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*Proceedings of the Madras Government, Public Works Department,
21st July 1871.*

No. 357. Read the following letter from the Officiating Deputy Secretary to the Government of India, Public Works Department, (Irrigation,) to the Acting Joint-Secretary to the Government of Madras, Public Works Department, Irrigation Branch, dated Simla, 19th May 1871, No. 164-I:—

In continuation of this office letter No. 206-I., dated the 26th May last, I am directed to forward, for information and circulation among Irrigation Officers, copies of a further report (with plans) by Mr. Tanner, M. I., C. E., of experiments on various mortars and concretes, with notes thereon by Captain Home and Lieutenant-Colonel Gulliver, Royal Engineers.

From Lieutenant-Colonel H. W. GULLIVER, R. E., Superintending Engineer, Sirhind Canal, to the Joint-Secretary to the Government of the Punjab, Public Works Department, Irrigation branch, dated 6th February 1871, No. 224.

I HAVE the honour to forward herewith a report of some experiments made by Mr. J. E. Tanner of Loodiana, on various mortars and concretes, with notes by Captain Home and myself.

Captain Home left the paper to be submitted when the result was known of crushing the specimens sent to Madhopoor to be tested.

The report on this point was not received until my departure on special duty. The heavy work I had then to do and my subsequent ill-health have detained the report until now.

• Captain Home urges that the cost of the experiments made by Mr. J. E. Tanner (Rs. 2,250) should be reimbursed to that Officer, as the value of the experiments to the Sirhind Canal alone is very great. In this opinion I concur, and solicit sanction to the amount being paid and charged against the contingencies of the masonry works estimate.

The late Colonel Anderson, R. E., Officiating Inspector-General of Irrigation, was also of opinion that this sum should be reimbursed, and stated the same to Mr. Tanner himself, asking him at the same time to compile the report now forwarded.

From J. E. TANNER, Esq., District Engineer, Delhi Railway, to the Superintending Engineer, Sirhind Canal, dated 23rd February 1870.

I HAVE the pleasure to forward a report on the experiments on limes and concrete made by me during the last eleven years.

With the report are tables showing the strength and hydraulic energy gained by adding different proportions of kunkur lime to fat lime, and in several tables are shown the great advantage that is gained by consolidating concrete.

In the report I have endeavoured to show how necessary it is to procure consolidation for concrete, and to facilitate such that the materials of which the concrete is composed should be of small size, while the water added in the mixing should be of minimum quantity.

The experiments, which were commenced in 1859, have cost me about Rupees 2,250.

Experiments on concrete made of small material, and on the strength of different proportions of kunkur lime added to fat lime, by J. EDWARD TANNER, Esq., M. I., C. E., District Engineer, Delhi Railway.

In 1859 the works I had to superintend seemed to require the use of concrete, and I made experiments to satisfy myself whether concrete composed of smaller brick or stone than that usually employed would not give more uniform strength, and whether the interstices, which are always to be seen in old concrete work when demolished, could not by that means be prevented, i.e., whether the mortar could not, by consolidation, be made to fill all interstices. So long as the brick or stone used is large, the pieces get one on the top of the other, and the rammers are not heavy enough,

nor the force used sufficient to break the pieces; therefore the stones receive the blow without yielding; and, however well the consolidation may be carried, the mortar is not distributed, and interstices without mortar are left. To a mass of concrete used under a foundation, such does no harm since all strain on it is vertical and in the same direction as the consolidation has been carried forward; it is, indeed, a crushing force it has to withstand; but for an abutment or revetment wall the thrust is lateral, when these interstices must render the concrete weak; therefore, instead of breaking the brick to pass through 2½-inch ring, it was broken small enough to pass through a ¼-inch ring.

The results of the experiments showed that concrete so made was undeniably stronger, and that the more it was consolidated the stronger it became; also that the amount of water used is the great secret on which the strength depends, for if too much water is used it cannot be consolidated. The necessity for the use of concrete no longer existing in 1860, the matter was laid aside by me till I assumed charge of the Sutlej bridge when I further experimented on it, of which the following is the result.

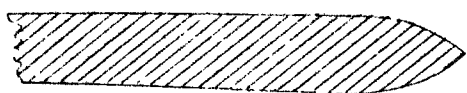
All prisms in the experiments, whether for mortar or concrete, were made 2 inches broad, 2 inches deep, and 12 inches long. The equation used throughout for ascertaining the value of rupture or cohesion per square inch from the breaking weight was—

$$W = \frac{B \times D^2}{L} - \frac{A}{2}$$

As I was seeking the value of transverse strength, and not a resistance to crushing, the prisms were broken with a breaking-down machine of ordinary construction.

The balanced lever of the machine was 5 feet long, and was worked at 10 to 1s. or 20 to 1, as the strength of the material that had to be broken required. All prisms were broken with 4 inches between supports, which in the equation equal L; therefore $\frac{B D^2}{L}$ was almost universally $\frac{2+4}{4}$; the few specimens that were slightly above or below the exact dimensions were calculated for accordingly. A, which in the equation is to represent the weight of prism between supports, was not made use of, as it was but a fraction of a lb., for $\frac{A}{2} = 0.55$ lbs.

The weight used was fine sand, which was allowed to pour very gently into a cylindrical cup at the end of the lever; when the prism broke, the sand was stopped, and the cylinder, with the sand it contained, was weighed. The section of the knife on which the whole weight bore is shown below:—



This was placed on the prism in the centre between the supports by means of a template. The strain was always applied at right angles to the plane of consolidation.

The question of mortar was the first consideration; yet at the Sutlej, as is generally the case in the Punjab, there is only fat lime from the hills and kunkur; it was not therefore a selection from different quarries as it would have been in other countries, but merely the selection of the best proportions of fat lime to kunkur. I first roughly analysed the surrounding quarries of kunkur, and found they were as nearly as possible the same as I had found in the quarries in the Mooltan jungle; and from the way in which it is ordinarily burnt, kunkur lime may be said to have about 60 per cent. of clay, with a slight admixture of sand to 40 lime,—care of course being taken that the kunkur is well cleaned before going into the kiln. While analysing the different specimens, two were brought to me, which are worthy of notice, for they were of an entirely different character, one from Kurryanah, 6 miles from Loodiana, which gave the same quantity of lime as the others,

but no sand whatever mixed with the clay. On further inquiry I found that such a small quantity was obtainable that, beyond some trials of it, it was not allowed to enter my mortars for the experiments. It does not go under the name of kunkur among the natives, but is called poondoo. It will set under water in a quarter of an hour. The other specimen was from a village called Chullabout, half-way between Loodiana and Umballa, too far to be of any use, but I mention it here to show that kunkur approaching eminently hydraulic lime is to be found even in the Punjab. The analysis showed it about 61 lime to 26 sand and clay; it has some minute-shells mixed with it. Some specimens brought, as those from Baboon Majra, had so much sand in their composition that, as regards lime for mortar, they could only be considered rubbish. Friends from various parts sent me specimens of kunkur, all of which I roughly analysed, and came to the conclusion that the kunkur quarries adjacent to Loodiana were, on a fair average, with regard to the amount of lime contained, i.e., that it was about 40 lime to 60 sand and clay.

The Berhampoor quarry selected by me for the Sutlej works is situated at the foot of the hills near Gurshunker in the Hoshiarpur District, as it was not only the nearest but also the most get-at-able of all quarries offered. The lime from the quarries is excessively fat, yielding 95 of lime to 5 of impurities. This is the lime which in all experiments is called F L, or spoken of as fat lime. The lime having to be burnt at the quarry and slaked before starting, I was determined to make all my measurements of it as a stiff paste, having determined the following:—That it required 28 to 30 lbs. of newly-burnt quick-lime, or 63 to 64 lbs. of the slaked lime as it arrived to make 1 cubic foot of the stiff paste.

The kunkur lime (unless otherwise mentioned) was also measured in paste, having been first ground to fine powder as pozzuolana is, which, according to the usual classified list of mortars it is, and which it represents from the manner in which it was used, i.e., as an addition to the fat lime, to give it the necessary hydraulic energy. The conditions belonging to the kunkur lime were in powder a weight of 82 lbs. to a cubic foot if the measure was not too violently shaken while filling, and 1 foot of dry powder made 1 cubic foot of the stiff paste.

The prisms of mortar Table No. 1 were made in June 1864. The paste was too stiff for mortar, yet not stiff enough for concrete; but, as the weight of each specimen is given, it will readily be seen to what extent they have been consolidated, and, though their relative value is higher than mortar would be, yet they would each bear the same relation one to the other as if they had been mortar. The prisms, as soon as made, were left exposed to the open air.

It will be seen from the table how exactly the hydraulic energy of the mixtures follows.

M. Vicats's classification of lime.—The fat lime of course depending on its surface for its strength, while the addition of fractions of the kunkur limes impart a certain amount of hydraulic energy, and when equal quantities of each are added together, we arrive at M. Vicats's eminently hydraulic lime. It is not surprising that, when passing the mixture that would give cement, the mixture shows so badly since the lime was not used as cement is, but was mixed as mortar, and was not allowed to set as cement would have. The value of the different mixtures after decrease, as would be foreseen. The kunkur lime by itself seems to have set its best in 60 days, and to have lost its strength from exposure to wind and rain after; the value of it in four or five years would have been greater had the prisms not lost their corners from exposure, and in those that hold a large per-centage of kunkur, the same is going on; indeed, the same will be found in all specimens of concrete where K L has been largely used.

1 F L to 1 K L is still on the increase, and to prove that the surface had no influence on its strength, a prism 2' x 2' had its surface rubbed off ¼ inch deep, thus reducing the prism to 1.5' x 1.5' when it gave the same strength nearly; the same being done to 1 F L; ¼ K L gave R = 230, and with F L R = 160, showing that the strength of these last two entirely depended on the exposed surface even after five years.

Table No. 2 contains prisms of the same, which, having been exposed 30 days in the open air, were placed for 30 days under water, and were broken the same day as those of 60 days in Table No. 1.

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M. Vicats's Table.

The resulting lime.						Lime.	Clay.
Slightly hydraulic	...	...	...	...	...	90 to 80	10 to 20
Hydraulic	...	...	...	...	...	80 to 70	20 to 30
Eminently hydraulic	...	...	...	...	...	70 to 65	30 to 35
Cement	...	...	...	...	...	About 50	50
Pozzuolana	...	...	...	...	...	As low as 10	90

Experiments made on the adhesion of mortar in 1864.

The sand of the Suttlej has only 33 per cent. of void after it has been well shaken down; therefore, by the usual rule of adding 50 per cent. to the void space for the amount of lime required for the sand, there is 1 of lime to 2 of sand.

The difference shown in Table No. 3 of the adhesion is, I believe, to be attributed to the fineness of the sand. The poondoo from Kurryana when used alone as cement gave $7\frac{1}{2}$ lbs. for adhesion per square inch after 15 days.

Concrete.

Tables Nos. 5 to 12 are examples of concrete composed F L—L—S (sand), B (brick-gravel) in various proportions. The addition of $\frac{1}{4}$ cement (which was an artificial cement made at Loodiana) undoubtedly gave greater strength at the end of 15 days, but at the end of the first month or so the prisms, whether made with the cement or without it, were even. I was led to add the cement from a paragraph in a French work which came to me as I was starting the prisms in Table No. 5, and, having commenced the first ones with the addition of cement, I continued it throughout, that all might have exactly the same mortar, and therefore would bear comparison one to the other better.

I had found great difficulty during my experiments of 1859 in making the prisms of equal weight; for, unless they were so, it was impossible to compare one kind of material to another, since, as is shown in Table No. 4, the same material, if consolidated to a greater extent, gives a far greater strength, and comparison is rendered useless. After several experiments on the best way of consolidating the concrete, I decided on the iron-rammers in use on the grand trunk road for consolidating the kunkur, and having found that the concrete consolidated by coolies with these rammers weighed 120 lbs. per cubic foot when dry, all the prisms were made so that they might be equal to that weight and no more. The weight of the same concrete when wet was 144 lbs. per cubic foot; therefore, as the prisms were $\frac{1}{8}$ of a cubic foot, the weight of concrete required for each prism was 4 lbs. Each prism was weighed at the end of 15 days, when they were equal to 120 lbs., and, after five years at a dry season of the year, they all weigh at the rate of 117 $\frac{1}{2}$ lbs. per cubic foot. The quantity of concrete required for each prism and the amount of consolidation requisite, having been thus decided on, the mould shown in drawing No. 1 was made; when the materials for each specimen had been mixed, 4 lbs. was weighed and evenly spread in the mould the block A being put in, the mould was placed under a pile engine, the ram of which weighed 112 lbs. and fell through 15 feet; the blows were continued until it was shown that the prism was exactly 2 inches deep by a mark on the block A (in red). Six prisms of each kind were made during the months of August and September 1864; the F L was allowed to stand for one hour as paste when the K L was added to it (in paste), and the two kinds of lime were well mixed together; these were allowed to stand for half an hour, after which the brick-gravel (thoroughly wetted beforehand) was added, then the sand (dry), and lastly the cement, dry, or in paste, as the quantity of sand added required.

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In examining the tables concrete it will be seen in all cases the strength has gone on increasing from the first day to the end of five years and six months, except in instances where the adulteration in the proportion of sand added to the lime was so much in excess as to render the specimen unfit for exposure to alternate rain and wind. But in all cases of each specimen that had been left in the open air for one month, and then placed under water for one year, the strength is invariably greater than that which had been left in the open air for 13 months, and it is particularly the case in those specimens that have the greater amount of sand and brick added, showing that any eminently hydraulic lime, whether it may be naturally so or made so by the addition of pozzuolana, is quite independent of the surface exposed to the atmosphere, and that under water it sets harder and quicker than if left exposed to the air even in such small prisms as 2" x 2".

During all these experiments I had noticed how uniform the strength was in every specimen, and that, after the concrete had set, there was not the slightest contraction to be detected; it, therefore, seemed quite possible to construct even an arch of it, and to prove how such would answer an arch, hereafter described, was made in August 1864. This arch had a very slight rise, and was only 6 inches thick at the key.

In November 1868, Captain Home, R. E., who had seen the different specimens, and was present at the testing of many of them, proposed that an arch of 45 feet span should be constructed, and kindly procured the sanction of Government that the experiment might be tried at the Government expense. The result of this arch is given subsequently.

At the same time, that is, in March 1869, I constructed the section of a roof 1 foot wide as shown in drawing No. 4. The concrete of which it was composed was 1 F L + 1 K L + 3 B, thus instead of the one sand used in the arch of 45 feet span, 1 B was substituted. On the piers A A a layer of sand, 3 inches thick, was placed, so that the roof should be entirely independent of the piers. The beams B B being made of sufficient weight to overcome the thrust of the arch when loaded with a weight of 200 lbs. per square foot. It was evenly loaded with pukka bricks to 380 lbs. per square foot on the 30th day, when it broke.

The two beams and the arch apparently gave at the same moment, and I cannot say whether it was the arch gave first or one of the beams.

When it broke, the beams had been loaded evenly to 470 lbs. per square foot, while the arched part was loaded to 380 lbs. The beams and the arch gave when eight bricks were placed on the centre of the arch as it were instantaneously.

Table No. 13 is added, giving some of the various materials that were tried for concrete, but which are not included in the series comprised in Tables Nos. 5, 4, 1, and 3. I would call attention to No. 46 in this table; it would seem that the fine soorkhee has given more strength to the concrete than the brick-gravel.

Table No. 14 is given showing the strength of cohesion of various stones, bricks, and concrete, and the authority for the trials.

Table No. 15 shows the weight per square inch at which cubes of 2" side cracked, and also that at which they were crushed. These experiments were made in the crushing machine at Madhopoor by Mr. J. L. Watson, Executive Engineer of the Workshops.

A report on a flat arch of 12 feet span, built in August 1864.

The arch was built of 12 feet span, 14 inches wide, segmental, having a rise of 14 inches and a depth of 6 inches at the key; the abutments were 16 inches long, and 14 inches wide, and were fastened by cement to the pukka floor; the haunches were carried up to the same height as the extrados of the key. Thirty days after completion (the centre having been struck on the 15th day) 21 men stood on it; but as it did not move, and I wished it to be broken, they were told to jump on it, and it broke, disclosing the whole arch to be composed of layers about $\frac{1}{4}$ of an inch in thickness; yet, notwithstanding it was composed of a series of layers, it was strong enough, when 30 days old, to carry more than a crowd of men as a dead-weight, light as the arch was for the rise given. I saw the fault of the layers not having joined themselves into one mass was

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owing to the quantity of water I had allowed to the concrete being too little; therefore I tried making blocks 2' x 2' and 1 foot thick, and there was no trouble in getting the whole to set in one mass; if the concrete is too dry, sprinkle water over it sparingly, for it wants but little; if it is too wet, sprinkle a little dry brick-gravel over it. But to tell on paper the exact consistency that it ought to have is impossible; practice alone can determine it. It ought to have a quick sandy motion when it is consolidated, but only just ought to be so.

Any one who wishes to use the concrete can find out easily by making two and three blocks not less than 2' x 2' by one foot thick.

A report on the construction and testing of a concrete arch built at Loodiana in February 1869.

Span 45 feet, consisting of an arc of 60°; depth of key 3 feet, 10 feet wide; abutments, each 10 feet in length, or a total length of 65 feet on the face over all by 10 feet wide.

The concrete was composed of one part of white or fat lime, measured wet, i. e., consisting of mortar; one part of ground kunkur lime measured dry; one part of sand measured dry; and two parts of brick broken to the size of small gravel, which was wetted well before measured.

The cost was as follows:—

860 Maunds of white lime, at Rs. 45 per 100 maunds	Rs.	A.	P.
1,260 " of kunkur, at " 18 per " "	387	0	0
Carting of " at " 18 per " "	226	12	9
Grinding " at " 18 per " "	24	0	0
2,560 Brick-gravel, broken to size of small gravel, at Rs. 5 per 100	36	2	0
1,260 Feet of sand, at Rs. 2 per 100	128	0	0
207 Water carriers and Beldars to mix concrete, at 3 Annas each	25	3	2
520 Coolies, at 2 Annas and 6 Pies each	38	13	0
Baskets, hire of rammers, and grind-stones, etc.	81	4	0
1 Head Maistree	9	10	4
	12	0	0
Cost of concrete	968	13	3
Making centre and carriage of the material necessary	51	12	0
Cost of striking centre and removing it	9	2	0
Total	1,029	11	3

The total quantity of concrete in arch, when it was consolidated, was 4,025 cubic feet, which compared against the quantity, 6,290 cubic feet, as measured loose while mixing, shows that the consolidation required 60 per cent., and the cost of the concrete in place Rupees 24-1-1½

The arch took 24 days to build, including abutments and foundations. When the centre was struck 44 days after completion, no subsidence whatever was to be detected.

Three months after completion, the 45 feet, i. e., the portion above span, was loaded evenly with sun-dried bricks to 100 tons; just as the last bricks were being placed, the arch started, giving the cracks shown in accompanying diagram.

It was left with this weight on it for 20 days; when, there being no signs of the cracks enlarging, an extra weight was added in the centre by building up a solid block 10' x 10' till it was equal to 41 tons, when the arch again gave with a similar start to that which it had given just visible, quite perceptible, at the same time giving the longitudinal crack across the key. These cracks, with the cracks on the ground also shown in the diagram, show most undeniably that the cause of yielding was owing to the foundations slipping in the sandy soil in which the abutments had been built.

Such had been foreseen to a certain extent, and had been provided against by weighing abutments before the loading was commenced; by building up a square block over each 10' x 10' till it was equal to 30 tons. This weight prevented the overturning of the abutments, but was

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not sufficient to prevent the slipping. The load had been estimated by weighing 10 bricks; but, after the weighing was finished, a block of 100 cubic feet, 5' x 5' x 4', built of the bricks used in weighing the arch was built and weighed, showing the weight to be 90 lbs. per foot, for the bricks were only sufficiently dry to handle.

As the cause of yielding was so palpable, it was no use adding more weight. Had the foundations stood firm, there is every reason to believe that the great weight of half a ton nearly on every square foot would not have hurt the stability of the arch; since not one single crack was perceptible except those that must occur when the abutments slip away from the thrust.

The whole weight was removed, and a shot was fired in one of the abutments on the 24th August, that it might be tested whether the system of carrying up the work by layers, 1 inch or so thick, would not leave evidence that the mass consisted of a series of layers 1 inch thick. The result of the blasting shows that there is not a trace of how the work had been built. The effect of the charge was exactly similar to what it would have been had the charge been fired in solid rock; only one piece of about 2 cubic feet was detached from the mass. It flew to a height of 20 feet and to a distance of 60 feet, where it landed unbroken.

One interesting fact was brought to light by the blasting, namely, what is the state of mortar in a large mass of work six months after it has been built? The mortar, consisting of one fat lime and one kunkur lime, is eminently hydraulic, and will set completely in 36 hours.

The results of the blasting showed that, although the mortar had set perfectly, the concrete was as wet as the day it was put in, and, although it was as hard as stone, had a piece been put into water, I do not believe it could have absorbed one drop. The outer 6 inches alone showed signs of dryness, notwithstanding the arch had been subjected to the enormous heat of an Indian summer. Hence the necessity of using hydraulic lime in massive work, as an Indian sun is not sufficient to dry work that is 5 feet in from the face.

The experiment, I think, has proved that a system of consolidating concrete composed of small materials and with little water in layers has been a success; but in future I would always recommend that brick should be substituted for the one part of sand, as in a smaller arch made at the same time with the same lime, etc., but with brick substituted for the sand (making it three of brick instead of two), the work was very much stronger; this arch is described above.

The value of R. proved to be 208 per square inch, and crushed with 617 lbs. per square inch.

The value of R. in roof proved to be 272 per square inch, and crushed with 1,022 lbs. per square inch. A slight crack appeared with 724 lbs. per square inch.

TABLE No. 1.
Mortars.

Age when broken.	FL.	1 FL + 1 KL.	1 FL + 1 KL.	1 FL + 1 KL.	1 FL + 2 KL.	1 FL + 3 KL.	1 FL + 4 KL.	1 FL + 5 KL.	1 FL + 6 KL.	K. L.	Remarks.
Sixty days	158	204	216	237	218	204	181	166	143	128	The prisms were left exposed in the open air after being made.
One year	267	...	289	302	...	230	200	162	142	105	
Four years and four months	...	366	337	345	337	300	...	158	...	45	
Five years and six months	450	374	363	379	301	286	176	142	99	21	
Specimens equal in weight to a cubic foot.	93 lbs.	97 lbs.	96 lbs.	95 lbs.	88 lbs.	87 lbs.	89 lbs.	87 lbs.	89 lbs.	93 lbs.	

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TABLE No. 2.
Mortars.

	F L.	1 F L + 1 K L.	1 F L + 1 K L.	1 F L + 1 K L.	1 F L + 2 K L.	1 F L + 3 K L.	1 F L + 4 K L.	1 F L + 5 K L.	1 F L + 6 K L.	K L.	Remarks.
Broken at sixty days ...	...	226	239	264	248	218	...	143	...	125	{ 30 days in the air. 30 " in water.
Specimens when taken from the water were equal in weight to a cubic foot.	...	115 lbs.	108 lbs.	108 lbs.	115 lbs.	108 lbs.	...	115 lbs.	...	117 lbs.	

TABLE No. 3.
Adhesion of Mortar.

Fat lime.	Kunkur.	Pondoo.	Sand.	Adhesion per square inch after 15 days.	Remarks.
1	1	...	...	16.2 lbs.	
...	...	1	...	7.5 "	
1	1	...	1	10.0 "	
1	1	...	1 1/2	6.2 "	
1	1	...	4	5.0 "	
...	1	...	...	3.2 "	
...	...	...	...	17.9 "	1 blue lias, 1 pozzuolana, 3 sand at 15 days (Pasley).

TABLE No. 4.
Showing difference in strength according to consolidation.

1 F L.	1 K L.	3 sand.	4 brick.	Age 30 days.	Consolidated to equal 170 lbs. per cubic foot ...	R = 300
					" " " 120 " " " "	R = 166

TABLE No. 5.
Concrete.

Parts of brick-gravel added.	1	2	3	4	5	6	to 1 F L + 1 K L + 1/2 cement.
Broken at 15 days ...	342	259	150	132	139	109	When made were left exposed to the open air.
" at 30 " ...	491	236	180	173	151	143	Do. do. do.
" at 13 months...	548	370	287	215	297	170	Do. do. do.
" at 5 years and 6 months ...	600	565	300	218	318	210	Do. do. do.
Broken at 13 months	...	446	434	401	361	271	These had been kept under water for 12 months.

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TABLE No. 6.
Concrete.

Parts of sand added.	1	2	3	4	5	6	7	8	to 1 F L + 1 K L + 1/2 cement.
Broken at 15 days ...	259	129	94	71	57	60	56	64	When made were left exposed to the open air.
" at 30 " ...	339	149	123	121	113	98	87	83	Do. do.
" at 13 months.	536	346	181	150	124	...	106	98	Do. do.
" at 5 years and 6 months ...	...	405	315	225	172	150	...	120	Do. do.
Broken at 13 months.	342	282	267	190	...	...	...	...	These had been kept 12 months under water.

TABLE No. 7.
Concrete.

Parts of sand added.	1	2	3	4	5	6	7	8	9	to 1 F L + 1 K L + 1/2 cement + 1 B.
Broken at 15 days ...	309	289	184	120	101	97	79	63	71	When made were left exposed.
" at 30 " ...	320	290	219	154	147	136	132	121	95	Do. do. do.
" at 13 " ...	520	...	316	316	276	124	...	123	106	Do. do. do.
" at 5 years and 6 months ...	...	390	270	240	225	165	135	126	110	Do. do. do.
Broken at 13 months	369	324	...	...	270	264	264	225	...	These were kept 12 months under water.

TABLE No. 8.
Concrete.

Parts of sand added.	1	2	3	4	5	6	7	8	to 1 F L + 1 K L + 1/2 cement + 2 brick-gravel.
Broken at 15 days ...	146	169	102	87	76	57	57	53	When made were left exposed to the open air.
" at 30 " ...	...	192	162	143	135	82	79	76	Do. do. do.
" at 13 months...	305	282	152	150	143	105	91	91	Do. do. do.
" at 5 years and 6 months ...	390	285	240	202	180	105	90	60	The last did not stand exposure.
Broken at 13 months...	394	327	300	316	286	207	150	...	These had been 12 months under water.

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TABLE No. 9.
Concrete.

Parts of sand added.	1	2	3	4	5	6	7	to 1 FL + 1 KL + $\frac{1}{2}$ cement + 3 brick gravel.
Broken at 15 days ...	100	71	67	71	41	49	49	When made was exposed to the open air.
Do. at 30 ,, ...	128	151	137	121	113	94	75	These last showed signs of exposure.
Do. at 13 months...	209	191	143	121	...	...	72	Do. do. do.
Do. at 5 years and 6 months...	270	255	225	152	105	76	60	These were kept 12 months under water.
Broken at 13 months...	324	309	300	287	200	173	124	

TABLE No. 10.
Concrete.

Parts of sand added.	1	2	3	4	5	6	to 1 KL + 1 FL + $\frac{1}{2}$ cement + 4 brick gravel.
Broken at 15 days ...	124	79	83	87	71	...	When made were left exposed to the open air.
Do. at 30 ,, ...	147	166	160	106	83	...	Do. do. do.
Do. at 13 months...	160	167	156	136	106	...	Do. do. do.
Do. at 5 years and 6 months...	168	150	...	135	120	...	Do. do. do.
Broken at 13 months ...	305	305	200	188	200	...	These had been kept 12 months under water.

TABLE No. 11.
Concrete.

Parts of sand added.	1	2	3	4	5	to 1 FL $\times$ 1 KL + $\frac{1}{2}$ cement + 5 brick gravel.
Broken at 15 days ...	83	64	42	64	40	When made were left exposed to the open air.
Do. at 30 ,, ...	136	98	91	79	70	Do. do. do.
Do. at 13 months...	177	153	106	91	89	Do. do. do.
Do. at 5 years and 6 months...	187	150	128	105	90	Do. do. do.
Broken at 13 months ...	361	277	211	196	204	These had been kept 12 months under water.

TABLE No. 12.
Concrete.

Parts of sand added.	1	2	3	to 1 FL $\times$ 1 KL + $\frac{1}{2}$ cement + 6 brick gravel.
Broken at 15 days ...	71	112	49	When made were left exposed to the open air.
Do. at 30 ,, ...	102	120	83	Do. do. do.
Do. at 13 months...	106	136	98	Do. do. do.
Do. at 5 years and 6 months...	165	150	120	Do. do. do.
Broken at 13 months...	295	282	248	These had been kept 12 months under water.

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TABLE No. 13.

Fat lime.	Kunkur lime.	Sand.	Brick gravel.	Brick dust.	Cement.	Weight A. C. ft. of the specimen when dry.	Age when broken in days.	How many days it had been in water.	Value of R.	No. in list.	Remarks.
$\frac{1}{2}$	$\frac{1}{2}$	4	...	1	$\frac{1}{2}$	126	45	...	154	No. 5	Made by hand.
...	...	...	...	...	...	126	65	...	181	"	" "
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	3	2	$\frac{1}{2}$	150	65	30	315	No. 6	" "
...	...	...	...	...	...	120	45	...	185	"	" "
...	...	...	...	...	...	120	65	...	236	"	" "
...	...	...	...	...	...	142	65	30	256	"	" "
1	...	7	...	1	$\frac{1}{2}$	122	45	...	107	No. 9	" "
...	...	...	...	...	...	122	65	...	168	"	" "
...	...	...	...	...	...	142	65	30	180	"	" "
...	1	3	2	...	...	117	30	...	102	No. 33	Made under pile engine.
...	...	...	...	...	...	116	2,007	...	210	"	" "
...	1	3	2	...	$\frac{1}{2}$	117	30	...	117	No. 35	Ferozepoor kunkur.
...	1	3	2	...	$\frac{1}{2}$	116	2,007	...	180	"	" "
...	1	1	1	...	$\frac{1}{2}$	117	30	...	83	No. 29	Loodiana kunkur.
...	...	...	...	...	...	116	2,007	...	91	"	" "
1	...	...	...	1	...	117	15	...	181	No. 46	" "
1	...	...	...	1	...	116	2,007	...	990	"	" "
1	...	...	...	4	...	117	15	...	91	No. 45	" "
1	...	...	...	4	...	116	2,007	...	315	"	" "
1	1	...	1	...	$\frac{1}{2}$	117	15	...	200	No. 41	With three ordinary earth added.
1	1	...	1	...	$\frac{1}{2}$	116	2,007	...	315	"	Without above.
1	1	...	...	1	$\frac{1}{2}$	117	15	...	174	No. 37	" "
1	1	...	...	2	$\frac{1}{2}$	117	15	...	196	No. 38	" "
1	1	...	...	3	$\frac{1}{2}$	117	15	...	166	No. 39	" "
1	1	...	...	4	$\frac{1}{2}$	117	15	...	143	No. 40	" "
...	...	...	...	...	...	116	2,007	...	255	"	" "
1	1	...	...	1	$\frac{1}{2}$	116	2,007	...	465	No. 37	" "

TABLE No. 14.

R or value of cohesion per square inch of stone and bricks, &c.

Welsh slate	...	...	...	...	G. Rennie	7,616
Agra red sand-stone	...	...	...	...	Tanner	1,514
Yorkshire blue-stone	...	...	...	...	G. Rennie	1,342
Bath-stone	...	...	...	...	Pasley	581
Sand-stone from Roopur	...	...	...	...	Tanner	400
Best concrete made at Loodiana (1 month)	...	...	...	...	Tanner	491
" " " " " (13 months)	...	...	...	...	"	548
" " " " " (5 years and 6 months)	...	...	...	...	"	990
Best concrete of which there is any record	...	...	...	...	Totton	389
Best concrete of 120 examples (1 year)	...	...	...	...	Pasley	117
Concrete with sand at Loodiana (No. 1)	...	...	...	...	Tanner	121
" " " " " (13 months)	...	...	...	...	"	123
" " " " " (5 years and 6 months)	...	...	...	...	"	126
Ordinary English concrete	...	...	...	...	Creasy	100

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R or value of cohesion per square inch of stone and bricks, etc.—(Concluded.)

Native bricks, burnt to klinker (3 examples)	...	...	Tanner	...	409	
Lahore bricks, Punjab Railway (3 "	...	...	"	...	356	
Native bricks, burnt blue (3 "	...	...	"	...	273	
Best London stocks (3 "	...	...	Barlow	...	213	
Native bricks, well burnt (3 "	...	...	Tanner	...	198	
London bricks, new (ordinary, 3 "	...	...	Barlow	...	193	
" " exposed for 2 years (3 examples)	...	...	"	...	165	
Artificial cement (16 days)	...	...	Pasley	...	205	
" " Loodiana made (16 days)	...	...	Tanner	...	181	

TABLE No. 15.

RECORD OF CRUSHING OF SPECIMENS OF CONCRETE AT MADHOPPOOR.

Experiments carried out by J. WATSON, ESQ., Executive Engineer, Workshops.

CONSTRUCTION.						No. of specimens in Table No. 13.	Weight per square inch, at which first crack appeared in specimen.	Weight per square inch, at which the specimen crushed.	Remarks.
Fat lime.	Kunkur lime.	Sand.	Brick-gravel.	Soor-khee or brick-dust.	Cement.				
1	1	4	...	1	1	5	1,474	1,658	2 years old.
1	1	4	...	2	1	6	720	879	6 months old.
1	1	7	...	3	1	6	1,518	2,193	5 years old.
1	1	8	...	2	...	9	617	733	5 ditto.
...	...	...	...	...	...	33		2,502	5 ditto, went suddenly, made under pile engine.
1	1	...	...	1	1	41	1,309	1,967	5 years old.
1	...	...	...	1	...	46	1,987	3,765	2 ditto.
1	...	...	...	1	...	46	3,366	4,515	5 ditto.
1	1	1	...	2	...	...		617	Arch built at Loodiana in March 1869, one year old.
1	1	...	...	3	...	...	761	1,024	Roof built at Loodiana in March 1869, one year old; average of these specimens gives 724 lbs. per square inch for the crack appearing, and 1,022 lbs. for crushing.
...	...	...	...	...	...	...	795	980	
...	...	...	...	...	...	...	617	1,062	

Memorandum by CAPTAIN R. HOME, R. E., Superintending Engineer, Sirhind Canal, on MR. J. E. TANNER's paper on concretes and cements, dated 28th February 1870.

I MUCH regret that the delay in obtaining the result of the crushing experiments on the concrete cubes sent to Madhopoor (which is owing to the machine being out of repair) should have prevented my forwarding the papers to Government myself. My departure for England in a few days forbids my doing so, and I can only leave a brief memorandum testifying to the care with which the experiments have been conducted, and to the uniform kindness of Mr. Tanner to myself and all officers attached to the canal who have applied to him for information on the subject of the manufacture of concretes and mortars and on the resources of the district generally.

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Since I have been in charge of the Sirhind Canal, the necessity for providing something better than brick-work for the large super-passages on the upper part of the canal has given me much anxiety. All works of this kind, with brick arches, which I have seen, leak in a manner which gives me great doubts of their permanence, whilst the enormous expense of constructing the large arches of the super-passages, with closely jointed bricks, even if by asphalt or other covering leakage could be prevented, would swell the cost of the main line of the Sirhind Canal, which, under any circumstances, is likely to be the most expensive piece of work of the kind in the country. Knowing that Mr. Tanner had been employed on concrete experiments for some years, I applied to him for assistance, which he readily gave. I had access to all his papers containing the result of his experiments for years, and assisted in breaking some of the concrete prisms to fill up his tables.

The result of my investigation was to me most satisfactory, both as regards the care with which the experiments had been conducted and also as to the value of the results.

Mr. Tanner, at my request, readily undertook to construct a length of one of my super-passage arches as an experiment, the cost of materials and consolidation being paid for by Government. The result of this experiment, with a cheap, and of course relatively inferior concrete, are embodied in Mr. Tanner's report.

I have no doubt myself, nor has Mr. Tanner, that the arch would have stood any test if the foundations had been good. The lines of fracture in the arch, and the cracks in the ground behind the abutments, sufficiently testify to the cause of failure.

I much regret the results. Had I been acquainted with the nature of the soil, I should certainly have recommended a foundation of piles under the abutments, which would have effectually prevented the mishap. Cubes have been cut from the materials of the arch, and their resistance to crushing will be seen in Mr. Tanner's tables. I have recommended the use of Mr. Tanner's concrete in my estimate for the main line for voussoirs or for monolithic arches, and have a strong belief myself in the value of the material; it can be made into blocks with hard surfaces with a core only hard enough to supply weight, and monolithic arches can be made in a similar manner, the spandrels being made of inferior material.

Mr. Tanner has appended to the letter forwarding his paper a memorandum of the cost of his experiments. I venture to hope that this sum may be reimbursed to him; the value of his experiments to the Sirhind Canal alone, carried out as they have been with the materials which must be used on it, would, in my opinion, fully justify such an expenditure on the part of Government.

Note by LIEUTENANT-COLONEL H. W. GULLIVER, R. E., Superintending Engineer, Sirhind Canal, on MR. J. E. TANNER's Report.

Mortars, Table No. 1.

Any of the mixtures ... 1 F L to 1 K L
Do. do. ... 1 F L to 2 K L
Do. do. ... 1 F L to 3 K L
varied only from 237 to 204 modulus of fracture at 60 days, one; 302 to 230 at one year;
" from 345 to 300 at four years and four months;
" from 379 to 286 at five " and six "
but they were left exposed to the air after being made. This is not fair to the kunkur lime, which requires to be kept wet while setting to give fair results.

In Table No. 2 broken at 60 days, R varied from 264 to 218.

The first 30 days the specimens were in the air, the next 30 in water. It will be seen that this immersion in water increased the strength as follows:—

1 F L to 1 K L	...	237 to 264
1 F L to 2 K L	...	218 to 248
1 F L to 3 K L	...	204 to 218

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It is unfortunate that the specimens were not also tried by immersing them for the first 30 days in water, and afterwards exposing them to the air, as I believe this would have increased the strength still further.

The advantage of the immersion in water is shown by the tables of the strength of the concrete.

Table No. 5.

Specimens containing 1 F L to 1 K L, $\frac{1}{4}$ cement, added to brick-gravel, gave the following results after 13 months in air, and one in air and 12 in water :—

<i>Parts of brick-gravel.</i>	<i>R. in air.</i>	<i>R. in water.</i>
1	548	Not tried.
2	370	446
3	287	434
4	215	401
5	297	361
6	170	271

so that the specimen containing five parts of brick-gravel set under water gave very nearly the same result as that with only two parts of brick-gravel set in the air.

How important this is in an economical point of view is evident.

Table No. 6.

In these experiments sand was added instead of brick-gravel with the following results :—

<i>Parts of sand.</i>	<i>R. in air.</i>	<i>R. in water.</i>
1	536	342
2	346	282
3	181	267
4	150	190

from which it will be seen that, while the two first specimens deteriorated under water, the two last improved considerably. I should fear some error in this case; it may be that there is not, for in Table No. 7 when one brick was added to each specimen, as well as sand, the results were as follow :—

<i>Parts of sand.</i>	<i>R. in air.</i>	<i>R. in water.</i>
1	520	369
5	276	270
6	124	264
8	123	225

But then again in Table No. 8, where another portion of brick-gravel was added to each specimen, the results were as follow :—

<i>Parts of sand.</i>	<i>R. in air.</i>	<i>R. in water.</i>
1	305	394
2	282	327
3	152	300
4	150	316
5	143	286
6	105	207

In this the specimens with the larger quantities of sand improved in a much larger proportion than the others. But those others also improved, while Tables Nos. 6 and 7 show that those with the smaller proportions of sand absolutely deteriorated when immersed in water. I cannot but think there must have been an error in the experiments, or faults in the specimens, for in Tables Nos. 9, 10, 11, and 12, in which the quantity of brick-gravel was increased, there is shown a regular superiority of the specimens immersed in water over those which were exposed to the air.

Tables Nos. 9, 10, 11, and 12 show the results of adding increased proportions of brick-gravel to the mortar made with various proportions of sand, and from all of them the advantage of the mixture being allowed to set under water is evident.

Tables Nos. 13 and 14 require no remarks.

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Table No. 15, shows the resistance to crushing of various specimens. From these it would appear that the simple mixture of one of fat lime and one of ground brick is by far the strongest, as in a specimen two years old the first crack appeared under a weight of 1,987 lbs. per square inch, and it required 3,765 lbs. to crush the same specimen.

The specimens crushed measured $2'' \times 2'' \times 2''$. It may be useful to add here the results of crushing specimens of the same size made by Mr. Palmer at Umritsur. The specimens crushed were cut out of the solid blocks, $2' \times 2' \times 1'$ made by that Officer, the report on which was submitted with Mr. Tanner's first report. They were all kept under damp earth while setting.

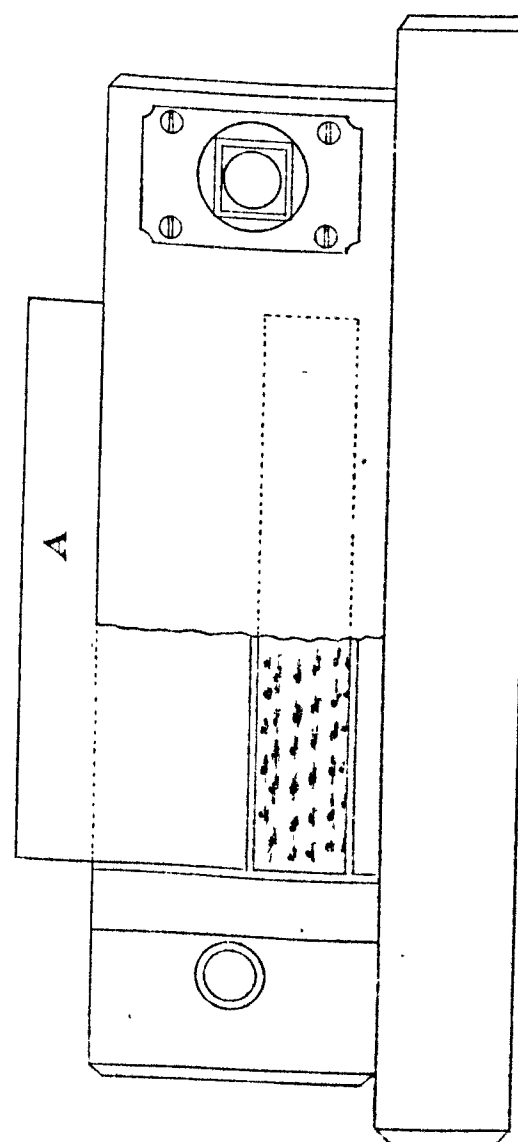
No. 23, in which 6 cubic feet of small kunkur and 2.5 cubic feet of kunkur lime were pounded in layers in a box $2' \times 2' \times 1'$ for 14 hours. First crack appeared under a weight of 1,925 lbs. per inch, and it crushed under 3,915 lbs.

No. 26, 6 cubic feet of small kunkur, with 1.7 cubic feet of kunkur lime, pounded into the same box for 7 hours, cracked under 1,180 lbs., and crushed under 1,460 lbs. per inch.

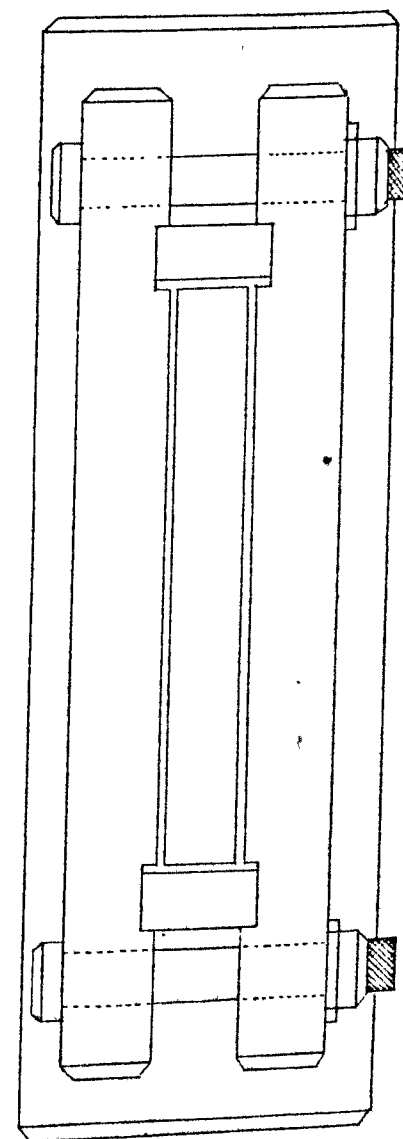
No. 31, in which six parts of large kunkur were mixed with a mortar made of one part fat lime, four parts kunkur lime, and one part sand, pounded for 12 hours, cracked with 1,592 lbs., and crushed with 1,910 lbs.

MOULD IN WHICH THE PRISMS OF CONCRETE WERE MADE.

Scale 3 inches to the foot.



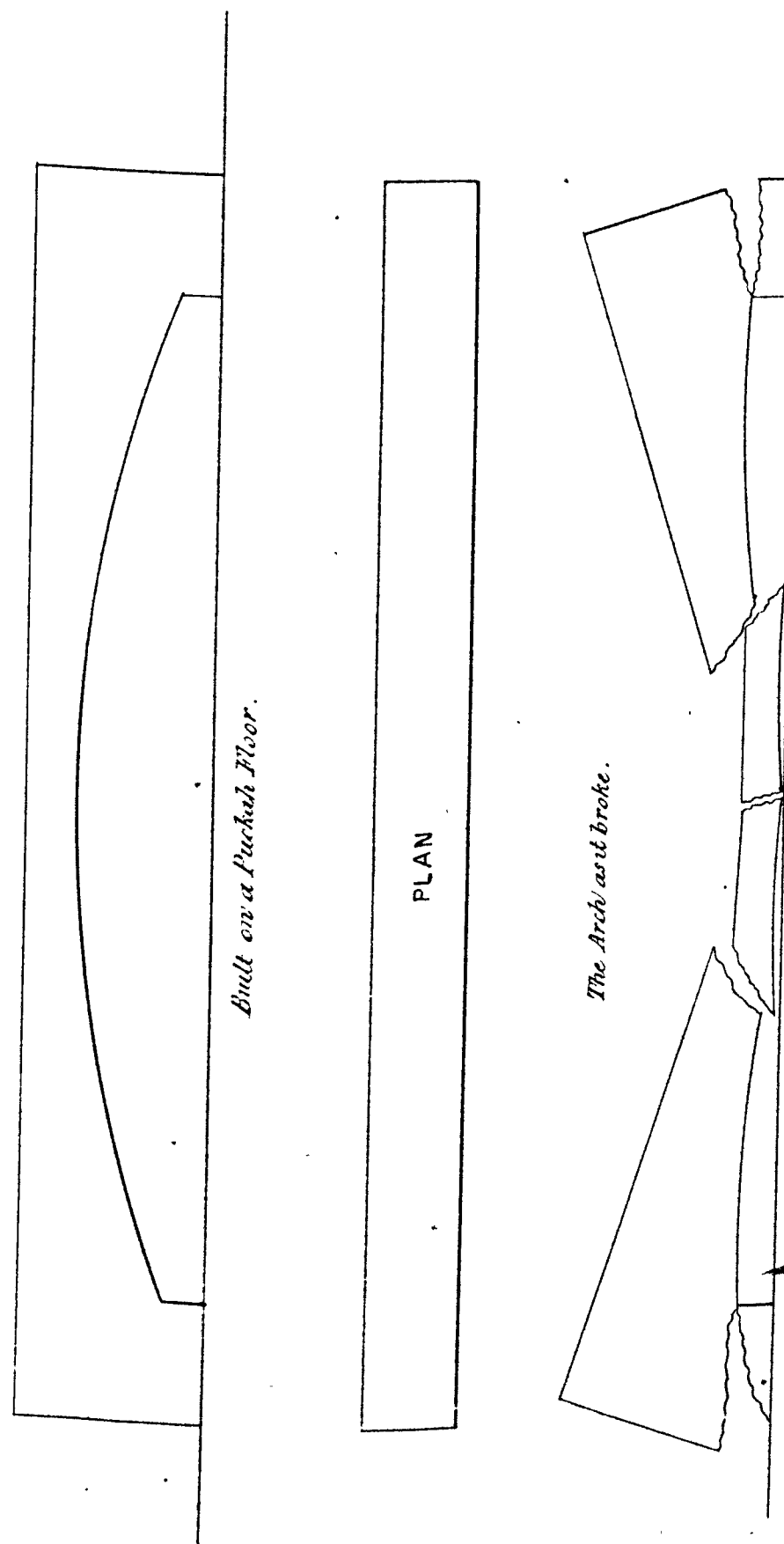
Made of Sal-wood lined with iron.



ARCH OF 12 FEET SPAN

BUILT AUGUST 1864.

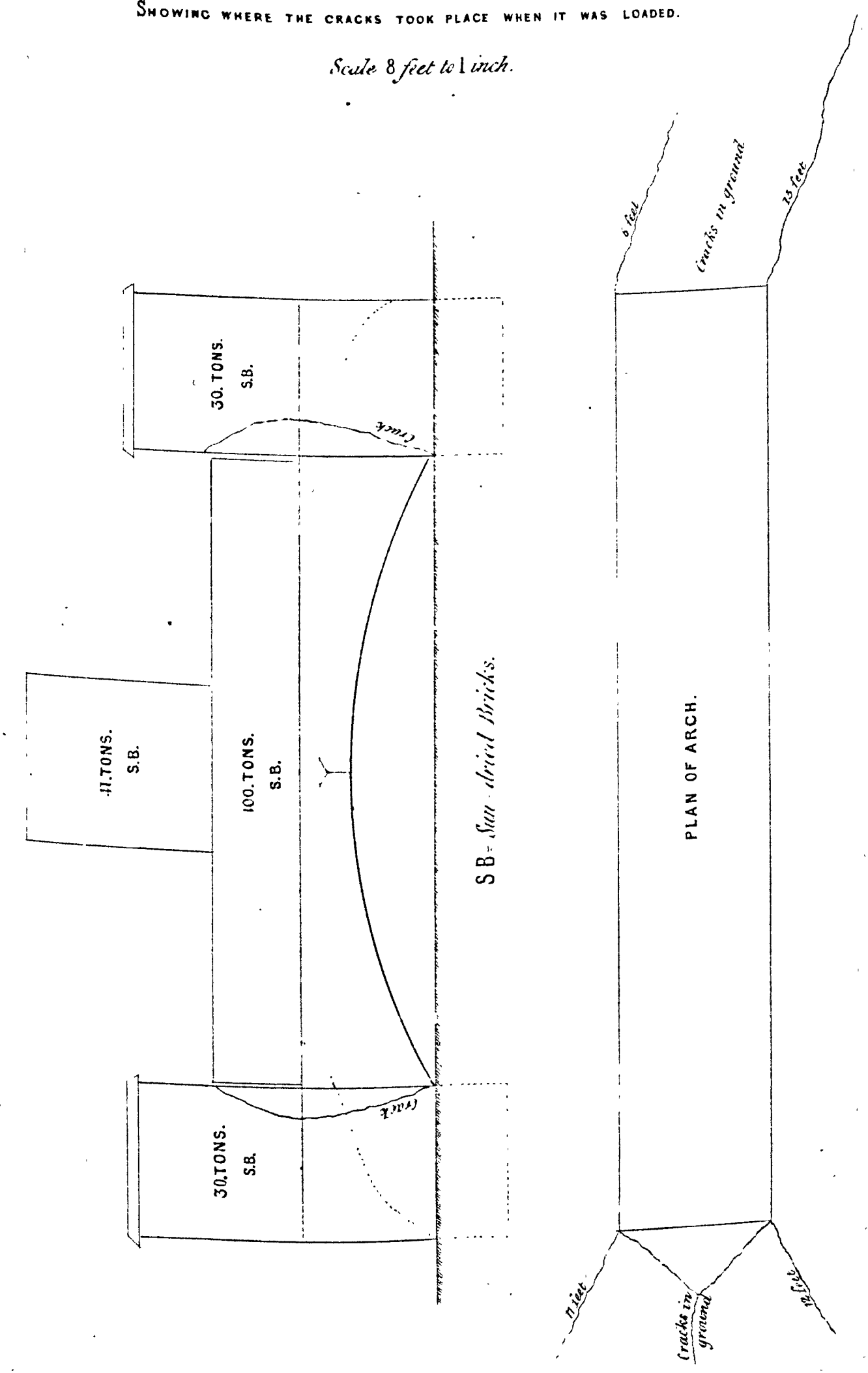
Scale $\frac{1}{2}$ inch to a foot.



ARCH CONSTRUCTED AT LOODIANA IN 1869.

SHOWING WHERE THE CRACKS TOOK PLACE WHEN IT WAS LOADED.

Scale 8 feet to 1 inch.

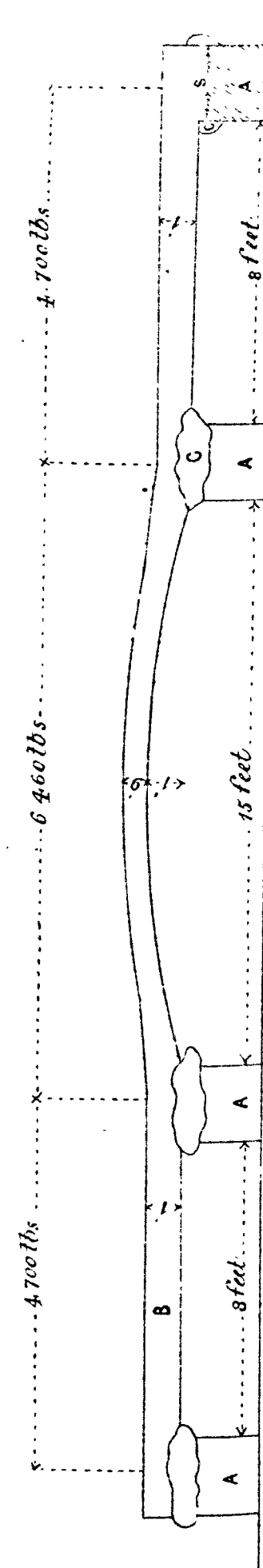


SECTION OF A ROOF ONE FOOT WIDE

MADE IN MARCH 1869.

Scale 4 feet to 1 inch.

The weight was of puchah bricks and was distributed evenly.



This model for a roof was made only one foot wide. S Represents the sand. C The clay put round the pier to keep the sand in place; the centres were struck on the 15th day and weighted on the 30th

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No. 358.

ORDER THEREON, 21st July 1871, No. 1,922.

IRRIGATION, No. 20.

ORDERED to be communicated to the
Chief Engineer for Irrigation and to all
Superintending Engineers, in continua-

tion of G. O., No. 1,636, dated 8th July 1870.

(True Extract.)

Colonel, R.E.,
Secretary to Government.

To the Acting Chief Engineer for Irrigation.
To all Superintending Engineers.
,, Major R. B. Kennedy.

Exd. E. C. Shunker.

P W Dept.

No 1922

12

27

Proceedings of the Madras Government.
Under date the 29th July 1871
Read the following

From the Government of India / S. E. No 1611 D/19 May 1871.

Ordered to be com-
municated to the Chief
Engineer for Irrigation and
to all Superintending Engin-
eers in continuation of G.O.
No 1636 dated 8th July
1870.


28.6.71



To
The Chief Engineer for
Irrigation
All Superintending Engineers
Major C.B. Kennedy

Recd 29/7/71

Govt of 1871 Madras.

PUBLIC WORKS.

Shri G. S. Chetty
for
Bridges

21 July 1922.

Nos. 257 & 258

1/1/22 R. 72