M.R.O. 1—10,006—23-2-50

(1) Number of pages _____

(2) Date of repair _____

(3) Initials of the Referencer _____

MADRAS RECORD OFFICE

Government of Madras

Public Works DEPARTMENT

G.O. No. / ~~B.P. No.~~	427	Press / ~~Mis.~~
Dated		824. ~~195~~

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N° 58

Bangalore 20th November 1873

From

Surgeon E. Nicholson B. Mo. S.
on Special Duty D. P. W.

To

The Chief Engineer and Secretary to Govt P. W. D.

Sir,

I have the honour to inform you of the results obtained in the examination of limestones since my report dated 14th April 1873.

1° Soon after that date specimens of limestones began to come in from every District in such numbers (nearly 700 up to date, besides clays) that it was hopeless to attempt any regular chemical examination of them in the comparatively short time available without neglecting the important practical investigation into the means necessary for imparting hydraulic properties to limes generally.

I therefore deferred systematic examination of them at least until I should have gone through some preliminary experiments on the typical materials used in hydraulic works.

I have every reason to be satisfied with having temporarily set aside the chemical method of investigation, for I find that while analysis is a very useful attendant on the more practical method of the kiln, it is of itself a very deceptive guide

2° Having completed my cement testing machine (described in my letter, G.O. 17th July 1873) and set up kilns, a kiln shed and trial cisterns, with the small sum remaining, at my disposal monthly after paying for office expenses, fuel and other contingencies, — I began a series of experiments with a view of ascertaining what results could be obtained with such materials as are at the disposal of every engineer, viz. brick, lime and sand, before attempting the employment of new materials.

3° After many preliminary experiments I settled upon the following tests for the quality of mortars and cements.

4° Tensile strength was determined on the standard bricket adopted by the Metropolitan Board of Works. This bricket of 7½ inches long (it may conveniently be shorter) and 1¼ inches thick, is 3 inches broad at each end, the middle portion for a length of 1¼ being only 1½ inches broad, thus presenting in the waist a section of 2¼ square inches. The broad ends are held by 2 clips which are pulled asunder by a gradually increasing strain until rupture of the bricket takes place; this strain can be applied in various ways, preferably by a lever machine. The instrument used in the Board of Works trials, and that of Henri Mangon are levers of the first kind; the machine I use is a lever of the second kind in which the disruptive force is applied to the lower clip of the bricket, the upper being suspended from a strap passed over the upper beam of the square frame. This machine answers perfectly well; and tested with weights is of considerable exactitude; it was made up for me by an Indian blacksmith at a cost not exceeding Rs 100.

5° At the beginning of October I received the Michele's patent cement-testing machine from England. I have no appliances for testing it with weights, but I can readily understand that, as Mr W. Parkes remarked in his letter (G.O. 14th May 1873), the indications are comparatively rough and not to be relied on within 15 or 20 lbs. The graduation of the arc is necessarily arbitrary, for while the counterpoise is rising, along it the short arm of the lever is traversing another arc of very different radius, and the friction of the axle tends to deaden the indication. The index slips back with the fall of the counterpoise instead of remaining steady; I have remedied this by attaching a friction spring of india rubber to the back of the index. The check bolts connecting the clips are liable to jam, and I should prefer them to be of less diameter. The bricket made & supplied use of, a form adopted to the peculiar clips of the machine; the waist of the bricket, instead of being square in section for a length of 1¼ inch is biconcave at the sides so that the standard section of 2¼ square inches is only found at one point.

This modification though convenient in some respects, appears to favour the bricket by throwing the line of rupture off from the narrowest part of the neck. Whichever be the cause, the dullness of the machine itself or the form of bricket, one thing appears certain that the machine is only adapted for cement to the exclusion of miscellaneous compositions, that above 300 lbs it gives a higher tensile strength than is shown by lever machines with the old form of bricket, and that the error increases with the weight indicated.

The following comparative experiments were made with brickets from the same batch of cement and in series of not less than three, the average of which was taken.

	Age	Lever Machine	Bricketts	Difference
1 Cement, 1 sand	6 days	334 lb.	318 lb.	— 6 per cent
Cement neat	7 days	345	365	+ 6 per cent
do	do	399	446	+12 —
do	28 days	437	581	+33
do	do	483	607	+26 —
do	34 —	557	635	+32

6° Adhesive strength was determined by the force required to tear asunder a joint made between two good bricks. I adopted the system of crossed bricks used by Colonel Sotten U.S.E. The bricks used were those made by the Sappers and Miners excellent for ordinary work and indeed fair superior

to any other brick I have seen in Bangalore. I have lately used some very superior bricks made by the Sappers and Miners expressly for the work; they are made of washed clay and felspar. The bricks being 4 by 4 inches broad, a cross-joint presents a surface of 18 square inches. They were joined under the pressure of a man leaning heavily on the uppermost and after a certain interval they were tested in the same machine that was used for breaking brickets. The bricket strap being slid aside was replaced by 2 stirrups which supported the ends of the upper brick whilst 2 other stirrups, a plate and hook connected the lower brick to the lever of the machine. By the addition of a small lever, having only 20 lbs preponderance, below the large lever, I have enabled the machine to test the weakest mortars as well as the strongest. Adhesive strength varies of course with different materials; as it is much less than the tensile strength of the mortar joint, it is not interfered with by the latter; the adhesion yields long before the joint itself, though a person seeing the joint broken from the shock and from the adhesion having yielded simultaneously on either side, might think the joint itself gone and that the adhesion of parts of the joint to the surface of the brick showed the adhesion to be stronger than the joint. This is a common error, but a moments reflection on the great tensile strength of mortars compared to their adhesive

strength will show that this is an error. The tensile strength of a mortar joint is on the average about seven times greater than its adhesiveness to the surface of the brick which it joins and it would therefore appear that the objection made by Major (now Major General) H.D.Y. Scott R.E. to Sir Charles Pasley's tests (viz. that the breaking weight of a joint "is a measure of the tenacity or adhesion of the mortar alone, or partly of its cohesion and partly of its adhesion") is ill-founded. But even were the weight required to tear a brick joint asunder effected by the tensile strength of the mortar, the test would still be of great value from its practical application to the quality of the mortar for bricklaying purposes.

7. The setting of the mortar under water is an important point. When the mortar is packed in a confined space the rapidity of setting may be taken as a measure of hydraulic energy. But when the mortar is placed under water without support, as in the form of a ball, another property, hydraulic plasticity, becomes apparent. Portland cement, though setting far more rapidly than Surki mortar, yet possesses much less hydraulic plasticity; a ball of cement (at least of the sample I worked with) will not stand if immersed in less than 2 hours after it was made, while Surki mortars have generally sufficient plasticity to enable them to stand immediate immersion. And some hydraulic limes which possess sufficient plasticity to stand immersion in the shape of a ball,

yet do not set hard for two or three weeks. The hydraulic energy of a lime or mortar is generally tested by the time required before a cake of the mortar immersed at once will support the weight of a loaded needle. Unfortunately this instrument has not been of a very uniform nature in the experiments extant. While Vicat's original needle was, I believe, 2 millimetres (.078 inch) in diameter at the flat point and loaded with one kilogramme (2.2 lbs), other diameters and weights have been freely used. Gillmore mentions 2 needles one of $\frac{1}{12}$ inch diameter loaded with $\frac{1}{4}$ lb. and another of $\frac{1}{24}$ inch diameter loaded with one lb. Mr. Dejoux does not describe the needle he uses, but he quotes French specifications in which a needle of $\frac{1}{12}$ inch loaded with 10 oz is used as a test for the hydraulic value of lime. I use myself Gillmore's two needles, the light one for ascertaining the 'soft' set and the heavy one for the 'hard' set, the lime or mortar being contained in a small chatty of about 2 inches diameter, such as are obtainable in the bazar at the rate of four annas a hundred. These needles are useful but I attach little importance to their indications comparatively with the numerical indications given by the adhesive strength of brick joints. Unless a lime is strongly hydraulic one may have to wait for days before any indications of setting take place; I prefer to join one or more pairs of bricks, immerse them at once and test

the breaking weight of the joints after 24 hours and after 7 days or even 28 days, and I believe that engineers desiring to test the quality of a lime will find this practical test far preferable to the needle test.

8. I use then but two processes for ascertaining the value of a lime or mortar, viz. the test for tensile strength, and the brick joint test for adhesive strength and hydraulic energy. I prepare with each composition 6 or more brickets and from nine to twelve brick joints and subject these to the following probation in air or water previous to trial in the machine.

	Probation in air	Probation in water	Day of trial	Indication
a. Tensile strength				
3 brickets	28 days (in damp box)	...	28th	Value for dry concrete and plastering
3 brickets	1 day (in damp box)	27 days	28th	Value for hydraulic concrete
b. adhesive strength				
3 brick joints	28 days (upon shade)	...	28th	Value for ordinary brickwork
3 brick joints	...	28 days	28th	Value for hydraulic brickwork
c. hydraulic energy				
1 brick joint	...	1 day	after 24 hours	hydraulic energy
1 do	...	7 days	8 day	do

In the case of feebly hydraulic mortars the brickets cannot be immersed so soon as 24 hours after making; seven days or even one month must

elapse; and it is also necessary to defer the immersion of the brick joints for one to seven days. In special cases it may also be well to try the effect of immersing joints made with cement or strongly hydraulic lime after one day in air, and thus to ascertain the gain or loss of strength by the delay in immersion.

9. The series of experiments now submitted, and the detail of which is appended, includes many preliminary experiments and is not so systematic as I should wish; moreover, having for a long time but few bricks capable of standing more than 20 lbs per sq. in. in the adhesive strength experiments without peeling, I was obliged to allow the bricks weakened by immersion to dry for 6 or 7 days before they could be tried; this exposure being favourable to the brick but generally unfavourable to the mortar. Having now explained the principles on which these experiments were conducted, I may proceed to give the results obtained. Quantities are always given in parts by measure unless otherwise specified. Lime is measured in the state of paste, as the volume of slaked lime produced by a given bulk of lime is variable, and measurements in lime quick are inconvenient. The volume of paste is the active volume of the lime when in combination with other materials; it is very constant, and does not differ greatly from that of the quicklime, being about equal to it in stone limes and about ½ greater in shell and other fat limes.

Experiments on mortars of Shell lime and sand.

10. The shell-lime commonly used for works near the Madras coasts may be taken as the type of the fat limes of India as chalk is that of the fat limes of Europe; both chalk and shells consist of nearly pure Carbonate of Calcium. The shell-lime which I used was sent me by the District Engineer Presidency. Its specific gravity in bulk was .86; it slaked in 15 minutes after being wetted; nearly doubling in bulk, sp. gr. .55. The slaked lime passed through a sieve of 45 meshes to the inch gave 22 per cent of siftings, principally unburnt shell, and 78 per cent of fine lime; this latter, sp. gr. in bulk 0.5 contained on analysis

1.7	foreign matters (brick dust &c)
12.4	Calcium carbonate
85.9	Calcium hydrate
100.	

The slaked lime required its weight (half its bulk) of water to become a paste, the volume of which was 1 1/3 that of the quick-lime, 2/3 that of the slaked lime. The sand used was good Bungalore pit-sand, principally formed from the decomposition of the gneiss rock. In some of the experiments it was sized by sifting, sand not passing through a sieve of 35 meshes being considered as course. From the experiments detailed in the Appendix Series A. I deduce the following conclusions.—

11. The strength of a mortar of fat lime and sand is owing nearly entirely to the effect of dessiccation. As long as it is kept damp it acquires no strength, and when dry (for it does not set) although hard and even resonant on the surface, it crumbles into powder directly the carbonated crust is broken through. Some effect is produced by the gradual combination of the sand and lime under favourable circumstances, such as sharpness, fineness or porosity of sand, as exposure to alternate damp and dryness after the first drying has taken place; But these effects are very irregular and so slow that after 30 years they are barely perceptible. This is clearly shown by the following table in which the average and best mortars of my experiments are contrasted with mortars tried by Captain Smith, Madras Engineers (quoted in the Roorkee C.E. college treatises) and by Sir Charles Pasley

	Age	Adhesive strength lbs per sq. in.
Series A average mortar, 3 sand	28 days	2.8
do best do, 1½ sand	do	4.6
Capt. Smiths mortar, 1½ sand	13 years	4.5
Chatham lines, best mortar	30 years	3.9

If this strength, even at 30 years old, be compared with that of mud it will be seen that the comparison is by no means favourable to the use of sand mortar of fat lime. (Bricks joined

with thatmixed formed by the ordinary, loamy soil of Bungalore showed in six days an adhesive strengthe of 5·3 lbs per square inch. A joint of the same mixed, but pointed ½ inch deep with good Surkie mortar, and left exposed to the weather, gave after 3 months an adhesive strengthe of 7·3 lbs per square inch.

12. This mortar is not only entirely devoid of hydraulic properties, and incapable of hardening in a damp atmosphere, but if submerged before complete dessiccation has taken place, the adhesion already acquired will disappear. This may happen after 7 days, and even after 28 days, but the strength will sometimes reappear on subsequent dessiccation. During immersion the strength is all but in abeyance.

13. The best results were obtained with 1 part of lime paste to 1½ of sand, but as much as 3 parts of sand may be used without great deterioration. Sand requires about ¼ of its volume of water to saturate it; we may therefore infer that 1 part of lime paste will just fill up the intervals of 2½ parts of sand; it is however hardly safe to allow no more lime than will be just sufficient to fill up the intervals; therefore the proportion of 1 to 2 will be found more generally applicable. Practically it will be found that sand moistened and mixed with ⅓ of stiff lime paste hardly increases in volume.

14. The hardening of the mortar being entirely due to dessiccation it is not necessary that the bricks should be soaked in water. When a hydraulic mortar is used, the bricks should be saturated by at least one hour's immersion before being laid, but in the case of mortars of sand and fat lime, saturation of the bricks appears to be positively detrimental; it is sufficient if they are dipped into water for a few seconds immediately before laying.

Experiments with mortar of sand and slightly hydraulic lime.

15. These experiments, detailed in the Appendix series B, were made with a lime made at Kistnarajpur near Bangalore, and procurable in the bazar. It is in small nodules of a pinkish grey colour which becomes greenish grey when powdered, resembling Portland cement in colour. In bulk its specific gravity is 0·95 powdered it is 1·0, when slaked the volume increases less than one third and the sp. gr. is 0·8. The slaked lime requires one-third of its bulk of water to become a paste, returning to the original volume of the quicklime. The slaked lime was found to contain

12·3	insoluble silicates
8·8	calcium carbonate and silicate
78·9	calcium hydrate
100·	

This lime may be taken as the type of the moderately rich kunkur limes of India, and being able to get it fresh, I made several series

of experiments with it. It is generally very badly burnt owing to the high price of fuel near Bangalore and in this case yields a large quantity of 'kurpsy' or unburnt refuse when slaked and beaten. Its price is merely less than one rupee per parcade of 2 ½ cubic feet, but although one parcade does not yield much more than its bulk of slaked lime after deducting the 'kurpsy' the slaked lime is sold at little more than half the price of the quicklime; it is probably much adulterated. For concrete work the whole lime, after slaking, may be ground into fluid paste; but for brickwork it must be separated from the 'kurpsy' & ground quick and then slaked.

16. This class of lime will not bear so much sand as shell-lime; as a rule not more than 2 parts of sand should be used to 1 part of lime, quick or in paste. Nevertheless some unusually good results were obtained with 3 parts of sand, of which one part fine was added first, the two other parts, coarse, being subsequently incorporated. The adhesive strength is from 5·8 to 8·9 lbs. at 28 days old, not immersed, the tensile strength 20 to 50 lbs per square inch.

17. Mortar made with this lime resists the action of water and even improves under it, but in proportion to the lapse of time at which before immersion. The tensile strength of the mortar especially improved by immersion after complete setting in air. Bricks giving only 24 lbs per sq. in. after four weeks in air attained a strength of 62 lbs by immersion for another four weeks.

Experiments with other hydraulic sand-mortars.

18. I have only been able to examine a few of the limes yielded by limestones already analyzed; this part of the work I reserved until I should have completed the preliminary experiments on typical materials. The results obtained from some of these limes are detailed in the Appendix, Series C, and may be summarized as follows:-

19. Bhowany, Kotamunglum. The composition of this limestone is given in the appendix to my report in G.G. 5th May 1873; it contained 60·9 per cent of silicates, 29 of calcium carbonate and 6·1 of magnesium carbonate. It is friable, in large blocks, and I marked it "too meagre!" I was however somewhat surprised to find, on burning half the sample, that a joint made with the lime, neat, gave the great strength of 19·9 lbs per sq. in. The lime does not slake & should be ground and used as a cement.

20. Kolar No 1, from Beirandhully on the Palar river. This nodular limestone contains 20·5 per cent of silicates, 59·4 of calcium carbonate and 5·3 of magnesium carbonate. The lime from it gave good results. Mortar made with 2 parts of sand showed after 28 days an adhesive strength of 16·1 lbs per sq. in.

dry; and 13·1 immersed. Tensile strength 72 lbs.

21. Kolar No 2. from Baitmenglum on the Kolar river. This nodular limestone contains 17·9 per cent of silicates, 76·2 calcium carbonate, and 6·5 of magnesium carbonate. Mortar made with the lime which it yielded and 2 parts of sand gave an adhesive strength of 6·6 lbs per sq. in. dry, and 51·1 lbs immersed. Tensile strength 46 lbs per sq. in. dry, and 61 lbs immersed.

22. Limes made from the specimens of lime stone sent from Palghat, Coimbatore and Secunderabad were only slightly hydraulic. In many limestones want of homogeneity prevents them from showing, when burnt, the hydraulic properties which their chemical composition seems to indicate.

Experiments on the addition of sugar to mortars.

23. The addition of raw sugar or jagery to the shell-lime mortars made in Madras has often been mentioned; but I have never seen the rationale of its employment correctly stated. In Burnell's treatise on limes and mortars, the use of sugar is ascribed to its influence in retarding setting. In the Roorkee treatise it is stated that the bad qualities of fat limes may be in some degree corrected by it as its influence is very marked in the first solidification

of the mortar. Captain Smith [Professional Papers, Madras Engineers] attributes the fact that mortars made of calcined shells have stood the action of the weather for centuries to this mixture of jaghery in their composition. That the sugar does some action is shewn both by my own experiments and by those of Captain Smith recorded in the Roorkee treatise.

	Age	Mortar without Sugar		Mortar with Sugar	
		Adhesive Strength lbs per sq in	Tensile strength lbs per sq in	Adhesive Strength lbs per sq in	Tensile Strength lbs per sq in
Capt. Smith's 1 lime 1 ± Sand	13 years	4·5	twice the adhesive	6·5	equal to the adhesion
E.N. Series D.	28 days	3·1	8·2	5·6	11

These experiments accord fairly, and shew that while some improvement doubtless attends the use of sugar, it is not so great as has been supposed. I have observed no difference in the solidification of the mortars made with and without sugar, except that the former take a sort of glaze on the surface. The reason of the beneficial action of sugar is, I consider, to be found in the greatly increased solubility of lime in a saccharine solution. Whilst water dissolves only about 1 per cent of lime, a moderately strong solution of sugar will dissolve as much as 3 per cent; it is evident that the dessiccation of the sugar solution will tend to strengthen the mortar

by allowing the lime to crystallize besides placing it in a more favourable position for combination with the sand. Ulteriorly the sugar probably becomes converted into carbonic acid and water, another circumstance tending to strengthen the interior of the mortar. It is quite impossible that sugar can act by retardation of the setting for such action is decidedly unfavourable to a mortar which hardens not by setting but by dessiccation. It may also be noted that while sugar improves lines of sand and fat lime which harden only by dessiccation it is utterly destructive of the setting properties possessed by a mortar of surkhi and fat lime. A mortar composed of 1 shell lime, 5 surkhi which showed an adhesive strength of 6·5 lbs per sq. in. only stood 1·1 lb when made up with jaggery water and the tensile strength of 110 lbs per sq. in. fell to 20 lbs.

Experiments on the addition of silicate of soda, or of alum-cake, to mortars.

24. The silicate of soda or of potash known as 'soluble glass' has been proposed for imparting hydraulic properties to fat limes. In Gillmore's treaties it is stated that this result may be obtained by forming this hydrate [of lime] into a paste with a requisite proportion of silicate of soda. My expectations were disappointed, for the mixtures which I made were quite worthless.

The same disappointment occurred in the case of alum-cake (a commercial sulphate of aluminium prepared from clay and containing silica). I had hoped that the formation of calcium sulphate, aluminate and silicate would ensue on the mixture of this substance with fat lime, and that hydraulic properties would thus be imparted, but the experiment was a failure.

Experiments on mortars of lime and surkhi.

25. After obtaining the results detailed in the Appendix Series E, I cannot but be surprised that the valuable properties of artificial pozzolanic made by grinding brick or other forms of burnt clay should have been so neglected, although so well known. Whatever be the cause of the alleged failure of mortar made with this pozzolana when subjected for years to the action of sea-water; nothing has ever been proved against them for ordinary building or for inland hydraulic works. It has been alleged that sand produces a cheaper, harder and stronger mortar. This is erroneous; except in the case of strongly hydraulic limes, which are by no means common, the use of surkhi instead of sand increases beyond comparison the strength of the mortar even for ordinary building purposes, whilst the objections of increased cost and inferior hardness are founded on a mistake. In the question of

strength. There is no comparison, as a glance at the results tabulated in the Appendix will show; and as regards hardness and cost, the combination of Surki and lime can be hardened by the addition of sand just as as plain lime can; while the decrease in the proportion of lime required to produce a mortar or concrete of superior strength more than compensates the difference of price between Surki and sand. Taking, for example the case of a shell-lime mortar made with 1 part of lime to 2 of sand, this will be found quite hard on the outside, but directly the outer crust is broken the whole crumbles away; its tensile strength is about 8 lbs per sq. in and it is utterly devoid of hydraulic properties. But if the shell lime be mixed with 3 parts of Surki (a material which can never hardly cost one-fourth the price of lime) the resulting mortar or rather cement will obviously be much cheaper, bulk for bulk, than the original lime (the cost being, say, that of 1 pucka seer of lime against that of ¼ pucka seer of lime and ¾ parah of Surki the latter rarely costing more than ⅓ the price of lime). Now this cement, which if used not for brickwork is at least four times as strong as either pure lime or lime mixed with sand, besides improving considerably by immersion, can be mixed with two-and-a-half its volume of sand forming a mortar or concrete the tensile strength of which is 120 lbs per sq. in. fifteen times that

of said mortar, while it is equally hard and much cheaper. The Surki cement, unmixed with sand, as a mortar in brickwork is not dearer than sand mortar inasmuch as the quantity of Surki which can be used without loss of strength is greater than that of sand; moreover the plastic nature of the Surki cement permits of joints being made with less than half the quantity which would be used in the case of sand mortar. This advantage is best shown when the bricks have fairly true surfaces, and considering the slight difference of price which there should be between well moulded bricks and badly moulded bricks it is worth while taking care that these should be as good as possible. Good table moulded bricks use much less mortar than ground moulded bricks besides being much stronger. Even when the worst and roughest ground moulded bricks are alone available there is yet considerable pecuniary economy in the use of the Surki cement, inasmuch as the proportion of lime in it can be diminished to less than half that which would be safe in sand mortar without the strength falling below that of the latter, or even of the bricks themselves.

26. Surki cement should then be diluted with sand in order to obtain hardness with little loss of tensile strength, as in the case of concrete,

but as a rule with surkie if the weakness of the bricks renders weakening of the mortar justifiable as a measure of economy. Very good hydraulic concrete may thus be made with only one twentieth of lime in the materials (1 lime 3 surki, 6 sand, 10 gravel) and hydraulic mortar may contain as little as one-fifth or one-sixth of lime

27. The surki I used was of two kinds; one was the ordinary Sappers and Miners brick (marked S & M) pounded; the other was the common country brick made near Bangalore, a very weak and roughly made article. These gave results nearly equally good, four better than those obtained with a surki made of fine washed clay. Surkii made with broken pottery (of the black kind made with blue clay and finished finish) gave also very good results. In each case the surkii was passed through a sieve of 45 meshes to the inch.

28. The advantage of combining surki with lime is best shown in the case of fat limes; the more hydraulic the lime is naturally, the less is the advantage of surki. When lime possesses hydraulic properties, sand mortar can be used for works which will not be at once subjected to the action of water, but in every case the substitution of surki for sand improves the strength of the mortar, makes it set much more quickly and enables it to resist at once the action of water. A lime which will

in three days when the work is immersed at once, while a mortar of moderately hydraulic lime and sand will rarely set firm under water in less than three weeks.

29. Surki cement answers well for plastering; it takes a polish equal to that of sand 'chunam', while it is far more durable and impermeable and its strength is not dependent, as in the latter, on the surface remaining sound. The colour is buff or reddish and somewhat irregular if the work is done in hot dry weather, but where the work can be protected from the sun, as inside houses, the colour would probably remain uniform and it would be more agreeable than the glare of white.

30. The theory of the action of surkii is based on the fact that the silicates of alumina forming clay are rendered more easily decomposable by heat. Clay is not acted on by acids in the cold, but when burnt it is nearly entirely decomposable. The manufacture of artificial or concentrated alum (sulphate of alumina) is founded on this property. Clay is reduced to a fine powder and roasted, it is then treated by dilute hot sulphuric acid; aluminium sulphate is formed and silicic acid set free. An analogous action takes place in the mixing and setting of surkii cement; the lime attacks the clay rendered decomposable in burning, unites with the silicic acid to form silicates, and probably also combines

with the liberated alumina. A good surki ~~composition~~ cement is then a silicate of lime analogous to Portland cement, and like it capable of hydrating and solidifying independently of atmospheric action. If the proportion of surki be sufficient to supply silicic acid to all the lime present, and the mixture well made, the composition is totally different from that of sand mortar; it is a true cement capable of setting of itself even under water instead of a mixture of lime and sand hardening by dessiccation and by the action of atmospheric carbonic acid on the outer surface. When the lime used in a sand mortar is hydraulic, it is true that some silicate is ultimately formed, even under water, but there is considerable inconvenience attending this secondary action as the conditions which enable the great excess of lime to harden are unfavourable to the setting of the silicate and vice versâ. In the very strongly hydraulic limes known as intermediate (between lime and cements) this antagonism becomes dangerous, as the silicates are apt to set before the free lime becomes hydrated and this reversal of the usual sequence of actions causes the disintegration of the set mortar. The use of surki fortunately renders the engineer independent of the quality of the lime

he uses; whether it be fat lime or hydraulic lime the effect is the same; the results may be somewhat superior with the latter, but against this advantage there must be considered the plasticity of the fat lime and the facility and economy of working with it. On the whole, I believe that when good and fine work is required, equal strength can be obtained with fat lime provided that care be taken in the preparation of the cement. This is especially shown when the superior material about to be described is used in the place of common surki.

Experiments with the improved puzzolana or lined Surki.

31. While the addition of surki may be termed the natural surkis (those prepared from bricks or burnt clay) to any ordinary lime affords a cement greatly superior to sand mortar both in strength and in hydraulic energy, yet the setting is slow when compared with that of Roman (natural) or Portland (artificial high burnt) cement. A surki cement takes 72 hours to acquire the same firmness which Portland cement attains in 15 to 24 hours, and it is therefore a desideratum to find if surki could not be improved so as to set more rapidly. The idea which presented itself to me, in order to obtain greater hydraulic

energy, was the preparation of the clay in some manner which would render it still more readily decomposible when mixed with lime. For this preliminary attack, the use of a small quantity of lime suggested itself; the addition of such a quantity as should disaggregate the clay and, by its action both in the wet way and by heat, transform the clay into highly acid silicates, capable of taking up their full quantity of lime when hydrated, then becoming neutral or basic silicates.

32. My experiments on this point are far from complete, as I have yet to ascertain the proper amount of lime to effect this action, the heat which should be used in burning, and the best way of using the surkii. As far as I have proceeded I have obtained results which promise success. The best result have been given by a surkii made of blue pottery clay and ten per cent of lime (by weight, quick). Five per cent gives indifferent results; twenty per cent seems somewhat better than 10 per cent but the experiments are not complete. The results detailed in the Appendix series C, promise I think, ultimate success. It would appear that by the use of surkii made with bricks of common clay mixed with lime, common fat lime can be made into a cement possessing greater cohesive strength than the best bricks and, when made into concrete, equalling concrete of Portland cement in its tensile strength, and in its rapidity of setting under water. The best results for cohesive strength were given by one part of lime paste to one of 10 per cent limed surkii; this does not set very quickly but in 28 days attains a strength of 31·1 lbs. on the sq. in. (1122 lbs on a pair of bricks lengthways). With 3 parts of surkii the setting is much more rapid, the joint attains an cohesive strength of 2·8 lbs per sq. in. after 24 hours under water and 16·5 lbs per sq. in. in 7 days; after this there is little or no increase. With 4 parts of surkii the strength fails. The best Concrete or mortar is made by combining 2 parts of surkii with 1 of lime paste and then adding an equal volume of sand. This mortar containing ⅓ of lime attains in 28 days (the 27 last under water) a tensile strength of 171 lbs per sq. inch and it also answers well for brick work, as it sets nearly as rapidly as the cement without sand and attains in 28 days under water (immersed immediately) an cohesive strength of 16·6 lbs per sq. inch. With 3 parts of surkii to 1 of lime, the concrete made by the addition to the cement of its volume of sand is somewhat superior in tensile strength, attaining 158 lbs per sq. inch

after 28 days (the 27 last under water).

33. Another sample of this kind of Surkie (unfortunately made in small quantity only) gave the best results I have hitherto obtained:— 1 part of shell lime paste with 3 of the Surkie gave an adhesive strength of 37 lbs and 34 lbs per sq. in. and 1 part of fat stone lime with 3 parts, half of ordinary Surkie and half of lime Surkie gave 35 and 36 lbs per sq. inch. In three out of the 4 experiments the joints did not give, the bricks yielded, though they were such hard bricks that a bricklayer had great difficulty in chipping them with the trowel. I would however mention that I cannot as yet definitively claim a superiority for this burnt Surkie over ordinary Surkie as the latter has sometimes given extraordinarily good results, but taking the experiments all round the best results have been obtained by the use of burnt Surkie and it undoubtedly possesses greater hydraulic energy.

Experiments with Country-made cements other than Surkie-cements.

34. Besides the cement made by the combination of puzzolana or Surkie with lime there are others which may be divided into the following types:—

a. Roman or Boulogne cement from naturally argillaceous limestones burnt at a low temperature.

b. American cement, from naturally argillaceous magnesian limestones burnt at a low temperature

c. Portland cement, from artificial argillaceous limestones burnt at the highest temperature

d. Lime and clay cement (twice kilned) burnt at a low temperature

35. The first of these may possibly be made in Bengal or India, as it would seem that in Bengal (Soane district) suitable marly limestones are found; a drawback to their use is the necessity of the composition being ~~kept~~ constant and the structure homogeneous; this would especially be felt in India where skilled superintendence is not always available. Limestones requiring frequent analyses to enable their composition to be rectified are hardly suitable for the Indian manufacture.

36. The second kind does not seem to be common in India; it could be artificially produced by the aid of the deposits of magnesite found both in Southern India and in Bengal; it is possible that an artificial composition of magnesite lime and clay would yield good results when burnt this however comes under the head of the fourth method.

37. The third method is ill adapted to India. The so-called Portland cement is a cement made (with a slight variation from Vicat's original process) from clay and chalk very intimately mixed and burnt at such a high

temperature that the proportion of clay can be reduced to a very low point. The excess of lime is forced into combination with the clay forming very basic silicates. Its production requires clay and chalk at a nominal cost, good coking coal at a low price, skilled labour and facilities for the employment of machinery. The failure of one of these conditions renders the manufacture costly, perhaps a losing speculation. Now in India there is no chalk, coal is either dear or inferior, the use of machinery expensive, skilled labour often precarious. The first of these objections is fatal to any competion with the cement imported from Europe. The hard limestones of India could not possibly be pulverized to the degree of fineness requisite for the perfect combination of the materials without an expenditure which would put all competitors out of the question.

38. The fourth method is the most promising. It is Vicat's first process and is well adapted for countries where the limestone is too hard to be reduced to sufficiently fine powder for the manufacture of cement by his second process. It was recognized by Sir Charles Paisley as good, and Indian experience has confirmed the value of this twice kilned lime cement. From the Roorkee C.E. College because it appears that this cement was used successfully on the Madras Eastern Coast canal and also at Singapore. The increased cost from the use of lime instead of limestone in this process would be compensated by the economy in grinding and the lesser heat required. The chalk and clay (Portland) cement requires a white heat and its clinkers is very hard and expensive to grind; while the lime and clay cement is burnt at a lowred heat and the kilned cement is as readily ground as chalk. The facility of preparation from materials to be obtained nearly every where, the low temperature in burning, the ease with which the burnt cement can be ground are strong recommendations and it only remains to be seen whether this cement could not for most purposes supersede imported cement.

39. The proportions recommended by various experimenters vary considerably and are somewhat confused by the variable specific gravity of lime, quick or slaked, and of clay, wet or dry.

The following are some of the proportions hitherto used:-

	By measure			By weight	
	Lime		Clay	Lime	Clay
	Quick	Slaked	wet	quick	wet
Sir Charles Pasley	1		1	1	2
Roorkee experiment		Same		Same	
E.C. Canal	7		5	1	12
	or 1		·71		
Singapore (Capt. Alan)		5	2		
	or 1		·62	1	1·1
Vicat's	2		1·58	1	1·05
	1				
E.N. Series H	1		·77	1	1·3

One advantage of this cement is that the proportion of lime can be diminished so that any degree of energy can be given to it. In Gillmore's treatise it is stated that 10 per cent of clay (added to 100 parts of lime) will confer moderately hydraulic energy, while it will never be necessary to exceed 54 per cent to produce a very active cement. This last proportion 54 by weight of clay to 1 of lime corresponds with the quantity indicated by Vicat's proportions by measure, and is probably not far from the exact number. Sir Charles Pasley's cement seems to have been over clayed. In the above table I have calculated weight from measure and vice versâ on the assumption that the specific gravity in bulk of quicklime was ·85, of slacked lime ·55, of wet clay 1·45.

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40. In my experiment detailed in the Appendix Series H, I obtained very good results, an adhesive strength of 21 lbs per sq. in. on dry joints (after 28 days) and 25 lbs on joints immersed after 3 days; but only 12·5 lbs when the joints were immersed at once. An experiment at Roorkee with Sir Charles Pasley's proportions gave a cement showing an adhesive strength of 10 lbs per sq. in. after 14 days under water. The cement would appear to be not so suitable for work requiring immediate immersion as the more plastic cements of lime and Surki; but the use of a light clayed composition used with Surki would perhaps answer better. I shall resume experiments on this composition.

41. If to the lime and clay a suitable proportion of magnesia (burnt magnesite) were added, it is probable that the cement would show some of the properties of the American natural cements so well known for their power of resisting the action of sea-water.

Comparative experiments with the above detailed Compositions and with imported Cement.

42. In order to obtain a standard of comparison for the foregoing experiments, I made a series of trials with Portland Cement

When the barrel was opened, the cement came up to the Board of Works standard, and when diluted with sand the results were rather better than those recorded by Mr Grant in his trials with a cement of higher quality; the breaking weights in lbs per sq. in. are given in the following table

	Mr Grant's Cplt.		Series I	
	7 days	1 month	7 days	28 days
Cement neat	202	308	181	220-228
" 1 sand	44	140	—	143
" 1½ "	—	—	—	123
" 2 "	23	56	—	78
" 3 "	12	26	—	62
" 4 "	—	14	—	—
" 5 "	—	10	—	37

The adhesive strength of Portland cement is affected by dilution with sand even more than the tensile strength; the contrary is the case when it is diluted with Surkhi the tensile strength becoming greatly affected while the adhesive strength is comparatively little impaired and the hydraulic energy even increased. There is however no reason for diluting Portland cement where adhesive strength is required, any apparent economy is counterbalanced by the increased thickness of joint required, and the strength descends to the level of that of a common Surkhi and lime cement. As a rule the use of Portland cement in brickwork is a waste of money. The value of Portland cement is in its great hardness and its tensile strength, and to obtain these the cement must be used neat. Where great hydraulic energy and plasticity are required the admixture of an equal proportion of Surkhi will be found useful; it doubles the adhesive strength in the first 24 hours when the cement is used under water for masonry or for stopping springs.

43. In the case of marine works it would appear prudent to use Portland cement whenever the cost is not excessive until Surkhi cements are cleared from the charge (though a desputed one) of being attacked by sea-water But the superiority of the limed Surkhi appears to be so great that there is so strong probability of its being able to resist the action of sea-water like the natural pozzolana of Italy. If such should be the case the use of cement made with it would effect an enormous saving in the construction of Indian harbour works. It will be seen that the strength of this cement increases by the addition of

moderate proportion (1 or even 2 parts) of sand, and by immersion, so that a mortar for concrete (béton) making may be obtained with it equal to that of Portland cement and sand as regards hydraulic energy and strength and at a small fraction of the cost. The following is a rough estimate of the cost of 100 cubic feet of sand mortar and of concrete made with these different materials, the proportions being taken from actual experiments.

Common Surki cement with 1 part of Sand

Tensile strength 127 lbs per sq. in.

	R.	A.	P.
18 c.ft. Quicklime @ 3½ as.	3	15	0
55 c.ft. Common Surki @ 1½ as.	5	2	6
60 c.ft. Sand @ ½ a.		12	0
Cost of 100 c.ft.	9	13	6

Cost of 100 c.ft. of moulded or rammed Concrete

50 c.ft. of the above mortar	R. 4	14	9
100 c.ft. of stone or ballast	3	2	0
	8	0	9

Lined Surki cement with 1 part of Sand

Tensile strength 171 lbs per sq. in.

	R.	A.	P.
25 c.ft. Quicklime @ 3½ as.	5	7	6
50 c.ft. Lined Surki @ 2½ as.	7	0	6
60 c.ft. Sand @ ½ a.		12	0
	13	4	0

Cost of 100 c.ft. of moulded or rammed Concrete

50 c.ft. of the above mortar	R. 6	10	0
100 c.ft. of stone or ballast	3	2	0
	9	12	0

Portland cement with 1 part of Sand

Tensile strength 143 lbs per sq. in.

	R.	A.	P.
66 c.ft. Cement @ Rs. 14 per cask of 5 c.ft.	184	12	0
66 c.ft. of Sand @ ½ a.		13	0
	185	9	0

Cost of 100 c.ft. of moulded or rammed Concrete

50 c.ft. of the above mortar	R. 92	12	6
100 c.ft. of stone or ballast	3	2	0
	95	14	6

The cost of Portland cement I have taken at the Bombay market price of 3 months ago. The above estimate is of course rough but it shows that the cost of the materials of moulded concrete blocks would in the case of Portland cement be about ten times greater than when lime and Artificial puzzolana are employed.

44. I am now having a quantity of lined clay bricks made up and when they are burnt I shall be able to carry out more extended experiments. I would suggest that as my office is close to the Ulsoor tank, experiments might easily be made on the formation of a jetty with blocks of moulded cement made from the ordinary Bungalore lime and surki either common or of the improved kind. Should such experiments seem desirable, a grant of funds would be required; Rs. 500 would be sufficient.

45. A few of the blocks could be sent to Madras for exposure to the action of sea-water. They

might be placed in an iron cage let down
below the surface of the sea at the head
of the pier, and capable of being drawn
up for inspection when necessary.

I have the honour to be
Sir
Your most obed[t] servant
Edward Nicholson
Surgeon R.N. R.V.
on Special Duty A.P.M.

P. W. 1873 Dept.
Rec'd 1st Cert for February

A. 6352 A

From

Surgeon E. Nicholson
B.M.S.

To The Chief Engineer and
Secretary to Govt. P.W.D

Bangalore 20th Nov. 1873
Received 21
No 58

Enc: 1.

P. W. 218/74
2

Report on examination of limestone
with Appendix

No 405
C. 16 Jany 1874

No. 427 - 21 "Feb 1874

No 16

Note by the Chief Engineer for Irrigation.

Surgeon Nicholson's report No. 58 of the 20th November 1873, contains much matter of interest on the subject of cements, and the record of the experiments made will be of considerable use to all those members of the Department who are capable of applying the results obtained from the use of the materials upon which Surgeon Nicholson has experimented, to the probably different materials which may be available for use in the several Districts and Ranges of the Presidency. I think however that a continuation of the experiments with the Bangalore limes and Shirki, which were necessary to obtain data from which

which general conclusions might be deduced, is hardly desirable, seeing that what is chiefly required is definite information as to the best means of employing particular lines on the principal descriptions of constructive work on which the Public Works Department is engaged. For instance the information regarding the use of burnt clay or Surki with shell lime is very valuable, and in Madras and other localities in which this description is alone, or most generally, employed, it is advisable that no time should be lost in introducing a mixture of burnt clay with the lime, which will then be much improved both as regards strength and hardness. Surgeon Nicholson's remarks regarding the non-setting of fat limes and sand, and their want of hardness below the surface are confirmed by daily experience. —

Paras 254 of the repo

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2 Which the Public Works Department requires is,—

1st A cement which will set with reasonable rapidity either under water or in very wet positions, and possess fair adhesive strength.

2ndly A cement which will be strong and hard in superstructures.—

For foundations for hydraulic works generally, bridges across rivers &c, an hydraulic cement is really essential. Where springs are not very trouble-some a very quick setting cement is not generally needed, because the water level can be kept down by bailing for 2 or 3 days without difficulty, but where the work has to be executed under water, or where springs are abundant rapidity of setting is necessary to prevent the cement remaining soft or being washed out. I have myself made cement which set perfectly under water. At the Nellore Anicut work

in—

in 1857-58 concrete foundations were laid in the water, and in that particular instance the cement was made of 1½ parts burnt clay and 1 part slaked lime, reduced to powder, made into balls, and reburnt. After 48 hours immersion the concrete was found to be very hard. The clay used was of a dark blue, very compact, greasy, description. No experiments were made on its tensile and adhesive strength. In Tanjore in 1862-63 similar proportions were found to answer very well with the lime and clay obtainable at the lower Coleroon Anicut. Lately at Dowlaishwaram the same proportions have given excellent results, with, however, air drying for 2 days before immersion of the brickets and concrete blocks. Some brickets of the 2¼ square inch cross section at the neck, which had been thus treated, were taken out of the water and tested, the breaking weight being about

about 375 lbs, and considering that the materials had been very imperfectly ground, the tensile strength exhibited may be considered very good. Here the burnt clay and slaked lime were mixed without subsequent reburning. Further experiments are in progress to ascertain the effect of reburning, as also that of mixing raw clay with slaked lime and burning the mixture. Concrete blocks made with cement of 1 lime, 1½, and 2, clay, respectively, give excellent results as regards strength and hardness, and it was found very difficult to break them up with a heavy hand hammer.-

3 What District and Range Officers now need to be told is the best way to make the most of the several descriptions of lime available with reference to the dry

or

or wet situations in which the cements and mortars are to be employed. It may be found also that some of the limes of which samples have been forwarded are not adapted to any constructive work, and are not capable of being improved sufficiently by any admixture to render them trustworthy; and, if so, it will be well to discontinue their use altogether. In the Coimbatore District on the Ambravatty Anicuts I noticed that fat limes had been used, and that the mortar had never set properly, but had dissolved out from the masonry to a very great extent, and the remedy is undoubtedly to be found in the mixture of proper proportions of burnt clay or Surki with the lime for the future. Again on the Madras Irrigation and Canal Company's Canal much of the leakage through culverts and aqueducts is due to the use of fat limes without the necessary mixture of clay. Another notable

example

example of the advantage of mixtures of Chunam with other materials may be observed in the case of Chunam floors. It is a common practice to alternate black and white squares, and the former generally wear much better than the latter, owing to the fact that the surface in the white squares is pure Chunam, and, in the black, a mixture of Lamp black or burnt Cocoanut shells with Chunam. For plastering near the coast great advantage will be derived from the mixture of clay and lime to form the cement, and as a matter of appearance too the grey resulting from the mixture, which may be varied by the addition of a little red or yellow ochre will be an improvement on

the

the glaring white of new plaster
of the ordinary kind, and on the
dirty look of the surface after
a few months exposure.—

Fort St. George
8th January
1874 —

W. Linklater Lieutt Colo R.E.
Chief Engineer for Irrigation

To,
The Secretary to Government
Public Works Department.—

P. W. 1874 Depart.
Ops: of Govt for Preliminary
Inv.ts
No 218 A.

From
The Chief Engineer &
Inspector.

To
The Secretary to Govern-
ment P.W.D.

Rec.d 8th
Dated 12th January
Received 14th 1874.
Encl. 2 Nos.

Note on Surgeon
Nicholson's report on
the subject of cements.

No 409
dt. 16 Jany 74

No 427 - 21st January 1874

Appendix

No	No of Trials	Composition, lime measured in parts	Brick-joints or brickets	Age: Days in air	Days in water	Days drying	Total Age	Breaking weight, average, lbs.	Adhesive strength lbs per sq. in.	Tensile strength lbs per sq. in.
								3	4	4
		Series A.					Mortars of Shell lime and sand			
48	2	1 lime, 1½ sand	Jt.	28	...	...	28	63	4·6	
	1		Jt.	22/24	21	6 4/24	28	49	2·7	25
	1		Bkt.	28	...	...	28	22		10
49	3	1 lime, 2½ sand	Jt.	28	...	...	28	57	3·1	
	1		Jt.	22/24	21	6 4/24	28	20	1	
	1		Bkt.	28	...	...	28	18		8·2
52	2	1 lime, 3 sand	Jt.	28	...	...	28	42	2·3	
	2		Jt.	28	21	7	56	82	4·1	
	1		Bkt.	28	...	...	28	11		5
53	2	1 lime, 4½ sand	Jt.	28	...	...	28	15	·8	
	1		Jt.	5	...	...	5	7	·4	
	1		Bkt.	28	...	...	28	10		4
115	5	1 lime, 3 sand.	Jt.	28	...	...	28	50	2·8	
	3	(Letters and the following	Jt.	56	...	...	56	47	2·6	
	1	The lime paste was		...	21	7	28	25	1·4	
	1	made from slaked		1	21	6	28	30	1·6	
	1	lime, unsifted.)		2	21	5	28	10	·5	
	1			4	21	3	28	0	0	
	3			7	21	0	28	0	0	
	3			28	28	0	56	9	·5	

N°	N° of trials	Composition (lime measured in parts)	Brick-joints or bricks	Age: Days in air	Age: Days in water	Age: Days drying	Age: Total age	Breaking weight, average lbs.	Adhesive strength lbs per sq. in.	Tensile strength lbs per sq. in
124	6	1 lime, 3 sand N°35	Jt.	28	...	...	28	48	2·6	
	1	(Sand sifted through N°35 sieve)	Jt.	7	14	...	21	13	·7	
	2	" "	Jt.	7	14	7	28	40	2·2	
	3	" "	Bkt.	28	...	...	28	18		8·2
	1	" "	Bkt.	7	14	7	28	23		10
125	3	1 lime, 3 sand N°45.	Jt.	28	...	...	28	37	2	
	1	" "	Jt.	7	14	...	21	8	·4	
	1	" "	Jt.	7	14	7	28	57	3·8	
	2	(kept in a box)	Bkt.	28	...	...	28	14		6·2
	2	" "	Bkt.	28	...	...	28	26		11·4
126	3	1 lime, 3 sand N°60	Jt	28	...	...	28	54	3	
	1	" "	Jt.	7	14	...	21	11	·6	
	1	" "	Jt.	1	20	...	21	8	·4	
	2	" "	Jt.	7	14	7	28	72	·4	
	3	" "	Bkt.	28	...	...	28	25		11
127	3	Jt same, left 24h.	Jt.	28	...	...	28	55	3	
	1	Then beaten up.	Jt.	7	14	...	21	17	·9	
	1	" "	Jt.	1	20	...	21	13	·7	
	2	" "	Jt.	7	14	7	28	49	2·7	
	1	" "	Jt.	1	20	7	28	30	1·7	

N°	N° of trials	Composition (lime measured in parts)	Brick-joints or bricks	Age: Days in air	Age: Days in water	Age: Days drying	Age: Total age	Breaking weight, average lbs	Adhesive strength lbs per sq. in.	Tensile strength lbs per sq. in
128	2	1 lime 2 sand N°60.	Bkts	28	...	...	28	48	2	21
	4	" "	Bkt	28	...	...	28	34		15
	2	" "	Bkt	18	10	...	28	12		5
	2	" "	Bkt	18	10	14	42	37		16

Series B. Mortars of stone lime (Bangalore) and sand.

77	1	lime nett	Jt.	28	...	...	28	119	6·6	
142	3		Jt.	...	28	...	28	27	1·4	
			Jt.	...	...	...	28	109	6	
78	2	1 lime, 1 sand	Jt.	28	...	...	28	125	6·9	
	1	" "	Jt.	...	21	7	28	190	10·5	
	2	" "	Jt.	28	21	7	56			
	2	" "	Bkt.	28	...	...	28	117		5·7
80	2	1 lime, 2 sand	Jt.	28	...	...	28	115	6·4	
	2	" "	Jt.	28	21	7	56	256	14·2	
	1	" "	Bkt.	28	...	...	28	55		2·4
81	4	1 lime, 3 sand	Jt.	28	...	...	28	161	8·9	
	2	(1 fine sand mixed	Bkt.	28	...	...	28	47		2·1
	2	first; then 2 coarse sand)	Bkt.	30	32	9	71	142		6·2
143	3	1 lime, 1 sand N°60	Jt.	28	...	...	28	112	6·1	
	3	" "	Jt.	...	28	...	28	16	·9	
	3	" "	Jt	56	...	...	56	96		
	2	" "	Jt.	28	28	...	56	90		

N°	N° of trials	Composition (lime measured in paste)	Brick-joints or brickets	Age: Days in air	Days in water	Days drying	Total age	Breaking weight, average. lbs.	Adhesive strength lbs per sq. in.	Tensile strength lbs per sq. in
141	3	1 lime, 2 sand N°60	Jt.	28	...	...	28	124	6.9	
	3		Jt.	7	21	...	28	92	5.1	
	1		Bkt.	28	...	...	28	40		17
	3	(in damp box)	Bkt	28	...	...	28	0		0
	1		Bkt	7	21	...	28	25		11

Series C. Mortars of Shell-lime and Sand with the addition of Sugar &c.

58	4	1 lime, 2¼ sand made with water containing 5 per cent of sugar	Jt.	28	...	...	28	102	5.6	
	1		Bkt.	28	...	...	28	25		11
123	3	1 lime, 3 sand	Jt.	28	...	...	28	53	3	
	3	5 p% jaggery in water	Bkt.	28	...	...	28	37		16
	3			56	...	...	56	38		17
129	3	1 lime, 2 sand N°60	Jt.	42	...	...	42	67	3.7	
	3	5 p% jaggery in water	Jt.	18	24	...	42	12	.6	
57	3	1 lime, 2¼ sand	Jt.	28	...	...	28	52	3	
	1	5 p% silicate of soda in water	Jt.	...	21	7	28	25	1.4	
	1		Bkt.	28	...	...	28	16		7

N°	N° of trials	Composition (lime measured in paste)	Brick-joints or brickets	Age: Days in air	Days in water	Days drying	Total Age	Breaking weight, average. lbs.	Adhesive strength lbs per sq. in.	Tensile strength lbs per sq. in
54	3	1 lime, 2½ sand	Jt.	28	...	...	28	32	1.8	
	1	5 p% alum cake in water	Jt.	...	21	7	28	0	0	
	3		Bkt.	28	...	...	28	30		13

Series D. Mortars of Shell-lime and Surkī

94	3	1 lime, 1½ SM surkī	Jt.	28	...	...	28	181	10	
	2		Jt.	...	21	7	28	370	20.5	
	3		Bkt.	1	21	6	28	136		62
95	1	1 lime, 2 SM surkī	Jt.	28	...	...	28	156	8.6	
	3		Jt.	...	21	7	28	200	11.1	
	1		Bkt.	28	...	...	28	217		99
	3			1	21	6	28	200		91
96	3	1 lime, 3 SM surkī	Jt.	28	...	...	28	139	7.7	
	3		Jt.	...	21	7	28	306	17	
	1		Bkt.	28	...	...	28	150		66
	3		Bkt	1	21	6	28	172		77
	1		Bkt	1	21	44	66	417		185
58	1	ditto.	Jt	28	...	...	28	125	7	
	2		Jt	1	21	6	28	485	27	
	1		Bkt.	1	21	6	28	210		95
97	3	1 lime, 4 SM surkī	Jt.	28	...	...	28	102	5.6	
	3		Jt	....	21	7	28	181	10	
	3		Bkt.	1	21	6	28	256	14.2	

No.	No. of trials	Composition (lime measured in paste)	Brick-joints or brickets	Age: Days in air	Days in water	Days drying	Total age	Breaking weight, average lbs	adhesive strength lbs per sq. in	Tensile Strength lbs per sq. in
102	3	1 lime, 5 SM surki	Jt.	28	...	...	28	116	6.4	
	3		Jt	...	21	7	28	161	9	
	1		Bkt.	28	...	...	28	243		110
	3			1	21	6	28	212		90
104	3	1 lime, 7 SM surki	Jt.	28	...	...	28	80	4.4	
	3		Jt.	...	21	7	28	89	5	
	2		Bkt.	28	...	...	28	136		62
	3		Bkt.	1	21	6	28	126		57
110	3	1 lime, 10 SM surki	Jt.	28	...	...	28	63	3.5	
	3		Jt.	...	21	7	28	79	4.4	
	1		Bkt.	28	...	...	28	115		52
	3		Bkt.	1	21	6	28	110		50
98	1	1 lime 2 CB surki	Jt.	28	...	...	28	193	10.7	
	3		Jt.	...	21	7	28	324	18	
	1		Bkt.	28	...	...	28	312		142
	3		Bkt	1	21	6	28	219		100
132	4	1 lime 3 CB surki	Jt.	28	...	...	28	312	17.3	
	4		Jt.	...	21	7	28	290	16.1	
	3		Bkt.	1	24	3	28	172		78
	3		Bkt.	1	27	...	28	347		158

No.	No. of trials	Composition (lime measured in paste)	Brick-joints or brickets	Age: Days in air	Days in water	Days drying	Total age	Breaking weight, average lbs	adhesive strength lbs per sq. in	Tensile Strength lbs per sq. in
103	2	1 lime, 4 CB surki	Jt.	28	...	...	28	117	6.4	
	3		Jt.	...	21	7	28	89	5	
	3		Bkt.	1	21	6	28	173		79
106	3	1 lime, 6 CB surki	Jt	28	...	...	28	60	3.3	
	2		Jt.	...	21	7	28	58	3.2	
	3		Bkt.	28	...	...	28	163		74
	3		Bkt.	1	21	6	28	120		54
107	3	1 lime, 9 CB surki	Jt.	28	...	...	28	40	2.4	
	2		Jt.	...	21	7	28	55	3	
	3		Bkt.	28	...	...	28	90		41
	3		Bkt.	1	21	6	28	73		33
99	1	1 lime, 2 chatty surki	Jt.	28	...	...	28	158	8.8	
	3		Jt.	...	21	7	28	294	16.6	
	2		Bkt.	1	21	6	28	288		131

Series E. Mortars of Stone-lime (Bangalore) and Surki

134	3	1 lime, 1 SM surki	Jt.	28	...	...	28	314	17.4	
	3		Jt.	...	21	7	28	293	16.2	
	1		Jt.	...	28	...	28	303	16.8	
	3		Bkt.	28	...	...	28	275		125
	3		Bkt.	1	21	6	28	219		99
	1		Bkt.	1	27	...	28	252		114

No.	No. of trials	Composition (lime measured in paste)	Brick joints or bricklets	Age: Days in air	Days in water	Days drying	Total age	Breaking weight, average lbs	adhesive strength lbs per sq. in	Tensile Strength lbs per sq. in
135	3	1 lime, 1½ SM surki	Jt.	28	...	...	28	287	16	
	3		Jt.	...	21	7	28	336	18·6	
	1		Jt.	...	28	...	28	282	15·6	
	2		Bkt.	28	...	...	28	275		125
	3		Bkt.	1	21	6	28	195		88
136	3	1 lime, 2 SM surki	Jt.	28	...	...	28	351	19·5	
	3		Jt.	...	21	7	28	303	16·8	
	1		Jt.	...	28	...	28	186	10·3	
	2		Bkt.	28	...	...	28	289		131
	3		Bkt	1	21	6	28	216		98
	1		Bkt.	1	27	...	28	240		109
137	3	1 lime, 3 SM surki	Jt.	28	...	...	28	351	19·5	
	3		Jt.	...	21	7	28	264	14·6	
	1		Jt.	...	28	...	28	214	11·9	
	2		Bkt.	28	...	...	28	333		151
	3		Bkt.	1	21	6	28	175		75
	1		Bkt.	1	27	...	28	327		148
138	3	1 lime, 4 SM surki	Jt.	28	...	...	28	213	11·8	
	3		Jt.	...	21	7	28	180	10	
	2		Bkt.	28	...	...	28	309		140
	3		Bkt.	1	27	...	28	222		101

No.	No. of trials	Composition (lime measured in paste)	Brick joints or bricklets	Age: Days in air	Days in water	Days drying	Total age	Breaking weight, average lbs.	adhesive strength lbs per sq. in	Tensile strength lbs per sq. in
139	2	1 lime, 5 SM surki	Jt.	28	...	...	28	276	15·4	
	3		Jt.	...	21	7	28	133	7·4	
	3		Bkt.	28	...	...	28	265		120
	2		Bkt.	...	...	...	28	203		92
	3		Bkt.	1	27	...	28			
140	3	1 lime, 7 SM surki	Jt.	28	...	...	28	90	5	
	3		Jt.	...	28	...	28	60	3·3	
	2		Bkt.	28	...	...	28	188		85
	3		Bkt.	1	27	...	28	150		68

Series F. Concretes of Surki mortar and sand

No.	No. of trials	Composition (lime measured in paste)	Brick joints or bricklets	Age: Days in air	Days in water	Days drying	Total age	Breaking weight, average lbs.	adhesive strength lbs per sq. in	Tensile strength lbs per sq. in
112	2	1 shell lime { 3 SM surki, 3 sand	Bkt.	28	...	...	28	240		109
	3		Bkt.	1	21	6	28	281		127
113	2	1 shell lime { 3 SM surki, 6 sand	Jt.	28	...	...	28	35	2	
	3		Bkt.	28	...	...	28	158		72
	2		Bkt.	2	21	5	28	274		124
114	4	1 shell lime { 5 SM surki, 5 sand	Bkt.	28	...	...	28	96		43
	3		Bkt.	6	19	5	28	202		91
69	1	1 kolar lime { 2 SM surki, 7 sand	Jt.	28	...	...	28	190	10·5	
	2		Jt.	...	21	7	28	347	19·2	
157	3	1 Bangalore lime { 2 cement, 7 sand, 1 sand (as used in building for concrete mortar)	Bkt.	1	27	...	28	243		111

No.	No. of trials	Composition (lime measured in paste)	Brick-joints or tickets	Age: Days in air	Age: Days in water	Age: Days drying	Age: Total Age	Breaking weight average lbs.	Adhesive strength lbs per sq. in.	Tensile Strength lbs per sq. in.
		Series G. Mortars of Shell-lime and limed Surki.								
144	3	1 lime, 1 surki	Jt.	28	...	...	28	262	14.5	
	1	(Surki made with blue clay and 10 per cent of shell lime)	Jt.	...	1	...	1	33	1.8	
	1		Jt.	...	3	...	3	144	8	
	1		Jt.	...	7	...	7	282	15.6	
	3		Jt.	...	28	...	28	561	31.1	
	3		Jt.	1	21	...	28	373	20.7	
	3		Blt.	1	27	...	28	229		104
	3	Concrete made with 1 of the mortar, 1 of sand	Jt.	28	...	...	28	262	14.5	
	1		Jt.	1	27	...	28	240	13.3	
	3		Blt.	28	...	...	28	264		120
	3		Blt.	1	27	...	28	285		130
145	3	1 lime 2 surki	Jt.	28	...	...	28	250	13.9	
	1	(Same as the preceding)	Jt.	...	1	...	1	64	3.5	
	1		Jt.	...	3	...	3	142	7.9	
	1		Jt.	...	7	...	7	291	16.2	
	3		Jt.	...	28	...	28	301	16.7	
	5		Jt.	1	27	...	28	368	20.4	
	3		Blt.	1	27	...	28	262		119
	3	Concrete made with 1 of the mortar, 1 of sand	Jt.	28	...	...	28	300	16.6	
	2		Blt.	28	...	...	28	346		157
	3		Blt.	1	27	...	28	377		171

No.	No. of trials	Composition (lime measured in paste)	Brick-joints or tickets	Age: Days in air	Age: Days in water	Age: Days drying	Age: Total Age	Breaking weight average lbs.	Adhesive strength lbs per sq. in.	Tensile Strength lbs per sq. in.
146	3	1 lime, 3 surki	Jt.	28	...	...	28	326	18.1	
	1	(Same as the 2 preceding)	Jt.	...	1	...	1	50	2.8	
	1		Jt.	...	3	...	3	210	11.6	
	1		Jt.	...	7	...	7	297	16.5	
	3		Jt.	...	28	...	28	296	16.4	
	3		Jt.	1	27	...	28	297	16.5	
	3		Blt.	1	27	...	28	268		121
	3	Concrete made with 1 of mortar, 1 of sand	Blt.	28	...	...	28	269		122
	3		Blt.	1	27	...	28	348		158
147	1	1 lime, 4 surki	Jt.	...	1	...	1	50	2.8	
	1	(same as the 3 preceding)	Jt.	...	3	...	3	138	7.6	
	1		Jt	...	7	...	7	190	10.5	
	1		Jt	...	9	...	9	210	11.6	
	2		Jt	...	28	...	28	210	11.6	
150	1	1 lime, 3 surki	Jt.	...	1	...	1	34	1.9	
	3	(Surki made with blue clay and 5 per cent of shell lime)	Jt.	...	28	...	28	211	11.7	
	3		Jt.	...	27	...	28	247	13.7	
	3		Blt.	1	27	...	28	173		78
	3	Concrete made with 1 of mortar, 2 of sand	Blt.	28	...	...	28	244		119
	3		Blt.	1	27	...	28	255		116

No.	No. of trials	Composition (lime measured in paste)	Brick joints or briquets	Age: Days in air	Age: Days in water	Age: Days drying	Age: Total age	Breaking weight, average lbs.	adhesive strength lbs per sq. in.	Tensile strength lbs per sq. in.
		Series H. Lime and clay cement (twice-kilned)								
43	2	Slaked shell lime and fine clay (dry) equal parts by weight	Jt.	28	...	...	28	422	23.4	
	2		Jt.	...	22	6	28	250	13.9	
	½		Jt.	3	19	6	28	500	27.5	
74	1	Ditto, 1 slaked lime, 2 clay	Jt.	28	...	...	28	84		
	1		Jt.	...	21	7	28	188		
	2		Jt.	1	21	6	28	105		
		Series I. Portland cement.								
156	3	Cement neat	Jt.	...	1	...	1	59	3.2	
26	1		Jt.	...	6	1	7	501	28	
26	2		Jt.	...	22	6	28	505	brick broke outside the joint	
148	7		Blt.	1	6	...	7	394		181
"	3		Blt.	1	27	...	28	483		219
47	6		Blt.	1	21	6	28	502		228
116	3		Blt.	1	21	6	28	471		214
"	3		Blt.	1	79	...	80	666		302
149	2	1 Cement, 1 sand	Jt.	8	...	8	8	278	15.4	
157	2		Jt.	28	1	...	1	51	2.8	
	2		Jt.	...	3	...	3	198	11	
	2		Jt.	...	7	...	7	306	17	
	6		Blt.	1	7	...	8	334		152
	3		Blt.	1	21	6	28	315		143
	3		Blt.	1	79	...	80	583		265

No.	No. of trials	Composition (lime measured in paste)	Brick joints or briquets	Age: Days in air	Age: Days in water	Age: Days drying	Age: Total age	Breaking weight, average lbs	adhesive strength lbs per sq. in	Tensile strength lbs per sq. in
	1	1 Cement, 1½ sand	Jt.	28	...	...	28	265	14.7	34
	½		Jt.	½	6	½	7	154	8.5	
	1		Jt.	½	21	6½	28	385	21.4	
	2		Blt.	1	21	6	28	272		123
	1	1 Cement, 2 sand	Jt.	28	...	...	28	150	8.3	
	2		Jt.	...	21	7	28	180	10	
	1		Jt.	...	28	...	28	147	8.1	
	1		Blt.	28	...	...	28	243		110
	3		Blt.	1	21	6	28	173		78
	1		Blt.	1	27	...	28	157		71
46	2	1 Cement, 3 sand	Jt.	1	21	6	28	290	16.1	
	2		Blt.	1	21	6	28	136		61
46	1	1 Cement, 5 sand	Jt.	28	...	...	28	148	8.2	
	1		Jt.	1	21	6	28	214	11.9	
	2		Blt.	1	21	6	28	81		37
158	1	1 Cement, 1 SM sand	Jt.	...	1	...	1	100	5.5	
	3		Jt.	...	3	...	3	264	14.6	
			Jt.	...	7	...	7	372	20.6	
			Blt.	1	21	6	28	246		112
			Blt.	1	79	...	80	426		193

No.	No. of trials	Composition (lime measured in paste)	Brick joints	Age: Days in air	Days in water	Days drying	Total age	Breaking weight, average lbs	adhesive strength lbs per sq. in.	Tensile strength lbs per sq. in.
44	1	1 cement, 5½ M sand	Jt.	1	21	6	28	611.	33.9	
	1	1 cement 2 SM sand	Jt.	28	...	...	28	255	14.1	
	2		Jt.	...	21	7	28	403	22.4	
	1		Jt.	...	28	...	28	276	13.3	
			Blt.	1	21	6	28	245		111
			Blt.	1	27	...	28	194		88

Series E (continued)

Mortars of Bangalore stone lime and country brick surki

Ingredients mixed, water from the trough in which they were being mixed, by hand, for brickwork and concrete.

152	3	1 lime, quick, entire 3 surki	Jt.	28	...	...	28	52	2.9	
	3		Jt.	1	27	...	28	113	6.2	
	3		Blt.	1	27	...	28	274		124
153	3	1 lime, slaked and beaten free of lumps 2 months before 3 surki	Blt.	1	27	...	28	269		122
154	3	Bitts of 152 kept 16 hours then beaten up again	Blt.	1	27	...	28	231		105

Note. From these last three experiments it is seen that roughness of material does not injure the quality of concrete as it does that of a mortar for brickwork. The tensile strength is nearly as good as that obtained with carefully prepared lime and surki.

Approximate standards of quality for mortars

	For masonry: Adhesive strength after 28 days (made with water if for hydraulic work) — lbs. per sq. in.	For concrete: Tensile strength after 28 days (at least 21 made with water, if for hydraulic work) lbs. per sq. in.
Indifferent	5	50
Good	10	100
Very good	15	150
Excellent	25	200

Edward Nicholson
Surgeon R.N.S.

Tensile Strength lbs per sq. in.

P.W. 21st Feby /74.
In N°408.

218A
P.W. 552 /73
1

P.W. 429 /73.

Irrig.
34X

Rec'd 20th Nov. /73

Rec'd the following:-

From Surgeon E. Nicholson (P.W. 429 20 Nov. /73)
"Chief Engr for Irrign - (" No. 16 of 8 Jan/74)

Ordered that these papers be communicated to all District Engineers for information.

2 The Government agree with the Chief Engineer for Irrigation in considering that the experiments already made by Dr Nicholson indicate sufficiently clearly the general direction in

in which an improvement
in the quality of cements
used on hydraulic and
other works should be
sought for, and the
latter Officer will now
be requested to report
what length of time
will be required for such
experiments upon the
different samples of lime
forwarded to him from
the several Districts as
will enable him to in-
dicate clearly, for the
information of Range
Officers, what admixtures
of lime and burnt clay
or surkie are for the
particular

particular lines likely
to be found most ad-
vantageous for wet
and dry work respectively,
and in the meantime
he will be desired to
turn his attention in
this direction.

3 His Excellency
the Governor in Council
does not consider it
advisable that concrete
blocks made at Bangalore
should be sent to Madras
for trial in sea water,
but in view of the
proposed harbour works
here it will be advisable
to try with the materials
which are likely to be
employed

employed what proportions
of laterite gravel, sand,
and Cement composed
of clay and shell lime,
will be most suitable,
and the Fort ditch will
probably be a good place
in which to place the
experimental blocks.
The Inspecting Engineer
for Ports and Commu-
-nications will be asked
to give his attention to
the subject, and to make
such proposals as may
seem to be needful for
obtaining the information
required. There seems
to be much reason to
conclude that a Cement

possessing

possessing to a sufficient
extent the more valua
properties of Dort land
Cement, can be prepared
at Madras, and also
in very many parts
of the Presidency, at
a cost so very much
below that of imported
Cement as to render it
most desirable that
the attention of all
Officers employed on
Hydraulic works
should be specially
called to the subject,
which had an im-
-portant bearing upon
the efficient maintenance
and economical up
keep

Keep of Works such as
Anicuts, waste weirs,
bridge floorings &c.

Mem. 10/1/74

GJO 427
1874

To
All Distt Engineers
" Irrig Engr for Bridges
" —— Do —— " Forest
Conservr
" Chief Engr for Irrig & C
" Chief Engr & manager
" C Engr for Rys
" Dr Nicholson
" Superintendg
" Dept

Dn. S & C Co.

Despatched 25/1/74