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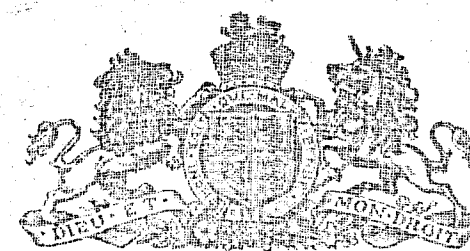
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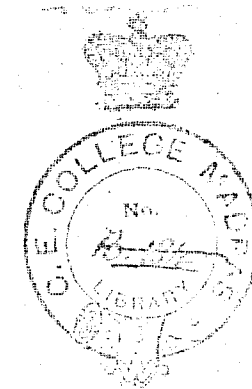
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FAILURE OF THE KALI NADI AQUEDUCT-
LOWER GANGES CANAL.

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செப்பனிருவதற்கு க. குருதசு
கொள்ளப்பட்ட நாள்.
செப்பனிரு முடித்த நாள்
மு.பா.ஏ. உதவியுடன்
கையொப்பம்.

CONTENTS.

	Date.	Page.	Plans.
Extract (being paragraphs 136 to 139 inclusive) from report on the Project for a Canal from the Ganges at Narora, to be termed the Lower Ganges Canal, by Captain W. Jeffreys, Superintending Engineer.	23rd November 1870.	1	
Extract (being paragraph 86) from report by the Chief Engineer of Irrigation, North-Western Provinces, by Colonel W. H. Greathead, R.E.	23th April 1871.	2	
Report by Captain Jeffreys, R.E., on the Aqueduct over Kali Nadi	9th January 1873	3	
Note by Lieutenant-Colonel H. A. Brownlow, R.E., Officiating Chief Engineer, North-Western Provinces, Irrigation Branch.	31st January 1873	4	
Report on the Accident to the Kali Nadi Aqueduct, Lower Ganges Canal, by Major F. J. Home, R.E., Superintending Engineer, 2nd Circle.	29th December 1884.	5	
Appendix A—General arrangements for providing temporary supply over Nadrai Aqueduct —		10	
Note on the failure of the Kali Nadi Aqueduct, Lower Ganges Canal, by Lieutenant-Colonel J. G. Forbes, R.E., Chief Engineer, Irrigation Branch.	25th June 1885.	11	
Note on the failure of the Nadrai Aqueduct over the Kali Nadi on the Lower Ganges Canal, by Colonel H. A. Brownlow, R.E., Inspector General of Irrigation.	15th August 1885.	13	
Report by W. Good, Esq., on the destruction of the Kali Nadi Aqueduct on the 17th July 1885.	27th July 1885.	15	
Note by Major F. J. Home, R.E., Officiating Chief Engineer, Irrigation Branch, North-Western Provinces, on the flood discharge of the Kali Nadi at the Lower Ganges Canal crossing on 17th July 1885.	19th August 1885.	21	
Note by Major F. J. Home, R.E., Officiating Chief Engineer, North-Western Provinces, on the width of the masonry channel for the new Kali Nadi Aqueduct, Lower Ganges Canal.	19th August 1885.	25	
Note by Major F. J. Home, R.E., Officiating Chief Engineer, Irrigation Branch, North-Western Provinces, on the destruction of the Kali Nadi Aqueduct.	22nd September 1885.	29	
Note by Colonel H. A. Brownlow, R.E.	13th October 1885.	32	
Letter No. C. 811L, from the Chief Engineer, North-Western Provinces, Irrigation Branch, to Secretary to Government of India, Public Works Department.	15th October 1885.	33	
Extract from note by Colonel H. A. Brownlow, R.E., Inspector General of Irrigation.	20th October 1885.	34	
Letter No. 280L, from Secretary to Government of India, Public Works Department, to Secretary to Government of North-Western Provinces, Public Works Department.	23th October 1885.	35	
Letter No. C. 944—I., from Joint Secretary to Government of North-Western Provinces, Irrigation Branch, to Secretary to Government of India, Public Works Department.	12th December 1885.	35	
Telegram from "Works," Calcutta, to Colonel Forbes, Lucknow	15th December 1885.	35	
Letter No. 1187, from the Superintending Engineer, 2nd Circle, North-Western Provinces, to the Joint Secretary to Government, North-Western Provinces, Irrigation Branch.	8th May 1886.	35	

95624

	Date.	Page.	Plans.
Note by Colonel J. G. Forbes, R.E., Chief Engineer, Irrigation Branch, North-Western Provinces, on the proposed new Aqueduct over the Kali Nadi at Nadrai, Lower Ganges Canal.		37	
Letter No. 1991, from the Secretary to Government of India, Department Public Works, to the Secretary to Government of the North-Western Provinces, Public Works Department.	25th November 1886.	39	
Despatch No. 24 P. W., from Government of India, to Secretary of State.	16th May 1887 .	40	
Memorandum by Colonel R. Home, R.E., Inspector General of Irrigation, on the new Aqueduct under construction in the Lower Ganges Canal at Nadrai.	28th April 1887 .	40	
Extract (paras. 1 to 4) from Secretary of State's Despatch No. 38 P. W.	7th July 1887 .	41	
Extract (paragraphs 1 to 4) from Despatch No. 2 P.W., to Secretary of State and enclosures referred to therein, being—		41	
(1) Letter No. 9511, of 19th November 1887 from the Government of the North-Western Provinces and Oudh.		42	
(2) A complete revised abstract of the estimate of the Kali Nadi Aqueduct.			
(3) A descriptive specification of the works.			
(4) A Note showing progress up to date.			
(5) Six tracings.			

FAILURE

OF THE

KALI NADI AQUEDUCT—LOWER GANGES CANAL.

Extract (paragraphs 136 to 139) from Report on the Project for a Canal from the Ganges at Narora, to be termed the Lower Ganges Canal, by CAPTAIN W. JEFFREYS, Superintending Engineer,—dated 23rd November 1870.

* * * * *

136. No actual measurements have been taken of the flood discharges of this river. We have been obliged to depend solely on the theoretical volume deduced from the calculations based on the longitudinal and cross sections of the Nadi, employing Eytelwein's formula for this purpose; and as the results thus obtained are almost always found to be considerably over the mark, we shall be on the safe side by adopting them as the basis on which to frame our design. Where the area of the catchment basin* is very large, as in the present case, no satisfactory results can be deduced from calculations based upon Meteorological Statistics. Allowing 6 inches to be the greatest known rainfall of 24 hours, and assuming that only one-fourth of this is passed off in surface-drainage,—which, according to Rankine and other authorities, is a small proportion,—we find the river would discharge 38 cubic feet per second for every square mile of area drained, whereas the highest flood† this Nadi has ever been known to pass down gives only 8.7 cubic feet per second per square foot.

137. There are two chief causes that may account for this great difference,—*1stly*, the greatest known rainfall in any one locality is never continuous over large areas; *2ndly*, in consequence of the extreme flatness of the country and the want of declivity in the natural outfalls of drainage, it necessarily takes a long time for the water to run off. The catchment basin of the Kali Nadi is more or less sandy, so that, except in the case of a heavy and continuous rainfall for many days successively, the greater part of the water is rapidly absorbed into the soil. The relation of the rainfall to the discharge of rivers and drainage channels is an extremely important subject, and one regarding which very little is at present known. This much is clearly established, that the smaller the area drained the nearer does the daily discharge of the outfall approach to the actual quantity of the rain which falls in the 24 hours. The proportion will, of course, vary in different countries, depending more or less on the character of the soil and the steepness of the slopes. The form of the catchment basin also exercises a great influence on the magnitude of the volume discharged. Tracts which are broad for their length will give larger discharges in proportion to their areas than long and narrow strips, simply because the water has less far to travel. The day will no doubt come when this subject will receive the attention it deserves. The services of a special officer might very profitably be employed in collecting data and framing a code of rules for determining the size of opening it would be desirable to give to drainage outlets under different circumstances. An article in the Roorkee Professional Papers, written by a Railway Engineer, shows that in the East Indian Railway very unequal provision has been made for the passage of drainage, and that, whereas some rivers have more than ample water-way, others again are contracted to an extent as to have necessitated the adoption of expensive protective measures to render the works safe from the effects of scour. I do not pretend to say that full provision should be made in every case, but it cannot be doubted that some systematic and uniform plan should be very desirable. In the case of large rivers a careful set of calculations based on the longitudinal cross sections of the channel, and aided by observed measurements of floods, form the most reliable data on which to determine the size of the openings; but in small streams the plan is by no means a satisfactory one, in consequence of the ever-varying section of the channel, and the inability to ascertain what the surface slope of the floods really is. A much more correct estimate may be gained of the actual requirements of the drainage by computing the quantity

of rain which falls within the drainage area, and by assuming that a certain proportion of this must be provided for.

138. Proceeding on this principle, and with such data as I have been able to obtain, I

Discharges of drainage outfall determined from area of catchment basins.				
For tracts of	1 to	10 square miles in extent	50 cubic feet per second	
Ditto	10 to	20 ditto	56	ditto.
Ditto	20 to	50 ditto	32	ditto.
Ditto	50 to	100 ditto	26	ditto.
Ditto	100 to	500 ditto	22	ditto.
Ditto	500 to	1,000 ditto	18	ditto.
Ditto	1,000 to	2,000 ditto	16	ditto.
Ditto	2,000 to	3,000 ditto	12	ditto.

have drawn up on a sliding scale a list showing discharges due to every square mile of area drained for tracts varying in extent. This scale, I believe, may be safely followed as a rough guide in designing

masonry works which have for their object the passing of drainage under canals or distributaries. It is not intended that this method shall supersede the ordinary one of calculating the discharge due to certain section of channel and slope of bed, but should be employed rather as an aid to the latter. Its principal value consists in affording very accurate data for comparing the extent to which provision is made in different works on the same system of canals, since it may be assumed that results cannot differ greatly in a tract of country which presents no very appreciable varieties of soil or climate.

139. Returning again to the Kali Nadi at the point of crossing in mile 34 of the main

Kali Nadi Aqueduct, line, we have a calculated volume of 26,382 cubic feet per second, and a catchment basin of 3,025 square miles in extent,

giving only 8.7 cubic feet per second per mile drained. If, with a view to allowing a considerable margin for safety, we substitute 12 for 8.7, we shall get a volume of 36,300 feet per second, to discharge which with a velocity of 10 feet per second seven bays of 33 x 15 will be required. To produce this velocity the water will be headed up about 2 feet, as shown by a dotted blue line on the section. It is fortunate, however, the difference in levels between the canal and the river admit of the arches springing from the supposed normal surface of highest known floods, so that, with the exception of 2 feet of heading up, abovementioned arch would never be subjected to submersion. It will be observed that in the design there are river wings of considerable length, founded on rows of deep wells. This feature will not add so much to the cost as may at first sight appear, since it enables the foundation to the wing walls of super-passage to be dispensed with; while it undoubtedly is a great additional source of strength and stability to the whole structure. The retaining walls of super-passages are 8 feet in thickness, through the centre of which runs a core of concrete, 2 or 3 feet thick, arched over with brick. It being necessary to provide accommodation for the passage of wheeled vehicles, it is proposed to have a roadway of 12 feet clear width, the projecting portions supported on deep stone corbels or brackets from 3 to 4 feet apart. Advantage is taken of this very marked feature in the elevation to introduce considerable architectural effect without any additional cost. Economical considerations alone determined the width of super-passage, it being contended that the waterway may be reduced until the current thereby created shall not exceed the maximum velocity against which boats are capable of being towed by ordinary means. This velocity I have fixed at 4½ feet per second or 3 miles an hour, which, for this short distance, is no unsurmountable obstacle to navigation. There are curtain walls to the sub-passage, but no masonry flooring, a layer of loose block kunkur taking the place of the latter. Pitching of the same material will also be largely used at the junction of the masonry wings with the river bank, and also in a similar position in the super-passage (see plan 34).

Extract (paragraph 86) from Report by COLONEL W. H. GREATERAD, Chief Engineer of Irrigation, North-Western Provinces,—dated 20th April 1871.

* * * * *

86. The design is for 7 arches of 35 feet springing from supposed high flood-line. No

Kali Nadi Aqueduct. cross section is given of the valley on the square, but on the line of canal, which is apparently not very oblique to the

valley; the width of the flood-surface is 4,500 feet, and there is nothing to show that any part of this water is not in movement. The flood velocity has not been observed, but it is proposed to create a velocity of 10 feet a second, which does not appear judicious in the sandy soil ascribed to the river's bed. I should reduce this to one-half by increasing the proposed waterway. To ascertain the greatest average rainfall on the whole basin, it will be desirable to collate the rain-gauge returns of all the stations at which they are established nearest to the borders of the basin. By this means Lieutenant Marshall, R.E., has obtained an average for the Upper Doab which appears quite reliable

Report by CAPTAIN W. JEFFREYS, R.E., for Superintending Engineer, 4th Circle, Irrigation Works, North-Western Provinces, in the Public Works Department, on the Aqueduct over Kali Nadi.

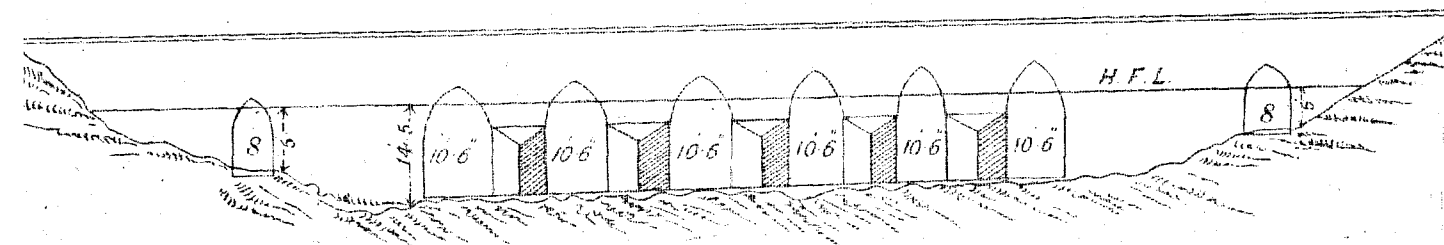
The aqueduct over the Kali Nadi will be built just half a mile above the bridge on the Bareilly and Hathras Road, and it will be seen from a survey of the river, which accompanies, that the valley here reaches its narrowest point. Taking into consideration that the trace of the proposed main channel is almost straight to the point where the bifurcation of the supply channel takes place, the line may be said in every way to be the best that could have been selected.

2. The first material alteration from the original design is in the width of super-passage, which has been increased from 127 to 192 feet in accordance with the orders of the Chief Engineer (paragraph 88 of his Note). By this arrangement, which is in accordance with my own views, a maximum volume of 5,374 feet will pass over the aqueduct with a depth of 9.4 feet and a velocity of 30 feet per second.

3. Next, as regards water-way, we find in the first place that the theoretical discharge of the highest known flood was very much over-estimated, owing partly to the section originally taken being slightly oblique to the direction of the current, and to our having taken the normal slope of river instead of the actual surface of the floods, which are here held up 1½ feet by the Bareilly and Hathras Road-bridge just below. Under these altered conditions, and employing Bazain's tables for the varying coefficient, we find the theoretical highest flood to be only 9,502 cubic feet per second.

4. The catchment basin of the Kali Nadi above Nundreye is found from careful measurement to be 2,593 square miles, which only gives a rateable discharge of 3.66 per mile. This proportion, which is very small, is due to the very sandy nature of the soil in the area drained, and to the increased number of public works by which the drainage is to a great extent intercepted.

5. Fortunately we have two methods of checking approximately the accuracy of the above figures. The Bareilly and Hathras Road-bridge already referred to one-half a mile downstream has the surface of the highest flood clearly defined on its face. The openings are nine in number, and give the following sectional area:—



$$\begin{aligned} 7 \text{ openings of } 10.5 \times 14.5 &= 1065.7 \\ 2 \text{ „ of } 5 \times 8 &= 80.0 \end{aligned} \quad \left. \vphantom{\begin{aligned} 7 \text{ openings of } 10.5 \times 14.5 &= 1065.7 \\ 2 \text{ „ of } 5 \times 8 &= 80.0 \end{aligned}} \right\} \text{ or } 1146 \text{ nearly.}$$

$$1145.7$$

The marks on the bridge and the levels lower down show that the water was headed up 1½ feet, the velocity due to which may approximately be arrived at from the formula $V = C \sqrt{29 h - 5.88}$.

(where $C = 0$)

If to this be added the normal velocity of approach, which is calculated at 1.48, we shall find the total velocity of discharge to be 7.36 feet per second, and the total volume 8,436 cubic feet per second.

6. These figures are sufficiently near to those arrived at in paragraph 3 as to warrant our assuming that the theoretical highest known flood lies between 9,000 and 10,000 cubic feet per second.

7. Besides this, we have another and more practicable test in some measurements actually taken of the Kali Nadi in flood during the season of 1871. As Mr. Codrington, the only officer at that time attached to the Lower Ganges Canal Survey Division, was absent on sick leave, the officers of the Aligarh Division were asked to undertake this duty, which they accordingly did at Oklana, 30 miles above the Nundreye crossing. The greatest volume

5, 6, 7, 8

measured, which is said to be one of the highest known by the villagers, was on the 18th August, and is recorded at 4,220 cubic feet per second. This quantity being obtained from a drainage area of 1,556 square miles, we have a right to assume that the actual discharge at Nundreyo on that or the following day, due to an increased catchment basin of 2,593 miles, would not exceed 7,033 cubic feet per second, which is singularly near the results obtained before in paragraph 5. There was no gauge of the Kali Nadi at Nundreyo in that year, but it would no doubt be found that a few inches would make the difference spoken of.

8. Although there is every reason to believe that the greatest volume of late years has never exceeded 9,500 cubic feet per second, it cannot be denied that a rateable proportion of 3.66 cubic feet per second per square mile of catchment basin is very small, and ought not to be wholly relied on in providing against future contingencies. It would, I think, be safer to design our work on the rateable proportion of 7 cubic feet per second per square mile of area drained. This is a rate that is often used in dealing with long and large catchment basins, and with such a sandy soil as that mostly found on the Anoopshuhur Branch Doab, there would not, I conceive, be any risk in employing it. The aqueduct and adjoining bed of river, if properly protected, might also easily stand a current equal to that which is supposed to have passed under the existing bridge, *viz.*, $7\frac{1}{2}$ feet per second, so that, with these data, we find that five openings of 35×14 will give the required result.

9. It is quite possible that these figures may be objected to as running too close to the theoretical limits of safety, but I cannot, with this "Mogul" Bridge of more than a century old staring me in the face, recommend any greater provision than that made in the design now submitted—a design that gives an effective water-way of 2,450 (or more correctly 2,380 superficial feet), that of the existing bridge being 1,146 feet, or less than one-half.

10. Returning again to the example already quoted of the Okhna Bridge on the Aligarh and Ramghat Road, we find that three openings of $42 \times 12 = 1,512$ superficial feet, give more than adequate provision for a catchment basin of 1,556 miles. At least we may judge this from the fact that the greatest velocity through centre arch in a supply of only 6 feet below the maximum measured only 2.4 feet per second. It so happens that the provision we are about to give of 2,380 feet for a catchment basin of 2,593 square miles very nearly corresponds with that of the Okhna Bridge.

11. I trust enough has been said to show that a fair and liberal allowance has been made in apportioning the water-way of this work. On other points in the design there is nothing more to add than what has been already described in my printed Report; the only alteration is the arching over of the spaces between the brackets that support the roadway. These adjuncts, it will be seen, are designed with a distinct purpose of utility, while it is hoped that the addition of so marked a feature will enhance the architectural effect of the whole structure.

12. The calculation for determining the velocities and discharges spoken of in the foregoing are added for reference.

Note by LEUTENANT-COLONEL H. A. BROWNLOW, R.E., Officiating Chief Engineer, North-Western Provinces Irrigation Branch, on an aqueduct over the Kali Nadi on the Lower Ganges Canal,—No. 202½ I—C., dated 31st January 1878.

A most carefully drawn design and project, doing the greatest credit to Major Jeffrey's skill and taste in designing.

2. As regards the waterway allowed for the river, although the flood volumes given by Major Jeffreys are perplexingly small, yet there seems no reason to doubt their accuracy; and making every allowance for improved facilities for the passage of drainage across the "public works" alluded to in paragraph 4 of his Report on estimate, we should only approach the condition of the valley before they existed. The Mogul Bridge, with its waterway of 1,150 superficial feet, has resisted all floods successfully for more than a century, so there is no good ground for distrusting the stability of our aqueduct with its proposed waterway of double the above area. At the same time, I hope that no further reduction will be recommended. We are rapidly draining and improving our portion of the public works in the upper valley of the Kali Nadi, and the wide-spread irrigation from the Ganges Canal and its branches over the whole drainage area under consideration has markedly raised spring levels, thereby decreasing absorptive power of soil and increasing flood discharge, so that the Mogul Bridge may yet be exposed to a strain which will either remove it or render its enlargement advisable. This would at once decrease depth of floods on the up-stream side by $1\frac{1}{2}$ feet (the amount of head-ing up now required to drive the floods through it), and reduce the available waterway through aqueduct arches to $5 \times 35 \times 12.5 = 2,187.5$ superficial feet. Still this amount of waterway would pass a flood 50 per cent. in excess of the present maximum, with a mean velocity of 6 feet, and I see no reason to apprehend a greater increase of flood volume or danger to the aqueduct from such a velocity.

3. I fully concur in Colonel Greathead's recommendation for the increase in width of the upper channel for the canal water from 127 feet, as originally designed, to 192 feet as now estimated. The increased velocity which would result from a narrower section would be dangerous in the earthen embankment beyond, and would necessitate a heavy expenditure in pitching to banks and bed.

4. As a matter of detail, I think that the blocks on which the extremities of the canal water-wings of aqueduct are founded should be sunk to the full depth of those on which the portions next to the abutments stand, as a crack is very liable to appear at the junction of masses of unequally founded masonry, and all chance of leakage at this point should be avoided as much as possible. For this reason too, the puddle cores of the embankments should be tied most carefully round the extremities of the wing-walls. But this will not affect amount of estimate, which may be forwarded to Government of India for sanction against the allotment for the Lower Ganges Canal.

Report on the accident to the Kali Nadi Aqueduct, Lower Ganges Canal,—dated Aligarh, 29th December 1884.

The aqueduct which carries the Lower Ganges Canal over the Kali Nadi (at 33 M. 3 F. 450 ft.) was almost carried away by a very heavy flood in the Nadi on the 2nd October 1884.

2. The registering gauge for the Kali Nadi is on the down-stream cut-water of No. 4 pier of the aqueduct (R. L. of zero 534.84) and the readings on this gauge during the flood which damaged the work are given below :—

1884.		
September	29th	5.5
"	30th	10.9
October	1st	14.2
"	2nd	18.7
"	3rd	18.2
"	4th	17.6
"	5th	...
"	6th	...
"	7th	14.0
"	8th	13.5
"	9th	13.0
"	10th	12.6
"	11th	12.3
"	12th	12.0
"	13th	11.7
"	14th	11.3
"	15th	11.0
"	16th	10.5
"	17th	10.3
"	18th	9.5
"	19th	9.1
"	20th	8.5
"	21st	7.6
"	22nd	6.6
"	23rd	6.1
"	24th	5.8

} Not recorded.

The gauge is only marked up to 14.5 feet, and the readings above that were registered by marks on the aqueduct wall by the Assistant Engineer; those for the 5th and 6th were, however, not recorded.

3. The highest previous flood since the aqueduct was built was on the 23rd September 1880, when the gauge rose to 16.3 feet. This flood was, however, of but short duration, the readings being—

1880.		
September	23rd	9.8
"	24th	16.3
"	25th	14.5
"	26th	13.7

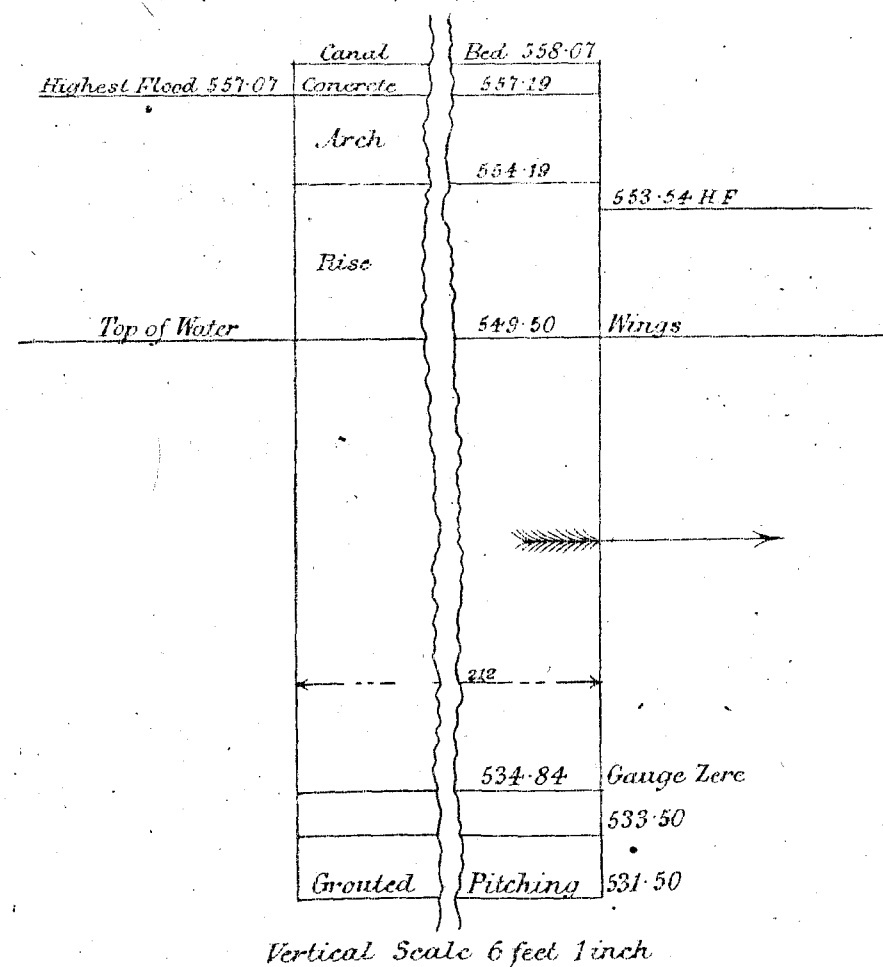
4. The magnitude of the flood of 1884 will appear still more striking if the height on the up-stream side of the aqueduct is taken into account. On the 2nd October 1884 the Assistant Engineer (Mr. F. G. Heaven) noted on the up-stream face of the aqueduct a flood

level corresponding to a reading of 22.2 feet on the down-stream gauge. The difference in surface level of flood above and below the aqueduct was, therefore, 3.5 feet, viz. :—

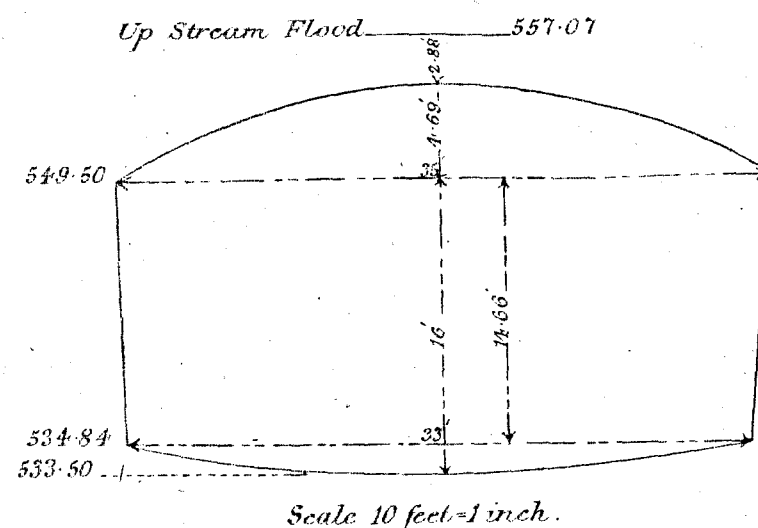
Up-stream	22.2
Down-stream	18.7
Difference	3.5

In the case of the flood of 23rd September 1880, it is recorded by Mr. Palmer (the then Executive Engineer) that the difference in surface level above and below the aqueduct was only 0.5 feet.

5. The height of the flood with reference to the principal points of the aqueduct will be seen from the following sketch :—



The elevation of each of the five spans of which the aqueduct is composed is as follows :—



6. Supposing the kunkur flooring to have remained intact up to the time when the maximum heading up was reached, the following calculations show that the flood discharge was about 37,000 cubic feet per second, with a mean velocity of 11.7 feet :—

CALCULATIONS.

Sectional area of each barrel.

Segment	$\frac{33}{11} = 111.36$
Trapezoid	$\frac{33-33}{2} \times 14.66 = 498.44$
Invert	$33 \times \frac{1.5}{2} = 23.10$
TOTAL	632.90

Total area of five spans.

$$632.90 \times 5 = 3165 \text{ s. ft.} = A.$$

Velocity.

Actual head	3.5
Additional head due to an assumed velocity of approach of 5 ft. per second	0.4
TOTAL HEAD	3.9 = H.

Taking barrel as an adjutage to an orifice, length 212, and smallest dimension 20.7 ft. the length is equal to 10 diameters and the coefficient is 0.74.

$$\text{Then } V = c \sqrt{2gH} = 0.74 \times 15.8 = 11.7 = V.$$

$$\text{Total discharge} = A \cdot V.$$

$$= 3165 \times 11.7.$$

$$D = 37,030 \text{ c. ft. per second.}$$

7. The discharge of 37,000 c. ft. per second given in the preceding paragraph does not represent the full flood discharge of the river owing to the heading up which took place above the aqueduct, and to the blocking up below by both the Hathras-Bareilly Road and the Cawnpore-Achneyra Railway. With a free flow for the river, the flood discharge would certainly have been larger, though it would not have lasted so long. It is difficult to say what the increase due to this cause would have been, but it would hardly be safe to estimate the full flood discharge of the river at less than 40,000 c. ft. per second.

8. Another point with reference to the flood discharge is the extent to which it was affected by the scour under the aqueduct before the work actually gave away. Soundings taken on the 8th October 1884, when the down-stream gauge had fallen from 18.2 to 18.5 feet, show that the increase to the sectional area was then—

No. 1 Bay (left)	30 × 10
No. 2 „	30 × 11
No. 4 „	30 × 10
No. 5 „ (right)	30 × 11.5
	30 × 42.5 = 1,275 s. feet

Deduct for No. 3 Bay, which was blocked by fallen masonry to the extent of 33 × 5 = 165 s. feet

Net increase to sectional area =	1,110 s. feet
Original area 633 × 5 =	3,165 s. feet

$$\text{TOTAL} = 4,275 \text{ s. feet}$$

On the morning of the 3rd October 1884, by which time the aqueduct has practically ceased to fall in and the Road and Railway had been breached, Mr. Good, Executive Engineer, observed that the head had fallen from 3.5 to 2.5 feet working with this head, and a sectional area of 4,275 s. ft. a flood discharge of about 44,500 c. ft. per second, and a mean velocity of 10.4 ft. is obtained from the following calculations :—

Actual head	2.5
Add for velocity of approach	0.5
TOTAL HEAD	3.0

Theoretical velocity	13.9
Coefficient	0.75
Mean velocity = 13.9 × 0.75 =	10.4
D = 4,275 × 10.4 =	44,460 c. feet per second.

9. It may appear that the mean velocities deduced above are very high, but it may be mentioned that, on the 3rd of October, the water which found its way under the right up-stream land wing rose up to above the level of the canal bed (which was dry at the time) and poured back into the Nadi over the top of the abutment.

R. L. Canal bed and top of abutment	558.07
R. L. Flood water above aqueduct on 3rd October	555.54
Height to which water was forced up	2.53 feet

Such a result could not have been attained without a very high flood velocity.

10. The catchment basin of the Kali Nadi at the aqueduct is given in paragraph 139 of the original report on the Lower Ganges Canal (page 67 of Part I of Collection) as 3,025 square miles. This area would give a factor of 13.2 c. ft. per square mile for a flood discharge of 40,000 c. ft. and a factor of 14.7 c. ft. per square mile for a discharge of 44,500 c. ft. A fresh map of the catchment basin is now under preparation, and the rain gauge returns are also being tabulated. As soon as they are ready a further report will be submitted on this subject.

11. Before proceeding to describe the accident, it is necessary to state that there is proof of the aqueduct having been in a sound condition three days before it fell. On the 30th September 1884, Messrs. Good and Heaven took a discharge through the aqueduct of what was up to that date the highest flood of the season, and for this purpose took soundings below the up-stream and above the down-stream curtain walls. The gauge reading at the time was 10.9, and the deepest sounding obtained was 11.2; the level of the block kunkur floor being at the highest point 0.34 feet below the zero of the gauge.

12. The first sign of any damage to the work was the subsidence of the canal floor about one-third of the way down No. 4 pier from the up-stream end. This was noticed at dawn on the morning of the 2nd October 1884, and was at once reported to Mr. Heaven, Assistant Engineer, who was then at Nadrai. Before Mr. Heaven reached the spot a hole about 12 feet in diameter had formed in the floor at this spot, which gradually increased in size towards the up-stream side. At 9 A. M. a portion of the up-stream canal revetment fell, and a further fall occurred about noon. By this time the extent of damage was about the same as is shown on the accompanying plan at canal bed level (sheet No. II), though small portions of the arches were still falling on the 3rd October.

13. The aqueduct is founded on circular wells. Those of abutments and piers are sunk to an average of 19 feet below bed of Nadi, or to R. L. 514.5, and the curtain wells, which are rectangular, to 10.5 feet, or to R. L. 523.0. The abutment and pier wells all rest on sand. The floor under the arches is of grouted block kunkur in the shape of an invert, R. L. of centre of invert being 533.50. The soundings taken on the 8th, 9th and 27th October are given on the accompanying chart (sheet No. III). They show on the 8th October a minimum R. L. of 511.0 (3.5 feet below well curb level) at up-stream end of No. 4 Bay, and a R. L. of 518.6 (4 feet above well curb level) at the point where the first subsidence in the canal floor was noticed.

14. The tendency of the river has always been towards its right bank, the strong stream being in No. 4 Bay, and silt being deposited in Nos. 1 and 2 Bays, above and below which silt banks also projected from under the left bank. These silt banks were cleared away before the rains of 1883, but still existed in a modified form before the rains of 1884. The flood which damaged the aqueduct appears to have had a strong set, as usual, through No. 4 Bay, to have washed out the block kunkur flooring and undermined the wells of No. 4 pier, those about a third of the way down having gone first. The soundings of the 8th October (6 days after the accident) show a bottom only 4 feet above the level of the well curbs, notwithstanding that a quantity of the arch had fallen into the bed.

15. The record plan shows that two of the wells at this point were about 9 inches out of line, but the base of the pier was within the edge of the wells. The geological section shows that the kunkur stratum, through which the wells were sunk to the sand below, was very high at the wells in question, and, consequently, more exposed to the action of the floods than where it had a greater dip. The moment this stratum was cut through there was nothing to stop the scour extending far below curb level. A note on the record plan states that "There were circular discs made of one-inch planking placed at the bottom of each well when cleared to curb level, on top of which was placed the concrete filling": a worse method of filling up the wells could hardly have been devised; but even if filled properly they could hardly have stood with so heavy a weight on them when once they had been undermined.

16. Out of 17 wells in each pier—

No. 4 pier has lost	12
" 3 " " "	5
" 2 " " "	1

No. 1 pier is intact, as are also both the abutments.

The curtain wells on the up-stream side are all gone, with the exception of the one next to the left abutment, and some of the wells under cut-waters are damaged. Of the down-stream curtain wells, only the following remain:—

No. 1 Bay	1 on left side.
" 2 Bay	1 on right side.
" 4 Bay	1 on right side.
" 5 Bay	1 on right side.

The wells under the down-stream cut-waters are all standing.

17. The ends of the down-stream water wings have been overturned and the remaining portions have separated from the rest of the work and are liable to be overturned. The up-stream water wings have not been damaged by this year's flood; the cracks in them are old ones.

18. The whole work has been most severely shaken, and there are numerous slight cracks in the portion which is still left standing, but there does not appear to have been any great subsidence in the canal floor as compared with the level of the tops of the abutments. It had been noticed during canal closures that there were always slight depressions in the floor.

19. It is only fair to the officers who were employed on the construction of the aqueduct to record that the brickwork is of the very best description. This is evident from an examination of the portions exposed by the accident, from the way in which parts of the brickwork are standing without support, and from the nature of the fractures. At pier No. 4 the up-stream end of the masonry projects 23 feet beyond the foundation well, and is standing without a crack in it. The masonry of pier No. 2 has been shown right across, at right angles to the stream, without a brick being displaced, the fracture being similar to that of a stone beam. Many other instances might be cited as testifying to the excellence of the brickwork.

20. The accident has left us with the following lengths of fairly sound work, viz.:—

Left abutment	The whole.
No. 1 Pier	"
" 2 "	197 feet from down-stream face.
" 3 "	153 " " "
" 4 "	60.5 " " "
Right abutment	The whole.

After deducting 10.5 feet for the roadway on left bank of canal, there remains 50 feet of sound floor at the narrowest point (over No. 4 pier) at our disposal for passing water across, and with half the base of the new wall on the sound portion of the pier, the minimum channel width is 46.5 feet. The orders of the Chief Engineer regarding the temporary restoration works are appended. The works in question were practically completed on the 21st December 1884, and water was passed over on the same day.

21. The failure of the aqueduct is clearly due to insufficient waterway, and even if it were possible, which is very doubtful, to restore and strengthen the work, nothing could be done which would add materially to the waterway. We should still be left with the most important work on the canal exposed to the very severe strain of a head of 3.5 feet during maximum floods—a strain which would be dangerous to a new work with the strongest foundations, and much more so to a patched work, the old portion of which has been much shaken. Taking into consideration the contingency of another accident to the work ten or fifteen years hence, when, owing to the irrigation being fully developed, the disastrous effects would be vastly intensified, it will, I feel quite sure, be far better to build a new aqueduct of sufficient waterway.

22. When the Chief Engineer inspected the works on the 6th November, and again early in December 1884, he gave orders for the preparation of rough estimates of the following works, the position of which will be seen from sheet No. I:—

- (1) Diversion of canal between the north regulator and the existing aqueduct.
- (2) New aqueduct of nine spans of 35 feet at about (33 miles 1 foot).
- (3) Removing existing aqueduct and remaking embankment.
- (4) Railway from Kasganj to new site of aqueduct *via* brickfields.
- (5) New cut for Kali Nadi, from bend above canal to Cawnpore-Ahmednagar Railway bridge.
- (6) Diversion of escape.
- (7) New bridge for Hathras-Bareilly Road.

23. The cost of the works is roughly estimated as follows:—

	Rs.
(1) Canal Diversion	1,40,000
(2) New aqueduct	8,00,000
(3) Removing old work	50,000
(4) Railway from Kasganj	65,000
(5) Kali Nadi diversion	75,000
(6) Escape diversion	12,000
(7) Bareilly road bridge	78,000
Total works	12,20,000
Tools and plant	1,00,000
Establishment charges for three years	1,80,000
GRAND TOTAL	14,50,000

APPENDIX A.

General arrangements for providing temporary supply over Nadrai Aqueduct, as ordered by Chief Engineer on the 18th October 1884.

1. Remove earthen slope inside aqueduct (left side) at once, and use it to fill in behind wings, as far as it will go.
2. Cut away all the overhanging concrete and brickwork, leaving only sound portions.
3. Fill up holes under aqueduct (sound portion first) with block kunkur up to R. L. 533.
4. Build wall along top of sound portion of aqueduct, on line already marked out, 10 feet high, 3 feet at top, 8 feet at base, about 1 foot of batter to be given outside by stepping and rest of batter to inside slop to increase available waterway.

N.B.—Lime of wall was subsequently shifted 6 feet further in at narrowest point of channel, so as to bring centre of wall over sound edge of No. 4 pier, and bottom width of wall was reduced from 8 to 7 feet.

5. Return wall to be built up-stream along top of pier No. 1 and joined on to existing right canal revetment.

N.B.—This was subsequently altered, and the wall built on top of up-stream abutment, earth banks being added as on down-stream side.

6. Return wall down-stream to be built on lime laid out on ground. It must be founded on a concrete wall of section shown in annexed rough sketch, and length to correspond with existing wings. Earth bank to be curved in to right bank as marked out on ground. Great care must be taken to join this new concrete wall to the back of the abutment so as to diminish, as far as possible, the chances and size of cracks.

N.B.—This was also modified and wall built on top of down-stream abutment.

7. Crib, 5 feet deep filled with pitching to be laid for a length of at least 80 feet and width bank to bank. Heavy block kunkur pitching to be laid beyond the cribs for at least another 50 feet in length, and both slopes to be heavily pitched for a corresponding length.

N.B.—A cistern, 2 feet deep, was subsequently given on the down-stream side.

8. Wall along aqueduct not to be founded on existing concrete. Concrete must be cut away, and wall founded on the brickwork.

9. Whole of existing plaster over concrete must be stripped off and new plaster of Portland cement put on $\frac{1}{2}$ inch thick and continued over old and new brickwork.

N.B.—Eventually only new side wall and bad portions of floor and old side wall were plastered.

10. Arrangements to be made for finishing the north regulator, east side (proposed curtain walls to be deferred), so that canal may be opened as soon as possible for boating purposes.

11. Arrangements to be made for purchase of 3 miles of light rails, and corresponding sleepers, fish-plates, spikes, &c.

12. Sixty wagons of existing pattern to be made up at Narora in addition to forty in hand.

13. Lower revetment walls of Nadrai escape fall to be built up 3 feet higher than at present. Side sloping walls to be stepped up from raised walls for convenience of access. Earthen slopes to be carefully pitched. Heavy pitching must be put in at return wall corners (better crute this part) and for 100 feet beyond, to protect slopes. Heavy pitching should also be put in below and beyond masonry floor; also pitching up-stream of crest wall must be re-laid and re-packed; much of it has shifted. All this must be done before water is passed over this fall, which will now have to carry an increased supply up to 1,200 cubic feet.

Note on the failure of the Kali Nadi Aqueduct, Lower Ganges Canal, by LIEUT.-COL. J. G. FORBES, R.E., Chief Engineer, Irrigation Branch,—No. C. 4334 I., dated 25th June 1885.

The accompanying Report, dated 29th December 1884, by the Superintending Engineer, 2nd Circle, Irrigation Works, North-Western Provinces, gives full details regarding the accident which occurred to the Kali Nadi Aqueduct at Nadrai on the 2nd October 1884, on which date a flood of about 44,000 cubic feet came down the river. After heading up 3.5 feet on the up-stream of the work, the stream rushed through the bays with an enormous velocity, at least 12 feet per second, tore out a portion of the block kunkur pitching, and eventually undermined the wells, when about one-fourth of the aqueduct proper, as shown on sheet No. 2, gave way and fell into the river. The entire structure, however, has been most severely shaken, and there are numerous slight cracks in the portion which is still left standing. The ends of the down-stream river wings have been overturned, and the remaining portions have separated from the rest of the work and are likely to fall.

The curtain wells on the up-stream side are all gone, with the exception of one next to the left abutment, and some of the wells under cut-waters are damaged. Of the down-stream curtain wells only four remain, but the wells under the down-stream cut-waters are apparently all standing.

Out of 17 wells in each pier, it is known that No. 4 pier has lost twelve, No. 3 five, and No. 2 one. No. 1 pier and the left abutment appear to be intact, but the condition of the right abutment is doubtful. A considerable portion of the clay puddling behind it was washed out by the scour which came round through the foundations of the land wings, and found its way out over the top of the abutment and between the wells. These are apparently whole, but it is extremely difficult to tell with certainty what action has taken place, as the bed is strewn with debris which has sunk down to some depth. Soundings taken a few days after the flood showed the bottom of the stream to be 16 feet below bed level, or only 4 feet above the well curbs.

2. Three days before the accident occurred, there is proof of the work having been in a thoroughly sound condition. On the 30th September 1884 the Executive and Assistant Engineers took a discharge through the aqueduct, and the soundings showed that the block kunkur pitching was in place, and at the proper level. There was nothing then to give rise to the slightest misapprehension, as everything was in good order. I may add that the Executive Engineer, Mr. Good, is a particularly observant, cautious, and painstaking officer, who would promptly have detected any signs of possible danger had they then existed.

The masonry of the structure, both as regards material and quality, is of the very best description, and reflects the greatest credit on the builder, the late Major Hall, R.E.

3. The primary cause of the damage is undoubtedly the insufficient amount of waterway allowed for the Kali Nadi.

When the project for the Lower Ganges Canal was first submitted in November 1870, it was calculated that the volume of the Kali Nadi was 26,382 cubic feet per second, but with a view to allowing a margin for safety, Captain (now Colonel) Jeffreys assumed a discharge of 36,000 cubic feet per second. To pass this amount it was proposed to give a waterway of seven bays of 35 x 15, which, with a heading up of the water of "about two feet," would give a velocity of 10 feet per second. (vide paragraph 139 of report on the project for the Lower Ganges Canal).

The Chief Engineer, Colonel Greathead, demurred to this and said (paragraph 86 of letter No. 12154, dated 20th April 1871) it did not appear judicious to create a velocity of 10 feet per second in the sandy soil ascribed to the river's bed. He suggested that this velocity "should be reduced one-half by increasing the proposed waterway" (or, in other words, that there should be 14 bays, 35 x 15), and instructed Captain Jeffreys to make further observations.

4. On the 9th January 1873 Major Jeffreys submitted a further report on the aqueduct over the Kali Nadi (vide Irrigation Proceedings No. 18, March 1873). In this report he stated that his former theoretical discharge "was very much over-estimated, owing partly to the section originally taken being slightly oblique to the direction of the current, and to our having taken the normal slope of river instead of the actual surface of the floods, which are here held up $1\frac{1}{2}$ feet by the Bareilly and Hathras Road Bridge just below. Under these altered conditions, and employing Bazin's tables for the varying coefficient, we find the theoretical highest flood to be only 9,502 cubic feet per second."

He pointed out that this gave only a rateable discharge per square mile over the catchment basin of 3.66 cubic feet, and added—"This proportion, which is very small, is due to the very sandy nature of the soil in the area drained, and to the increased number of public works by which the drainage is to a great extent intercepted."

He checked the above discharge by calculating the waterways given in the Mogul Bridge on the Bareilly-Hathras Road, and in the Okhna Bridge on the Aligarh-Hamghat Road;

and gave an actual discharge of the Kali Nadi on the 18th August 1871, when with a flood, "said to be one of the highest known," the volume measured was only 4,220 cubic feet per second. "The quantity being obtained from a drainage area of 1,556 square miles, we have a right to assume that the actual discharge at Nadrai on that or the following day due to an increased catchment basin of 2,593 miles would not exceed 7,033 cubic feet per second."

5. In summing up, however, Major Jeffreys said "although there is every reason to believe that the greatest volume of late years has never exceeded 9,500 cubic feet per second, it cannot be denied that a rateable proportion of 3.66 cubic feet per second per square mile of catchment basin is very small and ought not to be wholly relied on in providing against future contingencies."

He therefore assumed a proportion of 7 cubic feet per square mile of catchment basin, thus giving a discharge of about 18,000 cubic feet, to pass off which he proposed a waterway of 5 bays of 35 x 14, which with a velocity of $7\frac{1}{2}$ feet per second would provide for 17,850 cubic feet. He wound up by saying—"It is quite possible that these figures may be objected to as running too close to the theoretical limits of safety, but I cannot, with this Mogul Bridge of more than a century old staring me in the face, recommend any greater provision than that made in the design now submitted."

6. Although the flood volumes given by Major Jeffreys were considered by the Chief Engineer, Colonel Brownlow, to be "perplexingly small, yet there seems no reason to doubt their accuracy," and the design was therefore recommended to the Government of India for approval, which was accordingly granted and the work built.

7. Stern facts have now unmistakably proved that the proportion of 7 cubic feet per square mile is less than half of what ought to have been given, and 17 cubic feet should instead have been allowed. The reliance on the flood level shown on the Mogul and Oklana Bridges was unsafe, as apparently the fact was overlooked that in extraordinary high floods the approaches of road bridges are carried away, and the water makes a clean sweep round on either flank. In the flood of 1884 (and I believe also in that of 1889) every road bridge without exception had one or both of its approaches carried away; and the amount of waterway in the actual bridge is therefore no criterion of the volume of water passing down the stream in an extraordinarily high flood. Besides this, it was evidently forgotten that the Oklana Bridge was over the Kali Nadi alone, and that the Nim Nadi, which brought down about 10,000 cubic feet per second during the late flood, joined the Kali Nadi between Oklana and the proposed site of the aqueduct at Nadrai.

8. This dependence on the road bridges led to a lineal waterway of 175 feet only being given to the Nadrai aqueduct against 84 lineal feet* in the Mogul Bridge and 126 lineal feet at Oklana.

About two miles above the Nadrai aqueduct the Nim Nadi joins the Kali, and at some distance above the junction the Oudh and Rohilkhand Railway crosses the two streams. The bridge over the Kali Nadi has a lineal waterway of 280 feet; that over the Nim Nadi of 120 feet, thus giving a total amount of 400 lineal feet for the combined stream,† as against 175 feet allowed 45 miles lower down at Nadrai. At the Mogul Bridge, which is just below the aqueduct, the approaches on both flanks were carried away, the road for half a mile on the left bank was overtopped, and the embankment cut through and through by the water. Immediately below the Mogul Bridge the Cawnpore-Achneyra State Railway crosses the Kali Nadi by a bridge with a lineal waterway of 240 feet. Here the flood scoured out the bed to a depth of from 30 to 35 feet when the left embankment gave way behind the abutment, and a breach 120 feet in width was formed through which the flood poured and relieved the strain on the bridge.

9. The above considerations I think amply demonstrate that the waterway allowed in the Nadrai aqueduct was entirely insufficient. The first thing, however, we had to determine after the disaster was how best to utilise the ruined structure so as to enable it to carry down a supply for the irrigational wants of the Doab lower down.

After carefully inspecting the work on the 12th and 13th October (when a 12 feet flood was still passing down) instructions, which are fully detailed in the Appendix to Superintending Engineer's report, were given to carry out certain measures. Work was at once commenced, and by the energy and admirable management of Mr. Good, who was well assisted by Messrs. Nicolls and Bacon, water was passed over the damaged aqueduct on the 21st December, since which date upwards of 1,500 cubic feet per second has steadily been sent on to the lower branches, which were further supplemented by a constant supply of upwards of 1,800 cubic feet per second from the Upper Ganges Canal.

* Before the Lower Ganges Canal was opened, the waterway of the Mogul Bridge was increased, by the Irrigation Department, to 135 lineal feet.

10. After the question of the temporary supply had been settled, we had next to consider what permanent measures had to be adopted—

1st.—As regards the feasibility of so repairing the aqueduct as to make it absolutely safe.

2nd.—As regards the possibility of enlarging the waterway either by lowering the flooring and converting the work into a syphon, or by other means so as to enable it to pass off a flood of 44,000 cubic feet per second.

11. Naturally it was every person's first impulse to restore the existing aqueduct, but taking into consideration the very severe damage done to the work, and the totally inadequate amount of waterway provided, it was seen that the aqueduct could not be repaired with safety. The work might be patched up at a heavy cost, but no dependence could be placed on it; and the next heavy flood down the Kali Nadi would certainly cause a similar and probably a severer disaster than the present. The unanimous conclusion arrived at, therefore, by all the officers consulted* was that a new aqueduct must be built, and in this conclusion I entirely concur.

12. The accompanying map (sheet No. 1) shows the proposed site of the new aqueduct, and the necessary subsidiary works required.

The estimate of probable cost is as follows:—

	Rs.
(1) Canal Division	1,40,000
(2) New Aqueduct	9,50,000
(3) Removing old work	70,000
(4) Railway from Kasganj	65,000
(5) Kali Nadi Diversion	75,000
(6) Escape Diversion	12,000
(7) Bareilly Road Bridge	1,00,000
Total Works	14,12,000
Tools and Plant	1,50,000
Establishment (3 years)	1,75,000
GRAND TOTAL	17,37,000

This amount is nearly three lakhs in excess of that shown by Superintending Engineer, but since the date of his report the estimates have been worked out in detail, and the sum now entered may, I think, be confidently looked upon as accurate.

13. In anticipation of sanction the canal diversion has been commenced, and it is anticipated that water may be turned into it during the next canal closure in July or August.

Note on the failure of the Nadrai Aqueduct of the Kali Nadi on the Lower Ganges Canal.

It will be seen from the report of the Chief Engineer on the failure of the aqueduct, that I, having as Officiating Chief Engineer in January 1873 approved and recommended to the Government of India the adoption of the design, am responsible for the waterway given, and it is, therefore, incumbent on me to explain how I arrived at dimensions which have proved to be so very inadequate. This, owing to my having fortunately kept some old notes and calculations, I am enabled to do.

I may premise my explanation by remarking that trustworthy measurements of the flood discharge in the river dated from 1870 or 1871; that any local records which might have existed of floods in the river previous to 1857 had been entirely destroyed in the mutiny; and that the registers of rainfall were, at that time, except at the chief civil and military stations, open to great doubt, the accurate and extended registry of rainfall being a matter of comparatively recent date.

I see that I tabulated the weekly falls of July and August 1867 (the year of greatest rainfall in the Doab of which I could obtain records) at Meerut, Aligarh, and Mainpuri, of which stations the first was in and the two others were bordering on the catchment basin of

the Kali Nadi above the aqueduct. The greatest weekly fall was for the week, July 20th-27th:—

Meerut	9.21"
Aligarh	7.10
Mainpuri	8.20
Average	8.17

The heaviest daily falls were at—

	July 21st	22nd	23rd
Meerut	4.8	4.6	0.0
Aligarh	2.3	1.3	1.0
Mainpuri	1.3	3.2	2.2
Average	2.6	3.0	1.1

Allowing for a run off of $\frac{1}{3}$ of the rain as fast as it fell, the usual English allowance for flat sandy lands, there ought to have been a flood in the river of more than 70,000 c. ft. per second during the 23rd. Now, according to the information before me and to my own experience of the stream, there had not been more than about one-third of this volume flowing down the river.

In the first place Colonel Jeffreys' measurements gave 9,500 c. ft. per second as probable high flood discharge. This volume was, as I said at the time, "perplexingly small," but I doubled it in making my own estimate of a maximum flood. Secondly, whatever had gone down the river in 1867 had passed through the Mogul Bridge, below the site of aqueduct, without carrying anything away, although the bridge had only 1,150 s. ft. of waterway less than half of that of the proposed aqueduct. And, 3rdly, I had, on more than one occasion, once during this very year 1867, had an opportunity of roughly measuring the velocity and estimating the volume of a high flood in the river at Bulandshahr, higher up the stream than Nadrai. I had been much surprised to find how low the velocities and flood volumes were, the latter being quite as low as one-third of what I should have expected to find on theoretical considerations, drawn from English experience of flow off the ground. I attributed this to the native custom, so universally prevalent in Upper India, of holding the drainage water back in every available pond and hollow for purposes of cattle-watering and irrigation, and of growing sugarcane and rice in fields, bordered by solid ridges 12" to 18" high, in every tributary valley and depression of the ground for the sake of the moisture in the soil. The flow of the surface drainage is thus very much retarded, and the volume of floods reduced while their duration is prolonged.

I was, therefore, driven to fall back on estimate and conjecture for maximum flood discharge, and I see that I, ultimately, took this as 9 cubic feet per second per square mile of drainage area, or 23,400 cubic feet per second for a catchment of 2,600 square miles, the run off being assumed at $\frac{1}{3}$ of $\frac{1}{3}$ of a rainfall of 3" in 24 hours over the whole basin.

I must confess that I never expected more than this to come down the river to Nadrai, and, believing it to be the probable maximum discharge, I had no mind to make the waterway any greater than I considered absolutely necessary, because I had seen two arches of a bridge carried away by a flood with 2 out of the remaining 5 spans, choked with silt, shewing that mere width of span is no guarantee against injury by a sudden flood.

Where I erred was in under-estimating the rainfall of the tract.

The flood of October 2nd, 1884, which is discussed in the Chief Engineer's report, was evidently due to a rain storm, discharging 7" to 8" in 24 hours over the whole width of the basin and travelling down the stream with or just a little ahead of the flood it was creating. Now in 1873, I was, of course, aware of rainfall of 6" to 8" in 24 hours, but all the information in my possession pointed to their being very local and extending over areas not exceeding 50 square miles at the outside. To apply such a fall to the whole or even half of a basin comprising 2,600 square miles of the Gangetic Doab certainly never occurred to me. No one can regret this more keenly than I do myself: my only excuse is that I decided to the best of my judgment on the information and knowledge which I possessed at the time, both being unavoidably very imperfect. The estimated volume of the flood of October 2nd, 1884, was 44,500 cubic feet per second, and from the returns of rainfall in the local Gazette, I estimate that the average rainfall over the whole basin above Nadrai on September 30th was just 7". Applying my estimate of the "run off" to this fall, we obtain a flood discharge of $(2\frac{1}{3} \times 23,400 =) 54,600$ cubic feet per second, showing that my estimate of the proportion flowing off was not too low.

To show how very difficult it was for me to have arrived at any correct estimate of the maximum flood discharge with the information I possessed in 1873, I may mention that,

hardly had the designs been completed for a new aqueduct, based on the experience gathered from the flood of last year, when on the 17th July last an enormous flood, estimated at 125,000 cubic feet per second and due to a rainfall of 12" to 18" in 24 hours over about $\frac{2}{3}$ of the catchment basin, swept down the river, carrying away the aqueduct and wrecking the Oudh and Rohilkhand and Hathras-Kasganj Railways for hundreds of yards on either side of the stream and its tributary drainage lines. Seeing that the average annual rainfall of the tract is only from 30 to 40 inches, it most assuredly would never for one moment have entered my head to provide for such a fall as 12" to 18" in 24 hours, nor do I suppose that the recommendation would have been accepted had I made it. The very high flood of August 1878 in the Jumna was calculated to have discharged 110,000 cubic feet per second over the Okhla weir at the head of the Agra canal, the area of the catch-water basin of the river above this point being 7,800 square miles, of which area fully $\frac{2}{3}$ must lie in the Himalayas. I submit that it was a very pardonable error not to provide for a flood of larger volume as likely to flow off a drainage area of just $\frac{1}{3}$ the extent.

I have, however, said enough about my own share in this most unfortunate business, and the length of my explanations is due solely to my desire to show that my mistake was not caused by carelessness, or want of due consideration, but entirely by the unavoidably imperfect information as to the rainfall of the river basin which I possessed at the time the design for the aqueduct was prepared.

The expenditure entailed upon us by the flood of 17th July last will, I fear, be very far in excess of the sum (17½ lakhs of rupees) mentioned in the letter from the Government of the North-Western Provinces, and will in all probability be not less than 28½ lakhs of rupees for the Kali Nadi aqueduct alone. But it seems to me that we ought not to neglect the lesson taught us by this last great flood. There are several other drainage lines of very similar character to the Kali Nadi, crossed by the Lower Ganges canal, between Nadrai and the Seyngur river, and to the best of my recollection the aqueducts and syphon culverts which pass the drainage under the canal will, without exception, be found totally inadequate to carry in safety the waters of a flood at all approaching in magnitude that of July 17th, which discharged 55 cubic feet per second per square mile of drainage area. I see no reason to expect immunity from the repetition of such a flood in the tract lying immediately to the south-west of the Kali Nadi catchment, and, having regard to the very grave inconveniences and injury to agriculture that will be caused by the occurrence, say, 25 years hence, of a breach at the crossing of the Isan, Rind, or other stream similar to that which has just taken place at Nadrai, I think that we ought to look the matter boldly in the face, however unpleasant it may be to do so, and request the Government of the North-Western Provinces to enquire into and report on the steps necessary to guard against a repetition of the Kali Nadi disaster at the other drainage crossings on the Lower Ganges canal between Nadrai and the further bank of the Seyngur river. It may be considered advisable at some of the crossings of minor importance where temporary restoration of communication would not be difficult, to await the exceptional flood and decide them on the style and capacity of the new work, but the whole question ought, I think, to be taken up and carefully considered as soon as may be possible with regard to the present urgent demands on the time and attention of the irrigation staff arising from the catastrophe at Nadrai.

From W. GOOD, Esq., Executive Engineer, Narora Division, to the Superintending Engineer, 2nd Circle, Irrigation Works,—No. 3410, dated 27th July 1885.

I have the honour to submit a preliminary report on the destruction of the aqueduct over the Kali Nadi at Nadrai by the flood of 17th July 1885.

2. The heavy rains of the 14th, 15th and 16th led me to expect a high flood in the Nadi, and I stayed at Nadrai to observe its action.

3. The down-stream water level at aqueduct rose between noon and 6-30 p. m. on the 16th from R. L. 546.4 to R. L. 549.0.

4. At 4 a.m. on the 17th I was informed that the Nadi was in high and dangerous flood. I arrived at aqueduct half an hour later to find water on up-stream side a foot over canal flooring, i.e., at R. L. 559.0 and at down-stream side rushing from arches as from a fully charged pipe, settling to about R. L. 558.20.

5. As far as could be seen no damage of any kind had up to 4-30 a.m. occurred to the work.

6. Immediately after the water level a up-stream side rose 4 feet in one wave and the part of old right revetment over arch No. 1 fell in.

1972
221
23

7. At about 5 A.M. it became evident that the important part of aqueduct, the canal channel, was doomed, as vertical and horizontal cracks began to appear in new right revetment wall and as seen on down-stream face, the arch rings of Nos. 3 and 4 arches began to separate from the backing.

8. The left revetment wall and roadway over arches Nos. 3 and 4 part of arches themselves subsided at 6-15 A.M.

9. By 8 A.M. the flood at up-stream side had risen to within 8 inches of top of new right revetment wall R. L. 567.50 (water) and surged over it in waves 10 or 15 feet high, and then the whole of this right revetment from abutment to abutment, and including arches Nos. 3, 4, and 5, collapsed.

10. Arches Nos. 2 and 1 were blown up shortly after the piers standing out and partially supporting about 50 feet of left revetment wall which hung in current and greatly obstructed its flow.

11. At 9-30 A.M. the only vestige of aqueduct visible from face to face of abutment was the mass of left revetment mentioned in last paragraph. The current ran smoothly through and was practically confined between the revetment walls built last year over abutments. The water surface was now as given in annexed diagram and a series of floating objects timed by Mr. Garstin and myself from face of pilasters up-stream to face of pilasters down-stream, a length of run of 219 feet gave on the average a time of 12 seconds, and therefore a velocity of 18.25 feet per second on the surface.

12. It need hardly be said that with this velocity the action of stream below aqueduct was terrific. The water in main stream was piled up in waves 20 feet high and at intervals of about 100 feet apart, and laterally, especially towards the right, spread out into a formidable swirl which was fast cutting away the outer slope of left bank.

13. Up to this time, i.e., 9-30 A.M., the canal channel was dry, but there were strong symptoms that currents were cutting in through the up-stream land winds back of abutments. Every now and again the water burst up in spouts some feet in height through grate work of temporary canal channel.

14. At about 1 P.M. the current had fairly forced its way through at back of north-west land wing and through temporary canal bank at back of abutment, demolishing soon after first the north-west and then turning the north-east land wing.

15. The water now rushed up canal, being still impeded in its direct flow through by the mass of left revetment over arches Nos. 1 and 2. The water which rushed up canal found an exit in the Nadrai Escape.

16. At 3 P.M. the left revetment which had been so long blocking the waterway fell in, and in half an hour after the north-east land wing followed. By this time the flood had cut a channel about 100 feet wide at back of left abutment right through canal embankment; at back of right abutment also a current 50 feet wide was flowing.

17. The flood up-stream reached its maximum level at 3-45 P.M., and the following are the levels it attained:—

On right bank about 100 yards south of aqueduct. This being	
within 8 inches of top of canal bank	569.08
On right bank opposite the new Nadrai Inspection House	569.63

18. By 4-15 P.M. the water level up-stream had fallen one foot and by 5-15 another foot.

19. About 5 P.M. the flood attained its maximum level down-stream in the following levels:—

As measured at 14 feet fall on left bank a very trustworthy level	
corresponding to mile 32-5-0	561.04
At aqueduct itself mile 33-3-270	562.50
Opposite mileage 33-6½	562.23

20. At 6 P.M. the north abutment was invisible and a current 200 feet wide about was flowing in breach at back of it. The following velocity observations were again taken by Mr. Garstin and myself:—

Water level up-stream face	566.50
Down-stream	562.50
Length of run	216 feet
Timing mean	14 seconds
Velocity	15.5

21. The water levels had gone down by 7 P.M. to following:—

Up-stream	563.50
Down-stream	560.50

22. The levels since observed are as follows :—

Date.	Up-stream water level.	Down-stream water level.
18th July 1885—Morning	556.0	554.0
Ditto Evening	...	...
19th July 1885—Morning	...	550.5
Ditto Evening	} Not observed, as the heading up was im- perceptible.	549.7
20th July 1885—Morning		549.0
Ditto Evening		548.7
21st July 1885—Morning		547.8

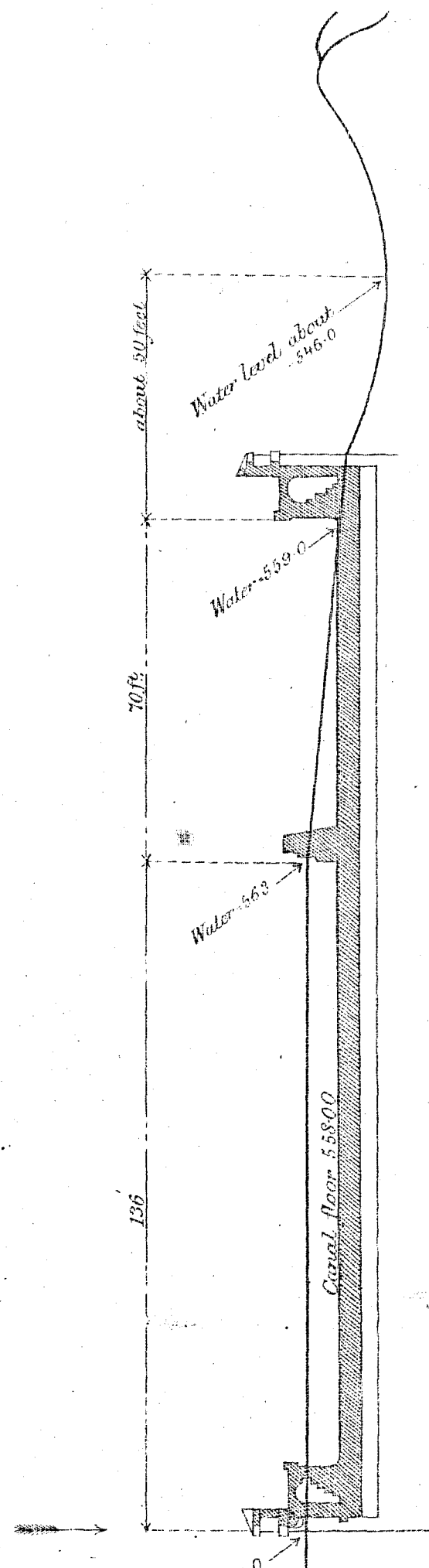
23. The only parts of aqueduct now in position are as follows :—

About $\frac{1}{3}$ rd the south abutment a good deal cracked and not likely to last, south-east land wing and south-west Nadi wing.

24. The breach at north side of aqueduct site is about 100 yards wide and now carries main current of stream; that round south abutment is from 15 to 30 yards across. Much of the outer slope of bank, especially at south-east side, has been scoured away.

25. No water passed down canal towards Asatpur, as I had the sleepers put into the south regulator at the first signs of danger, but it rose to $5\frac{1}{2}$ feet on up-stream gauge at regulator.

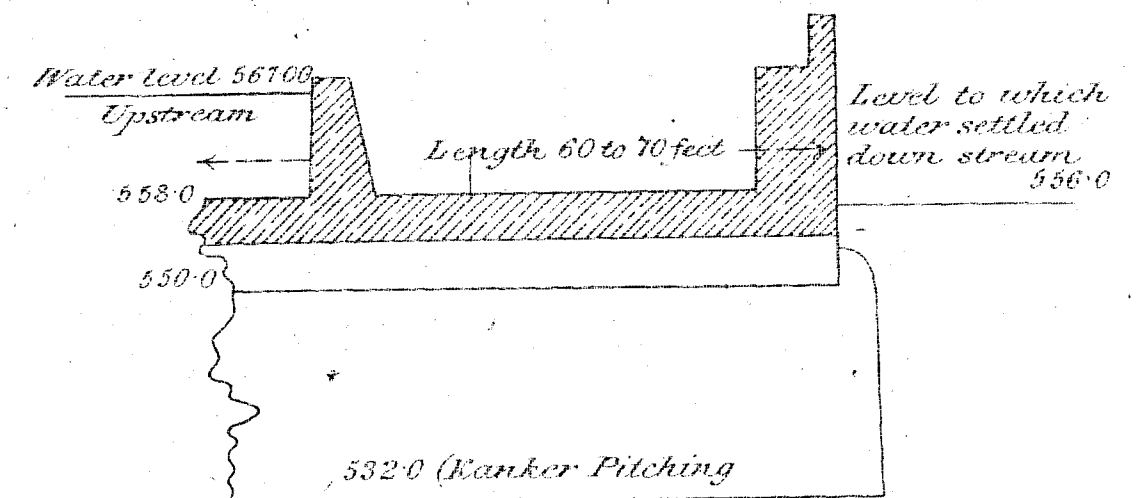
26. I annex a plan of breach and soundings taken on 21st July and three discharges calculated.



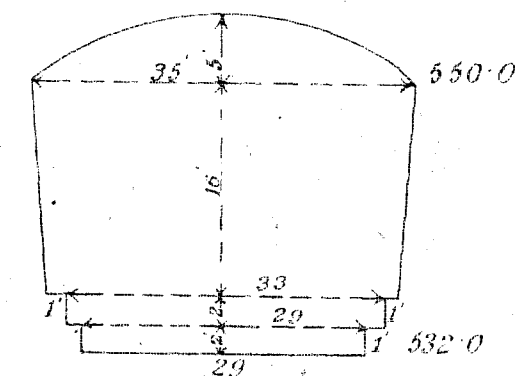
CALCULATIONS OF DISCHARGES.

(A)

Discharge at 8 A.M., i.e., just before arches were destroyed: water levels then were as follows:—



Water way was 5 arches of these dimensions



Therefore area was $= 5 \left\{ 2 \left(29 + 31 \right) + 14 \left(\frac{35 + 29}{2} \right) + \frac{1}{2} (35 \times 5) \right\} = 5 \{ 120 + 476 + 117 \} = 3565$

Now in the formula $D = A c \sqrt{2gh}$ take C as 0.90 and $D = 3565 \times 0.9 \sqrt{2 \times 32 \times 11} = 65131$ c.ft. per second.

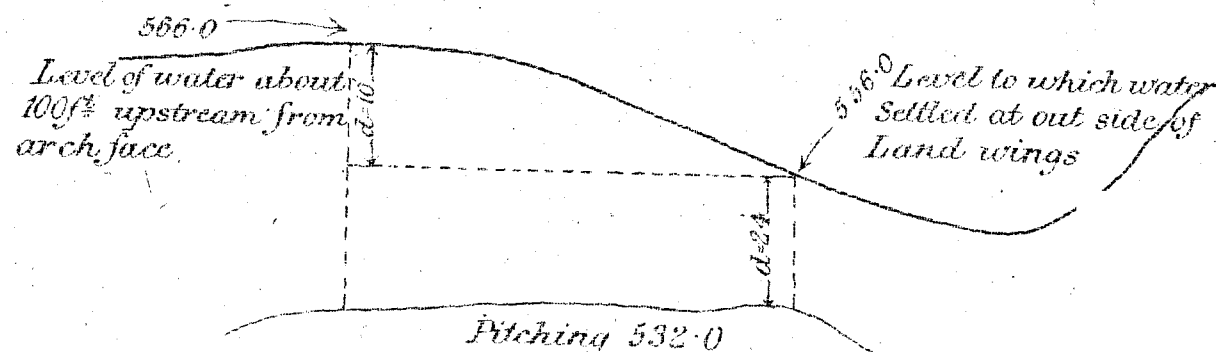
W. GOOD,
Executive Engineer,
Narora Division, Lower Ganges Canal.

(B)

Discharge at 9.30 A.M. At this time the arches had all disappeared and the current was flowing fairly between abutments but flood still rising.

It is proposed to consider the current as flowing over a submerged weir, the cill of which was level of pitching (532) and length being distance between abutments practically 200 feet and to deduct $\frac{1}{10}$ th from discharge, on account of probable obstruction by masses of piers.

The fall in current was like this, and velocity of approach 3 feet per second.



$$D = 5.04 \times 200 \left\{ 24 \sqrt{10 + 0.04 \times 3^2} + 3^2 \sqrt{(10 + 0.04 \times 3^2)^2 - 1} \right. \\ \left. \sqrt{(0.04 \times 3^2)^2} = 1008 \left\{ 77.23 + 22.23 - 0.13 \right\} \right. \\ \text{Deduct for obstruction by pier one-sixteenth} \quad \quad \quad 6.261 \\ \text{Net discharge} \quad \quad \quad \underline{93,914}$$

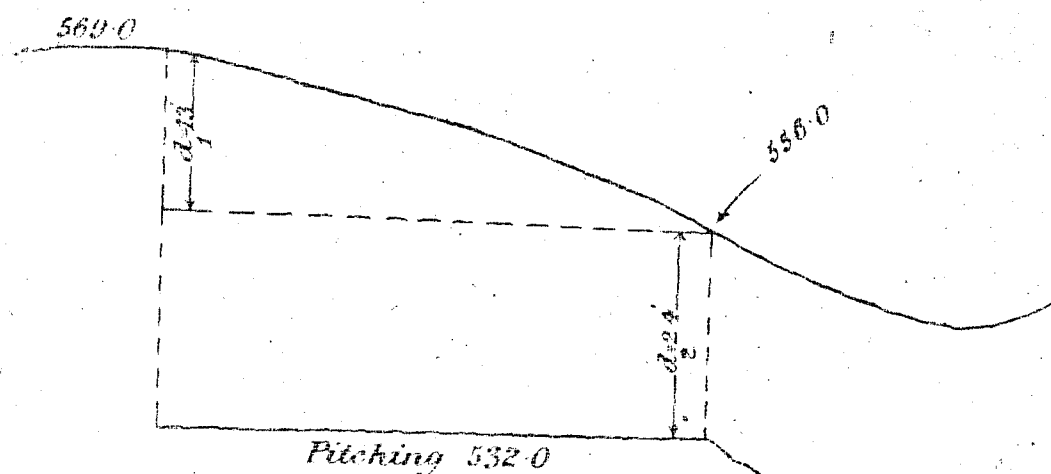
W. GOOD,

Executive Engineer,

Narora Division, Lower Ganges Canal.

(C)

Discharge at 2-50 P.M. At this time the flood had nearly ceased rising, but the breach at back of left abutment was about 100 feet wide—see para. 16 of report. The full discharge was certainly not less than this, but how much more ran it is difficult to say. Using same method of procedure as in last case (b) the outline of water is—



$$D = 5.0 \times 1200 \left\{ 24 \sqrt{13.36 + \frac{1}{2} \sqrt{(13.36)^2 - \frac{1}{2} \sqrt{(0.35)^2}}} \right. \\ \left. = 1008 \left\{ 87.72 + 32.55 - 0.13 \right\} \right. \\ \text{Deduct for obstruction by piers one-sixteenth} \quad \quad \quad 7,568 \\ \text{Net Discharge} \quad \quad \quad \underline{1,13,533}$$

W. GOOD,

Executive Engineer,

Narora Division, Lower Ganges Canal.

Note by MAJOR F. J. HOWE, R.E., Officiating Chief Engineer, Irrigation Works, North-Western Provinces, on the flood discharge of the Kali Nadi at the Lower Ganges Canal crossing on the 17th July 1883.

Mr. Good, Executive Engineer, Narora Division, Lower Ganges Canal, in his report on the destruction of the Kali Nadi aqueduct, states as follows:—

"Para. 16.—At 3 P.M. the left revetment, which had been so long blocking the waterway, fell in, and in half an hour after the north-east land wing followed. By this time the flood had cut a channel about 100 feet wide at back of left (north) abutment right through canal embankment. At back of right (south) abutment also a current 50 feet wide was flowing.

"Para. 17.—The flood up-stream reached its maximum level at 3-45 P.M. and the following are the levels it attained:—

"On right bank about 100 yards south of aqueduct	569.03
Do. opposite the new Nadrai Inspection House	569.53

"Para. 18.—By 4-15 P.M. the water level up-stream had fallen one foot, and by 5-1 another foot.

"Para. 19.—About 5 P.M. the flood attained its maximum level down-stream in the following levels:—

At 14 feet fall on left bank, a very trustworthy level, corresponding to mile	32-5-0	561.04
At aqueduct itself	33-4-270	562.50
Opposite	33-6-330	562.23

"Para. 20.—At 6 P.M. the north abutment was invisible and a current 200 feet wide about was flowing in breach at back of it. The following velocity observations were again taken by Mr. Garstin and myself:—

Water level up-stream face	566.50
Down-stream	562.50
Length of run	216 feet.
Timing (mean)	14 seconds.
Velocity	15.6 feet per second.

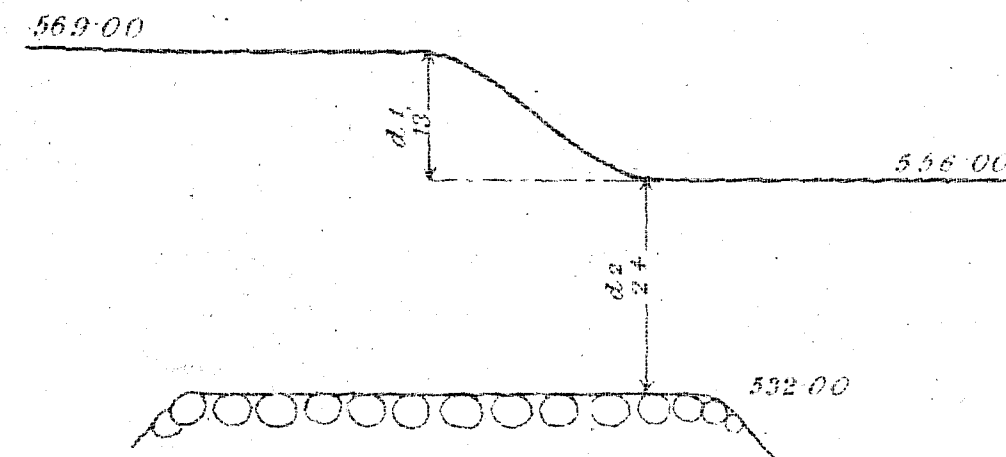
"Para. 21.—The water levels had gone down by 7 P.M. to the following:—

Up-stream	563.50
Down-stream	560.50

2. From the above it appears that at 3-45 P.M., when the flood up-stream reached its maximum, the conditions were as follows, viz.:—

(a)—Width between abutments $5 \times 35 + 4 \times 7$	203 feet
(b)—Breach behind left (north) abutment	100 "
(c)—Do. do right (south) do.	50 "
(d)—Up-stream flood level	569.0
(e)—Down-stream " "	556.0

The breach behind the left (north) abutment must have been much obstructed by the fallen masonry of the heavy land wings and by the kunkur pitching on left bank of Nadi at aqueduct, and that behind the right (south) abutment by the up-stream land and river wings which were still standing, so that the width of the breach may be taken at $(200 + \frac{100+50}{2}) = 275$ feet. The breach may then be treated as a submerged weir with crest at 532.00, the level of the kunkur pitching put into the Nadi bed before the rains, the velocity of approach being taken at 3 feet per second.



The crest of the so-called weir being very broad, the coefficient will be low and may be taken at 0.5.

Then in the formula.

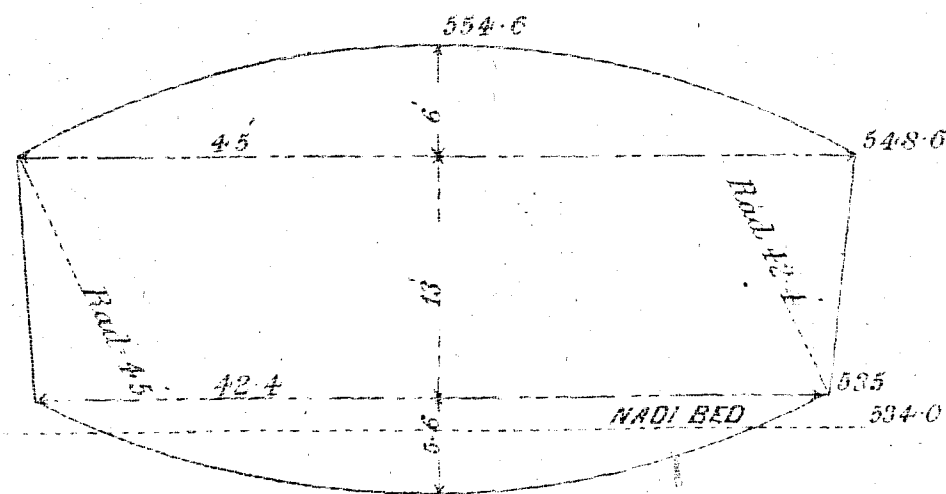
$$\begin{aligned}
 D &= 802 \text{ c. l. } \left\{ d_1 \sqrt{d_1 + 0.04 \sqrt{d_1^2 + \frac{1}{2} \sqrt{(d_1 + 0.04 d_1^2) \sqrt{(0.04 d_1^2)^2}}} \right\} \\
 C &= 0.5, 1. = 275, d_1 = 13, d_2 = 24, \sqrt{d_1} = 3.604, \sqrt{d_2} = 0.36 \\
 D &= 802 \times 0.5 \times 275 \left\{ 24 \sqrt{13.36} + \frac{1}{2} \sqrt{(13.36)^2} = \frac{1}{2} \sqrt{(0.36)^2} \right\} \\
 &= 275 \times 4.01 \left\{ 24 \times 3.655 + \frac{1}{2} \times 48.83 - \frac{1}{2} \times 0.216 \right\} \\
 &= 275 \times 4.01 \left\{ 87.72 + 24.415 - 0.108 \right\} \\
 &= 275 \times 4.01 \times 112.027 = 275 \times 451.2213 \\
 &= 124,086 \text{ c. ft. per second.}
 \end{aligned}$$

3. There are, of course, several assumptions in the above calculations, and there is a further doubt as to whether the flood volume was really at its maximum at the same time as the up-stream flood level. The widening and scouring out of the breach behind the north abutment might have reduced the up-stream flood level before the flood volume reached its maximum, and the breaches in the Cawnpore-Achneyra Railway might have had the effect of keeping the down-stream flood level fairly constant. It is, therefore, quite possible that the maximum flood volume might have been in excess of 132,475 c. ft. per second, but in that case the greater volume could not have lasted long.

4. It is considered, therefore, that the waterway of the new aqueduct should be calculated to pass a flood of, say, 130,000 c. ft. per second with a velocity of 8 feet per second. This gives a waterway of $\frac{130,000}{8} = 16,250$ square feet. There are two alternative designs; one for spans of 45 feet with inverts founded on concrete, and the other for spans of 60 feet with a floor of heavy blocks laid with their surfaces at a depth of 10 feet below the Nadi bed, the foundations of the work being wells sunk down to the clay stratum.

In the case of the 45 feet spans, we have—

Scale, 10 feet = 1 inch.

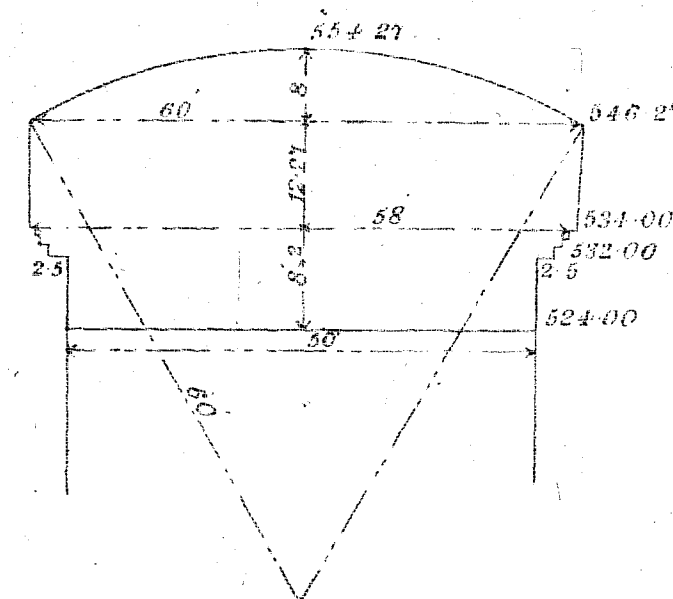


$$\begin{aligned}
 \text{Waterway of one span} &= 45^2 + \frac{45 \times 42.4}{2} \times 13 + 11 \\
 &= \frac{2025}{11} + 43.7 \times 13 + \frac{1727.7}{11} \\
 &= 184 + 568 + 163 \\
 &= 915 \text{ square feet}
 \end{aligned}$$

$$\text{and number of spans required} = \frac{16250}{915} = 17.7$$

In the case of the 60 feet spans we have—

Scale, 20 feet = 1 inch.



$$\begin{aligned}
 \text{Waterway of one span} &= \frac{60^2}{11} + 59 \times 12.27 + 56 \times 1 + 55 \times 1 + 50 \times 8 \\
 &= 327 + 724 + 56 + 55 + 400 \\
 &= 1,562 \text{ square feet}
 \end{aligned}$$

$$\text{and number of spans required} = \frac{16250}{1562} = 10.4$$

The down-stream flood level was 556.00 before the old aqueduct was outflanked, so that in both cases the openings would be submerged with a flood of 130,000 cubic feet per second.

5. Owing to the obstruction caused by the railway embankment it is difficult to say what the normal flood level would have been. According to the figures given in Mr. Good's report, it would be somewhere between 556.00 and 562.50, and it will be safe to assume that the maximum flood level on the down-stream side of the new aqueduct would not be above R.L. 559.00. The head required to generate a velocity of 8 feet per second, assuming velocity of approach of 3 feet per second and coefficient 0.8 feet, will be as follows:—

$$\begin{aligned}
 V &= 8.0 \times c. \sqrt{4 + 0.040^2} \\
 \sqrt{h + 0.36} &= \frac{8}{0.8 \times 0.8} = \frac{1}{0.8} \\
 h &= \frac{1}{0.64} - 0.36 = 1.56 - 0.36 = 1.2 \text{ feet.}
 \end{aligned}$$

This would make the maximum flood level on the up-stream side of the new aqueduct (559.00 + 1.20) = 560.20, or about 2 feet above the bed of the canal.

6. The catchment basin of the Kali Nadi at the Lower Ganges Canal crossing is 2,377 square miles, so that a flood of 130,000 cubic feet per second is equivalent to a run off of $\frac{130,000}{2,377} = 55$ cubic feet per square mile. Taking Colonel Dickens' formula of $D = C.M^{\frac{1}{2}}$ where—

D=flood discharge.
M=catchment in square miles.
C=a coefficient.

$$C = \frac{D}{M^{\frac{1}{2}}} = \frac{130,000}{2377^{\frac{1}{2}}} = \frac{130,000}{48.7} = 2669$$

against 825 deduced by Colonel Dickens; but his coefficient is calculated for steeper slopes than obtain in the Deah.

7. The catchment basin is long and narrow, having an average length of about five times its average breadth, which is rather against a high co-efficient of discharge, but Nadrai is situated just below the junction of the Nim Nadi, which tends to increase the maximum flood at that point. Out of the total area, about 840 square miles, or 35 per centum, is without the limits of canal irrigation. The bearing of the basin is about 324° east of south, so that the prevailing wind during the rainy season sweeps up it, but the heavy storms of rain which generate great floods are always cyclonic, and the direction taken by them is consequently uncertain. In the case of the flood of the 17th July 1885, the accompanying extract from the Meteorological report of the North-Western Provinces for July shows that it was caused by a small

cyclonic storm first observed at Allahabad on the 14th, and the rain gauge returns show that the centre of the storm was above the Oudh and Rohilkhand Railway: had the centre been lower down, or had the storm travelled down instead of across the basin, a still larger flood might have resulted, but so heavy a rainfall over so large an area in so short a time is not likely to be exceeded.

8. After spending a considerable amount of time and thought, the rain gauge returns for the basin, it is found that no trustworthy calculations of maximum flood discharge can be deduced from them. There are far too many unknown quantities. As an instance of this, take the case of the flood of the 2nd October 1885, which was generated by a storm passing down the whole length of the basin on the 29th and 30th September and the 1st October. There had been moderate rainfall at most of the stations on the 25th, 26th and 28th September, the averages for the whole basin being—

25th September	1.0
26th "	0.6
27th "	0.1
28th "	0.3
29th "	3.6
30th "	6.4
1st October	1.7

Dividing the basin into two nearly equal parts by a line through Bulandshahar, where the Kali Nadi is gauged, the distribution of the rainfall was—

	25th September.	26th September.	28th September.	1st October.	2nd October.	3rd October.	4th October.
<i>Rainfall.</i>							
Above Bulandshahar	0.3	4.8	6.4	0.8	NH	NH	NH
Below "	0.4	1.9	6.3	3.0	0.4	NH	NH
<i>Morning gauge readings.</i>							
At Bulandshahar	9.7	13.6	15.9	22.4 22.8*	22.5	18.2	17.5
At Nadrai	...	5.5	10.9	14.2	18.7	18.2	17.5

* Evening gauge readings.

Thus it is seen that the flood reached its maximum at Bulandshahar and Nadrai at about the same time, although the two points are 60 miles apart as the crow flies, and of course a great deal more if measured along the valley of the Nadi. It follows that the maximum flood volume at Nadrai must have been mainly due to rainfall over the lower portion of the basin, but over how much it is quite impossible to say.

9. In the case of the flood of the 17th July 1885, the rainfall and gauge readings of the Nadi were as follows:—

JULY 1885.										
	14th.	15th.	16th.	17th.	18th.	19th.	20th.	21st.	22nd.	23rd.
<i>Rainfall.</i>										
Jauli	0.2	5.7	1.3	...						
Meerut	0.95	3.25	(a)	...						
Bulandshahar	...	3.2	17.6	...						
Gangauli	...	1.7	18.2	0.7						
	(a)	(b)	(c)							
Barla	...	6.1	9.2	...						
Sikandra Rao	0.3	1.2	10.6	...						
Nadrai	1.6	1.2	2.2	...						
<i>Gauge readings.</i>										
Bulandshahar	8.7	8.8	{ 22.6 16.9 16.3 }	15.5	15.1	14.7	14.3	13.8	12.7	9.9
Nadrai (down-stream)	3.0	5.7	{ 10.8 11.2 14.2 }	18.4 27.7 24.7	19.2	{ 15.7 14.7 }	14.2 13.9	13.0	12.0	11.9

(a) This rain fell up to morning of 16th.

(b) Night of 14th and 15th 8.0
During 15th 1.1
6.1

(c) Night of 15th and 16th 7.0
During 16th 1.6
8.2

The rainfall at the stations given can be depended on: Captain Clibborn, Executive Engineer, was at Gangauli during the heavy rain; the fall at Barla was registered by Mr. Herbert Smith, who has an indigo factory there; and that at Sikandra Rao checks well with the record at the canal rain gauge: at the rest of the recording stations the rain gauges probably overflowed.

It will be noticed that the flood of July 1885 fell much more rapidly, both at Bulandshahar and Nadrai, than that of October 1884, the gauge readings two days after the maximum being lower in the former flood than in the latter. This was the natural result of a less evenly distributed rainfall.

10. It appears, then, impossible to check the calculated volume of the maximum flood at Nadrai by any reference to rainfall returns and catchment areas, but the sufficiency of the proposed waterway may be tested roughly by a comparison with that of the gap in the embankment caused by the flood. The sectional area of the beach, below proposed bed level of Nadi (534.00) as taken from the plan of breach which accompanied Mr. Good's report, is—

Between abutments of old aqueduct	$200 \times \frac{18.5 + 7.5}{2} = 2,400$
To north of old aqueduct	$= 310 \times \frac{20.5 + 18.5}{2} = 7,130$
Total square feet	9,530

Against a proposed area in the new aqueduct below
R. L. (534.0) of $11 \times 60 \times 10 =$ s. ft. 6,600

Considering that the whole accumulation of water due to a head of 13 feet had to be forced through the breach, the waterway provided appears to be sufficient.

The soil in the breach has been scoured out down to R. L. (547.50—44) = 503.50.

The geological sections taken at the proposed site for the new aqueduct showed the clay stratum at 505.00 and 506.00, which is very nearly the same level, so that there appears no fear of the clay stratum being disturbed.

Extract from Meteorological Report of North-Western Provinces for July 1885, page 1263, Part II, of Government Gazette for 29th August 1885.

Rainfall * * * * *

The heaviest rain fell on the 15th and 16th in the Meerut Division and the western districts of Rohilkhand, the heaviest of all being in the district of Bulandshahar. The average quantities measured in the two days at all the reporting stations in each district of this region were the following:—

Saharanpur	3.9	Aligarh	6.7
Muzaffarnagar	5.0	Bijnor	8.0
Meerut	3.8	Miradabad	7.0
Bulandshahar	11.7	Budaon	3.9

At Bulandshahar station 20.8 inches fell in the two days, and of this 17.6 fell on the 16th. The Collector of the district reports that this quantity is correct, but that the tahsil returns are probably much below the truth, the Ganges having been found running over in the morning. This opinion is confirmed by the observations made at some of the canal stations. From the best information obtainable, it seems that over about 1,000 square miles of the drainage area of the Kali Nadi, upwards of 20 inches of rain fell within a little more than 24 hours, so that the Kali Nadi had thrown into it upwards of 1,000,000,000 tons of water more than usual in a very short time.

The consequence was an unprecedented flood, which breached the Ganges Canal Aqueduct and the Cawnpore-Achnayra State Railway, besides doing much damage in other ways.

Wind * * * * *

The heavy rainfall of the 15th and 16th accompanied a small cyclonic storm first observed at Allahabad on the 14th.

Note by MAJOR F. J. HOME, R.E., Officiating Chief Engineer, Irrigation Works, North-Western Provinces, on the width of the masonry channel for the new Kali Nadi Aqueduct, Lower Ganges Canal, dated 19th August 1885.

The Lower Ganges Canal is designed to carry 4,100 cubic feet per second at the head; the Fatehgarh Branch, which takes off at 25½ miles, requires a supply of 625 cubic feet per second, and the loss by percolation and absorption between the head and the Kali Nadi crossing (mile 33) is certainly not less than 300 cubic feet per second, so that the ordinary supply

crossing the Kali Nadi would be $(4,100 - 825 - 300) = 3,175$ cubic feet per second. It might, however, be necessary to "tail" the head of the Fatehgarh Branch during a dry season, and in that case the supply crossing the Kali Nadi would be $(4,100 - 300) = 3,800$ cubic feet per second. The extreme case would be when, owing to any accident to the Upper Ganges Canal, the supply of the Bewar, Cawnpore, Etawah, and Bhognipur Branches had to be met from the Lower Ganges Canal alone.

The full supplies of the Mainpuri, Cawnpore, Etawah, and Bhognipur Divisions, aggregating 4,100 cubic feet per second, would then have to be passed over the new aqueduct.

Allotted full supplies, including percolation, &c.—

Mainpuri Division	700 c. ft.
Cawnpore "	1,300 "
Etawah "	1,050 "
Bhognipur "	1,050 "
TOTAL	4,100 c. ft. per second.

2. This supply of 4,100 cubic feet per second would allow of $(4,100 - 3,175) = 925$ cubic feet per second being passed on in a famine year in addition to the ordinary full supply of 3,175 cubic feet per second, or an addition of 30 per centum, and it appears, therefore, a safe basis for the calculation of the width of the masonry channel of the new aqueduct. The possibility of an accident happening to the Upper Ganges Canal during a year of drought has not been lost sight of, but it is maintained that in an emergency of this kind all the works on the canal would have to bear an extra strain, and that if it can be shown that the strain on the new aqueduct will not be dangerous, it is needless to add largely to the cost of the work by increasing the width of the channel to meet so remote a contingency.

3. The earthen channel of the embankment across the Kali Nadi Valley has a bed width of 192 feet, and side slopes of $1\frac{1}{2}$ to 1, and the masonry channel of the original aqueduct had a width of 192 feet, the same as the bed of the earthen channel: the slope of the canal bed is 0.5 feet per mile, or 0.095 per 1,000. The accompanying table gives the discharges in earthen and masonry channels of the above dimensions for depths from 6 to 9 feet, and a comparison of the two shows that the masonry channel is unnecessarily wide, while a third column shows that a masonry channel of from 155 to 160 feet would pass the volumes of the earthen channel with the same surface slope, and with velocities varying from 2.68 feet per second for a 6 feet depth to 3.43 feet per second for a 9 feet depth.

4. Now the velocity over the Solani Aqueduct, Upper Ganges Canal, is 4.24 feet per second, thus—

$$\begin{aligned} \text{Width of channel} &= 2 \times 60 = 120 \text{ feet.} \\ \text{Depth of water (full supply)} &= 10 \text{ "} \\ \text{Discharge (Do.)} &= 6,779 \text{ cubic feet per second.} \\ \text{Mean velocity } \frac{6,779}{120 \times 10} &= 4.24 \text{ feet per second.} \end{aligned}$$

Also during the first-half of this year, a supply was forced over the remains of the old aqueduct with a mean velocity of 5.5 feet per second without endangering the safety of the embankment below it, the bed and banks being duly protected with puddle and pitching. With these examples before us, a mean velocity of 4 feet per second for the maximum discharge of 4,100 cubic feet per second, corresponding to a depth of 8.0 feet in the earthen channel, can hardly be objected to, and this gives a width of 130 feet, thus:—

$$\text{Width of channel} = \frac{4100}{5.5 \times 4} = 128 \text{ feet.}$$

The last columns of the table give the results for such a channel with a slope of 0.150 per 1,000, and show that for a discharge of 4,926 cubic feet per second, corresponding to a depth of 9.0 in the earthen channel, the mean velocity would only be 4.21 feet per second or slightly less than with full supply at the Solani Aqueduct.

5. The heading up due to the contraction of the masonry channel to 130 feet will be quite nominal. The length of the channel will be about 800 feet, and the heading up due to this length will be only 0.044 feet, thus:—

$$\begin{aligned} \text{Fall through channel in 800 feet at } & 0.150 \\ & \text{---} = 0.120 \text{ feet.} \\ & 1,000 \\ \text{Normal slope of ditto ditto } & 0.095 \\ & \text{---} = 0.076 \text{ "} \\ & 1,000 \\ \text{Difference=heading up= } & 0.044 \text{ feet.} \end{aligned}$$

For a channel 1,000 feet long, the heading up would be $(0.150 - 0.095) = 0.055$ feet.

6. Finally, it may be urged against the construction of the masonry channel that navigation will be impeded by it, but it will be seen from the discharge table that the velocities will be as follows:—

	C. ft.	Depth.	Velocity.
Ordinary full supply	3,319	7.0	3.35
Maximum ditto	4,111	8.0	3.95

These velocities are lower than those on the Solani Aqueduct, and in many points of the Cawnpore Branch, and considering the short length of the aqueduct channel, it can hardly be contended that they will cause a serious obstruction to navigation.

7. It is maintained, then, that with a masonry channel 130 feet wide, and proper protection to the bed and slopes of the earthen channel above and below, the safety of the canal will not be endangered by any supply which the earthen channel can carry; that there will be no real hindrance to navigation; and that, consequently, it would be waste of money to make a larger channel.

Table of discharges in earthen and masonry channels of the Kali Nadi Aqueduct for depths of 6 feet and upwards.

Depth.	Earthen channel bed=192 feet. Slope=0.095 per 1,000.			Masonry channel bed=192 feet. Slope=0.095 per 1,000.			Masonry channel to discharge volumes of earthen channel. Slope=0.095 per 1,000.			Proposed masonry chan- nel 130 feet wide. Slope=0.15 per 1,000.		
	Area.	Velocity.	Discharge.	Area.	Velocity.	Discharge.	Bed width.	Velocity.	Discharge.	Area.	Velocity.	Discharge.
6.0	1,188	2.10	2,494	1,152	2.72	3,129	155	2.68	2,494	760	3.33	2,598
1			2,567									
2			2,640									
3			2,713									
4			2,786									
6.5	1,220	2.22	2,860	1,248	2.85	3,563	156	2.82	2,860	845	3.49	2,951
6			2,935									
7			3,010									
8			3,085									
9			3,161									
7.0	1,393	2.32	3,237	1,344	2.99	4,019	155	2.97	3,237	910	3.65	3,319
1			3,317									
2			3,397									
3			3,477									
4			3,557									
7.5	1,496	2.43	3,637	1,440	3.12	4,492	157	3.09	3,637	957	3.80	3,700
6			3,720									
7			3,803									
8			3,886									
9			3,970									
8.0	1,600	2.53	4,054	1,536	3.24	4,985	157	3.23	4,054	1,040	3.95	4,111
1			4,142									
2			4,231									
3			4,320									
4			4,409									
8.5	1,704	2.64	4,498	1,632	3.37	5,499	159	3.33	4,498	1,105	4.09	4,518
6			4,587									
7			4,676									
8			4,765									
9			4,854									
9.0	1,809	2.73	4,943	1,728	3.50	6,015	160	3.43	4,943	1,170	4.21	4,926

The 19th August 1885.

F. J. HOME, Major, R.E.,
Offg. Chief Engineer, Irrigation Works, N.-W. P.

Calculations for discharge of earthen channel of Lower Ganges Canal in the Kali Nadi embankment.

Formula used—Jackson's Table IX for canals in earth above the average—Side slopes 1 to 1.

Data— Bed width = 192 feet.

Sides slopes = $1\frac{1}{2}$ to (taken as 1 to 1).

Slope of bed = $\frac{0.5}{5000}$ or $\frac{0.09}{1,000}$.

Depths of water.	6.0	6.5	7.0	7.5	8.0	8.5	9.0
Q for S = 0.100	2,673	3,062	3,467	3,897	4,340	4,815	5,291
Q for S = 0.050	1,934	2,223	2,524	2,843	3,182	3,535	3,888
Differences for S = 0.050	739	839	943	1,054	1,168	1,280	1,403
Differences for S = 0.005	74	84	94	105	116	128	140
Q for S = 0.095	2,599	2,978	3,373	3,792	4,224	4,687	5,151
Bed 150 feet.							
Q for S = 0.100	2,404	2,757	3,119	3,499	3,904	4,330	4,756
Q for S = 0.050	1,739	2,003	2,272	2,548	2,836	3,176	3,496
Differences for S = 0.050	665	754	847	951	1,048	1,154	1,260
Differences for S = 0.005	67	75	85	95	105	115	126
Q for S = 0.095	2,337	2,682	3,034	3,404	3,799	4,213	4,630
Differences for bed = 20	262	296	330	368	405	442	472
Differences for bed = 12	157	178	203	233	255	283	313
Q for { Bed = 192 } S = 0.095	2,494	2,860	3,237	3,637	4,054	4,498	4,943

F. J. HOME, Major, R.E.,

The 19th August 1885.

Offg. Chief Engineer, Irrigation Works, N.-W. P.

Calculations for discharge in a rectangular masonry channel 192 feet wide, as in old Kali Nadi Aqueduct.

Formula used—Jackson's Table VIII for rectangular section in new rubble or in old brickwork or ashlar.

Data— Bed width = 192 feet.

Slope of bed = $\frac{0.095}{1000}$.

Depths of water.	6.0	6.5	7.0	7.5	8.0	8.5	9.0
Q for S = 0.100	3,358	3,822	4,312	4,819	5,344	5,897	6,451
Q for S = 0.050	2,428	2,773	3,136	3,513	3,906	4,319	4,732
Difference for S = 0.050	930	1,049	1,176	1,306	1,438	1,578	1,719
Difference for S = 0.005	93	105	118	131	144	158	172
Q for S = 0.095	3,265	3,717	4,194	4,688	5,200	5,739	6,279
Bed 150 feet.							
Q for S = 0.100	2,486	2,830	3,188	3,561	3,962	4,357	4,753
Q for S = 0.050	1,796	2,050	2,316	2,592	2,884	3,189	3,483
Difference for S = 0.050	690	780	872	969	1,063	1,168	1,270
Difference for S = 0.005	69	78	87	97	107	117	127
Q for S = 0.095	2,417	2,752	3,101	3,464	3,855	4,240	4,626
Difference for bed = 50	848	965	1,083	1,224	1,345	1,499	1,653
Difference for bed = 8	136	154	175	196	215	240	264
Q for { Bed = 192 } S = 0.095	3,129	3,563	4,019	4,492	4,985	5,499	6,015

F. J. HOME, Major, R.E.,

The 19th August 1885.

Offg. Chief Engineer, Irrigation Works, N.-W. P.

Calculations for widths of a masonry channel to discharge the same volumes as the earthen channel of the Kali Nadi embankment with the same slope of bed.

Formula used—Jackson's Tables VIII and IX.

Depths of water.	6.0	6.5	7.0	7.5	8.0	8.5	9.0
Q for { Earthen channel— Bed=192 ft. S=0.095 }	2,494	2,860	3,237	3,637	4,054	4,498	4,943
Q for { Masonry channel— Bed=150 ft. S=0.095 }	2,417	2,752	3,101	3,464	3,855	4,240	4,626
Difference of Q	77	108	136	173	199	258	317
Differences of Q for masonry channel—Bed width=50 feet.	848	965	1,083	1,224	1,345	1,499	1,653
Bed widths for differences of Q	4.5	5.9	6.2	7.1	7.4	8.6	9.6
Widths of masonry channel will carry the same volumes as earthen channel.	155	156	156	157	157	159	160

F. J. HOME, Major, R.E.,

The 19th August 1885.

Offg. Chief Engineer, Irrigation Works, N.-W. P.

Calculations for discharge of a masonry channel 130 feet wide with a slope of 0.15 per 1,000.

Formula used—Jackson's Table VIII.

Depths of water.	6.0	6.5	7.0	7.5	8.0	8.5	9.0
Q for bed = 150 feet	3,020	3,431	3,861	4,307	4,795	5,288	5,742
Q for bed = 100 feet	1,964	2,230	2,507	2,790	3,085	3,393	3,702
Difference for bed = 50 feet	1,056	1,201	1,354	1,517	1,710	1,875	2,040
Difference for bed = 30 feet	634	721	812	910	1,026	1,125	1,224
Q for { Bed = 130 feet S = 0.15 }	2,598	2,951	3,319	3,700	4,111	4,518	4,926

F. J. HOME, Major, R.E.,

The 19th August 1885.

Offg. Chief Engineer, Irrigation Works, N.-W. P.

Note by Major F. J. HOME, R.E., Officiating Chief Engineer, Irrigation Works, North-Western Provinces, on the destruction of the Kali Nadi Aqueduct, (at 33m. 2½f.) of the Lower Ganges Canal.

On the 17th July 1885, the portion of the Kali Nadi aqueduct which had been spared by the flood of the 2nd October 1884 was swept away by a flood of far greater magnitude, and the canal embankment was breached on both flanks. All that now remains of the aqueduct is the up-stream right river wing, a portion of the right abutment (badly cracked), and an isolated portion of the down-stream right land wing.

2. The accompanying report by Mr. W. Good, Executive Engineer, Narora Division, Lower Ganges Canal, who was an eye-witness of the destruction of the aqueduct, gives full details of the accident. It will be seen that the heading up amounted to 13 feet, even after the flanks had been turned, against 3.5 feet during the flood of October 1884, and that the flood rose with great rapidity. Mr. Good calculates the maximum flood at not less than 113,533 cubic feet per second, but as shown in separate note on the flood (Appendix B), the volume could hardly have been less than 130,000 cubic feet per second. The volume of the flood of October 1884 was calculated at about 44,000 cubic feet per second, so that this year's flood was nearly three times as great.

3. After inspecting the works on the 23rd July 1885, and consulting with the officers

Major Harrison, R.E., Superintending Engineer, 1st Circle.
Major Skipwith, R.E., Officiating Superintending Engineer, 2nd Circle.
Mr. W. Good, Executive Engineer, Narora Division.

named in the margin, it was decided that no canal water could possibly be passed over the gap by temporary expedients. With one abutment gone entirely, and the remaining portion of the other badly cracked, any attempt to get water across was plainly hopeless, and it followed the Bewar, Cawnpore, Etawah, and Bhognipur Branches must be cut off from the

Lower Ganges Canal as a source of supply, and be dependent on the Upper Ganges Canal for their water, until a new aqueduct has been built.

4. After carefully considering the question of supply, it was found that by reducingatably the supplies of the five divisions above Gopalpur, the Upper Ganges Canal could send on to the Cawnpore, Etawah, and Bhognipur Branches about three quarters of their respective full supplies, but that there would be great difficulty in feeding the Bewar Branch, which takes off at about 6 miles below the aqueduct and 16 miles above the junction works of the Upper and Lower Canals at Gopalpur. The levels do not allow of the branch being fed back up the channel of the Lower Ganges Canal from Gopalpur, and the only way in which water could be delivered would be by a new channel from about mile 197 of the Upper Canal to about mile 46 of the Lower Canal (see sketch map), and thence up the latter channel to the head of the branch. The length of this new channel would be about 11½ miles, and its cost not less than R 60,000.

5. The advantage to be gained by constructing this feeder was the maintenance of a part of the irrigation on the Bewar Branch, and the disadvantages were—

(a)—That it would cost R60,000 without bringing in any increase of revenue, as the water required for it would have to be taken from the Cawnpore, Etawah, and Bhognipur Branches.

(b)—That the already limited supply would be scattered over four branches instead of three, which means greater loss by percolation and absorption.

(c)—That the loss in the new feeder, and in the wide channels of the Lower Ganges Canal and Bewar branch, would be much greater than in the Cawnpore, Etawah, and Bhognipur Branches.

(d)—That if the Bewar Branch were closed altogether, a reduction could be made in the establishment and maintenance charges.

6. On the above considerations it was decided, with the consent of His Honour the Lieutenant-Governor, to close the Bewar Branch altogether, and to give the whole of the available supply to the Cawnpore, Etawah, and Bhognipur Branches. The necessary notification was published in the Local Government Gazette as No. C. 573 I., dated 4th August 1885.

7. The increased flood volume which has to be provided for necessitates considerable alterations in the programme laid down in Colonel Forbes' note which accompanied No. C. 549 I., dated 21st July 1885, to the address of the Government of India. The waterway of the aqueduct must be largely increased, and made sufficient to pass off a flood of 130,000 cubic feet per second in safety, and, on the other hand, the width of the masonry channel for the canal must, in view of the increased length of work, be decreased as far as is consistent with the passage of the full supply which the eastern channel can carry.

8. The main features of the design for the new aqueduct which is now submitted have been settled in correspondence with Colonel Brownlow, R.E., Inspector General of Irrigation. The work will have 11 spans of 60 feet each, and will be found on circular wells sunk down to the clay stratum which is found at about R.L. 506, nearly 30 feet below the proposed bed of the Nadi diversion. A boring at the aqueduct site, completed on the 19th September 1885, shows a stratum of stiff yellow clay 10 feet thick between R. Ls. 506.5 and 496.5, and six other borings at the same site, which were not continued down through the clay stratum, show its surface at about the same level. There is, therefore, every hope of finding a homogeneous stratum of sufficient thickness, but this will be definitely ascertained from the additional borings now in hand. The soil in the bed of the Nadi under the aqueduct, and for 50 feet above and below it, will be dredged out to R.L. 519.00, or to 15 feet below the bed of the Nadi, and a sunken floor of heavy concrete blocks, 5 feet thick, will be laid with its surface at R. L. 524, or 10 feet below the bed of the Nadi, so as to protect the foundations from scour during heavy floods. The floor has been designed and estimated as 5 feet thick, but it is thought that a thickness of 2½ feet will be ample for the flat portion, the sloping ends being made 5 feet thick with a double layer of blocks; a convenient size for the blocks would be 4' x 4' x 2½' = 40 cubic feet, or about 18 tons. The waterway available down to the level of this sunken floor is shown in the separate note on the floods (Appendix B) to be 17,152

square feet, which, with a velocity of 8 feet per second, is capable of discharging 137,456 cubic feet per second, or rather more than the estimated flood volume.

9. As regards the width of the masonry channel for the canal, it is shown in the accompanying note and calculations (Appendix C) that the proposed channel, 130 feet wide, will discharge the full supply for canal at head (4,100 cubic feet per second) with a depth of 8 feet and a mean velocity of 3.95 feet per second. The ordinary full supply at this point (3,175 cubic feet per second) would be carried with a depth of 7 feet and a mean velocity of 3.65 feet per second. With a depth of 9 feet, which is probably more than the earthen channel would stand, the discharge would be 3,950 cubic feet per second, and the mean velocity 4.21 feet per second. These velocities are all lower than at the Solani aqueduct, Upper Ganges Canal, where with full supply there is a mean velocity of 4.24 feet per second. In the case of 4,100 cubic feet being passed over the aqueduct the heading up required to give the increased slope through the masonry channel would not be more than half an inch. Provision has been made for pitching the canal bed for 100 feet above and 310 feet below, and the canal slopes for 310 feet both above and below the aqueduct, so that no danger need be feared from the effects of the increased velocity. The cost of this pitching is estimated at R15,532, and the cost of every additional foot in width of channel is fully R10,000, so that there can be no question about the economy of the proposed contraction of the masonry channel.

10. The total cost of the aqueduct with a width of 10 feet for the canal roadway is estimated at R20,16,691, and the cost of an additional 10 feet in width to allow to the Hathras-Bareilly Road being carried over it would be R1,09,563.

11. The following items in the original programme will remain unaltered, viz. :—

	R
Railway from Kasganj	65,000
Kali Nadi Diversion	75,000
Escape do.	12,000

The original provision of R1,40,000 for the canal diversion will be reduced to R75,000, that being the actual expenditure on the work before the aqueduct was carried away.

The provision of R70,000 for removing the old work will not now be required, but in its place a sum of R1,42,000 will be needed for filling up the breach, as shown in Appendix F.

Two new items have been added to the provision, viz., R10,000 for preliminary operations, including protection of breach, &c., and R60,000 for buildings, including workshops and quarters for establishment, as detailed in Appendix G.

12. The only item in the original provision which remains to be noticed is that of R1,00,000 for the Bareilly Road Bridge, and the circumstances under which this item was entered as a charge against the canal are as follows. After the flood of October 1884, the road bridge remained intact, although the embankment across the valley was badly breached, and as there was no difficulty in restoring communication across it, the Buildings and Roads Department was content to let the bridge stand as it was and take its chance of the occurrence of another large flood. The case of the canal was different: the aqueduct was damaged, and it was found necessary, in connection with the new aqueduct which it was decided to build higher up, to divert the Nadi away from the existing road bridge, so that a new bridge for the road across the Nadi diversion became indispensable. The cost of this new bridge could not fairly be charged against the road, which had already restored its communication across the old bridge, and it was therefore entered as a charge against the canal.

13. The flood of the 17th July 1885 has, however, changed the conditions considerably; the road bridge has been so seriously damaged that communications cannot be maintained across it during the rains; the embankment has been swept away for a considerable distance on its left flank; and if the road is to be maintained on its present alignment, a large outlay must be incurred on a new bridge and repairs to the embankment. The new bridge would, of course, have to be built over the Nadi diversion, but it does not appear that the change of site would entail any additional expense, and there is no reason why the canal should bear any portion of its cost.

14. The outlay against the original provision of R1,00,000 for the Bareilly Road Bridge is estimated at R1,309, and this sum is all that is fairly chargeable against the Lower Ganges Canal.

15. Now that the road has been so badly damaged, the present alignment should certainly be abandoned, and the road diverted either across the new aqueduct for the Lower Ganges Canal or across the Cawnpore-Achneyra Railway Bridge. In the former case, the road would be kept well out of the reach of the highest floods by being added to the down-stream (left) side of the canal embankment in the shape of a berm, a result only attainable on the present alignment by a high embankment, which, in addition to those of the canal and the Cawnpore-Achneyra Railway, would make a third obstruction within about a mile. The road would be

passed over the aqueduct by the addition of a width of 10 feet to the canal roadway, and over the Nadrai escape head by an addition of 12 feet to the present roadway. After crossing the escape head the road would rejoin the existing alignment by a watershed line along the high bank of the Nadi. The increase in length of the road would be about a mile. The accompanying note (Appendix II) shows that the cost of the diversion over the aqueduct would be—

	R
Additions to aqueduct	1,09,563
„ to escape head	2,733
Road diversion	26,464
Total for works	1,38,760

This is probably less than the cost of a new bridge on the present alignment with proper embankments, but after consulting with Colonel Lang, R.E., Chief Engineer, Roads and Buildings Branch (see note at end of Appendix II), it is found that the diversion over the railway bridge will be shorter and cheaper, and the latter will consequently be carried out by the Roads and Buildings Branch, quite independently of the works required for the canal.

16. The revised provision for the works chargeable against the Capital Account of the Lower Ganges Canal is compared below with the original provision :—

Name of work.	Original provision.	Revised provision.
	R	R
Preliminary operations	...	10,000
Canal diversion	1,40,000	75,000
New aqueduct	9,50,000	20,16,691
Removing old work	70,000	...
Filling in breach	...	1,42,000
Railway from Kasganj	65,000	65,000
Kali Nadi diversion	75,000	75,000
Escape/diversion	12,000	12,000
Barrelly road bridge	1,00,000	1,309
Buildings	...	60,000
Total work	14,12,000	24,57,000
Tools and plant	1,50,000	2,50,000
Establishment	(a) 1,75,000	(b) 5,65,000
TOTAL PROVISION	17,37,000	32,72,000

(a) For three years at estimated actual cost.

(b) At 23 per centum on the cost of works.

The total increase of Rs 10,45,000 under "Works" is covered by the increase in cost of the aqueduct (Rs 10,66,691). The provision for tools and plant bears about the same proportion to the total cost of works as in the original programme. The provision for Establishment is proportionately owing to the percentage laid down by the Public Works Code having been applied. The urgency of the work necessitates an ample allowance under this head, as work may have to be carried on day and night.

Note by COLONEL H. A. BROWNLOW, R.E., dated 13th October 1885.

Major Home is correct in saying that the main features, or rather outlines, of the design were settled in communication with me; but when I suggested a waterway of 11 spans of 60 feet, I had not seen the calculations of probable maximum flood discharge, and was under the impression that 125,000 cubic feet per second represented the largest volume with which we should have to deal. But, having studied the calculations given in Major Home's Appendix B, I see so many elements of uncertainty in the various assumptions made that I should be very unwilling to affirm positively that the maximum discharge had not been 33, or even 50, per cent. greater than 125,000 cubic feet.

The assumption of width of breach is necessarily uncertain. It seems to me that it cannot well have been less, and may have been more than that assumed in the calculation. It is impossible to say for certain that the assumed reduced level of crest of submerged weir (R. L. 532.00) is correct, unless the pitching at that level was found intact after the flood, which I do not gather from the papers that it was. It may all have disappeared before 3.45 p.m.; indeed, judging from the very high velocities measured, most probably had done so, in which case we have to deal with a considerably increased value of d_2 in the calculation. Again the velocity

of approach has most probably been assumed far too low, when taken as only 3 feet per second, for the marked acceleration of bottom velocities above a strong contraction of a river channel would prevent any fair inference being made by ordinary rules of velocity of approach from mere observation of surface velocity. Lastly, 0.50 is most probably far too low a coefficient of discharge for volumes and depths so great as those involved in the calculation under discussion. Taking all these doubts and arguments into consideration, I am strongly of opinion that it will require at least 15 spans of 60 feet to pass such a flood as that of 17th July last in safety; but before finally recommending the adoption of this increased waterway, I thought it right to telegraph to Colonel Forbes, the Chief Engineer of Irrigation Works in the North-Western Provinces, for his opinion on this point. He has not expressed any in the papers now sent up; is on the spot, and can readily clear up any doubtful points by reference to officers who witnessed the flood; and where such heavy expense is already involved, I think it only proper that the Government of India should have the advice of the local Chief Engineer before further outlay is incurred.

There is another point which, I think, requires consideration in the design. In the calculations of "Pressure on base of pier wells," it is assumed that the weight of the well itself is balanced by the resistance to sinking due to the corbellings between wells and the friction due to the earth pressure around them. But, under the conditions of construction shown in the design, i.e., with the bed of river dredged out to 15 feet below dry weather level, in order to admit of laying of a sunken floor, it is plain that no dependence can be placed on the corbelling to sustain weight of well, and that the frictional stability of only 15 out of the 30 feet of depth of the well can be relied on for the same purpose. Not more than 140 lb per superficial foot can be allowed as frictional stability of wells, only 15 feet down in undisturbed soil, so that, for a 20 feet well, we have—

Weight = 3141 s. feet $\times$ 30 feet $\times$ 110 lb = 1,036,530 lb.
Frictional stability = 62.83 s. feet $\times$ 15 feet $\times$ 140 lb = 131,943 lb.

Balance unsupported 904,587 lb.

or $\frac{904,587}{314} = 2,880$ lb or 1.28 tons per s. foot. But the other pressures amount to 3.1 tons, so that 4.38 tons per square foot will be real pressure on the soil underlying base of well. This pressure should not however, in my opinion, exceed $2\frac{1}{2}$ tons. On no account would I reduce the thickness of the proposed sunken floor below 5 feet unless it can be laid in a dry bed, so as to ensure bond and fair abutting of blocks, which would not, I fear, be possible. In view of the pressing urgency of the work, immediate provisional sanction should be given to the estimate now submitted, so as to admit of work being pushed on without any delay, but a copy of this note might go to the Government of the North-Western Provinces with a request that the questions raised in it may receive careful consideration.

From COLONEL J. G. FORBES, R.E., Chief Engineer, Irrigation Works, N.-W. P. and Oudh, to the Secretary to the Government of India, P. W. Dept.,—No. C. 811 L, dated 15th October 1885.

With reference to your telegram No. 92, dated 10th instant, I have the honour to state that as Major Home, Officiating Chief Engineer, in his Note on the destruction of the Kali Nadi Aqueduct, had stated that "the main features of the design for the new aqueduct" (consisting of 11 spans of 60 feet each) "had been settled in correspondence with Colonel Brownlow, R.E., Inspector General of Irrigation," I did not think it incumbent on me to enter into any very detailed examination of the figures on which the calculations of discharge, waterway, &c., were based.

2. I have now done so, and after carefully going over the facts and figures previously brought forward, concur with Inspector General of Irrigation in considering that, on the whole, it would be advisable to increase the number of spans proposed.

3. As stated by the Inspector General of Irrigation Works, there are many elements of uncertainty in the calculation of the flood volume; but the data given by Major Home are the only ones we have to go upon, and in making his calculations, although many assumptions are necessarily made, he has allowed a margin.

4. The waterway proposed in the design forwarded to Government of India was 11 spans of 60 feet. This gave a total superficial area of 17,182 square feet, which for the 2,377 square miles of catchment basin is equivalent to a waterway of 7.23 square feet per square mile of area. This amount may possibly be considered somewhat too small, as 7.10 square feet per square

mile were found insufficient in the waterways of the Sind, Punjab and Delhi Railway during the floods of 1878 in the Jullunder District, when 11 inches of rain fell in 24 hours. The two cases, however, are not quite analogous, as the Kali Nadi area is much larger than those crossed by the Sind, Punjab and Delhi Railway, and other conditions also are somewhat different.

5. Inspector General of Irrigation proposes 15 spans of 60 feet. This would give 9.85 square feet of waterway per square mile; but this, I think, is unnecessarily large. For although it is true that on the Gunduk embankments, waterways of 10 square feet per square mile were insufficient, and had to be increased to 13 and 14 square feet, yet it must be borne in mind that the catchment areas were very small, and were situated at the foot of the hills.

6. I would recommend 13 spans of 60 feet each, with two abutment piers dividing the waterway into 5 bays in the centre and 4 bays on either side. This would give 8.54 square feet of waterway per square mile of catchment area.

Note by COLONEL H. A. BROWNLOW, R.E., dated 20th October 1885.

On receiving Colonel Forbes' telegram above noted, I ordered case to be held over pending receipt of the report by him on the question of waterway of aqueduct. I have been giving the matter much thought, and after due consideration of Colonel Forbes' memorandum, I still adhere to my recommendation of 15 spans of 60 feet. Colonel Forbes says that, "although many assumptions are necessarily made, he (Major Home) has allowed a margin." Major Home obtains by calculation a maximum volume of 132,475 cubic feet per second, admitting that there are many assumptions in the calculation; that there is a further doubt whether the flood volume was really at its maximum simultaneously with the maximum surface level attained by the flood (*a most reasonable doubt*), and that "it is quite possible that the maximum flood volume might have been in excess of 132,475 cubic feet per second, but in that case the greater volume could not have lasted long." He then assumes the maximum flood discharge at 130,000 cubic feet per second, which seems to me allowing a margin in the wrong direction. But as stated in my Note of 13th October, the values assumed by Major Home, in his calculation, for—

- (1) the width of breach, 1,
- (2) d_1
- (3) velocity of approach,
- (4) coefficient of discharge,

cannot have been more, but may very well have been considerably less, than the truth, and Colonel Forbes does not touch the question of above values in his memorandum? I know that it is impossible to assign accurate values to them, but, in such a case as this, we ought to keep well on the safe side; and much as I respect Colonel Forbes' judgment, I do not think that he has made out any case for giving only 13 spans. I have arrived at my 15 in the following way, rough and ready I admit, but still the best I can hit on. If we know correctly the *maximum* flood volume, I would be satisfied to let it pass through the bridge, with its strong sunken floor, with a velocity of 8 feet per second. This velocity is undoubtedly high, but maximum floods occur very rarely, and occasional high velocities do not do permanent damage. But I have no mind to increase this velocity to any great extent, and I can give no reason why the coefficient of discharge, with such abnormally great values of d_1 and d_2 as 13 feet and 24 feet, should not have been 0.75 instead of 0.50. Indeed my own opinion is that it was *very much* nearer the former than the latter figure, and Major Home himself assumes the value of C as 0.80 in a precisely analogous calculation a little further on (in Appendix B of General No. 12425). This increase in value of C immediately increases the discharge 50 per cent. and necessitates an increase of 50 per cent. in area of water-way if we are to maintain the velocity at 8 feet a second. This would require 16 to 17 spans; but, having regard to thickness of the sunken floor and *extreme rarity* of maximum floods, I think we may rest content with 15 spans, divided as proposed by Colonel Forbes into 3 sets of 5 by abutment piers. If therefore Secretary agrees with me, I think we should tell the Government of the North-Western Provinces that, after careful consideration of the matter and of the Chief Engineer's Note, the Government of India would prefer that 15 bays of 60 feet each, divided as mentioned above, should be given to the aqueduct. This would dispose of the first part of my Note of 13th, and, with reference to the concluding portion, we might briefly embody the substance of it in our letter, and ask for a revised abstract of estimate showing exact amount requiring sanction; authority to go on at once with the work being provisionally granted.

From the Government of India, P. W. Dept., to the Secretary to the Government, N.-W. P. and Oudh, P. W. Dept.,—No. 2801, dated 28th October 1885.

No. C.6901, of 4th September 1885. I am directed to acknowledge the receipt of your letters "C.7441," 30th " " noted on the margin, on the subject of the rebuilding of the "C.8111," 15th " " Nadrai Aqueduct on the Lower Ganges Canal.

2. After careful consideration of the papers submitted with your letters under reply, including the note by the Chief Engineer, the Government of India prefer that the new aqueduct should be built with fifteen bays of sixty feet each, divided into three sets of five each by abutment piers, and a telegram to this effect was despatched to you on the 26th October 1885.

3. In returning the estimates received with your letter No. C.7441, of the 30th September 1885, for revision on this basis, I am directed to request that the foundations of the piers may be so designed that the pressure on the underlying soil may not exceed 2½ tons to the square foot, and that in making the calculations due allowance may be made for the loss of friction and earth pressure on the sides of the wells owing to the excavations necessary for laying the sunken floor; and to remark that the thickness of the proposed sunken floor should on no account be reduced below five feet, unless it can be laid in a dry bed so as to ensure bond and a fair abutting of the blocks of which it is to be composed.

4. I am to request that a revised abstract of the estimate, showing the exact amount requiring sanction, may be submitted as early as practicable, and to communicate authority to proceed with the work in the meantime.

From COLONEL J. G. FORBES, R.E., Joint Secretary to the Government, N.-W. P. and Oudh, P. W. Dept., Irrigation Branch, to the Secretary to the Government of India, P. W. Dept.,—No. C.9441, dated 12th December 1885.

With reference to correspondence ending with your letter No. 2801, dated the 28th October 1885, I am directed to submit, for the orders of the Government of India, the question as to the diameter and depth of wells to be used for the foundations of the new Nadrai Aqueduct.

2. The papers marginally noted give full information on the subject. They are forwarded in original, to save time; and it is requested they may be returned as soon as possible.

1.—Memorandum by Major F. J. Home, R.E., on well foundations for the piers, dated 14th November 1885.
2.—Memorandum in continuation of above, dated 13th December 1885.
3.—Estimates, Nos. I, II, III and IV, with detailed calculations.

3. The Chief Engineer concurs with the Superintending Engineer's opinion, and recommends that estimate No. II for one row of wells, 20 feet in diameter below piers (two rows below abutments), sunk to a depth of 40 feet, be adopted; and as the waterway is now increased by 1,500 superficial feet more than that ordered by the Government of India, Colonel Forbes would further strongly recommend that the spans of the arches be reduced from 60 to 50 feet. This will thus further reduce the pressure on wells; reduce the cost, both in masonry and earthwork; and, furthermore, will give the great advantage of enabling work to be carried on in a less dangerous space than the present orders admit of.

4. I am to request the favour of early orders as to the dimensions, &c., of the wells being communicated by telegraph.

Telegram from "Works," Calcutta, to COLONEL FORBES, Lucknow,—dated 15th December 1885.

Your 944 of 12th. Government of India agrees to proposals in your paragraph 3, the total clear waterway to level of surface of sunken floor being maintained at not less than 23,430 superficial feet.

From the Superintending Engineer, 2nd Circle, Irrigation Works, North-Western Provinces, to the Joint Secretary to the Government of the North-Western Provinces and Oudh, Public Works Department, Irrigation Branch,—No. 1157, dated 8th May 1886.

I have the honour to submit, for sanction, designs and estimates for a new aqueduct over the East Kali Nadi (at 33 miles 1 f.) of the Lower Ganges Canal, and subsidiary works amounting to Rs 49,73,100 as follows, viz:—

	R
(1) Works	49,73,100
(2) Establishment at R23 per cent.	8,45,800
(3) Tools and Plant	4,50,000
Total	49,73,100

2. The original aqueduct, which consisted of five spans of 33 feet each, was partially destroyed by the flood of the 4th October 1884, but it was at once repaired, and water was run over it on the 21st December 1884, in time for the "Rabi" irrigation.

3. The flood of the 4th October 1884, the volume of which was calculated to be from 40,000 to 50,000 c. feet per second, caused so much damage to the old aqueduct that the necessity for a new aqueduct of increased waterway was at once recognised, and it was proposed to build a new work with nine spans of 35 feet a little higher up. The canal was to be diverted round it, and it was hoped that the old aqueduct, which had been strongly protected in the bed of the nadi, would have held together until the new work was completed.

4. By the commencement of the rains of 1885, the canal diversion had been completed nearly up to bed level, and rough designs and estimates for the new aqueduct and contingent works had been prepared, but on the 17th July 1885 a flood of three times the magnitude of that of the 4th October 1884, and calculated to have discharged between 130,000 and 140,000 c. feet per second when at its height, entirely swept away the remains of the old aqueduct and upset all former calculations.

5. This extraordinary flood, which is fully described in Appendix A, headed up 13 feet at the canal crossing, and rose nearly to the top of the canal bank, the depth of water on the up-stream side of the aqueduct being 34 feet above the bed of the nadi, and on the down-stream side 21 feet. It turned the left flank of the aqueduct, and scoured out a breach in the embankment 300 feet long right down to the clay stratum which is found at 30 feet below the nadi bed. Taking the discharge at 130,000 c. feet per second, the run off per square mile of catchment (2,377 square miles) was nearly 56 c. feet per second, which is quite unprecedented in the annals of floods in these provinces.

6. In September 1885 an estimate was submitted for an aqueduct of eleven spans of 60 feet founded on wells sunk down to the clay stratum at 30 feet below the bed of the nadi, with a floor of concrete blocks 5 feet thick sunk 10 feet below the nadi bed, so as to give increased waterway during extraordinary floods. The waterway of this aqueduct aggregated 17,182 s. feet, which gave a waterway of 7.23 s. feet per square mile of catchment (the total catchment being 2,377 square miles) and a mean velocity of 7.56 feet per second with a flood of 130,000 cubic feet per second. The width of the canal channel was reduced from 192 to 130 feet in accordance with the calculations given in Appendix C.

7. The estimate was returned with the Government of India's No. 280 I., dated 28th October 1885, for amendment in the following particulars, viz., the number of spans was to be increased from eleven to fifteen, and they were to be divided into three sets of five spans each by abutment piers. The foundations of the piers were to be designed so that the pressure on the underlying soil might not exceed 2½ tons to the square foot, and in making the calculations due allowance was to be made for the loss of friction and earth pressure on the sides of the wells owing to the excavations necessary for laying the sunken floor, and the thickness of the proposed sunken floor was on no account to be reduced below 5 feet unless it could be laid in a dry bed so as to ensure bond and a fair abutting of the blocks composing it.

8. The design now submitted has been drawn out in accordance with the above conditions and provides a waterway of 23,325 s. feet or at the rate of 9.81 square feet per square mile of catchment. With a flood of 140,000 c. feet per second the mean velocity through the aqueduct would be 60 feet per second. The foundation wells will be sunk down through the clay stratum till the bottoms of the curbs are 41½ feet below the nadi bed, that being the depth at which the pressure at the bases of the pier wells will not exceed 2½ tons. The cost of the aqueduct is estimated at Rs29,82,300.

9. Besides the aqueduct proper, subsidiary works, which have been arranged under the following heads, will be required:—

	R
II.—Preliminary operations	32,000
III.—Railways	1,02,000
IV.—Buildings	70,000
V.—Canal diversion	1,15,000
VI.—Nadi	1,00,000
VII.—Escape	10,000
VIII.—Filling in breach	1,90,000
IX.—Miscellaneous works	76,000
Total Subsidiary Works	6,95,000

A description of these works will be found with the estimate of cost.

10. The total of the estimate for 1—Works will then be Rs37,50,000, viz.:—

Aqueduct proper	Rs 29,82,300
Subsidiary works	6,95,000
Total (1) Works	Rs 36,77,300

The cost of establishment has been calculated at the usual rate of 23 per centum, and amounts to Rs8,45,800, and tools and plant are estimated to cost Rs4,50,000 as shown in the separate abstract for them.

11. As shown in the report on the aqueduct proper, it is hoped that the works will be completed by October 1889, and that water will be passed over the new aqueduct in time for the irrigation of "Rabi," 1889-90.

12. In submitting this estimate I would bring to the special notice of Government the great assistance that I have received from Mr. M. Nethersole, Assistant Engineer, who has been posted to my office as Personal Assistant for the last twelve months. Mr. Nethersole has prepared the whole of the designs for the new aqueduct, and they do credit to his taste and ability. He has also worked out all the calculations for the stability of the different parts of the work, and has taken out the quantities. The design and estimate submitted in September 1885 were also his work.

13. In addition to the general abstract of cost appended to this letter, the following books are also submitted, viz.:—

- Book 1.—Report and estimate of aqueduct proper.
- " 2.—Report and estimate of subsidiary works and tools and plant.
- " 3.—Appendices.
- " 4.—Drawings.

LOWER GANGES CANAL.

NEW AQUEDUCT OVER KALI NADI (AT 33 MILES 1 P.).

General Abstract of Cost.

Details.	Amount.	Total.
1.—WORK.	R	R
I.—Aqueduct proper	29,82,300	
II.—Preliminary operations	32,000	
III.—Railways	1,02,000	
IV.—Buildings	70,000	
V.—Canal diversion	1,15,000	
VI.—Nadi	1,00,000	
VII.—Escape	10,000	
VIII.—Filling in breach	1,90,000	
IX.—Miscellaneous works	76,000	
Total, 1.—Works		36,77,300
At 23 per centum, 2.—Establishment		8,45,800
3.—Tools and Plant		4,50,000
GRAND TOTAL, KALI NADI AQUEDUCT		49,73,100

F. J. HOME, Major, R.E.,

Superintending Engineer, 2nd Circle,

Irrigation Works, N.-W. Provinces.

Note by COLONEL J. G. FORBES, R.E., Chief Engineer, Irrigation, North-Western Provinces, on the proposed new Aqueduct over the Kali Nadi at Nadrai, Lower Ganges Canal.

The estimate submitted by the Superintending Engineer is divided as follows:—

	R
I.—Works—	
(a) Aqueduct	29,82,300
(b) Subsidiary Works	6,95,000
Total Works	36,77,300
II.—Establishment	8,45,800
III.—Tools and Plant	4,50,000
GRAND TOTAL	49,73,100

2. The design has been prepared in accordance with the following conditions ordered by the Government of India:—

- (1) The aqueduct to have 15 spans of 60 feet, divided by abutment piers into three sets of five spans each.
- (2) The maximum pressure on the foundations of piers not to exceed $2\frac{1}{2}$ tons on the square foot.
- (3) The thickness of the sunken concrete floor not to be less than 5 feet, "unless it can be laid in a dry bed so as to ensure bond, and a fair abutting of the blocks" of which it is to be composed.
- (4) The total superficial area of waterway down to level of sunken floor to be 23,430 square feet.

3. Conditions (1), (2), and (4) are definitely settled, but as regards (3), there is still some doubt, as the thickness of the floor is to be dependent on "bond, and a fair abutting of blocks." The laying of these concrete blocks, as ordered by the Government of India, to a thickness of 5 feet will be a most tedious and expensive work, costing nearly 6 lakhs of rupees; and the completion of the aqueduct will be greatly delayed. It is worthy of serious consideration then whether this thickness is absolutely necessary, or whether by sinking the wells deeper we may not be able to do away entirely with the concrete floor altogether, and in lieu of it have block kunkur pitching.

4. The old aqueduct had a waterway of 5 spans of 35 feet, resting on wells sunk 20 feet below bed level, and notwithstanding that in the flood of October 1884 the main set of the stream was on two of these spans only, the scour did not extend down more than 20 or 25 feet. In the larger flood of 1885, however, the bed of the river was scoured out to the clay stratum which is found 30 feet below. In the present aqueduct we are giving 15 spans of 60 feet, founded on wells 40 or 50 feet below bed, and a concrete block floor 5 feet in thickness sunk 15 feet below bed is proposed to be added as an additional safeguard.

5. As the limit of pressure fixed by the Government of India on the base of the wells fixes also their minimum depth, it will be convenient before proceeding further to consider this point.

The calculations submitted by Superintending Engineer show that the pressure will vary from 2.5 tons per square foot on base of pier wells* to 1.5 tons on the abutment wells. It would be possible to equalise the pressure by spacing the abutment, land and river wing wells further apart, or by not sinking them so deep, or by a combination of the two methods; but this is obviously objectionable, and as the river wings are not bonded into the main work, and the wells are to be *fully* loaded before hearting, the ultimate difference in the pressure may not be considered of much consequence.

6. I would, however, most strongly advocate (in fact in my opinion it is absolutely necessary) that all the wells should be sunk to a *minimum* depth of 50 feet.

In the calculations submitted by Superintending Engineer, it is true that the condition laid down regarding the maximum pressure on the foundation is just attained when the wells have been sunk to a depth of 40 feet; but in these calculations the wells are supposed to be spaced only 1 foot apart, whereas it has been found necessary to lay them at 2 feet intervals. Besides, in these calculations there are necessarily so many assumptions and elements of uncertainty that some margin must be given, and it certainly would not be safe to stop the wells at a less depth than 50 feet, which theoretically will give a pressure on the base of the piers of about 1.5 tons per square foot, according to Rankine's formula, or 2.74 tons if the friction is considered as not acting entirely round the circumference. This extra depth entails an addition to the estimate of Rs2,00,000.

7. The general design for the work has been most carefully worked out, and except on some minor details, such as the thickness of the arch which appears to be too slight, the stone corbelling for wells, and the concrete plug for wells, further remarks are at present unnecessary.

The thickness of the arch should certainly not be less than 4 feet at the key.

The combination of stone corbelling and brackets for the wells does not seem to me to be a good one. I consider it would be far better and safer to do all the corbelling required in brickwork alone.

The wells will be hearted entirely with ordinary lime concrete put in as rapidly as possible after the loading is completed; a plug of cement concrete is therefore unnecessary, and may be omitted from the estimate.

* The formula used is Rankine's, which is practically for independent wells, and not for a row of contiguous wells. If friction is only taken into account as acting on two planes on opposite sides of the well, instead of all round the circumference, the pressure on the base of the pier wells is nearly 4 tons per square foot.

The saving effected by doing away with the stone corbelling and the concrete plugs will be Rs1,388.

8. In the Abstract submitted by Superintending Engineer no allowance is made for receipts on Capital Account, which may be estimated as follows:—

	R
(1) <i>General</i> .—Sale of timber, iron-work, &c., in centering	20,000
Doors, timber, &c., in dismantled buildings	5,000
(2) <i>Railway</i> .—Sale of old permanent-way	15,000
	40,000
(3) <i>Tools and Plant</i> estimated at Rs4,50,000, which when sold on completion of work will realize, say	1,50,000
Total receipts on Capital Account	1,90,000

9. Providing for the above alterations, the general summary of the estimate will be as follows:—

I.—Works—	R	R
(a)—Aqueduct	31,30,912	
(b)—Subsidiary work	6,95,000	
		38,25,912
II.—Establishment		8,79,980
III.—Tools and Plant		4,50,000
IV.—Suspense		...
	Total	51,55,892
V.—Deduct receipts on Capital Account		1,90,000
	GRAND TOTAL	49,65,892

10. But with the wells sunk to a depth of 50 feet, is it really necessary to have a concrete floor 5 feet thick? By doing away with this floor (which costs about 6 lakhs of rupees) and substituting for it a flooring of block kunkur 3 feet in thickness, not only will there be a very material saving in cost, but the time in building the work will certainly be lessened by at least six months. With the very ample waterway now given to the aqueduct, and with the knowledge that at 30 feet below bed level there is a clay stratum varying from 2 to 9 feet in thickness across the whole width of the stream, and that, notwithstanding the totally inadequate waterway formerly allowed, the abnormally high flood of 1885 did not scour *below* this clay stratum, I have no hesitation in saying that I consider the proposed concrete floor as unnecessary to the safety of the work.

11. If this view is accepted, and a kunkur floor, 3 feet thick (in large blocks), is substituted for the concrete, the general summary of the estimate will be reduced as below:—

I.—Works—	R	R
(a)—Aqueduct	28,06,455	
(b)—Subsidiary works	6,95,000	
		35,01,455
II.—Establishment		8,05,564
III.—Tools and plant		4,50,000
IV.—Suspense		...
	Total	47,57,019
V.—Deduct receipts on Capital Account		1,000
	GRAND TOTAL	45,77,019

12. I would draw attention to the very complete manner in which this estimate has been submitted by the Superintending Engineer, Major F. J. Home, and to the remarks he makes regarding the great assistance he has received from Mr. Nethersole, Assistant Engineer, who is one of the most promising and painstaking officers in the Irrigation Department.

From the Government of India, P. W. Dept., to the Secy. to the Govt. of the N.-W. P. and Oudh, P. W. Dept., No. 199 L, dated 25th November 1886.

In reply to your letter No. C. 828 L, dated 18th October 1886, forwarding estimates and plans of the proposed new aqueduct at Nadrai, I am directed to state that the Chief Engineer's

proposal to provide a block kunkur floor, 8 feet thick, instead of the concrete floor, is accepted by the Government of India, and to communicate provisional approval of the reduced estimate for the aqueduct amounting to Rs 45,67,019 for direct charges.

2. Formal sanction cannot be accorded until the revised estimate for the entire Lower Ganges Canal Project, of which the estimate is a component part, receives the approval of Her Majesty's Government, and I am to request that the revised estimate for the canal may be submitted as early as practicable.

3. The original estimates and plans are herewith returned.

From the Government of India, Public Works Department, to the Right Hon'ble Viscount Cross, Her Majesty's Secretary of State for India, No. 24, dated Simla, 16th May 1887.

With reference to our Despatch No. 15 P. W., dated 9th March 1886, we have the honour

I.—Works—	R	R	to report, for Your
(a) Aqueduct	28,06,455		Lordship's inform-
(b) Subsidiary works	8,95,000		ation, that the re-
II.—Establishment		35,01,455	building of the Kali
III.—Tools and Plant		8,05,564	Nadi aqueduct at
		4,50,000	Nadrai, on the
	Total	47,57,919	Lower Ganges Canal,
Deduct—Receipts on Capital Account		1,90,000	is estimated to cost
	GRAND TOTAL	45,67,919	Rs 45,67,019* for direct
			charges.

2. A revised estimate for the entire Lower Ganges Canal project, of which the aqueduct is a component part, is now under preparation and will be submitted for the approval of Her Majesty's Government as early as may be practicable.

3. As the aqueduct is on the main supply channel of the Lower Ganges Canal system, it was a matter of urgent necessity to complete the new work at the earliest possible date. The work was, consequently, commenced in the working season of 1885-86, and we have accorded provisional sanction to the estimate for the amount noted above, in order to regularize the outlay as incurred.

4. We enclose a note by the Inspector-General of Irrigation, who lately visited the works now in progress at Nadrai, from which it will be seen that he considers their progress satisfactory, and that, with the alterations noted, the project should be completed on the design which we have approved.

5. The work is urgently needed to prevent loss of revenue, for, in consequence of the failure of the old aqueduct, the Bewar Branch has been closed and the Cawnpore, Etawah and Bhognipur Branches are entirely dependent for supply on the Upper Ganges Canal. We trust that our action in this matter will meet with Your Lordship's approval.

Memorandum by COLONEL R. HOME, R.E., Inspector-General of Irrigation, on the new Aqueduct under construction on the Lower Ganges Canal at Nadrai, dated 28th April 1887.

I visited Nadrai on the 20th and 21st March, accompanied by Colonel Jeffreys, R.E., Officiating Chief Engineer, and Mr. Grant, his Under-Secretary, and after examining the plans and records connected with the new aqueduct, I inspected the works.

The new aqueduct, of which the principal dimensions were fixed in consultation with the Government of India, consists of 15 spans of 60 feet each and is divided into three sections by abutment piers. The canal channel has been narrowed from 196 feet in earthen section to 130 feet between the masonry walls of the aqueduct.

The foundations of the main and pier abutments consist of a double row of wells of 12 feet in outside diameter and the intermediate piers of a single row of wells 20 feet in diameter.

At the time of my visit, with the single exception of the down-stream main abutment, of which the well curbs only are in position, the foundation wells of all piers and abutments had been built to full height and had been carried down to the clay, which is found at 30 feet below the bed of the nullah, and labour was concentrated on some of the piers which were being sunk through the clay to their full depth of 50 feet. A temporary workshop had been erected, the arrangements for manufacture and supply of materials had been carefully worked out, and the works were progressing satisfactorily under the supervision of an energetic and intelligent staff.

Before proceeding on furlough the Chief Engineer, Colonel Forbes, R.E., had informed me that explorations with the boring rod showed that the clay stratum found at 30 feet below the

bed of the nullah was continuous under the whole work, and he suggested that if, on further investigation, the result of previous observations was confirmed, there would be no necessity for the sunken floor under the arches of the aqueduct which had been originally included in the specification of the work.

At Nadrai I saw a record of borings at 100 feet apart along the whole length of the work, which showed that there was clay of every site which varied from 2 feet to 9 feet in thickness. If further observations show that such thicknesses are maintained throughout the whole area, I entirely concur with Colonel Forbes that the sunken floors which it was proposed to lay at 15 feet below the level of the nullah bed may safely be dispensed with.

On looking over the designs for the works, the absence of training works above the aqueduct attracted my attention. The trough of the nullah is much wider than the waterway through the aqueduct, and I am of opinion that without training works it will be impossible to ensure that each bay of the aqueduct will do its proper share of work in passing off high floods, such as occurred in 1884 and 1885. The attention of the Government of the North-Western Provinces will be invited to this matter.

As regards the estimate I was informed that doubts were entertained as to the sufficiency of the provision for special plant, but that if the sunken floor were dispensed with, the saving in cost would cover any possible excess on tools and plant in addition to the cost of the proposed training works. The works were not far enough advanced to allow of an opinion being formed of the possibility of savings on other heads of the estimate. About 20 lakhs of rupees had already been spent on the works.

From the Secretary of State for India (Viscount Cross), to the Government of India.

I have received your Excellency's Public Works letter No. 24, dated 16th May 1887, reporting that you had accorded provisional sanction to a total estimate of Rs 45,67,019 for the reconstruction of the Kali Nadi Aqueduct at Nadrai on the Lower Ganges Canal.

2. I greatly regret the very serious nature of the accident that has led to this unforeseen and extremely heavy expenditure, which so much exceeds the amount at first thought likely to be necessary, and will apparently lead to an addition to the cost of the Lower Ganges Canal of an amount nearly one-fourth of the whole sum which had been previously spent, and thought to have completed the work.

3. The cause of the disaster appears to have been an altogether unprecedented rainfall over a considerable area, amounting to about 18 inches in 24 hours; and while I do not question the careful attention given to the subject by the Engineers who were responsible for the original design, and who did not contemplate that the works would have to stand such a strain, the result shows the paramount importance of obtaining every possible information that experience can supply before determining the extent of the waterway of such works, and I cannot resist the evidence now brought forward to show that the much enlarged structure now proposed is really necessary.

4. I trust that all needful care will be taken to keep down the expenditure within the lowest limits that are compatible with the reconstruction of the aqueduct in a manner that shall place it beyond any possible risk in the future.

From the Government of India, to the Secretary of State for India, No. 2, dated 3rd January 1888.

We now enclose the documents which are noted below, and which, we trust, will afford to your Lordship all the information which is desired.

2. It will be noticed that the estimate, as now submitted by the Government of the North-Western Provinces, aggregates Rs 49,98,810, and exceeds by Rs 4,31,791 the total of that which was reported to your Lordship with our Despatch No. 24 Public Works of the 16th May last. The letter from the North-Western Provinces Government enters fully into the causes of this excess, which is mainly due to the fact that while provision has been made for the training works which the Inspector-General of Irrigation considers to be necessary, provision is also retained for the sunken floor, the necessity of which has yet to be proved.

3. We have considered it desirable to allow the estimate to stand for the present at the total of Rs 49,98,810 until the well-sinking through the clay has been further advanced. The Inspector-General of Irrigation is still of opinion that it will be ultimately proved that the construction of the floor is unnecessary. In that case the total cost of the work, as noted in the concluding paragraph of the letter above quoted, will be Rs 46,30,000, or only about half a lakh

General Abstract of Revised Estimate—continued.

Head.	Sub-head.	Quantities.	Rate.		Amount.	Total.
			R.	Per		
	Brought forward	...	...	...	R.	
	Brickwork in arching	77,164	35 0	100 c. ft.	27,007	
	Vonsoir bricks	23,605	14 0	100 sq. ft.	3,305	
	Portland cement plaster	5,636	33 0	ft.	1,85,988	
	Well-sinking, 20' wells	9,171	24 0	"	2,20,104	
	" 13' "	2,340	8 0	"	18,720	
	" 12' "	330	40 0	"	13,200	
	Iron railings	193	16 0	cwt.	1,928	
	Sheet piling	461	12 0	"	5,532	
	Ironwork, wrought	102	1,264 0	each	1,28,928	
	Well curbs, 20' wells	44	565 0	"	24,860	
	" 13' "	122	488 0	"	59,536	
	" 12' "	5	14,000 0	set	70,000	
	Centerings	2,630,961	5 0	100	1,31,039	
	Contingencies	...	...	...	...	
	TOTAL AQUEDUCT	...	...	...	27,52,000	27,52,000
	Kunkur Floor.					
	Dredging	5,600,000	20 0	1,000	1,12,000	
	Block kunkur	1,500,000	12 0	100	1,80,000	
	Contingencies, say	...	...	...	8,000	
	TOTAL KUNKUR FLOOR	...	...	...	3,00,000	3,00,000
	Subsidiary Works.					
	(a) Preliminary operations	...	...	...	32,000	
	(b) Railways	...	...	...	1,02,000	
	(c) Buildings	...	...	...	70,000	
	(d) Canal Diversion and works in connection	...	...	...	1,15,000	
	(e) Nadi Diversion	...	...	...	1,00,000	
	(f) Escape Diversion	...	...	...	10,000	
	(g) Filling in Breach at old Aqueduct site	...	...	...	1,90,000	
	(h) Miscellaneous works	...	...	...	76,000	
	Total Subsidiary Works	...	...	...	6,95,000	6,95,000
	TOTAL I—WORKS	...	...	...	...	37,47,000
II.	Establishment (23 per cent.)	...	...	...	8,61,810	8,61,810
III.	Tools and Plant—					
	(1) Well-sinking machinery	...	...	...	2,21,010	
	(2) Lime-grinding and miscellaneous	...	...	...	2,33,363	
	(3) Repairs	...	...	...	2,50,150	
	(4) Contingencies at 5 per cent.	...	...	...	35,477	
	Total III—Tools and Plant	...	...	...	7,40,000	7,40,000
	TOTAL	...	...	...	...	53,48,810
	Deduct Receipts on Capital Account.					
	Selling value of Tools and Plant	...	...	...	2,60,000	
	Railway material, &c.	...	...	...	50,000	
	Miscellaneous receipts, timber, fittings, &c.	...	...	...	40,000	
	Total Receipts	...	...	...	3,50,000	3,50,000
	NET AMOUNT OF ESTIMATE	...	...	...	...	49,98,810

J. G. FORBES, Colonel, R.E.,
Chief Engineer, Public Works Department,
Irrigation Branch, North-Western Provinces.

Enclosure No. 3 to Despatch No. 2 Public Works of 1888.

LOWER GANGES CANAL.

Descriptive Specifications of the works in connection with the Aqueduct over the Kali Nadi at Nadrai.

Conditions fixed by the Government of India. 1. The design has been prepared in accordance with the following conditions ordered by the Government of India:—

- (1) "The aqueduct to have 15 spans of 60 feet divided by abutment piers into three sets of five spans each."
- (2) "The maximum pressure on the foundation of piers not to exceed $2\frac{1}{2}$ tons on the square foot."
- (3) "The thickness of the sunken floor not to be less than 5 feet, unless it can be laid in a dry bed so as to ensure bond and a fair abutting of the blocks of which it is to be composed."

The question of the necessity of a floor is still under consideration; and until such time as the well-sinking through the clay stratum is further advanced, it cannot be definitely settled. The present estimate provides for a block kunkur floor 5 feet in thickness.

- (4) "The total superficial area of waterway down to level of sunken floor to be 23,430 square feet."

2. The catchment basin of the Kali Nadi at the Lower Ganges Canal crossing is 2,377 square miles, and the calculated flood discharge on the 17th

Catchment. July 1885 is 132,475 cubic feet per second, or at the rate of
Flood discharge. 55.7 cubic feet per second per square mile of catchment.

Waterway given. The design provides for 15 spans of 60 feet with a kunkur floor laid with its surface at a depth of 10 feet below the nadi bed: the soil above this floor would be scoured out by a flood similar to that of July 1885, and the arches would be entirely submerged; the waterway above the sunken floor would then be—

$15 \times 1,555 = 23,325$ square feet, or at the rate of $\frac{23,325}{2,377} = 9.81$ square feet per square mile. The mean velocity, supposing the maximum flood to be 140,000 cubic feet per second, would be $\frac{140,000}{23,325} = 6$ feet per second, and the heading up required to generate this velocity, assuming a velocity of approach of 3 feet per second, would be 0.5 feet.

Height from bed of nadi to bed of canal. 3. The available height from bed of nadi (R. L. 534.00) to bed of canal (R. L. 528.57) is 5.43 feet and has been disposed of as follows:—

Concrete over arch	0.35
Arch ring	4.15
Versed sine of 60° arc	8.00
Nadi bed to springing	11.77

TOTAL 24.27 feet

Height of roadway above canal bed. The canal roadway has been kept at (R. L. 570.77) 12.5 feet above the canal bed, as in the old aqueduct.

4. The whole work will be founded on wells sunk to R. L. 482.50, or 51.5 feet below bed of nadi, that being the depth at which the pressure at the bases of the pier and abutment pier wells will not, under the most unfavourable circumstances, exceed the limit fixed by the Government of India. The pressure at the bases of the pier and abutment pier wells will be equal, but, owing to the abutments having to carry only half the arch, the pressure at the bases of the abutment wells will not exceed two-thirds of that on the pier wells. The pressure at the base of the river wing wells is calculated at little over half that on the abutment wells, and as there is no practical objection to it, a vertical joint will be given between the river wings and the abutments.

It would of course be possible to equalize the pressure at the bases of all the wells by spacing the abutment and wing wells further apart, or by not sinking them so deep, or by a combination of the two methods; but it is obviously desirable to keep the abutment and river wing wells as close together as possible, so as to minimize the chance of earth slipping between them from behind, and it will most certainly be safer to sink all wells to the same depth.

5. There will be three sizes of wells, viz.,—20 feet diameter for the piers and left (canal) land wings; 13 feet diameter for the river wings; and 12 feet diameter for the abutments, abutment piers, and right (canal) land wings. The wells will be hearted with concrete, put in as rapidly as possible after the sinking, and any testing that may be necessary is completed. The tops of all except the land wing wells will be at R. L. 530.00 or 4 feet below nadi bed, and sufficient corbelling will be sunk below that level to allow of all exterior corbelling being completed at R. L. 532.00 and the exterior corbelling of the abutment and abutment pier wells at R. L. 534.00. The tops of the land wing wells will be at R. L. 532.00 and all corbelling will be above that level.

6. The sunken floor (if found necessary) will be laid with its upper surface at R. L. 524.00, or 10 feet below the nadi bed, to a distance of 25 feet above and below the faces of the aqueduct, and will end with aprons 25 feet long sloping downwards at an angle of 1 in 5 to R. L. 519.00, so as to protect the main portion of the floor. At the abutments and river wings the floor will be laid with a slope from R. L. 532.00 to the centre of the side bays.

7. The excavation of the pit for the black kunkur floor below R. L. 535.00 will be done by dredging from barges by hand and steam power; above that level the excavation will be done by pumping and hand labour in the usual manner.

The spring level being at about 540.00 and the bottom of the floor at 519.00, the depth of water would be 21 feet, and depth which it would be very expensive to pump out over such a large area.

8. The backs of the abutment and river wing wells will be closed by a line of sheet piling 1½" thick; the piling will be 15 feet long, and will be driven to R. L. 517.00 or 2 feet below the bottom of the sunken floor. This protection should prevent all chance of settlement of earth behind the abutments and river wings, especially as the filling in will be good puddle. This completes the description of the work to be done below nadi bed R. L. 534.00.

9. In view of the great length of the new aqueduct every endeavour has been made to reduce its width to the utmost extent consistent with safety. In the old aqueduct the width of the canal channel was 192 feet, the same as the bed width of the earthen channel. In the new design the width has been reduced to 130 feet, as with this width the aqueduct will be capable of carrying any supply that the earthen channel can carry with safety. An 11 feet roadway for wheeled traffic has been provided on the left bank, and a 6-foot bridle-path on the right bank. To obtain these widths corbelling has been resorted to as far as possible. The width from face to face of arch in new aqueduct is 143.7 feet as against 212 feet in the old, or a reduction of 68.3 feet.

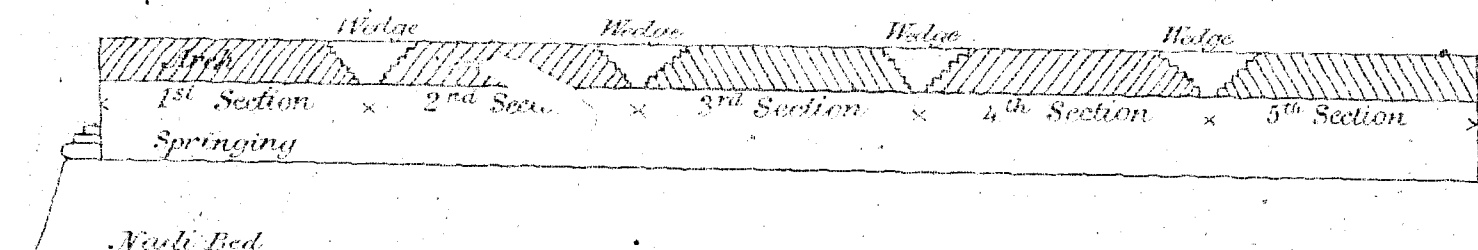
10. As compared with the old aqueduct, the other alterations in the superstructure are the lightening of the load on the arches by the adoption of spandril arches (similar to those adopted at the Solani Aqueduct on the Ganges Canal) and an arched sub-way under the road, a different disposition of the land wings, and an increase in height and length to the river wings, which now run back to well beyond the ends of the land wings and protect thoroughly the flanks of the work. Octagonal pilasters have also been introduced at the abutments and abutment piers, which besides adding to the architectural effects afford means of approach to all the lower parts of the work, and provide quarters for the patrolling establishment of the embankment. Still water gauges have been provided on both flanks, up and down stream, so as to allow of high floods being accurately recorded.

11. The calculations for the stability of abutments, abutment piers, piers, river and canal wings have been worked out in great detail. The arch has been divided into three equal portions; the thickness of the centre portion has been made 4.15 feet and of the side portions 4.58 feet. The spandril arches have a span of 4 feet piers, 1.7 feet and arch 83 feet thick. Over the tops of the spandril arches there will be one course of flat bricks laid in Portland cement, and over the whole of the canal floor a layer of fine Portland cement concrete, so as to make it thoroughly water-tight. The sides of the Canal Channel will also be plastered with Portland cement with the same object.

12. The land wings on the left bank of the canal have, to save masonry, been designed in the shape of a double wall, the space between being filled up with puddle. The right bank land wings being of a less width, will be built up solid. The river wings have been designed with a berm at R. L. 549.80 and their tops at R. L. 558.62. The maximum flood level up-stream is calculated at 559.50, and down-stream at 559.00, but it is by no means certain that these levels would be reached with a clear valley, and there would be no danger from the wings being topped by so small an amount for a short time.

13. The nadi and canal approaches are shown clearly on the general plan of the work. In the case of the nadi, the centre set of 5 spans has been taken as the waterway for ordinary goods, and this will be excavated down to bed level (534.00). Opposite the two side sets of 3 spans berms will be left at R. L. 540.00, or 6 feet above nadi bed. A good splay will be given above and below the aqueduct to both the central channels and the berms. In the case of the canal, the approach and exit will be neatly curved in, and the slopes pitched. At the exit the bed will also be pitched throughout as a protection against the extra velocity at this point.

14. As regards turning the arches, each set of five spans will be dealt with separately; there will be five sets of centerings, each about 32 feet long, or equal to one-fifth of the whole length of the arch from face to face. Each arch will therefore be turned in five sections, the different sections being joined together by masonry wedges built afterwards. See sketch below:—



15. The whole site will be enclosed with embankments well above maximum flood level, so that there can be no interruption to the work except during periods of actual rainfall.

16. The works in connection with the main aqueduct but subsidiary to it are—

(1) *Preliminary*.—Under this head come Surveys, Boring Experiments, Groynes, and Tree Spur protection at site of breach, Masonry Outlets for draining Aqueduct site, Recovering Stores submerged by flood, and Temporary Bridges over Kali Nadi.

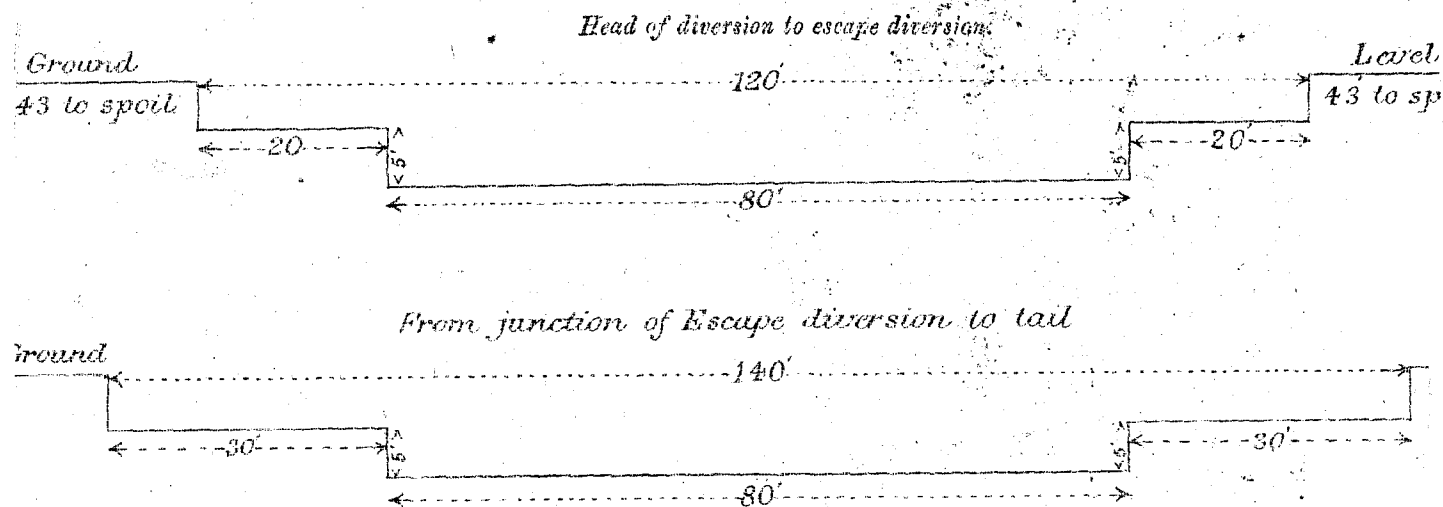
(2) *Railways*.—The large quantity of stores and materials required renders a branch from the Cawnpore-Achneyra Railway absolutely necessary, and the proximity of the Kasganj Station to the aqueduct site facilitates the connection. The main branch is 2.5 miles long and the aggregate length of sidings required is 3.6 miles; the total length of railway to be provided is therefore 6.1 miles.

(3) *Buildings*.—Under this head is included quarters for the large staff of officers, subordinates, and work-people employed; sheds for stores and lime; extensive workshops; hospital and dispensary; and land and wells required in connection with the different buildings.

(4) *Canal Diversions*.—The flood of October 1884 only partially damaged the old aqueduct and after carrying out the necessary repairs a supply was passed over it in December 1884, which, by means of a diversion round the new site, it was hoped to maintain until the new aqueduct was completed. Work on this diversion was pushed on vigorously, and it was nearly completed when the great flood of the 17th July 1885 carried away the remains of the old aqueduct, and rendered it impossible to maintain a supply across the breach. The diversion bank is now utilized as a protection to the west

side of the new aqueduct site, but it is necessary to provide for the expenditure incurred up to the date of the great flood.

- (5) *Nadi Diversion.*—It will be seen from the general site plan of the works that the position of the new aqueduct necessitates the diversion of the nadi, and the opportunity has been taken to straighten its course by cutting off the long loop commencing at about a mile above and ending about a mile below the canal crossing. The average bed width of the natural channel of the nadi is about 80 feet and the average depth of digging along the line of the diversion, with a bed slope of 1 foot per mile, is about 12 feet. The cross sections to be adopted are sketched below:—



The berm will be 5 feet above bed throughout, and as this is about spring level, the excavation of the centre channel will be all "wet" earthwork, while that of the upper portion will be dry. The spoil, excepting in the wide portions above and below the aqueduct, will be nowhere more than 3 feet high, so as not to obstruct high floods, and openings through it will be left at every 200 feet. It will be levelled off so as to be fit for cultivation.

- (6) *Escape Diversion.*—The Nadrai Escape, which now runs parallel to the canal, will be divided so as to give it a proper junction with the nadi diversion, which it would otherwise join at right angles.

- (7) *Filling in breach and puddling bed of canal throughout the Embankment.*—The total length of the breach is 650 feet and the mean depth of scour below nadi bed is 27 feet. Up to nadi bed the filling in will have side slopes of 5 to 1. At nadi bed berms of 20 feet will be left. A second berm 30 feet wide will be left at R. L. 561.00, the side slopes from nadi bed to top of embankment R. L. 571.00, being made 2 to 1. A layer of puddle, 3 feet thick, will be laid across the breach at nadi bed level, and core walls will be carried up from it to within 2 feet of the top of the bank. The bed of the embankment will further be covered with a layer puddle 1½ feet thick throughout the whole length, from the north regulator to the Hathras Road Bridge.

- (8) *Miscellaneous works.*—The following works are grouped together under Miscellaneous, as it is difficult to find a suitable place for them under the other headings:—

- Work done on Hathras-Bareilly Road Bridge.
- Loss of stores during flood of July 1885.
- Well and shafting for turbine at 14 feet fall.
- Clearance of canal bed from head to mile 33.

The only item that calls for remark is (d) Clearance of canal bed. Owing to the small supply which can be run from the head at Narora during the construction of the new aqueduct, there will be a considerable growth of weeds which it would be impossible to keep down without incurring a large annual expenditure. There will also be deposits of silt owing to the accumulation of weed, and these deposits, even if cleared away every year, would be sure to re-form. It will therefore be necessary to allow for a thorough clearance of the canal channel just before water is passed over the new aqueduct. The cost of this clearance is estimated at Rs50,000.

J. G. FORBES, Colonel, R.E.,
Chief Engineer.

Enclosure No. 4 to Despatch No. 2 Public Works of 1888.

A short account of the work done on the Nadrai Aqueduct from the commencement to the end of October 1887, as called for in letter No. 144 I., dated 3rd August 1887, from the Secretary to the Government of India, Public Works Department.

The progress to date on the above works for the important items is given below, leaving I.—Aqueduct, for the last.

II.—*Preliminary.*—Under this are included Surveys; Boring Experiments; Earthwork in Groynes; Bunds across Canal Channel above and below site of work; Tree Spur protection; Masonry Outlets for Pumping Stations during flood; Temporary Bridge over Kali Nadi.

The works contemplated have been carried out including two lines for borings at a distance of 200 feet from centre line of Canal on each side, the bore holes being at 100 feet intervals.

The resulting geological sections had an important bearing on the designs of the aqueduct foundations.

III.—*Railways.*—These consist of (1), a branch line from Kasganj Station, 12,500 feet (2½ miles) long, and two sidings aggregating 13,900 feet. The work is all complete, and the cost compared with the estimate is as follows:—

	R		R
(1) Estimates	1,02,000	{ Cost	48,000
(2) "	"	{ "	52,549
	1,02,000		1,00,549

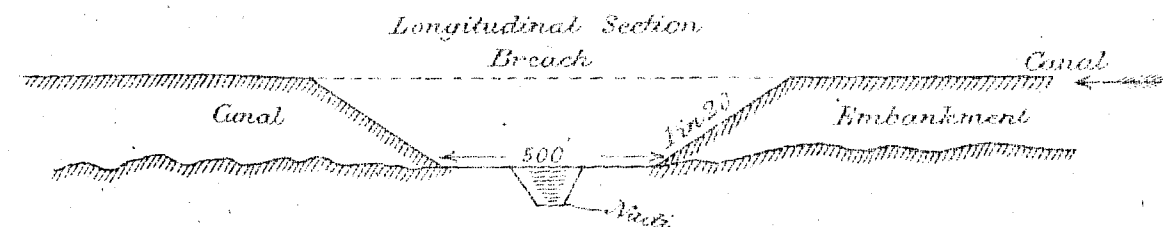
IV.—*Buildings.*—Include Officers' and Subordinates' quarters; Workshop Buildings and Enclosures; Hospital; Store Godown, &c. They are practically all complete.

V.—*Canal Diversion.*—This work was required in accordance with first design for new aqueduct; a portion now forms part of the circular embankment enclosing site of present work. The actual cost was found to be Rs78,335.

VI.—*Nadi Diversion.*—About one-third of the total quantity of earthwork has been done, but all the wet excavation remains, the expenditure being only Rs13,000 to end of September, against an estimate of Rs1,00,000. Work cannot be commenced above the aqueduct until the centre bay is arched and ready to pass water, and on the down-stream side the wide portion is covered by a circular embankment, so that practically work has been limited to the narrow portion of channel below, and this has been excavated to spring level.

VII.—*Escape Diversion.*—One-fourth of the work is done, and it will soon be completed.

VIII.—*Filling Breach.*—Tramway made at a cost of Rs1,500; rest of work executed consists of puddling canal-bed and removing earth where puddle is to be laid. The expenditure to end of September, Rs14,400, against the estimate of Rs1,90,000. Of course, this work cannot be put in hand fully until aqueduct is advanced further. At present the order is to reduce width of breach to 500 feet and finish off ends to a slope of 1 in 20, thus:—



IX.—*Miscellaneous.*—This estimate includes Expenditure incurred on Hathras Road Bridge before flood of 1885; Loss of Stores by that flood; Temporary Bridge over Nadi; Blast-ing old Aqueduct, &c. Advantage is being taken of the proximity to the works of the 14-feet fall in the escape to set up a turbine for grinding lime, which will be ready in less than two months; and although it has arrived somewhat late, it is anticipated that very considerable saving will be effected by the employment of water power. A careful contour survey of the nadi above and below the weir site is in hand with a view of designing the necessary training works in the river, although it will not be possible to carry them out until the aqueduct is near completion. Clearing canal bed between Narora and Nadrai of weeds, silt, &c., accumulating during construction of aqueduct is a very uncertain item: the extent of work to be done can only be ascertained when work is actually put in hand. A saving under this head is possible.

After describing the preliminary and subsidiary works, I now proceed to give an account of the progress made on the aqueduct proper taken by sub-heads.

I.—AQUEDUCT PROPER.

1. *Earthwork, Dry.*—Work is practically done. It includes excavation of canal embankment for new site and foundation pit to spring level, the soil from same having come in for construction of circular bund enclosing works.

2. *Earthwork, Wet.*—Includes excavation from spring level, R. L. 540 to R. L. 530, a depth of 10 feet, down to level of base of piers; also removal of slush dredged out of wells. The work executed to date is principally on removal of dredged stuff as above and on excavating bays Nos. 5, 6, 7 and 8 to about R. L. 535.00.

3. *Puddle.*—This is in connection with superstructure; is estimated to cost R14,386, but no expenditure yet.

4. *Pumping.*—The expenditure to end of September (R9,000) is entirely connected with well-sinking, estimate R40,000.

5. *Kunkur Pitching.*—Estimate for this amounts to R22,541. No progress possible beyond collection of materials, which has been done and charged for under materials at site.

6. *Road Metalling.*—Estimate R1,071. No expenditure.

7. *Brickwork, 1st class, in lime.*—Progress to date is altogether in building wells; work stands thus—

Estimated	c. ft. 3,712,293 at 30	R11,13,688
Executed to end of September 1887	1,509,000 at 29-21	4,41,000
October 1887	1,551,000 not known yet.	

About 4ths of the work under this head has therefore been executed.

The total quantity of bricks required is 495 lakhs, and of these 365 lakhs have been provided and a contract entered into for the supply of the remaining 130 lakhs before 1st July 1888.

8. *Brickwork in Portland cement.*—No expenditure.

9. *Brickwork Pila in lime.*—This is temporary brickwork on wells in order to sink them below spring level. The progress to date is as follows:—

Estimated	c. ft. 393,841 at R 18	R 70,892
Executed to end of September	280,000 at „ 11-39	23,000

The low rate is due to the use of bricks in *mud*, but this is not satisfactory and has been given up.

10. *Concrete in Portland cement.*—No progress.

11. *Concrete in lime.*—Estimate R2,11,388: materials ready, but no progress to date pending orders to heart wells. The question will be decided in a few weeks, when result of test lading wells Nos. 142 and 150 is known.

12. *Concrete Blocks.*—These were in Major Home's first estimate in connection with sunk floor, but pending final orders on the subject, the further construction of blocks was stopped. Estimated cost, including laying, R4,44,456. Expenditure to date R12,000.

13. *Stonework fine dressed.*—

14. *Kunkur fine dressed.*—

15. *Brickwork, non-vitrified arching.*—

16. *Portland cement plaster.*—

17. *Well-sinking—20'* } The progress to end of October is shown in the two statements

18. Ditto —13' } marked A and B appended.

19. Ditto —12' }

It is seen from statement B that wells in the two abutment piers and intermediate piers of the centre section are all sunk to full depth with exception of two wells in No. 8 pier and three in No. 10 abutment pier, and these five are in the last stage of sinking. We are therefore ready to begin concreting at once. The wells in No. 5 abutment pier will not be concreted until those in No. 4, the adjoining pier, are all down to full depth—

Estimated	20' wells 5,636 c. ft. at R 33	R 1,85,938
Executed	20' „ 3,938 „ at „ 22-69	89,400
Estimated	{ 13' „ } 9,171 „ at „ 24	2,20,104
Executed	{ 12' „ } 5,618 „ at „ 14-89	83,700

The executed rate is low, because a large proportion of the progress is through sand only.

22. *Iron railings.*—

23. *Sheet piling.*—

24. *Iron-work wrought.*—

25. Ditto cast—

26, 27, and 28. *Well Kerbs.*—These are all completed at estimated cost.

29. *Centering.*—Estimate is for five sets of 6 centering frames, each at R14,000 per set, which amounts to R70,000. Three frames have been made for purposes of testing.

30. *Contingencies.*—The expenditure on this head to end of September is R21,797 against an estimate of R1,31,039, and is about 1½ per cent. on the total expenditure.

The Total expenditure, including materials at site	R 14,28,578
Deduct value of materials at site	4,26,000

Total expenditure, less materials at site 10,02,578
on which amount the contingencies fall a little over 2 per cent. This is satisfactory.

<i>Lime manufacture.</i> The total quantity of lime required is	C. faet. 1,450,000
Quantity manufactured and ground to date	625,000
Quantity for which there is kunkur at site (600,000 c. feet kunkur)	475,000
Still to be collected for	350,000

Total as before 1,450,000

STATEMENT A.

Well-sinking—Progress in lineal feet.

Description.	12' AND 13' WELLS.		20' WELLS.		ALL SORTE.		Grand Total, all sorts.
	Sinking through upper sand to clay. (R. L. 537.75 to 510.25)	Sinking through clays and to final position. (R. L. 510.25 to 427.50)	Sinking through upper sand to clay. (R. L. 537.75 to 510.25)	Sinking through clay and to final position. (R. L. 510.25 to 427.50)	Sinking through upper sand to clay. (R. L. 537.75 to 510.25)	Sinking through clay and to final position. (R. L. 510.25 to 427.50)	
Total in Aqueduct	4,565	4,606	2,805	2,831	7,370	7,437	14,807
Done to end of September	4,332	1,286	2,759	1,179	7,091	2,465	9,556
Done in October	49	267	3	146	62	413	465
Total to end of October	4,381	1,553	2,762	1,325	7,153	2,878	10,021
Balance to be done	184	3,053	43	1,506	227	4,559	4,786

STATEMENT B.

Showing position of wells at end of October 1887.

Position.	STAGE No. I.		STAGE No. II.		STAGE No. III.		Sinking complete.
	Not yet built up.	Being sunk in upper sand.	Resting on clay.	Sinking through clay.	Through clay and resting 10 feet short of final position.	Being sunk in final stage.	
North abutment	3	21	26	4	...	4	...
Pier No. 1	...	...	8	...	...	...	...
" 2	...	...	8	...	...	...	...
" 3	...	...	8	...	...	...	...
" 4	...	...	6	1	1	...	...
" 5 (abutment pier)	...	...	...	...	...	...	26
" 6	...	...	...	...	...	...	8
" 7	...	...	...	...	...	...	8
" 8	...	...	...	...	...	2	6
" 9	...	...	...	...	...	...	8
" 10 (abutment pier)	...	...	...	...	...	3	23
" 11	...	...	...	...	...	...	8
" 12	...	...	6	2	...	...	...
" 13	...	...	8	...	...	...	...
" 14	...	...	8	...	...	...	...
South abutment	2	23	36	...	...	...	...
Total at end of October	5	44	113	7	1	9	89
Total at end of September	5	44	126	1	9	11	69