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MADRAS RECORD OFFICE

Government of Madras

Public Works' DEPARTMENT

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Not to be folded or roughly handled

No. 424. Read the following Circular letter from Captain G. T. SKIPWITH, R.E., Assistant Secretary to the Government of India, Public Works Department, (Civil Works—Miscellaneous,) to the Governments of Madras and Bombay, in the Public Works Department, General, Irrigation, and Railway Branches; the Governments of Bengal, North-Western Provinces and Punjab, in the Public Works Department, General and Irrigation Branches; the Chief Commissioners of Oudh, Central Provinces, British Burmah, Mysore and Coorg, and Assam; the Resident at Hyderabad; the Agents of the Governor-General for Central India and Rajpootana; the Superintendent of Port Blair, and Chief Commissioner, Andaman and Nicobar Islands; the Inspector-General of Military Works; the Director of State Railways; the Consulting Engineers to the Government of India for Guaranteed Railways, Calcutta, Lahore and Lucknow, dated Fort William, 23rd April 1875, No. 31 P. W:—

I AM directed to forward, for general information, the accompanying copy of a printed memorandum, dated the 17th May 1873, by Mr. H. Leonard, M.I.,C.E., late Officiating Chief Engineer, Bengal, containing an account of the results of certain experiments undertaken for ascertaining the strength of ordinary brick-work, and of the weights which may safely be placed upon foundations on the ordinary alluvial soil of Bengal.

APPENDIX A.

WEIGHT ON FOUNDATIONS OF BUILDINGS.

THOUGH few, if any, of our buildings in Bengal have fallen, many of them cracked, some of them badly. On commencing several new buildings in Calcutta last year we naturally considered the question, whether we could do any thing to prevent bad cracks and settlements. The cause of both settlements and cracking seemed to be the compression of the soil under the buildings, and taking this view of it, the question arose, what is a safe weight to put on this Bengal alluvial soil without causing serious disturbance of it? Finding nothing at all reliable on the subject, we decided on making a small series of experiments at Akra, where facilities were available or near at hand.

2. *Series No.* 1 gives the result of the trials made. The scale on which they were made was not a mere toy scale, the piers of masonry dealt with were such as might be used on real work, and though the results may not be an infallible guide, they certainly do give definite information; they show, beyond doubt, that, with a weight of one ton to the square foot, the compression of the earth is very small, in fact what might be due to disturbance of the surface in opening the foundations; while with two tons to the foot, sinking is decided, quite enough to cause bad cracks. If one part of a building were built with a load of one ton to the foot, and other parts with a load of two tons to the foot, the building would certainly crack, and if other parts were built with a weight of three tons to the foot, there would be very bad cracks.

3. I consider that safe conclusions to draw from the results of the experiments are these. If it be desired to provide against sinking of *the whole structure*, the weight per foot on the earth, whatever may be the *depth* at which the foundation is laid, should not be more than one ton per square foot; and that, if *unequal sinking cracks* are to be provided against, the weight on all parts of the foundations should be equal per square foot; unless that the most heavily loaded portion carries less than one ton per square foot; with this weight, and, of course, with lighter weights, no perceptible compression takes place, and hence no unequal settlement would occur from unequal loading.

Depth at which Foundations may be laid.

4. The next point for experiment was, at what depth is the soil best fit for building on? We had trials made at depths of 2 *feet* 6 *inches*, that is, just below the usually disturbed soil; at 4 *feet*, where the true alluvial deposit was undisturbed; at 8 *feet*, where a different, though not better, soil was touched, and at 11 *feet*, where the soil was wet and soft. All through this series the effects of weight per foot considered in the three paragraphs above were kept in view. *Series No.* 1 gives also the results of the experiments.

5. The conclusions which may be drawn from the results of these trials are not so clear as they are in the case of the weight on foundation; but it is evident that shallow foundations have the disadvantage of being affected by climatic influence, as heavy rain caused the masonry laid at a depth of 2 feet 6 inches below the surface to sink considerably. Again, it appears that foundations laid at a depth of 11 feet below the surface sink more than those laid at depths of 4 feet and 8 feet. This is difficult to explain. It may be that when the foundations are opened to a depth of 11 feet, the bottom, relieved of such a weight of earth, "blows up" a little, though hardly perceptibly, and the first effect of weighting it is to force this blown-up surface down to its original state, and that, when thus pressed down to what it was before the earth was removed from it, it may bear pressure as well as the earth at smaller depths. The conclusions which I am inclined to draw from the experiments are these:—The foundations of important buildings should be laid so deep that they cannot be affected by climate. The ground, if undisturbed, is as good at a depth 4 feet below the surface as it is at greater depths, and it is about the same up to 8 feet deep. I would lay it down as a rule that in undisturbed alluvial soil, foundations of *important buildings* should not be laid at a less depth than 4 feet, nor at a greater depth than 6 feet.

Strength of Spread Foundations.

6. Having settled on one ton to the square foot as the weight to be carried on the soil, it became necessary to spread out the foundations a good deal to get the area required, and then the question arose at what angle should they spread, or what depth of masonry should there be at the weakest point? Some sections of foundations which I saw seemed to me to be too weak. In order to help to settle the question I had the experiments *No.* 2 *series* made; the result may be practically stated thus: for a pressure of one ton to the foot, on Bengal soil, the thickness at the toe of the slope should not be less than 1 foot 6 inches (see record of experiments), and the stepping at an angle of not more than 45°. I take 1 foot 6 inches because with a thickness of 9 inches the projections broke off, as shown in the sketch in the record of experiments; while with a thickness of 1 foot 9 inches, no symptoms of weakness showed even when the work was fresh. With good masonry of mortar, which will set in damp or wet, I feel certain that the dimensions given above are enough, but with bad masonry—bad from whatever cause—considerably more strength should be given.

7. I think it likely that this question of footings *breaking off* has not been sufficiently attended to; the result of such an occurrence can be seen by looking at the sketch in experiment *No.* 1 of this series, where, instead of an area of 12 feet, that is, the width of the footing, by 2 feet long, to rest on, the area is reduced by the outer sides breaking off to less than half, that is, to the width between the cracks, by 2 feet; and instead of a weight of one ton per foot on the foundation soil, we should have a weight of over two tons, which means a subsidence of 2 or 3 inches, and cracks of probably the same width.

17th May 1873.

H. LEONARD, M.I.C.E.,
Offg. Chief Engineer, Bengal.

Proceedings of the Madras Government, Public Works Department,
18th June 1875.

FIRST SERIES.

Experiments made at Akra for the purpose of testing what weight the ordinary undisturbed alluvial soil of Calcutta, which fairly represents Lower Bengal soil, can bear.

Number of experiments.	Depth below surface of ground.	Size of Pier constructed.	Total height of Pier.	Materials.	Total contents of Pier.	Weight of Pier at 100 lbs. per cubic foot.	Superficial area of Pier.	Age of Pier.	Load, excluding weight of Pier.	Weight per square foot, *including weight of Pier.*	Result of Loading.		Remarks.
											Days.	Sinking.	
	FT. IN.	FT. IN.	FT. IN.		C. FT.	TONS CWT. QR. LBS.	S. FT.		TONS CWT. QR. LBS.	TONS CWT. QR. LBS.			
1*	1 4	3 2½ square.	2 11¼	Bricks with mortar, two of soorkee to one of lime.	30·88	2 3 0 8	10·29	6 days.	41 0 0 0	4 3 3 13·8	1st 2nd 3rd	 3⅜	The pier sank 3⅜ inches with this load by compressing the ground on which it stood; the surrounding ground was not visibly disturbed, except for a distance of about 2 or 3 inches immediately in contact with the pier, which seemed to be caused by friction on two sides, the load being slightly in excess on those sides.
2†	2 6	3 2½	5 0½	Do. do....	51·89	2 6 1 9·4	10·29	...	10 7 3 8	1 4 2 20·3	1st 2nd 3rd	1/16 1/4 5/16	From this experiment it would appear that only the ground under the masonry sinks, the surrounding ground not being disturbed to any appreciable extent. Immediately on lowering screw jacks.‡

* The object of this experiment was to ascertain whether the ground under the masonry alone is compressed, or whether the compression extends for some distance round the foundation.

† The object of this and the eleven following experiments is to show the compression of the soil at different depths, and under different weights.

‡ The frame carrying the load was supported by screw jacks at each corner during the work of loading, when the desired load was on, the screw jacks were lowered, and the load was brought to bear on the masonry.

Experiments made at Akra for the purpose of testing the ordinary undisturbed alluvial soil of Calcutta, &c.—(Continued.)

Number of Experiments.	Depth below surface of ground.	Size of Pier constructed.	Total height of Pier.	Materials.	Total contents of Pier.	Weight of Pier at 100 lbs. per cubic foot.	Superficial area of Pier.	Age of Pier.	Load, excluding weight of Pier.	Weight per square foot, including weight of Pier.	Result of Loading. Days.	Result of Loading. Sinking.	Remarks.
	FT. IN.	FT. IN.	FT. IN.		C. FT.	TONS CWT. QR. LBS.	S. FT.		TONS CWT. QR. LBS.	TONS CWT. QR. LBS.			
3	2 6	3 2½	5 0½	Bricks with mortar, two of Soorkee to one of lime.	51·89	2 6 1 9	10·29	...	20 14 2 19	2 4 3 5·6	1st	1	On lowering screw jacks.
											2nd	1¾	
											3rd	1 11/16	
											4th	1⅞	
											5th	2	
											6th	2⅛	
											7th	2⅛	
4	2 6	3 2½	5 0½	Do. do....	51·89	2 6 1 9	10·29	...	31 1 2 3	3 4 3 17·2	1st	5⅛	Do. do.
											2nd	5⅛	
											3rd	5⅛	
											4th	5⅛	Very heavy rain fell on the night of the 4th.
											5th	6 5/16	The sinking of this block is considerably more than in experiments which were 4 feet and 8, respectively, below the ground level; a good deal of rain fell during the time this experiment was in progress, and the soil to the depth of foundation was, no doubt, saturated.
											6th	7 5/16	
											7th	7 7/16	
											8th	Not measured	
											9th	7 7/16	It shows fairly the danger of shallow foundations.
											10th	7 11/16	
5	4 0	2 9½	5 9	Do. do..	42·12	1 17 2 12	7·76	..	7 16 2 21	1 5 0 4·3	1st	3/16	Immediately on lowering the screw jacks. No further sinking took place with this weight for a space of seven days.
6	4 0	2 9½	5 9	Do. do..	42·12	1 17 2 12	7·76	..	15 10 3 22	2 4 3 17·4	1st	9/16	
											2nd	15/16	
											3rd	15/16	
											4th	15/16	No further sinking took place.
7	4 0	2 9½	5 9	Do. do..	42·12	1 17 2 12	7·76	..	23 5 0 24	3 4 3 5·2	1st	1¼	On lowering screw jacks.
											End of 1st	2⅝	
											3rd	3	
											5th	3¼	No further sinking. The Executive Engineer states "heavy rain fell during part of the time of the last loading, by which the ground was flooded, and most probably water percolated to the foundation. This, combined with very strong wind blowing from the south and east, caused the unequal settlement of the block."
8	8 0	3 2½	10 6½	Do. do..	108·50	4 16 3 14	10·29	..	10 6 0 20	1 9 1 22·5	1st	3/16	No sinking was observed from the 2nd to the 7th day.
9	..	3 2½	10 6½	Do. do..	108·50	4 16 3 14	10·29	..	20 13 0 3	2 9 2 5·9	1st	0/16	
											2nd	1/16	
											3rd	5/8	
											4th	11/16	
											5th	11/16	
											6th	11/16	
											7th	11/16	

Experiments made at Akra for the purpose of testing the ordinary undisturbed alluvial soil of Calcutta, &c.—(Continued.)

Number of Experiments.	Depth below surface of ground.	Size of Pier constructed.	Total height of Pier.	Materials.	Total contents of Pier.	Weight of Pier at 100 lbs. per cubic foot.	Superficial area of Pier.	Age of Pier.	Load, excluding weight of Pier.	Weight per square foot including weight of Pier.	Result of Loading. Days.	Result of Loading. Sinking.	Remarks.
	FT. IN.	FT. IN.	FT. IN.		C. FT.	TONS CWT. QR. LBS.	S. FT.		TONS CWT. QR. LBS.	TONS CWT. QRL. BS.			
10	...	3 2½	10 6½	Bricks with mortar, two of Soorkee to one of lime.	108·50	4 16 3 14	10·29	...	30 19 3 14	3 9 2 17·4	1st	1⅛	The result of this experiment tends to show that the bearing power of soil at 8 feet depth is no better for light weight than at 4 feet, but for heavy weight it seems to bear more.
												1⅝	
											3rd	1 11/16	
											4th	1 11/16	
											5th	1¾	
											6th	1¾	
											7th	1¾	
											11th	1 11/16	
11	11 0	3 2½	14 0½	Do. do. ..	144·53	6 9 0 5	10·29	...	10 7 3 27	1 12 3 0·8	1st	Nil	On lowering screw jacks.
											End of		
											2nd	3/16	Extra load put on to make the weight equal to a ton to the foot, exclusive of brickwork.
											3rd	7/16	
											4th	Sunday	
											5th	13/16	
											8th	⅞	
											9th	15/16	In this and the two following experiments the foundation carried more than in the preceding experiments. But even allowing for this, the ground seemed to be capable of bearing less at 11 feet than at 4 or 8 feet.
											10th	1″	
											12th	1″	
											13th	1 1/16	
12	11 0	3 2½	14 0½	Ama bricks with mortar, two of Soorkee to one of lime.	144·63	6 9 0 5	10·29	...	20 17 0 23	2 13 0 9·5	1st	1½″	On lowering screw jacks.
											2nd	3″	
											3rd	3″	
											4th	3″	
											5th	Sunday	
											6th	3⅛	
											7th	3 3/16	
											8th	3 3/16	
											9th	3 7/16	
13	11 0	3 2½	14 0½	Do. do.	144·63	6 9 0 5	10·29	...	31 4 0 6	3 13 0 20·5	1st	3¾″	Do. do.
											2nd	6 11/16	
											3rd	Sunday	I think the greater sinking in the case of this pier may be explained in this way. At a depth of 11 feet the ground, which gets soft, *rose* before the load was put on, and hence sunk more when again under heavy pressure.
											4th	6⅞	
											5th	6 15/16	
											6th	6 15/16	
											7th	7	
											8th	7	
											9th	7 1/16	
											10th	Sunday	
											11th	7⅛	
											12th	Not measd.	
											13th	7⅛	
											14th	7 3/16	
											15th	7 13/16	
											16th	7¼	
											17th	Sunday	
											18th	7 5/16	

Proceedings of the Madras Government, Public Works Department, 18th June 1875.

Experiments made at Akra for the purpose of testing the ordinary undisturbed alluvial soil of Calcutta, &c.—(Continued.)

Number of experiments.	Depth below surface of ground.	Size of Pier constructed.	Total height of Pier.	Materials.	Total contents of Pier.	Weight of Pier at 100 lbs. per cubic foot.	Superficial area of Pier.	Age of Pier.	Load excluding weight of Pier.	Weight per sq. foot, *including weight of Pier.*	Result of Loading. Days.	Result of Loading. Sinking.	Remarks.
	FT. IN.	FT. IN	FT. IN.		C. FT.	TONS CWT. QR. LBS.	S. FT.		TONS CWT. QR. LBS.	TONS CWT. QR. LBS.			
14*	4 0	2 10 square	7 4½	Third class Akra bricks with mortar composed of two of Soorkee to one of lime.	59·20	2 12 3 12	8·03	15 days	8 0 0 0	1 6 2 0·7	1st 7th 14th	1 1 4 16	The pier loaded with one ton per foot was left standing for three months, but no further sinkage than what was recorded on the 14th day was discovered during the remainder of the time.

* The object of this experiment was to ascertain if, without adding weight, sinking occurred from long standing

SUMMARY.

No.	Depth of Foundation below surface of the ground.	Maximum sinking with weight per square foot of 1 ton.	2 tons.	3 tons.	Rmarks.
		Sinking.			
		Inch.	Inch.	Inch.	
1	2 feet 6 inches	$\frac{5}{16}$	$2\frac{1}{8}$	$7\frac{7}{8}$	Including the weight of brickwork.
2	4 feet	$\frac{8}{16}$	1	$3\frac{1}{16}$	
3	8 „	$\frac{5}{16}$	$\frac{11}{16}$	$1\frac{31}{16}$	
4	11 „	$1\frac{1}{16}$	$3\frac{1}{2}$	$7\frac{1}{2}$	Exclusive of ditto.

SECOND SERIES.

To test the strength of Splayed Foundations.

No.	Foundation of Pier.	Plinth of Pier.	Foundation of Pier below ground level.	Age of Pier.	Quality of bricks and proportions of ingredients.	Total load.	Position of cracks.	Remarks.
						TONS. CWT. QRS. LBS.		
1	6′ × 2′	2′2½″ × 2′ × 2′	1′	19 days...	1st class Akra bricks and mortar composed of two of Soorkee to one of lime.	12 1 0 14	*Vide* Sketch No. 1.	The pier was constructed on the natural soil, and loaded at the rate of 1 ton and 38½ lbs. per square foot. On lowering the screw jacks, 2 bricks and 17 mortar joints on the north and 2 bricks and 9 mortar joints on the south cracked, and as the load preponderated more on the north side, the wall on that side sunk about ½ inch in the centre, and was 2 inches out of plumb. *Second day.*—It was seen that the former cracks on both sides became wider by 1 brick and 2 mortar joints on the north, and 1 brick and 14 mortar joints on the south side. *Third day, Sunday.*—No observations taken. *Fourth day.*—No further cracks appeared, but the former ones became rather wider. An additional load of ¼ ton per foot was put on upon when the pier sank about 3 inches on the south side. If concrete were added, of course it would be stronger, but this was to test the strength of the masonry, not of masonry and concrete.
2	6′ × 2′	2′ × 2′ × 2′2⅓″	4′ 6″	3 months and 2 days old.	1st class Akra bricks and mortar composed of two of Soorkee to one of lime.	20 18 1 16·83	*Vide* Sketch No. 2.	Experiment on splayed foundation wall having a footing of 6 inches in depth, and off-sets being at an angle of 45°. With ½ ton load to the foot, which remained on one hour, no perceptible disturbance. With ⅔ ton to the foot no perceptible disturbance. „ ¾ „ „ „ 1 „ which remained on all night, 13 hours, nothing perceptible. „ 1¼ tons „ one hour on, the wall slightly sunk in the ground, no disturbance in the brickwork. With 1½ ton the foot one hour on, slight cracks appeared in the wall marked A on the elevation. „ 1¾ „ „ the former cracks became wider and additional cracks in the wall took place, which are marked B on the elevations. The cracks in the two lowest courses were about ¾ inch in width. The wall sunk about ⅓ brick in the ground, settlement being fairly even. Executive Engineer adds that the experiment No. 1 was on a wall similarly constructed to the one herein reported, but was only 19 days old. On comparing the two experiments, the difference in the strength of foundations is very marked, and this no doubt is owing to the difference in the age of the masonry, 19 days and 3 months. The masonry of this trial was very carefully built, good hand and good mortar, most probably better work than could be expected in all parts of the foundations of a large building, and was kept free from all extraneous moisture; it cracked with a load of 1½ tons to the foot. This is not much in excess of the weight on foundations of some of the large buildings, in Calcutta, it is believed; it would, therefore, appear to be too weak in design to leave a safe margin for indifferent or careless work and other contingencies.
3	6′ × 2′	2′ × 2′ × 2′1½′	4′ 6″	15 days...	1st class Akra bricks composed of two of Soorkee to one of lime.	27 1 1 12	*Vide* Sketch No. 3.	With ¼ ton to the foot, one hour on, no disturbance perceptible. „ ½ do. do. do. do. „ ¾ do. do. do. do. „ 1 do. do. do. do. „ 1¼ do. do. do. do. „ 1½ do. do. a very slight settlement in the ground but no disturbance of the brickwork. „ 1¾ do. do. the foundation sunk in the ground a little more, about ½ an inch, and the masonry cracked slightly, as shown at the places marked A on the sketch. „ 2 do. the load remained on all night, 13 hours, the former cracks marked A became a little wider, and the additional cracks marked B were shown. „ 2¼ do. the former cracks marked A and B became a little more open; and the fresh cracks marked C appeared. The wall sunk about 2 inches on the south side, and not quite so much on the north side. *Remarks by the Executive Engineer.*—This mode of giving footings to foundations is a mean between those shown in Nos. 1 and 4, which were all green masonry, 19 and 15 days old.

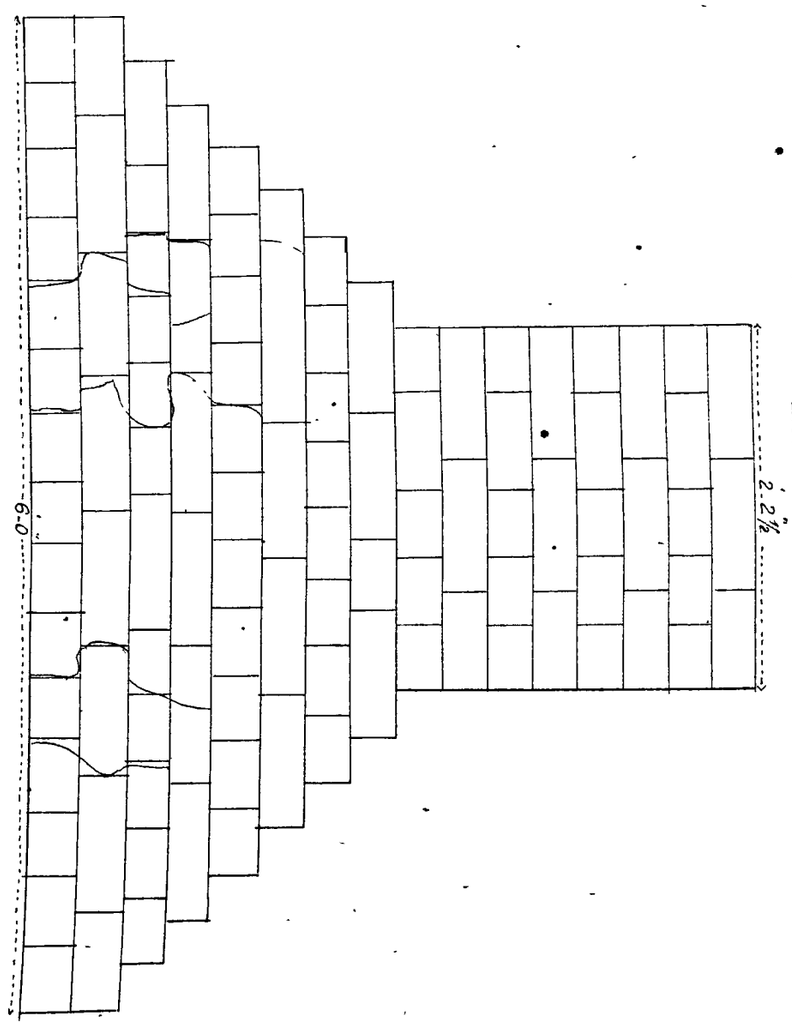
Proceedings of the Madras Government, Public Works Department,
18th June 1875.

To test the strength of Splayed Foundations.—(Contd.)

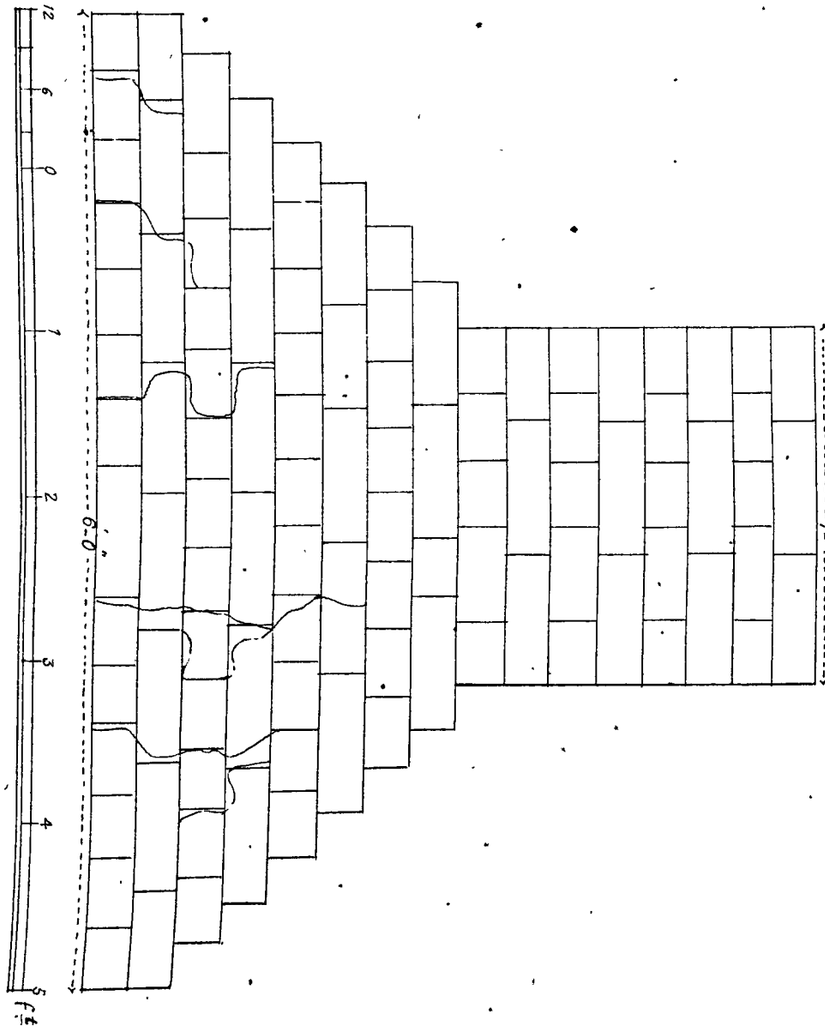
No.	Foundation of Pier.	Plinth of Pier.	Foundation of Pier below ground level.	Age of Pier.	Quality of bricks and proportions of ingredients.	Total load.	Position of cracks.	Remarks.
						TONS. CWT. QRS. LBS.		
4	6′ × 2′	2′2½″ × 2′ × 2′1½″	4′	15 days...	1st class Akra bricks and mortar composed of two of Soorkee to one of lime.	11 9 2 10	*Vide Sketch No. 4.*	The weight was put on the plinth, the off-sets being at an angle of 45°, commencing from the height of 1′ 4½″ of masonry. No crack in the masonry was visible after bearing weight 48 hours, when the load and pier tipped over on the north side. The soil below was soft in moisture, the heavy rain that fell on the 24th and 25th of last month having saturated the ground.
5	6′ × 2′	2′2½″ × 2′ × 2′1½″	4′	3 months old.	1st class Akra bricks composed of two of Soorkee to one of lime.	23 18 0 0·16	*See Drawing No. 4.*	The masonry is the same as No. 4, only older. With ¼ ton to the foot, one hour on, no disturbance. " ½ do. do. do. " ¾ do. do. do. " 1 do. do. do. " 1¼ do. do. foundation sunk slightly, but no disturbance in the masonry. " 1½ tons to the foot, one hour on, foundation sunk more, but no disturbance in the masonry. " 2 tons to the foot, 13 hours on, foundation sunk one brick, but no disturbance in the masonry. This experiment shows that a foundation of this shape is rather too strong.

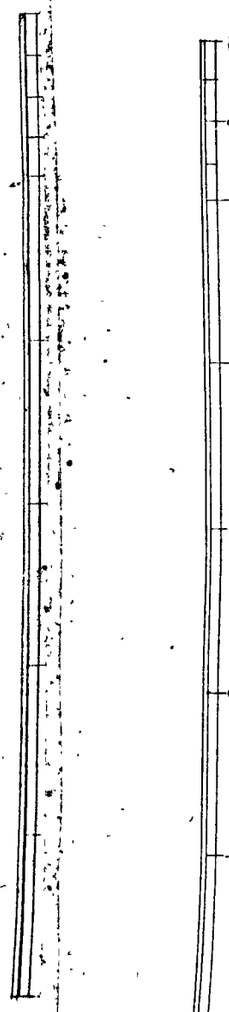
No. 1.

North Elevation



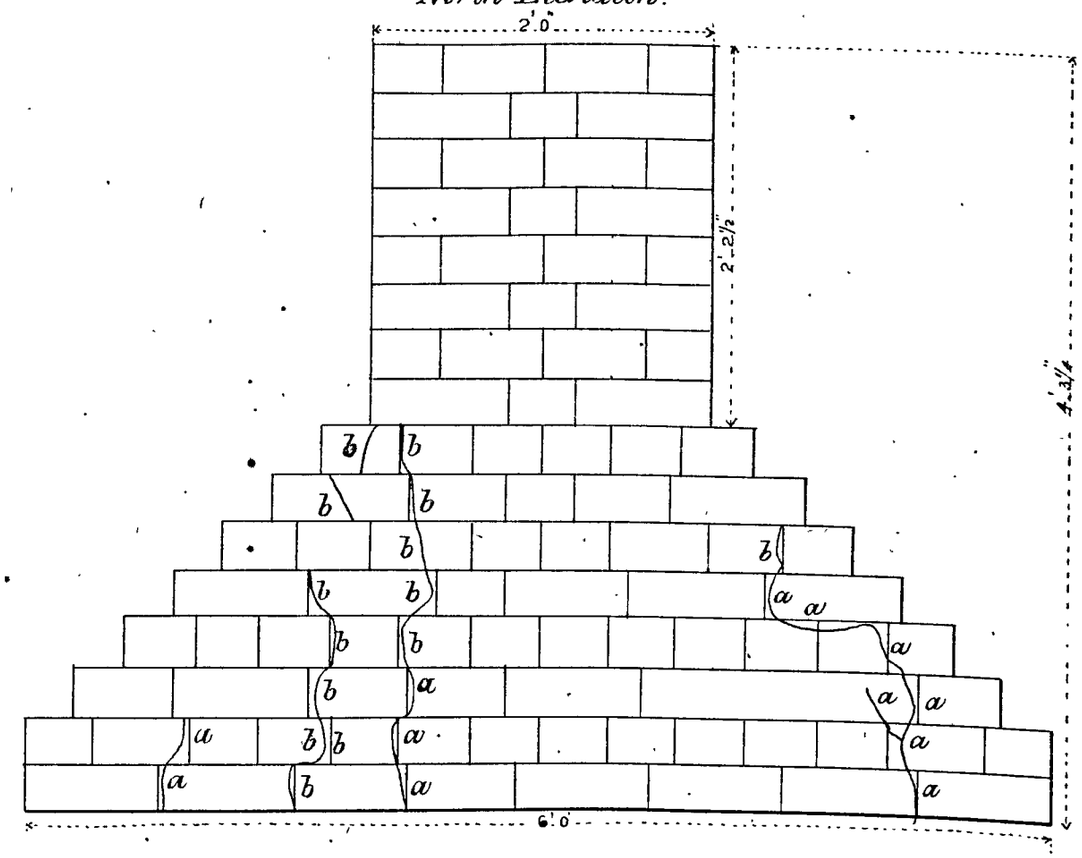
South Elevation



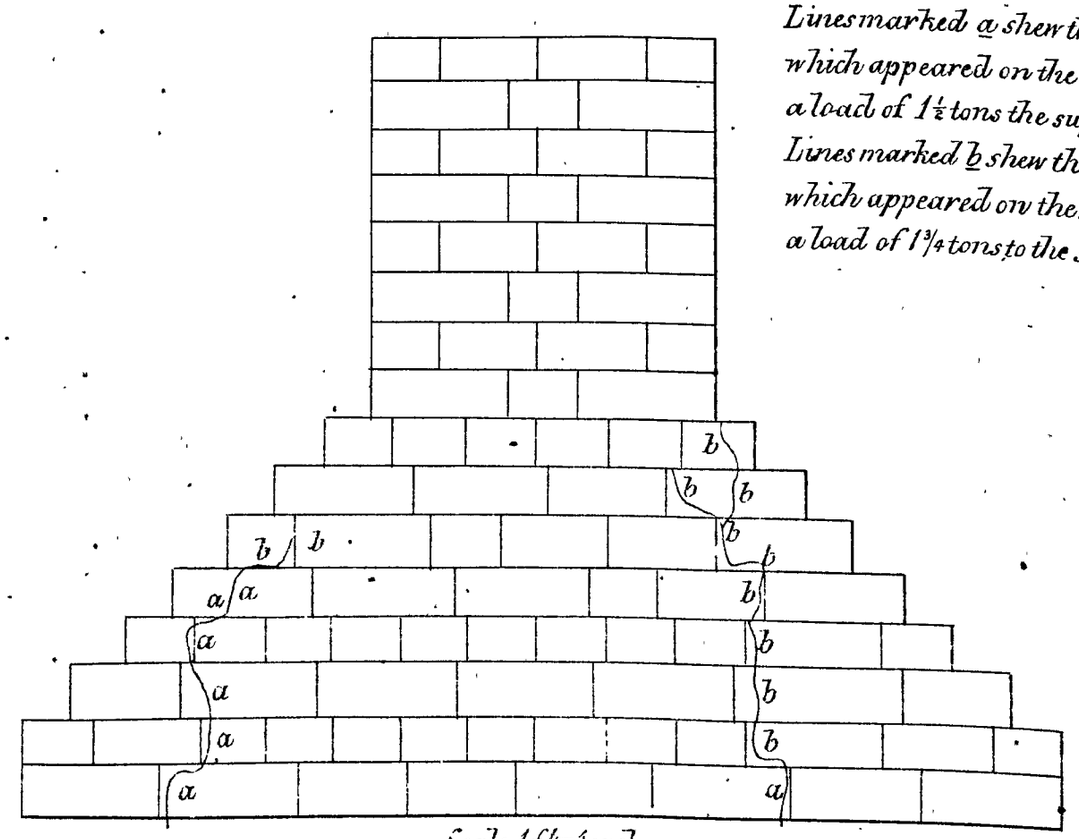


No. 2

North Elevation.

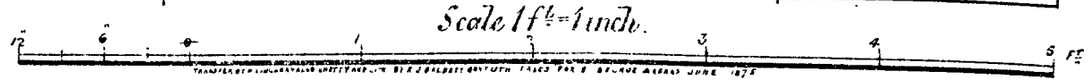


South Elevation.



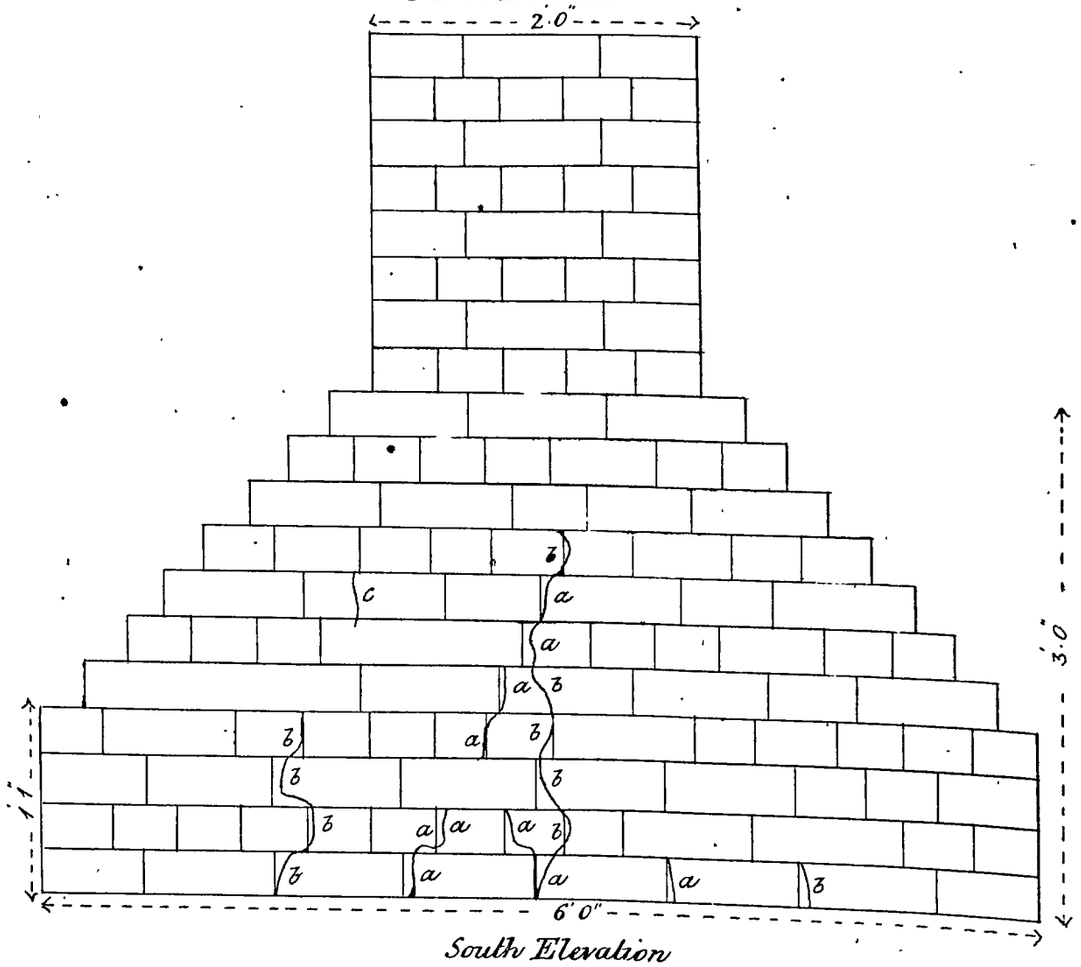
Lines marked a shew the Cracks which appeared on the wall with a load of 1½ tons the sup^l. feet.
Lines marked b shew the Cracks which appeared on the wall with a load of 1¾ tons to the sup^l. feet.

Scale 1 f^t. = 1 inch.

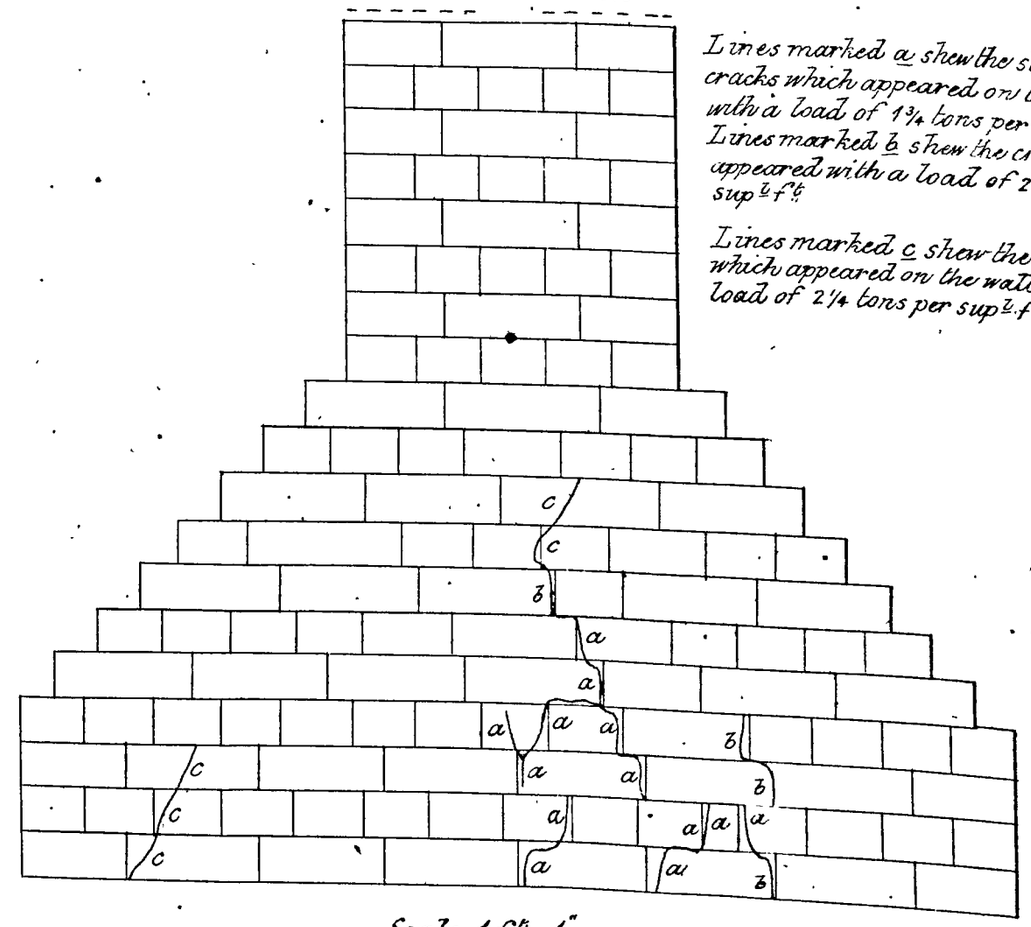


No. 3.

North Elevation



South Elevation



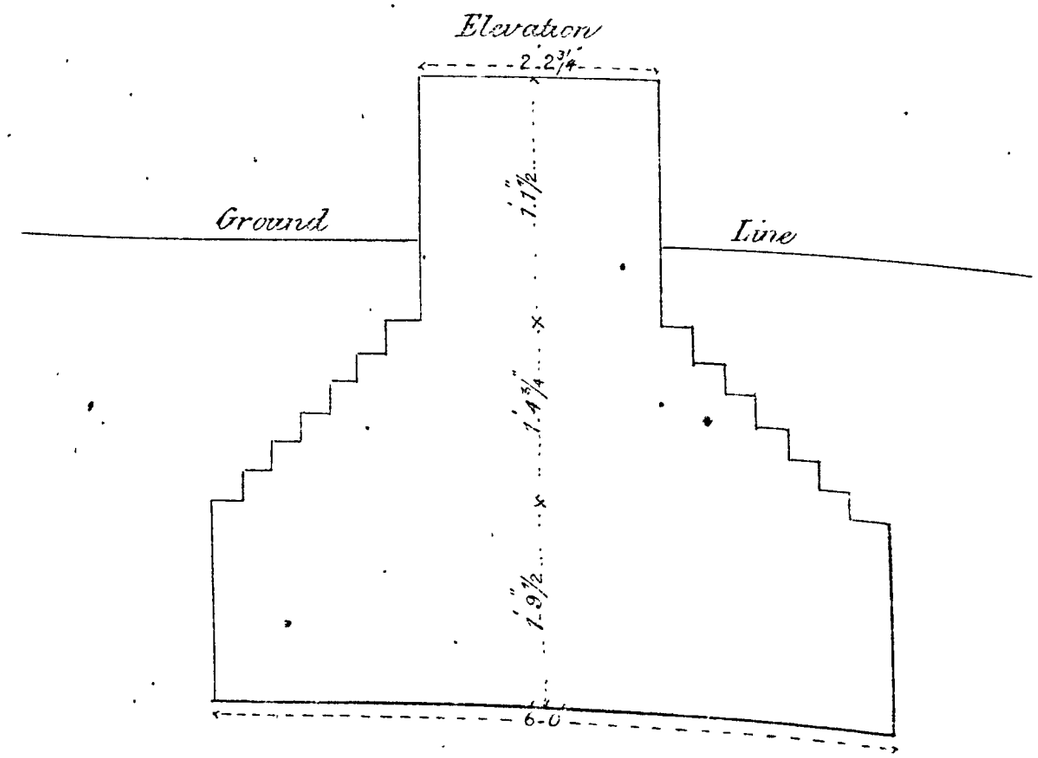
Lines marked a shew the slight cracks which appeared on the wall with a load of 1¾ tons per sup.t f.t
Lines marked b shew the cracks which appeared with a load of 2 tons per sup.t f.t

Lines marked c shew the cracks which appeared on the wall with a load of 2¼ tons per sup.t f.t.

Scale 1 f.t = 1"

12 6 0 1 2 3 4 5 f.t

Nº 4



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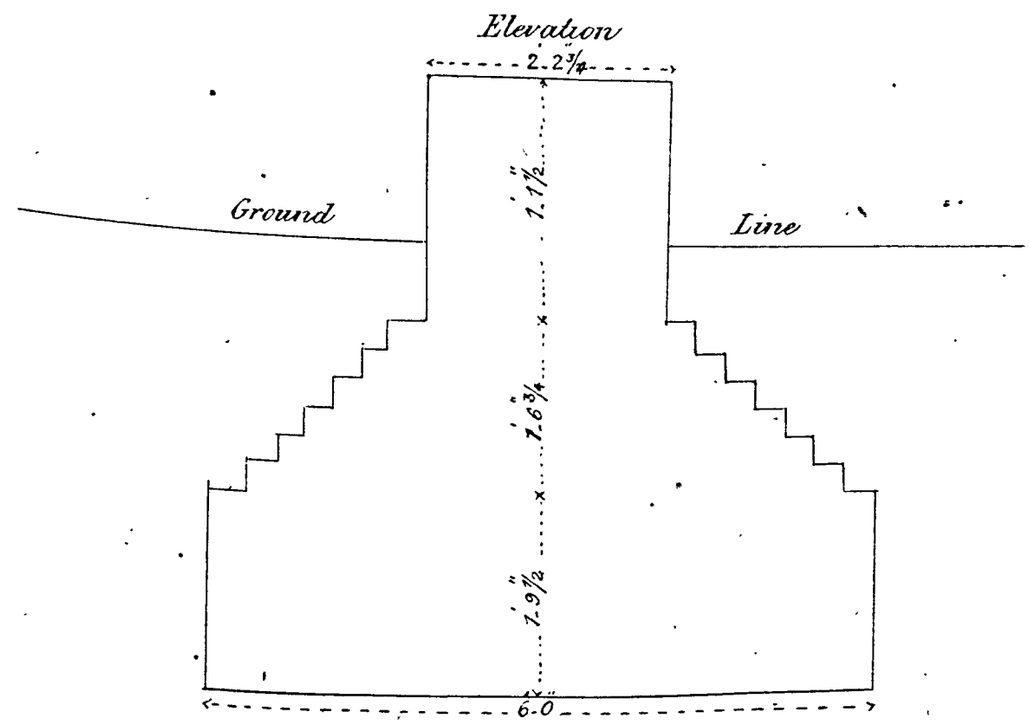

Proceedings of the Madras Government, Public Works Department,
13th June 1875.

No. 425.

ORDER THEREON, 18th June 1875, No. 1,750.

CIVIL WORKS, No. 47.

Communicate to all Superintending and District Engineers.

(True Extract.)

M. [illegible] R.T.,
Offg. Joint Secretary to Government.

To Superintending Engineers.
" District Engineers.
To the Chief Engineer for Irrigation.
" Consulting Engineer for Railways.

Exd. S. T. Austin
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Enclosure to Circular No. 31, Public Works.

APPENDIX A.

Weight on Foundations of Buildings.

Though few, if any, of our buildings in Bengal have fallen, many of them cracked, some of them badly. On commencing several new buildings in Calcutta last year, we naturally considered the question, whether we could do any thing to prevent bad cracks and settlements. The cause of both settlements and cracking seemed to be the compression of the soil under the buildings, and taking this view of it, the question arose, what is a safe weight to put on this Bengal alluvial soil without causing serious disturbance of it? Finding nothing at all reliable on the subject, we decided on making a small series of experiments at Akra, where facilities were available or near at hand.

2. *Series No.* 1 gives the result of the trials made. The scale on which they were made was not a mere toy scale, the piers of masonry dealt with were such as might be used on real work, and though the results may not be an infallible guide, they certainly do give definite information; they show, beyond doubt, that, with a weight of one ton to the square foot, the compression of the earth is very small, in fact, what might be due to disturbance of the surface in opening the foundations; while with two tons to the foot, sinking is decided, quite enough to cause bad cracks. If one part of a building were built with a load of one ton to the foot, and other parts with a load of two tons to the foot, the building would certainly crack, and if other parts were built with a weight of three tons to the foot, there would be very bad cracks.

3. I consider that safe conclusions to draw from the results of the experiments are these. If it be desired to provide against sinking of *the whole structure*, the weight per foot on the earth, whatever may be the *depth* at which the foundation is laid, should not be more than one ton per square foot; and that, if *unequal sinking cracks* are to be provided against, the weight on all parts of the foundations should be equal per square foot; unless that the most heavily loaded portion carries less than one ton per square foot; with this weight, and, of course, with lighter weights, no perceptible compression takes place, and hence no unequal settlement would occur from unequal loading.

Depth at which Foundations may be laid.

4. The next point for experiment was,—at what depth is the soil best fit for building on? We had trials made at depths of *two feet six inches*,—that is, just below the usually disturbed soil; at *four feet*, where the true alluvial deposit was undisturbed; at *eight feet*, where a different, though not better, soil was touched, and at *eleven feet*, where the soil was wet and soft. All through this series the effects of weight per foot considered in the three paragraphs above were kept in view. *Series No.* 1 gives also the results of the experiments.

5. The conclusions which may be drawn from the results of these trials are not so clear as they are in the case of the weight on foundation; but it is evident that shallow foundations have the disadvantage of being affected by climatic influence, as heavy rain caused the masonry laid at a depth of two feet six inches below the surface to sink considerably. Again it appears that foundations laid at a depth of eleven feet below the surface sink more than those laid at depths of four feet and eight feet. This is difficult to explain. It may be that when the foundations are opened to a depth of eleven feet, the bottom, relieved of such a weight of earth, "blows up" a little, though hardly perceptibly, and the first effect of weighting it is to force this blown-up surface down to its original state, and that, when thus pressed

down to what it was before the earth was removed from it, it may bear pressure as well as the earth at smaller depths. The conclusions which I am inclined to draw from the experiments are these:—The foundations of important buildings should be laid so deep that they cannot be affected by climate. The ground, if undisturbed, is as good at a depth four feet below the surface as it is at greater depths, and it is about the same up to eight feet deep. I would lay it down as a rule that in undisturbed alluvial soil, foundations of *important buildings* should not be laid at a less depth than four feet, nor at a greater depth than six feet.

Strength of Spread Foundations.

6. Having settled on one ton to the square foot as the weight to be carried on the soil, it became necessary to spread out the foundations a good deal to get the area required, and then the question arose, at what angle should they spread, or what depth of masonry should there be at the weakest point? Some sections of foundations which I saw seemed to me to be too weak. In order to help to settle the question I had the experiments *No. 2 series* made; the result may be practically stated thus,—for a pressure of one ton to the foot, on Bengal soil, the thickness at the toe of the slope should not be less than one foot six inches (*see* record of experiments), and the stepping at an angle of not more than 45°. I take one foot six inches because with a thickness of nine inches the projections broke off, as shown in the sketch in the record of experiments; while with a thickness of one foot nine inches, no symptoms of weakness showed even when the work was fresh. With good masonry, of mortar, which will set in damp or wet, I feel certain that the dimensions given above are enough, but with bad masonry,—bad from whatever cause—considerably more strength should be given.

7. I think it likely that this question of footings *breaking off* has not been sufficently attended to; the result of such an occurrence can be seen by looking at the sketch in experiment No. 1 of this series, where, instead of an area of twelve feet, that is, the width of the footing, by two feet long, to rest on, the area is reduced by the outer sides breaking off to less than half, that is, to the width between the cracks, by two feet; and instead of a weight of one ton per foot on the foundation soil, we should have a weight of over two tons, which means a subsidence of two or three inches, and cracks of probably the same width.

H. LEONARD, *M. I. C. E.*,
Offg. Chief Engineer, Bengal.

The 17th May 1873.

FIRST SERIES.

Experiments made at Acra for the purpose of testing what weight the ordinary undisturbed alluvial soil of Calcutta, which fairly represents Lower Bengal soil, can bear.

Number of experiments.	Depth below surface of ground.	Size of Pier constructed.	Total height of Pier.	Materials.	Total contents of Pier.	Weight of Pier at 100lbs. ⅌ c. ft.	Superficial area of Pier.	Age of Pier.	Load, excluding weight of Pier.	Weight per sq. ft., *including weight of Pier.*	Result of Loading.		Remarks.
	Ft. In.	Ft. In.	Ft. In.		C. ft.	Tons. cwt. qr. lbs.	S. ft.		Tons. cwt. qr. lbs.	Tons. cwt. qr. lbs.	Days.	Sinking.	
1*	1 4	3 2½ square.	2 11¼	Bricks with mortar, two of soorkee to one of lime.	30·83	2 3 0 8	10·29	6 days	41 0 0 0	4 3 3 13·8	1st 2nd 3rd	⅞ 3⅜	The pier sank 3⅜ inches with this load by compressing the ground on which it stood; the surrounding ground was not visibly disturbed, except for a distance of about 2 or 3 inches immediately in contact with the pier, which seemed to be caused by friction on two sides, the load being slightly in excess on those sides. From this experiment it would appear that only the ground under the masonry sinks, the surrounding ground not being disturbed to any appreciable extent.
2†	2 6	3 2½	5 0½	Ditto	51·89	2 6 1 9·4	10·29	...	10 7 3 8	1 4 2 20·3	1st 2nd 3rd	3/16 ¼ 5/16	Immediately on lowering screw jacks.‡

* The object of this experiment was to ascertain whether the ground under the masonry alone is compressed, or whether the compression extends for some distance round the foundation.
† The object of this and the eleven following experiments is to show the compression of the soil at different depths, and under different weights.
‡ The twine carrying the load was supported by screw jacks at each corner during the work of loading, when the desired load was on, the screw jacks were lowered, and the load was brought to bear on the masonry.

Experiments made at Acra for the purpose of testing the ordinary undisturbed alluvial soil of Calcutta—(contd.).

Number of experiments.	Depth below surface of ground.	Size of Pier constructed.	Total height of Pier.	Materials.	Total contents of Pier.	Weight of Pier at 100 lbs. ₹ c. ft.	Superficial area of Pier.	Age of Pier.	Load, excluding weight of Pier.	Weight per sq. ft., *including weight of Pier.*	Result of Loading. Days.	Result of Loading. Sinking.	Remarks.
	Ft. In.	Ft. In.	Ft. In.		C. ft.	Tons. cwt. qr. lbs.	S. ft.		Tons. cwt. qr. lbs.	Tons. cwt. qr. lbs.			
3	2 6	3 2½	5 0½	Bricks with mortar, two of soorkee to one of lime.	51·89	2 6 1 9	10·29	...	20 14 2 19	2 4 3 5·6	1st	1	On lowering screw jacks.
											2nd	1¾	
											3rd	1 13/16	
											4th	1⅞	
											5th	2	
											6th	2⅛	
											7th	2⅜	
4	2 6	3 2½	5 0½	Ditto ditto ...	51·89	2 6 1 9	10·29	...	31 1 2 3	3 4 3 17·2	1st	5⅛	Ditto ditto.
											2nd	5½	
											3rd	5½	
											4th	5½	Very heavy rain fell on the night of the 4th.
											5th	6 3/16	The sinking of this block is considerably more than in experiments which were 4 feet and 8, respectively, below the ground level; a good deal of rain fell during the time this experiment was in progress, and the soil to the depth of foundation was, no doubt, saturated.
											6th	7 5/16	
											7th	7 7/16	
											8th	Not measured.	
											9th	7 7/16	It shows fairly the danger of shallow foundations.
											10th	7 11/16	
5	4 0	2 9½	5 9	Ditto ditto ...	42·12	1 17 2 12	7·76	...	7 16 2 21	1 5 0 4·3	1st	3/16	Immediately on lowering the screw jacks. No further sinking took place with this weight for a space of seven days.
6	4 0	2 9½	5 9	Ditto ditto ...	42·12	1 17 2 12	7·76	...	15 10 3 22	2 4 3 17·4	1st	9/16	
											2nd	15/16	
											3rd	15/16	
											4th	15/16	No further sinking took place.
7	4 0	2 9½	5 9	Ditto ditto ...	42·12	1 17 2 12	7·76	...	23 5 0 24	3 4 3 5·2	1st	1¼	On lowering screw jacks.
											End of 1st	2⅝	
											3rd	3	
											5th	3¼	No further sinking.
8	8 0	3 2½	10 6½	Ditto ditto ...	108·50	4 16 3 14	10·29	...	10 6 0 20	1 9 1 22·5	1st	3/16	The Executive Engineer states "heavy rain fell during part of the time of the last loading, by which the ground was flooded, and most probably water percolated to the foundation. This combined with very strong wind blowing from the south and east caused the unequal settlement of the block."
9	...	3 2½	10 6½	Ditto ditto ...	108·50	4 16 3 14	10·29	...	20 13 0 3	2 9 2 5·9	1st	9/16	No sinking was observed from the 2nd to the 7th day.
											2nd	9/16	
											3rd	9/16	
											4th	11/16	
											5th	11/16	
											6th	11/16	
											7th	11/16	

Experiments made at Acra for the purpose of testing the ordinary undisturbed alluvial soil of Calcutta—(contd.).

Number of experiments.	Depth below surface of ground.	Size of Pier constructed.	Total height of Pier.	Materials.	Total contents of Pier.	Weight of Pier at 100 lbs. per c. ft.	Superficial area of Pier.	Age of Pier.	Load, excluding weight of Pier.	Weight per sq. ft., *including weight of Pier.*	Result of Loading. Days.	Result of Loading. Sinking	Remarks.
	Ft. In.	Ft. In.	Ft. In.		C. ft.	Tons. cwt. qr. lbs.	S. ft.		Tons. cwt. qr. lbs.	Tons. cwt. qr. lbs.			
10	...	3 2½	10 6½	Bricks with mortar, two of soorkee to one of lime.	108·50	4 16 3 14	10·29	...	30 19 3 14	3 9 2 17·4	1st	1⅛	The result of this experiment tends to show that the bearing power of soil at 8 feet depth is no better for light weight than at 4 feet, but for heavy weight it seems to bear more.
												1⅛	
											3rd	1 11/16	
											4th	1 11/16	
											5th	1¾	
											6th	1¾	
											7th	1¾	
											11th	1 13/16	
11	11 0	3 2½	14 0½	Ditto ditto ...	144·53	6 9 0 5	10·29	...	10 7 3 27	1 12 3 0·8	1st	Nil	On lowering screw jacks.
											End of 2nd	1/16	Extra load put on to make the weight equal to a ton to the foot, exclusive of brickwork.
											3rd	7/16	
											4th	Sunday	
											5th	13/16	
											8th	7/8	
											9th	15/16	In this and the two following experiments the foundation carried more than in the preceding experiments. But even allowing for this, the ground seemed to be capable of bearing less at 11 feet than at 4 or 8 feet.
											10th	1″	
											12th	1″	
											13th	1 1/16	
12	11 0	3 2½	14 0½	Ama bricks with mortar, two of soorkee to one of lime.	144·63	6 9 0 5	10·29	...	20 17 0 23	2 13 0 9·5	1st	1½″	On lowering screw jacks.
											2nd	3″	
											3rd	3″	
											4th	3″	
											5th	Sunday	
											6th	3⅛	
											7th	3 3/16	
											8th	3 3/16	
											9th	3 7/16	
13	11 0	3 2½	14 0½	Ditto ditto ...	144·63	6 9 0 5	10·29	...	31 4 0 6	3 13 0 20·5	1st	3¾″	Ditto ditto.
											2nd	6 11/16	
											3rd	Sunday	I think the greater sinking in the case of this pier may be explained in this way. At a depth of 11 feet, the ground, which gets soft, *rose* before the load was put on, and hence sunk more when again under heavy pressure.
											4th	6⅞	
											5th	6 15/16	
											6th	6 15/16	
											7th	7	
											8th	7	
											9th	7 1/16	
											10th	Sunday	
											11th	7⅛	
											12th	Not measd.	
											13th	7⅛	
											14th	7 13/16	
											15th	7 13/16	
											16th	7¼	
											17th	Sunday	
											18th	7 5/16	

Experiments made at Acra for the purpose of testing the ordinary undisturbed alluvial soil of Calcutta—(concld.).

Number of experiments.	Depth below surface of ground.	Size of Pier constructed.	Total height of Pier.	Materials.	Total contents of Pier.	Weight of Pier at 100 lbs. ℘ c. ft.	Superficial area of Pier.	Age of Pier.	Load, excluding weight of Pier.	Weight per sq. ft., *including weight of Pier.*	Result of Loading. Days.	Result of Loading. Sinking.	Remarks.
	Ft. In.	Ft. In.	Ft. In.		C. ft.	Tons. cwt. qr. lbs.	S. ft.		Tons. cwt. qr. lbs.	Tons. cwt. qr. lbs.			
14*	4 0	2 10 square.	7 4½	Third class Acra bricks with mortar composed of two of soorkee to one of lime.	59·20	2 12 3 12	8 03	15 days	8 0 0 0	1 6 2 0·7	1st 7th 14th	⅛ ¼ $\frac{5}{16}$	The pier loaded with one ton per foot was left standing for three months, but no further sinkage than what was recorded on the 14th day was discovered during the remainder of the time.

* The object of this experiment was to ascertain if, without adding weight, sinking occurred from long standing.

SUMMARY.

No.	Depth of Foundation below surface of the ground.	Maximum sinking with weight per square foot of: 1 ton.	2 tons.	3 tons.	Remarks.
		Sinking. Inch.	Inch.	Inch.	
1	2 feet 6 inches	$\frac{5}{16}$	2⅛	7⅞	Including the weight of brickwork.
2	4 feet	$\frac{3}{16}$	1	$3\frac{1}{16}$	
3	8 „	$\frac{3}{16}$	$\frac{11}{16}$	$1\frac{13}{16}$	
4	11 „	$1\frac{1}{16}$	3½	7½	Exclusive of ditto.

SECOND SERIES.

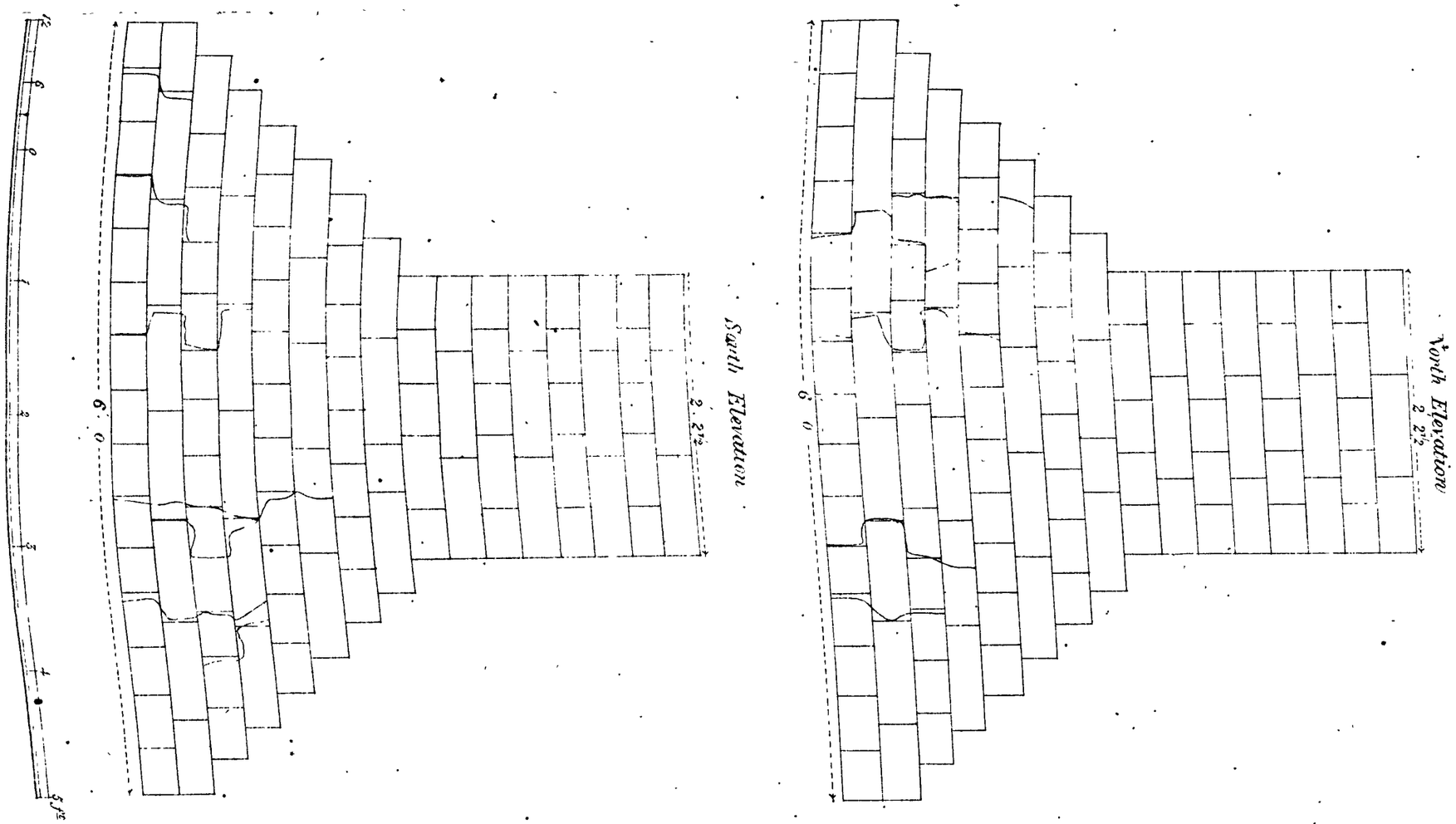
To test the strength of Splayed Foundations.

No.	Foundation of Pier.	Plinth of Pier.	Foundation of Pier below ground level.	Age of Pier.	Quality of bricks and proportions of ingredients.	Total load.	Position of cracks.	REMARKS.
						Tons. cwts. qrs. lbs.		
1	6′×2′	2′2½″×2′×2′	1′	19 days ...	1st class Acra bricks and mortar composed of two of soorkee to one of lime.	12 1 0 14	*Vide* Sketch No. 1.	The pier was constructed on the natural soil, and loaded at the rate of 1 ton and 38½ lbs. per square foot. On lowering the screw jacks, 2 bricks and 17 mortar joints on the north and 2 bricks and 9 mortar joints on the south cracked, and as the load preponderated more on the north side, the wall on that side sunk about ½ inch in the centre, and was 2 inches out of plumb. *Second day.*—It was seen that the former cracks on both sides became wider by 1 brick and 2 mortar joints on the north, and 1 brick and 14 mortar joints on the south side. *Third day, Sunday.*—No observations taken. *Fourth day.*—No further cracks appeared, but the former ones became rather wider. An additional load of ¼ ton per foot was put on upon when the pier sank about 3 inches on the south side. If concrete were added, of course it would be stronger, but this was to test the strength of the masonry, not of masonry and concrete.
2	6′×2′	2′×2′×2′2½″	4′ 6″	3 months and 2 days old.	Ditto ditto	20 18 1 16·83	*Vide* Sketch No. 2.	Experiment on splayed foundation wall having a footing of 6 inches in depth, and off-sets being at an angle of 45°. With ¼ ton load to the foot, which remained on one hour, no perceptible disturbance. With ½ ton to the foot no perceptible disturbance. „ ¾ „ „ „ „ 1 „ which remained on all night, 13 hours, nothing perceptible. „ 1¼ tons „ one hour on, the wall slighly sunk in the ground, no disturbance in the brickwork. „ 1½ „ „ one hour on, slight cracks appeared in the wall marked A on the elevation. „ 1¾ „ „ the former cracks became wider and additional cracks in the wall took place, which are marked B on the elevations. The cracks in the two lowest courses were about ¾ inch in width. The wall sunk about ½ brick in the ground, settlement being fairly even. Executive Engineer adds that the experiment No. 1 was on a wall similarly constructed to the one herein reported, but was only 19 days old. On comparing the two experiments, the difference in the strength of foundations is very marked, and this no doubt is owing to the difference in the age of the masonry, 19 days and 3 months. The masonry of this trial was very carefully built, good hand and good mortar, most probably better work than could be expected in all parts of the foundations of a large building, and was kept free from all extraneous moisture; it cracked with a load of 1½ tons to the foot. This is not much in excess of the weight on foundations of some of the large buildings in Calcutta, it is believed; it would therefore, appear to be too weak in design to leave a safe margin for indifferent or careless work and other contingencies.
3	6′×2′	2′×2′×2′1½″	4′ 6″	15 days ...	1st class Acra bricks composed of two of soorkee to one of lime.	27 1 1 12	*Vide* Sketch No. 3.	With ¼ ton to the foot, one hour on, no disturbance perceptible. „ ½ ditto, ditto, ditto ditto. „ ¾ ditto, ditto, ditto ditto. „ 1 ditto, ditto, ditto ditto. „ 1¼ ditto, ditto, ditto ditto. „ 1½ ditto, ditto, a very slight settlement in the ground, but no disturbance of the brickwork. „ 1¾ ditto, ditto, the foundation sunk in the ground a little more, about ½ an inch, and the masonry cracked slightly, as shown at the places marked A on the sketch. „ 2 ditto, the load remained on all night, 13 hours, the former cracks marked A became a little wider, and the additional cracks marked B were shewn. „ 2¼ ditto, the former cracks marked A and B became a little more open; and the fresh cracks marked C appeared. The wall sunk about 2 inches on the south side, and not quite so much on the north side. *Remarks by the Executive Engineer.*—This mode of giving footings to foundations is a mean between those shown in Nos. 1 and 4, which were all green masonry, 19 and 15 days old.

To test the strength of Splayed Foundations.—(contd.).

No.	Foundation of Pier.	Plinth of Pier.	Foundation of Pier below ground level.	Age of Pier.	Quality of bricks and proportions of ingredients.	Total load.	Position of cracks.	REMARKS.
						Tons. cwt. qrs. lbs.		
4	6′ × 2′	2′2¾″ × 2′ × 2′ 1½″	4′	15 days.	1st class Acra bricks and mortar composed of two of soorkee to one of lime.	11 9 2 10	*Vide* Sketch No. 4.	*The weight was put on the plinth, the off-sets being at an angle of 45°, commencing from the height of 1′ 9½″ of masonry.* No crack in the masonry was visible after being weighted 30 hours, when the load and pier tipped over on the south side. *The soil below was soft from moisture, the heavy rain that fell on the 24th and 25th of last month having saturated the ground.*
5	6′ × 2′	2′ 2½″ × 2′ × 2′1½″	4′	3 months old.	1st class Acra bricks composed of two of soorkee to one of lime.	23 18 0 0 16	*See* Drawing No. 4.	The masonry is the same as No. 4, only older. With ¼ ton to the foot, one hour on, no disturbance. „ ½ ditto, ditto, ditto. „ ¾ ditto, ditto, ditto. „ 1 ditto, ditto, ditto. „ 1¼ ditto, ditto, foundation sunk slightly, but no disturbance in the masonry. „ 1½ tons to the foot, one hour on, foundation sunk more, but no disturbance in the masonry. „ 2 tons to the foot, 13 hours on, foundation sunk one brick, but no disturbance in the masonry. This experiment shows that a foundation of this shape is rather too strong.

P. W. D. Press—15-5-75—960.



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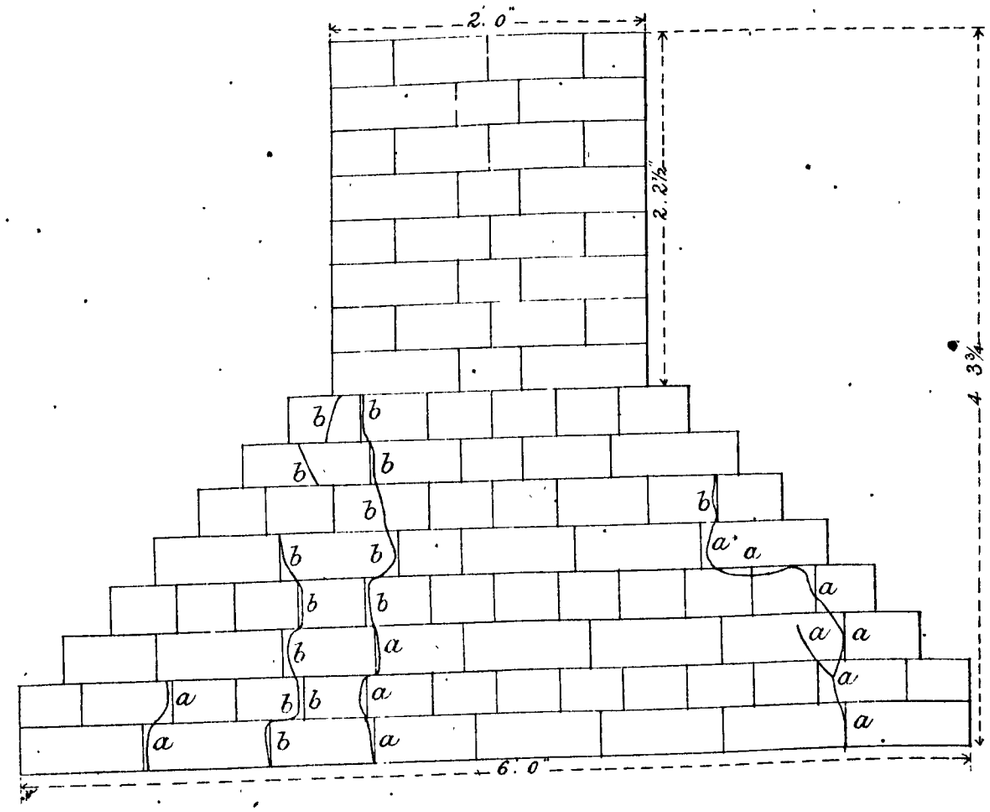
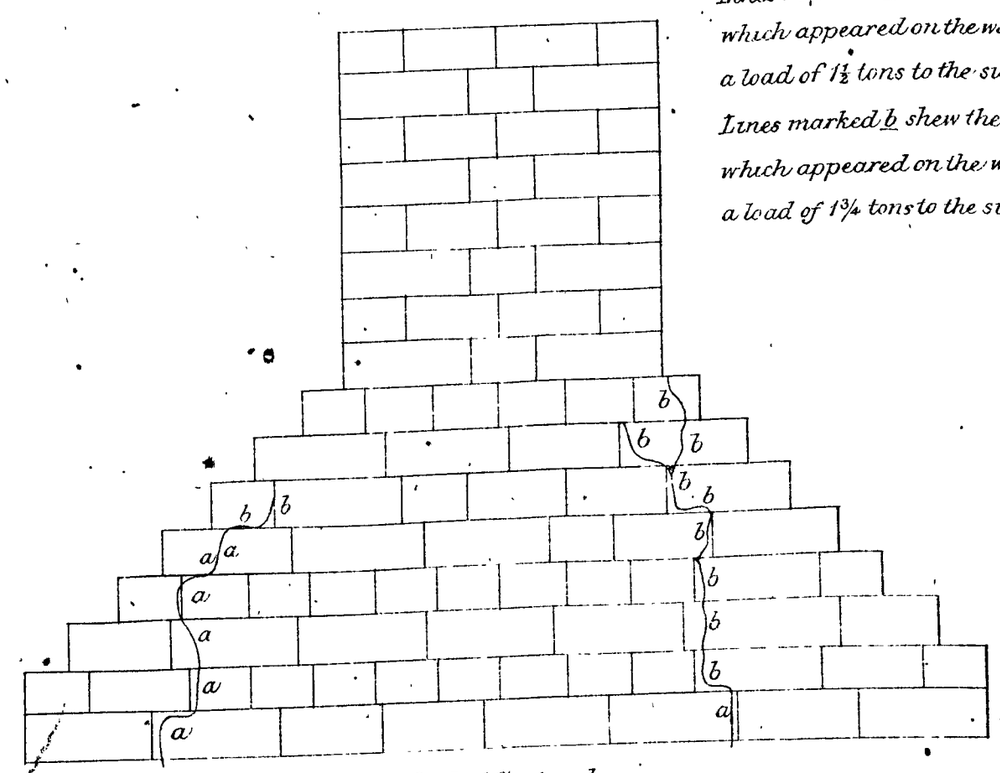
North Elevation



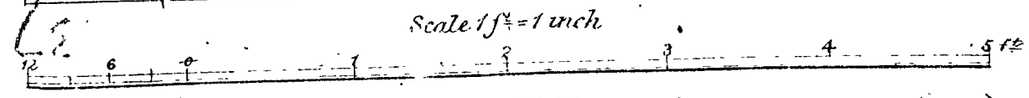
South Elevation



Lines marked a shew the Cracks which appeared on the wall with a load of 1½ tons to the sup^L ft

Lines marked b shew the Cracks which appeared on the wall with a load of 1¾ tons to the sup^L ft

Scale 1 ft = 1 inch



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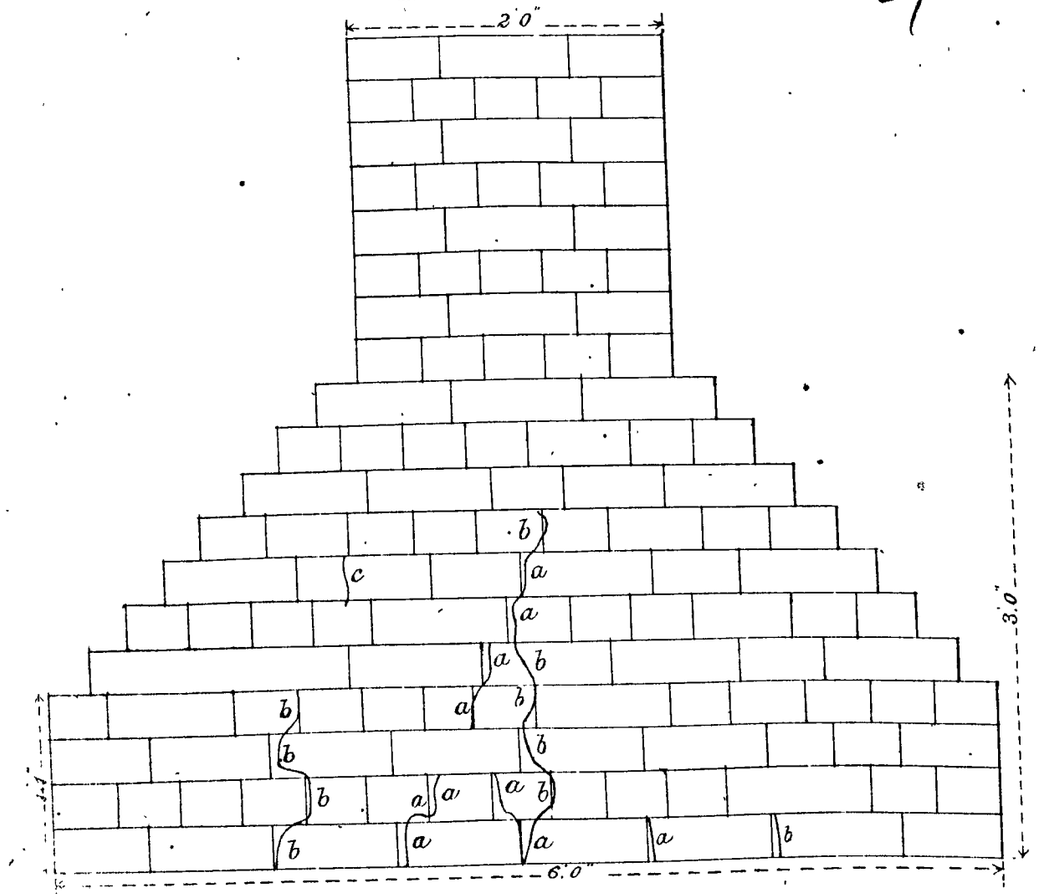
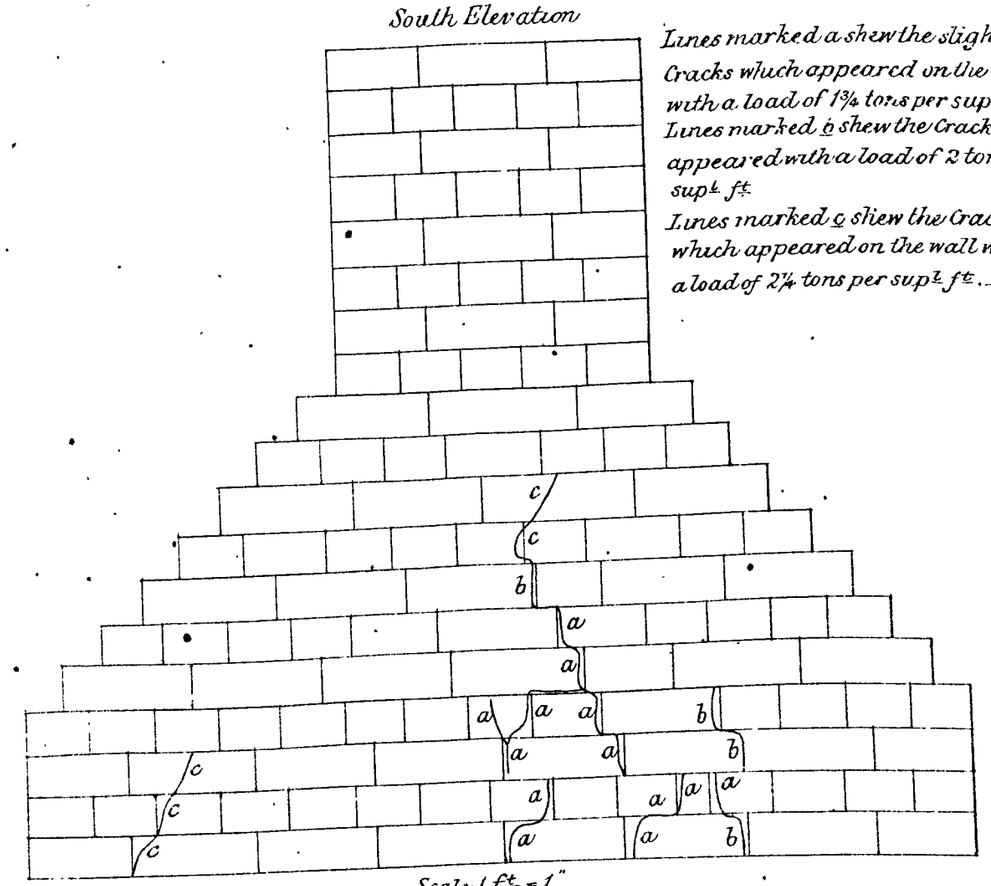
North Elevation

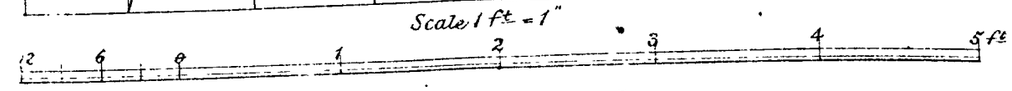


South Elevation



Lines marked a shew the slight Cracks which appeared on the wall with a load of 1¾ tons per sup^t ft
Lines marked b shew the Cracks which appeared with a load of 2 tons per sup^t ft
Lines marked c shew the Cracks which appeared on the wall with a load of 2¼ tons per sup^t ft.—

Scale 1 ft = 1"



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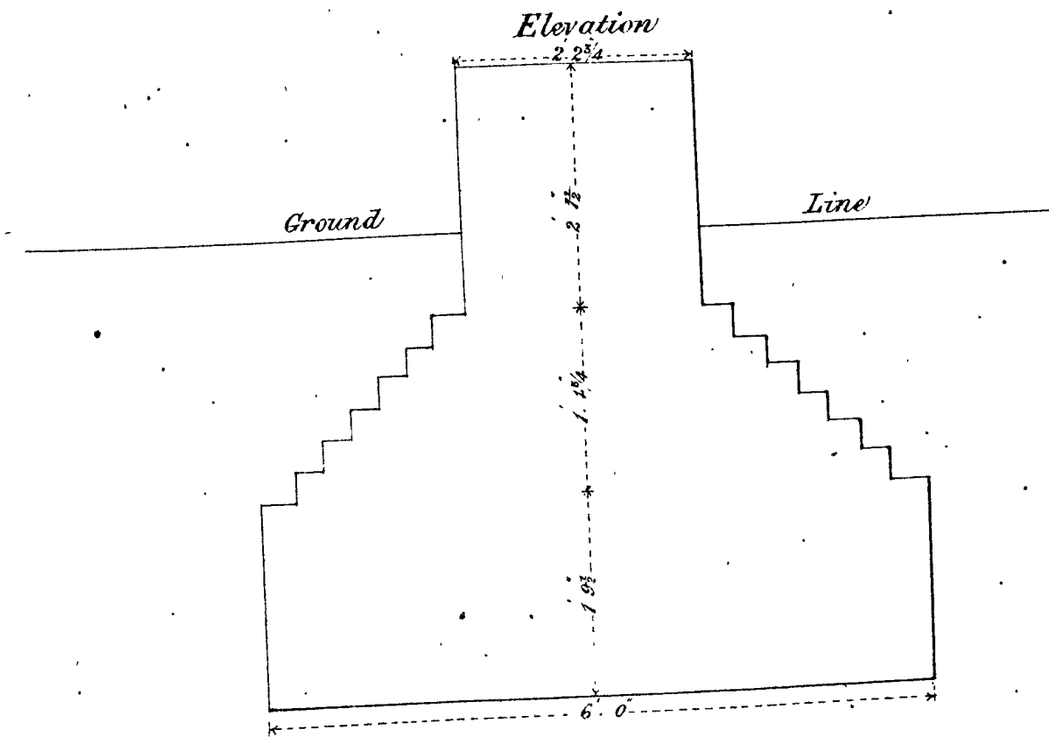
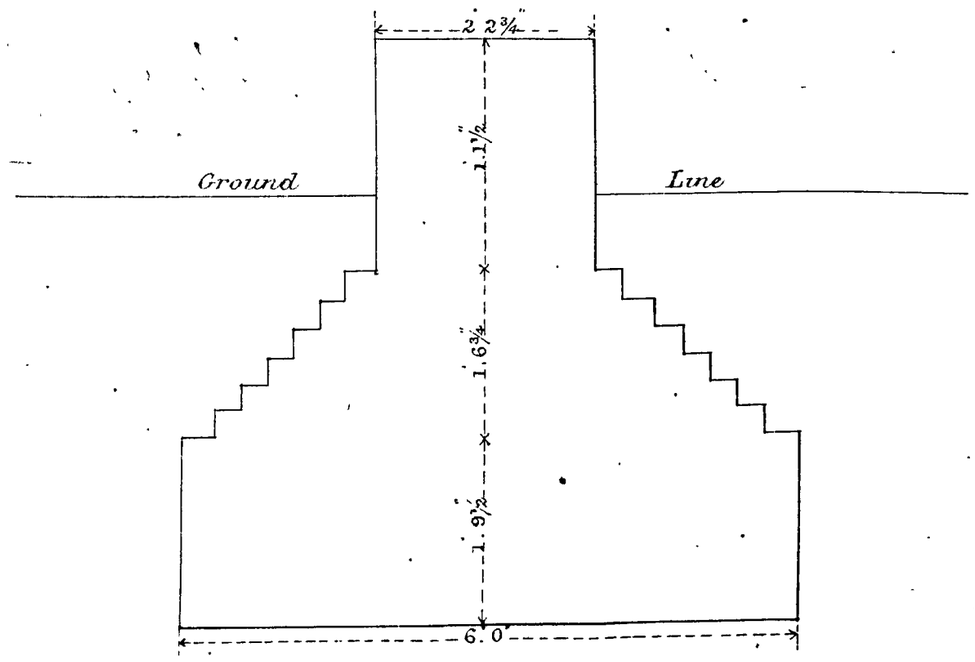


Nº 5:

Elevation



CIRCULAR No. 31 PUBLIC WORKS.

GOVERNMENT OF INDIA.

PUBLIC WORKS DEPARTMENT.

CIVIL WORKS.

Miscellaneous.

To

THE GOVERNMENTS OF MADRAS AND BOMBAY, IN THE PUBLIC WORKS DEPARTMENT, GENERAL, IRRIGATION AND RAILWAY BRANCHES.

THE GOVERNMENTS OF BENGAL, NORTH WESTERN PROVINCES AND PUNJAB, IN THE PUBLIC WORKS DEPARTMENT, GENERAL AND IRRIGATION BRANCHES.

THE CHIEF COMMISSIONERS OF OUDH, CENTRAL PROVINCES, BRITISH BURMAH, MYSORE AND COORG, AND ASSAM.

THE RESIDENT AT HYDERABAD.

THE AGENTS OF THE GOVERNOR GENERAL FOR CENTRAL INDIA AND RAJPOOTANA.

THE SUPERINTENDENT OF PORT BLAIR, AND CHIEF COMMISSIONER, ANDAMAN AND NICOBAR ISLANDS.

THE INSPECTOR GENERAL OF MILITARY WORKS.

THE DIRECTOR OF STATE RAILWAYS.

THE CONSULTING ENGINEERS TO THE GOVERNMENT OF INDIA FOR GUARANTEED RAILWAYS, CALCUTTA, LAHORE AND LUCKNOW.

FORT WILLIAM, APRIL 23, 1875.

SIR,

I am directed to forward for general information, the accompanying copy of a printed Memorandum, dated the 17th May 1873, by Mr. H. Leonard, M. I., C. E., late Officiating Chief Engineer, Bengal, containing an account of the results of certain experiments undertaken for ascertaining the strength of ordinary brick-work, and of the weights which may safely be placed upon foundations on the ordinary alluvial soil of Bengal.

I have the honour to be,

SIR,

Your most obedient Servant,

Capt. R. E.

Asst. Secy. to the Govt. of India.

To the Secy. to the Govt. of Madras.

P.W. Department

Wr. 1875 Dept.
No. 3610

GOVERNMENT OF INDIA.

PUBLIC WORKS DEPARTMENT.

CIVIL WORKS.
Miscellaneous.

To

THE GOVERNMENTS OF MADRAS AND BOMBAY, IN THE PUBLIC WORKS DEPARTMENT, GENERAL, IRRIGATION AND RAILWAY BRANCHES.

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1. ✓

CIRCULAR No. 31 PUBLIC WORKS.

Dated April 23, 1875.

Received June 2nd. 1875

Forwards for information, a printed Memorandum, containing an account of the results of experiments undertaken for ascertaining the strength of ordinary brick-work, and of the weights which may safely be placed upon foundations on the ordinary alluvial soil of Bengal.

No. 92, P. W. D. Press—7-5-75—29.

Both Order

Communicated to all Superintending and District Engineers.

No. 424/5

1730

Copy 2-6-75

3610

Govt. of {1875} Madras.

PUBLIC WORKS.

To

Supg Engineers

Dated

Issued

Recd. Encl

G. O. 18 June 1730

No. 474-475

printed Memo., contain an account of the communicated to all Superintending and District Engineers.

Results of Experiments undertaken for ascertaining the strength of ordinary brick-work, and of the weights which may safely be placed upon foundations on the ordinary alluvial soil of Bengal. — Circular of the Government of India, forwarding for information, a

[illegible] Order