(Paper No. 3064.)

"Cement Concrete."

By FRANCIS JOHN PRESTON, Assoc. M. Inst. C.E.

MUCH vagueness still exists as to the method of correctly apportioning the component parts of cement concrete. In a note¹ read before the Conference of the Institution in May, 1897, Mr. John Kyle, M. Inst. C.E., gives the following: "Proportion of Materials: . . . if of hand-broken metal, say 4 parts to pass a $3\frac{1}{4}$ -inch ring, 2 to pass $1\frac{1}{4}$ -inch, and 2 gritty sand and 1 of cement." If it is admitted that in making good concrete it is essential that all the interstices of the aggregate should be filled with mortar, and that a small surplus of mortar should be allowed for surrounding the stones, such concrete cannot possibly be made with the proportions quoted, nor indeed with 6 parts of any ordinary-sized broken stone. Further, such concrete cannot be made if proportions of 1 of cement, 2 of sand and 7 or more of shingle are used, as they often are. Even 6 parts of shingle leave only a small margin of mortar in excess of interstices. One part of cement and 2 parts sand make $\frac{(1+2)3}{4}$ parts = 2.25 parts of mortar; or, if the quantity of mortar is given, then the quantity of cement and sand will be $\frac{1}{3}$ part greater. Slight variations, depending on the kind of sand employed, may occur.

The percentage of interstices of several samples of broken stone of the kind mentioned averaged 48 per cent. The percentage of interstices of several samples of shingle tested varied between 33 per cent. and 38 per cent. It is given² by Mr. J. W. Sandeman, M. Inst. C.E., as 50.9 per cent. for broken stone and 33.6 per cent. for gravel. With a concrete composed of 1 part of cement, 2 parts of sand, and 6 parts of broken stone, with 48 per cent. of interstices, the following results are obtained:—

	Parts.
Mortar = $\frac{(1 \text{ part cement} + 2 \text{ parts sand}) 3}{4}$. . .	= 2.25
Interstices = 6 parts $\times$ 0.48	= 2.88

¹ Engineering Conference, 1897. Notes, Sect. II, 25 May, No. 1a, "Concrete in Relation to Marine Works," p. 2. In the Library Inst. C.E.

² Minutes of Proceedings Inst. C.E., vol. liv. p. 260.

That is to say, the interstices are largely in excess of the mortar provided, and $10\frac{1}{2}$ per cent. of the concrete will be made up of hollow spaces.

In the case of concrete composed of 1 part of cement, 2 parts of sand and 7 parts of shingle, taking the lowest percentage of interstices, viz., 33 per cent. :—

Mortar (as before)		=	Parts. 2·25
Interstices = 7 parts $\times$ 0·33		=	2·31

With 1 part of cement, 2 parts of sand, and 6 parts of shingle :—

Mortar (as before)		=	Parts. 2·25
Interstices = 6 $\times$ 0·33		=	1·98
Mortar in excess of interstices		=	<u>0·27</u>

So that the mortar is 5 per cent. of the aggregate in excess of the interstices, which is barely sufficient.

Of broken-stone concrete, therefore, made according to the proportions quoted, $10\frac{1}{2}$ per cent. would consist of hollow spaces. It is possible that such concrete may be good enough for the purposes for which it was intended, but it cannot be generally recommended.

In order to correctly determine the component parts of concrete, it is necessary (1) To fix the proportion of cement to sand to be used; 1 to 2 will be found a useful proportion for most works. (2) To ascertain the quantity of mortar the selected proportion will make. (3) To know approximately the percentage of interstices of the aggregate. (4) To fix a certain percentage of mortar in excess of the interstices for surrounding the stones and to cover variations in the percentage of interstices of the same aggregate. Mortar equal to 10 per cent. of the aggregate is usually ample.

The percentage of interstices can be ascertained sufficiently approximately by filling a tank, the cubic contents of which are known, with samples of the aggregate. If the tank is then filled with water to the top, *i.e.*, if all the interstices are filled and the quantity of water required is noted, the percentage of interstices can be calculated. If, as a check, the water is drawn off and measured again, the percentage of interstices must lie between the water filled in and that drawn off; or, if the materials used absorb much water they should be soaked before being placed in the tank.

The following examples are given to show how the ratios of cement, sand and aggregate per 100 parts of finished concrete can be correctly ascertained.

(1) In this case the proportions selected are, 1 part of cement, 2 parts of sand, and broken stone having 48 per cent. of interstices; the amount of mortar required in excess of interstices to be equal to 10 per cent. of aggregate.

Then if	$x =$	aggregate without excess of mortar,
$x + \frac{1}{10}x =$	100 parts of finished concrete,	
and	$x =$	90.90 parts = aggregate.
Mortar in excess of interstices }	$=$	9.09 „ (10 per cent. of aggregate).
	<u>99.99</u>	„
Interstices (to be filled with mortar)	$= 90.9 \times 0.48$	Parts. = 43.63
Mortar in excess of interstices	$= 90.9 \times 0.10$	= 9.09
		<u>Total mortar required . . = 52.72</u>
To find cement and sand add $\frac{1}{3}$		= 17.57
and divide by		<u>3) 70.29</u>
Cement, 1 part		= 23.43
Sand, 2 parts		= 46.86
Aggregate		= 90.90
		<u>161.19</u>

It will be seen that with this class of stone barely 4 parts can be used to 1 of cement.

(2) One part of cement, $2\frac{1}{2}$ parts of sand, shingle having 30 per cent. interstices; mortar in excess of interstices to be equal to 15 per cent. of aggregate.

If	$x =$	aggregate,
$x + 0.15x =$	100 parts,	
and	$x =$	86.95 parts . . = aggregate.
Mortar in excess of interstices }	$=$	13.04 „ . . = 15 per cent. of aggregate.
	<u>99.99</u>	„
Interstices (to be filled with mortar)	$= 86.95 \times 0.30$	Parts. = 26.08
Mortar in excess of interstices	$= 86.95 \times 0.15$	= 13.04
		<u>Total mortar required . . = 39.12</u>
To find cement and sand, add $\frac{1}{3}$		= 13.04
		<u>7) 52.16</u>
		<u>7.45</u>
		<u>2</u>
Cement, 1 part		= 14.90
Sand, $2\frac{1}{2}$ parts		= 37.25
Aggregate		= 86.95
		<u>139.10</u>

If, instead of fixing the quantity of mortar to be used certain ratios, such as 1 part of cement, 2 parts of sand, and 6 of stone, are fixed, it is necessary to determine whether such ratios allow sufficient mortar, and if this were done such ratios as 1 part of cement, 2 of sand and 6 of broken stone would probably not be specified in connection with good work.

(3) Suppose ratios of 1 part of cement, 2 parts of sand, and 4 of broken stone, having 48 per cent. of interstices are selected, and it is required to know how much cement, sand and stone are used in making 100 parts of finished concrete.

If x = cement, $2x$ = sand, $4x$ = stone:

$$\begin{array}{rcll} \text{Mortar} & = & \frac{(x + 2x) 3}{4} & \dots \dots \dots = 2.25 x \\ \text{Interstices} & = & 4x \times 0.48 & \dots \dots \dots = 1.92 x \\ \text{Mortar in excess of interstices} & & & \dots \dots \dots = \underline{0.33 x} \end{array}$$

Aggregate. Mortar in Excess
of Interstices.

$$\begin{array}{rcll} 4x + 0.33x & \dots \dots \dots & = & 100 \text{ parts,} \\ 4.33x & \dots \dots \dots & = & 100 \text{ ,,} \\ x & \dots \dots \dots & = & 23.09 \text{ parts cement,} \\ 2x & \dots \dots \dots & = & 46.18 \text{ ,, sand,} \\ 4x & \dots \dots \dots & = & 92.36 \text{ ,, stone.} \\ & & & \underline{161.63 \text{ parts.}} \end{array}$$

In this case, the amount of mortar in excess of the interstices is $8\frac{1}{4}$ per cent. of the aggregate.

The various proportions of any kind of concrete may thus be derived from the necessary data.