

Public Works (1890) Department.

RAILWAY BRANCH.

G.O., No. 1603 *Ry.*

DATED 24th October

[Despatch Abstract.]

Kistna Bridge, Bezurada. — Ten copies of the abstract estimate for the construction of the — forwarded by the Govt of India, forwarded to the Consulting Engineer for Railways.

BACK PAPERS.

FURTHER PAPERS.

G.O.	No.	Department.	Date.	G.O.	No.	Department.	Date.

No. 1089, dated—June 1890.

From—The Engineer-in-Chief, East Coast Railway,

To—The Secretary to the Government of Madras, P. W. Dept.

I have the honour to forward, for the information of Government, three alternative plans for bridging the Kistna River near Bezvada, with estimates to correspond, and a report on the project prepared by Mr. Spring, who has been engaged on this work since his arrival here.

As Mr. Spring has gone into the question involved in very considerable detail, it is only necessary for me to touch on the main points at issue. The three most important questions—in fact the only ones we have at present to settle—are the site for the bridge; its length, which involves all questions of waterway, cost, and such like; and the most economical and advisable span to be adopted.

As regards the site of the bridge, I never had any second opinion on that subject, but as Colonel C. J. Smith appeared to be in favour of that above the anicut, hoping, I think, to find rock at a moderate depth below the bed, I had borings taken on the line he suggested. These borings showed that the material passed through was practically identical with that below the anicut, nothing having been met with but sand and clay down to a depth of 110 feet. No rock having been found in the river bed, we were relieved from the necessity of comparing the value or risk of well foundations on rock 30 or 40 feet below the river bed with deep ones sunk below possible scour. The borings having reached a depth lower than any wells are likely to be sunk in this river, were then stopped; and as there was no further reason for considering the up-stream site, plans and estimates were prepared for a bridge below the anicut.

The site now proposed is about half a mile below the dam and in direct continuation of the line of the Nizam's Railway, passing the town of Bezvada at its south angle, but injuring no buildings or valuable property. Mr. Spring in his report enters fully in the details of this subject, and quotes largely from his experience and that of other Engineers on the Punjab rivers. I think his information very valuable, and would be more so if applied to a bridge built either above the anicut or further down stream ; but in the present instance the case is, in my opinion, much simplified. The plans show that the flood water of the Kistna is, at Bezvada, much narrowed and completely confined by the two hills between which the anicut is built. The hills cannot be turned, and by connecting them with the abutments of the bridge by means of solid pitched banks, we trained the river for the half mile between the anicut and the bridge with a canal of constant breadth, with even solid side slopes, so ensuring, as much as possible, a uniform flow. The nearer we approach this object the more likely will it be that each span of the bridge will do its proper share of work, and that a fairly uniform depth will be maintained in each span. I do not suppose that in a river three-fourths of a mile wide, we can attain all we could wish for in this way, but I feel assured that we can approach it more nearly in this manner and without risk than by ten times the outlay if the bridge were built upstream.

As regards the length of the bridge, it would, in my opinion, be perfectly useless to give it a greater length of waterway than that afforded by the anicut; in fact, if we did so, it would be more likely to cause cross-currents and back-waters, which it is advisable to avoid.

The designs prepared are for —

One of 17 spans of 202 ft. giving 3,434 l. ft. of waterway ;

"	14	"	250'	"	"	3,500	"	"	and
"	12	"	300'	"	"	3,600	"	"	

During moderate floods the crest of the dam gives 3,400 l. ft. of clear flow and 3,700 l. ft. in very high water.

To what extent, if any, it would be desirable to narrow the bridge below 3,400 ft., it is very difficult to say; we could still ensure a fairly even flow, but with increased velocity, and then it appears to be a question how deep we can afford without danger to let the beds scour. The only way in which we could arrive at any practical conclusion would be to build the side training works as soon as possible to suit the length of bridge fixed on and note the action of the current during the ensuing floods. At all events, I feel assured that at present we are perfectly safe in proposing a bridge which gives between 3,400 to 3,600 l. ft. of clear waterway founded on wells sunk 75 to 80 feet below the river bed, and let the question of shortening it by one or two spans remain over for the present.

With reference to the best span to adopt, if other things were equal, and we could accurately calculate the cost of our foundation work, then I would be induced to accept the 200 feet span in which the cost of the masonry and that of the iron and roadway are practically equal. I have had much experience in well-sinking, and can only venture to say now that there is nothing more uncertain; deep well foundations may turn out most easy or most trouble-

some, and to make a sound forecast with reference to them is next to impossible. With all the other work there is no difficulty in seeing our way, so that I am of opinion that it would be safe and more wise to reduce the number of uncertain elements, namely, the wells, and reject the 200 feet span bridge, in which there are 16 besides those of the abutments which are common to all. It would then become a choice between the 250 and the 300 feet spans.

To enable you to compare readily the cost of each design, I have thrown Mr. Spring's figures into the following form, from which you can compare the cost of the bridges proper as well as that of the bridges with each main head item added one by one:—

	17 spans of 202 feet.	14 spans of 250 feet.	12 spans of 300 feet.
Cost of Bridge proper	25,04,500	27,41,500	29,72,300
Approaches	2,54,000	2,54,000	2,54,000
Bridge and Approaches	27,58,500	29,95,500	32,26,300
Training-works	5,10,000	5,10,000	5,10,000
Bridge, Approaches, and Training-works	32,68,500	35,05,500	37,36,300
Service works and Plant	3,68,000	3,68,000	3,68,000
Total Bridge, Approaches, Training-works, Stores and Plant	36,36,500	38,73,500	41,04,300
Establishment	1,62,500	1,68,000	1,87,700
Contingencies	37,99,000	40,41,500	42,92,000
	1,16,000	1,19,500	1,34,000
	39,15,000	41,61,000	44,26,000

The above table shows that the 200 feet span bridge, both by itself and with the other items added, is about 2.4 lakhs cheaper than the 250 feet span one, and about 4.8 lakhs less than that with 300 openings.

Again, the 250 feet span bridge by itself is 2.3 lakhs less than the 300 feet span one, and taken with approaches, &c., costs 2.6 lakhs less than the larger span bridge.

If the 200 feet span design is selected, I think the cost of the piers must be somewhat increased, but this would not be to a greater extent than 22 to 30,000 rupees. The 200 feet span bridge can without doubt be built for considerably less than the others, but taking all the circumstances of the case into consideration, such as the uncertainty and delay with respect to foundations, blocking the river course, and conveying more numerous eddies and cross-currents, I feel justified in recommending either of the two larger span bridges. From a purely engineering point of view, I don't think it matters much which is selected, but from an economical one the cheaper one appears to be the most advisable.

Mr. Spring has gone into very considerable detail, not only in the report but in the preparation of drawings. Doubtless all the girder designs will be prepared in Sir Alexander Rendell's Office, but I beg to suggest that all the points noted by Mr. Spring, with reference to details which tend to simplify erection, and such like, be brought to Sir A. Rendell's notice.

Whatever design is selected by Government, it is most desirable that the preliminary operations be put in hand at once. These are—erection of staff quarters, shops, store-sheds, and the collection of materials. A considerable quantity of tools and machinery will be required. Such articles are very expensive in England just now, and markets are in an uncertain state. There is much of what we require in India, both in Government and other stores; these we could get, I suppose, on application; but, as my experience teaches me that to purchase machinery (particularly from lists) without careful examination, is unwise to the last degree, I suggest that Mr. Spring be permitted to proceed to the chief Store centres in India, with a view to selecting and purchasing such articles as we shall require for the construction of the bridge.

On his ascertaining what articles cannot be procured readily in India, he could then prepare an indent on England for the remainder. During the next two months little can be done at Bezvada; it is therefore the best opportunity (possibly the only one) Mr. Spring may have for a most necessary duty.

*Extract from the Proceedings of the Government of Madras, P. W. [7809
Dept., No. 1034 R., dated 18th July 1890.*

Read the following:—

Letter from the Government of India, Public Works Department, No. 582 R. C., dated 3rd July 1890.

Telegram from the Engineer-in-Chief, East Coast Railway Survey, dated 11th July 1890—

“Most important that Spring should go to chief Store depôts at once to procure plant for Kistna Bridge. Please sanction this.”

Endorsement from the Officiating Consulting Engineer for Railways, Madras, No. 497 A., dated 14th July 1890, with enclosures.

Letter from the Engineer-in-Chief, East Coast Railway Survey, No. 1039⁴, dated—June 1890, forwarding plans, report, and estimate for the construction of a bridge over the Kistna River at Bezvada.

Offg. Consgr. Engr. for Rys., Madras' endorsement No. 497 A., dated 14th July 1890.

Submitted to Government.

The Engineer-in-Chief forwards three alternative estimates for bridging the Kistna River at Bezvada, as follows:—

	Rs.
17 spans of 202 feet, giving 3,434 l. ft. of waterway, and costing	39,15,000
14 „ 250 „ „ 3,050 „ „ „	41,61,000
12 „ 300 „ „ 3,600 „ „ „	44,26,000

These bridges provide for a mixed broad and narrow-gauge railway and for a roadway, all on the same level.

2. The site selected for the bridge is about half a mile below the anicut, and is in my opinion preferable to that proposed above it. If the bridge were built above, it would be impossible to predict exactly what effect the piers would have upon the currents in the river approaching the anicut, but if it be placed half a mile below, and the river between the bridge and the anicut is trained in an even channel, an equalization in the velocity of the water over the whole discharging channel must be produced, and the general result must be beneficial to the stability of the foundation of the anicut.

3. The bridge should, in my opinion, have about the same length of waterway as is given at the anicut (*i. e.*, between 3,400 and 3,600 feet, depending upon whether the flood is moderate or very great), and should offer as little obstruction as possible to the equal flow of water over the total length between its abutments. I therefore think that moderately large spans with no pitching round the piers should be adopted. Pitching round the piers is of course desirable when the stability of the bridge only has to be considered, but in this case the stability of the anicut is of infinitely greater importance than the stability of the bridge. It is possible, though not probable, that the deepening of the bed of the river between piers heavily pitched might in time of an abnormal flood reach as far back as the apron of stone at the base of the anicut, and endanger the structure. Piers must to a certain extent obstruct the channel and cause unequal currents, and it is desirable, I think, in the present case not to increase the obstruction by heaping in pitching also. I believe piers founded 80 to 90 feet below the cold weather level of the water in the river would be perfectly safe without any pitching; the spans should, I think, be 250 feet, and the total waterway 3,500 feet.

4. It is proposed to construct the bridge for a broad and narrow-gauge railway and a roadway all on the same level. The broad gauge is of course necessary, and the narrow gauge is also, I think, required, as the Southern Mahratta Railway should have access to the town of Bezvada even if no extensions of the metre gauge is ever permitted north of the Kistna River. A fourth rail should, in my opinion, be laid for the metre-gauge track, otherwise the unequal weights will cause unequal deflections in the girders and consequent oscillation in the metre-gauge trains. The roadway, if constructed, will not, I think, be of any value; the distance between the points at which carts would enter upon and leave the railway would be about $\frac{3}{4}$ mile apart, and the time of transit would probably not be much under half an hour, and there is not room for two carts to cross each other. When the East Coast Railway is open throughout, probably at least three metre-gauge and four broad-gauge trains would cross the bridge daily each way, or at least 14 trains in all, or the trains would average $1\frac{3}{4}$ hours apart. It would be necessary to begin clearing the bridge at least 30 minutes (the time of transit of a cart) before the time arranged for the arrival of a train, leaving only 70 minutes for cart traffic. If late trains, engines running light, and the other contingencies of railway working, be taken into consideration, no time would be left for cart traffic, and I therefore think that the provision of a cart road would be an unnecessary expense unless it is required for military purposes; footways might be provided outside the girders for the passage of foot passengers.

It may be thought that I have over-estimated the number of trains that will cross the bridge, but if it be borne in mind that the whole of the railways and manufactories in Southern India must eventually receive their supply of coal from the Singareni mines across this bridge, it will, I think, be admitted that my estimate of the traffic to be expected is not excessive.

5. In my last paragraph I stated that in my opinion 14 broad and metre-gauge trains would pass the Kistna Bridge daily soon after the opening of the East Coast Railway, and it is possible that this number might be largely exceeded, and I am therefore of opinion that the masonry of the bridge should be built for a double line of railway, the girders for the second line being erected when required. The immediate extra cost would not probably exceed one lakh of rupees, whilst the ultimate saving might be more than ten times that amount.

6. I am therefore of opinion—

- That the site chosen for the bridge is suitable.
- That provision should be made for both broad and metre-gauge trains across the bridge, but that separate rails should be provided for the latter, so that a passing narrow-gauge train would cause an equal deflection in both girders.
- That the provision of a roadway for carts at rail level between the girders will be useless unless required for military purposes, but footways might be provided outside the girders.
- That provision should be made in building the bridge for a double line of railway, but that only girders for one line should be at first erected.
- That the bridge should be 14 spans of 250 feet.
- That the wells should be sunk about 80 to 90 feet below cold weather level of the water in the river, and no pitching should be used round the piers.
- That each pier might be founded on two wells, 25 feet in diameter, pitched six feet apart and corbelled out to meet each other. The wells might also be corbelled out about 3 or 4 feet up and down stream to carry the cut water of the piers.

7. When the design of the bridge has been finally approved of, the well curbs might be obtained from Richardson and Cruddas, Bombay, or some other firm in India, to save time. Mr. Spring might also, as suggested by the Engineer-in-Chief, be deputed under his orders to visit the completed works in India where suitable plant is for sale, in order to select what is requisite for the construction of the bridge. In the meantime the collection of stone and other material for the bridge should be put in hand. It is useless bringing the well curbs to site if there is no stone to build the wells with. Quarters for the use of the staff must also be built, and no time should be lost in commencing this very necessary work.

8. The rates entered in the estimate are not, in my opinion, excessive, but at the same time they leave a margin which should prevent any call for extra funds in future.

Office Note to Chief Engineer for Irrigation, dated 14th July 1890.

No. 1034 R., dated 18th July 1890.

Order thereon by the Govt. of Madras, P. W. Dept.

Ordered that the following telegram be despatched to the Engineer-in-Chief, East Coast Railway Survey :—

“Please order Spring to proceed to Simla about 1st August to discuss plans, Kistna Bridge, with Consulting Engineer to Government of India. Plans and estimates will be sent on from here as soon as possible.”

and that the following letter be addressed to the Government of India :—

No. 1035 R., dated 18th July 1890.

[7809

From—Lieut.-Col. T. GRACEY, R.E., Offg. Joint Secy. to the Govt. of Madras, P. W. Dept., Ry. Branch,

To—The Secretary to the Government of India, P. W. Dept.

I am directed to forward, for the consideration of the Government of India, copy of the Proceedings of this Government, No. 1034R., dated 18th July 1890, with which is embodied the estimate by the Engineer-in-Chief, East Coast Railway Survey, for constructing a bridge over the Kistna River at Bezvada.

2. I am to state that the Government of Madras generally concurs in the proposals and suggestions made by the Officiating Consulting Engineer, and especially as regards the uselessness of constructing a roadway for carts on the same level with the railway.

3. The Chief Engineer for Irrigation has been consulted, and states that he has no objection whatever to the proposals made for bridging the river at the site chosen.

4. I am directed to state that His Excellency the Governor in Council attaches great importance to the completion of the bridge over the Kistna at Bezvada, and requests that very early orders for commencing the work may be given. He considers that the iron well curbs should be obtained in India, and that Mr. Spring should, after completing his work at Simla, be deputed to visit the various depôts where suitable plant is available for the bridge-works, and in the meantime the collection of materials and the construction of staff quarters should be put in hand.

KISTNA BRIDGE.

REPORT AND ESTIMATES.

INDEX.

Para.	Subject.
	I.—THE SITE SELECTED.
1	Site generally.
2	Up-stream site.
3	Reasons for rejection of upper site.
4	Objections to site in very close proximity to anicut.
5	Reasons for selection of down-stream site.
	II.—APPROACHES.
6	The bounds of the project.
7	The two canal bridges.
8	The approaches.
	III.—TRAINING WORKS.
9	River training in general.
10	Facilities for successful training at site selected.
11	Design of the training bunds.
12	Construction of the training bunds.
13	Permanent tramway for training works.
	IV.—RIVER DISCHARGE.
14	Known discharge of the Kistna.
	V.—SPAN SECTIONS.
15	Pier protection stone.
16	Type sections of spans as influenced by pier protection stone.
17	Span cross sections.
	VI.—VELOCITY.
18	Fall in bed of Kistna.
19	Probable velocity in open river.
20	Variations in the velocity of parts of a river surface.
21	” ” in the spans of a bridge.
22	Span sections most favourable for discharge.
23	Probable velocities through spans.
	VII.—SPANS REQUIRED.
24	Probable duty of a 300 feet span.
25	” discharge of ten 300 feet spans.
26	” causes of local abnormal velocities.
27	How to secure uniform span discharge.
28	Minimum possible number of spans of full discharging action.
29	Ten spans of 300 feet recommended.
	VIII.—REASONS AGAINST OVER-CONSTRICTION.
30	Extra spans needed to dispose of early part of flood before scour occurs.
31	Difficult to alter position of southern training bund.
32	Ten 300 feet spans recommended.
	IX.—OBSERVED ACTION OF THE CHENAB RIVER.
33	Examination of sections of Chenab spans, and average depth of scour.
34	Irregular working of the Chenab spans.
35	Comparison of Chenab spans with the “type span”.
36	Extraordinary changes occurring in span sections.
37	Chenab soundings.
38	Length of anicut no true measure of length of bridge.
39	Fewer spans would have sufficed to carry the Chenab.
40	Reasons for reference to Chenab figures and observations.

7. When the design of the bridge has been finally approved of, the well curbs might be obtained from Richardson and Cruddas, Bombay, or some other firm in India, to save time. Mr. Spring might also, as suggested by the Engineer-in-Chief, be deputed under his orders to visit the completed works in India where suitable plant is for sale, in order to select what is requisite for the construction of the bridge. In the meantime the collection of stone and other material for the bridge should be put in hand. It is useless bringing the well curbs to site if there is no stone to build the wells with. Quarters for the use of the staff must also be built, and no time should be lost in commencing this very necessary work.

8. The rates entered in the estimate are not, in my opinion, excessive, but at the same time they leave a margin which should prevent any call for extra funds in future.

Office Note to Chief Engineer for Irrigation, dated 14th July 1890.

No. 1034 R., dated 18th July 1890.

Order thereon by the Govt. of Madras, P. W. Dept.

Ordered that the following telegram be despatched to the Engineer-in-Chief, East Coast Railway Survey :—

“Please order Spring to proceed to Simla about 1st August to discuss plans, Kistna Bridge, with Consulting Engineer to Government of India. Plans and estimates will be sent on from here as soon as possible.”

and that the following letter be addressed to the Government of India :—

No. 1035 R., dated 18th July 1890.

[7809

From—Lieut.-Col. T. GRACEY, R.E., Offg. Joint Secy. to the Govt. of Madras, P. W. Dept., Ry. Branch,

To—The Secretary to the Government of India, P. W. Dept.

I am directed to forward, for the consideration of the Government of India, copy of the Proceedings of this Government, No. 1034R., dated 18th July 1890, with which is embodied the estimate by the Engineer-in-Chief, East Coast Railway Survey, for constructing a bridge over the Kistna River at Bezvada.

2. I am to state that the Government of Madras generally concurs in the proposals and suggestions made by the Officiating Consulting Engineer, and especially as regards the uselessness of constructing a roadway for carts on the same level with the railway.

3. The Chief Engineer for Irrigation has been consulted, and states that he has no objection whatever to the proposals made for bridging the river at the site chosen.

4. I am directed to state that His Excellency the Governor in Council attaches great importance to the completion of the bridge over the Kistna at Bezvada, and requests that very early orders for commencing the work may be given. He considers that the iron well curbs should be obtained in India, and that Mr. Spring should, after completing his work at Simla, be deputed to visit the various depôts where suitable plant is available for the bridge-works, and in the meantime the collection of materials and the construction of staff quarters should be put in hand.

KISTNA BRIDGE.

REPORT AND ESTIMATES.

INDEX.

Para.	Subject.
	I.—THE SITE SELECTED.
1	Site generally.
2	Up-stream site.
3	Reasons for rejection of upper site.
4	Objections to site in very close proximity to anicut.
5	Reasons for selection of down-stream site.
	II.—APPROACHES.
6	The bounds of the project.
7	The two canal bridges.
8	The approaches.
	III.—TRAINING WORKS.
9	River training in general.
10	Facilities for successful training at site selected.
11	Design of the training bunds.
12	Construction of the training bunds.
13	Permanent tramway for training works.
	IV.—RIVER DISCHARGE.
14	Known discharge of the Kistna.
	V.—SPAN SECTIONS.
15	Pier protection stone.
16	Type sections of spans as influenced by pier protection stone.
17	Span cross sections.
	VI.—VELOCITY.
18	Fall in bed of Kistna.
19	Probable velocity in open river.
20	Variations in the velocity of parts of a river surface.
21	" " in the spans of a bridge.
22	Span sections most favourable for discharge.
23	Probable velocities through spans.
	VII.—SPANS REQUIRED.
24	Probable duty of a 300 feet span.
25	" discharge of ten 300 feet spans.
26	" causes of local abnormal velocities.
27	How to secure uniform span discharge.
28	Minimum possible number of spans of full discharging action.
29	Ten spans of 300 feet recommended.
	VIII.—REASONS AGAINST OVER-CONSTRUCTION.
30	Extra spans needed to dispose of early part of flood before scour occurs.
31	Difficult to alter position of southern training bund.
32	Ten 300 feet spans recommended.
	IX.—OBSERVED ACTION OF THE CHENAB RIVER.
33	Examination of sections of Chenab spans, and average depth of scour.
34	Irregular working of the Chenab spans.
35	Comparison of Chenab spans with the "type span".
36	Extraordinary changes occurring in span sections.
37	Chenab soundings.
38	Length of anicut no true measure of length of bridge.
39	Fewer spans would have sufficed to carry the Chenab.
40	Reasons for reference to Chenab figures and observations.

	INDEX—continued.
Para.	Subject.
	X.—THREE DESIGNS COMPARED.
41	Comparison of cost of three bridges of equal length.
42	" " discharging power.
43	The comparison which is "considered" fairer than either.
	XI.—ENGINEERING ADVANTAGES OF LARGE SPANS.
44	Risks in the sinking of numerous wells.
45	Possible effects of a breach in the anicut.
46	Cause of the extended down-stream influence of an abnormal current.
47	The larger class of spans recommended.
	XII.—WELLS.
48	The double polygonal well.
49	Size of the wells.
50	Material of the wells.
	XIII.—PIERS AND ABUTMENTS.
51	Design and material of the piers.
52	" of the abutments.
	XIV.—THE 206 FEET GIRDER BRIDGE.
53	Design of the wells and piers considered inadequate.
54	206 feet girder modelled on that of the Chenab.
55	206 " " bridge condemned.
	XV.—THE 252 FEET GIRDER BRIDGE.
56	The general design of the 252 feet girder bridge.
57	Special features in the design of the girder.
58	Influence of breadth of girder on material required for wind pressure.
	XVI.—THE 300 FEET GIRDER.
59	The girder generally.
60	The type of girder.
61	Scantling of girder.
62	Booms.
63	Vertical struts.
64	Diagonal ties.
65	Cross girders, ordinary.
66	" " special.
67	" " top.
68	" " middle.
69	Trimmers.
70	Gauges.
71	Roadway.
72	" expansion.
73	Road kerb.
74	Guard rails.
75	Longitudinal sleepers.
76	Bed-plates.
77	Hand-railing.
78	Chattering of ties.
79	Rivets.
	XVII.—CONSTRUCTION FORECAST.
80	Programme for completion in March 1893.
81	" for first working season.
82	" for second and third working seasons.
83	Permanent staff.
84	Foremen staff.
85	Labour.
86	Importance of an early start for collection of plant and stores.
	XVIII.—THE ESTIMATE.
87	Possible reduction in rates.
88	Lowest possible estimate of final cost of entire scheme.

KISTNA BRIDGE.

Report, Design, and Estimate by Mr. F. J. E. SPRING, M.I.C.E., Executive Engineer, Kistna Bridge.

I.—SITE SELECTED.

Site generally.—The bridge which is the subject of this report is intended to connect the Bellary-Kistna metre-gauge Railway with His Highness the Nizam's Guaranteed broad-gauge Railway. The River Kistna is here confined by the natural features of the country into a width, between permanent bank, of three-quarters of a mile. The site where the river is narrowest has been chosen for the anicut, at the town of Bezvada, and from the flanks of this anicut the Buckingham Canal takes off on the south side, and the Ellore, Masulipatam, and Vesey Canals on the north side. The existence of the anicut has had a very considerable influence upon the question of the site as well as upon the design of the Railway bridge which is now under consideration.

2. *Up-stream site*.—I have not had the advantage of a perusal of previous papers on the subject of the crossing of the Kistna, so, except from hearsay, I know nothing about the opinions which have been expressed by Sir G. Molesworth and Mr. Furnivall, and by the Madras Irrigation authorities, with reference to the site and to the scheme generally. I understand, however, that a position for the Railway bridge on the up-stream side of the anicut has received a considerable degree of support, and I know that borings have been recently taken near the proposed up-stream site, in the expectation that ground more favourable for foundations would be discovered there than was known to exist at the down-stream site.

3. *Reasons for the rejection of the upper site.*—Certain dangers and difficulties would have had to be encountered at any up-stream site which do not exist at the position which has now been fixed upon as the basis of the project herewith submitted for approval. The river would have had to be trained beneath a bridge of about the same length as the anicut, and though the up-stream terminals of the training bunds of a river with a moderate rise of flood need, with proper precautions, give rise to no very special anxiety, the training works heads of such a river as the Kistna, with 30 feet of flood, would, unless, as in the present project, they terminated in permanent unerodable banks, have been a constant source of danger and anxiety. Were the up-stream position selected another difficulty also would have had to be met and provided for, that, namely, of the crampedness of the space which at either side of the river is there available for the stations and junctions of existing and future lines of railway. There is a third and more serious difficulty which would have to be encountered by the Irrigation Department had the up-stream site been selected, namely, the impossibility of ensuring that all the spans of the bridge would work equally well, and the probability that some comparatively small portion of the anicut would always encounter the worst of the stream. In the absence of a bridge on the up-stream side the river now concentrates itself between the hills, and flows over the anicut in a broad equable channel. For a considerable distance, however, down stream from the piers of a bridge with the usual boulders around them, great swirls occur, which in themselves would be a source of danger to the neighbouring anicut. Worse than this is the fact that, owing to the obstacles presented by boulder-protected piers to the free traversing of the main stream from side to side at will, it somehow happens that in a bridge which is too large for its work a comparatively small number of the spans, four perhaps, or six, are usually to be found doing far more than their fair share of the work, and passing the water through at quite an abnormal velocity, while the remainder of the spans are doing little, or even doing nothing. A concentration of current of this sort upon a portion of the anicut of limited length could not but be a source of serious danger to it sooner or later.

4. *Objection to a site close to the anicut.*—Were the bridge constructed in close proximity to the anicut, the flow through the openings would, by the influence of the latter work, doubtless be equable enough: but not only would access to and from such a position have been exceedingly difficult, and well-sinking have been likely to have been constantly impeded by the occurrence of anicut stone, but the "blows" and subsidences so constantly occurring during well-sinking operations would almost certainly have injured the anicut: and this is a contingency which, under no circumstances, could be permitted to occur, so serious would be the effect on the canal operations.

5. *Reason for the selection of the down-stream site.*—The site which has been fixed upon in the present project is about half a mile down stream from the anicut, and therefore well out of the influence of the abnormal velocity to be found in its neighbourhood. It is in exact continuation of the present alignment of the Nizam's Railway terminus. It has this surpassing advantage, to my mind, over any other site that might be selected, of presenting such a direction towards the flow from the anicut that, by smooth symmetrical training bunds, which at their upper ends terminate in permanent unerodable banks, the river may be led, without any violent deflection, between the abutments of the bridge.

II.—APPROACHES.

6. *The bounds of the project.*—In the absence of any definite understanding as to the precise point at which the operations of the Bellary-Kistna Railway may be considered to end,

and those of the Kistna Bridge to commence, at the south side, I have, as a matter of convenience, assumed that the bridge over the Buckingham Canal will form a part of the Kistna Bridge project, and that the Bellary-Kistna Railway staff will bring their line up to its south abutment. Taking the south end of the Buckingham Canal bridge, therefore, as the starting point, I have similarly considered the north end of the Bezvada Canal bridge as the terminal point of the project referred to in the present Report and Estimate. North of the Bezvada Canal the ground is owned by the Nizam's Railway, and it appears probable that, whatever work is needed to connect the Kistna Bridge project with that Railway, and with the East Coast Railway, it will at least form no portion of the present project. This matter of terminals is, however, a detail which can be settled at leisure.

7. *Two canal bridges.*—The distance from point to point is about a mile and three quarters. For the purposes of the present estimate, I have considered that the two canal bridges, each consisting of three spans of 60 feet girders on 30 feet wells, are likely to cost about Rs. 75,000 each. This rate is based upon experience of the running foot rate of similar bridges elsewhere. If these bridges are omitted from the project, the estimate may be cut down by something over a lakh. These canal bridges would of course carry a roadway for carts.

8. *The approaches.*—The estimate of the cost of the approaches covers that of the necessary cart-road, and also that of a third rail for the metre gauge. In accordance with the wishes of the Government of India in the case of the Chenab Bridge at Sher Shah, separate estimates have been prepared for the bridge proper, the approaches, and the training works.

III.—TRAINING WORKS.

9. *River Training in general.*—The papers which are already in the possession of the Government of India upon the subject of the training of the River Chenab at Sher Shah, and of the River Indus at Derah Ghazi Khan, and the more recent report which by this time has probably been made regarding the training of the Indus at Kaffir Kot, make it, perhaps, unnecessary that I should here re-open the question whether the training of such a river as the Kistna by means of the smooth protected embankment system is, or is not, feasible and practicable. To my mind the question has been definitely settled, and it would add nothing to what is already known and on record were I here to attempt anew to handle a subject which has been already so ably dealt with.

10. *Facilities for successful training at the site selected.*—The site which is now proposed for the bridging of the Kistna is so exceptionably favoured by nature and by circumstances that the question which I understand to be a source of difficulty to many Engineers, that, namely, of the possibility of the training bunds being outflanked, does not here arise for consideration at all. Both the training bunds can be made to abut, at their up-stream ends, into ground into which there is no danger of the river eroding.

11. *Design of the training bunds.*—The question of the possible out-flanking of the bunds being therefore set at rest, it remains to determine, first, what should be the section of the bunds, and, second, to what extent is it permissible, by their aid, to constrict the waterway. Plate 2 shows in detail the cross section which I propose to adopt. It is a modification of the bund recently constructed, and in successful action on the Chenab, with such additions and alterations as appear to me to be called for by the different conditions prevailing on the Kistna, the greater scour, namely, of the river, and the comparative cheapness and plentifulness of stone.

12. *Construction of the training bunds.*—The bunds which guide the river between the abutments of the bridge will, as on the Chenab, be formed of a bank of sand faced on front with a sufficient covering of loose stone. The pit from which the sand for the bank is obtained will be so dug that it may form the bed for the horizontal layer of loose stone, laid at low-water level, which forms the continuation of the stone-faced slope, and which, as the river gradually undermines it, may be expected to dribble down until the full depth of the river, where scour occurs, has become covered with the desired layer of protecting stone.

13. *Training work permanent tramway.*—The plans and estimates provide for the permanent establishment of a maintenance railway from the quarries to the training works on both sides of the river.

IV.—RIVER DISCHARGE.

14. *Known discharge of the Kistna.*—In arriving at a decision as to the waterway which for theoretical, modified by practical, reasons it is advisable to provide at the Kistna Bridge, we have at our disposal a figure, for the discharge of the river, which is of greater value and authenticity than those usually at hand when the waterway of an Indian bridge is under consideration. The Canal Department's anicut, which is situated about half a mile above the bridge site, passes the whole of the flood waters of the Kistna, except the comparatively small share of it which is carried off by the canals on each flank. These floods have, I understand, been reliably gauged. The highest known flood, with reference to which the present bridge has been designed, is said by the Canal Department to have discharged, at its height, 820,000 feet per second. This figure may, I think, be accepted as relieving me from the necessity of trying to arrive independently at the discharge of the river from considerations of drainage area and rainfall.

V.—SPAN SECTIONS.

15. *Pier-protection stone.*—As in all the large up-country bridges for the last twenty years, a mass of some half a lakh of cubic feet of loose stone thrown around each pier forms an essential feature of the design. The subject of the ultimate form and destination of this pier-protection stone, like that of the training of rivers, has already received the careful attention of well-known experts, and the Government of India are in possession of very full information on the subject. I may therefore be excused from attempting here to handle this important subject with that degree of care to which it is entitled. It is well known that this pier stone is, in the smaller class of spans, usually engulfed in considerable quantities, and also that the larger the spans the less is the engulfment. Probings, annually made during several years, at some of the large bridges, clearly show that the ultimate tendency of this pier-protection stone is to assume a slope which gives to each span a cross section of which those represented on Plate 2 are a fair type.

16. *Type sections of spans as influenced by pier-protection stone.*—The stone may sink lower than is shown in the type, and may be engulfed down the side of the wells in large quantities. I prefer, however, for the present purpose, to refer to the typical section, because not only is this typical section the one which, by the constant care of the maintenance engineer in keeping his stone within touch at the piers, the span has ever a tendency to assume, but because by taking the larger section which would be given if both masses of stone dropped far below the wells, I should be calculating on a far larger area than I should be justified in expecting to occur, or in counting on for use in an argument in favour of lessening the number of spans.

17. *Span cross sections.*—The maximum possible depth of scour of 50 feet below lowest low-water having been assumed, Plate No. 2 gives a set of three comparable sections of the three classes of spans—206, 252, and 300 feet—for which estimates are now submitted. I now proceed to investigate the discharging power of the three sorts of spans.

VI.—VELOCITY.

18. *The fall of the bed of the Kistna.*—Up to the present I have been unable to procure any record of the velocity of the Kistna in flood. Levels run for a distance of 5 miles down from the anicut show a fall, during the low-water season, of 0.60 feet per mile, or 1 in 8,800: this figure, however, is unfortunately not a very reliable one, as a rise in the river was in progress while the levels were being run, and this had to be approximately allowed for. Arrangements are now being made for ascertaining the velocity of the river during the ensuing flood season. In the meanwhile the following considerations have led me to assume a velocity, based upon the data which are available, which will perhaps suffice for the present investigation; because the margin, which practical reasons compel me to allow, is, I think, large enough to cover any errors in the nice ascertainment of the true velocity of the stream.

19. *Probable velocity.*—The discharging conditions of a section of an unbridged river and those of a bridge are two entirely different things. In the unbridged river the velocity at the different parts of the breadth of the stream is very much more equable than at a bridge, the boulder-protected piers of which present a serious barrier to the side traversing and to the automatic equalisation of the several currents. The unobstructed area at the bridge site, from bank to bank, during highest flood, is 143,000 square feet, without scour. This area would pass the full discharge of 820,000 feet per second at a mean velocity of 5.73 ft. sec. When the Mississippi formula is applied to this area, and to a fall of 0.6 feet per mile, a velocity of 5.04 ft. sec. is arrived at. If this latter velocity is fairly correct, the 820,000 feet of water would need a cross sectional area of 164,000 square feet, and this it would have no difficulty in providing for itself by a comparatively moderate scour of 8 or 9 feet over the erodable portion of the floor of the bridge.

20. *Variation of the velocity.*—For a 33-feet flood this velocity, 5 feet per second, or 3½ miles per hour, is extremely slight. The surface current will doubtless considerably exceed this in places, and though in some of the spans of the bridge, as is always the case, the surface velocity will rise to perhaps nearly double this, other spans will stand comparatively idle. In the following forecast of what the spans are likely to do, I have attached due importance to this well-known irregularity in their mode of action.

21. *Variations of velocity in the spans of bridges.*—So much as regards the velocity of the river through the unobstructed river channel. The problem of its passage through the spans of the bridge presents greater complications. No known formula is perhaps quite applicable to the case of any one span in a long series on a broad river. As already mentioned, the local differences in the velocity are quite extraordinary. I have in my mind the case of certain spans through which a well-trained crew found it impossible to pull a boat, while a few minutes later the same boat actually drifted upwards through a neighbouring span. The surface of the flood water across a great river is seldom or never level or even nearly so: local deep scour through certain spans has always, up to a certain limit, a tendency to cause its own increase; the deepened span attracting to itself, as it were, more and more of the current, by, I suppose, the favourable alteration of the hydraulic mean depth.

22. *Most favourable span sections for discharge.*—The most favourable cross section for discharge purposes which ever is likely to occur, in any one span, is represented on Plate 2, where a scour of 50 feet below low-water is shown as occurring in the middle of the spans. It

would be quite unfair to take these maxima cross sections in estimating the number of spans that will suffice to pass the river, because only two or three out of all the spans will ever be working so well: the others will always be in a more or less silted up condition. We have, however, arrived at the general conclusion that an average velocity of 5 feet per second may be expected in the unobstructed river, and it will now be interesting to enquire what velocity we may expect in the hardest worked span.

23. *Probable velocity through the spans.*—Taking then the areas and perimeters shown on the plan as appertaining to the 206, 252, and 300 feet spans, and applying the ascertained fall of the river, we obtain velocities which vary with different formulæ, but which may fairly be taken as for the above three classes of spans—7, $7\frac{1}{2}$, and $7\frac{3}{4}$ feet per second.

VII.—SPANS REQUIRED.

24. *Probable duty of a 300-foot span.*—I shall first take the class of the 300-foot girders, which I am of opinion ought to be adopted, and shall afterwards take up the case of the waterway required by the other classes of span. It will be seen from Plan No. 2 that a 300-foot span, which is doing its utmost, may be reckoned on as offering for the passage of the water an area of about 19,000 square feet, and it has been seen that for this span a velocity of, let us say, 7 feet per second may be counted on. Now it is fairly certain, judging from experience in other rivers, that at least in some of the spans the velocity will not be greater than 2 feet per second, and that there will be no scour at all, but that the river will run gently over the unaltered cold weather bed. Such a span would present an area of, say, 6,000 square feet. Thus the best of the spans would be doing a duty of 133,000 cubic feet per second, while the worst would be passing only 12,000. Between these two extremes there would be all manner of spans. It is of course impossible to foretell what they would all do, but it appears to me that ten of them may very fairly be assumed as likely to work in the following manner.

25. *Probable discharge of the 300-foot span.*—

No.	Area.	Velocity.	Discharge.
2	19,000	7	2,66,000
3	17,000	6	3,06,000
2	15,000	5	1,50,000
2	14,000	3	84,000
1	6,000	2	12,000
TOTALS . 10	1,53,000	5.34	8,18,000

This action of the ten spans would practically dispose of the whole of the water, and my estimate of the probable action of the ten spans is, I think, an extremely moderate one. The above figures might of course be manipulated to any extent. I do not pretend to offer them as more than the merest indication of what the action is likely to be.

26. *Probable causes of local abnormal velocities.*—I am well aware that to estimate the discharging power of the typical span of 300 feet with stone-defended piers, as I have done, by the use of the Mississippi or any other formula, is likely to lead to very misleading results. What influences the discharge, in the case of a sudden constriction of a breadth of 307 feet of water, so that it may flow between piers 288 feet apart, and over a bed whose form is largely determined at the moment of action by the water itself, is not the fall per mile of the bed of the river in the locality, but rather the local afflux on the up-stream side. This in its turn is limiting its own channel, and, secondly, by the extent to which such backing up or afflux will after a while be relieved by the withdrawing influence of the neighbouring spans in which less backing up has occurred. The problem is indeed an altogether insoluble one, and all we can do is to bring general experience and common sense to bear upon the answers which are suggested by theory. As I already have said, some favoured spans work with a quite abnormal velocity and discharging power, while others are doing little or nothing.

27. *Problem to be solved—how to secure uniform span discharge.*—The problem which Engineers who have been working at this subject of the training and bridging of the great Indian bridge shall equally bear their fair share of the work? It is obvious that so long as any one span is likely to beget an entirely abnormal velocity which gives rise to a dangerous local scour, the foundations are and must be kept uneconomically deep. As long as rivers were untrained and were bridged across from sandy bank to sandy bank without regard to the obvious fact that the breadth was an incident of the instability of the soil, so long were to be found at very large bridges the two objectionable features—idle spans and abnormally deep spans.

28. *Minimum possible number of spans with full discharging action.*—Now it appears to me to be obvious that what is not too much for one span is not too much for the others, and that, consequently, if we are prepared with our foundations to stand the risk, in any one span of a series, of such a scour as would erode for itself the typical section shown on Plate 2, we ought logically to be in no dread of the effects of causing similar action in the remaining spans. The con-

clusion led up to by such a line of argument is this, that to carry off 820,000 cubic feet of water per second, with a mean velocity of 7 feet per second, the necessary area, 117,000 square feet, is offered by six spans of 300 feet.

29. *Ten spans of 300 feet recommended.*—For certain practical reasons connected with the construction of the training works, I am not prepared to recommend that the Kistna be bridged by these six spans of maximum capacity. I have indeed prepared the estimate for 12 spans, but for reasons depending on velocity, and on the probable partial action of many of the spans, I have, as already explained, arrived at the conclusion that the bridge may, with perfect safety and convenience, and with an ample margin for all contingencies, be made to consist of ten spans of 300 feet.

VIII.—REASONS AGAINST OVER-CONSTRICTION.

30. *Floods often rise quicker than sufficient scour can occur to carry them off.* This necessitates extra spans.—The practical reasons which warn me off from attempting so severe a constriction of the river as, with a slight up-stream afflux, would force it to scour for itself the typical section of bed, are the following. The formation of great depth of channel is a matter of time, often a matter of many days' duration. At the subsidence of a flood a deposit of sand quickly fills up, in whole or in part, those spans in which the water had scoured for itself the typical section of channel. Were we always certain that floods would rise as slowly as channels could be scoured, we might with equanimity face the position. It is certain, however, that the bed of the river would never be ready in time for a suddenly rising flood, and it is therefore obviously suggested by prudential considerations that ample openings should always be ready to allow of the passage of a rising flood, during the first few hours or days, until it has had time to scour for itself the usual large cross sectional area in a limited number of the spans. It thus comes to pass that in my suppositious ten-span bridge referred to in para. 25, most of the spans fall so far short of their fullest working capacity.

31. *Difficult to alter the position of southern training bund.*—The second and more obvious reason which prevents my recommending that any attempt be made to drive the river into fewer spans than ten is this. There are practical difficulties about the construction, during the cold season, of the southern training bund in a more forward position than the one which is shown on the plan. The bund must be constructed in the dry bed of the river if it is possible to do so; and to advance its position farther to the northward would cause it to encroach on the cold weather channel. Moreover, there are certain deeply scoured holes at the down-stream side of the southern flanks of the anicut, which I dare not encroach on too nearly. As regards the northern training bund, I have plenty of room to push it southwards on the dry bed of the river, but I prefer not to venture too far, as by so doing I should cause too violent a deflection of the current from over the anicut—a current which has the not unimportant characteristic of being already in possession of a very definite direction. Had the anicut been absent, I should have had no dread of such a deflection of the current arriving from the upper reaches, because by the influence of the training bunds it would after a while have automatically assumed a suitable direction of its own.

32. *Ten spans recommended.*—For these reasons I am averse to recommending that the river be constricted into fewer than ten spans of 300 feet, or their equivalent in other spans: but for the reasons already given I am confident that these ten spans will be amply sufficient, because in the estimate, which in para. 25 was made of the probable duty that would be performed by each of the spans, I endeavoured to err on the side of safety.

IX.—OBSERVED ACTION OF THE CHENAB BRIDGE.

33. *Examination of cross section of the Chenab spans; and average depth of scour.*—Since writing the above paragraphs it has occurred to me to examine and analyse some sections which I had taken of all 17 of the Chenab Bridge spans, so as to ascertain how far they support me in the opinions expressed above as to the probable discharging capacity of the Kistna spans. The results are interesting, and I think remarkably confirmatory. I have taken out the area of each of the openings for the space enclosed, above, by the line of highest known flood, below, by the bed of the river as ascertained by careful soundings, and at the sides, by the piers. The sections which I refer to were taken at two critical periods—one at the time of a very high flood, and the other at lowest low water. The entire area of the low-water section was 6,400 square feet, and with a mean velocity all over of 2.33 ft. sec. this would give the known cold weather discharge of 15,000 cubic feet per second. To this cold weather discharge, however, I merely incidentally refer, and shall invite careful attention to a comparison between the areas intercepted between high flood level above and flood bed and cold weather bed respectively below. These two areas were 52,300 square feet and 37,500 square feet, thus indicating that a scour took place of which the area was 21,800 square feet, or close upon three-fifths of the cold weather area between bed and high flood line. This scour of 21,800 square feet would, if distributed over the spaces between the spans which the absence of stone protection rendered at all susceptible of scour, average a depth all over of about 10 feet. This is very fairly corroborative of what I anticipated at the end of para. 19.

34. *Irregular working of the Chenab spans.*—I may now ask attention to the extremely irregular manner in which the seventeen Chenab spans were working. Omitting three spans which show areas of 480, 800, and 1,070 feet, the remaining 14 varied in area between such wide extremes as 7,400 feet and 2,140 feet. I regret that I possess no record of the velocities

obtaining in these spans; they varied, as I have said elsewhere, between the extremely high and the extremely low. I have, however, a very distinct recollection of their approximate relative velocities, and though in the following estimate of the work that they were doing I cannot be absolutely right, yet my figures may fairly be accepted as showing that in designing such a bridge as the Kistna the fullest allowance must be made, such as has been made in para. 25, for the irregular manner in which we know by experience that the spans will be certain to work.

Number of spans.	Area.	Estimated velocity.	Discharge.	Number of spans.	Area.	Estimated velocity.	Discharge.
1	480	2	960	10	3,000	3	9,000
2	800	2	1,600	11	1,070	1	1,070
3	3,840	10	38,400	12	2,430	2	4,860
4	4,200	8	33,600	13	2,250	3	6,750
5	2,140	3	6,420	14	2,700	4	10,800
6	2,630	4	10,520	15	6,150	8	49,200
7	2,910	4	11,640	16	7,400	10	74,000
8	4,550	6	27,300	17	4,200	8	33,600
9	5,500	5	27,500				
						TOTAL .	347,220

Three and half lakhs is, I believe, the latest reliable figure for the flood discharge of the Chenab, so that the above figures, which were arrived at independently of any reference to the $3\frac{1}{2}$ lakhs, may be accepted as fairly reliable enough, though the velocities have only been estimated.

35. *Comparison of Chenab spans with the "Type span."*—We thus find one span doing quite an abnormal amount of discharge work, and it will be useful if for a moment we consider this span separately. For a proper comparison between the areas of the typical span represented on Plate 2 and of Chenab span No. 16 at the time when its section was made, we must deduct from the former the difference between the areas corresponding to a 15-foot rise of flood, as on the Chenab, and a 33-foot rise, as on the Kistna. Deducting, therefore, 3,550 from 11,350, which is the area of the type 252 feet span on Plate 2, we get 7,800 as the area at which the Chenab span ought to have been working, and this is sufficiently near to the actual area, 7,400 square feet. The reason why a larger area than 3,840 and 4,200 had not been scoured out at Nos. 3 and 4, is that for the purpose of holding a pile bridge and some girder staging a considerable quantity of stone had been spread right across these spans, so that, in spite of their very high velocity, they were not scoured out to anything near the typical sections. A mean velocity of about 6 feet per second would carry the whole estimated volume of the Chenab flood through the area found to exist in the spans of the bridge.

36. *Extraordinary changes that occur in span cross sections.*—I may here note in passing, merely for the sake of recording the extraordinary changes that occur in the beds of our rivers, that of the nine spans which were all that were running at all three months later than the floods referred to, Nos. 15, 16, and 17 were for all practical purposes silted up, and offered an area of only 320 square feet each, while Nos. 3 and 8, with 1,850 square feet each, were practically doing the whole of the cold weather discharge of the river, which, by that time, had dwindled down to perhaps 15,000 cubic feet per second.

37. *Soundings in the Chenab.*—The deepest soundings found in any span during the floods of 1889 were 50 feet, or only about 35 feet below lowest low-water; while the deepest soundings found in any one span during the cold weather, when the river was lowest, were 22 feet, which occurred in the middle of span No. 3, which even then maintained its high velocity.

38. *Length of the anicut no true measure of the length of the bridge.*—A further reference (see para. 39) to the experience of the Chenab will, I hope, need no apology. The problem now under solution is one which, if we attempt to solve it by the use of purely theoretical reasoning, we are likely to bring to a false conclusion; and equally so if we merely decide on general grounds to bridge a distance equivalent in length to the existing anicut. Had the hills at the site of the anicut been 600 or 800 feet nearer, the anicut would undoubtedly have been so much shorter. The accident of the length of the anicut is, to my mind, quite inadequate as a guide to the length of the bridge.

39. *Fewer spans would have safely sufficed to carry the Chenab.*—On referring to the table of the working of the Chenab spans as given in para. 34, we find that had they all been working as well as No. 16 was working, five spans of 200 feet would have amply sufficed to carry the whole of the river. Even if we take No. 9, and allow it the perfectly permissible velocity of 8 feet per second, we find that eight spans of 200 feet would have amply sufficed. It will be recollected that early in 1888, Mr. J. R. Bell strongly recommended the use of nine spans of 250 feet, and that this amount of waterway would have fully sufficed for all contingencies of the floods and of the traffic, is now, I think, conclusively proved by the figures which I herewith offer. I would go further and say that I would now have no hesitation in bridging the Chenab with six spans of 300 feet, using a small percentage of the money saved in judiciously reinforcing the training bunds.

40. *Reasons for referring to Chenab figures and observations.*—I may be permitted to say that my reason for entering so minutely into all these figures and arguments is this, that it may not be thought, if my views fail to impress themselves upon others, that they have been arrived at with insufficient care and data on which to base them. A certain line of reasoning was put forward by Mr. Bell, when the Chenab scheme was under consideration, in favour of nine spans of 250 feet, while Mr. Mallet argued for, I think, 24 spans of 150 feet. Sir G. Molesworth split the difference with 17 spans of 200 feet. By the erection of these 17 spans of 200 feet, the problem will have been brought no nearer a solution unless the facts and observations recorded by the Engineers concerned with the finished structure may aid, as I am now trying to make them aid, in the final settlement of the disputed question.

X.—THE THREE DESIGNS COMPARED.

41. *Comparison of cost of three designs of bridges of equal length.*—The estimates now submitted cover the cost of approaches and training works. Whichever of the three classes of spans is decided on, the approaches and training works will remain unaltered. In comparing the various possible designs, therefore, in this paragraph, I shall omit all reference to the cost of the approaches of the bridge, or to the training of the river: the figures will be those of the net bridge only. The estimates provide for three alternatives to span a breadth of about 3,650 feet—

17 spans of 206 feet girders, to cost	Rs. 30,64,000
14 " of 252 " " " "	" 33,10,000
12 " of 300 " " " "	" 35,75,000

It would appear from these figures that the smaller spans possess the undoubted advantage of being five lakhs cheaper than the large ones. I shall however proceed to put the comparison in another way. In the above estimates mere length is looked on as the important factor of the problem, whereas, from my point of view, the really important factor is the efficiency of the discharging power. As regards the design for the 206-foot girder bridge, it ought, I think, to be rejected altogether; the piers and wells are insufficient in weight for the height of flood to which annually they will be subjected, and most certainly insufficient for the contingency of a breach in the anicut. The cost of one span of piers, wells, girders, and a proportionate share of other contingent charges, is as follows for each design:—

1 span of 206 feet, costs	Rs. 1,54,000
1 " of 252 " " " "	" 2,08,000
1 " of 300 " " " "	" 2,51,000

If, therefore, we again, as I claim erroneously, take length of bridge as the standard of comparison and compare a length of ten spans of 300 feet with the nearest length of the other designs, we have—

15 spans of 206 feet girders, costing	Rs. 27,58,000
12 " of 252 " " " "	" 28,94,000
10 " of 300 " " " "	" 30,73,000

The difference between the cost of the bridge of small spans and that of large is now considerably less than before.

42. *Comparison of cost of three designs of bridges with equal maximum discharging power.*—Taking next the maximum typical area of span section as the true standard of comparison, in place of mere length between abutments, which I say is not a fair standard at all, we find that the following are roughly equivalent in discharging power:—

	Sq. ft.	Rs.
17 spans of 206 feet, giving an area of	11,350 each	= 193,000 = 30,64,000
13 " of 252 " " " "	15,030 "	= 195,700 = 31,02,000
10 " of 300 " " " "	19,360 "	= 193,600 = 30,73,000

43. *The comparison which I consider fairer than either of the above.*—I don't at all wish to be understood as thinking that I have proved that all three designs of bridge will cost about the same for equal efficiency. There are so many disturbing causes which prevent an accurate estimate being formed of the discharging power of the various designs that no mere manipulation of figures can be accepted as giving necessarily a reliable comparison. The designs have been compared with the aid of two standards, length between abutments, and maximum discharging capacity. For bridges which are too long for their work, as all three bridges are, for reasons connected with the establishment of the training bunds, both these standards are false standards for comparison. Taking everything into consideration, and mentally weighing all conceivable sources of disturbance, I offer the following as presenting to my mind a truer comparative view of the relative values of the three designs than either of the comparisons which have been hitherto made:—

16 spans of 206 feet	Rs. 29,10,000
12 " of 252 " " " "	" 28,94,000
10 " of 300 " " " "	" 30,73,000

Of these three designs, which, from my point of view, are all round fairly comparable as possessing equal powers of passing the river, the last, viz., ten spans of 300 feet, has surpassing advantages over the others. I shall now, in greater detail, give my reasons for, as an Engineer, arriving at the conclusion.

XI.—ENGINEERING ADVANTAGES OF LARGE SPANS.

44. *Risks in the sinking of numerous wells.*—The borings which have so far been made in the bed of the Kistna have brought nothing to light but sand and clay. It by no means follows, however, that because no boulders have been met with by the boring tools they may not be found in considerable numbers during the well-sinking, not in layers or in masses, but accidental and isolated. I consider it quite beyond the bounds of practical possibility that any of the ancient stones should have found their way so far down stream as the bridge site, farther, indeed, than 300 or 400 feet. The adjoining country, however, is of a rocky formation, and it is consequently by no means improbable that occasional boulders may be frequently met with in the process of sinking. The fewer the wells the less will be the risk of this costly and troublesome source of disturbance, and this is one, and an important, reason of my preference for the larger spans.

45. *Possible effect of a breach in the anicut.*—There is, however, a far more important reason for the preference. The risk of a breach occurring in the anicut can never be entirely kept out of sight. It is doubtless a remote contingency, and will probably never occur, but the designer of the bridge is bound to give it due consideration, and the extra expenditure which its consideration must dictate is only a premium of insurance against an always possible contingency. The result of such an accident would probably be the formation, for several hours or days or weeks, of a far-reaching current of exceptional depth, breadth, and velocity. Such a current would have no chance of losing itself in a boil at the foot of the steep face of the anicut, as is done by the ordinary overflow: it would shoot forward through the breach at a high velocity and in a horizontal direction; and not only would it travel at little abated speed for a considerable distance down stream, but it would, by the deposition of sand on its flanks, and by the other methods peculiar to abnormal local currents of this description, soon influence the water on both sides of it in such a way as would soon undoubtedly result in the establishment of the main body of the river in a comparatively narrow but deep and rapid channel, and in the neighbouring water at both sides of it standing comparatively slack.

46. *Cause of the extended down-stream influence of an abnormal current.*—The curious effect just referred to may often be noticed when, owing to the influence of a long up-stream funnel-mouthed shoal, the centrifugal effect of a bend, or some other cause, a local afflux, or backing up occurs at one of the spans of a bridge, resulting in an extraordinary local excess of velocity and consequent extra scour. Whatever the cause, induction by friction against the neighbouring water, action like that of an injector, or mere natural deposition of silt at the outer sides of the current, the result is found to be this, that at the down-stream side of what I may call the nozzle of the hose, a deep and far-reaching channel is soon formed, which extends its influence far beyond the distance to which it might have been thought that the effects of the nozzle would reach.

47. *The larger class of spans recommended.*—As in the event of the failure of the anient such a channel will surely occur, extending down to the bridge, and as the larger spans which offer a liberal type section may be considered as perfectly safe from its effects, I strongly urge that the larger, or 300-feet, spans be adopted. I here feel called upon to say that my reason for so fully detailing the line of mental argument which have led up to my recommending the adoption of a design which bears the appearance of extravagance, is this. Being aware that my reasoning has no mathematical or absolute value, I hope to be understood as desiring to lead others to my own conclusions by the use of my own process of reasoning, which I offer for what it is worth.

XII.—WELLS.

48. *The double polygonal design.*—For the wells, I have adopted the double octagonal form for the following reasons. The best of all wells is perhaps the single circular well, but for long piers, such as are necessary for a rise of flood like that in the Kistna, the single circular well is the least economical. The worst class of foundation is perhaps two or more small circular wells in a group. The oval well with two apertures is an attempt to get over the constant tendency of two contiguous wells to draw together during the sinking; but it has this great disadvantage, that there are always two parts of the perimeter of the curb which are so much farther away from the dredgers than the other parts that the well is apt to stand on an undredged pivot or knife-edge and overbalance itself crooked. Mr. J. R. Bell's introduction of the double polygonal well has effectually got rid of this trouble, and the double hexagons used on the Chenab acted excellently. In a well of so large an area as is needed for the Kistna, however, the side of a hexagonal well is rather too long for a sufficiently rigid curb. Moreover, the two projecting corners at each side of the well project farther into the span than is compensated for by the area which they enclose. Cutting off these objectionable corners soon suggested the octagon, and this is the form of the double well which has now been designed.

49. *Size of the wells.*—The octagonal curb which gives shape to the well is 9 feet on a side, the two contiguous portions being so truncated that the mid wall of the well is only of the same thickness as the steining. The bond rods which pass up through the well form a regular double octagon with a common side, and each of the sides of the double octagon is 6' 9". The well is corbelled out at the top, so as to carry the very important temporary dam wall which permits of the superstructure of the piers being founded considerably below water level, and also to allow of the temporary loading for the sinking of the last few feet of the well.

50. *Material of the wells.*—As there is no brick clay anywhere near the bridge, it will be necessary to build the wells of stone. The stone which is available on the spot is not of too good a quality, but in durability it is at least as good as brick, and it stands a comparatively cheap dressing, which will allow of my completely squaring all the stone to be used in the wells. Judging from the appearance of the mortar used in the anicut, there will be nothing to fear in the matter of this material, which is of excellent quality.

XIII.—PIERS AND ABUTMENTS.

51. *Design of the piers, and the material.*—The design of the pier has been kept of a massive and simple character. Owing to the comparatively inferior quality of the stone that is available, it has not been considered advisable to give pointed cut waters to the piers. They have therefore been kept semi-circular at the ends. For the upper corbelling and the coping and bed stones, some excellent gneiss is procurable from quarries situated a few miles away on the line of railway.

52. *Design of the abutment.*—The design of the abutments has greater pretension to architectural effect. Much of this appearance is however produced by the protrusion on the face of the work of those features which have been introduced into its mass for the purpose of lightening the weight of the masonry. The small houses or huts at the ends of the girder will be needed for the permanent traffic jemadars, whose duty it will be to pass the foot and cart traffic in safety over the bridge between trains. Large and well-dressed blocks of gneiss will be available for the upper portion of the abutment, and for the parapet and huts. The necessity for keeping the training bunds above flood level unfortunately gives the abutments a dwarfed appearance. This, however, cannot well be avoided without undue and unremunerative outlay.

XIV.—THE 206-FEET GIRDER BRIDGE.

53. *Design of the wells and piers considered inadequate.*—I have already referred to the fact that the wells and piers, which form the basis of the estimate of the 206-foot girder bridge, are considerably lighter than those used for the 252 and the 300-foot spans. I had at first designed them for the use of the larger spans, but subsequently, on obtaining more information about the condition of the Kistna in flood, I designed the more massive well and pier which is illustrated on Plate 4. A glance at Plate 5 will show what the lighter well is like, because having drawn the abutment standing on this lighter well, I have let the drawing stand unaltered. In the estimate, however, I have allowed for the use of the heavier well for the heavier spans. The half pier, which forms the front of the abutment, is the half of the lighter and not of the heavier pier; this also will be altered if the 300-foot span is decided on, and the drawing of the whole abutment will be quickly altered to suit the heavier design. Plates 4 and 5 will, in the meanwhile, serve to illustrate the character of the design for the masonry of the 206-foot spans. I repeat, however, that, though good in proportion to the spans which they carry, they are altogether unsuitable for use in such a river as the Kistna.

54. *206-foot girders modelled on that of the Chenab.*—For the 206-foot girders I have not been at pains to modify the design of the Chenab girder of similar span. The girder is a most excellent one, good in design for the manufacturer as well as for the erector. It has formed the model on which I have sketched the two larger spans, but I have modified it, for this purpose, in many details, which will be found on the drawing of the 300-foot girder, and more particularly in the details of the roadway. I have been obliged to add a few tons to the weight of the 206-foot girder on account of the arrangements which are necessary for the third rail.

55. *206-feet design altogether condemned.*—Before closing all reference to the 206-feet design I may usefully recapitulate my reasons for condemning its adoption. If it is to be accepted at all, the wells and piers must be made so much heavier than those that have been designed, that it will at once be beaten in economy by the 252-feet bridge, length for length. It offers far greater cause for anxiety, than does either of the larger spans, in the always possible event of a breach in the anicut. There is a greater risk in the larger number of foundations. With the same length of bridge the piers and their necessary protection stone offer far more obstruction to the river than is offered by either of the other designs. I hope now that I have succeeded in making all this sufficiently clear to secure the concurrence of Government.

XV.—THE 252-FOOT GIRDER BRIDGE.

56. *The general design of the 252-foot project.*—Though I have, all through this report, contended for the adoption of the 10 spans of 300 feet, still I am by no means so extremely averse to the 12 spans of 252 feet as I am to the 16 spans of 206 feet. The 252-foot span is a fairly reasonable one, and the girder, as sketched in Plate No. 8, has so many features in its favour that I would offer no further objection to its adoption but for the following consideration. The over-ground portion of any bridge with deep foundations is mere child's play as compared with the well-sinking: most of the risk and anxiety are concentrated in the work of the foundations: and to have two less double 80-foot wells to sink is with me a very strong argument for the smaller number of larger spans. Nevertheless, all the objections to the 206-foot spans, in the matter of the chance of a breach occurring in the anicut, are applicable, though with diminished force, to the 252-foot spans.

57. *Special features in the design of the girder.*—The design of the 252-foot girders has some special features of interest. It will be seen that I have followed the main lines of Sir A. Rendell's design of the Chenab girders, doing away, however, with the raking end pillars, and substituting vertical ones, for reasons which will be explained in later paragraphs concerning the 300-foot spans. The use of the double system of 45° triangulation with a depth of 24 feet, causes the verticals, and consequently the cross girders, to be spaced 12 feet apart instead of 10. This results in an economy in the vertical struts as well as in the Chenab girders, both of which, and particularly the verticals, have an excess of strength in the Chenab girders. The result is a proportionate economy without a corresponding excess of weight in the rail-trimmers. These latter, though somewhat deficient in strength in the Chenab girders, are rather heavier than is necessary in my 300-foot span, but their cross section is admirably suited to the 12 feet spacing of the cross girders in the 252 feet design.

58. *Effect of breadth of girder on account of material required to resist wind stresses.*—Another interesting cause conduces to the relative economy of the 252-foot girders, namely, that, owing to their distance apart, a function of the breadth of the metre-gauge rolling stock which is not centrally railed, being greater in proportion to their span than is the case with the 300-foot spans, the effect on the booms of the stresses induced by wind action requires to be met with a less proportionate weight of metal than in the larger span is needed. The details of the roadway, as shown on the 300-foot span plate, will equally well suit the 252-feet.

XVI.—THE 300-FOOT GIRDER.

59. *The girder.*—In describing the design of the 300-foot girder somewhat minutely, I do so in the hope that this span will be the one selected, and that consequently the indent will soon be forwarded home. I am therefore particular in explaining the details, and in giving my reasons for introducing some special features into the design. I have on the drawings given only sufficient detail to allow a clear comprehension being formed of the essential points. It will be seen that I have followed generally the broad outlines of the Chenab girder, which has proved itself exceptionally easy of erection. This facility of erection has been testified to, in conversation with me, by both the makers—Messrs. P. W. Maclellan and the Horsely Company—and it doubtless had an appreciable influence on the cost per ton of the girders in England, as it certainly had on the cost of erection. Any alterations which I have made in such existing practice as I am acquainted with, have been made with special reference to labour or to erection facilities. It is only after very careful consideration that in the following paragraphs I lay stress upon certain forms of design for certain parts of the structure: and I hope that in these details I may secure Sir A. Rendell's concurrence.

60. *The type of girder.*—The Whipple Murphy type has been chosen on account of the facilities which it offers for erection. The span, 300 feet, has been measured from centre to centre of bearings. With a depth of 30 feet, or one-tenth of the span, and with 45° bracing, we very conveniently get three systems of triangulation. As with the raking end pillars of the Chenab girders, much difficulty was often experienced, and sometimes in critical circumstances in making good the end top joint, the end pillars of the Kistna girders have been designed vertical, and this will greatly facilitate erection. The vertical end pillars have also this small advantage, that they make it very easy at any time hereafter to arrange for foot-paths, if needed, over the top boom, and they also allow of the passage of a travelling crane, over the top of the finished girders, towards the more forward spans that are in process of erection. The difficulty of making a good top end joint with the raking pillars, particularly in the face of a rising flood, or of a sinking staging, is what has principally induced me to press for the vertical end pillar.

61. *Scantlings of girder.*—The dimensions of the principal parts of the truss, as written or scaled on the drawing, have no pretensions to being anything more than approximate for estimate purposes and for draughtsmanship. They have been based upon a roughly assumed dead-load of 420 tons *plus* a live-load of two heavy engines at centre, and the rest of the span covered with loaded wagons. An allowance has also been made for the effect on the booms of a 30-lb wind considered as acting over an aggregate of surfaces equal in area to that enclosed by the outlines of the top bottom and ends of a girder. As already mentioned, it results from the small breadth of the pair of girders, in comparison with their span, that this allowance for wind is proportionately larger than it would have been had the girders been spaced farther apart. For the rough purposes of draughtsmanship for which the calculations were undertaken, an all-round unit stress of 6.5 tons has been considered sufficient.

62. *Booms.*—The side plates and angle irons of the booms have been kept of uniform dimensions throughout. Changes of cross section have been made by varying the dimensions of the main top and bottom plates only, and such changes occur only at the main joints. It might perhaps be an advantage to make the side plates and the angles a little heavier, as for such heavy pieces of boom they may perhaps be damaged in transit. I think, however, that careful attention to packing at the ends of the pieces, and the insertion of temporary diaphragms in the lower boom, corresponding to the permanent ones in the upper, will get rid of this difficulty. As in the Chenab girders, a short piece of the horizontal flange of the upper inside angle iron of the lower boom is cut away at such joint, to allow of the insertion of the cross girder, and this gap is subsequently covered by a plate. At the main joints, which separate the main pieces of boom, the outer lower angle irons can be covered in the usual manner, but as

the covering of the inside lower angle iron would interfere with the seating of the cross girder, the cover angle must be rivetted on the inside, and this necessitates the cutting away of a corner of each of the vertical struts that occur at a main joint.

63. *Vertical struts.*—In the Chenab girders the vertical struts were made of one uniform section. This, though a sacrifice of economy, mattered little in so shallow a girder. In a deeper girder, however, it is worth while to more fairly proportion them to their work. Strong verticals are however so valuable an aid to the erection of the top booms that I prefer to keep to the full dimensions for all the vertical struts that occur at the main joints, but to lighten the intermediate ones, as the centre of the span is approached, into closer accord with the dimensions dictated by theory.

64. *Diagonal ties.*—I should like the diagonal ties to be sent out each in two pieces of about 20 feet long, and I should like them to be *packed* on the insides of the rail-trimmers. I have shown them attached to the booms precisely as in the Chenab girders, but have not gone into the details of the rivetting of these or indeed of any part of the girder.

65. *Cross girders, ordinary.*—To allow of sufficient clearance for metre-gauge vehicles, running on the third rail, it has been found necessary to space the main girders farther apart than on the Chenab Bridge. The greater height of the girders would also no doubt have rendered necessary this increased spacing. The resulting increase in the span of the cross girders is compensated for by the extra depth which the greater height of the boom side plates allows of being given to them. I have not given the top of the cross girders a bow form, but have kept both flanges horizontal. The side slope of the road is a matter of no importance whatever, and if it were, it could be given otherwise than by the shaping of the cross girder web, by which no weight, to speak of, is saved, and the cost of manufacture is certainly enhanced.

66. *Cross girders, special.*—The design of the last cross girder in each span is a special thing which I would insist on. It will be seen that the end cross girders have been made double as strong as the others. It will also be seen that a strong bracket or gusset stands on top of these special cross girders at each end, connecting them to the end pillars of the main girder. These round-topped brackets serve a secondary purpose of supporting the ends of the roadway kerb plates; but they and the end cross girders of extra strength have been specially designed for another and a more important purpose. However carefully a girder on a high staging may be erected, especially a girder carrying the rails in a longitudinal timber lying in a narrow trough, it is in most cases found necessary to lift and slightly shift the whole of the span, after the staging has been removed. The necessary movement may be only a fraction of an inch, but usually some shifting must occur. When the whole series of girders has been erected, and a careful survey made of every joint from a truly laid out centre line, it is found perhaps that a new and improved centre line, best suited to the majority of the joints, can with advantage be laid out. This, however, probably requires the slight movement of one or more of the girders. The line of rails upon a bridge must be straight, and there is not room for much straightening upon a narrow longitudinal timber. When, therefore, the girders come to be shifted, room must be found for the application, near their ends, of four hydraulic jacks upon rollers; and there is no room anywhere for the safe application of these jacks but close to the ends of the last cross girder. It was often a matter of much anxiety watching the behaviour of the flanges of the angle irons of the Chenab cross girders under such circumstances, and I have therefore taken care to strengthen them sufficiently in the present design.

67. *Cross girders, top.*—The top cross girders are placed 30 feet apart, at the joints of the pieces of main top boom. To allow of their the better aiding the roadway for the important purposes of wind bracing, I have inserted a horizontal triangular gusset between the top cross girder and the underside of the horizontal flange of the inner angle iron of the top boom. The top cross girders which occur at the extreme ends of the main girders are of special design, as shown on the drawing.

68. *Cross girders, middle.*—Though the girders are very high, I have not thought it necessary to stiffen the vertical struts by a cross girder, fixed at chimney height, except at the main joints, 30 feet apart. The real use of this middle cross girder at the main joints is that during erection there may be a stiff frame at each main joint upon which the top pieces of boom may safely be erected. This frame is formed of the two vertical struts, and their top and middle and bottom cross girders, all service bolted in place.

69. *Trimmers.*—I would insist on adherence to my design for the trimmers. They consist of two ordinary channel bars of suitable dimensions, held together by short pieces of the same bar, such as at the works are sawn off the main bars. These short pieces are rivetted at suitable intervals, as shown on the drawings. The important object which has been attained by the use of these trimmers, in place of the Z bars used on the Chenab Bridge, is that the timbers can be laid in them fair and square, and without any chipping or cutting whatever. As regards the spacing of these trimmers, I have arranged them so that the running rail shall be nearly central on the timbers and in the trimmer. To crowd the running rail up towards the side may be all very well on a drawing, but in practice the result is either a crooked line of rails or dogspikes driven too near the edge of the timber to have any holding value. Room has been found for the placing of the rail in the middle of the trimmer by the use of a special guard rail instead of the ordinary rail that is generally used for that purpose. The method of arranging for the support of the ends of the trimmers from span to span, and for their expansion with the girder, will be described in the paragraph about the roadway.

70. *Gauges.*—By the provision of a third rail the roadway has been designed so as to carry the metre as well as the broad gauge. The third rail makes a more economical job than the two extra rails, because the girder would in any case have had to be spaced farther apart than would have sufficed for the broad-gauge vehicles. The arrangement for the third rail adds some 20 tons to the weight of a span.

71. *Roadway.*—The roadway is of the Chenab type modified in small details. Provision has been made for the passage of cart traffic over the bridge on the level of the rails. This will of course be safeguarded by the use of signal bells, batteries, signal posts, gates, and the other arrangements used elsewhere under similar circumstances, in charge of competent jemadars. The side slopes for the off flow of water given on the Chenab are of no practical use: the water will flow off fast enough from a level cross section. The pitch of the corrugated plates differs slightly from that of the Chenab ones, being in even inches to suit the even spacing of the cross girders. These floor sheets ought to be sent out rivetted together, so that two pieces only may go to a 10 feet length. They can be well enough packed, so sending them out in larger pieces need cause no anxiety. The iron strips which in the Chenab girders were rivetted over the battens are omitted as unnecessary. The hardwood battens are shown as fixed, in the usual manner, by coach screws from below. The corrugated sheets have been designed so that their edges are just a little way back from, instead of being flush with, the inner side of the rail-trimmers, because the flushness is a source of trouble in getting the timber into place. The longitudinal spaces, between the rails and the battens, are filled in, on one side with a long strip of hardwood spiked down, and on the other side with the special guard rails to be described later on. There are three breadths of corrugated plates, but the 1' 2" plates and the 2' 4" plates will be got, at the works, by cold sawing the 3' 6" plate.

72. *Roadway expansion.*—I have departed from the usual practice of making the junction of the two roadways come midway between the spans. In the Chenab design there was a middle wall on the pier on which the ends of the trimmers and of the roadway met, and rested or slid. This was not a good arrangement. My last cross girder of each span is, as already explained, of extra width, for other reasons, and I make use of the wide top of this special cross girder to allow of the expansion on it of the trimmers and roadway as shown in the detail drawings. At the *fixed* end of a girder all the trimmers and the roadway are fixed to the top of the first special cross girder, while the rolling end of the next girder has its trimmers and roadway prolonged forward until they rest on, and slide on the top of, the same special cross girder. All this is explained in the drawings. There will of course be a flap chequer plate of the usual sort at the junction between the two roadways. The sliding of the kerb plate is described farther on.

73. *Road kerbs.*—For the kerb plate on the outside of the roadway, to keep carts off the bearings, I have adopted a form similar to the one sent out many years ago for the Alexandra Bridge—a plate rolled to quadrant section and finished with flanges. There is no need for a separate passenger foot-path; they will make use of the cart road as unconcernedly as they do all over the country. As already explained, the kerb plate is supported at the ends of the girder, on the curved topped bracket, which, for other reasons, stands on the top of the end cross girder. The end of the kerb plate of the rolling end of a span will, like the trimmers and the rest of the roadway, slide on the first cross girder of the next span, that is, on the bracket portion of that cross girder. The arrangement is shown on the drawing.

74. *Guard rails.*—Instead of using ordinary rails which occupy much valuable room inside the trimmers, and which, if flat-footed, push the main rail out of its proper central position, I have designed a special section of small Z bar. The small side of this Z bar will be held down at bottom by the special double-headed dogspike which holds the rail on that side. The Z bar is backed by a hardwood strip, and both are squeezed to the inside of the trimmer, and held in place away from the rail, by a strong hook bolt which hooks around the upper flange of one of the trimmer channels. This Z bar guard rail must be strongly fished on the side away from the rail: and it would be advisable to have extra hook bolts close to the joint. Should it happen that through faults of erection the straight main rail does not always lie midway on the longitudinal timber, the top flange of the guard Z bar can be allowed to overlie the corrugated plates, occupying the half inch which is the flushness of the roadway battens above the corrugations.

75. *Longitudinal sleepers.*—The longitudinal sleepers will be provided in the country, sawn to multiples of 10 feet in length and 12" x 7" in section. As already explained, they will drop into place in the improved trimmers without any further carpentry. I am particular about the position of the bolts by which the timbers are held in the trimmers: the use of an auger through the timber from side to side to suit the holes in the iron trimmers is very objectionable: the auger seldom goes straight, and the result is either that the heart of the wood is cut up, or that the bolt is driven through with a bend, and its thread injured by the edges of the hole in the trimmer. I wish the holes in the channel bars to be made of such a height that the top of the timber bolt may be just $6\frac{1}{2}$ " above the top table of the short cross channel pieces, in other words, $\frac{1}{2}$ " below the top surface of the 7" timber. Two square saw cuts and the finishing touch of a gouge will then suffice to prepare a clean passage for the bolt, and there will be a slight clearance below the foot of the rail. In preference to the above I, however, much prefer vertical bolts holding down the timber at each of the short channel distance pieces, unless Sir A. Rendell objects to them.

76. *Bed-plates.*—For bed-plates, knuckles, saddles, and rollers, nothing that I have seen is an improvement on the Chenab arrangement. They might be made a little more massive, perhaps, and higher, as shown on the plan. There is one detail to which I would invite the attention of Sir A. Rendell's office. That is, that it is impracticable to *build in* the holding-down bolts; they have to be beheaded, jagged, and leaded, after the final straightening up of the girders, into holes jumped in the masonry. I jump these holes 2 or 3 feet deep, and I require room for the jumpers to work without fouling the girders. The holes therefore in the bottom part of the main bed-plate casting should be so designed that a jumper standing in any of them may clear the boom.

77. *Hand-railings.*—The hand-railing should be of 1½" gas-pipe, three at each side, fixed by clips to the bracings. There should be short pieces of chain to hang across on rings and hooks, from girder to girder, in continuation of the gas-pipe hand-railing.

78. *Chattering of the ties.*—To prevent the noisy chattering of the counter-ties during the passage of a train it is usual to show certain rivets connecting the counters one to the other and to the verticals, with instructions that the holes for these rivets must be drilled in India after the test train has passed. This is a very objectionable arrangement, as all sorts of unlawful cross stresses are engendered. If chattering must be stopped at all—and I don't think that it will cause annoyance in a 300-feet span with so large a dead-load—I would stop it thus. Where the ties cross one another and the struts, drill ¾" holes, and in these holes use ½" bolts, inserting between the pieces a strong spring steel split washer. The head of the bolt might be made like the head of a rivet, cup-shaped, to be cold rivetted over after being screwed down on the spring washers.

79. *Rivets.*—As regards rivets, I should only require half of the usual percentage of spare rivets of each size. About the packing of these spare rivets, they should be separately put up span for span, and the boxes marked "*Spare rivets, Span No.—*" For the other half of the usual quantity of spare rivets, I want rivet steel bar in sufficient quantity. I require with this rivet bar a first class machine which I would specify as follows: The machine that came out for the Chenab Bridge did not fulfil these requirements. "A combined *bolt, rivet, and nut-making* machine, with suitable dies for the sizes of rivets used on the bridge, and for suitable sizes of service bolts and nuts. The dies must *not* be made of cast iron. The machine must be of the sort that takes in the heated end of the bar, and afterwards, *not before*, cuts off the required length. Bolt and nut heads must need no dressing after coming out of the dies." For each size of rivet used in the bridge I require the following snaps for hand-rivetted, made of the most suitable steel: 400 snaps for the 1-inch rivets, and 100 for each of the other sizes, assuming that 1-inch rivets are the size used in the main joints. The size of the snaps and also the length of the rivets should be that suitable for hand, and not hydraulic rivetting.

XVII.—CONSTRUCTION FORECAST.

80. *Programme for completion in March 1893.*—Knowing very little yet about the labour or conditions of working at this side of India, I find it difficult to make a confident forecast of the programme of work. For a similar bridge up-country, I should allow myself the whole of two working seasons at the end of a summer of preparation. I ought to get all the wells down and several of the piers up in one *whole* cold season, and with ease complete the piers and abutments, and get up all the girders and finish off in another whole cold season. The coming working season will, however, be so cut up before an actual start can be made, that I cannot count on it as more than a half season, and I therefore scarcely see my way to promising the completion of the job before the 31st of March 1893. But I think I can safely, bar accidents, offer this as a programme.

81. *Programme for first working season.*—If there is one thing more absolutely essential than another, it is that both training bunds should be completed in one working season: any tinkering with these important works can only lead to disaster: the Engineer must not attempt to make a start with them unless he is absolutely certain of completing them before the first to make a start with them unless he is absolutely certain of completing them before the first sea-floods, and also of holding them with the aid of his tramway and stone trains for the first season after completion. So far as I can yet judge, I don't think that I could feel confident of establishing these training bunds during the coming cold weather. Supposing the staff to get on the ground in tents in October, it will be at least the end of December before quarters are ready; workshops built, fitted, and working; stores established; quarries opened; railways laid down; mortar machinery running; and the thousand preparations made before work can be begun with a rush and economically. Thus I should not get a fair start at the training works till half the season was over, and could certainly not finish them before the floods came. I could probably sink a few wells, and could certainly get the preparation of all material into full working order. This latter would then go on all through the first cold weather and the rains of 1891, and I ought to have everything I required on the ground in time for an early start in October 1891.

82. *Programme for 2nd and 3rd seasons.*—By that time, with a thorough command of the labour and resources of the district, I should, without hesitation, go through with the training works, and before the rains of 1892 I could easily have established them, and completed the wells and the piers, and possibly some of the girders. The finishing off of the remaining girders, and of all the odd jobs about the approaches, &c., would be comparatively light work for the cold weather of 1892-93, and the bridge might be opened in April 1893.

84. *Foremen staff*—Now about Foremen. If the work is to be done smartly and economically, I hope not to have permanent subordinates forced upon me, merely because they happen to be in the Department. The reason why I lay so much stress on the matter is that in the time at my disposal it will be impossible to teach men their trades. I can lay my hands upon as picked a lot of skilled tradesmen as are to be found in India, well-sinkers, masons, erectors, rivetters, &c., and these are the men that I wish to secure.

85. *Labour*.—A large part of the skilled manual labour must be imported, but there will be no difficulty about that. I can get any quantity of all sorts; my estimate rates of course allow for this contingency. There appears to be plenty of local unskilled labour; and one result of the Canal Department's operations at Bezvada for so many years has been that there will be no difficulty about the stone supply.

86. *Importance of an early start for collection of plant and stores.*—While on this question of general “bandobust,” I wish to lay stress upon the importance of my being permitted now at once to go on tour and select what plant and stores I consider necessary. The preparation of English Indents for plant and stores will take much consideration, and in the present state of the rising home metal market it is particularly desirable that I should get all I can in the country. There is, however, no worse sort of economy than buying rubbishy plant which, long before the work is over, will have cost more than its worth when new in renewals, repairs, and wasteful working; personally I can judge of what is or is not rubbish but I cannot reliably buy from a catalogue. If the question of the cost of my travelling arises, I would point out that it would probably be more than covered by the benefit of the proper selection of one article. I propose to arrange for a suitable store establishment, and for the early construction of the necessary store-yard and proper sheds, for the care of everything that between this and September is sent to the bridge. I also want Mr. W. Albert, as already mentioned, to get the plant that arrives into order. These are matters of all importance, if any sort of a fair start is to be made at the close of the rains, and I beg strongly to urge that mere routine may not be allowed to interfere with my making early preparations in a business-like way.

87. *Possible reduction in rates.*—With reference to the rates that have been inserted in the estimate, I may freely say that I believe I have kept myself on the safe side, and particularly in certain items. The first thing I would draw attention to is that at the close of the work a large amount will certainly be realized by the sale and transfer of surplus articles of plant and stores. This I have roughly estimated at 1½ lakhs on the whole project. The sales on the completion of the Chenab Bridge have, I believe, been considerably in excess of this amount, but I cannot at this moment refer to the figures. The principal items in which economy will probably occur are the following:—

Special plant debitable to the work for well sinking	Rs. 86,000
" " " " " for girder erecting	53,000
Ordinary "plant for the general use of the work	60,000

I have a fair idea that I may succeed after a careful study of, and selection from, such plant as is available in India, in considerably reducing all these items; but I prefer for the present to allow them to stand in the estimate. The allowance for establishment is also perhaps excessive, it is the usual percentage on the Indian items of the estimate, and amounts to Rs. 1,87,000; but I hope that much less than this may suffice: for the present, however, I prefer to let this item stand. I don't think that the masonry rates are too high; quarries will have to be newly opened, and all stone will have to be fairly squared: the stone wells will also require very careful building. The principal item in which I hope after a few months to see my way to considerably reducing the rate of, is the stone-pitching in the training works; it is quite possible that this may be reduced by one-third: I cannot however as yet count upon being able to make such a reduction until I get to know how the quarries will open out, and what are the conditions of labour.

88. *Lowest possible estimate of final cost of entire scheme.*—I don't wish the figure which I am now about to offer to be taken at all as authoritative, or as more for the present than a hopeful guess; but I may say that, considering all possible circumstances, it appears as if it might in the end turn out that a bridge across the Kistna of ten spans of 300 feet, with its approaches and training works, may perhaps, after all credits are realized, have cost, inclusive of the two canal bridges, about 37 lakhs.

F. J. E. SPRING, *Mem. Inst. C. E.,*
Exe. Engr., Kistna Bridge Divn., East Coast Railway.

WALTAIR;
The 20th June 1890.

Quantity.	Description.	Rate.	Amount.	Head of Account.
		Rs.	Rs.	
Lump sum	Preliminary Expenses	350	10,000	Preliminary.
240 tons	Well curbs and bond iron	25	84,000	Kistna Bridge.
862,000 c. ft.	Well sinking, labour and stores	10	2,15,500	Ditto.
862,000 "	" " special plant, debitable to work	80	86,200	Ditto.
100,500 "	" " Well concrete in cement	30	80,400	Ditto.
194,000 "	" " " in mortar	60	58,200	Ditto.
113,300 "	" " " masonry in cement	100	1,13,300	Ditto.
526,500 "	" " " in mortar	60	3,15,900	Ditto.
401,500 "	Superstructure, masonry, ordinary	100	2,40,900	Ditto.
47,600 "	" " ashlar	40	47,600	Ditto.
3,700 l. ft.	Pile bridging & reclamation of sites for piers & girders	6	1,48,000	Ditto.
600,000 c. ft.	Stone protection round piers	240	36,000	Ditto.
5,300 tons	Girder work delivered at port	12	12,72,000	Ditto.
5,300 "	Carriage of girders to site of work	45	63,600	Ditto.
5,300 "	Girder erection and rivetting, labour, and stores	10	2,38,500	Ditto.
5,300 "	Girders, special plant, debitable to work	5	53,000	Ditto.
5,300 "	Girder painting	6	26,500	Ditto.
3,700 l. ft.	Longitudinal teak sleepers, three of them	10,000	22,200	Ballast and P. W.
5 miles	Temporary Railways for service of bridge	...	50,000	Ditto ditto.
Lump sum	Temporary Workshops and Store buildings	...	20,000	Stations and Bds.
" " "	Temporary quarters	5	80,000	Ditto ditto.
3,700 l. ft.	Battened roadway	...	18,500	Level crossings.
Lump sum	Plant, ordinary	...	60,000	Plant.
	Establishment, 7 per cent. on Indian outlay except plant	...	1,37,000	Establishment.
	Contingencies, 5 per cent. on Indian outlay, except Plant	...		
	and Establishment	...	97,700	Contingencies.
	Total	...	35,75,000	
			or Rs. 945	per foot run.
The above estimate is for 80 feet wells.				
	Every 10 feet of additional well = Rs. 1,25,000.			
	Add—Approaches	...	2,80,000	
	Training works	...	57,1,000	
	GRAND TOTAL	...	44,26,000	

ABSTRACT OF ESTIMATE OF APPROACHES AND TRAINING WORK OF THE KISTNA BRIDGE.

Quantity.	Description.	Rate.	Amount.	Head of Account.
	APPROACHES.	Rs.	Rs.	
400 acres.	Land	150	60,000	Land.
5,000,000	Earthwork in approaches, roads, and service lines	6	30,000	Earthwork.
50,000	Road metal on approach roads, in place	8	4,000	Ditto.
Lump sum	Buckingham Canal Bridge	...	45,000	Major Bridges.
"	Bezvada Canal Bridge	...	45,000	Ditto.
100,000	Ballast	6	6,000	Ballast and P. W.
No. 6	Level crossings, gates, &c., at the three bridges	500	3,000	Level crossings.
1 mile	Fencing, double, post and wire	3,000	3,000	Fencing.
1½ "	Permanent Way, three rails, in place	33,000	58,000	Ballast and P. W.
	Establishment, 7 per cent. on Indian charges	...	15,000	Establishment.
	Contingencies, 5 per cent. on Indian charges	...	11,000	Contingencies.
	TOTAL	...	2,80,000	
	TRAINING WORKS.			
		8	1,60,000	Earthwork.
20,000,000	Earthwork	8	3,20,000	Kistna Bridge.
4,000,000	Stone pitching	15,000	30,000	Ballast and P. W.
2 miles	Service Railway for permanent use	...	35,700	Establishment.
	Establishment, 7 per cent.	...	25,300	Contingencies.
	Contingencies, 5 "	...		
	TOTAL	...	5,71,000	

F. J. E. SPRING,
Executive Engineer.

20th June 1890.

ABSTRACT OF ESTIMATE, KISTNA BRIDGE, 17 SPANS OF 212 FEET, ON SMALL PIERS,
20 SMALL WELLS 80 FEET DEEP.

Quantity.	Description.	Rate.	Total.
		Rs.	Rs.
220 tons.	Preliminary	...	10,000
900,000 feet	Well curbs and bond iron	350	77,000
900,000 "	Well sinking, labour and stores	10	2,25,000
84,000 "	" " special plant	80	90,000
190,000 "	" " concrete in cement	30	67,200
98,000 "	" " mortar	100	57,200
528,000 "	" " masonry in cement	60	98,000
278,400 "	" " mortar	60	3,16,800
32,000 "	Pier masonry, ordinary	60	1,67,040
81,000 "	" " ashlar	100	32,000
20,400 "	Abutment masonry, ordinary	60	48,600
3,900 "	" " ashlar	100	20,400
3,700 "	Girder work, all, including plant and painting	312	12,16,800
800,000 "	Pile bridging and reclamation	40	1,48,000
3,700 "	Stone protection round piers	6	48,000
5 miles.	Teak sleepers	6	22,200
3,700 l. ft.	Temporary railway	10,000	50,000
	Workshops and staff quarters, temporary	...	1,00,000
	Battered roadway	5	18,500
	Plant, ordinary	...	60,000
	Establishment	...	1,11,700
	Contingencies	...	79,760
	TOTAL	...	30,64,000
	Add—Approaches	...	2,80,000
	Training work	...	5,71,000
	GRAND TOTAL	...	39,15,000

ABSTRACT OF ESTIMATE OF KISTNA BRIDGE WITH 252 FEET SPAN, LARGE WELLS AND
PIERS, 80 FEET FOUNDS, SMALL WELLS UNDER ABUTMENTS—NO. OF SPANS 14.

Quantity.	Description.	Rate.	Total.
		Rs.	Rs.
43.4 tons	Preliminary Expenses	...	10,000
214.5 "	Well curbs and bond iron, small wells	350	15,120
180,000 c. ft.	" " " large "	350	74,987
180,000 "	Well sinking, labour and stores, small wells	25	45,000
747,500 "	" " " special plant	10	18,000
747,500 "	" " " labour and stores, large wells	25	1,86,875
19,500 "	" " " special plant	10	74,750
105,500 "	Well masonry in cement, small wells	100	19,500
16,900 "	" " " mortar "	60	63,300
38,000 "	" " " concrete in cement "	80	13,520
87,100 "	" " " mortar "	30	11,400
168,100 "	" " " cement, large wells	80	69,680
98,200 "	" " " mortar "	30	50,430
456,300 "	" " " cement "	100	98,200
282,900 "	" " " mortar "	60	2,73,780
32,100 "	Pier masonry ordinary	60	1,69,740
81,000 "	" " ashlar	100	32,100
21,000 "	Abutment masonry, ordinary	60	48,600
4,400 tons.	" " ashlar	100	21,000
3,700 l. ft.	Girder work, all, including plant and painting	312	13,72,800
700,000 c. ft.	Pile bridging and reclamation	40	1,48,000
3,700 "	Stone protection round piers	6	42,000
5 miles	Teak sleepers	6	22,200
3,700 l. ft.	Temporary Railway	10,000	50,000
	Workshops and staff quarters, temporary	...	1,00,000
	Battered roadway	5	18,500
	Plant, ordinary	...	60,000
	Establishment	...	1,17,400
	Contingencies	...	83,118
	TOTAL	...	33,10,000
	Add—Approaches	...	2,80,000
	Training works	...	5,71,000
	GRAND TOTAL	...	41,61,000

F. J. E. SPRING,
Executive Engineer.

20th June 1890.

ABSTRACT OF ESTIMATE, PRINCIPAL QUANTITIES,
TAKEN FROM THE DETAILED ESTIMATES OF THE VARIOUS DESIGNS.

Quantity.	Description.	Rate.	Amount, Rs.	Total, Rs.
	SMALL WELLS AND PIERS.			
11 tons	Well curbs and bond iron	350	3,850	
45,000 feet	" Sinking	35	15,750	
4,200 "	" cement concrete	80	3,360	
9,500 "	" mortar concrete	30	2,850	
4,900 "	" cement masonry	100	4,900	
26,400 "	" mortar masonry	60	15,840	
17,400 "	Pier masonry, ordinary	60	10,440	
2,000 "	" " ashlar	100	2,000	
	Total	...	59,000	
	LARGE WELLS AND PIERS.			
16 tons	Well curbs and bond iron	350	5,600	
62,000 feet	" sinking	35	21,700	
6,700 "	" cement concrete	80	5,360	
12,900 "	" mortar concrete	30	3,870	
7,600 "	" cement masonry	100	7,600	
35,100 "	" mortar masonry	60	21,060	
21,800 "	Pier masonry, ordinary	60	13,080	
2,500 "	" " ashlar	100	2,500	
	Total	...	81,000	
	ABUTMENTS FOR EITHER DESIGNS.			
	<i>Superstructure only.</i>			
40,500 feet	Abutment masonry, ordinary	60	24,300	
10,200 "	" " ashlar	100	10,200	
	Total	...	34,500	
	GIRDERS.			
		Tons.	Rate.	Cost.
		One span.	Rs.	Rs.
3,900 tons	17 spans of 206 feet	230	{ English . 240	55,200
			{ Indian . 72	16,560
4,400 "	14 " 252 "	314	{ English . 240	75,360
			{ Indian . 72	22,608
5,300 "	12 " 300 "	440	{ English . 240	1,05,600
			{ Indian . 72	31,680
				1,37,289

ABSTRACT OF ESTIMATE OF COMPARATIVE COST OF ONE SPAN
OF EACH OF THE THREE DESIGNS.

Description.	Amount.	Total.
	Rs.	Rs.
206 FEET SPAN.		
Well and pier, small, as on last table	59,000	
Other items depending on length of bridge	9,500	
Girder, English	55,200	
" Indian	16,560	
Establishment	5,950	
Contingencies	4,290	
Total	...	1,50,500
Pitching	...	3,500
TOTAL	...	1,54,000
252 FEET SPAN.		
Well and pier, large, as on last table	81,000	
Other items depending on length of bridge	12,000	
Girders, Indian	22,608	
" English	75,360	
Establishment	8,092	
Contingencies	5,740	
Total	...	2,04,800
Pitching	...	3,200
TOTAL	...	2,08,000
300 FEET SPAN.		
Well and pier large, as on last table	81,000	
Other items depending on length of bridge	14,000	
Girders, Indian	31,680	
" English	1,05,600	
Establishment	8,940	
Contingencies	6,380	
Total	...	2,47,600
Pitching	...	3,400
TOTAL	...	2,51,000

F. J. E. SPRING,
Executive Engineer.

20th June 1890.

[illegible]

20th June 1890.

F. J. E. SPRING,
Executive Engineer, Kistna Bridge.

SUPPLEMENTARY REPORT ON KISTNA BRIDGE GIRDERS.

REVISED DESIGN FOR A 300 FEET GIRDER.

1. *New design offered.*—Since sending up the Kistna Bridge plans and estimates I have had more leisure to go carefully again into the girder design. I now therefore submit a revised design which in several of its principal features is a distinct improvement on the previous one. I mentioned in para. 61 of the report that the girder drawing then submitted did not pretend to greater accuracy of design than was needed for rough purposes of draughtsmanship. The present girder has been designed with greater care, and will, I think, be found in Sir A. Rendell's office to be fairly correct in its dimensions.

2. *Difference between new and old designs.*—This design differs in one very essential particular from the previous one, in this, that it is a double and not a triple system of triangulation, with 45 degree bracing. From this it results that the vertical struts and the cross girders are 15 feet apart instead of 10. This has of course led to the strengthening of the cross girders, and of the rail-bearers. I have also spaced the main girders 20 feet apart between centres instead of 18, and the effect of this increased spacing upon the wind stresses has been that less metal is required in the booms to meet wind stresses than was previously needed. This increased spacing will not necessitate the alteration of the piers, which were already sufficiently long: it gives me a very much more satisfactory girder, and particularly so for road traffic.

3. *Booms*.—Instead of making the boom side plates and angles uniform throughout and altering only the main plates, I have given heavier side plates and bottom angle bars towards the middle of the span, and this has allowed me to avoid the use of too heavy main plates, which for a breadth of 3' 6" and a length of 30 feet are, I understand, difficult to procure.

4. *End pillars.*—The present end pillars differ from the previous ones in having open lattice bracings on one face, to allow of better access to the rivet connections of the special end cross girders.

5. *Special end cross girders.*—I have omitted the upper gussets or buttresses that stood on the special end cross girders in the former design, and have found more room for the connection with the boom, to allow of the use of fourteen $1\frac{1}{4}$ " rivets for the connection. As these rivets will have to carry 100 tons in the event of the girder ever having to be lifted, they will of course receive special attention when being driven. The design of the special end cross girder is more practicable than the former one, which would have given trouble in the manufacture, and had not been carefully thought out.

6. *Trimmers*.—As the rail-bearers for the broad gauge are so much deeper than in the previous design, they cannot well be of channel iron. They must therefore be built, as shown on the present drawing; they are a little too strong, but in rail-bearers this is a fault on the right side. The rail-bearers of the metre rail may be of channel as previously designed, and as shown on the present drawing.

7. *Roadway*.—The 2 feet extra width of roadway now given is a great advantage as it will allow of two opposite streams of road traffic. I don't think that the original quadrant section of road kerb would have kept the loads of country carts sufficiently far from the bracings. I have therefore carried the Weston plates right through the road from side to side, and have laid down two old metre-gauge rails as guards, about 2 feet 6 inches from the sides of the girder. This will allow of the side walks being used by foot-passengers. These kerb rails will be bolted down through the Weston plates by little hook bolts about 3 feet apart at alternate sides of the rail.

8. *Rail guards*.—A design of Mr. J. R. Bell's for an improved form of rail guard has suggested a modification which I think is a further improvement on Mr. Bell's. I have shown a sketch of Mr. Bell's, and alongside of it my modification, and I would press that the latter be adopted. The guard rail of a long bridge may be called upon to serve such very important functions that it ought I think to be scientifically designed. Instead of Mr. Bell's trough, which is heavy and expensive, I have designed two similar Z bars of special section, on the lower flanges of, and between, which the rail stands. To give the usual cant to the rail Mr. Bell canted the surface of the timber, this is a difficult thing to do satisfactorily as the long timbers warp very much in the sun, so I have canted the rail by the use of a specially designed bearing plate, which serves the purpose also of fishing the rail guards together.

9. *Rail fastenings*.—In the foot of the flat-footed rail, at intervals of 3 feet on both sides, a nick is milled out. In this nick lie the holding-down bolts, which hold together the rail the bearing plate the timber and the trimmer. The rail guards of course have their lower flanges holed at the same 3 feet intervals, so that the bolts may pass through them. Mr. Bell had passed these bolts down through the timber and through two holes in the cross plate on which the timber rested, and then through the screwed holes in a double nut below. The disadvantage of this was that if, as with the greatest care may always happen, a joint of the main girder was slightly out of line, the rails had to follow its crookedness. To allow of the absolute straightening of the rails I have altered Mr. Bell's design as follows. Instead of two holes in the plate connecting the two sides of the trimmer, on which the timber rests, I have a slot, through which the two bolts pass to the double nut below. The slot is managed thus. Instead of putting one short 12" piece of channel bar across the trimmer at 3 feet intervals, for the timber