13	270	366	775	859	1067	892	832
	14	..	..	..	18	303	404	780	891	972	852	781
	15											
	16	..	..	..	22	327	363	602	725	844	806	723
	18	..	..	..	15	383	308	570	723	785	728	724
	20	..	..	..	56	703	225	590	718	760	674	636
	22	..	..	..	52	833	166	554	649	731	643	604
	24	..	..	..	188	918	42	510	691	695	632	574
Natural (Lehigh Valley)	23	0.1	4.6	10.2	13	32	212	251	252	311	275	356
	24											
	25	..	..	..	18	39	185	218	215	289	300	341
	27	..	..	..	21	42	150	188	220	257	272	314
	29	..	..	..	20	52	128	178	202	246	248	256
	31	..	..	..	21	57	112	173	199	224	259	309
	33	..	..	..	27	85	104	172	182	267	246	290
	35	..	..	..	38	137	93	121	178	260	286	319
	37	..	..	..	34	160	85	108	168	262	306	326
	39	..	..	..	67	233	85	119	202	252	371	400
Natural (Rosendale)	23	2.3	12.4	21.9	22	59	138	177	271	332	284	264
	24	..	..	..		78	125	141	264	342	309	310
	25	..	..	..	35	120	150	164	216	308	318	321
	27	..	..	..	49	143	117	116	194	305	345	272
	29	..	..	..	76	166	96	105	164	272	320	267
	31	..	..	..	117	212	72	72	159	270	371	225
	33	..	..	..	115	235	62	71	147	277	379	244
	35	..	..	..	127	400	50	64	112	245	318	315
	37	..	..	..	198	828	59	62	96	..	284	351
	39	..	..	..	260	1057	54	56	85	..	355	364

NOTE. — Results shown are the averages of six briquettes made.

Such dusty screenings are also especially bad for granolithic surfacing for sidewalks, and must not be used.

SHARPNESS OF SAND

In the past all specifications have called for clean, "sharp " sand in spite of the fact that in many parts of the country where sharp sand is not obtainable, sand with rounded grains is furnished and used with perfect satisfaction.

Comparative laboratory tests under conditions as nearly as possible identical uphold the practice of using sand with rounded grains. They indicate, as may be inferred from the previous discussion in this chapter, that the chief difference in natural sands is due to the size of the grains, and while the sharpness of grain may exert a certain influence it is of so much less importance than the size of the grain that *the requirement of sharpness for sand should be omitted from concrete specifications.*

Referring to columns (11) and (22) in the table on page 136, and to Fig. 49, page 141, it is evident that the difference in strength of nearly all the mortars made with the various sands is explained by the differing percentages of cement and densities without reference to the character of the grains. The only noticeable exception is with the artificial sand, M′, which consists of mixed sizes of crushed quartz. Mr. Feret‡ believes that this exception may be due to chemical action produced by the large quantity ($\frac{1}{9}$ its weight) of impalpable quartz. Sand N′, also crushed quartz, but containing none of this fine powder, produces a mortar similar in strength to like mortars of natural sand having rounded grains.

Other tests of Mr. Feret§ and comparative tests, in the United States, of mortar with crushed quartz and natural sands generally confirm the above conclusion. The variation in the shape of the grains of natural sands and crushed quartz is illustrated in Figs. 62, 64, and 65, page 175.

EFFECT OF NATURAL IMPURITIES IN THE SAND UPON THE STRENGTH OF MORTAR

A clause to the effect that a sand for mortar or concrete shall be "clean" is almost universally found in masonry specifications. The necessity for this requirement is often questioned by cement experimenters, because the results of tests of mortar to which percentages of loam or clay have been added, often give higher results than those of mortar made with cement and pure sand.

‡Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1897, Vol. II.

§Annales des Ponts et Chaussées, 1892, II, p. 124.

As a matter of fact, it is impossible to make a general statement either to the effect that natural impurities in sand are beneficial or that they are detrimental. In some cases fine material may be of actual benefit, while in others the contrary is true.

The case is covered by three conditions: (1) the character of the impurities; (2) the coarseness of the sand; (3) the richness of the mortar.

Character of Impurities. If the fine material is of ordinary mineral composition, such as clay, the mortar is affected only mechanically, and the results depend upon the coarseness of the sand of which the fine material is a part and the richness of the mortar, as indicated in paragraphs which follow. One exception to this general rule is when the clay is in such condition as to "ball up" and stick together so as to remain in lumps in the finished concrete. On the other hand, a small percentage of clay well distributed may be valuable for making the concrete or mortar work smooth, and especially for increasing its water-tightness (see p. 343).

Vegetable or Organic Impurities. When the impurities are of an organic nature, like vegetable loam, they frequently have been found to prevent the mortar or concrete from hardening or to retard the hardening for so long a period as to make the sands entirely unfit for use. A very minute quantity of vegetable matter may produce injury, so small a percentage in fact that frequently a sand which has passed careful inspection fails in practice to set properly with any brand of cement; therefore a test is absolutely necessary for any sand which has a suspicion of organic matter.

The following tests of 1 : 3 mortar made with sand satisfactory in appearance, but which nevertheless caused the fall of a concrete building, are given

Effect of Vegetable Impurities in Sand

By Sanford E. Thompson, 1908. *See p, 154b,*

Sand.	Tensile strength of 1: 3 mortar at 7 days. Lb. per sq. inch	Tensile strength of 1: 3 mortar at 28 days. Lb. per sq. inch.
A*	4	93
B†	43	114
B washed	129	201
W‡	165	
Standard Ottawa	200	300

* Poorest portion of bank; reddish and dark in appearance.
† Average sand from bank which passed inspection.
‡ A medium good sand from another bank similar to B in appearance, mechanical analysis, and chemical composition except nearly free from vegetable impurity.

in the following table. They are averaged from different series and for convenience in comparison the results are all converted to the basis of standard sand mortar, considered as 200 pounds in 7 days and 300 pounds in 28 days. The mortars were stored in air to conform to the actual conditions. Comparative tests on mortars from the same sands stored in moist air and in water corroborated the results.

The cause of the failure was traced in the expert investigation, to vegetable impurities in the sand which had washed down into the bank from the soil above. The poorest sand, *A*, showed by mechanical analysis only 4% by weight of fine material passing a No. 100 sieve and 1.61% silt by washing, but this silt was found to contain nearly 30% of vegetable matter corresponding however to only 0.5% in the total sand. The vegetable matter appeared to coat the grains of sand so as to prevent adhesion of the cement and also retarded the setting.

Effect of Fine Material in Filling Voids. Lean mortars may be improved by small admixtures of pure clay or by substituting dirty for clean sand, provided it is free from vegetable matter, because the fine material increases the density. Rich mortars, on the other hand, do not require the addition of fine material, and it may be positively detrimental, because the cement furnishes all the fine material required for maximum density. This is illustrated in experiments by Mr. Griesenauer* in which an admixture of even 2 per cent of clay (based on the weight of the sand) slightly reduced the strength of 1 : 2 mortar, while 20% of clay, added to the 2 parts of sand, reduced the strength about 30%. In 1 : 3 mortar, on the other hand, the addition of 2% slightly increased the strength, and there was no appreciable injury up to 20% addition.

In experiments by Mr. E. S. Wheeler† clay reduced the strength of neat and 1 : 1 mortars, but improved leaner mixtures.

In this connection, of course, it must be borne in mind that if the sand is composed largely of fine material, the strength of the mortar is comparatively low, as indicated in preceding pages.

EFFECT OF MICA IN THE SAND UPON THE STRENGTH OF MORTAR

The effect of mica in screenings from stone of a micaceous nature has been the subject of considerable controversy. Tests by Mr. Feret‡ in France indicated that the presence of 2% of mica has but slight influence upon the tensile strength of mortar, but a greater one upon its compressive

* *Engineering News*, April 28, 1904, p. 413.
† Report Chief of Engineers, U. S. A., 1895, p. 3004, and 1896, p. 2827.
‡ Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1897, Vol. II.

strength. More recent tests by Mr. W. N. Willis* in 1907 on mortars made with standard Ottawa sand into which mica was introduced are illustrated in Fig. 57a. He found that the presence of mica increased the voids and decreased the strength. The sand used in tests, loosely shaken, contained 37% voids, but as mica was added, the voids increased rapidly until with 20% mica the voids were 67% with a corresponding decrease in weight, and three times the amount of water was required for mixing.

It is thus evident that the reduction in strength was largely due to the decrease in density and not entirely caused by the slippery character of the grains. In crushed stone screenings it is probable that the effect of the same percentage of mica in the natural state would be less marked.

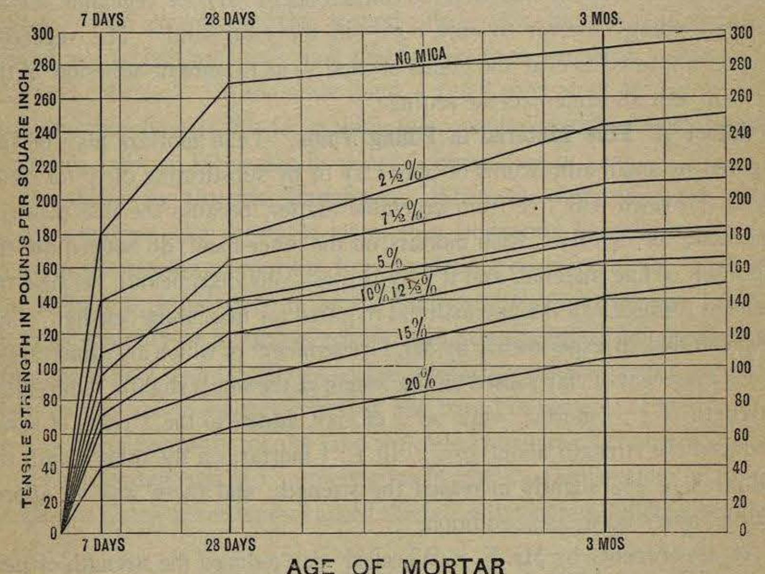

Fig. 57a.—Effect of the Addition of Mica upon 1 : 3 Mortar of Standard Sand. By W. N. Willis. (See p. 154d.)

Black mica, which has a different crystalline form, is not injurious to mortar.

EFFECT OF LIME UPON THE STRENGTH OF MORTAR

As a principal constituent of mortar in masonry construction, lime is inferior to cement in durability and strength. However, not only because of its relative cheapness, but also because a small addition of slaked or hydrated lime may increase the density of the mortar and cause it to work easier under the trowel, a limited quantity often can be used to advantage in mortar which is to be subjected to high loading.

* *Cement Age*, Mar. 1907, p. 172.

For concrete, lime has been suggested, as mentioned in Chapter XIX, on Water-tightness, as a suitable ingredient to fill the voids and thus render it more impermeable.

Although lime mixed with neat cement is apt to decrease its strength, in combination with sand for cement mortars, a small admixture of lime may add to the strength of the mortar. The questions as to whether lime is beneficial, and as to the amount which can be used, are determined by the character of the cement, the coarseness of the sand, and the proportions in which the two are mixed. The effect of lime in cement mortar or concrete is chiefly mechanical. In a porous mortar or concrete a small quantity of it assists in filling the voids, and if it is thoroughly slaked so as to contain no quicklime, its expansion need not be feared.

Since even a neat cement paste has 35% to 45% water plus air voids, the inference might be drawn that the addition of lime would increase its density, and thus that the lime would be valuable even in very rich mortars. However, it seems to be practically impossible, except under high pressure, to replace the water which occupies the voids in neat cement paste with lime or any other fine powder. But it is evident that a lean mortar, such as a 1:4, or even a 1:3, should be improved by the addition of lime, and that this is true is illustrated in the following tests by Mr. E. S. Wheeler.* In these experiments the addition of 10% of lime — based on the weight of the cement — increases the strength of 1:3 mortar, and as shown by item (3) in the table, a 1:3⅓ mortar with 10% of lime is stronger than a 1:3 mortar with no lime. Items (4) and (5) illustrate the reduction in

Effect of Lime Paste upon the Strength of Portland Cement Mortar.
By E. S. Wheeler. (See p. 155.)

Item	Proportions cement plus lime to sand by weight	Proportions cement to sand by weight	Cement	Lime†	Sand	Average Tensile Strength.	
						at 28 dys.	at 3 mos.
	parts	parts	grams	grams	grams	lb. per sq. in.	lb. per sq. in.
(1)	1:3	1:3	200	0	600	201	236
(2)	1:2¾	1:3	200	20	600	242	265
(3)	1:3	1:3⅓	180	20	600	238	264
(4)	1:3	1:4	150	50	600	168	171
(5)	1:3	1:6	100	100	600	57	70

*Report Chief of Engineers, U. S. A., 1896, p. 2823.

†The weight of the lime paste was 2.7 times the weights in this column.

strength when the lime becomes more nearly a principal ingredient. Each value is an average of five briquettes**

With another brand of cement and sand of different coarseness the relative quantity of lime to produce similar results will differ, but the general principle will still hold. In determining the amount of lime to add without decreasing the strength of a certain mortar, tests should be made with the materials to be employed.

In scientific experiments by Mr. Feret* the maximum strength of 1:4 mortar of Portland cement and sand from Saint Malo† was reached with an addition of 4% or 5% by weight of hydrated lime powder. As the mortar became richer, the lime had less effect, until at proportions 1:2, the addition of lime reduced the density, and at proportions 1:1½ the strength was also lowered.

A larger number of bricks can be laid in a given time with mortar containing lime than with a lean cement mortar because the lime fills the pores in the mortar so that it spreads more readily without crumbling and adheres better to the bricks in "buttering" them.

Unslaked Lime. Unslaked lime mixed with cement either for mortar or concrete is liable to produce expansion in the masonry and it is therefore never permissible to use it under any circumstances. Builders recognize that lime, putty, or paste is much improved by standing for several days, or, better, for months, before being used, because all the small lumps are thus slaked. This thorough slaking is especially necessary when lime is to be used, even as a very small ingredient, in important concrete and masonry construction; an admixture of even 2% of ground quicklime may seriously reduce the strength of the mortar.‡

Weight and Volume of Lime. In proportioning lime to cement, the method of measurement must be clearly stated. The volume of common lime or quicklime increases in slaking to about 2½ times its volume measured loose in the lime cask, the exact increase varying with the chemical composition and the purity of the lime. The weight of lime paste is about 2½ times the weight of the same lime before slaking. Hydrated lime powder also occupies more volume than quicklime from which it is made.

GROUND TERRA-COTTA OR BRICK AS A SUBSTITUTE FOR SAND

Experiments by Mr. E. S. Wheeler§ indicated that for a mortar of light weight terra-cotta may be ground and used instead of sand. Tests with

*Chimie Appliquée, 1897, p. 481.

†See p. 137.

‡Report Chief of Engineers, U. S. A., 1895, p. 2999.

§Report Chief of Engineers, U. S. A., 1896, p. 2866.

**See tests by Dr. E. W. Lazell, Transactions American Society for Testing Materials, Vol. VIII, 1908, p. 418.

both Portland and Natural cement mixed with the ground terra-cotta in various proportions gave at the end of three months tensile strengths which are not appreciably different from the strengths obtained with standard crushed quartz. Red brick pulverized* may also be used for the same purpose with good results.

EFFECT OF REGAGING MORTAR AND CONCRETE

Engineers have frequently specified and insisted that concrete or mortar be used immediately, that is, within one hour or one-half hour after it is gaged. As opposed to this requirement, tests by various experimenters indicate with singular unanimity that, at least for Portland cements, it is unnecessary, and that Portland cement concrete or mortar may remain for at least two hours in the mortar bed without deterioration. In fact, the ultimate tensile and compressive strength appears to be thus increased.

The results of such tests lead to the following conclusions:

(1) The tensile or compressive strength of Portland cement mortars or concretes is not lowered by standing two hours after mixing.

(2) Continuous gaging increases the ultimate strength.

(3) Regaging makes the cement slower setting.

Because of the Slow Setting and Hardening it is Scarcely ever Advisable in Practice to Permit the Regaging of Mortar or Concrete.

With Natural cements, however, the results of experiments are somewhat contradictory. It is probable that some Natural cements are injured, and, therefore, if circumstances require delay in placing Natural cement mortar, the effect of such delay should be determined by tests upon the brand to be used.

Mr. E. Candlot (see page 124) states that the adhesive quality of cement mortar is reduced by regaging.

Extended tests to determine the effect of regaging neat cements and mortars have been made by Mr. P. Alexandre† and Mr. E. Candlot‡ in France, by Mr. Henry Faija§ in England, by Mr. James E. Howard¶ at the Watertown Arsenal, U. S. A., and by Mr. Thomas F. Richardson at the Wachusett Dam, Massachusetts.

Mr. Richardson in the course of his experiments made a batch of 1:2 mortar from each cement, cut it into two portions and, leaving half of it in

*Report Chief of Engineers, U, S. A., 1896, p. 2830.

†Annales des Ponts et Chaussées, 1890, II, p. 340.

‡Candlot's Ciments et Chaux Hydrauliques, 1898, p. 355.

§Butler's Portland Cement, 1899, p. 307.

¶Tests of Metals, U. S. A., 1901, p. 497.

the mortar box, had the other half worked continuously. At various periods ranging from seven minutes to two hours, samples were taken from each portion, and made into tensile briquettes. Several brands of American and English Portland cements, both slow and quick-setting, and several brands of Natural cement having different periods of set, were tested. Referring to the results Mr. Richardson states:*

For the quicker setting cements there was a considerable falling off in strength in the briquettes broken seven days after being mixed, and a somewhat less falling off for those broken twenty-eight days after mixing; but at the age of six months all the mortars which had been allowed to stand, or which were worked continuously for one and one-half and two hours, showed a considerable gain in tensile strength.

A typical series of tests with Rosendale cement, which attained its initial set in forty minutes and its final set in ninety minutes, and coarse sand (passing a No. 8 and retained on a No. 30 sieve) is presented in the following table:

Effect of Regaging upon the Tensile Strength of 1:2 Natural (Rosendale) Cement Mortar. (See p. 158.)

BY THOMAS F. RICHARDSON.

Age	Periods of Sampling.				
	Immediately	After one hour		After two hours	
		Worked	Not Worked	Worked	Not Worked
	lb. per sq. in.	lb. per sq. in.	lb. per sq. in.	lb. per sq. in.	lb. per sq. in.
7 days	27	23	21	19	15
28 days	22	34	27	32	29
3 months	120	155	141	192	150
6 months	163	223	191	225	213

As a result of his tests, Mr. Richardson allowed the contractor, when necessary, to use the mortar on the dam up to two hours after being mixed. This was often a great convenience because of the distance of the mortar-mixing machine from the dam.

Mr. Howard at the Watertown Arsenal took samples of neat Portland

*Personal correspondence.

cement after longer periods of setting, in some cases up to one hundred and two hours. In general, his specimens showed at the age of one month no appreciable difference, whether they were taken when first gaged or at four, or in some cases eight, hours after gaging. The strength of specimens taken after longer periods of standing was found at the age of one month to be lower. Natural cements showed an immediate falling off, due to regaging, on the thirty days' tests, but the tests were not extended beyond this age.

The Setting of Regaged Mortars. The experiments of Mr. Candlot were made chiefly upon mortars which had attained their final set, as determined by the pressure of the thumb. These mortars, after regaging, set much more slowly than normally gaged mortars, and he states that the set occurred at approximately the same time with all cements. "Thus, whether a mortar originally sets in ten minutes or three hours, when regaged it requires, in either case, about eight to ten hours." He concludes from this action that, in Portland cements, aluminate of lime, which plays an important part in the setting, has no action on the hardening.

Consequently regaging should have little influence upon siliceous products, while it would be expected to seriously affect aluminous cements. This is the effect in practice, for limes and Portland cements can be regaged without bad results, while the strength of Natural Vassy cement is considerably lowered by regaging.*

Effect of Regaging upon Adhesion. Mr. Candlot* found that mortars which had set several hours before molding, although usually showing as great compressive or tensile strength as normal mortars, gave much lower strength in adhesion, the reduction in strength being often 50%. (See p. 124.)

TESTS OF SAND FOR MORTAR AND CONCRETE

Since it is frequently impossible even for the most expert engineer to determine positively whether or not sand is fit to use for mortar and concrete,† it should always be tested for important structures. The experience of one of the authors during the last few years in the investigation of failures of concrete structures leads to the conclusion that unless the sand is from a bank of known quality **it is even more necessary to test the sand than to test the cement.**

The test recommended by the Joint Committee on Concrete and Reinforced Concrete in 1909 is as follows:

Mortars composed of one part Portland cement and three parts fine

*Candlot's Ciments et Chaux Hydrauliques, 1898, pp. 358 and 360.
†See p. 154b.

aggregate, by weight, when made into briquets should show a tensile strength of at least 70 per cent of the strength of 1 : 3 mortar of the same consistency made with the same cement and standard Ottawa sand. To avoid the removal of any coating on the grains which may affect the strength, bank sands should not be dried before being made into mortar but should contain natural moisture. The percentage of moisture may be determined upon a separate sample for correcting weight. From 10 to 40 per cent more water may be required in mixing bank or artificial sands than for standard Ottawa sand to produce the same consistency.

Sieves for Testing Sand. Since the relative strength of sand mortars, which are free from organic or other impurities is governed by the sizes and relative sizes of the grains, mechanical analysis tests are recommended by the Reinforced Concrete Committee of the National Association of Cement Users, 1909, as frequently of great value in selecting a sand.

The relative strength of mortars from different sands is largely affected by the size of the grains. A coarse sand gives a stronger mortar than a fine one, and generally a gradation of grains from fine to coarse is advantageous. If a sand is so fine that more than 10 per cent of the total dry weight passes a No. 100 sieve, that is, a sieve having 100 meshes to the linear inch, or if more than 35 per cent of the total dry weight passes a sieve having 50 meshes per linear inch, it should be rejected or used with a large excess of cement.

For the purpose of comparing the quality of different sands a test of the mechanical analysis or granulometric composition is recommended, although this should not be substituted for the strength test. The percentages of the total weight passing each sieve should be recorded. For this test the following sieves are recommended:*

0.250 inch diameter holes.†
No. 8 mesh holes 0.0955 inch width No. 23 wire
No. 20 " " 0.0335 " " No. 28 "
No. 50 " " 0.0110 " " No. 35 "
No. 100 " " 0.0055 " " No. 40 "

The effect of mechanical analysis or granulometric composition upon the strength of mortar is illustrated in table, page 159b. By this table the relative strength of different sands may be approximately estimated.

Washing Test for Organic Impurities. To determine the percentage of organic impurities, the silt can be removed from the sand by placing it in a large bottle and washing it with several waters. The wash water is evaporated, and the residue is screened through a No. 100 mesh sieve to remove coarse particles which do not affect the strength. The silt passing

* Sheet brass perforated with round holes passes the material more quickly than square holes. Round holes corresponding to sieves No. 8, 20 and 50 respectively are approximately 0.125, 0.050, 0.020 inch diameter.

† A No. 4 sieve, having 4 meshes per linear inch, passes approximately the same size grains as a sieve with 0.25 diameter holes.

this sieve is weighed to obtain the percentage in the original sand, and then ignited in a platinum crucible to determine, after driving off the water, the percentage of combustible organic matter.

Although data on the subject is incomplete, tests by Mr. Thompson tend to indicate that if the silt in a sand has more than 10% organic matter, and at the same time if the organic matter amounts to over 0.1% of the total sand, the use of the sand may be dangerous.*

Microscopical Examination of Sand. An examination of grains of dirty sand with a microscope will frequently show a crust of organic matter on the grains which is not readily brushed off.

Chemical Composition of Sand. A sand found by chemical test to contain a large per cent, say, 95 per cent, of silica is apt to be of excellent quality for mortar. However, this is by no means a sure test or a necessary test, since sands are frequently found with as low as 75% of silica which make first-class mortar or concrete.

Tests by New York Board of Water Supply of 1 : 3 Mortar Made With Sands of Different Mechanical Analysis. (*See p.* 159a)

Percentages Passing Sieves.				Tensile Test. Lb. per sq. in.		Compression Test. Lb. per sq. in.	
No. 4.	No. 8.	No. 50.	No. 100.	7 days.	90 days.	7 days.	90 days.
100	70	12	5	213	613	2690	5640
100	86	21	6	263	412	1915	4660
100	99	26	2	177	325	905	2170
100	97	28	6	178	282	1070	1500
100	94	44	12	139	228	905	1130
100	100	52	14	122	170	275	810
100	100	94	48	80	149	330	490

EFFECT OF GAGING WITH SEA WATER

Mr. Alexandre† concludes from his own and other experiments which extend to a three-year period, that there is no essential difference in strength of mortars gaged with fresh and with sea water. Briquettes gaged with sea water, however, usually set very much slower than those gaged with fresh water.‡

Crushing tests made by the authors in 1909 on six 3-inch cubes of 1 : 2 : 4 concrete 14 months old, three of which were gaged with sea-water and three with fresh water, gave a result which indicated no appreciable difference between the two; the specimens gaged with sea-water averaging 4070 lb. per sq. in. and the fresh water cubes 3870 lb. per sq. in.

* See "Impurities in Sand for Concrete" by Sanford E. Thompson, Transactions American Society of Civil Engineers, 1909.

†Annales des Ponts et Chaussées, 1890, II, p. 332.

‡Alexandre and Feret in Commission des Méthodes d'Essai des Matériaux de Construction, 1895, Vol IV, p. 111.