Paper No. 250

ERRATA

1. Page 304, Para. 4—" (Mix 1 : 4 : 6)" to *read* " (Mix 1 : 4.6)."
2. Page 304, Para. 5—" 1 : 5 : 8 " to *read* " 1 : 5.8."
3. Page 306 .. Water-cement ratios, on Plate No. 2 should *read* " 0.4, 0.5, 0.6" *instead of* " 0.3, 0.4, 0.5"
4. Page 307, Para. 1—*Substitute* " money " *for* " cement."
5. Page 307, Para. 3—*Read* " aggregate/sand " *for* " Sand/aggregate."
6. Page 308, Para. 6—" Modulous " to *read* " Modulus."
7. Page 309 .. The table on this page is to be numbered " Table No. 2."
8. Page 312—13 .. Acknowledgments to Prof. A. N. Walsh on page 313 should follow immediately below Table 3 on page 312.
9. Page 313, first and second lines—" Table 1 " should *read* " Table 2."
10. Page 313 .. In the formula, the multiplication sign is to be replaced by the symbol X.
11. Page 314, second line, *Delete* " $\frac{3}{4}''$."
12. Page 315, Para. 3, third line : *Add* (1 : 5 mix) *after* " sand " in third para.
13. Page 321 second line .. *Delete* " real."
14. Page 321 .. *Delete* " real " from column 1, Table 8.
15. Page 324 .. The heading " Verification of the workability of the mixes " is to be preceded by the number " 9."
16. Page 325 .. The heading " The voids in the combined aggregate " is to be preceded by the number " 10."
17. Page 326 .. The heading " Total surface area of the aggregates " is to be preceded by the number " 11."
18. Page 327 .. The heading " Workability Factor " is to be preceded by the number " 12."
19. Page 328 .. *Substitute* " Table 12 " for " Plate 12 " at the end of first para.

PAPER No. 250.

RATIONAL CONCRETE MIXES COMPARED TO ARBITRARY MIXES USING TYPICAL PUNJAB RIVER SAND AND GRAVEL

By

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1. Scope and Objects of the Paper

The advantage to be gained both in economy and in the quality of cement concrete by combining the sand with the coarser aggregates in the mix in the most perfect proportions is now generally recognised by Engineers in charge of important works, but in the every-day use of cement on the more common class of work a large number of consumers still continue to use the old arbitrary mixes of 1 : 2 : 3,—1: 2: 4. etc. etc., without reference to the type of sand they are obliged to employ.

This Paper makes no claim to present any new departure on concrete mix design but has been written with the object of emphasising the economy which can be effected by any user of cement who cares to make a mechanical analysis of the raw materials available for his particular concrete work with particular reference to the fine sand problem in the plains of the Punjab.

An analysis of the results which follow will illustrate this point very clearly and it only remains to be added that the user is not only repaid by being in a position to carry out more work at less cost, but automatically produces a concrete which is more dense and impermeable and which is less likely to cause disappointment through shrinkage cracks by oversanding.

For the purpose of our tests the sand and aggregate used was fine river sand and $\frac{3}{4}''$ river run shingle obtained from the Ambala District through the courtesy of the Superintending Engineer, P.W.D., Ambala.

No attempt has been made in this Paper to show the still greater advantages to be obtained by manipulation of the fine sand, or by the addition of coarse particles to make the sand conform to the more perfect material as it is felt that the places in the Punjab where this would be possible are in the minority.

As a study of the full range of tests carried out may prove somewhat tedious to all except those who are actively engaged on this class of work, it was felt to be appropriate to take the unusual step of starting the Paper at the end, that is, with an examination of the conclusions arrived at as a result of the tests.

2. Analysis of Results

Plate No. 1 illustrates the marked decrease in the cement requirement of rational mixes compared to arbitrary mixes or, *vice versa,* the greater strength obtained in compression using the same quantity of cement with a rational mix as with an arbitrary mix.

It will be seen that the percentage economy in the requirements of cement per cubic yard of concrete can be as high as 19% when 28 days strengths are the deciding factor, varying with the mix employed and the age at which the strength of the concrete is compared, figures which require no further comment. It might, however, be interesting to study the result of this in rupees, annas and pies per 100 cubic feet of concrete in one of the more commonly used arbitrary mixes of say 1 : 2 : 4.

We will assume that the cost of the various materials is as follows:

Cement	..	Rs. 42 per ton.
Gravel	..	Rs. 8 per % c.ft.
Sand	..	Rs. 5 per % c.ft.

From the table No. 10 on page 323 it will be seen that the compression strength at 28 days of an arbitrary mix of 1 : 2 : 4 (mix 1 : 4 : 6) having a 1″ slump is 5,500 lbs. per sq. inch requiring 5.8 sacks of cement per cubic yard of concrete.

Reference to the curves on Plate No. 2 illustrating the strengths of various rational mixes will show that for a similar 28 days compression strength of 5,500 lbs. per sq. inch the rational mix would be 1 : 5 : 8 and the proportion would be 1 : 2.02 : 5.45 requiring 4.9 sacks of cement per cubic yard of concrete.

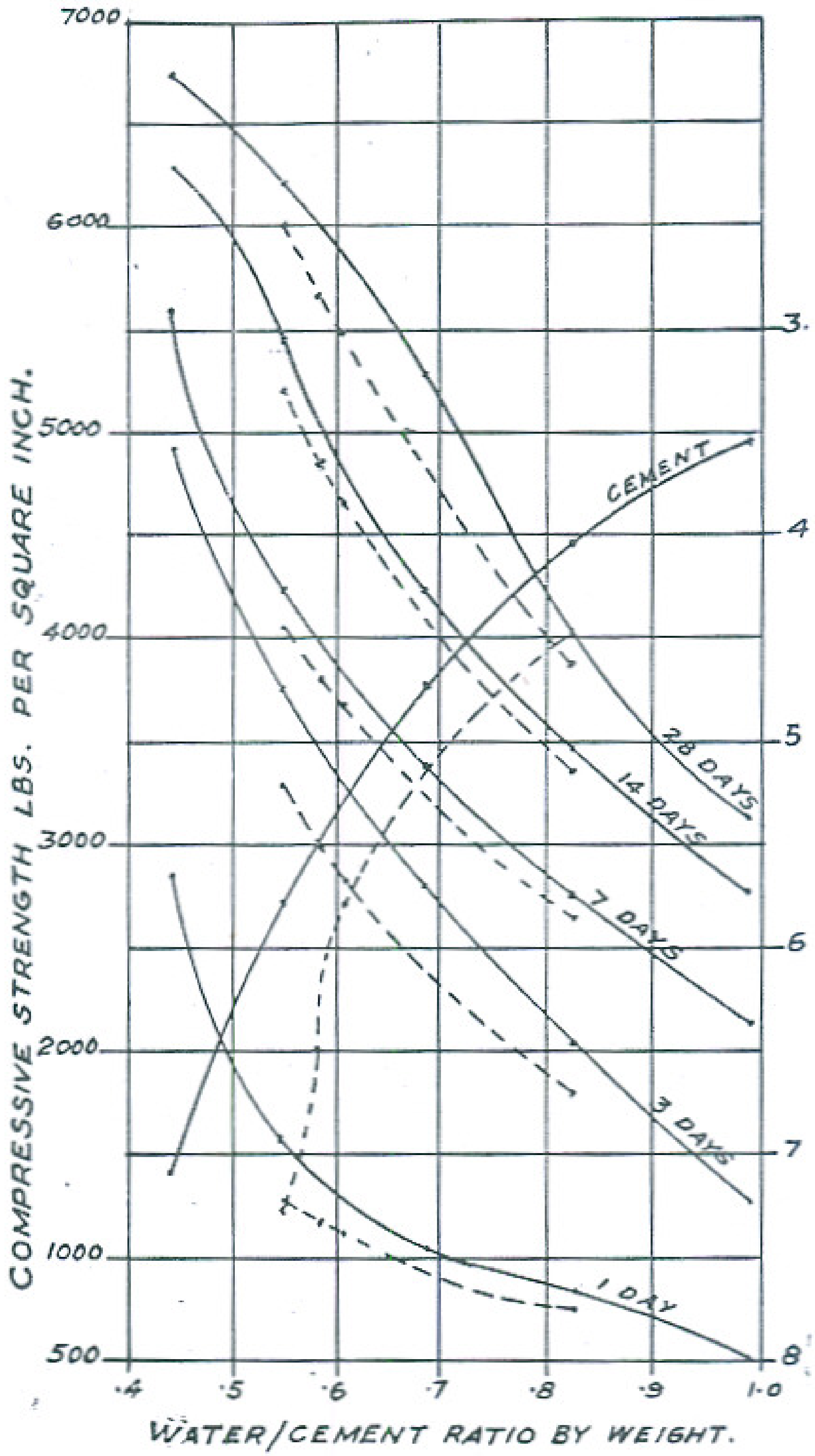
The comparative cost of these two mixes is set out below:

Cost of 100 c.ft. of Concrete

Material	Rational Mix		Arbitrary Mix	
	Quantities	Amount	Quantities	Amount
		Rs.		Rs.
Cement ..	18.15 bags	38.11	21.48 bags	45.108
Sand ..	36.66 c.ft.	1.833	42.96 c.ft.	2.148
Gravel ..	98.92 c.ft.	7.913	85.92 c.ft.	6.873
Total ..	..	47.856	..	54.129

Saving per % c.ft. Rs. 6.273.

PLATE I
PAPER NO. 250



FULL LINES INDICATE RATIONAL MIXES AND DOTTED LINES INDICATE ARBITTARY MIXES.

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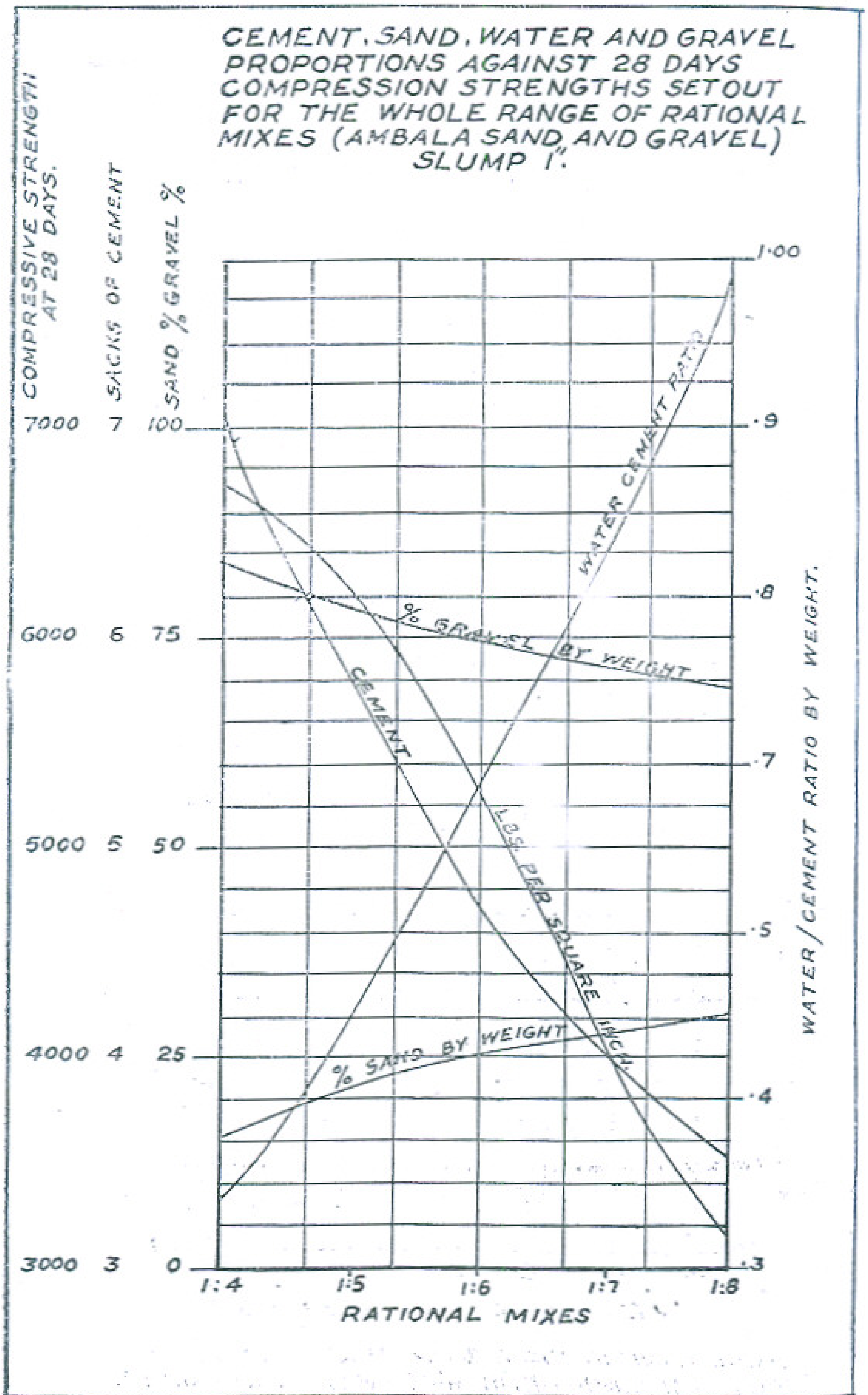
PLATE 2
PAPER NO. 250



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It will be seen that the arbitrary mix requires 13.1% more cement than the correct rational mix and attention is drawn specially to the great disparity of the proportion of the sand to coarse aggregate between these two mixes; in the rational mix the proportion of gravel to sand by volume is in the ratio of 2.7 to 1 whereas in the arbitrary mix the ratio by volume of gravel to sand is in the ratio of 2 to 1.

These latter figures clearly illustrate the large amount of over-sanding which takes place when an arbitrary mix of 1 : 2 : 4 is made, using fine sand, and this would, of course, be even more pronounced on a richer mix of 1 : 2 : 3.

This point is further emphasised in the Table No. 1 given below wherein the sand aggregate ratios for various mixes are set out together with the weight of one c.ft. of the wet rodded concrete mix showing the greater density of the rational concrete mix. Note in particular that the disparity of aggregate/sand ratio is progressively pronounced the richer the mix.

TABLE NO. 1

Arbitrary Mixes				Wt. of 1 c.ft. of wet concrete rodded	Aggr. sand ratio	Rational Mixes				Wt. of 1 c.ft. of wet concrete rodded	Aggr. sand ratio
Mix	*Proportion*					Mix	*Proportion*				
	Cement	Sand	Aggr.				Cement	Sand	Aggr.		
				Lbs.						Lbs.	
1 : 3.1 ..	1	2	2	147	1	..	..	..	..	..	..
1 : 3.9 ..	1	2	3	150	1.5	1 : 4	1	.833	4.033	158	4.85
1 : 4.6 ..	1	2	4	151	2	1 : 5	1	1.5	4.925	156	3.28
1 : 6.2 ..	1	3	5	150	1.67	1 : 6	1	2.16	5.69	154	2.63
	..	..	..	..	..	1 : 7	1	2.8	6.41	152	2.29
	..	..	..	..	..	1 : 8	1	3.524	7.174	151	2.03

When studying Plate No. 1 it will be noted that the compression strength curves for rational mixes at different ages do not follow the usual curve against varying water/cement ratios and it should here be pointed out that in the usual curve one given mix is treated with varying proportions of water whereas in the curves attached to this Paper the slump is maintained as a constant factor by varying the water/cement ratio to follow the different proportions of sand to coarse aggregate in each mix.

3. Method of investigation

The investigations for grading were conducted on the lines advocated by Professor Walsh of University College, Cork, as fully described in his admirable book on this subject, "How to Make Good Concrete," and to which the reader is referred for greater detail of procedure.

It is beyond the scope of this Paper to discuss Professor Walsh's methods in detail but in order to enable the reader to follow the method it is necessary to incorporate his type grading curves for sand and coarse aggregate alongside of those type grading curves drawn up for the particular sand and aggregate under investigation and the validity of Professor Walsh's claims which are the result of a great deal of research are accepted.

The object of the investigation is to endeavour to combine the Ambala gravel and sand, in spite of the imperfections of the latter in such a proportion as to follow, as nearly as possible, the ideal type gradings for combined aggregates reproduced on Plates 5, 6, 7, 8 and 9.

4. Nature of Materials

Cement as manufactured at the Bhupendra Cement Works of the Patiala Cement Company, Ltd., was used throughout the tests, the cement having an average residue of 5.5 on the 170^2 mesh and 0.1 on the 72^2 mesh with a specific gravity of 3.1.

The Ambala sand had a fineness modulus of only 1.145 as gauged according to Professor Abrams method and it should here be recorded that various authorities decry the use of sand for concrete mixes having a fineness modulous of less than 1.5.

The Ambala gravel as received was found to be well graded, having a fineness modulus of 6.485 as the following Table No. 2 showing the sieve analysis for the sand and gravel will show:

SIEVE ANALYSIS OF AMBALA SAND AND GRAVEL

	Gravel		Sand	
	Percentage by weight passing each sieve	Percentage by weight coarser than each sieve	Percentage by weight passing each sieve	Percentage by weight coarser than each sieve
3/4″ ..	100	*Nil*	100	0
3/8″ ..	43	57	100	0
No. 4 ..	7.5	92.5	98	2.0
No. 8 ..	1.0	99.0	97.5	2.5
No. 14 ..	*Nil*	100.0	96.5	3.5
No. 28 ..	*Nil*	100.0	95.0	5.0
No. 48 ..	*Nil*	100.0	72.5	27.5
No. 100 ..	*Nil*	100.0	26.0	74.0
		648.5		114.5
Range in size ..	..	0–$\frac{3}{4}$ inch	..	0–$\frac{3}{8}$ inch
Fineness Modulus	..	6.485	..	1.145

Important Note

Before proceeding to examine the type grading it should be explained that in numbering his type curves from Nos. 4—10 Professor Walsh expressed by these numbers the quantity of combined aggregate in cubic ft. which should be added to 112 lbs. of cement. Thus No. 4 curve requires the addition of 4 cubic feet of combined aggregate (*i.e.*, loose sand and gravel) to 112 lbs. of cement, No. 5 five cubic feet and so on. Further, in expressing mixes in this Paper, a mix of 1 : 2 : 4 means 112 lbs. of cement to 2 c.ft. dry sand to 4 c.ft. dry coarse aggregate. Sieve Nos. employed in the Paper differ slightly from those used on Professor Walsh's gradings; the sieves being unobtainable but the ratio of one sieve to a succeeding sieve is of the same order.

DEFINITION OF THE DIFFERENT MIXES REFERRED TO IN THE PAPER

1. *Mix* .. Cement weight to loose volume of mixed fine and coarse aggregates.
2. *Rational Mix* ... Same as "mix" but designed on rational lines.

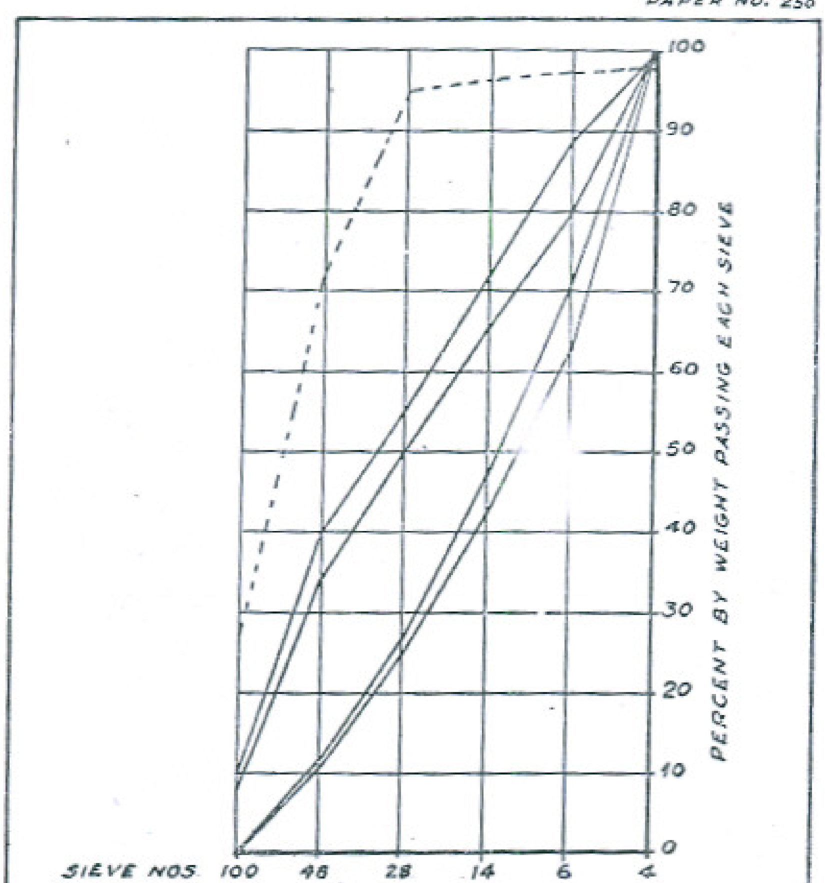
3. *Arbitrary Mix* .. Same as mix but using well defined round figures of loose volume representing proportions of fine to coarse aggregate.
4. *Field Mix* .. Actual loose proportions by volume of the separate aggregates.
5. *Real Mix* .. Cement weight to volume of combined fine and coarse aggregate after light rodding or compacting.

5. Grading of Sand

From his type grading curves for combined aggregate Professor Walsh derives the upper and lower limits of the most suitable sand to be used for the mixes represented by his type gradings.

These limits are reproduced below on Plate No. 3 and the dotted line represents the sieve analysis grading of the Ambala Sand.

PLATE 3
PAPER NO. 250



SAND GRADINGS FROM TYPE CURVES (WALSH'S) NOS. 4. 5. 6. 8. 10 FOR 3/4 AND 1½ AGGRS. ALL LIE WITHIN THE INNER ZONE.
ALL POSSIBLE GRADINGS IN THE VARIOUS ZONES, OF THE DIAGRAMS FOR 3/4 AND 1½ AGGRS. LIE WITHIN THE OUTER BOUNDRIES.

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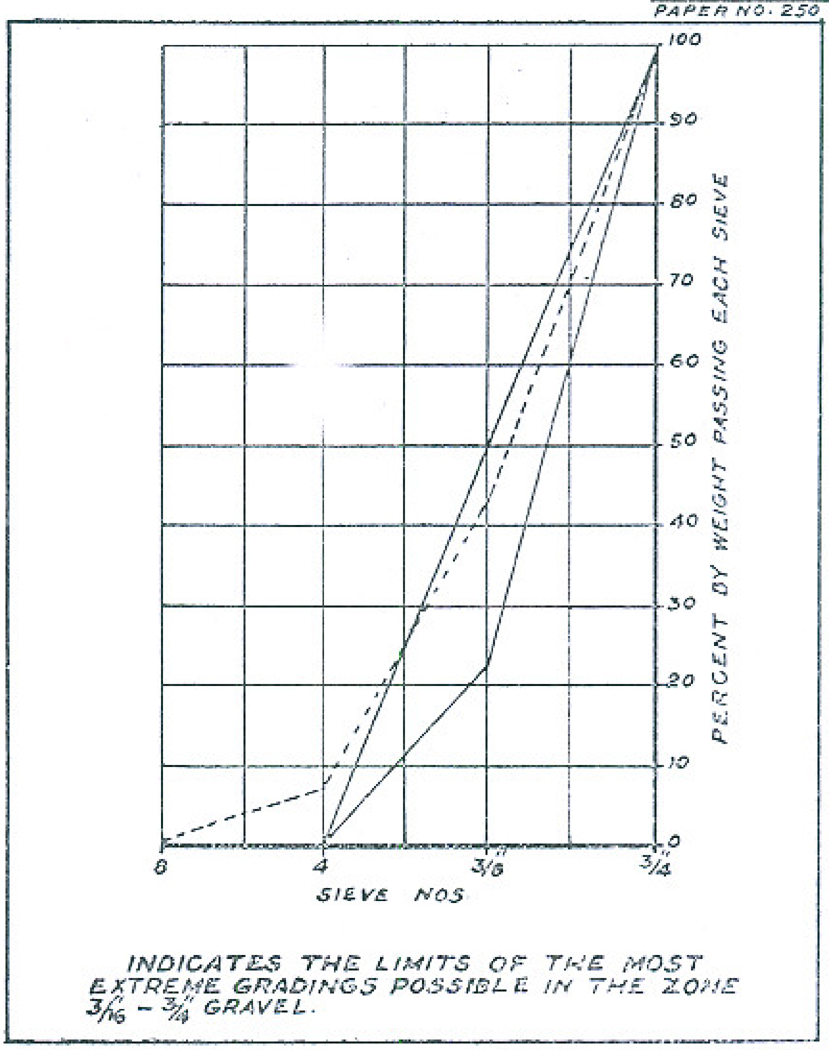
It will immediately be seen that the Ambala sand lies well outside the finer or upper limit and should, therefore, normally be discarded in favour of coarser material.

We in the Punjab, however, can rarely obtain coarse sand and the object of this Paper is to examine how far it is possible to make the best use of this fine sand.

6. Grading of Gravel Aggregate

In a similar way, the gravel grading curve illustrated below (Plate No. 4) shows the upper and lower limits for 3/16″ to ¾″ gravel aggregate derived from the type grading curves, and the dotted line that of the Ambala gravel under investigation.

PLATE 4
PAPER NO. 250



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It will be seen that, apart from an excess of fines below the No. 4 sieve, the gravel lies within the required limits.

7. Grading of Combined Sand and Gravel

We will now consider the question of combining the Ambala sand and gravel in the correct proportions for a mix of 1 : 5, that is, 112 lbs. cement to 5 cub. ft. of combined aggregate.

It is obvious from our comparison of the material to Professor Walsh's type grading curves above that we shall be unable to combine the two to give the ideal grading, as whatever proportions of sand to gravel we adopt we shall always have a preponderance of fines, but there is one such proportion only which will give the closest approxi mation to the desired grading :

For ideal conditions for a 1 : 5 mix the grading curve should li between the ideal grading curves for the mixes of 1 : 6 and 1 : 4 bu it is also true that if we have a preponderance of fines at one end o the curve, we can average out by arranging a preponderance of coars parts at the other end of the curve.

In other words, the fineness modulus of the combined mix wil be approximately the same as the fineness modulus of the ideal combined mix.

Table No. 3 gives the sieve analysis of the ideal combination for a 1 : 5 mix according to Professor Walsh and if we work out the fineness modulus of this grading by transforming the percentage by weight passing each sieve to the percentage by weight coarser than each sieve, adding these together and dividing by 100 we arrive at the fineness modulus figure of 5.34.

TABLE 3

TYPE GRADINGS FOR VARIOUS PROPORTIONS OF GRAVEL AGGREGATES OF $\frac{3}{4}$ IN. MAXIMUM SIZE

Curve Ref. No.	Mix (number of c.ft. of dry combined aggregate to 112 lbs. cement)	Sieve Sizes — Percentage by weight passing each sieve (Gravel and Sand Aggregates)								Apprx. proportion of water to cement in gls. per 112 lbs. of cement for easy workability.	Kind of aggregate.
		No. 100 (0.0060 in.)	No. 52 (.0116 in.)	No. 25 (0.0236 in.)	No. 14 (0.0474 in.)	No. 7 (0.0949 in.)	3/16" (0.187 in.)	$\frac{3}{8}$" (0.375 in.)	$\frac{3}{4}$" (0.75 in.)		
10	10	2.0	12.5	25	30.5	39	50	77	100	13.0	
8	8	1.0	9.5	22.5	28	35.5	48	71	100	10.5	
6	6	0.5	8	18	24.5	32	42	63	100	7.5	
5	5	0	6	14.5	22	28.5	37	58	100	6.2	$\frac{3}{4}$" gravel and sand
4	4	0	3.5	10	16	23	32	51	100	5.1	
	Equivalent to 1 : 2 : 4 } 6.3	0.6	8.3	19.5	25	32.5	43.5	65	100	8.4	
	Equivalent to 1 : 1½ : 3 } 4.9	0	6	14	21	27.5	36.5	57	100	6.1 upper limits	

With acknowledgments—How to make Good Concrete—Prof. A.N. Walsh

The fineness modulus of the Ambala gravel (Table No.1) is 6.485 and of the Ambala sand (Table No. 1) is 1.145 so that it is now possible to determine the proportion of sand to gravel to give the desired fineness modulus of 5.34 as follows :

The correct percentage of gravel in the combined mix is expressed by the equation :

$$\frac{F_mG}{100} \times \frac{+ F_mS(100-X)}{100} = F_mA.$$

where X is the percentage of gravel

F_mG the Fineness Modulus of the gravel

F_mS the Fineness Modulus of the sand

FmA the desir d Fineness Modulus of the combined mix.

so that in this particul r case we have

$$\frac{6.485}{100} \times \frac{+ 1.145\ (100-X)}{100} = 5.34$$

From which X = 78.5%. The balance of 21.5% represents the correct sand proportion.

The sieve analysis of a combined mix containing such proportions can now be worked out arithmetically and is compared to Prof. Walsh's type grading sieve analysis for mix 1 : 5.

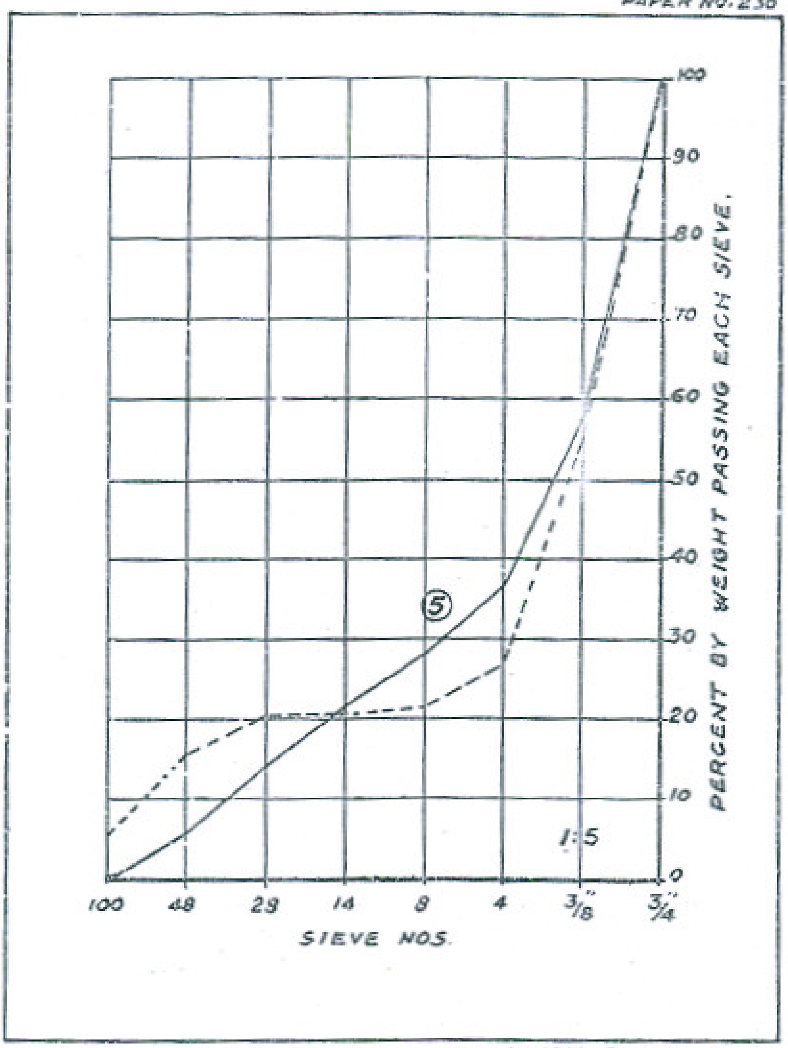
TABLE 4

Mix	By Weight	Sieve Analysis % by Weight passing each sieve								Fineness Modulus (Abrams)
		100	48	28	14	8	4	3/8"	3/4"	
1:5	Gravel 78.5	0	0	0	0	0.8	6.0	33.75	78.5	
	Sand 21.5 ..	5.5	15.6	20.4	20.7	21.0	21.1	21.50	21.5	
	1 mixed aggregates ..	5.5	15.6	20.4	20.7	21.8	27.1	55.25	100	5.34
	2 Walsh's type grading No. 5	0	6.0	14.5	22.0	28.5	37.0	58.0	100	5.34
	Difference between 1 and 2 ..	+5.5	+9.6	+5.9	—1.3	—6.7	—9.9	—2.75	..	

It will be seen that the Ambala combined aggregate is coarser than Prof. Walsh's type grading on sieves $\frac{3}{8}''$, $\frac{3}{4}''$ No. 4, No. 8 and No. 14, the difference being $(2.75+9.9+6.7+1.3)=20.65$ whereas it is finer on sieves 28, 48 and 100, the difference being $(5.9+9.6+5.5)=21$. In other words, we have balanced the curve as nearly as possible, the Ambala combined aggregate having more middle and coarse particles. The excess of coarse particles will balance the excess of fines and will not alter the density or workability of the concrete.

It is now desirable to compare this grading with the ideal grading curve for mix 1 : 5 according to Prof. Walsh and this is reproduced below in Plate No. 5, the dotted line representing the Ambala mix.

PLATE 5
PAPER NO. 230



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It will be seen that the curve bears out the study of the sieve analysis, running as much below the typical curve No. 5 as above it.

Our proportions have so far been expressed as percentages by weight and it only remains to find the equivalent volumes.

The weight of the Ambala sand was found to be 92 lbs. per c.ft. (dry), the gravel 102 lbs. per c.ft. (dry) and the combined aggregate 128 lbs. per c.ft. (dry) in loose sand.

The weight of 5 cubic feet of combined aggregate will, therefore, be :

$$128 \times 5 = 640 \text{ lbs.}$$

The weight of the sand portion $\frac{640 \times 21.5}{100} = 137.6$ lbs.

The weight of the gravel portion $\frac{640 \times 78.5}{100} = 502.4$ lbs.

The volume of the sand will be $\frac{137.6}{92} = 1.5$ c.ft.

The volume of the aggregate will be $\frac{502.4}{102} = 4.925$ c.ft.

The field mix will, therefore, be :

112 lbs. cement : 1.5 c.ft. sand : 4.925 c.ft. gravel.

Sieve analysis for combined aggregates to give mixes of 1 : 4, 1 : 6, 1 : 7 and 1 : 8 have also been tabulated and the percentage proportions are represented in Table 5 and the corresponding curve comparisons in Plates 6, 7, 8 and 9.

TABLE 5
GRADINGS OF COMBINED AGGREGATES

Mix	By weight	Sieve Analysis % by weight passing each sieve								Fineness Modulus
		100	48	28	14	8	4	$\frac{3}{8}''$	$\frac{3}{4}''$	
1:4	Gravel 84.3	0	0	0	0	0.8	6.3	36.2	84.3	
	Sand 15.7 ..	4.1	11.4	14.9	15.2	15.3	15.4	15.7	15.7	
	1 mixed aggregates ..	4.1	11.4	14.9	15.2	16.1	21.7	51.9	100	5.64
	2 Walsh's type grading No. 4	0	3.5	10.0	16.0	23.0	32.0	51.0	100	5.64
	Difference between 1 and 2 ..	+4.1	+7.9	+4.9	—0.8	—6.9	-10.3	+0.9	..	
1:5	Gravel 78.5	0	0	0	0	0.8	6.0	33.75	78.5	
	Sand 21.5 ..	5.5	15.6	20.4	20.7	21.0	21.1	21.50	21.5	
	1 mixed aggregates ..	5.5	15.6	20.4	20.7	21.8	27.1	55.25	100	5.3
	2 Walsh's type grading No. 5	0	6.0	14.5	22.0	28.5	37.0	58.0	100	5.3
	Difference between 1 and 2 ..	+5.5	+9.6	+5.9	—1.3	—6.7	—9.9	—2.75	..	
1:6	Gravel 74.5	0	0	0	0	0.75	5.6	32.0	74.5	
	Sand 25.5 ..	6.6	18.5	24.2	24.6	24.9	25.0	25.5	25.5	
	1 mixed aggregates ..	6.6	18.5	24.2	24.6	25.7	30.6	57.5	100	5.12
	2 Walsh's type grading No. 6	0.5	8.0	18.0	24.5	32.0	42.0	63.0	100	5.1
	Difference between 1 and 2 ..	+6.1	+10.5	+6.2	+0.1	—6.3	—11.4	—5.5	..	
1:7	Gravel 71.85	0	0	0	0	0.7	5.4	30.9	71.85	
	Sand 28.15 ..	7.3	20.4	26.7	27.2	27.4	27.6	28.15	28.15	
	1 mixed aggregates ..	7.3	20.4	26.7	27.2	28.1	33.0	59.1	100	4.98
	2 Walsh's type grading No. 7	0.8	9.0	20.0	26.0	34.0	45.0	67.0	100	4.98
	Difference between 1 and 2 ..	+6.5	+11.4	+6.7	+1.2	—5.9	—12.0	—7.9	..	
1:8	Gravel 69.3	0	0	0	0	0.7	5.2	29.8	69.3	
	Sand 30.7 ..	8	22.3	29.2	29.6	29.9	30.1	30.7	30.7	
	1 mixed aggregates ..	8	22.3	29.2	29.6	30.6	35.3	60.5	100	4.84
	2 Walsh's type grading No. 8	1.0	9.5	22.5	28.0	35.5	48.0	71.0	100	4.84
	Difference between 1 and 2 ..	+7.0	+12.8	+6.7	+1.6	—4.9	—12.7	—10.5	..	

PLATE 6
PAPER NO. 250

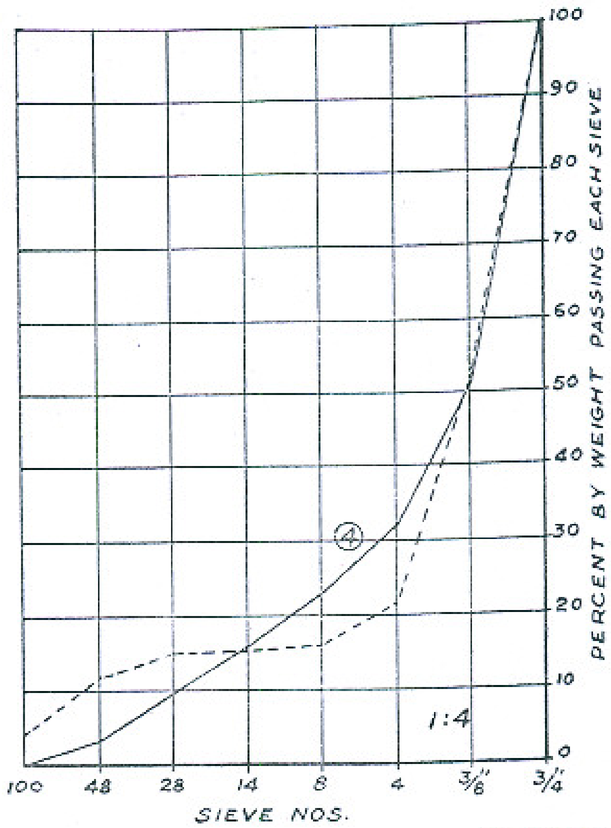


PLATE 7
PAPER NO. 250

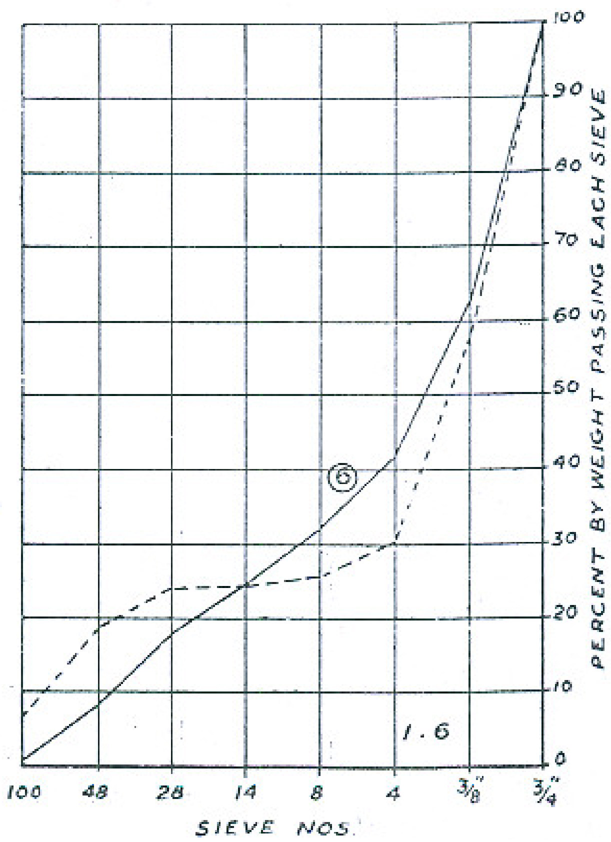


PLATE 8

PAPER NO. 250

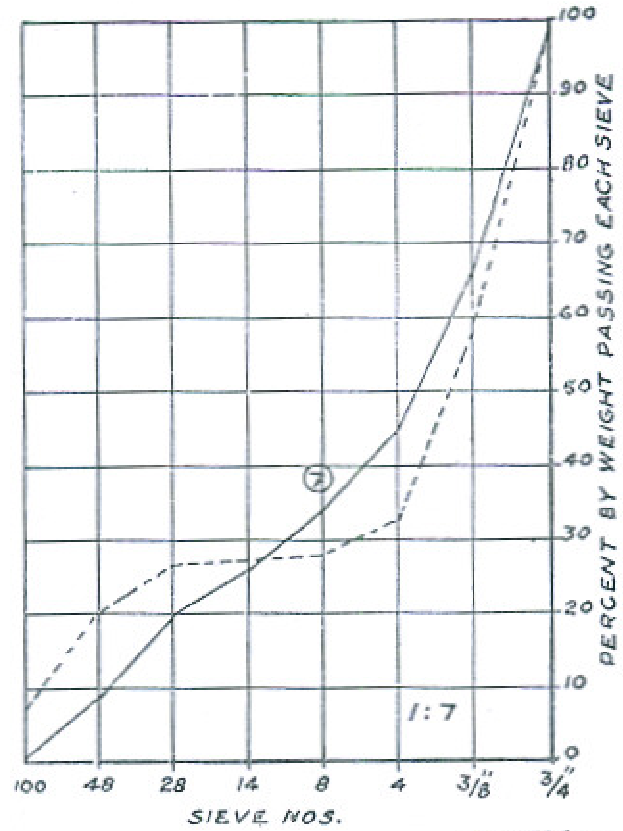
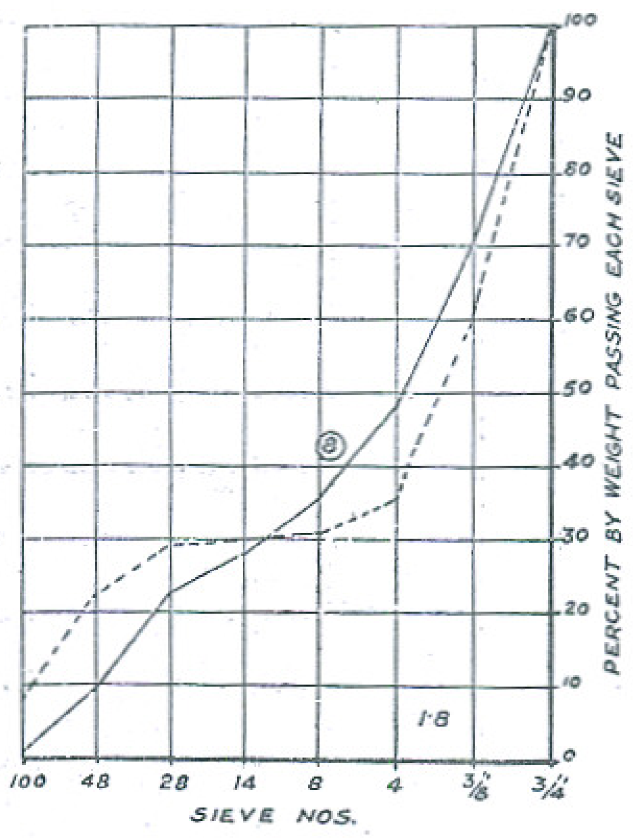


PLATE 9

PAPER NO. 250



The corresponding field mixes together with other physical characteristics compared to similar figures relating to the more orthodox arbitrary mixes are shown in Table No. 6 below :

TABLE NO. 6

FIELD MIXES

Mix	Real mix lightly rodded	Field Mix			% by Weight		Weight in lbs. of c.ft.			
		Cement sack	Sand c.ft.	Gravel c.ft.	Gravel	Sand	Gravel	Sand	Combined aggregate loose volume	Combined aggregate lightly rodded
1 : 4	1 : 3.9	1	0.833	4.033	84.3	15.7	102	92	122	125
1 : 5	1 : 4.96	1	1.5	4.925	78.5	21.5	102	92	128	129
1 : 6	1 : 5.91	1	2.16	5.69	74.5	25.5	102	92	130	132
1 : 7	1 : 6.84	1	2.80	6.41	71.85	28.15	102	92	130	133
1 : 8	1 : 7.88	1	3.524	7.174	69.3	30.7	102	92	132	134
ARBITRARY MIXES										
1 : 6.2	1 : 5.8	1	3	5	64.9	35.1	102	92	126	136
1 : 4.6	1 : 4.4	1	2	4	69.0	31.0	102	92	129	135
1 : 3.9	1 : 3.7	1	2	3	62.5	37.5	102	92	127	134
1 : 3.1	1 : 3.0	1	2	2	52.6	47.4	102	92	124	130

We started this Paper with a cost comparison of a 1 : 2 : 4 (Mix 1 : 4.6) arbitrary mix with that of a rational mix of 1 : 5.8, both mixes giving the same strength at 28 days and it will now be interesting to draw up the sieve analysis and grading curve for the arbitrary mix to see how far it lies at or near the zone of the typical grading curves for Prof. Walsh's mix of 1 : 4.6 which has been derived by interpolation.

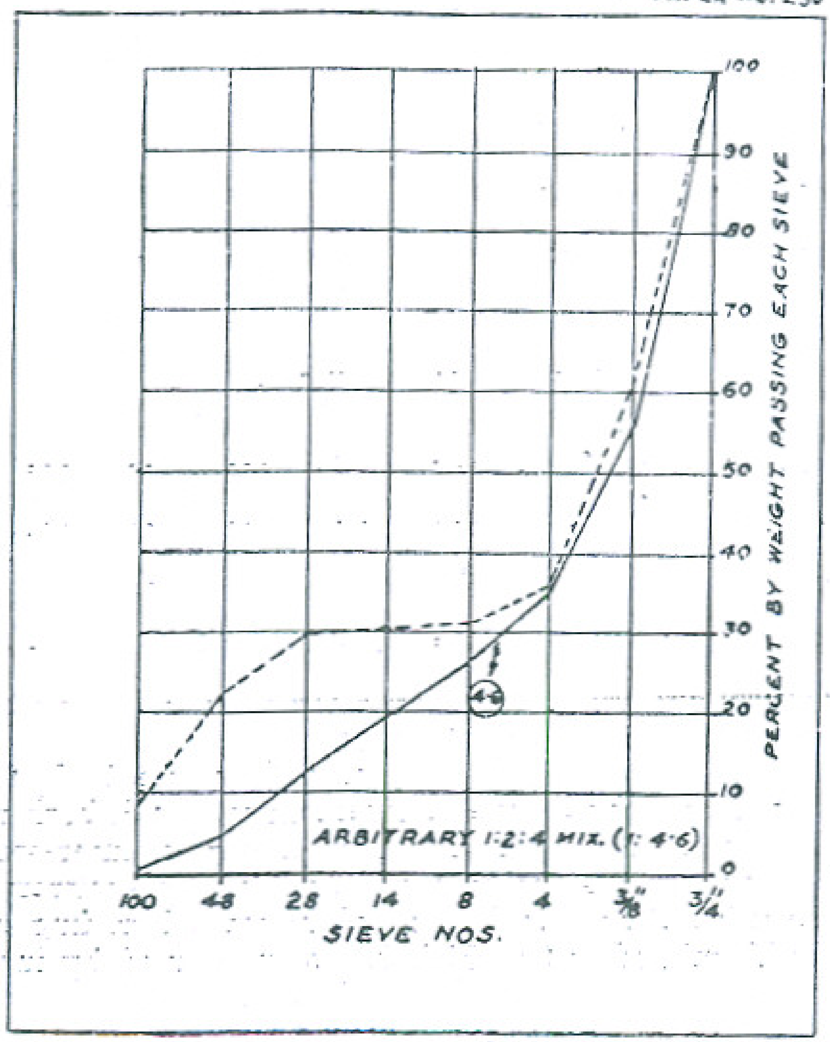
These are illustrated on Table No. 7 and Plate No. 10.

TABLE NO. 7

Arbitrary Mix	By weight	Sieve Analysis % by weight passing each sieve								Fineness Modulus (Abrams)
		100	48	28	14	8	4	3/8"	3/4"	
1:4.6	Gravel, 69.0	0	0	0	0	0.7	5.2	29.7	69.0	
or	Sand, 31.0	8.1	22.5	29.5	29.9	30.2	30.4	31.0	31.0	
1 : 2 : 4 (1)	Ambala Mixed Aggregates	8.1	22.5	29.5	29.9	30.9	35.6	60.7	100	4.828
(2)	Walsh's Type Grading No. 4.60	..	5.0	12.7	19.6	26.3	35.0	55.2	100	5.462
	Difference between 1 and 2 ..	+8.1	+17.5	+16.8	+10.3	+4.6	+0.6	+5.5	..	

PLATE 10

PAPER NO. 250



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It will be noted that the lower part of the arbitrary mix curve lies wholly above the ideal curve for the same real mix indicating oversanding or an excess of fines.

In extension of Tables Nos. 5 and 7, a similar Table No. 8 has been drawn up incorporating the sieve analysis of the usual arbitrary mixes from which comparisons of actual concrete mix results comparing strength and economy will now be made with those of rational mixes.

TABLE NO. 8

SIEVE ANALYSIS OF ARBITRARY MIXES

Arbitrary Mixes	By Weight	Sieve Analysis % by weight passing each sieve								Fineness Modulus (Abrams)
		100	48	28	14	8	4	⅜″	¾″	
Real Mix 1 : 4.6 or 1 : 2 : 4	Gravel, 69.0 Sand, 31.0	0 8.1	0 22.5	0 29.5	0 29.9	0.7 30.2	5.2 30.4	29.7 31.0	69.0 31.0	
	Mixed aggregates ..	8.1	22.5	29.5	29.9	30.9	35.6	60.7	100	4.828
1 : 6.2 or 1 : 3 : 5	Gravel, 64.9 Sand, 35.1	0 9.1	0 25.4	0 33.3	0 33.9	0.65 34.2	4.9 34.4	27.9 35.1	64.9 35.1	
	Mixed aggregates ..	9.1	25.4	33.3	33.9	34.85	39.3	63.0	100	4.61
1 : 3.9 or 1 : 2 : 3	Gravel, 62.5 Sand, 37.5	0 9.8	0 27.2	0 35.6	0 36.2	0.6 36.6	4.7 36.8	26.9 37.5	62.5 37.5	
	Mixed aggregates ..	9.8	27.2	35.6	36.2	37.2	41.5	64.4	100	4.48
1 : 3.1 or 1 : 2 : 2	Gravel, 52.6 Sand, 47.4	0 12.3	0 34.4	0 45.0	0 45.7	0.5 46.2	3.9 46.5	22.6 47.4	52.6 47.4	
	Mixed aggregates ..	12.3	34.4	45.0	45.7	46.7	50.4	70.0	100	3.96

8. Rational and Arbitrary Mixes in Practice

For the purpose of ease of comparison the water-cement ratio used for each of the rational mixes worked out in the foregoing and for each of the arbitrary mixes was adjusted so as to maintain a slump of 1″ in all cases.

These were of necessity determined by actual practical tests and worked out as follows :

TABLE NO. 9

Mix	Water Used		C.ft. of water per sack	Gallons of water per sack
	$\frac{\text{Water}}{\text{cement}}$ by weight	$\frac{\text{Cement}}{\text{water}}$ by weight		
1 : 4 ..	0.44	2.273	0.791	4.931
1 : 5 ..	0.55	1.818	0.989	6.163
1 : 6 ..	0.69	1.455	1.237	7.704
1 : 7 ..	0.825	1.212	1.484	9.245
1 : 8 ..	0.99	1.01	1.781	11.094
ATBITRARY MIXES				
1 : 4.6 or 1 : 2: 4 ..	0.605	1.653	1.088	6.780
1 : 6.2 or 1 : 3: 5 ..	0.825	1.212	1.484	9.245
1 : 3.9 or 1 : 2: 3 ..	0.587	1.705	1.055	6.574
1 : 3.1 or 1 : 2: 2 ..	0.550	1.818	0.989	6.163

The resulting strength figures at different ages and the quantity of cement required to attain these results are tabulated in the Table No. 10 and the essentials more clearly illustrated on the set of curves under Plate No. 1 depicting the final results.

TABLE NO. 10

COMPRESSIVE STRENGTHS AT DIFFERENT AGES OF THE VARIOUS MIXES. SLUMP 1″ CONSTANT THROUGHOUT

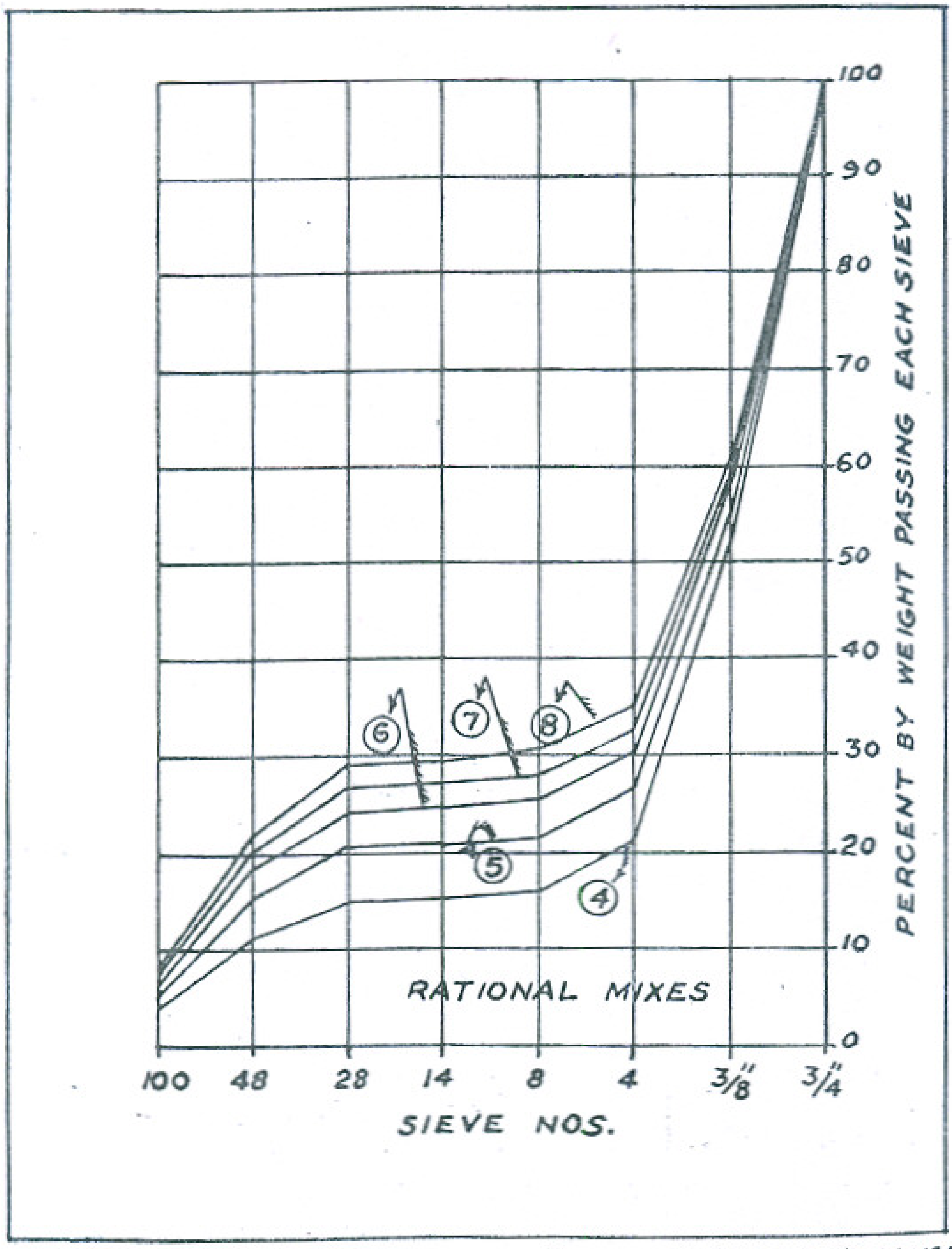
Mixes	Field Mixes	Weight of 1 c.ft. of rodded wet concrete when made	Compressive Strengths					Sacks of cement per c.yd. of concrete
			1 day	3 days	7 days	14 days	28 days	
Rational Mixes								
		lbs.						
1 : 4		158	2,844	4,891	5,560	6,281	6,725	7.1
1 : 5		156	1,563	3,740	4,200	5,469	6,225	5.78
1 : 6		154	1,031	2,810	3,375	4,200	5,275	4.73
1 : 7		152	844	2,025	2,750	3,469	4,035	4.02
1 : 8		151	500	1,275	2,150	2,800	3,125	3.54
Arbitrary Mixes								
1 : 4.6 or 1 : 2 :4	1 : 2 : 4	151	1,156	2,875	3,700	4,675	5,500	5.8
1 : 6.2	1 : 3 : 5	150	750	1,797	2,656	3,375	3;850	4.44
1 : 3.9	1 : 2 : 3	150	1,172	2,953	3,780	4,775	5,725	6.51
1 : 3.1	1 : 2 : 2	147	1,266	3,281	4,050	5,200	6,000	7.3

Special attention is drawn to the greater density of the rational mixes as indicated by the weight of one cubic foot of the wet rodded concrete.

The curves on Plate No. 11 illustrate the actual type grading curves for the sand and gravel under investigation and can safely be used for materials of this type to a maximum of ¾″ gravel. Where larger aggregates are used or aggregate consisting of broken stone other type grading curves are to be made up and will differ owing to the different particle shape.

PLATE II

PAPER NO. 250



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Verification of the Workability of the Mixes

Professor Walsh's work, which has been the background for these experiments, is based on the principle that for maximum density of the finished concrete the fines and middle portions of the combined mix should, within limits, be kept at the minimum whereas for maximum workability they should, within limits, be the maximum.

These conflicting demands have been met in the case of the sand and gravel under investigation by ensuring that the fineness modulus of the combined aggregates for each mix is maintained as closely as possible to that of the typical type grading, and it will now be interesting to verify by some other method the workability of the mixes as designed.

It has been recognised that for a mix to be workable the *volume of cement paste must be at least equal to the volume of the voids in the rodded mixed aggregates but in actual practice cement paste should be in excess. For any required degree of workability, the necessary excess amount of cement paste depends (a) upon the consistency of the cement paste itself,—lower water-cement ratios requiring larger excess amounts than higher ones,—and (b) upon the surface area of the aggregate,—the larger the surface area, the greater the excess required.*—KENNEDY, *American Concrete Journal.*

Let us, then, examine these factors in the 1 : 5 mix as already designed in the proportions 1 : 1.5 : 4.925.

For the purpose of the investigation, consider the following data:

Specific gravity of Ambala combined aggregate	2.6.
Specific weight of 1 c.ft. of the combined aggregate	162 lbs. $= w_s$.
Unit weight of 1 c.ft. of the combined aggregate	129 lbs. $= w$.
Absolute volume of 1/112-lb. bag of cement ..	0.58 c.ft. $= Z$.
Real Mix of 1 : 5 mix, *i.e.*, in terms of dry, lightly rodded mixed aggregate ..	4.96 c.ft. $= Y$.

The Voids in the Combined Aggregate

These will be $\dfrac{(w_s - w)\,Y.}{w_s}$

and in this case :

$$\frac{(162-129)}{162}\,4.96 = 1.02.$$

The cement paste available to fill these voids will be :

$$Z + \frac{112 \times w_c}{62{\cdot}4} \text{ where } w_c = \text{water-cement ratio.}$$

The water-cement ratio in the 1 : 5 mix was 0.55 (Table 9), so that the cement paste is :

$$0{\cdot}58 + \frac{112 \times {\cdot}55}{62{\cdot}4} = 1{\cdot}57 \text{ c.ft.}$$

The excess of cement paste over voids is :

$$1.57 - 1.02 = 0.55 \text{ c.ft.}$$

From which the first law of workability is satisfied.

Total Surface Area of the Aggregates

On the assumption that the ratio of surface to volume of each individual particle is similar to that of a sphere or $\frac{6}{d}$ where d is the average diameter *in feet* of the particles on each size of sieve the total surface area of the mix will be :

$$S = \frac{6w}{w_s} \Sigma \left[\frac{p'}{d'} ps + \frac{p}{d}(1 - ps) \right] Y$$

where $\frac{p'}{d'}$ is the summation of the quotients obtained by dividing the proportion of the total weight of the "sand" retained on each sieve (p′) by the average diameter of the particles in feet retained on the same sieve (d′)

where $\frac{p}{d}$ is the same as the above for the gravel

and p_s = the percentage of sand to total aggregate by weight.

(C. T. KENNEDY—*American Concrete Journal*, February, 1940.)

The values of $\frac{p}{d}$ and $\frac{p'}{d'}$ are shown in Table No. 11 below :

TABLE NO. 11

	% by Weight coarser than each sieve								
	100	48	28	14	8	4	3/8″	3/4″	1½″
Sand	74	27.5	5.0	3.5	2.5	2.0	0	0	0
Gravel	100	100	100	100	99.0	92.5	57	0	0

	(—SAND—)			(—GRAVEL—)	
Sieve	d′ Feet	p′	p′/d′	p	p/d
1½″	0.1875	0	0	0	0
3/4″	0.0938	0	0	0	0
3/8″	0.0469	0	0	0.570	12.1535
4	0.0234	0.020	0.8547	0.355	15.1709
8	0.0117	0.005	0.4274	0.065	5.5556
14	0.00586	0.010	1.7065	0.010	1.7065
28	0.00293	0.015	5.1195	0	0
48	0.001465	0.225	153.5836	0	0
100	0.000733	0.465	634.3793	0	0
			796.0710		34.5865

Inserting in the formula we have :

$$S = \frac{6 \times 129}{162} \Sigma \left(796 \times \frac{21.5}{100} + 34.6 \times \frac{78.5}{100}\right)$$

= 952 sq. ft. per c.ft. of combined aggregate.

The Workability Factor

By this is meant the average thickness of the cement paste surrounding the aggregate particles in ten-thousandths of a foot = K so that we have :

$$K = \frac{U}{S} \times 10{,}000 \qquad \text{(Kennedy)}$$

where U = the volume of excess cement paste from which K for the 1 : 5 real mix is :

$$K = \frac{0.55}{4.96 \times 952} \times 10{,}000 = 1.17.$$

It has been found that it is possible closely to predict the ultimate compression strengths of concretes where the workability factor is 1 or greater than 1, whereas mixes with a workability factor below 1 invariably yield strengths lower than those predicted.

The workability factors for all of the mixes mentioned in this Paper have been calculated in a similar manner and are reproduced in Table No. 12.

TABLE NO. 12

Mix	$\frac{\text{Water}}{\text{cement}}$ ratio by weight	Cement paste	Voids	Excess cement paste (U)	Surface area in s.ft. of 1 c.ft. of combined aggregates (S)	Workability factor (K)
1 : 4 ..	.44	1.37	0.90	0.47	712	1.70
1 : 5 ..	.55	1.57	1.02	0.55	952	1.17
1 : 6 ..	.69	1.82	1.09	0.73	1121	1.10
1 : 7 ..	.825	2.06	1.22	0.84	1222	1.01
1 : 8 ..	.99	2.36	1.36	1.00	1336	0.95
			Arbitrary Mixes			
1 : 4.6 or 1 : 2 : 4 ..	.605	1.67	0.73	0.94	1348	1.56
1 : 6.2 or 1 : 3 : 5 ..	.825	2.06	0.93	1.13	1522	1.28
1 : 3.9 or 1 : 2 : 3 ..	.587	1.64	0.64	1.00	1594	1.70
1 : 3.1 or 1 : 2 : 2 ..	.55	1.57	0.60	0.97	1898	1.70

If slump was an indication of the workability, all these mixes, which were made to give one-inch slump, would be equally workable, but it should be noticed that the workability factor decreases slightly as the water-cement ratio by weight increases. (See Plate 12.)

This is explained in the case of rational mixes by the first part of the second workability law which lays down that the necessary excess amount of cement paste depends upon the consistency of the cement paste itself—lower water-cement ratios requiring larger excess amounts than higher ones. It will also be noticed that the workability factors for the arbitrary mixes are higher than those worked out for rational mixes. The second part of the second law of workability—which explains this—runs as under. The necessary excess amount of cement paste depends also upon the surface area of the aggregate—the larger the surface area, the greater the excess required. But this higher workability factor in the case of arbitrary mixes is built up at the cost of density of the resulting concrete. (Table 10.)

All the arbitrary mixes shown here contain more fines than necessary, which increase the surface area of the aggregate. In short they are oversanded.

DISCUSSION

In opening the discussion, the Author reminded the members that some years ago the A. C. C. Cement Works at Wah, then the Punjab Portland Cement Co., Ltd., issued a so-called concrete proportion calculator which was primarily designed to illustrate the economy which could be affected in the production of cement concrete by the addition of coarse grit particles to the more common sands available from the Five Rivers of the Punjab.

Whilst serving its purpose very well as a rough and ready estimator such a device could not hope to deal with more than one aspect of the problem and a modification of the method of proportioning by voids was adopted after selection of the most suitable fineness modulus for the many tests involved. The type of coarse aggregate employed being well graded and the same throughout the tests, the proper comparison of the results on the different sands was substantially correct.

Where materials far removed from the ideal had of necessity to be made use of it was necessary to examine the proportion of the aggregates for each mix 1 : 4, 1 : 5 and so on in greater detail. The Paper presented a series of properly designed mixes in the range of 1 : 4 to 1 : 8 for one group of such material only.

The Author pointed out that the mixes as designed were far from being ideal but merely the best possible compromise when using the whole of the poor quality of sand considered, and that better results could be achieved where a certain percentage of the fines could be rejected or where coarse sand or grit could be added and such manipulation of the sand should always be resorted to wherever practicable. All tests shown in the paper were on a dry basis and where wet materials were being used, provision for the bulking of the sand was to be made.

It was convenient to control the workability of the mixes described in the Paper to a slump of one-inch so that all comparisons were made on a fair basis but my colleague, Mr. Murdeshwar, who carried out all the tests, made additional tests on mixes having a four-inch slump and these confirmed the conclusions arrived at.

The compression tests were carried out on a standard Adler compression machine using four-inch cubes, the cubes having in all cases been cured in moist air for 24 hours and later immersed in water. The results shown in the Paper were an average of the test results on three cubes.

The method of proportioning used in the Paper was a great advance on the method of proportioning by voids or by fineness modulus only. Proportioning by voids alone appeared simple but was incorrect inasmuch as it was based upon the fallacy that the voids in the coarse aggregate were filled by the sand and that the voids in the sand were filled by the cement paste. In actual practice, when the cement paste was included, the paste and the sand pushed aside the coarse aggregate and increased the real volume of voids.

Proportioning by fineness modulus alone was dangerous as this took no account of grading, and an aggregate within the presumed "safe" range of fineness modulus might produce a harsh and unworkable concrete.

For small jobs it might not always be convenient to carry out the full tests for a mechanical analysis of the sand and aggregate available but in such cases where fine sands were being used, it would invariably be found to be better and more economical to use arbitrary mixes of the ratio of about $1 : 1\frac{1}{2} : 4\frac{1}{2}$ in preference to the more usual $1 : 2 : 4$ and the Paper would have served its purpose if this fact had been made clear.

Mr. G. C. Khanna stated that the Paper should be of special interest to the road engineer, the railway engineer and also to the irrigation engineer. The subject of proportioning concrete mixtures had received very meagre attention at the hands of engineers in the Punjab, and, therefore, the Authors deserved a debt of gratitude for contributing a Paper on the subject. It was possible to design a concrete mixture of high compressive strength by using a suitable water-cement ratio, and grading of fine and coarse aggregates.

High compressive strength concrete had a low dead weight, as compared to its strength; therefore, this type of concrete was eminently suitable for structures having larger spans. In the Paper the Authors had designed a mixture which could bear a compressive strength of 6,725 lb. per square inch.

Nobody in India had been able to get such good results before, and, therefore, the Authors must be congratulated on this achievement.

In this Paper proportions of cement and aggregates were given for varying strengths of concrete. The Speaker selected one example, that of 1 : 4 mix, to give his own ideas on the subject based on actual experiments conducted about seven years ago.

In Table No. 1, page 307, the following proportions were suggested for a rational mix, *i.e.*, 1 part cement, 0.833 parts sand and 4 parts coarse aggregate. In the opinion of the Speaker that was not a rational mix at all, as it was an undersanded harsh mix. The quantities of cement and sand when mixed together were not even sufficient to fill the voids in the coarse aggregate. The reason for low proportion of sand was that the Authors had used a very badly graded sand. In an article published in *Concrete and Constructional Engineer* for August, 1933, on the same subject, it was stated that sand should have a fineness modulus not less than 2.5 nor more than 3.5, so as to conform to curves given by Walsh. The sand used by the Authors had a fineness modulus of 1.145, which was distinctly low. The sieve analysis of sand given on page 309 showed that sand was deficient in coarser grains, *i.e.*, those which could be retained on sieves Nos. 8, 14 and 28. The value of X according to the formula given on page 313 for a sand of fineness modulus of 2.5 came to 68 per cent. The correct sand proportion was therefore 32 per cent. This would give a more rational mixture than the one suggested by the Authors, as the quantity of sand in the former would be roughly 50 per cent. of the coarse aggregate.

It was not difficult to get sands which had a fineness modulus of about 2.5. By mixing coarse and fine sands together, an ideal grading could be obtained.

Water-worn gravel like Chandigarh, Pathankot or Mari Indus should be screened through $\frac{1}{4}''$ screens and the screenings should be separated from dust. From the screenings could be collected the required quantity of coarse-sized grains suitable for mixing with sand. The resulting mixture would be a well-graded sand which would conform to Walsh's curves much better than the grading given by the Author. Quite a large number of engineers preferred a mixture of Pathankot and Ravi sands to those sands being used individually.

In cases where coarse sand was not available, the Speaker suggested that the old orthodox method of mixing be used rather than the formula of Walsh which was likely to give erroneous results.

Mr. S. L. Kumar regretted that the Paper was given to the members on the first day of the session and that the members had no opportunity of going through it carefully. The Author's work, however, would be of considerable use to those Punjab Engineers who could not manage to get coarse sand for their cement concrete. The Paper showed how, with fine sand, the requisite strength of concrete could be obtained if the aggregates were rationally mixed. The value of the Paper would have been considerably enhanced if some of the matter had been rearranged, for example, if definitions given on page 309 had been given in the beginning of the Paper.

It was not understood why the Author defined the nominal mix 1 : 2 : 4 as consisting of 112 lb. of cement to 2 c.ft. dry sand and 4 c.ft. of coarse aggregate. Ordinarily, every engineer regards 1 : 2 : 4 mix as consisting of 1 c.ft. of cement, 2 of sand and 4 of coarse aggregate. The disadvantage of adopting a definition different from the established practice is quite clear. Thus fairly high values of the strength of 1: 2 :4 concrete given on page 304 were likely to cause suspicion until one saw that this 1 : 2 : 4 mix was much richer than the ordinary 1 : 2 : 4 mix. If the Author must stick to his definition, it should be given in the beginning of the Paper. Again, the Author used such words as "sack" of cement and "bag" of cement with the same meaning. It would perhaps be better to use the word "bag" only and define it as being equal to about one cwt. of cement.

There were a certain number of misprints on page 304 which made for confusion. In paragraph 3 it was stated that an arbitrary mix 1 : 2 : 4 was the same thing as the mix of 1 : 4 : 6. Actually, the latter should be 1 : 4.6. A similar misprint existed in the 4th paragraph.

It was presumed that Bhupindia cement, which was used in the experiments referred to in the Paper, was an ordinary Portland cement and not a rapid-hardening one. This fact should have been clearly stated to enable engineers to compare the strength values of different mixes given in the Paper with the other test results at their disposal. It would perhaps be better still if the average certified tensile and compressive strengths of this cement at 3 and 7 days were also included in the Paper.

Mr. Kanwar Sain in a written communication conveyed that the Paper was a welcome contribution as it drew attention to the important subject of basing concrete mixes on rational lines instead of arbitrary lines usually followed in the Punjab. Various theories had been proposed in the past, the oldest perhaps was the void method of proportioning concrete. The basic idea of that method had been to produce a concrete in which the void space would be a minimum. Knowing the volume of voids in the coarse aggregate, sufficient mortar of fine aggregate and cement was specified to fill the coarse aggregate voids, often using 10 per cent. excess mortar. Strength of concrete was varied by increasing or decreasing the cement content of the mortar. With a coarse aggregate high in voids this method would result in a better working concrete. The production of a concrete having zero voids was, of course, impossible since the mortar which was added might itself have as high as 40 per cent. voids. Concretes proportioned in this manner might or might not be of the greatest density possible for the materials employed. Actual strength attained must in any case be determined by actual strength tests.

An improvement on the above method was the Fuller's theory of maximum density for proportioning concrete. The assumption in this method was that with fixed cement content an aggregate containing the cement, so graded as to have maximum density, would have maximum strength. It was claimed that strength increased with increase in density. Sand and gravel were separated into a number of sizes and re-combined to have a grading which would closely coincide with the "ideal" grading curve or curve of maximum density. This method, however, was not developed so as to be of great practical value. Tests of aggregates from numerous sources showed that an aggregate could be screened and recombined to have widely different gradings and yet produce concrete of approximately the same quality.

Another method advocated for proportioning concretes was based on the surface area theory. This theory assumed that strength was dependent upon the ratio of weight of cement to surface area of the aggregate and that for a group of aggregates having different surface areas and cement contents proportional to surface areas, equal strengths would be obtained. Tests had, however, shown that a normal sand might be regraded and so increased in fineness as to double the surface area and yet produce a concrete having the same cement content and flowability, equal in strength to the mixture having one-half the surface area. Tests did not bear out the basic claims of the surface-area theory but indicated that the surface-area factor was only one of the many which affected compressive strength and that it was not in itself a criterion of strength.

A more recent theory was that of water-cement ratio. This theory assumed as its basis that the strength of concrete was solely dependent upon the ratio of the volume of mixing water to the volume of cement for aggregates from the same source of supply. It was further claimed that aggregates having the same fineness modulus would require the same quantity of mixing water to result in the same consistency when cement contents were equal. Some important critics had contended that this theory provided sufficient water to bring the neat cement pastes in the mixture to the same consistency but did not make allowance for the varying water requirements of the aggregates.

Professor Walsh, in his valuable contribution, "How to Make Good Concrete," appeared to take all the theories into consideration and the authors of the Paper had done a service to Punjab engineers in showing how Professor Walsh's methods could be applied to Punjab aggregates.

The various steps involved had been stated with such clarity that no repetition or emphasis on any point appeared to be called for.

There was, however, one important criticism. The Authors relied for their experiments on proportions based on the weight of cement and the volumes of sand and coarse aggregate. This was undoubtedly in line with the present Punjab practice, but this method of mixing the ingredients on a volumetric basis might upset all the nice calculations made for regrading. In all advanced countries there was a definite trend in replacing the volumetric method of mixing by a weight method of mixing the ingredients not only on big jobs but even on small jobs. There was a growing demand by state, country and city engineers for the better grading of concrete to be had by proportioning aggregates by weight instead of by volume. In view of this demand suitable scales for weighing wheelbarrow loads of ingredients had been manufactured. The scales were of light weight to enable them to be loaded easily into trucks for movement from place to place. They were provided with three beams; the upper one is blank, being a tare bar to balance the empty barrows or carts. The two lower beams were graduated 500 by 2 lb., one beam for sand and the other for stone. When required to weigh three aggregates, another beam was provided at a small extra price. The scales were only nine inches high. One firm manufacturing such scales was The Canadian Fairbanks Morse Co., Limited, Montreal, Canada.

Another difficulty which an engineer in the field had to encounter was that from the same source of supply there might be a wide range within which the aggregates varied. Unless he had a well-equipped concrete laboratory in charge of an officer who understood the concrete proportioning thoroughly and would have the courage of conviction to vary the mixes daily in accordance with the results of the field tests, the whole lecture on rational methods of proportioning concrete might be a wash-out.

Mr. Kanwar Sain, however, entirely agreed with the Authors that arbitrary volume proportions were justified neither by practical nor scientific considerations. The almost universal assumption that a concrete made of one volume of cement, two volumes of fine aggregate and four volumes of coarse aggregate would give us a strength required for the design at 28 days had been proved false in many localities and yet such a proportion was often specified and owing to the general failure to test field concrete, the inferior product was seldom discovered.

Reinforced concrete design had been fairly well standardized and reliable stresses had been established after much study and experiments, but little attention was directed towards obtaining a concrete equal in strength to that assumed in designs. The adoption of a proper system of field inspection and tests of concrete should do much to eliminate the common practice of specifying arbitrary proportions without proper knowledge of the concrete-making qualities of aggregates to be used.

In a written reply the Authors thanked *Mr. G. C. Khanna* for his congratulations on the achievement of having obtained a compressive strength of 6,725 lb. per square inch at 28 days but pointed out that such strengths with a 1 : 4 mix are in no way remarkable when the mix is properly designed. In fact the strengths in these particular tests were undoubtedly limited by the strength of the Siwalik sands and gravel used as coarse aggregate and 28-day strengths of anything up to 8,000/9,000 lb. per square inch with such a mix and low water-cement ratio were not unheard of when harder aggregates such as dolomites or even ordinary limestone are made use of.

With regard to Mr. Khanna's statement that the 1 : 4 mix shown in Table No. 1, page 307, was not a rational mix at all but was undersanded and that the volume of cement and sand together was insufficient to fill the voids in the coarse aggregates, the Authors concluded that Mr. Khanna had failed to take into account the natural fine contents of the gravel between Sieves 4 and 8 as shown in Table No. 2.

In any case the statement was incorrect as there was an excess of cement plus sand of almost 12 per cent. over the voids in the coarse aggregates after deducting the amount of cement necessary to fill voids in the sand, even when the voids in the coarse aggregates and sand were considered in terms of loose volume as illustrated below:

1 : 4 *Mix* (112 lb. cement, 0.833 c.ft. sand, 4.033 c.ft. gravel)

Voids in gravel (loose volume) $= \frac{162-102}{162} \times 4.033 = 1.494$ c.ft. (A).

Voids in sand (loose volume) $= \frac{162-92}{162} \times 0.833 = 0.36$ c.ft.

Volume of 112 lb. cement (93.4 lb. cement c.ft.) $= 1.2$ c.ft.

Volume of cement remaining after filling voids in sand $= 1.2 - 0.36 = 0.84$ c.ft.

Arbitrary volume of mixed sand plus cement available to fill voids in coarse aggregate $= 0.833 + 0.84 = 1.673$ c.ft. (B).

Excess of "B" over "A" $= 1.673 - 1.494 = 0.179$ c.ft.

$$\frac{0.179 \times 100}{1.494} = 11.98\%$$

For further clarification the Authors drew attention to the workability factor of this particular mix shown in Table No. 12 whence it would be seen that the mix, far from being harsh and undersanded, was a very fat mix, in fact the fattest of all the rational mixes described and that in spite of the low water-cement ratio there was an available excess of cement paste.

Dealing with the statement that the sand should have a fineness modulus of not less than 2.5 and that in such a case the correct rational mix would require a sand proportion of 32 per cent., the authors point out that the Speaker had failed to assimilate the purpose of the Paper which was to show how to make the best use possible of an admittedly poor material and sufficient emphasis had already been made in the Paper and in the Authors' introduction to the effect that the mixes as designed were merely the best possible compromise when using sand of the poor quality under investigation and wherever coarse sand was available it should naturally be made use of.

In the absence of any reason or data being given for the Speaker's concluding criticism, that Walsh's method was likely to give erroneous results when applied to the use of fine sand, and that the old orthodox method of proportioning should be adhered to, the authors stated that they felt they could not do better than refer the Speaker to a more detailed study of the Paper under discussion when they were confident that such a conclusion would be modified.

In their reply to *Mr. S. L. Kumar*, the authors were grateful for their attention being drawn to the various misprints which could not be corrected owing to the late publication of the Paper and these had already been put right. They also agreed that they were incorrect in speaking variously of "sacks" of cement and "bags" of cement and that one of these words should have been standardised throughout.

In reply to Mr. Kumar's query as to why the Authors defined their nominal mixes in respect of cement as consisting of 112 lb. of cement instead of 1 c.ft. of cement, the Authors stated that it should clearly be understood that the weight of 1 c.ft. of cement varied widely according to the make of cement, the fineness to which it was ground and more particularly the degree of compactness. For instance, 1 c.ft. of normal cement ground to a fineness of 5 per cent. on the 170^2 mesh would weigh anything from around 78 to 98 lb. per c.ft. whereas 1 c.ft. of finely ground rapid-hardening cement might vary between 75 to 90 lb.

It would, therefore, be seen that the adoption of a standard weight of cement which was, after all, purchased by weight, was the only proper procedure as the quantity of cement would then in all cases be consistent and, in fact, this had been the established practice for many years.

With regard to Mr. Kumar's query as to the type of cement used in the experiments, the authors invited reference to page 308, heading 4, which showed that the cement was normal Portland cement having a residue of 5.5 per cent. on the 170^2 mesh and not rapid-hardening cement.

Dealing with the wish expressed by Mr. Kumar to have the average tensile and compression strengths of this cement included in the Paper, the Authors referred the reader to pages 272—4 of last year's Paper No. 239, where such figures were reproduced in full.

The Authors thanked *Mr. Kanwar Sain* for his appreciation of the Paper and continued that Mr. Kanwar Sain had dwelt at some length on the various theories leading up to the present-day practice of proportioning cement-concrete mixes and had appreciated that Professor Walsh's system takes most of these theories into consideration.

With regard to the criticism that the method of proportioning the aggregates by weight instead of by volume should have been adopted in the tests, the Authors referred Mr. Kanwar Sain to Plate No. 2 of the Paper which embodied all the important results pertaining to the rational mixes investigated when it would be noted that these graphs denoted the proportion of sand and gravel for the various mixes by percentage weight only.

When it was desired to proportion by weight it was therefore only necessary to convert the percentage weights from this graph into actual weight derived from the weight of the combined aggregate for the mix shown in Table No. 6 and in the manner shown on page 315. The Authors were in entire agreement with Mr. Kanwar Sain that the method of proportioning by weight is the only sound one. In fact, all modern automatic ready-mixed concrete plants were designed to proportion by weight.

The authors were of the opinion that the contingency put forward regarding the necessity of varying the mixes in the field daily to suit variations in the quality of the aggregates was not quite so black as was painted as, after all, even in concrete mixes, a certain degree of latitude was allowable and first class concrete could still be produced even with proportions of fine or coarse particles slightly in excess of the strictly correct rational quantities.

In order to provide for this contingency it should normally be sufficient always to err *slightly* on the side of an excess of fines in the mix.

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All drawings should be submitted in actual size for reproduction; he limit of size is 7½ inches in height and 5 inches in length. These mits should on no account be exceeded.

All drawings should be in one colour only. In addition to a omplete drawing a tracing on the mat side (not the glossy side) of he cloth but without any lettering or printing should also be sent. 'he lettering will be arranged by the Honorary Secretary.

These tracings should be in good black ink ("Pelican" Waterroof Ink is recommended) and should be rolled, not folded.

The salient points of a diagram are more easily appreciated if ıere is little printing on it. Accordingly the explanations should e given in the text and not on the diagram and all dimensions that re not essential should be omitted.

The number of plates of drawings to be submitted with each aper should not exceed six, unless the Council agree to allow an ıcrease in any special case.