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TESTS CARRIED OUT ON SAND FROM THE SUTLEJ RIVER AND PUNJAB PORTLAND CEMENT.

A. N. M. ROBERTSON, B.A., B.E.

AND

A. WEIGHALL.

This paper gives the results of a series of tests made during August and September 1923 in order to ascertain if the fine sand of the Sutlej River could be used in combination with Portland Cement of local manufacture to give a satisfactory mortar for use on Works.

The results of the tests have already been published in a series of Notes which were prepared at the time, and printed subsequently by order of the Chief Engineer, Irrigation Branch, Punjab.

It was considered that they might also with advantage be prepared in the form of a paper for discussion at the Punjab Engineering Congress as this would lead to a general discussion on the question of mortars used on Engineering Works in the Punjab, and members of the Congress would be able to add valuable information from the results of their experience, so that a record would be obtained which would be useful for future reference.

The following series of tests were carried out :—

(*a*) *Tests of Sand.*

(*i*) Fineness.

(*ii*) Percentage of voids.

(*iii*) Relation of volume to weight.

(*b*) *Portland Cement.*

Relation of volume to weight.

(*c*) *Tests of Ballast.*

Voids.

(*d*) *Portland Cement—Sand Mortars.*

(*i*) Shrinkage of cement mortars.

(*ii*) Tensile strength of Standard Briquettes made from the mortars—

(*a*) after 7 days,

(*b*) after 28 days.

(*iii*) Compressive strength of cubes made from the mortars—

(*a*) after 7 days,

(*b*) after 28 days.

(*e*) *Portland Cement—Sand Mortars with addition of Lime Cream.*

(*i*) Tensile strength of Briquettes—

(*a*) after 7 days,

(*b*) after 28 days.

(*ii*) Compressive strength—

(*a*) after 7 days,

(*b*) after 28 days.

(*f*) *Tensile strength of Portland Cement—Sand Mortars prepared by a Mistri under ordinary working conditions—*

(*a*) after 7 days.

(*g*) *Quantity of dry materials required to make a hundred cubic feet of Portland Cement Concrete.*

Materials used.—The sand was obtained from the following weir sites on the Sutlej River :—

1. Islam.
2. Suleimanke.
3. Ganda Singhwala.
4. Ferozepore (same site as No. 3 at a lower stage of the river).
5. Rupar.

Standard sand was also moulded into Briquettes in the same proportion as the other sands in order to compare the results obtained from it with those of the Sutlej sand.

The Portland Cement come from the Punjab Portland Cement Company's Works at Wah near Hassan Abdal in the Punjab.

The white lime comes from Solon near Simla.

The results of the tests are stated below :—

(a) Tests of sand.

(*i*) *Fineness.* The sands were passed through a set of the standard screens. The results are shown on the next page.

Results of test on sand in tabular form.

Fineness.	Islam.	Suleimanke	Ganda Singh-wala.	Ferozepore	Rupar.	Standard.
Retained on 20 mesh	0·5	0·1	0·1	2·0*	1·2	..
Passed 20, retained on 30	..	0·1	0·1	0·1	0·2	100
,, 30 ,, 76	28·3	46·6	13·5	26·0	61·3	..
,, 76 ,, 100	27·4	24·1	9·7	26·5	19·1	..
,, 100 ,, 180	35·8	24·7	64·3	40·5	14·8	..
,, 180 ,, 200	0·7	0·4	1·5	0·5	0·1	..
,, 200	3·5	2·1	6·8	4·3	1·2	..
Total ..	96·2	98·1	96	99·9	97·9	100
Voids ..	40%	41%	42%	42%	40%	35%
Weight of sand per cubic foot shaken material ..	95lbs.	92lbs.	94lbs.	94lbs.	92lbs.	102lbs.

* *Notes*—1. The 2·0 retained on 20 mesh is pea kankar which was present throughout the sample.
2. The Ferozepore sample when screened at Lakheri was a little finer than the samples tested at Ferozepore.

The difference between the total weight in each case and the weights of the various grades of fineness when added together shows a small loss : due partly to losses of material retained on the screen and partly to small errors in weighment. It will be seen that Rupar sand at the upstream end of the series is the coarsest sand followed in order by Suleimanke and Islam, Ganda Singhwala sand being the finest.

As Ganda Singhwala occupies a position between Rupar and Suleimanke it was to be expected that the sand from there would be next to Rupar sand on the scale.

A second sample of sand was selected from the Ganda Singhwala weir site at a lower stage of the river. It was coarser than the first sample, but not coarser than the samples obtained from Islam and Suleimanke downstream. It is referred to Ferozepore sand in the tests.

The Rupar sand was not clean.

The Islam and Suleimanke and Ferozepore sands are clear grey micaceous sands.

Standard sand is of a size that passes the 20 mesh, and is retained on the 30. It will be seen that little sand of this grade has been obtained from any of the samples. The bulk of the sand from Rupar and Suleimanke falls into the next grade—

passed on 30 retained on 76 mesh to the square inch.

The Islam sand is very evenly divided between the three grades below that of the standard sand.

The Ganda Singhwala sample consisted of very fine material, 43 per cent. passing the 100 mesh and being retained on the 180.

No grading found necessary.—The results obtained showed that it was of little use to attempt to grade the sands by adding Rupar sand to the finer samples.

(*ii*). *Percentage of voids.*—All sands were tested for voids. The results are given in the tabular statement for fineness already quoted.

The method adopted was as follows :—

Two glass vessels graduated to read cubic centimetres were used. 50 c. cs. of dry sand was placed in one. 35 c. c. of water in the second.

The sand was gradually poured into the water, and the combined volume noted. From this the voids were deduced as follows :—

Example—				Ferozepore Sand.
Sand	..	..	..	50 c. c.
Water	..	..	..	35 „
Sand and Water	..	..	..	64 „

Water not absorbed by voids in sand 64—50=14.

Water absorbed by voids 35—14=21 c. c.

Voids in 50 c. cs. sand=21 c. c.

Therefore percentage of voids is 42 per cent.

(*iii*). *Relation of volume and weight.*

The method by which this relation was determined was as follows :—

A vessel of known volume was taken and filled with the material under test. It was shaken till no further reduction in volume was noted, and the material just filled the vessel. Weighment then gave the required result. The volume of the vessel was 634 c. c. The weights of the sands were above 950 grammes. The results are shown in the tabular statement already quoted.

This gives a ratio for material shaken down till no further reduction in volume is noticeable.

It cannot be accepted for general use on works where quantities of sand are being handled in bulk, and where a varying amount of consolidation takes place depending on how the labour fills the measuring boxes. Several experiments were made to determine the correct figure to adopt in such cases, the material used being Suleimanke sand. Using a small tin of ·32 cubic feet capacity, the average of three fillings gave 79·3 lbs. per cubic foot. A value of 80 lbs. per cubic foot was taken for the earlier experiments on concrete blocks carried out at Suleimanke. A subsequent weighment in a 2·0 cubic feet measuring box gave the value of 86 lbs. per cubic foot.

These figures were obtained under actual working conditions at Suleimanke.

Further experiment carried out at Simla with more accurate appliances, using 1 cubic foot and 2 cubic feet, gave the following

results. In each case the figure represents the mean of five weighings :—

1 cubic foot 77·3 lbs. per cubic foot.

2 cubic feet 79·05 lbs. per cubic foot.

These latter figures are considered to be a reliable value for dry Suleimanke sands.

(b) Portland Cement.

Relation of volume and weight.

It was necessary to arrive at a similar ratio for the cement.

The results for the material shaken till no further reduction in volume was noticeable give a figure of 104 lbs. per cubic foot for the Wah Portland Cement.

Cement filled loosely into the small ·32 tin at Suleimanke gives a figure of 74·3 lbs. per cubic foot. In estimating the weights of cement to be used, as representing certain volumes, a value of 75 lbs.=1 cubic foot was taken for the earlier set of experiments on concrete blocks at Suleimanke. This was a very low figure, reversing the density ratio and making sand heavier than cement for equal volumes.

It was considered however that the 75 lbs. figure for cement and the 80 lbs. figure for sand were the proportion likely to have obtained when weighing out small quantities loosely for the preparation of the briquettes and cubes in the tests. They should be used when determining the weight volume ratio used in the concrete blocks.

This question was considered by the Chief Engineer, and finally orders were issued that for calculating the ratios to be used on works, a value of 90 lbs.=1 cubic foot should be taken for cement. Subsequent weighments made at Simla in a 1·0 c. ft. box gave a value of 85·6lbs. per cubic foot for the Wah cement. This figure is the mean of five weighments for cement filled into the box under the conditions likely to obtain on works and is considered to be a reliable result.

(c) Tests of Ballast.

Voids.

Two series of tests were carried out at Suleimanke. On the first occasion, the material was placed in tramway skips of

25 cubic feet capacity. Three kinds of ballast were tested—

(*a*) Delhi stone ballast.

(*b*) Jhama brick ballast.

(*c*) Nalagarh stone ballast.

All the ballast was hand-broken.

(*a*) contained a good deal of fine material and resembled machine-broken ballast, (*b*) had very little of the finer stuff, (*c*) was ordinary hand-broken ballast. The material was kept in water for 12 hours before test.

25 c. ft. of saturated ballast was placed in the skip and a measured quantity of water was poured into the ballast till its surface reached the level of the surface of the material. From this the amount of the voids was calculated.

The results are as follows :—

Name of ballast.	*Percentage of voids.*
Delhi stone	36 per cent.
Jhama brick	45 „
Nalagarh stone	36 „

On the second occasion, tests were made in a pacca masonry tank of 62·5 cubic feet capacity prepared by the Executive Engineer in charge of the Works at Suleimanke—Mr. H. W. Nicholson who made some experiments in the tank himself. Delhi ballast gave the low figure of 26 per cent. against a former result of 36 per cent. In the latter case, however a great deal of fine material was in the sample. On the first occasion the stone was scraped off the top of the heap, and had less fine stuff in it.

There is no doubt that as a whole the Delhi ballast is better graded than the hand-broken Nalagarh stone. Its average value for voids would probably be under 30 per cent. It was not tested further, as it is not likely to be required for the work. Its significance, however, lies in the fact that Nalagarh stone when machine-broken is likely to show similar figures for voids, and this will lessen the amount of mortar to be used with it. Nalagarh hand-broken ballast was tested twice, once by Mr. Nicholson, who obtained a value of 32 per cent. for voids and again by the officers-in-charge of the tests, when it gave 34 per cent. These figures are in close agreement and it may be said to contain one-third of voids.

(d) Portland Cement—Sand Mortars.

(*i*). *Shrinkage of cement mortars.*—As a corollary to tests for voids in ballast, it was necessary to obtain figures for shrinkage of the cement and sand when made into a mortar paste, so that the quantities which should be added to the ballast to form the different grades of concrete might be determined. The results vary. Time did not permit of a further check being made. It is considered that the mortar for the 1 : 3 and 1 : 4 mixtures was too dry and the reduction figures were somewhat too small, while for 1 : 6 mixture it is too large as the paste became sloppy, the 30 per cent. of water being too much. The figures for the other mixtures are considered to be more accurate, as the mortar paste was of the right consistency :—

Proportions by weight.	Proportions by volume taking cement 75 lbs. per c.ft., sand 80 lbs. per c. ft.	Total volume dry material.	Percentage water added by volume.	Wet paste volume.	Shrinkage.
			Per cent.		Per cent.
1 : 3 ..	1 : 2·8	3·8	25	3·05	20
1 : 4 ..	1 : 3·75	4·75	25	3·9	18
1 : 5 ..	1 : 4·7	5·7	30	4·4	23
1 : 6 ..	1 : 5·6	6·6	30	4·8	27
1 : 7 ..	1 : 6·6	7·6	25	5·64	26
1 : 8 ..	1 : 7·5	8·5	25	6·38	25

When carrying out the second series of tests on concrete blocks at Suleimanke, the 1 : 3 and 1 : 4 mortars were again tested. The results were—

1 : 3 cement mortar .. 27 per cent. shrinkage.

1 : 4 „ „ .. 26 „ „

These figures are considered to be of greater accuracy than those of 20 per cent. and 18 per cent. noted above. They have been adopted when proportioning the materials for blocks 21 to 29 of

the series given in the statement which accompanies the report. The experiments were carried out using the ·32 cubic foot capacity tin as a unit.

The required number of tins were filled with dry material. The mortar was then mixed dry and wetted till it formed a stiff paste and then remeasured in the tins. The resultant loss of volume was in accordance with the figures given above.

(*ii*). *Tensile strength of standard Briquettes made from the mortars.*

Ratios of from 1 : 3 up to 1 : 8 (by weight) were tested, the proportions being weighed out on a chemical balance and mixed by trained briquette moulders from the Bundi Cement Works.

These tests represent the average figure for a set of six briquettes in each case, and form an important feature of this paper, taking up the greater part of the time spent on making the experiments. It took over ten minutes to prepare each briquette. Their preparation was seen by a number of Officers of the Department who were in Simla at the time. When made, they were placed over water for a day and then removed from the moulds and placed in water until they were taken out for test in the machine. The results are given in tabular form below.

The amount of water added to the various mixtures followed closely the proportions of 12 per cent. by weight on the total dry materials, varying from 24 cubic centimetres to 28 cubic centimetres for weights of 200—225 grammes of dry material.

The proportions of dry materials were as follows :—

Cement.	Sand.	Cement.	Sand.
		Grammes.	Grammes.
1	3	50	150
1	4	40	160
1	5	34	170
1	6	30	180
1	7	25	175
1	8	25	200

Average tensile strength in lbs. per square inch for mortars of Sutlej River Sand and Wah Cement.

Mortar.	Islam.		Suleimanke.		Ganda Singhwala.		Rupar.		Standard.	
	7 day.	28 day.	7 day.	28 day.	7 day.	28 day.	7 day.	28 day.	7 day.	28 day.
1 : 3	343	447	351	594	289	497	344	553	540	604
1 : 4	242	424	259	471	230	422	266	435	334	394
1 : 5	191	337	189	364	177	335	206	388	260	267
1 : 6	153	267	150	281	122	262	176	334	206	204
1 : 7	133	235	118	243	106	226	133	240	189	179
1 : 8	107	210	90	202	92	172	116	217	149	148

It will be seen that all sands have given good results, and show a satisfactory increase of strength between the 7 day and 28 day period. The Suleimanke sand has given the highest results for the weir sites. It must be noted that the 7 day tests on the standard sand were carried out at Lakheri, and in higher temperature there it was found that higher results than those obtained at Simla were recorded. The 28 day tests for the standard sand were carried out at Simla hence there is little increase in strength shown.

The Ferozepore sand tensile tests which were carried out at Lakheri show a similar increase of strength over that of the sands tested at Simla, owing to the higher temperature in which they were prepared. They are therefore given separately and are as follows :—

Ferozepore Sand tested at Lakheri.

Mortar.	7 day.	28 day.
1 : 3	488	563
1 : 4	392	409
1 : 5	275	384
1 : 6	191	294
1 : 7	155	232
1 : 8	127	216

These results are also shown graphically on the plates which accompany this paper.

(iii) Compressive strength of cubes made from the mortar.

The cubes were all made and tested at Lakheri. The figures are given overleaf. (In each case two cubes were tested).

Statement showing average compressive strength in lbs. per square inch for cubes of Sutlej River Sand and Wah Portland Cement.

Proportion of Cement and Sand.	Islam.		Suleimanke.		Ganda Singhwala.		Ferozepore.		Rupar.		Standard.	
	7 day.	28 day.	7 day.	28 day.	7 day.	28 day.	7 day.	28 day.	7 day.	28 day.	7 day.	28 day.
1 : 3 ..	2,160	2,965	2,035	3,570	2,020	2,895	2,330	3,605	2,330	3,885	4,815	6,450
1 : 4 ..	1,598	2,555	1,475	2,360	1,325	1,890	1,630	2,260	1,570	2,690	3,095	4,325
1 : 5 ..	1,110	1,850	920	1,630	1,045	1,490	1,025	1,635	1,180	1,940	3,010	3,040
1 : 6 ..	720	1,385	665	1,155	805	1,045	635	1,125	845	1,435	1,455	2,250
1 : 7 ..	670	1,030	560	1,005	880	855	610	945	675	1,010	1,180	1,595
1 : 8 ..	555	825	420	740	440	700	480	760	565	780	840	1,230

The results are also shown graphically in the plates which accompany the paper.

They exhibit the same characteristics as those for tension.

(e) Portland cement and sand mortars with the addition of lime cream.

(*i*) *Addition of slaked lime to mortars. Breaking tests*—In addition to the tests laid down by the Sub-Committee, a further series were suggested by Mr. East of Messrs. Killick Nixon and Company, Managing Agents of the Cement Firm. He advised the addition of white lime in certain proportions to the mortars of test (*d*). These instructions were carried out, with lime in the form of a thin paste or cream having been added to mortars, of the following proportions for each of the sands.

1	cement	:	4	sand
1	,,	:	5	,,
1	,,	:	6	,,

The results of the seven day tensile tests have shown that such mortars give a strength considerably above that of the cement and sand mortars. The greater tensile strength at 7 days exhibited by the briquettes to which lime cream had been added was however not maintained on the 28 days test. Generally speaking the change has been from a 20 to 25 per cent. excess strength at 7 days to a figure equal to or about 8 per cent. below the figure for the plain mortars at 28 days. The figures are given below, the tensile strength for the plain mortar being again shown for comparison :—

Sand.	1 : 4		1 : 5		1 : 6	
	7 day.	28 day	7 day.	28 day	7 day.	28 day
Islam sand	242	424	191	337	150	267
Islam sand with lime cream ..	308	388	234	346	188	279
Suleimanke sand	259	471	230	422	266	435
Suleimanke sand with lime cream	309	430	250	351	188	287
Ganda Singhwala sand ..	230	422	177	335	122	262
Ganda Singhwala sand with lime cream	284	388	212	319	181	272
*Ferozepore sand.. ..	392	409	275	384	191	294
Ferozepore sand with lime cream	427	436	327	397	248	307
Rupar sand	266	435	206	388	176	334
Rupar sand with lime cream ..	314	443	244	345	193	281

*Ferozepore sand was tested at Lakheri.

Method followed in determining the amount of white lime cream to be added to the cement mortars.—The extract from the book "Portland Cement and Concrete" published privately by the Wouldham Cement Company which Mr. East sent as a guide to follow when adding white lime to the mortars, showed a proportion of ½ lime paste to 1 of cement by volume.

To bring this to its equivalent by weight the following values have been taken :—

Cement=90 lbs. per c. ft.

40 grammes cement=28 c.c.

therefore 14 c.c. of white lime paste are needed per 40 grammes cement.

The white lime was mixed with water to a consistency that gave 25 c.c. paste to 25 c. c. clear water after standing for 24 hours. 50 c.c. of this mixture gave 14·7 grammes dry slaked lime.

The first mortar 1 : 4 contained the following proportion of materials :—

Cement	..	..	..	40 grammes.
Sand	..	..	..	160 ,,
White lime cream	..	..	..	28 c.c.

From the figures given above—

14·7 grammes white lime to 50 c.c. cream it will be seen that the dry slaked lime in the above mortar equals $14{\cdot}7 \times \frac{28}{50} =$ 8·1 grammes, or some 20 per cent. by weight of the cement.

The volume of the water used is practically the same as before, 24 c.c.

For 1 : 5 mixture the proportions were :—

170 grammes sand.
34 grammes cement.
28 c.c. lime cream.

This is equivalent to some 24 per cent. by weight of the cement.

For 1 : 6 mixture the proportions were :—

180 grammes sand.
30 grammes cement.
30 c.c. lime cream.

or 8·8 grammes slaked lime, a ratio of 29 per cent. white lime to cement.

(ii). Compressive strength of cement—sand mortars with addition of lime cream.

The following statement shows the comparative results between the plain mortars and those to which the lime cream had been added.

They exhibit the same characteristics as those for tension. The mortars with white lime, however, remain somewhat stronger than the plain mortars, except for Rupar sand, though the ratio of the excess strength is obviously diminishing. The result for the Ganda Singhwala sand 1 : 5 mortar with lime cream is anomalous, and can only be explained on the assumption that some error occurred in proportioning the mortar.

Test for compression (made at Lakheri).

(Figures give compressive strength in lbs. per square inch.)

Sand.	1 : 4		1 : 5		1 : 6	
	7 day	28 day	7 day	28 day	7 day	28 day
Islam sand	1,598	2,555	1,110	1,850	720	1,385
Islam sand with lime cream ..	1,610	2,565	1,365	1,895	1,080	1,440
Suleimanke sand	1,475	2,560	920	1,630	665	1,155
Suleimanke sand with lime cream	1,550	2,340	1,370	1,685	1,070	1,230
Ganda Singhwala sand ..	1,325	1,890	1,045	1,490	805	1,045
Ganda Singhwala sand with lime cream	1,685	1,780	1,035	2,865	820	1,020
Ferozepore sand	1,630	2,260	1,025	1,635	635	1,125
Ferozepore sand with lime cream	2,050	2,470	1,190	1,770	1,055	1,315
Rupar sand	1,570	2,690	1,180	1,940	845	1,435
Rupar sand with lime cream ..	1,845	2,510	1,480	1,850	1,050	1,415
Standard sand	3,095	..	2,010	..	1,455	..

(f). Tensile strength of Portland Cement in sand mortars prepared by a mistri under ordinary working conditions.

Islam sand and Wah cement were used. The quantity of water was not measured. These tests formed extra tests and were carried out under the orders of Mr. Stainton, Chief Engineer, Buildings and Roads Branch. Briquettes of Punjab cement and Islam sand in proportions 1 : 2 up to 1 : 8 were prepared by a mistri under

ordinary working conditions ; eight briquettes of each kind were made. They were tested after 7 days and the results are shown in the accompanying statement. Though not reaching the values of the briquettes made for the regular tests, they have given quite satisfactory results.

Mortar.	Strength in lbs. per square inch.
1:2	479
1:3	280
1:4	206
1:5	153
1:6	99·5
1:7	75
1:8	60

(g). Quantity of dry materials required to make a hundred cubic feet of Portland Cement Concrete.

From the result obtained for ballast voids and mortar paste, it was possible to proportion the materials for the construction of the concrete blocks. The volume of mortar paste required to fill the voids was first ascertained, then the amount of dry materials was calculated from the percentage of shrinkage. No extra percentage of mortar was added to this figure. The question of the volume ratio being somewhat uncertain, it was decided to weigh all sand and cement put into the mixer with each batch.

This was done, at first assuming that—

75 lbs. cement represents 1 c.ft.
80 lbs. sand „ 1 „

Should any objection be raised to these figures, it is therefore still possible to say what are the proportions (by volume) of the concrete in the blocks for any weight which may be taken as equivalent to a cubic foot for each material. The proportions by weight are of course the 1 : 3, 1 : 4, 1 : 5 figures. Twelve blocks were constructed on these ratios.

Proportioning materials by weight.—Practically speaking there is no difficulty in weighing out the sand and cement for the work, it takes no longer than filling and levelling off the material in the gauge boxes. Ballast of course is not weighed, it is merely filled into the hopper of the mixer.

Should the use of cement concrete become general, it would be sound practice to insist that the cement, at any rate, should be added by weight. This will give a consistency in the material outturned which cannot be attained if gauging is done by volume.

Manufacture of the concrete blocks. *Test (c).*

The concrete was mixed in a concrete mixer with a 5 cubic feet hopper and was placed in 5′×5′×2′ moulds with smaller moulds of 2′×2′×1′ for surplus material.

The following mixtures were prepared during the first visit to Suleimanke :—

	Cement.		Sand.	Stone.
Delhi stone ballast ..	1	: 2·8	(by Vol.)	8·5
,, ,, ,,	1	: 3·0	(by weight).	8·5
,, ,, ,,	1	: 3·75	(by Vol.)	10·6
,, ,, ,,	1	: 4	(by weight)	10·6
,, ,, ,,	1	: 4·7	(by Vol.)	12·2
,, ,, ,,	1	: 5	(by weight)	12·2
Jhama brick ballast ..	1	: 2·8	:	6·8
,, ,, ,,	1	: 3·75	:	8·6
,, ,, ,,	1	: 4·7	:	9·8

Method of proportioning blocks.—These figures are obtained by finding—

(*a*) The voids in the ballast.

(*b*) Taking the amount of mortar paste required to fill the voids.

(*c*) Calculating the amount of dry material required to make the paste.

(*d*) Dividing this amount into cement and sand from the volume figures.

(*e*) Dividing 100 cubic feet ballast by the volume of the cement to get the ratio of stone to 1 of cement.

Example—1 : 3 Delhi ballast.
Voids 36 per cent.
Shrinkage on 1 : 3 mortar 20 per cent.
Therefore dry material=45 cubic feet per cent. and dividing by 1+2·8=3·8 gives 11·8 cubic feet cement.
100/11·8=8·5 the ratio for stone to cement.

The second series of blocks.—On preparing the data for the first 12 blocks, it was seen that though figures for cement and sand were exact, the ballast figures were based on the fillings of the hopper. When preparing the second series of blocks the ballast figures were checked by first measuring the ballast into one of the 5′×5′×2′ moulds and then using up as much of this as was necessary to make a full block of concrete. The second series is therefore more accurate for ballast used per 100 cubic feet

concrete. A higher percentage of water was used, 19 per cent. to 23 per cent. as compared with 14 per cent. to 16 per cent. As a result the concrete appeared to set better in the moulds and should show no joints on inspection.

Work at Suleimanke.—Two visits were made to Suleimanke, the first from September 6th to 10th, the second from September 21st to 24th. The Chief Engineer, Sutlej Valley Project, after considering the results shown for the first series of blocks, passed the following orders :—

(*a*) Blocks need not be made with the 1 : 6, 1 : 7 and 1 : 8 mortars, as no useful purpose would be obtained by making blocks of such lean concrete.

(*b*) The following blocks were to be made :—

(*i*) Completion of the 1 : 5 : 7 and 1: 4 : 8 series by a set of 1 : 3 : 6 blocks.

(*ii*) Construction of a series of blocks using Nalagarh Stone Ballast in the following proportions : a ratio of 90lbs. per cubic foot being taken for cement ; sand to be added by volume only.

	Cement.		*Sand.*		*Ballast.*	
Ratios.	1	:	3	:	6	
	1	:	3	:	7	
	1	:	4	:	7	
	1	:	4	:	8	
	1	:	5	:	7	
	1	:	3			Proportioned with a 10 per cent. surplus of mortar, over that required to fill the voids in the stone
	1	:	4			
	1	:	5			

Completion of Suleimanke work.—The instructions given were carried out and eleven more blocks made. Full details regarding all the twenty three blocks are given in the statement which accompanies this paper. Comments on the results are as follows :—

Figures in accompanying statement showing quantity of materials required per hundred cubic feet of concrete.

In this statement the results for the full series of blocks are shown. On the left hand the figures per 100 cubic feet concrete are

given with a blank column for pricing the outturn at whatever rates may seem desirable. In column 3, the 90lbs. ratio figures are given for all blocks. The different methods by which each set of blocks was proportioned are also shown across the statement and separate one series from another. The right hand side shows the actual quantities handled and the actual outturn. Differences in the percentage allowed for mortar shrinkage and differences in the number of mixes required to make up a concrete block, obscure the comparison in some cases between one block and another. In only one case, however, has any actual error been noted ; in block No. 19, 1 : 4 : 8 where there is a small deficiency in the sand figure (some 2 cubic feet per 100). Blocks 21 and 23 are considered to owe their high figures for ballast per 100 cubic feet to the fact that they were made from newly broken ballast, just filled into the 5′×5′×2′ moulds before use in the mixer. The difference between the figures for ballast in the first and second series of blocks has already been noted on.

This concludes the information obtained during the series of tests.

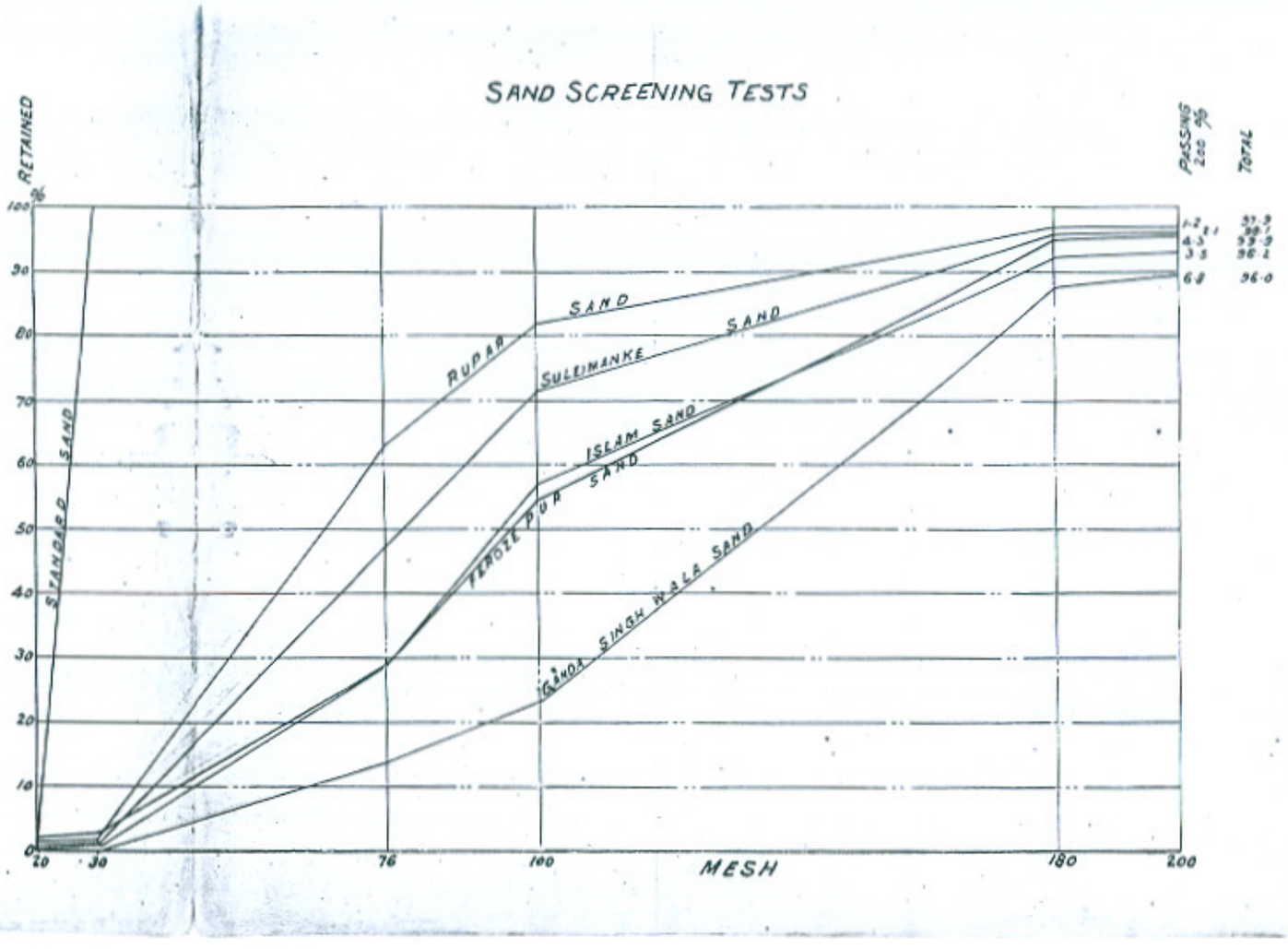
The results showed that it was possible to use the fine sands of a Punjab river like the Sutlej in combination with the local Portland Cement manufactured at Wah. An agreement was accordingly entered into between the Company and the Irrigation Branch, Punjab, Public Works Department, for a supply of the cement for use on the works under construction for the Sutlej Valley Project.

Statement showing the results of experiments on concrete Blocks carried out at Suleimanke.

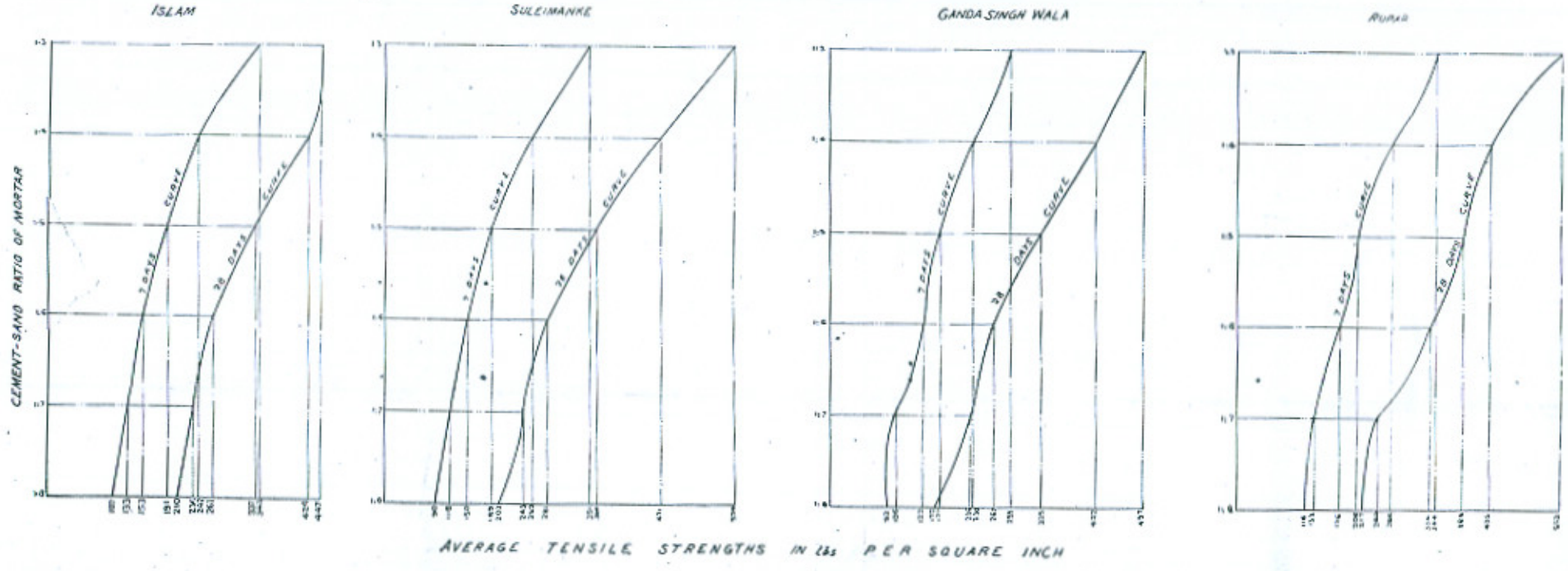
No. of Block.	Description of Block.	Proportions on ratio 90 lbs. Cement = 1 c. ft.	Voids in Ballast.	Quantity of materials required per hundred cubic feet of concrete.						Price per % c. ft. concrete.	Quantity of materials actually used in Blocks.						Concrete in Blocks.
				Ballast c. ft.	Sand.		Cement.		Water.		No. of mixes.	Ballast.	Sand.		Cement.		
					C. ft.	lbs.	C. ft.	lbs.					C. ft.	lbs.	C. ft.	lbs.	
	Blocks with Cement added in proportion 75 lbs. Cement = 1 c. ft. and Sand = 80 lbs. per c. ft. Mortar filling voids only.																
	Delhi Stone Ballast.																C. ft.
1	1 : 2·8 : 3·5 ..	1 : 3·4 : 10·2	36 per cent.	98·6	32·5	2,602	11·6	867	Averaged 14 c. ft. to 16 c. ft. per %.	..	10	Taken at 5 c. ft. per mix.	..	1,320	..	440	50·73
3	1 : 3·75 : 10·6 ..	1 : 4·5 : 12·7	Ditto	94·4	32·8	2,623	8·7	656		..	10		..	1,300	..	350	52·99
5	1 : 4·7 : 12·2 ..	1 : 5·6 : 14·6	Ditto	89·5	34·7	2,773	7·4	555		..	9		..	1,395	..	279	50·3
	Jhama Brick Ballast.																
2	1 : 2·8 : 6·8 ..	1 : 3·4 : 8·2	45 per cent.	94·0	39·0	3,120	13·9	1,040		..	10		..	1,660	..	555	53·2
4	1 : 3·75 : 8·6 ..	1 : 4·5 : 10·3	Ditto	91·3	39·5	3,158	10·5	789		..	9		..	1,557	..	391·5	49·3
6	1 : 4·7 : 9·8 ..	1 : 5·6 : 11·8	Ditto	85·2	40·9	3,273	8·7	655		..	9		..	1,728	..	346·5	52·8
	Blocks proportioned by volumes :—above weight—volume ratio. 75 lbs. for Cement and 80 lbs. for Sand adhered to.																
	Delhi Stone Ballast.																
7	1 : 5 : 7 ..	1 : 6 : 8·4	..	70·9	50·6	4,050	10·1	759	Averaged 14 c. ft. to 16 c. ft. per %.	..	8	Taken at 5 c. ft. per mix.	..	2,284	..	428	56·4
	Jhama Brick Ballast.																
8	1 : 5 : 7 ..	1 : 6 : 8·4	..	76·8	54·8	4,384	11·0	821		..	8		..	2,284	..	428	52·1
	Nalagarh Stone Ballast.																
9	1 : 5 : 7 ..	1 : 6 : 8·4	..	74·5	53·2	4,254	10·6	797		..	8		..	2,284	..	428	53·7
	Delhi Stone Ballast.																
10	1 : 4 : 8	1 : 4·8 : 9·6	..	78·6	39·3	3,143	9·8	739		..	8		..	1,600	..	376	50·9
	Jhama Brick Ballast.																
11	1 : 4 : 8 ..	1 : 4·8 : 9·6	..	80·7	40·3	3,226	10·1	758		..	8		..	1,600	..	376	49·6
	Nalagarh Stone Ballast.																
12	1 : 4 : 8 ..	1 : 4·8 : 9·6	..	80·3	40·2	3,213	10·1	758		..	8		..	1,600	..	376	49·6

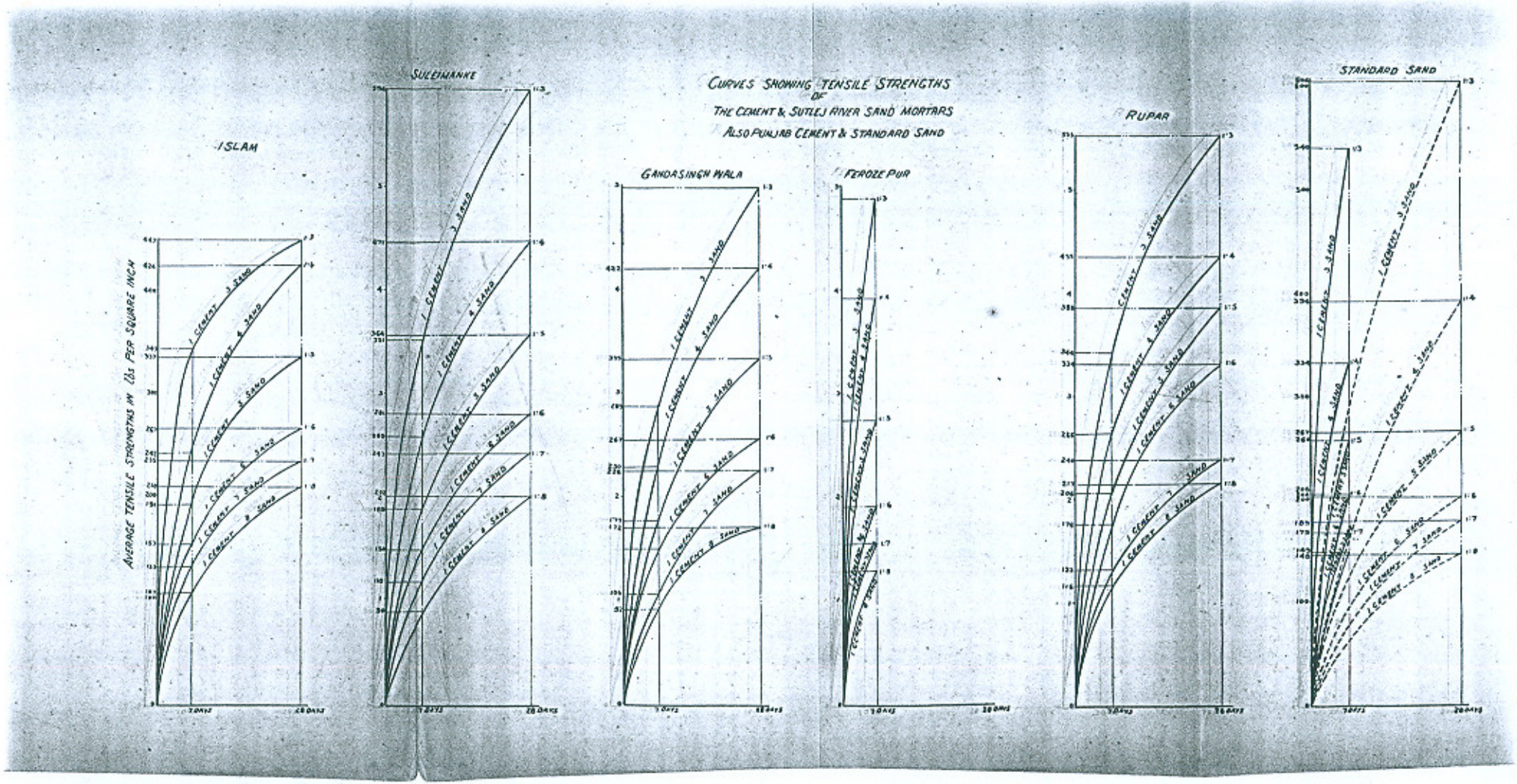
Statement showing the results of experiments on concrete Blocks carried out at Suleimanke—concluded.

	Description of Block.	Proportions on ratio 90 lbs. Cement = 1 c. ft.	Voids in Ballast.	Quantity of materials required per hundred cubic feet of concrete.						Price per 100 c. ft. concrete.	Quantity of materials actually used in Blocks.						Concrete in Blocks.
				Ballast c. ft.	*Sand.*		*Cement.*		Water.		No. of mixes.	Ballast.	*Sand.*		*Cement.*		
					C. ft.	lbs.	C. ft.	lbs.					C. ft.	lbs.	C. ft.	lbs.	
	Blocks proportioned by volumes :—above weight—volume ratio. 75 lbs. for Cement and 80 lbs. for Sand adhered to—*concluded.*																
	Delhi Stone Ballast.																
13	1 : 3 : 6 ..	1 : 3·6 : 7·2	..	86·0	37·5	3,003	12·6	946	20·4	..	8	45·8	20	1,600	..	504	53·28
	Nalagarh Stone Ballast.																
14	1 : 3 : 6 ..	1 : 3·6 : 7·2	..	97·7	44·1	3,531	14·8	1,112	21·3	..	9	49·83	22·5	1,800	..	567	50·98
	Jhama Brick Ballast.																
15	1 : 3 : 6 ..	1 : 3·6 : 7·2	..	96·2	42·0	3,359	14·1	1,058	21·0	..	8(+1of3)	49·83	21·75	1,740	..	548	51·8
	Blocks with Cement added in proportion 90 lbs. Cement = 1 c. ft.—Sand added by volume—Block 16 1 c. ft. Sand = 77lbs. Blocks 17—23 1 c. ft. Sand = 75·5 lbs.																
	Nalagarh Stone.																
16	1 : 3 : 6 ..	As in column 2	34 per cent.	94·7	45·3	3,484	15·0	1,354	23·0	..	9(+1 of 2·5)	49·83	23·8	..	..	712	52·82
17	1 : 3 : 7 ..	,, ,, ,,	,,	97·0	41·4	3,124	12·8	1,156	19·9	..	9	48·33	20·6	..	..	576	49·83
18	1 : 4 : 7 ..	,, ,, ,,	,,	94·0	49·7	3,753	12·4	1,112	22·0	..	9	48·67	25·7	..	..	576	51·8
19	1 : 4 : 8 ..	,, ,, ,,	,,	99·0	42·2	3,190	11·6	1,046	20·7	..	9(+1of2)	49·83	21·3	..	..	526	50·35
20	1 : 5 : 7 ..	,, ,, ,,	,,	82·6	57·6	4,351	11·5	1,033	25·3	..	9	46·03	32·1	..	..	576	55·74
	Blocks with 10 per cent. excess of Mortar over voids in Stone. Cement = 90lbs. per c. ft. Sand by volume 1 c. ft. Sand weighed 75·5lbs.																
21	1 : 3 : 7·8 ..	As in column 2	..	103·1	36·8	2,778	12·2	1,102	23·3	..	10	53·33	19·2	..	..	575	52·2
22	1 : 4 : 9·9 ..	,, ,, ,,	..	94·3	38·9	3,070	9·7	868	17·3	..	10	48·83	20·1	..	..	450	51·83
23	1 : 5 : 12·3 ..	,, ,, ,,	..	100·0	41·9	3,307	8·4	754	20·5	..	10(+1 of 3)	49·83	20·8	..	..	376	49·83

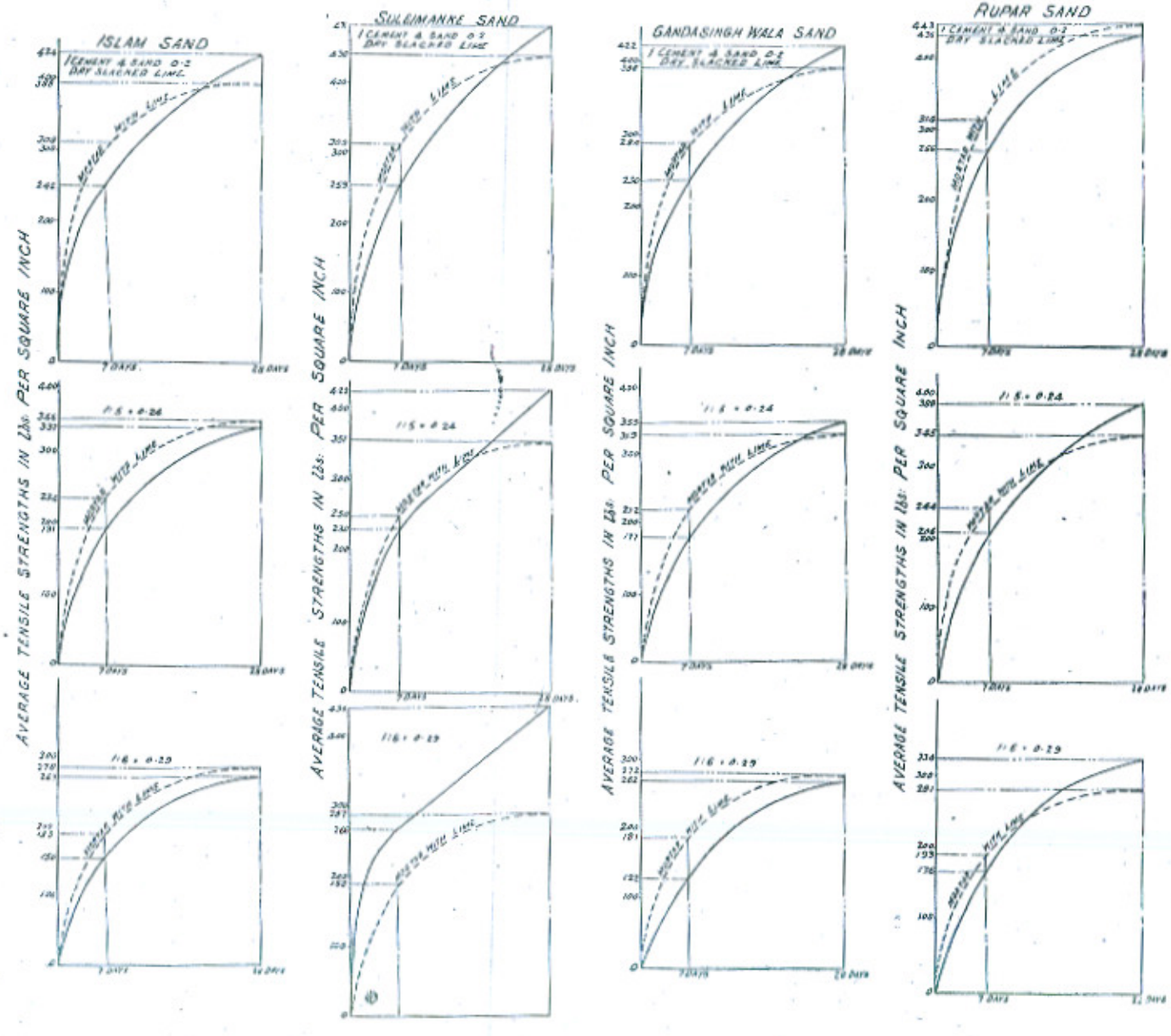

SAND SCREENING TESTS
RETAINED %
PASSING 200 %
TOTAL
STANDARD SAND
RUPAR SAND
SULEIMANKE SAND
ISLAM SAND
FEROZE PUR SAND
GANDA SINGH WALA SAND
MESH
20
30
76
100
180
200
0
10
20
30
40
50
60
70
80
90
100
1·2
2·1
4·3
3·5
6·8
57·3
59·1
59·9
96·2
96·0

CURVES SHOWING TENSILE STRENGTHS
OF
THE VARIOUS MORTARS AT 7 DAYS AND 28 DAYS

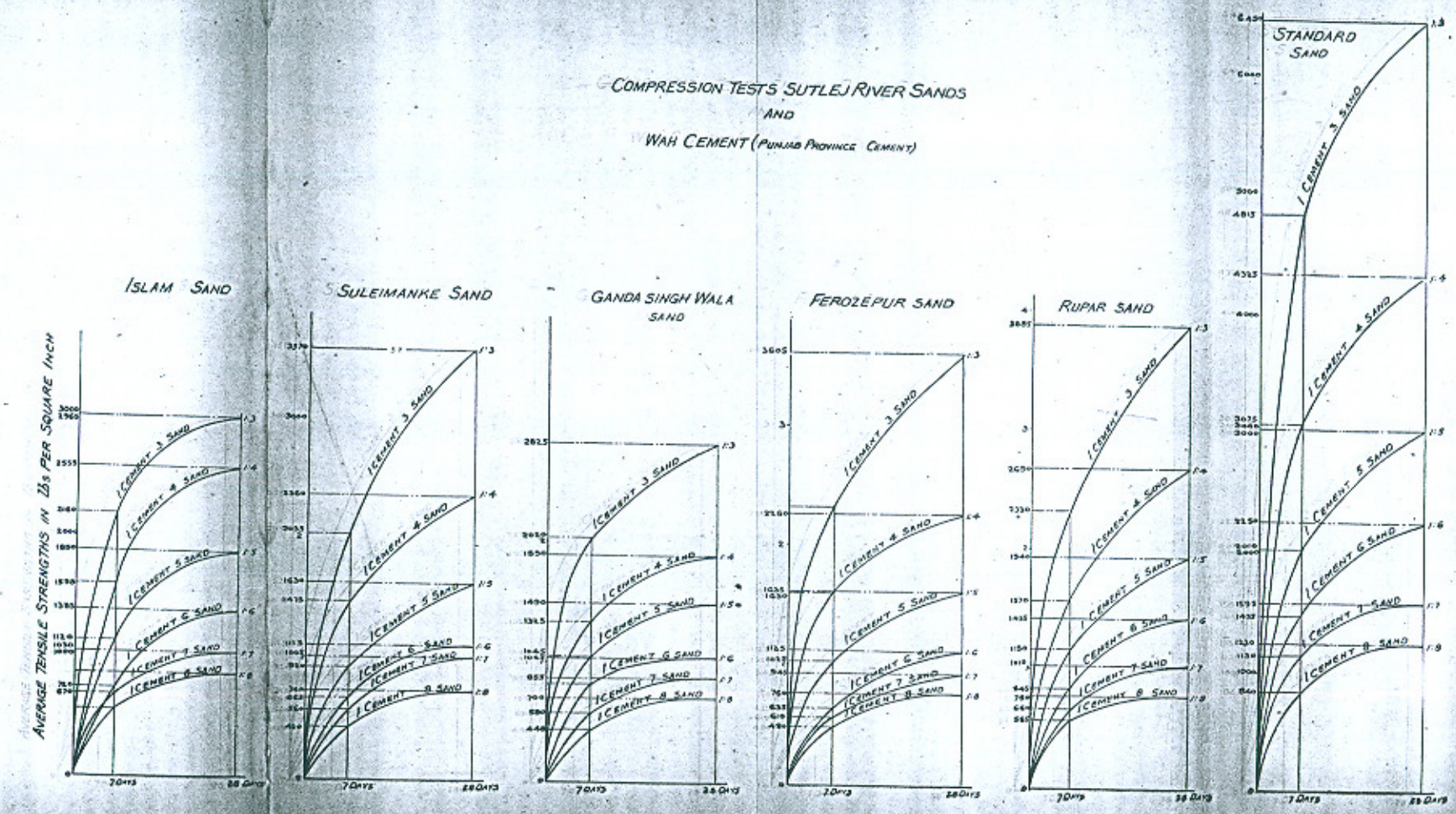



CURVES SHOWING TENSILE STRENGTHS
OF
THE CEMENT & SUTLEJ RIVER SAND MORTARS
ALSO PUNJAB CEMENT & STANDARD SAND
ISLAM
SULEIMANKE
GANDASINGH WALA
FEROZE PUR
RUPAR
STANDARD SAND
AVERAGE TENSILE STRENGTHS IN LBS PER SQUARE INCH
1 CEMENT 3 SAND
1 CEMENT 4 SAND
1 CEMENT 5 SAND
1 CEMENT 6 SAND
1 CEMENT 7 SAND
1 CEMENT 8 SAND
7 DAYS
28 DAYS

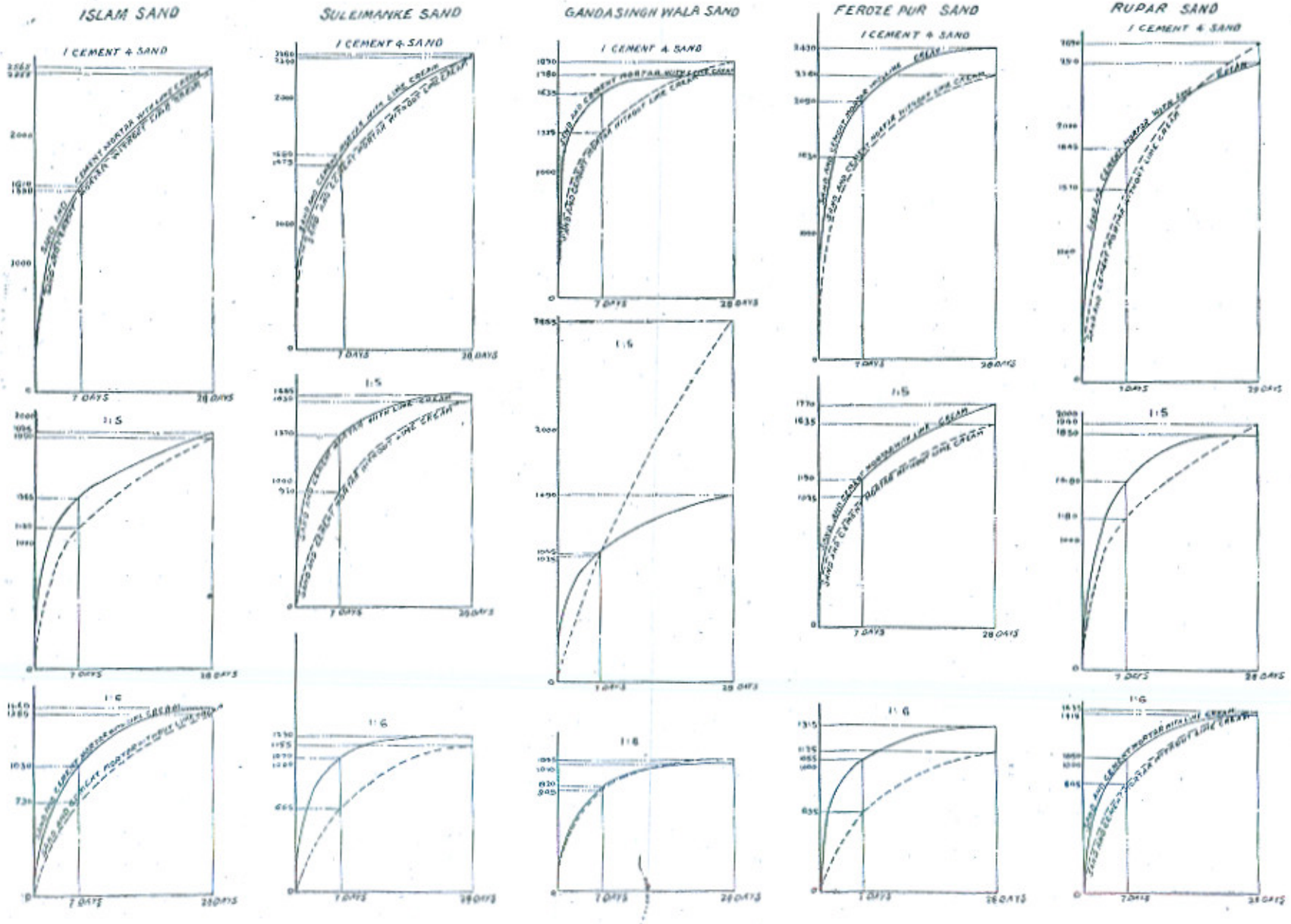
CURVES COMPARING TENSILE STRENGTHS
OF
PUNJAB CEMENT AND SUTLEJ RIVER SAND.
WITH SIMILAR MIXTURE TO WHICH LIME CREAM HAS BEEN ADDED



COMPRESSION TESTS SUTLEJ RIVER SANDS AND WAH CEMENT (PUNJAB PROVINCE CEMENT)



COMPARING COMPRESSIVE STRENGTHS OF SAND AND CEMENT MORTAR WITH & WITHOUT WHITE LIME CREAM



DISCUSSIONS.

MR. A. N. M. ROBERTSON, introducing his paper stated that Mr. Weighall had written regretting his inability to attend the Congress as owing to the Manager of the Punjab Portland Cement Works at Lakheri having gone on leave, he had to take charge.

The information given in the paper was already known to many members of the Congress as it had been based on the notes prepared while the tests were being carried out, which had been printed and circulated in the Irrigation Branch and also, he believed, in the Roads and Buildings Branch of the Punjab Public Works Department.

The tests were the outcome of several meetings between the representatives of the Punjab Government and the Company who had constructed the Cement Works at Wah near Hassan Abdal. The points which had to be decided were whether a satisfactory mortar could be made from the Wah cement and the fine local sand from the weir sites on the Sutlej River, and if so was it possible to use proportions for the mortars which could enable them to compete with the local kankar lime mortar. The series of experiments detailed at the beginning of the paper had been drawn up at a joint Committee meeting of the Government officers of the departments concerned and the Company's representatives.

It was to be noted that the tests had been made with cement and sand mortars only. Kankar lime mortars had not been tested, nor had there been any intention of comparing the actual strengths of the two classes of material.

It was well-known that a Portland cement and sand mortar could give strengths much greater than those of the various hydraulic lime mixtures and if mortars of equal strengths were to be compared, the proportion of sand to cement in the former became very high and it was questionable if such proportions could be safely used in practice.

The question of the relation of weight to volume had given some difficulty when proportioning the materials. The test briquettes and cubes had been made up from materials weighed out on a chemical balance. When it became necessary to use such mortars in bulk for the construction of concrete blocks, the material had to be measured out by volume as usual and the question had arisen as to what volumes had to be taken which corresponded to a series of mortars proportioned in ratios of 1 : 3, 1 : 4, etc., by weight for test purposes.

Page 6 described the values taken and the reasons for accepting them.

On page 16, the question of objections raised to these ratios had been dealt with, and it was pointed out, that when constructing the concrete blocks, all cement and nearly all sand had been weighed. It was, therefore, possible to modify the volume proportions shewn in the 2nd column of the statements on pages 21 and 22, as might seem desirable to any one who wished to accept different relations between weight and volume for either cement or sand.

On page 17, the statement showing the blocks prepared at Suleimanke should have had brackets connecting the figures indicating proportion by volume and proportion by weight for the Delhi ballast, and the figures for jhama brick ballast indicated the volume proportions only. The 1 : 3, 1 : 4 and 1 : 5 values by weight should also have been added, as in the case of Delhi ballast. The results which had been obtained by the addition of white lime cream to the mortar were interesting. It had appeared at first that a stronger mortar was likely to be obtained. This would have been important as it would have cheapened the mortar which could have been employed on works, but unfortunately the increase in strength had not been maintained in the same proportion, and the only advantage in the addition of the lime cream seemed to be that it increased the fluidity of the mortar and made it more plastic and easier to handle.

Some experiments in the addition of hydrated lime to Portland cement mortars mentioned in Messrs. Hool and Johnson's Concrete Engineer's Hand-book also shewed that sometimes this extra strength was obtained but that it did not always so happen.

The author had not been in touch with the recent experience in the use of cement and Sutlej sand on the works of the Sutlej Valley Project and would be interested to hear what the Officers in charge of the works where the concrete was being employed, had to say about the material when actually used on works.

MR. K. G. MITCHELL read the written notes of Mr. C. E. Blaker who was unable to attend the Congress. The writer congratulated Mr. Robertson on having amassed a quantity of information in a short time, and pointed out that but for the statement in the first paragraph of the paper which defined the purpose for which the experiments and tests were made, some of the results obtained would be liable to be misleading. This was especially so in the case of the tensile and compression tests made with Wah cement and Sutlej sands which were much higher than could be expected in practice.

After making allowances for practical conditions, they still shewed, however, that sufficiently strong mortar could be made from fine Sutlej sand, for practical use.

The question, then, was how much higher were the test results than the strengths which could be reasonably expected in practice. It was evident that the conditions of test were the most favourable possible, *viz.*, freshly matured cement packed in airtight boxes and skilled testers, which meant use of the correct quantity of water required for maximum strength. In addition, some of the briquettes appeared to have been gauged and cured in a high temperature, which tended to more rapid increase of strength.

It was a pity that these controlling factors had not been recorded and it would have been of value to know especially what water ratio $\frac{\textit{Weight of water}}{\textit{Weight of cement}}$ had been used in gauging, whether the briquettes had been made strictly in accordance with the British Standard Specification for making cement and sand briquettes, particularly that the mortar had been patted into the moulds with a standard spatula and that no ramming or hammering had been indulged in and what was the temperature of gauging and of curing. It would have been useful to know also what percentage of clay there was in the sand samples, as the presence of clay might be advantageous or the reverse according to the quantity.

The control, *viz.*—the 1 : 3 standard sand test shewed in tension 540 lbs. after 7 days and 604 lbs. after 28 days, against 200 and 250lbs. respectively required by the British Standard Specification. This standard was however likely to be raised soon to 250 lbs. at 7 days and 300 lbs. at 28 days. Mr. Robertson's tests with standard sand were thus rather more than twice as high as the probable raised British Standard.

The writer's own tests with Wah cement and standard sand made from cement newly received from the works in bags as ordinary commercial consignments, usually had given results about 30 per cent. higher than the said revised Standard, when tested strictly in accordance with the British Standard Specification and with water ratio 0.237 for " normal consistency " of the cement. They gave, therefore, the highest value of fresh Wah cement under commercial conditions to be expected for the standard sand control.

The 30 per cent. margin was available to meet deterioration due to storage and other causes. The storage factor was an important one, especially in the case of cement used by the Irrigation Branch, which was stored in and distributed from central godowns to the works.

Professor Duff Abram's tests of concrete made from American Portland Cements, stored for various periods before gauging shewed that compared with its strength when freshly matured, there was, for 28 days old concrete, 20 per cent. loss of strength after two months storage,

30 per cent. after 6 months and 40 to 50 per cent. after 12 months—depending on the manner of storing the cement. There was no reason to suppose that Wah Cement differed in this respect from the American Cements, (the writer had at present tests in progress to ascertain this), in which case the 30 per cent. margin obtained in the writer's tests was by no means excessive if the cement was to be stored, and indicated that Wah Cement should not be stored for more than 4 months if it was to be up to the revised British Standard when issued to works.

The writer therefore recommended that when framing an estimate as to the probable strength in practice of different mixes of Sutlej sands, Mr. Robertson's results should be divided by two.

It was further noteworthy that according to Professor Duff Abram's researches, Mr. Robertson's results for Sutlej mortars in compression were about twice as great as could be expected in practice for normal consistency, *i. e.*, when the quantity of water necessary for maximum strength of the mortar was used and which gave a dry mix—*e. g.*, for 1 cement : 3 Islam sand, modulus of fineness of sand (m) =0·88, Mr. Robertson's strength was 2,695 lbs. against Professor Duff Abram's 1,700 lbs. approximately.

1 : 3 Suleimanke sand, m =1·09.
Robertson's 3,570 lbs. Professor Duff Abram's 1,800 lbs.

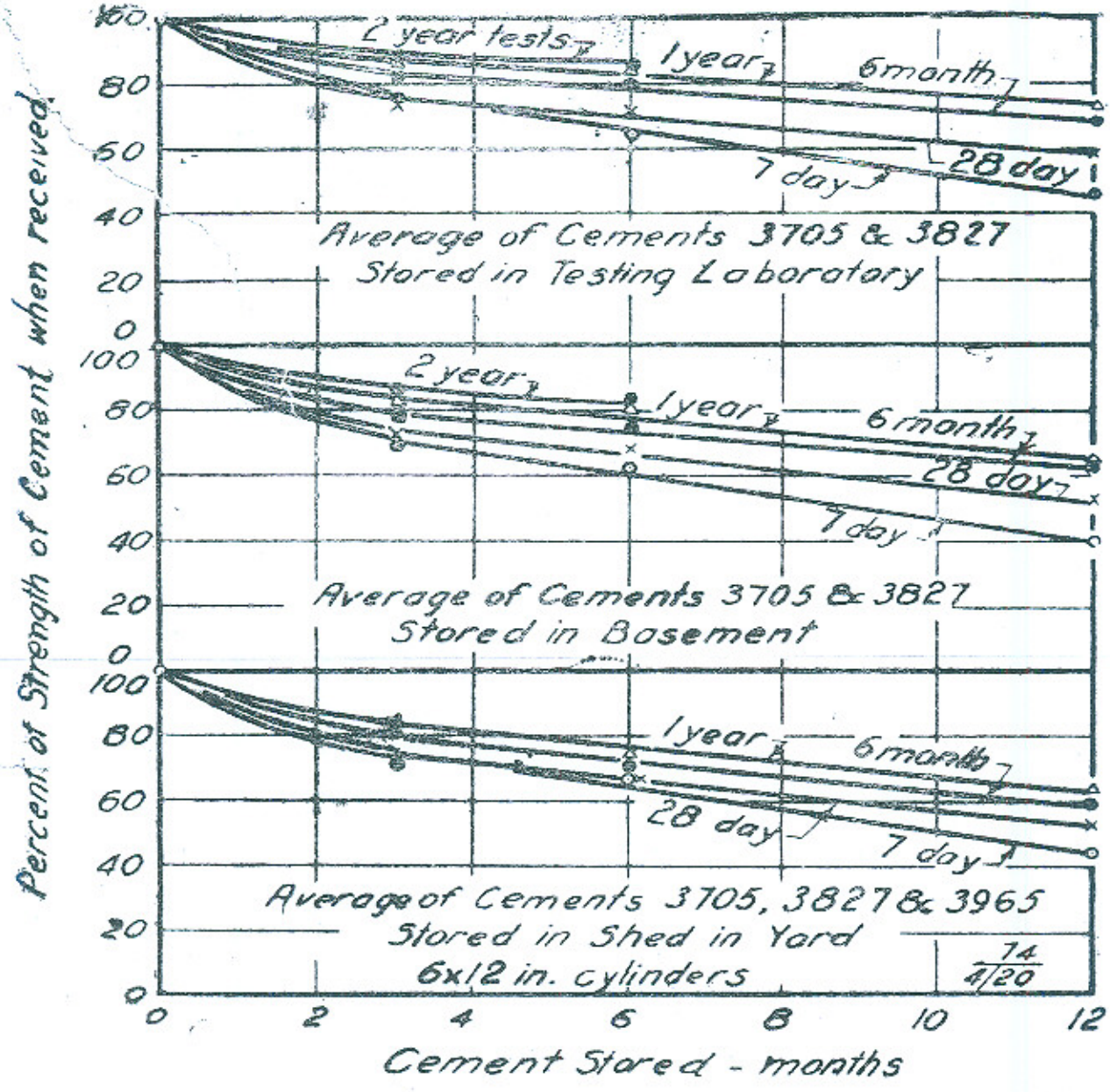
1 : 4 Gandasinghwala sand, m,. =0·38.
Robertson's 2,825 lbs., Professor Duff Abram's, 1,350 lbs.

1 : 4 Ferozepore sand, m = 0·94.
Robertson's 3,605 lbs., Professor Duff Abram's 1,700 lbs.

1 : 4 Rupar sand, m =1·25.
Robertson's 3,885 lbs., Professor Duff Abram's 1,850 lbs.

The results of the masons tests given in section (**f**) of the paper were, for the above mentioned conclusions, much more nearly those likely to be obtained in practice with fresh cement. A mason used about 50 per cent. more water than did the cement tester making briquettes for the standard tests, with consequent still further reduction of strength.

The writer also pointed out that the old method of proportioning by voids adopted by Mr. Robertson was now known to be quite unreliable. It gave neither the densest nor the strongest cement which could be had from the same quantity of cement and inert material. Its inaccuracy was due to the varying effect of moisture in the volume of voids in a sand and the impossibility of expelling all imprisoned air. For density, it was better to proportion on the basis of Fuller's curve and for strength by Professor Duff Abram's system as now universally adopted in America.



RELATIVE STRENGTH OF 1-6 CONCRETE FROM STORED CEMENTS.

Ex. Bulletin No 6
D/June, 1920.

Comparative tests made with Wah Cement.

B. S. Test.	Standard, 1920.	Alipore, 1st September 1923.	Rasul January 1924.	Mr. Robertson's Tests.
1. Fineness of Grinding.				
Residue on mesh 180×180 ..	Not more than 14%	7·70%	1·5%	Not recorded.
Ditto 76×76 ..	Not more than 1%	·10%	trace.	
3. Tensile Strength (Neat).				
7 days (=W) Average of six	Not less than 450 lbs.	715	685	
28 days. briquettes ..	Not less than $W+\frac{40,000}{W}$	804	735	
4. Tensile Strength (Cement and Standard Sand).				
7 days (=W) Average of six	Not less than 200 lbs.	391	345	540
28 days. briquettes .	Not less than $W+\frac{10,000}{W}$	448	400	604
5. Setting Time.				
Initial ..	Not less than 20 mts.	56 mts.	25 mts.	Not recorded.
Fural ..	Not more than 10 hrs.	2 h. 0 m.	6 h. 49 m.	
6. Soundness.				
Temperature of testing ..	58°—64° F.	84°—91°F.	56°—58°F.	
Temperature of gauging ..	ditto	84°F.	56°—58°F.	
Temperature of damp box ..	ditto	81°F.	56°F.	
Water ratio for neat cement briquettes ..	..	0·20 (Derivation doubtful).	0·24 (As determined by Prof. Abram).	

NOTE.—As the Rasul test was made at an appreciably lower temperature than the Alipore test, appreciably lower tensile strengths in the case of the Rasul test are to be expected for the same cement.

MAJOR E. P. ANDERSON, R. E., said that this was a most valuable and interesting paper on which the authors were to be congratulated, and the Congress as a whole seemed to him to be under a debt of gratitude to the Chief Engineer of the Irrigation Project concerned for initiating the experiments and allowing the publication and discussion of the results.

Owing to absence on tour he had, unfortunately, received the proof too late to bring with him for comparison the results of similar tests made on the Khyber Railway construction ; some of these would be contributed by correspondence. Two results might, however, be stated in general terms and were of practical interest. First, the addition to a 1 : 2 lime surkhi mortar of cement in the proportion of 10 per cent. of the lime, doubled the tensile strength and halved the setting time. Secondly, a cement mortar made of 1 cement to 2 surkhi without any sand had given surprisingly good results on test, and had been extensively used where sand was unobtainable. The surkhi used was made from bricks burnt at Landi Kotal and very well ground in a ball mill—an improvement on the familiar disintegrator to which he would call the attention of those not already familiar with it ; it was both cheaper to work and turned out better surkhi. He asked the authors what size of blocks they used for crushing tests on concrete and whether they had found any variations in the results of testing the same materials in blocks of different sizes. This seemed to be a point on which a more thorough standardisation of test conditions was desirable.

MR. H. W. NICHOLSON said it had fallen upon him to make all arrangements last hot weather at Suleimanke for the tests described in the paper and he could therefore guarantee that the results as reported were absolutely correct.

With regard to irregularities in the voids percentage with crushed stone, the proportions of the crushes continually varied and it was impossible to keep a constant proportion of sand. A considerable quantity of mass concrete had been laid at Suleimanke, on the lines laid down in the paper. Sample blocks made in connection with the experiments described, such as blocks made of cement concrete to which lime cream had been added, and blocks tested for expansion would be available for inspection by members of the Congress who would visit Suleimanke.

With regard to Mr. Blaker's remarks, the speaker emphasized that the tests given in the paper were not laboratory experiments. He had recently cut out one cubic foot blocks out of the work at Suleimanke for testing in compression and it would be interesting to compare the results obtained with those given on page 15 of the paper.

MR. W. P. THOMPSON said that the paper was an exceedingly interesting one to him. He would like to ask how the sand obtained at Rasul compared with the sands with which the experiments described in the paper were made and also how were the results of the tests to guide practical engineers and whether the results obtained from the experiments were being made use of by the adoption of cement instead of kankar lime mixtures.

MR. F. H. BURKITT remarked that on the construction of the Islam Weir on the Sutlej Valley Project 20 per cent. lime had been added to the concrete by mistake in a certain place and the results obtained had been

good. He pointed out that in many places it would pay to put in stronger concrete mixtures and reinforce, rather than adhere to weak mixtures of thicker section.

MR. E. S. LINDLEY referred to the table giving the fineness of sands on page 3 of the paper from which it appeared that the Suleimanke sand was coarser than the Ferozepore sand although the latter place was much higher up the river. The late Mr. R. G. Kennedy had also found the same unusual conditions.

MR. H. W. NICHOLSON said that he could explain the matter. The Ferozepore sand had been taken when the river was high whereas the Suleimanke sand was excavated from deep pits.

MR. E. R. FOY said that in reply to the query raised by Mr. Thompson, the whole point was to find out if it was possible to produce cement sand mortars for use on the Sutlej Valley Project, at the same cost as kankar lime mortar and also to ascertain what was the richest mixture which they could afford to use, in order to compete with kankar lime mortar. If people in other places wished to use cement in place of lime, they should work out the comparative costs and ascertain the cheapest mixture that could be efficiently employed, in the same way.

MR. D. J. MORRIS congratulated the authors on preparing an excellent paper for the Congress, the value of which lay in the fullness of the information given. The tests described in the paper were of special interest to Punjab Engineers as they dealt with what might be termed poor or fine sands, and in the plains such sands were more often than not the only material possible. Better sands were of course available near the hills, but freight charges would, except for works of a special nature, generally render their use prohibitive. All would agree that the strengths shewn were surprisingly good.

The Rupar sand noted in the paper was really a misnomer, as the sand in question was not from Rupar but from a bank of blown sand some distance down the Sirhind Canal in the direction of Doraha. This sand was much finer than the true Rupar sand.

It was interesting to compare the sands used on the tests with what was usually called a good sand. The usual specification was that it should be clean and coarse. Generally sands out of which more than 30 per cent. passed the 40 sieve, were classed as fine sands. By coarse, however, it was not meant that all the particles should be comparatively large. The best sand was one graded from fine to coarse so as to reduce the voids to a minimum. Such a sand however had the appearance of being coarse as the percentage of fines *i. e.* passing the 40 sieve, would be about 15—20 per cent. only. In such a sand the percentage of voids would be about 28, and good natural sands with about 25 per cent. fines usually gave about 30 to 35 per cent. of voids. Mica—commonly found in Punjab sands—should be avoided as far as possible, as 10 per cent. of this substance in a 1 : 3 mortar would reduce the strength as much as 40 per cent. The old specification that sand should be sharp had now been proved to be valueless, as round grains gave just as good results in test.

The speaker asked whether in the experiments for determination of voids at the bottom of page 4, the sand was shaken down.

Referring to the table on page 10, it was interesting to note that the standard sand gave the highest figures in each case for the 7 day tests, and the lowest for the 28 day test except in the case of the 1 : 8 mortar. This was explained at the top of page 11 and shewed the effect of temperature on testing. This fact had an interesting corrollary in that the British Standard Specification laid down that the temperature of testing should be 58°—64° F. and that the strength at 28 days should not be less than

$$7 \text{ day} + \frac{40{,}000}{7 \text{ day}} \text{ for neat cement and}$$

$$7 \text{ day} + \frac{10{,}000}{7 \text{ day}} \text{ for 1 : 3 mortar ; the minimum}$$

strengths at 7 days being 450 and 200 lbs. for cement and 1 : 3 mortar respectively. Heat increased the strength rapidly so that a very high 7-day value was obtained, after which the strength did not increase so rapidly. The result was that what was really a very strong cement did not pass the specification while a much weaker one might do so. This applied more especially to neat cement tests and to shew what this meant an example was given in the table below.

Test.	*7 day.*	*Required by Specification.*		*Actual.*	*Remarks*
A	650	Increase	.. 62	70	Passes
		Strength	.. 712	720	
B	750	Increase	.. 53	40	Fails
		Strength	.. 803	790	

Similar discrepancies however also crept in for sand briquettes.

Temperature also affected the setting time. The British Standard Specification required an initial set of not less than 20 minutes at 58°—64° F. Temperature quickened the setting time so if used at 80° or 90° F. this cement might set in 10 minutes or less. Cement makers in India, therefore, it was understood, manufactured for an initial set of 60 minutes.

The speaker considered the addition of 20 per cent. of lime in the experiments too much and that 10 per cent. would have given better results. The only result of the 20 per cent. addition was to quicken the setting, otherwise the mortars weakened. The main idea however was to render the lean mixtures more workable.

No tests at the time were made for soundness. These had since been made and went to shew that with 10 to 20 per cent. lime screened to pass a 20 mesh and slaked for over 6 hours, expansion was only 2·5 to 5·2 m.m. against 10 m.m. allowed for neat cement by the British Standard Specification. Generally sieving the slaked lime had a very marked effect on the expansion, and where it was not done

expansion was high. The less the lime content also and the greater the time of slaking the lower the expansion. Where the lime was not screened the expansion was high. This shewed that great care would be required on works in slaking and screening. There was a danger that where unslaked particles got into mortar they would expand and so not only upset its soundness but also its strength. It was the speaker's opinion that it would be better to use a little more cement and proportion the concrete on voids. Actually, it was believed, the difference of cost between 1 : 4 : 8 and 1 : 3 : 7·8 was small and when the cost of lime was added to the former together with the extra cost of storage, screening, and slaking the difference would be smaller still.

The 10 per cent. extra mortar in blocks 21 to 23 was considered small. The void space was not constant, and when mortar was added to a coarse aggregate the larger particles got wedged apart. The 10 per cent. noted therefore was not merely a factor of safety. Actually the void space may increase up to 20 per cent. and in the opinion of the speaker it was not wise to use less than 15 per cent. extra mortar paste when proportioning by this method.

In practice when dealing with cement concrete one was very liable to cling to old standard mixtures such as 1 : 2 : 4, 1 : 3 : 6 etc. used years ago when cement manufacture was not nearly as good as at present. In 1904, the British Standard Specification asked for a minimum of 400 lbs. The present British Standard asked for 450 lbs. but any cement which did not give 550 lbs. would be considered poor. The engineer's business was to provide a structure that would meet all the needs, present and future, of the situation at a minimum cost. This would not be effected by using a 1 : 3 : 6 mixture where 1 : 4 : 8 using modern cement would meet the case with a reasonable factor of safety. In dealing therefore with so-called lean mixtures and fine local sands, the authors had by their paper supplied a definite need.

THE AUTHOR replying to the points raised in the discussion said that with regard to the relation of volume to weight, there was nothing more to be said as the paper had dealt with that question fully.

In regard to the first point raised by Mr. Morris, they had not used sieves of 40 meshes. The answer to the next point as to whether the sand was skaken down was in the affirmative, otherwise it would have been in inconstant relation of volume to weight.

Regarding the limit to which white lime cream could safely be added the Concrete Engineer's Handbook agreed that deterioration of the concrete would result if 20 per cent. was exceeded.

With reference to Mr. Blaker's very valuable written notes he was prepared to accept the recommendation that the strength of concretes which could be reasonably obtained in actual practice on works would be about 50 per cent. of the test results.

He agreed with Major Anderson that the size of the blocks used for testing in compression had an effect on the results. Many years ago, tests on blocks at the Mangla Head Works disclosed that larger blocks on the whole gave lower results. He would not discuss the points raised by Mr. Thompson again because they had been fully covered by Mr. Foy.

SUBSEQUENTLY COMMUNICATED.

Major E. P. Anderson, R. E., wrote, in continuation of what he had said in the discussion, that the following were the comparative results of a series of tensile tests on cement sand mortars of different strengths, made with Haro sand on the Khyber Railway construction—

	7 *days.*
Neat cement	.. 100 per cent.
1 cement : 2 sand	.. 46 ,,
1 ,, : 3 ,,	.. 23 ,,
1 ,, : 4 ,,	.. 13 ,,
1 ,, : 5 ,,	.. 18 ,,
1 ,, : 6 ,,	.. 3 ,,

Compression tests made at Bundi on mortars of 1 lime to 3 surkhi, plain, and with the addition of 10 per cent. cement, gave after 28 days the following results :—

1 lime 3 surkhi. 265 lbs. per square inch average,

$\frac{1}{10}$ cement, 1 lime, 3 surkhi 575 lbs. per square inch average, the increase being due to the addition of the cement.

The cement surkhi mortar used by Mr. Bayley on the 2nd Division of the Khyber Railway was proportioned—

1 cement (by volume)

2 surkhi (,,)

and on test gave the following results :—

Tensile, 7 days, 481 lbs. per square inch,

28 days, 523 lbs. per square inch,

setting time, initial 160 minutes

final 652 minutes

It was important to note that although the surkhi in this case appeared to have no detrimental effect on the cement and merely to have played the part usually taken by sand, such might not be the case with surkhi made from clay of a different chemical composition. This result confirmed broadly the conclusion of the authors of the paper that cement mortars of satisfactory strength could be made with sands hitherto regarded as too fine for the purpose. The importance of this fact in the Punjab could not be over-rated.