12. For the purposes of this specification, the yield point shall be determined by the careful observation of the drop of the beam, or halt in the gage, of the testing machine.

13. In order to determine if the material conforms to the chemical limitations prescribed in paragraph No. 2 herein, analysis shall be made of clean drillings taken from a small test ingot.

14. **Variation in Weight.** A variation in cross section or weight of more than 2½% from that specified will be sufficient cause for rejection.

15. **Finish.** Finished material must be free from injurious seams, flaws, or cracks, and have a workmanlike finish.

16. **Annealing.** All bars which, owing to their shape or size, are liable to be under strain after cooling, must be reheated to a temperature not less than 1250° (Fahrenheit) nor more than 1375°, and this heating and subsequent cooling must be done in an approved manner.

CHAPTER IV

THE CHOICE OF CEMENT

When the construction under consideration is not of a grade to warrant the testing of different cements before making a selection, the question often arises as to whether, for example, Portland or Natural cement is most desirable from the standpoint of economy, or whether common lime or a mixture of lime and cement is suitable for the purpose.

Although the decision must often depend upon local conditions, a few general rules may be formulated relating to the classes of construction for which different kinds of cement and lime are adapted, followed by illustrations of the methods for making a selection where there is a choice between two cements and between different brands of the same cement.

THE CLASS OF CEMENT

Portland Cement should be used in concrete and mortar for structures subjected to severe or repeated stresses; for structures requiring strength at short periods of time; for concrete building construction; for work laid under water or with which water will come in contact immediately after placing; for thin walls subjected to water pressure; for masonry exposed to wear or to the elements; and for all other purposes where its cost will be less than that of Natural cement concrete, or mortar of similar quality.

Natural Cement may be substituted for Portland in concrete, if economy demands it, for dry unexposed foundations where the load in compression can never exceed, say, 75 lb. per square inch (5 tons per sq. ft.) and will not be imposed until three months after placing; for backing or filling in massive concrete or stone masonry where weight and mass are the essential elements; for sub-pavements of streets, and for sewer foundations.

In mortar Natural cement is adapted for ordinary brickwork not subjected to high water pressure or to contact with water until, say, one month after laying, and for ordinary stone masonry where the chief requisite is weight and mass.

Natural cement concrete or mortar should never be allowed to freeze, should never be laid under water, in exposed situations, in columns, beams, floors or building walls, or in marine construction.

Mixtures of Portland and Natural Cements, unless mixed at the factory and sold as Improved Natural Hydraulic Cements, are not advised under any conditions.

Sand Cement* is recommended by the United States Army Engineers for grouting†, and it is sometimes employed as a substitute for Natural cement. Its use in place of pure Portland cement is often worth investigation and testing in combination with the aggregate.

Puzzolan or Slag Cements are limited to certain proper uses by the engineer officers of the U. S. Army‡ as follows:

> Puzzolan cement never becomes extremely hard like Portland, but Puzzolan mortars and concretes are tougher or less brittle than Portland.
>
> The cement is well adapted for use in sea water,§ and generally in all positions where constantly exposed to moisture, such as in foundations of buildings, sewers, and drains, and underground works generally, and in the interior of heavy masses of masonry or concrete.
>
> It is unfit for use when subjected to mechanical wear, attrition, or blows. It should never be used where it may be exposed for long periods to dry air, even after it has well set. It will turn white and disintegrate, due to the oxidation of its sulphides at the surface under such exposure.

Hydraulic Lime, which has the property of setting under water, is extensively employed on the continent of Europe, especially in France, when in the United States common lime would be used, and frequently in place of hydraulic cement. Beton-Coignet is a mixture of hydraulic lime with cement and sand. Candlot‖ gives as the proportions most frequently employed, 1 cubic meter (35.3 cu. ft.) sand, 125 to 150 kilograms (276 to 331 lb.) lime, and 50 to 60 kilograms (110 to 132 lb.) cement. Hydraulic lime is not manufactured in the United States.

Common Lime is not suitable for a principal ingredient in concrete. It will not set in contact with water, sustain heavy loads, or resist wear.

The use of lime mortar, in the building laws of some cities, is limited to chimney construction in frame buildings, while other cities permit its use in walls of all except fireproof buildings. The Boston building laws (1896) limit the stresses on brick laid in lime mortar to 7 tons per square foot.

Lime and Natural Cement mortar is suitable for ordinary building brickwork, for light rubble foundations and for building walls.

Lime and Portland Cement mortar is adapted for the same purposes

*See page 48.
†Professional Papers No. 28.
‡Professional Papers No. 28.
§See Chapter XVI, by R. Feret.
‖Ciments et Chaux Hydrauliques, 1898, p. 289.

as mortars of lime and Natural cement, but are of superior quality and strength.

Hydrated Lime* is preferable to common lime paste or putty for use with Portland cement, because if properly manufactured it is more thoroughly slaked and is easily handled and measured.

Choice Determined by Cost. — When the character of the structure admits of either Portland or Natural cement, the choice is based upon the relative cost, which, in turn, is dependent upon the proportions that may be adopted in either case. The sand in Portland cement mortar is usually limited, by practical considerations of handling with the trowel, to proportions 1:3 in some instances and to 1:4 in others, while the most common proportions for Natural cement mortar are 1:2, that is, one part cement to two parts sand, by volume.

The relative cost, after assuming the proportions of the two substitute classes of mortar, is governed primarily by the quantity of cement in a cubic yard of mortar. For example, from table on page 229, 3.32 bbl. of cement (based on a barrel of 3.8 cu. ft.) are required per cubic yard of 1:2 mortar, while 2.48 bbl. are required for 1:3 mortar. Hence, if a decision lies between 1:2 Natural mortar and 1:3 Portland mortar, and the smaller item of quantity of sand is disregarded, the mortar produced from Natural cement at $1.00 per barrel will cost the same as that produced from Portland cement at $(\$1.00 \times \frac{3.32}{2.48}) = \$1.34$ per barrel. Similarly, since 1:4 mortar requires 1.98 bbls. of cement per cubic yard, Portland cement mortar one part cement to 4 parts sand is equivalent in cost to 1:2 Natural cement mortar when Natural cement is $1.00 per barrel and Portland cement is $(\$1.00 \times \frac{3.32}{1.98}) = \$1.68$ per barrel; that is, when Portland cement delivered on the job costs 68% more than Natural cement. Allowance for difference in quantity of sand brings the Portland values still lower, as shown in the table on page 45. With Portland and Natural cement mortars of equal cost, the Natural cement produces brickwork of lower cost because, a fact usually overlooked in estimates, a bricklayer can lay in a given time about 10% more brick with Natural cement mortar of proportions 1:2 than with Portland cement mortar of proportions, say, 1:3.

From the results of the comparatively few available tests, Portland cement concrete at the age of six months appears to be at least three times

*See S. Y. Brigham in *Engineering News*, Aug. 27, 1903, p. 177, and Charles Warner in *Rock Products*, Feb., 1904, p. 26.

as strong as Natural cement concrete in the same proportions, while at earlier periods the ratio is still larger. Since Portland cement concrete mixed 1 : 2 : 4 is only about 1½ times stronger than a 1 : 4 : 8 Portland mixture, it is very evident that the choice between Portland and Natural cement for concrete is determined, as in mortars, by practical considerations other than relative strength.

The following elementary example illustrates the method of estimating the comparative cost of Portland and Natural cement concrete:

Example. — What price can be paid per barrel for Portland cement to make a concrete 1 : 4 : 8 of equivalent cost to a 1 : 2 : 4 Natural cement concrete, if Natural cement costs $1.00 per barrel, sand $0.75 per cubic yard, and stone having 45% voids $1.50 per cubic yard?

Solution. — By reference to the table of quantities of materials on page 17, we find that the 1 : 2 : 4 Natural concrete will cost per cubic yard for materials only:

1.57 barrels cement at $1.00	$1.57
0.44 cubic yards sand " 0.75	0.33
0.88 " " stone " 1.50	1.32
Total materials	$3.22

The sand and stone for the 1 : 4 : 8 Portland mixture will cost, on the other hand, per cubic yard of concrete:

0.48 cubic yards sand at $0.75	$0.36
0.96 " " stone " 1.50	1.44
Cost of sand and stone	$1.80

Subtracting $1.80 from $3.22 leaves a difference of $1.42 which may be paid for the Portland cement in one cubic yard of concrete, and since by the quantity table 0.85 barrels of cement are required for a cubic yard of 1 : 4 : 8 concrete, the price for the Portland cement may be $1.42 ÷ 0.85 = $1.67 per barrel.

If the Natural cement had cost $1.25 per barrel, the price which could have been paid for Portland would have been approximately 25% higher or $2.09 per barrel.

This determination may be expressed in a formula:

$$x = \frac{am + bn + cr - (b'n + c'r)}{a'}$$

in which a, b, and c represent respectively the quantities of cement, sand, and stone required for a cubic yard of the Natural cement concrete, and m, n, and r their respective unit costs, while a', b', and c' represent similar

quantities for the Portland cement concrete, and x the required price per barrel of the Portland cement.

The following table is made out on this basis.

Prices of Portland Cement to produce Mortar or Concrete of equal cost to that from Natural Cement at $1.00 per barrel. (*See p.* 44.)

Proportions of Natural Cement Mortar	PROPORTIONS OF PORTLAND CEMENT MORTAR.							Proportions of Natural Cement Concrete.	PROPORTIONS OF PORTLAND CEMENT CONCRETE.				
	1 : 1	1 : 1½	1 : 2	1 : 2½	1 : 3	1 : 3½	1 : 4		1 : 2 : 4	1 : 2½ : 5	1 : 3 : 6	1 : 4 : 8	1 : 5 : 10
	$	$	$	$	$	$	$		$	$	$	$	$
1 : 1	1.00	1.23	1.46	1.69	1.92	2.15	2.38	1 : 2 : 4	1.00	1.15	1.32	1.67	2.01
1 : 1½		1.00	1.18	1.37	1.55	1.74	1.92	1 : 2½ : 5		1.00	1.14	1.44	1.72
1 : 2			1.00	1.15	1.30	1.46	1.61	1 : 3 : 6			1.00	1.26	1.51
1 : 2½				1.00	1.13	1.26	1.39						
1 : 3					1.00	1.12	1.23						

NOTE.—When the Natural cement is higher or lower than $1.00 per barrel, multiply its cost by the figures in the table to obtain approximate corresponding cost of Portland cement with which it is compared. Values make no allowance for difference in strength or labor of laying mortar.

The equivalent prices for Portland cement in mortars will be still nearer the price for Natural if allowance is made for the difference in the labor of laying brick, which in some cases may correspond to a difference of 30 cents per barrel of cement. It is evident from the table that for mortar Portland can rarely be substituted for Natural cement without increasing the cost of the work. A field still open for investigation is the employment as a substitute for Natural cement of Portland cement mixed with slaked lime or hydrated lime. The lime is so finely divided that it fills the voids and thus permits the use of more sand.

SELECTION OF THE BRAND

A precise comparison of costs of different brands of the same class of cement is impossible without thorough laboratory tests, described in Chapter VII, page 63. If the choice lies between two cements both of which have been found to be sound (see p. 77) and to set up properly, the degree of fineness, which may be readily ascertained with two sieves as described on page 67, is an aid to the decision. The finer cement will usually produce the stronger mortar.

The cheapest cement is not always the most economical. A method of comparing the relative economy of cements offered by bidders at different prices is illustrated in the following table for which the authors are indebted to Mr. D. M. Andrews. Ten brands of Portland cement were submitted to the Government at prices ranging from \$2.77 to \$3.29.* Experiments showed that sample No. 5 was the strongest, with No. 4 a close second. The relative strength of the different brands in proportions 1:3, based on the strongest as 100.0, is given in the column headed Relative Strength of Mortar, and the column following this gives the product of the relative strength multiplied by the relative cheapness. In the case under consideration brand No. 5 was selected for purchase, because, although No. 4 gave higher economy, it appeared slightly unsound. Other data with reference to each brand was observed, including the volumes of the barrels, their gross net weights, the percentages of water used in mixing the pastes and mortar, the time of setting of the mortar, and the strength and relative economy of mortars with sand proportioned to price of cement, that is, for example, using 19% more sand with cement No. 10 than with No. 1, because the former's price was 19% greater.

*The price of Portland cement has since been materially lowered.

Relative Economy of Different Priced Portland Cements.

By D. M. Andrews.

No. of Sample Barrel.	Price per Barrel.	Relative cheapness.	Fineness.		Time of Setting		Tensile Strength.						§Relative Strength of 1:3 Mortar	Relative Economy × Strength Cheapness.	Remarks.
					Initial.	Final.	Neat.			1:3 Mortar.					
			No 50 sieve.	No. 100 sieve.	Hours.	Hours.	7 days.	30 days.	60 days.	7 days.	30 days.	60 days.	60 days.	60 days.	
1	\$2.77	100.0	93.3	87.6	2	8	324	437	430	66	128	168	79.7	79.7	
2	2.79	99.3	99.3	87.3	8‡	8‡	282	429	468	62	103	124	59.1	58.7	
3	2.82	98.2	98.2	89.7	2	3¼	272	373	431	35	65	87	41.2	40.5	Air pat cracked very slightly.
4	2.82	98.2	100.0	99.6	5	9¼	369	460	564	144	184	209	99.4	97.7	
5†	2.89	95.8	99.0	86.2	7¼	7¼	449	543	631	114	175	210	100.0	95.8	Lumpy and gritty on mixing.
6	2.90	95.5	94.6	77.0	4	6¼	150	227	264	25	57	90	42.8	40.9	
7	2.93	94.5	100.0	90.0	4	8	440	588	568	127	156	202	96.2	90.9	
8	3.02	91.7	99.5	89.4	2¼	7	418	476	561	89	134	174	82.4	75.6	Pats crack'd slightly.
9	3.05	90.8	98.5	91.2	3½	7¼	436	518	502	93	126	144	68.2	62.0	
10	3.29	84.2	99.4	92.7	2½	5	365	496	573	78	117	141	67.1	56.5	

†Accepted in preference to No. 4 because air pat slightly defective.
‡Cement not yet set.
§Based on the highest, No. 5, as 100.0.

CHAPTER V

CLASSIFICATION OF CEMENTS.

From an engineering standpoint, limes and cements may be classified as

- Portland cement.
- Natural cement.
- Puzzolan cement.
- Hydraulic lime.
- Common lime.

Typical analyses of each of these are presented in the following table. The composition of Natural cement, even different samples of the same brand, is so extremely variable that their analyses cannot be regarded as characteristic of locality.

Typical Analyses of Cements.

	Portland Cement		Natural Cement							Common Lime	
			American		Engl'h	French					
	Lehigh Valley[1] (mixed rock)	Western[2] (marl and clay)	Eastern Rosendale[3]	Western Louisville[3]	Roman[4]	Vassy[5]	Grappiers[6]	Puzzolan Cement[7]	Hydraulic Lime (Le Tiel)[8]	Lime[9]	Magnesian Lime[10]
Silica SiO_2	21.31	21.93	18.38	20.42	25.48	22.60	26.5	28.95	21.70	1.03	1.12
Alumina Al_2O_3	6.89	5.98	15.20	4.76	10.30	8.90	2.5	11.40	3.19	1.27	0.68
Iron Oxide Fe_2O_3	2.53	2.35		3.40	7.44	5.30	1.5	0.54	0.66		
Calcium Oxide CaO	62.89	62.92	35.84	46.64	44.54	52.69	63.0	50.29	60.70	97.02	58.51
Magnesian Oxide MgO	2.64	1.10	14.02	12.00	2.92	1.15	1.0	2.96	0.85	0.68	39.6[illegible]
Sulphuric Acid SO_3	1.34	1.54	0.93	2.57	2.61	3.25	0.5	1.37	0.60		
Loss on Ignition	1.39	2.91	3.73	6.75	3.68	6.11	5.0	3.39	12.20		
Other constituents	0.75		11.46	3.74	1.46			0.30	0.10		

[1]W. F. Hillebrand, Society of Chemical Industry, 1902, Vol. XXI.
[2]W. F. Hillebrand, Journal American Chemical Society, 1903, 25, 1180.
[3]Clifford Richardson, *Brickbuilder*, 1897, p. 229.
[4]Stanger & Blount, Mineral Industry, Vol. V, p. 69.
[5]Candlot, Ciments et Chaux Hydrauliques, 1898, p. 174.
[6]Le Chatelier, Annales des Mines, September and October, 1893, p. 36.
[7]Report of the Board of U.S. Army Engineers on Steel Portland Cement, 1900, p. 52.
[8]Candlot, Ciments et Chaux Hydrauliques, 1898, p. 24.
[9]Rockland-Rockport Lime Co.
[10]Western Lime and Cement Co.