PAPER No. 120.

REINFORCED CONCRETE BRIDGES ON THE SIRHIND CANAL.

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Advantages—Strength of *kankar* slabs—Different types—Road bridge—Loading—T-beams—Expansion joints—False-work—Costs—Tests of joints—Foot bridge—Temperature variations in concrete—Appendices.

Advantages.

A considerable number of reinforced concrete bridges have been built on the Sirhind Canal during the last two years ; as this type has been found more economical than arch bridges and also easier to build during short closures. Most of these have been slabs of small span, but four parapet-girder bridges of 30-foot span have been completed and others are in progress.

This paper gives a brief description of some points in two designs which have been, or are being built, together with certain practical details of construction and of cost.

A reinforced concrete slab is specially suitable in a case where it is desired to raise an old bridge which is submerged, as it causes no thrust on the abutments, which can be increased in height without being strengthened.

Strength of Kankar Slabs.

There are many places in the Punjab where the cost of the carriage of stone for a reinforced concrete bridge would be prohibitive, but where *kankar** of good quality is available at very low cost, therefore, if it can be shown that concrete using this material is satisfactory, a reinforced concrete design can be adopted in many places where it otherwise could not, resulting in considerable saving in money and trouble. This was the case on the Sirhind Canal, and in order to settle the point a complete series of tests on *kankar* slabs was carried out at Rupar and Doraha, in 1925 and 1926. A report on the experiments was printed by the Chief Engineer and issued to officers of the Irrigation Department. Table No. 3 of that report, being an abstract of the results, is given as Appendix A.

These tests show that a working stress of 500 lb. per square inch may safely be adopted for a mixture 1 : 2 : 4, if the *kankar* is well graded, up to $\frac{3}{4}$-inch in size.

* Kankar.—Concretionary nodules of limestone.

Different Types.

The types of bridges described in this paper are—

(a) 30-foot clear span road bridge 8·5-foot roadway, parapet girders.

(b) 30-foot span foot bridge, 4-foot roadway, 5 feet between parapets—parapet girders ; supported on slab cantilevers, 15 feet long, making 60-foot spans between piers.

Two road bridges have been built ; one of one span at mile 2 on the Sutlej Navigation Channel, of *kankar* concrete, was completed in November 1926, and one of four spans on the Bhatinda Branch, of shingle concrete, in April 1927.

These show no cracks or other unsatisfactory signs up to date, although they have been tested with heavy carts. Another bridge of this type, of two 30-foot spans, is now being built with *kankar* ballast in mile 47 of the Bhatinda Branch.

One foot bridge of one 30-foot span, of *kankar* ballast, was completed in August 1927, at mile 28 of the Sutlej Navigation Channel. Another with a centre pier and cantilevers making two 45-foot spans has now been built, with shingle ballast, over the Chamkaur Escape, near mile 12 of the main line.

Road Bridge.

After the road bridge on the Sutlej Navigation Channel was finished, certain minor alterations were made in the design : one made on the advice of Mr. B. M. Sullivan, was the reduction in the number of stiffeners from 3 to 2 in order to improve the appearance. These can be seen in the illustration of the bridge in mile 2 of the Bhatinda Branch.

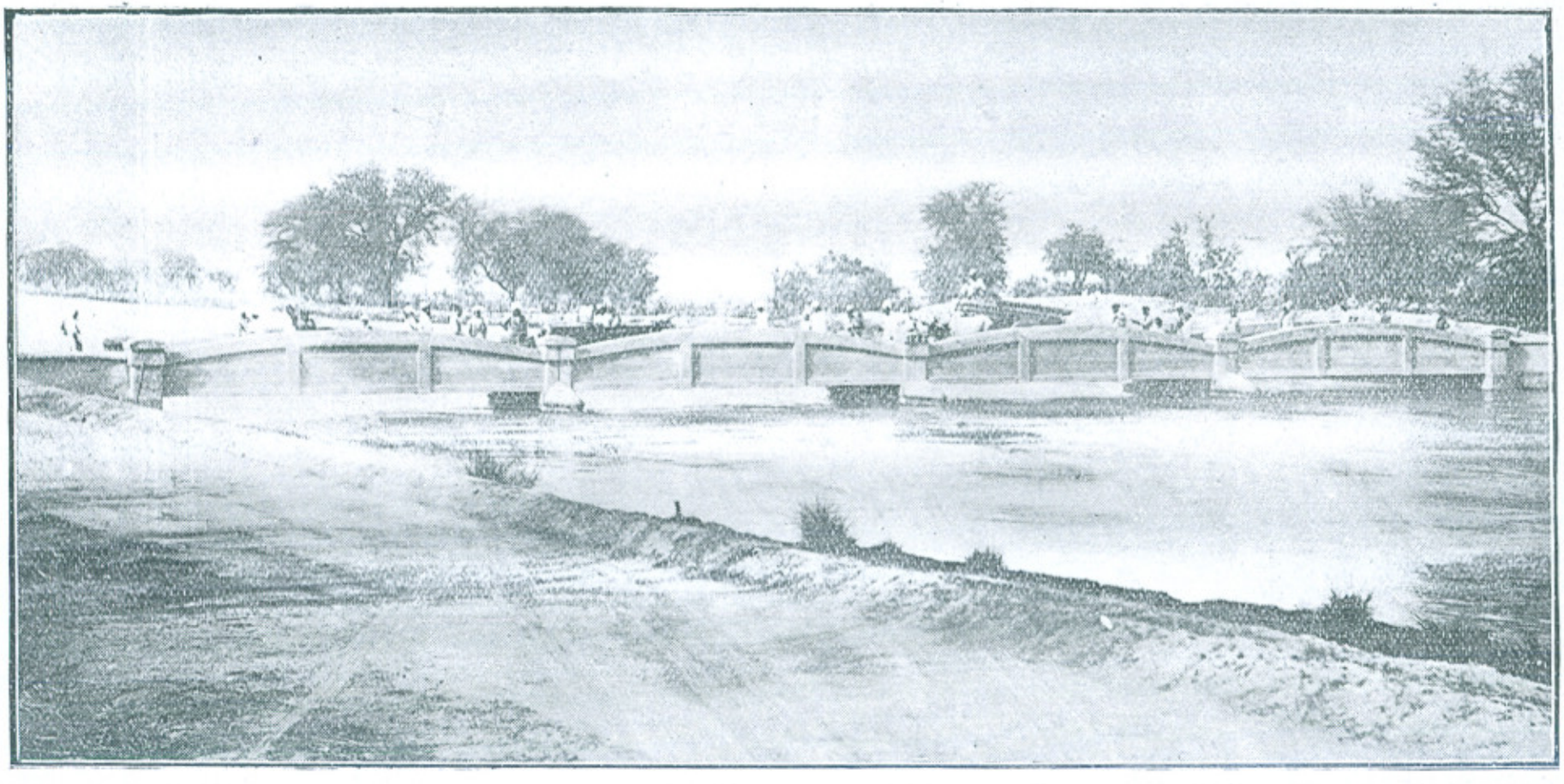
Loading.

The bridge is designed to carry carts with a load of 8,000 lb. per axle and a crowd of 40 lb. per square foot. The working stresses in the calculations were taken as 500 lb. and 15,000 lb. per square inch in the concrete and steel respectively.

8,000 lb. is equivalent to an axle load of 3 tons plus 20 per cent. impact, which is sufficient with slow moving carts. This was for the slab. For the parapet-girders 10 per cent. impact was allowed, this being sufficient according to standard works.

T-Beams.

Alternative designs for parapet-girder and T-beam types had been worked out for 14-foot and 18-foot span bridges, and the parapet girder type was found to be slightly cheaper in each case. It is more economical in abutments, since the T-beam requires them to be unduly high and this difference increases with the span. Parapet-girders also look well



Road Bridge over Bhatinda Branch Canal. 30-foot Spans.

from the architectural point of view, and provide a strong parapet without extra cost. This type therefore was adopted for the 30-foot span.

The slab is regarded as a fixed beam, *i.e.*, it is assumed that the parapets will not bend. The effective span of the slab is taken as 120 inches, and a considerable factor of safety is allowed in taking the length across the reinforcement on which the axle weight will come. The case of one wheel of a cart in the centre of the bridge giving maxima negative bending moments is also considered.

It was assumed that the point of contraflexure in the slab was at about 0·211 of the effective span from the girder. Therefore alternate bars were bent up, 3 inches on either side of that point.

Calculations showed that in the parapet girders, a uniform crowd of 110 lb. per square foot gave a greater bending moment than one or two carts plus a crowd of 40 lb. per square foot, even when one parapet took 0·7 of the weight of the carts. This uniform load was therefore taken for girder calculations. The load, being on one side of the parapet only, causes a certain torsion, which was calculated.

A parapet girder, being higher in the centre than at the ends, the formula $wl^2/8$ for the bending moment due to the dead load would not be accurate, and this was also allowed.

Stirrups were designed to take two-thirds of the shear ; they also act as suspensory bars.

Expansion Joints.

Expansion Joints are provided in the form of two steel plates at one end of each span. They slide over each other before the tension in the main tension bars becomes too high ; it remains to be seen whether they will work satisfactorily after a few years or go out of action owing to rust. It was not considered necessary to spend money on a more expensive joint, because the total contraction in one span would not exceed 0·1 inch, and it appeared probable that even if the expansion joint did not work, the abutments, being thin, would give to this extent without developing dangerous cracks. So far as can be seen at present this is what happens.

The density of reinforced concrete is taken as 150, but in reality it is under 145 lb. per cubic foot.

False-work.

The cost of false-work is an important item in these bridges (see Appendix B). It can be reduced considerably by using the same forms several times. In the Sutlej-Navigation-Channel Bridge the cost was Re. 1-1-0 per cubic foot of concrete. In this case an earth centering was used underneath. The outside false-work of parapet girders was made of brick. Only the inner false-work was of wood, so that it could be used again.

In the case of the bridge on the Bhatinda Branch the false-work costs only annas 10 per cubic foot of concrete. The piers and abutments were built during the rotational closures of the branch, and holes were made so that rolled steel beams to support the false-work, could be placed across the spans. These beams were supported in the centre by iron rails on concrete foundations in order to reduce the deflection. They were first fixed over the two outer spans, and the false-work and bridge were built on them with water running underneath. A month later during another rotational closure, the false-work, which was supported on sand cylinders, was taken down, and the beams were slid through the holes in the piers on to the centre two spans, which were completed in the same way while the canal was running. Thus the whole of the superstructure was built without any special closure.

Cost.

If an arch design had been adopted this could not have been done, and the estimated cost of such a bridge was Rs. 24,000, while the total cost of this bridge was Rs. 18,750.

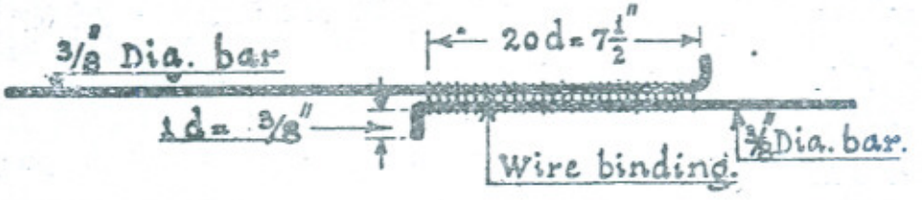
On completion, half the cost of the timber false-work was debited to the bridge, and half to the other bridge on which it is now being used. When that is finished the timber will be used again on a third bridge which is to be built this winter, so that the cost of false-work should be less than annas 10 per cubic foot of concrete.

A point which needs considerable attention in these designs is the question of joints in the main tension bars. It is easy to show that if a joint is made with an overlap of 40 diameters, each bar having full mortar adhesion and no hooked ends, the strength of the joint at the usual working stresses will be equal to that of the bar ; but in a parapet girder it is advisable to keep all the main tension bars inside the stirrup, and there is no room for the bars at the joints to be kept separate so as to develop the full adhesive strength. For this reason, in the 30-foot road bridges the joints were made with the bars touching and with hooked ends. The same difficulty would occur in a T-beam where the webs of the Ts for economy would be wide enough only to take the bars without joints.

Tests of Joints.

In order to ascertain the comparative strengths of joints experiments were made at Rupar in the summer of 1927. Two slabs of 9 feet clear span, 12 inches wide and 5 inches effective depth, each having three bars of $\frac{3}{8}$ inches diameter, were tested to destruction. They failed by tension at about 27·4 tons per square inch, the maximum compressive stress being 2,040 lb. per square inch.

Six other similar slabs were made, in which each bar had a joint in the centre of the span, with 20 diameters overlap and hooked ends as below :—



In two slabs (type *a*) the overlap was tightly bound throughout with wire. In two others there was a short piece of wire binding at each end of the overlap (type *b*), while in the last two slabs (type *c*) there was no wire binding at all.

All the six slabs failed when the tension in the steel was about 36,500 lb. per square inch, but although type *a* failed at this point the slab stood under an increased load, causing a tension of 47,000 lb. (21 tons) per square inch before collapsing. Types *b* and *c* on the contrary, failed suddenly, and crashed to the ground at the tension of 36,500 lb. per square inch. Calculations showed that when type *a* failed at 36,500 lb. per square inch, assuming that adhesion was applied to only half the surface of each bar, the concrete in the hooks was subject to a compression of 2,433 lb. per square inch, and that the adhesion stress was 377 lb. per square inch. Therefore a joint of any one of those types, with 40 diameters overlap, should be as strong as the bars, even without large hooks ; but bad workmanship might cause failure. On the advice of Mr. J. H. Johnston the usual English practice of allowing full adhesion has been adopted in the 30-foot span foot bridge, although this means that some of the bars are outside the stirrups.

In certain tests Continental steel was used, and some of the bars failed at about 20 tons per square inch.

The Superintendent, Central Workshops, Amritsar, some time ago advised against the use of Continental steel.

In the two bridges (one of each type) built with earth centerings, extra reinforcement was provided in the top of the parapet girders, to take the negative bending moments induced when the centering had only partly been removed.

Foot Bridge.

For the 30-foot span foot bridge, working stresses of 50 lb. per square inch with a live load of 100 lb. per square foot v

The parapet-girder was calculated as in the case of the road bridge, and a crowd on the top of the parapet was allowed for.

The bridge of this type, on the Sut'ej Navigation Channel, was supported on an earth centering, but all the side false-work was of timber and was used again for the Chamkaur bridge. The cost of this false-work was Rs. 1-4-0 per cubic foot of concrete: this rate for the foot bridges being higher than for the road bridges because of the lighter sections.

As the floor of the foot bridge was much thinner than that of the road bridge, four stiffeners of greater depth were provided for the parapet-girders in place of two.

The cantilever is designed as a slab, since, the bridge being narrow, this is cheaper than two ribs. It is necessary to provide strong cross reinforcement at the end, as the load of the bridge is transmitted by the two parapet-girders resting on the edges of the cantilevers, thereby inducing a cross bending moment and shear. Double symmetrical reinforcement was used at this point.

The cantilever in longitudinal section is a parabola. This shape simplifies calculations for weight, and gives the correct depth at 5 feet from the pier with a slightly excessive depth at 10 feet. This cannot be avoided, as the theoretical depth of the cantilever at the end, for uniform loading, would be much less than the 20 inches which has to be allowed for concentrated loading.

The cantilever parapet was designed to withstand the charge of a buffalo. It is not monolithic with the floor. The cantilevers are first built with parapet holding-down bars, then the 30-foot span is made, and after the cantilevers have taken the strain the parapet is built. This is necessary to avoid excessive tension in the latter.

Expansion joints of two steel plates are provided at the ends of the cantilevers under the parapet-girders.

The pier is of reinforced concrete and has been designed for the case of a live load on one span only. A considerable factor of safety has been allowed in the calculation of the pier reinforcement, as it is intended to build this type of bridge across the main line of the canal where the piers will be bumped by boats.

In these calculations for the pier and cantilever, working stresses of 600 and 16,000 lb. per square inch are allowed, as this type is being built at Chamkaur and on the main line, where stone ballast will be used.

Temperature Variations in Concrete.

Another point which needs consideration in designing reinforced concrete bridges is the extent of temperature variation inside the structure. This is most important in the case of an arch where the expansion and contraction stresses have to be calculated.

In order to get some definite information on this subject an experiment was made at Rupar, where there was an old concrete arch of 45 feet span. On the top of this a block of concrete was built, 6 feet long, 2 feet high, and 6 feet wide, to represent part of a concrete arch : on the top of the block was placed a foot of earth, as on an arch, and at both ends earth was placed to represent the continuation of the arch. The sides were exposed. One foot below the top of the concrete block, maxima and minima thermometers were imbedded at varying distances from the south face of the concrete. These were put in in November 1926 and taken out at the end of September 1927. The variations recorded are given below—

No.	Distance from south face of block.	Range of temperature.	Variations.
A	6″	104° to 56° F.	48° F.
B	1′	100° to 60°	40°
C	2′	98° to 62°	36°
D	3′	97° to 61°	36°

thus an allowance of 40° Fahr., as usually assumed in the United States of America, should be sufficient.

APPENDIX A.

Comparative Strengths of Slabs made with different aggregates.

Serial No.	Composition.	m	Mean r	Mean ultimate y inches.	Mean ultimate c lb. per sq. inch.	Mean ultimate f tons per sq. inch.	Cause of failure.	No. of cases included in this average.	Remarks.
1	1 cement : 2 sand : 4 broken boulders upto $\frac{3}{4}''$ gauge.	15	0·0054	30/32	..	29·8	f	1	m = modular ratio. $r = \frac{\text{area steel}}{\text{area concrete}}$.
2	1 cement : 2 sand : 4	15	0·0053	16/32	..	30·6	f	2	y = deflection.
	kankar upto $\frac{3}{4}''$ gauge	15	0·0083	24/32	2,578	..	c	2	c = compression in concrete.
3	1 cement : 2 sand : 1 pea-*kankar* : 3 brick ballast upto $\frac{3}{4}''$ gauge	17	0·0052	17/32	..	30·1	f	2	f = tension in steel.
		17	0·0083	$23\frac{1}{2}$/32	2,507	..	c	2	
4	1 cement : 2 sand : 4 brick ballast upto $\frac{3}{4}''$ gauge.	18	0·0052	18/32	..	29·8	f	2	
		18	0·0082	21/32	2,527	..	c	2	

APPENDIX B.

Average cost per cubic foot of reinforced concrete of the bridges constructed on the Sirhind Canal.

No.	Description of Bridges.	Material for concrete.	Steel.	Centering.	Labour.			Total.	Quantity of concrete.	Net cost of concrete, less steel and false work.	Remarks.
					Concrete.	Steel.	Total.				
1	2	3	4	5	6	7	8	9	10	11	12
		Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Cub. ft.	Rs. a. p.	
1	Reinforced concrete slabs.	0 14 0	0 10 0	0 8 6	0 4 0	0 3 6	0 7 6	2 8 0	110	1 2 0	Mean of 7 bridges.
2	Parapet-girder type, 13-ft. span.	0 13 0	0 8 0	0 13 0	0 4 0	0 2 0	0 6 0	2 8 0	252	1 1 0	Mean of 2 bridges.
3	30-ft. clear span cart-bridge.	1 0 0	0 11 0	1 1 0	0 4 0	0 3 0	0 7 0	3 5 0	765	1 5 0	Sutlej Nav. Channel Chainage, 10,000.
4	30-ft. clear span cart-bridge.	0 14 0	0 10 0	0 10 0	0 3 0	0 5 0	0 8 0	2 10 0	2,690	1 1 0	Bhatinda Branch Chainage, 3,000.
5	30-ft. clear span, foot-bridge, parapet-girder.	1 0 0	0 10 0	1 4 0	0 3 0	0 5 0	0 8 0	3 6 0	365	1 3 0	Sutlej Nav. Channel Chainage 1,41,000.
6	30-ft. span foot-bridge, as above, with 15-ft. cantilevers making 60-foot spans.	0 14 6	0 8 0	0 11 0	0 3 3	0 6 3	0 9 6	2 11 0	1,770	1 2 0	Chamkaur Escape Chainage 7,000.

APPENDIX C.

Prices of Materials and Labour in the cases of R. C. Bridges on Sirhind Canal.

Items.	One-span cart-bridge 30 ft. clear at mile 2 S. N. C.	Four-span cart-bridge 30 ft. clear each at chainage 8,000, Bhatinda Branch.	One-span foot-bridge 30 ft. clear at mile 28 S. N. C.	Two-span foot-bridge, cantilever type, 45 ft. clear at charinage 7,000 Chamkaur Drain.	Remarks.
1	2	3	4	5	6
	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	
Steel rods per maund	13 0 0	(*a*) 13 12 0	13 10 0	13 4 0	(*a*) High rate because bars were bought through Controller of Stores who added 10 per cent. departmental charges. The carriage charges in this bridge were less than in any other.
Cement per cwt. ..	66 0 0	63 0 0	70 0 0	68 0 0	
Fine aggregate (sand) (*e*)	17 0 0	(*b*) 7 8 0	20 0 0	(*b*) 8 12 0	
Course aggregate (*e*) ..	(*c*) 18 0 0	(*d*) 17 0 0	(*c*) 20 0 0	(*d*) 18 4 0	
Timber Deodar per cub. ft.	3 4 0	3 8 0	3 8 0	3 4 0	(*b*) Cost of carriage less than for others. Sand used in all was brought down from Rupar.
Masons per day ..	2 0 0	2 0 0	2 0 0	2 0 0	
Carpenters per day ..	2 0 0	2 0 0	2 0 0	2 0 0	(*c*) kankar locally collected.
Blacksmiths per day ..	2 0 0	2 0 0	2 0 0	2 0 0	(*d*) Rupar Bajri.
Coolies per day ..	0 12 0	0 12 0	0 12 0	0 12 0	(*e*) Cost per 100 cub. ft.

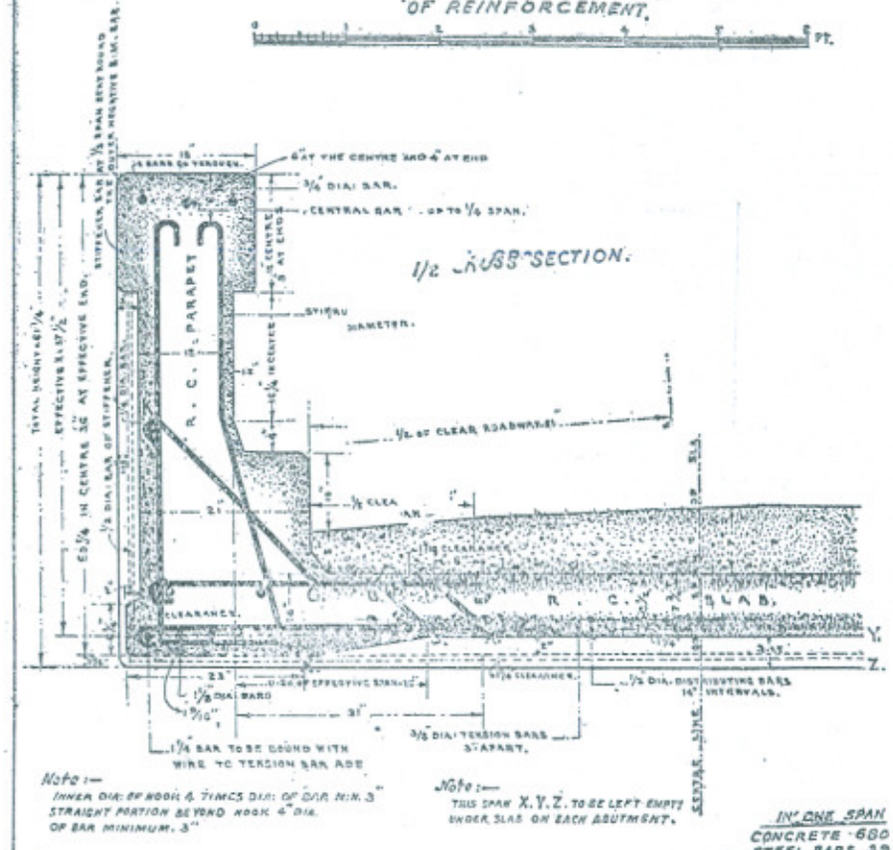
APPENDIX D.

Costs of Reinforced Concrete Bridges Built on Sirhind Canal.

Sub-head.	*One-span of 30 ft. clear cart-bridge at mile 2, Sutlej Nav. Channel.*		*Four-span cart-bridge 30 ft. clear each at chainage 8,000, Bhatinda Branch.*		*One-span foot-bridge 30 ft. clear at mile 28, Sutlej Nav. Channel.*		*Two-span foot-bridge 45 ft. clear each cantilever-type, chainage 7,000, Chamkaur Drain.*	
	Total cost.	Cost per ft. of waterway.	Total cost.	Cost per ft. of waterway.	Total cost.	Cost per ft. of waterway.	Total cost.	Cost per ft. of waterway.
1	2	3	4	5	6	7	8	9
	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.
Spans, reinforced-concrete, including false work.	2,550 0 0	85 0 0	7,800 0 0	65 0 0	1,350 0 0	45 0 0	4,000 0 0	44 0 0
Piers, wings, abutments, foundation and pitching.	*a* 570 0 0	19 0 0	9,000 0 0	75 0 0	*a* 300 0 0	10 0 0	*b* 4,000 0 0	44 0 0
Total ..	3,120 0 0	104 0 0	16,800 0 0	140 0 0	1,650 0 0	55 0 0	8,000 0 0	88 0 0

NOTE.—*a.* Bridge built on old abutments.
b. Pier of reinforced-concrete.

R.C. ROAD BRIDGE
36-FOOT SPAN.
½ CROSS SECTION SHOWING DETAILS OF REINFORCEMENT.



Note :—
INNER DIA: OF HOOK 4 TIMES DIA: OF BAR MIN. 3"
STRAIGHT PORTION BEYOND HOOK 4" DIA. OF BAR MINIMUM. 3"

Note :—
THIS SPAN X. Y. Z. TO BE LEFT EMPTY UNDER SLAB ON EACH ABUTMENT.

IN ONE SPAN
CONCRETE 680 CFT.
STEEL BARS 33 MDS.

⅓ OF SLAB TENSION BARS TAKE LINE A. B. E.
⅓ OF SLAB TENSION BARS TAKE LINE A. D. B. F.
⅓ OF SLAB TENSION BARS TAKE LINE A. D. F.
WHEN BARS TAKE LINE A. D. E. BARS K. G. C. ARE ADDED.

A.P.S. Tandon 15/9/27
SUPERINTENDING ENGINEER.
SIRHIND CANAL CIRCLE.
AMBALA.

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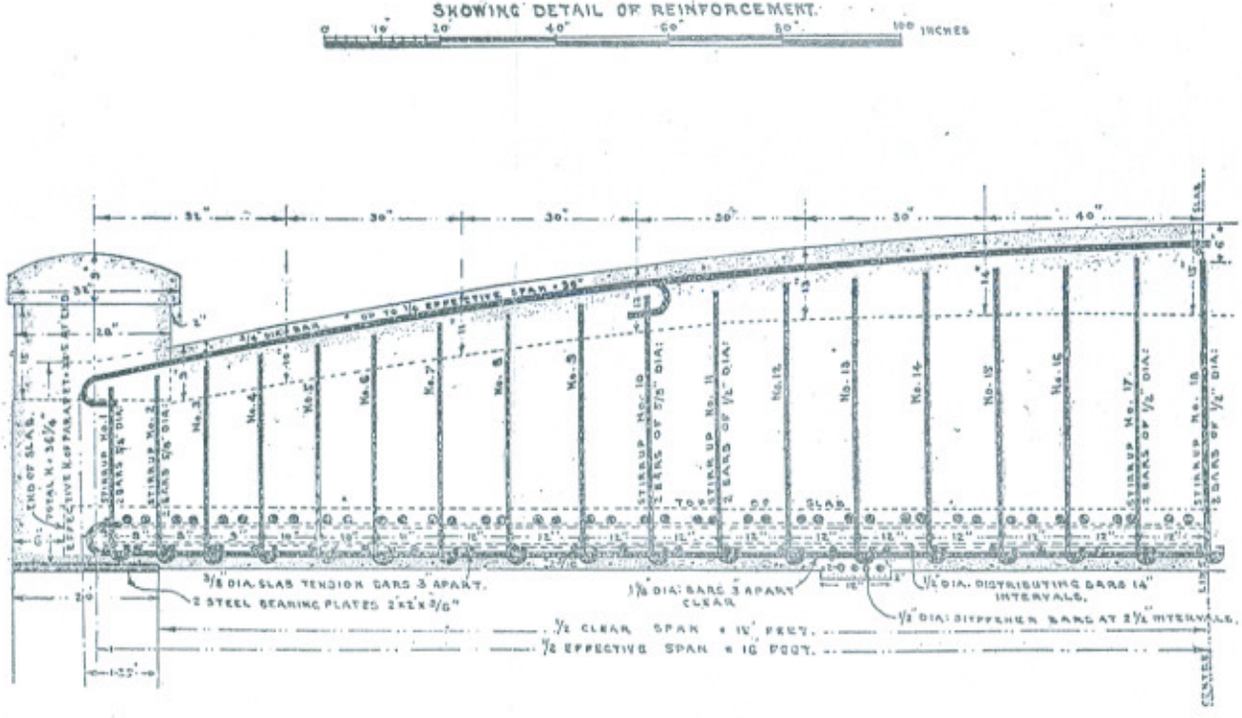
R.C. ROAD BRIDGE

30-FOOT SPAN

HALF LONGITUDINAL SECTION OF PARAPET GIRDER

SHOWING DETAIL OF REINFORCEMENT.

B.



ONE SPAN { Steel bars 39 Mds.
Reinforced Concrete 680 Cu. Ft.

A.G. Faun 15/9/27.

SUPERINTENDING ENGINEER,
SIRHIND CANAL CIRCLE.
Ambala Cantt.

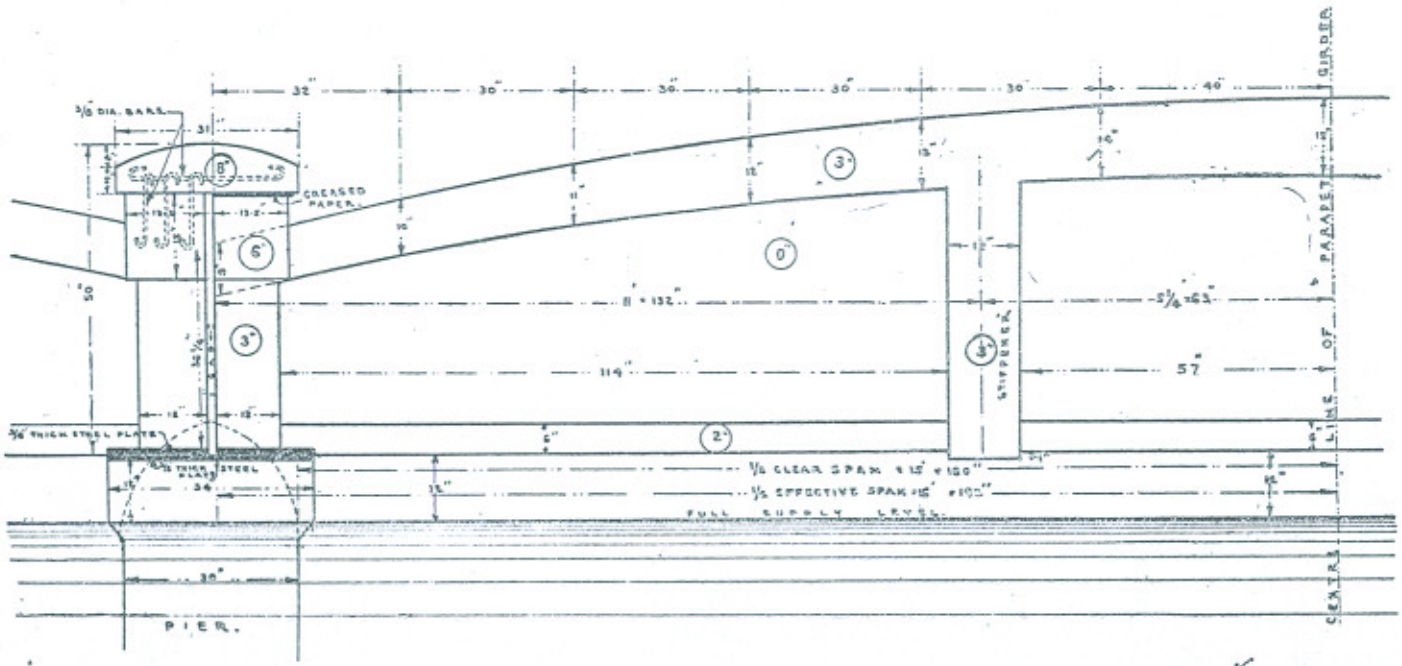
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R.C. ROAD BRIDGE

30-FOOT SPAN

HALF ELEVATION OF R.C. PARAPET SHOWING
DETAIL OF EXPANSION JOINT AND PROJECTION OF VARIOUS
PARTS BEYOND FACE OF PARAPET.

INCHES. 0 10" 20" 40" 50" 60" INCHES.



Rgt Tawa 15/9/27

SUPERINTENDING ENGINEER
SIRHIND CANAL CIRCLE.
AMBALA.

NOTE.-

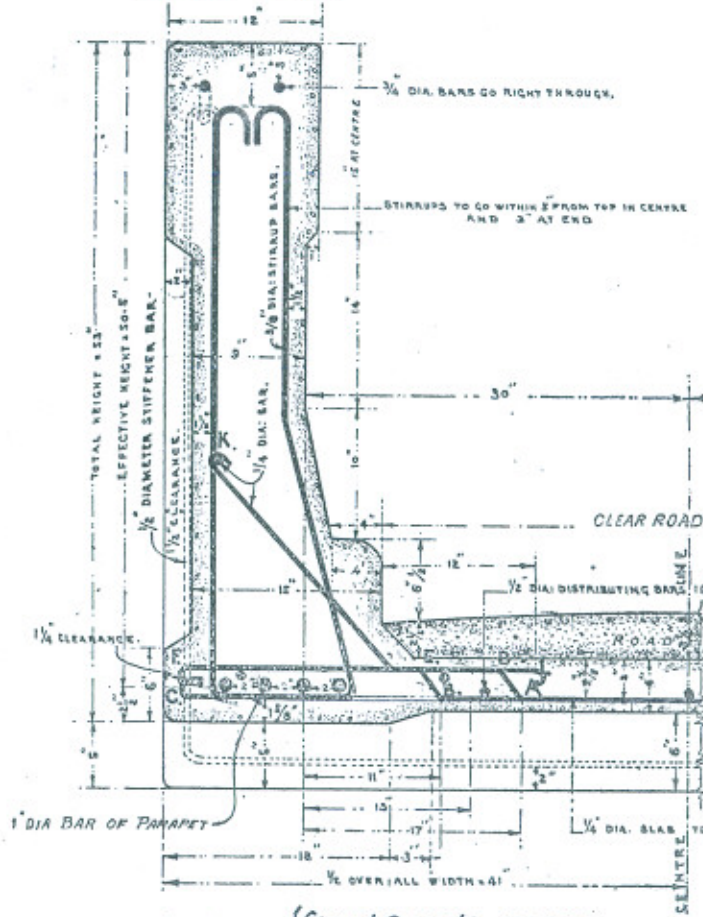
1/3 SLAB TENSION BARS	ABC
1/3 " " "	ABEF
1/3 " " "	ADEF
BARS KEL ARE ADDED AT TOP IN PLACE OF BARS	ABC

REINFORCED CONCRETE FOOT BRIDGE
30-FOOT SPAN.
CROSS SECTION SHOWING REINFORCEMENT

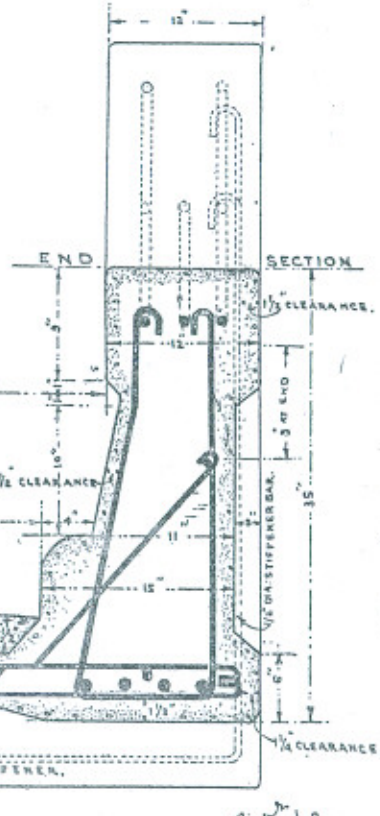
(D)

0 5 10 20 30 40 50 INCHES

CENTRAL SECTION



CENTRAL ELEVATION



ONE SPAN { Cement Concrete = 370 C FT.
Steel bars = 23 Mds.

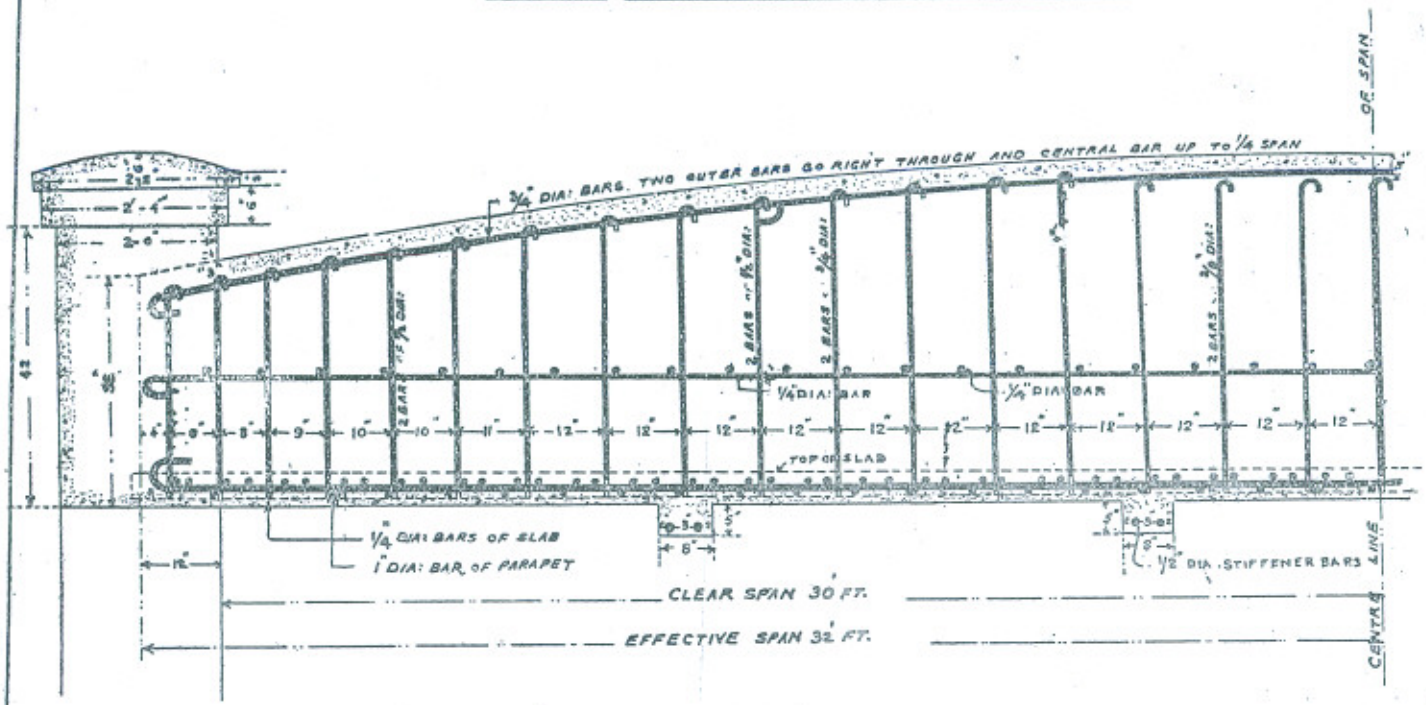
Supdtg. Engr 13/9/27

Superintending Engineer
Sirhind Canal Circle.
Ambala Cantt.

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REINFORCED CONCRETE FOOT BRIDGE
30-FOOT, SPAN.
LONG: SECTION OF PARAPET
SHOWING REINFORCEMENT.

(E.)



ONE SPAN { CEMENT CONCRETE = 370 CFT.
STEEL BARS = 23 MDS.

A.P.S. Tawney 15/9/27
SUPERINTENDING ENGINEER
SIRHIND CANAL CIRCLE.
AMBALA CANTT.

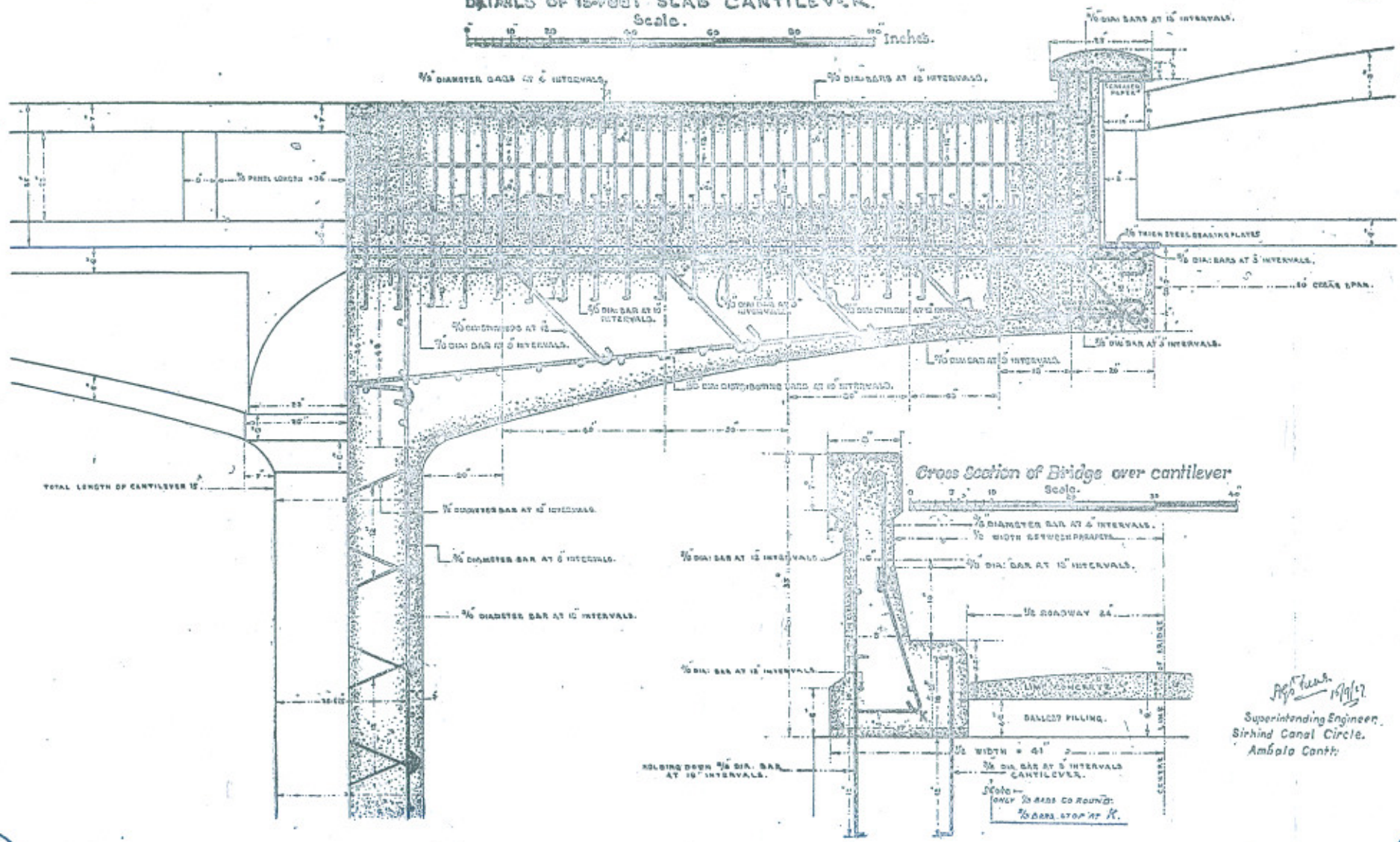
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Reinforced Concrete Foot Bridge.

30-FOOT SPAN

DETAILS OF 15-FOOT SLAB CANTILEVER.

Scale. 0 10 20 30 40 50 60 Inches.


⅝ DIAMETER BARS AT 6" INTERVALS.
⅝ DIA. BARS AT 12" INTERVALS.
⅝ DIA. BARS AT 15" INTERVALS.
TOTAL LENGTH OF CANTILEVER 15'
½ DIAMETER BAR AT 12" INTERVALS.
⅝ DIAMETER BAR AT 6" INTERVALS.
⅝ DIAMETER BAR AT 12" INTERVALS.
HOLDING DOWN ⅝ DIA. BAR AT 12" INTERVALS.
⅝ DIA. BAR AT 3" INTERVALS.
⅝ DIA. BAR AT 5" INTERVALS.
½ DIA. BAR AT 12" INTERVALS.
½ DIA. BAR AT 6" INTERVALS.
½ DIA. BAR AT 12" INTERVALS.
½ DIA. BAR AT 3

DISCUSSION.

Author.—Mr. Fane in introducing his paper remarked that its object was to encourage the use of reinforced concrete where stone was absent, using kankar rather than stone. He considered it would result in a saving both of money and trouble. He had used this material extensively in various types of buildings with successful results. In the South-East of the Punjab there is no stone of good quality and therefore it must be carried in by rail. It would be cheaper in these circumstances to use local sand and local kankar.

He pointed out that the reinforced concrete form of construction saves closures of canals caused by the use of arched construction and he estimated that these closures represented a loss of Rs. 20,000 per day in summer and half that amount in winter. He explained the work carried out on the Bhatinda Branch and stated that it was all carried out without any special closures but during ordinary closures of ten day periods. With brick construction this would be impossible. Mr. Fane explained the erection of the false work of the concrete bridges and showed that in addition to the initial cost being low, a further reduction occurred owing to the false work being used again on other bridges. He described the method of building while the canal was in flow and remarked that Mr. Blaker was training subordinates in reinforced concrete work who had proved themselves to be practical men.

Mr. F. H. Burkitt remarked that he had seen these bridges of Mr. Fane's during construction. They struck him very much more favourably than brick masonry bridges. The parapet girder type was cheaper than the T-slab design. He had just constructed a bridge of 35 feet span. He had worked it out on parapet girder lines and found it cost rather more. The advantage of the T-slab design is that it is somewhat more rigid.

Mr. A. N. Khosla remarked that the Department owes a debt of gratitude to Mr. Fane for having demonstrated the use of kankar as a possible aggregate in reinforced concrete work and for having introduced the use of reinforced concrete on a large scale in bridge construction.

Regarding form work, it would be noticed that in spite of the economies affected by Mr. Fane by using them over again, their cost is still a very considerable proportion of the total cost of the reinforced concrete work.

Another feature that makes the design expensive is the parapet girders which, in themselves cost more than the roadway they are intended to carry. This applies with greater force in the case of foot bridges.

A possible source of weakness in the parapet girder type is the fact that the safety and strength of the roadway is entirely dependent on these girders and if an accident happens to one of them such as a heavy fast moving automobile charging full force against it, the whole structure may collapse. This danger does not exist in the case of the T-beam design. Mr. Fane has taken this into consideration in his design.

By using the parapet type Mr. Fane has saved considerably in head room and therefore, in the cost of approaches.

To economise in form work, in head-room and materials the speaker explained that he had designed a method of reinforced concrete through construction for bridges, in which the cost of the roadway is reduced to almost one-third of Mr. Fane's figures, and the form work at site is entirely eliminated. It consists of reinforced concrete troughs, pre-cast with the full amount of tensile and shear reinforcement and cured for full 28 days, placed on the piers as soon as they are ready and fitted with 1 : 2 : 4 concrete to the necessary section of the roadway at site. These troughs serve as form work, save mistakes in placing of reinforcement and shorten the time of construction and of opening to traffic.

In order to bind the pre-cast work to the concrete at site vertical stirrups, tied to the tensile reinforcement, project out of the pre-cast work and are calculated for the full strength required in shear at the planes of contact of the old and the new work, without allowing credit for the strength of a layer of neat cement grout laid between the two sets of concrete.

The speaker exhibited a trough design for a 30′ clear span. See diagram attached to Paper No. 121.

Mr. C. E. Blaker congratulated Mr. Fane on having made a start in erecting reinforced concrete bridges over the canals. He considered the design an absolutely original one, evolved apparently to allow of construction while the canal is in flow. He pointed out that the design is of single span and cantilever construction which, in ordinary reinforced designing along normal lines is exceptional. The ideal before the concrete bridge designer is the reduction in the amount of the reinforcement in order to save cost. The greatest reduction is brought about by introducing monolithic principles of design. The piers and girders being monolithic reinforce each other. He pointed out that designers in the Punjab are faced with greater temperature ranges than in Europe where a combination of three spans and two piers had proved suitable. He recently had occasion to investigate the possibility of designing and constructing two piers and three spans in combination. But found that it would be dangerous as the stressing on the pier heads would be too great. The monolithic construction was therefore reduced from three spans and two piers to two spans and one pier.

He pointed out that there is a vast difference between a girder bridge based on these lines and on those of Mr. Fane's design. In his opinion a continuous girder span would have been much cheaper than the cantilever type adopted as the maximum moment in the former is $\frac{W\,l}{10}$ while in the latter it is $\frac{W\,l}{4}$. He would like to enquire from Mr. Fane if he adhered to the mixture of 1 cement, 2 sand and 4 kankar nodule.

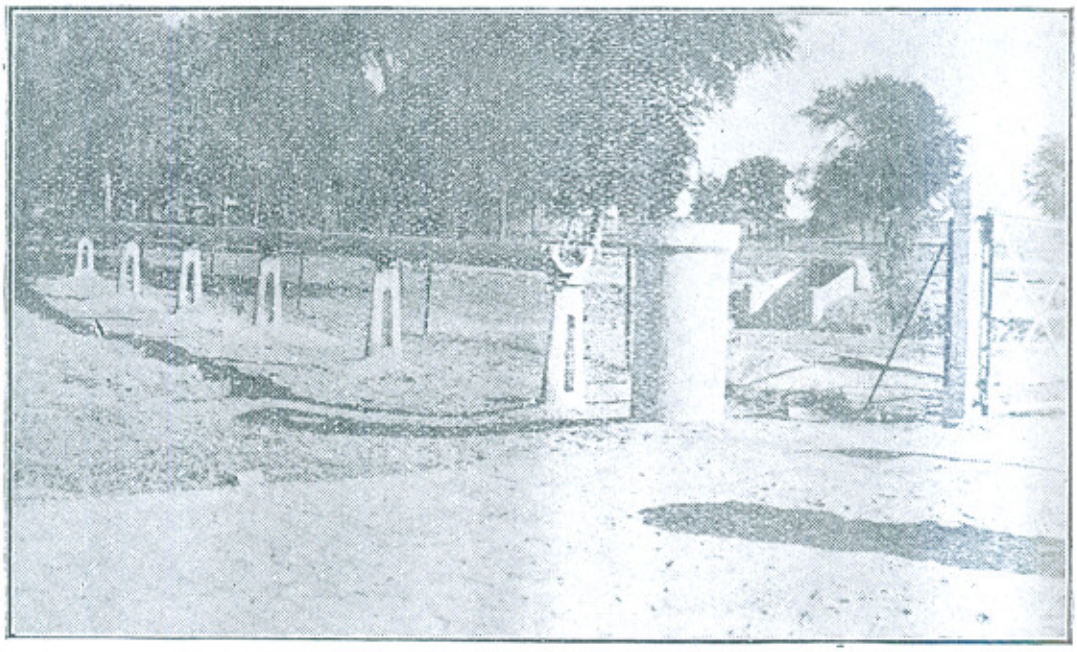
Mr. Fane.—Yes.

Mr. Blaker stated that this interested him as many officers have been sceptical as to the suitability of kankar in concrete construction and that it is generally accepted that the most suitable coarse aggregated to use is pebble or gravel owing to the ease with which they are tamped. He was gratified to hear Mr. Fane's remarks about the men trained by him.

Mr. Nicholson pointed out that a good point in the design was the saving of earth work in approaches. He thought the bridges should be designed to carry 5 ton lorries, which will soon supersede the lighter bullock carts.

Mr. G. R. Sawney enquired if an overlap of forty diameters was sufficient.

Mr. Fane replying to the discussion stated that had he visualized the possibility of five ton lorries using the bridges and added the cost to his estimates Government would not have passed them. Regarding the overlap of the rods ; according to the London County Council requirements forty diameters without a hook was sufficient. Where bars touched and had hooks he considered forty diameters sufficient. It should not be less and the rods should be bound with wires.



The origin of the Reinforced Concrete Trough.