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NOTES ON CONCRETE.

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The few notes on "Cement Concrete" which he proposed to lay before you contained no information that was not already well known; but as there appeared to be an absence of uniformity in specifying concrete mixtures, it was hoped that these notes would serve to explain more clearly the principle that should be followed in deciding the ratios in which the various aggregates and cement should be mixed, and perhaps lead to a profitable discussion on the proportioning and mixing of this important material.

In nearly all the specifications of cement concrete the author had perused, the general practice had been to describe it as consisting of so many parts of stone, broken to a stated gauge, and sand, or so many parts of gravel to one of cement. A specification of this kind drawn by a competent engineer, who had made the necessary tests to determine the percentage of interstices in the stones, and the shrinkage of the mortar made from the given ratio of cement and sand, so that the mortar resulting from the mixture might fill the interstices in the stones with from 8 per cent. to 12 per cent. of excess mortar, may be relied on to produce good, solid concrete, the strength of which will depend on the ratio of cement to sand. However, if another engineer was to fix on the same ratio of stone, sand or gravel, and cement to make concrete, without first having made tests to determine whether the mortar made from the cement and sand would fill the interstices in the stones or gravel, the concrete resulting from the latter might be of very different quality and strength.

Much vagueness seems to exist as to the method of apportioning correctly the component parts of cement concrete. Mr. Hayter, in a discussion on "Concrete for Harbours," in 1887, and Mr. F. J. Preston, in a paper on "Cement Concrete," in 1898, directed attention to this want of uniformity, and suggested that there should be a recognised procedure in specifying concrete mixtures. Mr. Hayter instanced a 6 to 1 concrete comprised of 6 parts of gravel, shingle, and sand (of approved quality) and 1 part of Portland cement; and another 6 to 1 concrete comprised of 4 parts of stone, gravel, or shingle (without sand), 2 parts of sand, and 1 part of cement.

In the first case, gravel mixed with sand as found in position might be used. In the second case, the stone, gravel or shingle, and sand must not be combined, but separate. The measurement of the component parts would then be as under:—

For the first case, 1 cubic foot of cement would be mixed with 6 cubic feet of gravel and sand.

In the second case, 1 cubic foot of cement would be mixed with 4 cubic feet of stone or gravel, and 2 cubic feet of sand, measured separately; but when the stone and sand were mixed together, the sand would occupy, more or less, the interstices of the gravel or shingle, and the space occupied by these two components when put together would be less than that of the gravel or shingle, and sand, in combination. In the second case, therefore, instead of being 6 to 1, the mixture was between 4 to 1 and 6 to 1, and, the cement being the same, the resulting concrete would be stronger.

Mr. J. R. Mackenzie, in the same discussion, directed attention to the vague ideas generally prevailing with regard to concrete, it being referred to variously as "thoroughly sound," "strong," "hard," and "dense." One author mentioned that a particular 7 to 1 concrete was quite equal to an ordinary 5 to 1 concrete.

These examples show that the method of specifying concrete in terms of the cement and total aggregates does not convey a clear definition of either the value or the strength of the mixture.

Engineers are often called upon to prepare specifications for concrete mixtures suitable for foundations for machinery, cranes, buildings, water-tight walls, and other structures, and it is important that the natural aggregates found in the district where the machinery or structure is to be erected should be used to the largest possible extent. If it should be found necessary to use broken stone, in combination with the gravel or shingle found in the district, they should be combined in such proportions as would produce the strongest concrete, with a minimum quantity of mortar.

Keeping in view the class of work for which the concrete is intended, it is generaly admitted—

Firstly: That, with similar materials, the strength of concrete is determined by the relative proportions of sand and cement comprising the mortar (provided the mortar fills the interstices of the aggregates).

Secondly: That to make good, sound concrete it is essential that all the interstices in the aggregates should be filled with mortar.

Thirdly: That a small surplus of mortar should be allowed for surrounding the stones, more especially where rubble concrete is to be made, or the depositing of fairly large stones in the body of the concrete is to be done.

To produce concrete of maximum strength with a given ratio of cement to the other materials, it is evident that the less the volume of mortar used (keeping in view the above conditions), the less the quantity of sand required and the greater the proportional strength of the mortar. It is, therefore, of great importance to mix the stones and shivers, or stones and gravel or shingle, so that the volume of interstices to be filled with mortar should be from 34 per cent. to 40 per cent. of the volume of the stone or gravel. By doing this, concrete may be made with a minimum quantity of mortar and of maximum strength.

In order to correctly determine the component parts of solid concrete, it is necessary—

(1) To fix the proportion of cement to sand to be used;
(2) To ascertain the quantity of mortar the selected proportion of cement will make;
(3) To know approximately the percentage of interstices in the aggregate;

(4) To fix on a certain percentage of mortar in excess of the interstices for surrounding the aggregate and keeping them slightly apart, and also to cover variations in the percentage of the interstices of the same aggregate.

The quantity of excess mortar for this purpose usually varies from 8 per cent. to 12 per cent. The percentatge of interstices of the various classes and mixtures of aggregates to be used for making concrete can be ascertained fairly accurately by filling a measuring vessel, say a 20-gallon drum or other suitable vessel. The measuring vessel should not be less than 20 gallons capacity. If it has a capacity of 30 or 40 gallons, and is made of cubical shape, the result will be more accurate.

The measuring vessel should be filled with a sample of the aggregate, care being taken that the stone, and shivers or gravel, are mixed thoroughly together in the proportions desired, and then they should be shovelled into the measuring vessel. If the vessel be then filled with water, i.e., if all the interstices are filled and the quantity of water noted, the percentage of interstices in the mixture can be calculated.

If the material used absorbs much water, it should be soaked or thoroughly sprayed with water before being put in the measuring vessel.

The following figures, giving the contraction of material when made into mortar, have been taken from a paper by Mr. J. W. Sanderson, M.I.C.E., in the Proc. of the I.C.E., 54:—

TABLE I.

	Proportions.		
	1 cem. to 1 sand.	1 cem. to 2 sand.	1 cem. to 3 sand.
	%	%	%
First, by admixture separately with water	15·00	16·66	17·5
Second, by admixture with each other.	5·00	5 00	5·00
Third, by cement setting to hardness from the condition of mortar	4·00	4·00	4·00
Total ratio of contraction of the materials in percentage of their own volume	24·00	25·66	26·50
Total ratio of contraction on material in percentage of the volume of water when set	31·56	34·53	36·05

It will be seen from these figures that the average total contraction of the material of which the mortar is composed is 25.38 per cent., but in the following cail-culations to determine the volume of mortar from any given proportion of cement and sand, the contraction will be taken at 25 per cent. of the volume of the dry material. The examples given hereunder are intended to explain how the various ratios of cement, sand, and aggregates are determined for the making of concrete mixtures of any given proportion, and with any fixed quantity of excess mortar:—

(1.) In this example the proportions selected are 1 cement, 2¼ sand. Find the quantity of broken stone or gravel containing 42 per cent. of interstices, required to make solid concrete containing 7 per cent. excess mortar :

Then if x = aggregate without excess mortar.

$$\frac{x + x}{14 \cdot 3} = 100 \text{ parts finished concrete.}$$

$$x = 93 \cdot 46 \text{ parts} = \text{Aggregate.}$$

Mortar in excess of interstices = 6·34 parts = 7% of aggregate.

	Parts.
Interstices to be filled = 93·46 x 0·42	39·25
Mortar in excess of interstices 93·46 x 0·07	6·34
Total mortar required	45·79
To find cement and sand add $\frac{1}{3}$	15·26
Divide by	3¼)61·05
Cement 1 part	18·78
Sand 2¼ parts	42·25
Aggregate	93·46
	154·49

The following are the quantities of dry material based on the above ratios estimated to make a cubic yard of solid concrete:—

If 18.78 of cement make 100 of concrete, how much is required to make 27 cubic feet or 1 solid yard?

100 : 27 :: 16·78 : 507 cubic feet cement.

507 x 2·25 = 16.78, 11·396 „ „ sand.

507 x 5 = 11·396, 25·348 „ „ stone.

$$\text{Mortar} \frac{(507 + 11 \cdot 396)}{4} = 12 \cdot 345 \text{ „ „ mortar.}$$

Interstices in aggregate 25·348 x 0 42 = 10·64 cubic feet.
Excess mortar 12·345 — 10·64 = 2·7 cubic feet.
Then 25·346 + 2·7 = 27·048 cubic feet solid concrete.

One cask of cement assumed to contain 4.25 cubic feet will make 23.63 cubic feet of solid concrete.

18.78 : 4.25 :: 100 : 22.63 cubic feet.

(2.) In this example the proportions selected are 1 cement, $2\frac{3}{4}$ sand. Required: The volume of stone or gravel containing 48 per cent. of interstices to make solid concrete containing 8 per cent. mortar.

Then if x = aggregate without excess of mortar $x + \frac{x}{12 \cdot 5} =$ 100 parts of finished concrete.

x = 92·6 parts = aggregate.

Mortar in excess of interstices 7·4 = (8% of aggregate).

	Parts
Interstices to be filled with mortar	
92·6 x 0·48	44·43
Mortar in excess	7·4
Total mortar required	51·85
To find cement add $\frac{1}{3}$	17·23
Divide by $(1 + 2\frac{3}{4})$ 3·75)	69·13
Cement 1 part	18·435
Sand $2\frac{3}{4}$ parts	50·7
Aggregate	92·6
	161·735

Then 92·6 ÷ 18·44 = 5 parts of stone to 1 of cement, and $2\frac{3}{4}$ of sand only can be used if the concrete is to have 8 per cent. excess mortar.

The concrete in No. 2 example would not be of such good quality as No. 1 concrete, as the mortar in the former is weaker, being 1 cement to $2\frac{3}{4}$ sand, as compared to 1 cement to $2\frac{1}{4}$ sand; and on account of the interstices of the stone or gravel being 6 per cent. greater, it would require about 15 per cent. more cement to make the No. 2 concrete of the same quality as the No. 1 concrete.

(3.) In this example the proportions selected are 1 cement, 3 sand. Required: The volume of broken stone or gravel containing about 40 per cent. interstices to make solid concrete containing 10 per cent. excess mortar.

Then if x = aggregate without excess mortar $x + \frac{x}{10} = 100$ parts finished concrete and x = 90·60 parts of aggregate.

Mortar in excess of interstices = 9·09 = 10% of aggregate.

	Parts.
Interstices to be filled with mortar 90·90 x 0·40 =	36·36
Mortar in excess of interstices	9·09
Total mortar	45 45
To find cement and sand add $\frac{1}{3}$	15·15
and divide by	4)60·60
Cement 1 part	15·15
Sand 3 parts	45·45
Aggregate	90·90
	151·50

90·90 ÷ 15·15 = 6 of stone or gravel to 1 of cement.

(4.) If 15.15 of cement gives 100 of gravel, how much is required for 1 cubic yard 27 cubic feet?

100 : 15·15 :: 27 :	4·08	cubic feet of cement.
4·09 x 3	12·27	,, ,, sand.
4·09 x 6	24·54	,, ,, aggregate.

$$\text{Mortar}\ \frac{(4{\cdot}09 + 12{\cdot}27)\ 3}{4} = 12{\cdot}27 \text{ cubic feet.}$$

Interstices 25·54 x 40 = 9.82 cubic feet.
Excess mortar 2·45 cubic feet.

Then 24·54 + 2·45 = 26·92 cubic feet of concrete if the composition of 1 cement, 3 sand, and 6 aggregate contain 10 per cent. of excess mortar.

The foregoing examples will serve to explain the method of proportioning the cement, sand, and aggregates to make concrete of any required composition. If, however, certain ratios of cement, sand, and aggregate be fixed for making concrete, it is necessary to determine whether such ratios allow sufficient mortar to fill the interstices.

Suppose the ratios of 1 cement, $1\frac{1}{3}$ sand, and 3 parts of aggregate containing 43 per cent. of interstices are selected, it is required to know if the mortar composed of the above ratios will fill the inetrstices in the aggregate:

Let x = cement

$\frac{4x}{3}$ = sand

5x = aggregate containing 45% of interstices.

Mortar $\frac{x + \frac{4x}{3}}{4}$ = 1·75 cubic feet.

Interstices 5 x 0·45 = 2·25

Insufficient mortar 0·50

Then 50 x 100 ÷ 5 = 10% of concrete will be made up of hollow spaces, but as the interstices are 45 per cent. of the volume of concrete,

Then (10 x 100) ÷ 45 = 22% of voids in the mortar.

If, instead of fixing the quantity of mortar to be used, certain ratios, such as 1 part cement, 2 of sand, 5 of aggregate having 42 per cent. of interstices, are selected, and it is required to know how much cement, sand, and aggregate are used in making 100 parts of finished concrete:

Let x = Cement

2x = Sand

5x = Aggregate

Mortar $\frac{(x + 2x)3}{4}$ = 2·25

Interstices = 5x x 0·42 2·10

Mortar in excess 0·15

Aggregate mortar in excess, 5x + ·16·x = 100 parts

5·15 x = 100

x = 19·42

2x = 36·84

5x = 92·10

150·36

In this example there is only 3 per cent. excess mortar, and the following quantities are required to make 1 cubic yard of solid concrete.

3.24 cubic feet cement equal 10.48 cubic feet sand, 26.2 cubic feet of aggregate containing 42 per cent. of interstices.

In the foregoing examples no reference has been made to the probable strength of the concrete mixtures made in accordance with the ratios of cement, sand, and aggregates given, because so much depends mainly on the character of the cement, sand, and aggregate used, and also on the care with which the mixing is done.

There is, however, much valuable information relative to the strength of concrete to be found in two papers read by Mr. J. Grant before the Institute of Civil Engineers and published in their Proceedings, Volumes XXV. and XXXII., and also in a valuable paper on the "Strength of Concrete" by Professor W. H. Warren, M.I.C.E., read before the Royal Society of New South Wales in 1901. I should like to call special attention to Professor Warren's paper, as the information given in connection with various tests and mixtures is very complete; and as the aggregates are those used for making concrete as used in various public works, they have a special value as a standard of comparison, because the samples tested consisted of various ratios of cement, sand, and aggregate.

The general practice followed in the drawing of specifications for concrete mixtures may be gathered from the following examples of specified proportions of cement, sand, and aggregate used in some of the concrete works executed in the State:—

(No. 1.) The concrete to be composed of—

1 measure of cement to 2 measures of broken stone, broken to pass through ¼in. mesh, and caught upon a ⅛in. mesh sieve.

The following are the quantities of dry material required to make 1 solid yard of concrete:—

13.5 cubic feet cement.

27.0 cubic feet of broken stone.

The cement, when mixed with water and allowed to set hard, will shrink about 14 to 16 per cent. Then,

13.5 x 0.14 equal 1.89, and

13.4 - 1.89 equal 11.61 cubic feet of solid mortar.

In this example there could not be any excess mortar, as the broken stone measures exactly 1 cubic yard.

Therefore, 11·61 x 100 ÷ 27 = 43% of interstices.

The defect in this concrete seems to be that there was little or no excess mortar in the mixture to keep the stone slightly apart, to ensure a solid concrete.

(No. 2.) This concrete to be composed of 1 measure cement, 1.3 sand, and 3.61 of broken stone; one-third of the latter to consist of shivers and two-thirds of hard metal gauged by a $2\frac{1}{2}$in. ring.

The following are the quantities of dry material required to make 1 solid yard of concrete:—

6.41 cubic feet of cement
9.63 ,, ,, of sand
7.63 ,, ,, of sand
15.30 ,, ,, of hard metal.

There seems to be a discrepancy between the composition, as stated, and the measurement of the quantities given to make 1 solid yard:

6.41 cement x 3.61 equal 23.14 measures of stone. Now, 15.3 measures of stone mixed with 7.65 measures of shivers could not possibly make 23.14 measures, for the shivers would to a large extent fill up the interstices in the stone broken to $2\frac{1}{2}$in. gauge. The specification should read:

> 23.14 measures of broken stone and shivers mixed in the ratio of two-thirds of stone broken to $2\frac{1}{2}$in. gauge to one-third of shivers.

Then 27 − 23.14 equal 3.86 cubic feet of excess mortar will be required, so that the 23.14 cubic feet of stone may make 1 solid yard of concrete.

$$\text{Mortar}\frac{(6\cdot41 + 9\cdot63)\,3}{4} = 12\cdot03 \text{ cubic feet of mortar}$$

Then 12.03 − 3.86 equal 8.17 cubic feet volume of interstices in the mixture of broken stone and shivers.

Then 8·17 x 100 ÷ 23·14 = 35·3 % of interstices.

(No. 3) Concrete of the same specification is composed of 1 measure of cement, 2.5 measures of sand, 5.1 of broken stone, gauged by a $2\frac{1}{2}$in. ring, and the following are the quantities of dry material required to make 1 solid yard of concrete:—

4.78 cubic feet cement
11.95 ,, ,, cement
24.30 cubic feet,

$$\text{Then}\frac{(4\cdot78 + 11\cdot95)\,3}{4} = 12\cdot45 \text{ cubic feet mortar}$$