PAPER No. 202.

A NOTE ON THE BUILDING OF TWO REINFORCED CONCRETE BOX CULVERTS ON THE NORTH WESTERN RAILWAY.

(By S. L. Kumar, Assistant Bridge Engineer.)

Although a number of R. C. siphons have been in use for a number of years, the two reinforced concrete box culverts built under the supervision of the author in 1935 were the first of their kind to be constructed on the North Western Railway.

Special interest attaches to these new box culverts. They were the first structures in the North of India to be designed and built in accordance with the Revised Code of Practice for Reinforced Concrete. Based on the British Code, the permissible working stresses in ordinary grade reinfored concrete of 1 : 2 : 4 mix have been rasied from 600 to 750 lb. per square inch for the concrete in compression and from 16,000 to 18,000 lb. per square inch for the steel in tension. That the adoption of these higher working stresses was fully justified is shown by the results of compression tests carried out on concrete cylinders cast at the time of pouring the concrete at the site of the work. The results of these tests have been tabulated and are given in Appendix C. Another interesting feature was the grading of the mixture by the fineness modulus method, *vide* Appendix B.

The first of these two culverts was built in Amri station-yard at mile 66-9-10 on the Kotri-Dadu Section of the railway and for convenience is referred to as the Amri Culvert. The second and the larger one was on the main line at mile 236-15-16 between Sariab and Quetta. This is referred to as the Quetta Culvert.

In each case, the design was chosen to suit the local conditions. The Amri Culvert replaced a 15-feet girder span built at the time of the construction of the old Indus Valley Railway more than fifty years ago. The stone masonry of the old bridge had weathered badly and had cracked and bulged to such an extent that complete reconstruction before the next monsoon was considered absolutely imperative. The Bridge Branch were renewing other spans on the same section and so the work of rebuilding the whole of this particular bridge was entrusted to them. A design had already been prepared for new masonry abutments but it was dropped on the grounds of economy, the temporary arrangements for carrying the traffic over the abutments during reconstruction being

more costly than the building of the R. C. box culvert. The latter was built under the existing bridge, which continued to carry the traffic at a restricted speed.

The 12-feet girder bridge, which the Quetta Culvert replaced, had been badly damaged in the historic earthquke of the 31st May 1935, and so the box culvert was chosen for its earthquake resisting properties.

The Amri Culvert.

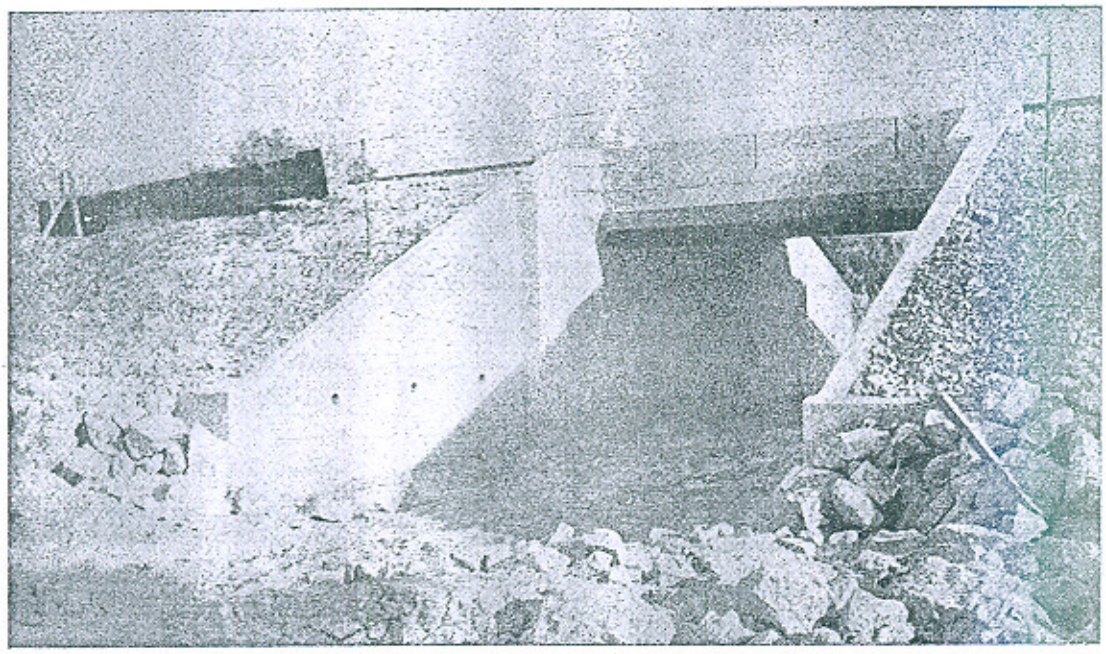
This culvert is a box 12′—9″ wide and 6′—11″ high. The plans for the work were received from the Deputy Chief Engineer, Bridges, by the beginning of May, 1935. Actual concreting was started on the 30th May. With the exception of the flooring concrete which was done with ordinary Portland Cement, the rest of the work was done with Rapid Hardening Swasticrete or Bundi Cement.

The flooring concrete was hand-mixed but for the remaining work a mixer was employed. Since the mixer had only seven revolutions per minute instead of the usual 12, the time of mixing (counting from the instant when the mixer was fully charged) was raised from 2 to 3 minutes. Each mix gave about 5 c.ft. of mixed concrete and it was possible to mix about 60 c.ft. per hour.

The country round about Amri is very hot in the day time, the temperature frequently rising above 115 degrees Fahrenheit. It was, therefore, feared that such a high temperature might cause surface dessication and a too rapid setting at the surface without giving adequate time for the core to set properly. Consequently, it was decided to lay all the concrete at night. Even so the conditions were none too pleasant. The work was, however, completed in humid heat amid swarms of mosquitoes and sand-flies. The country being extremely malarious, bambor oil was distributed to the labourers every night.

Slump tests were taken frequently, slumps upto four inches being allowed for those portions of the culvert, which were difficult to concrete on account of heavy reinforcement as for example at the junction of the side walls with the floor. For the positions more easily reached the slump was between 1″ to 2″. At intervals test cylinders of 4″ diameter and 8″ length were also cast and the results of the tests taken to determine the compressive strength after 28 days are given in Appendix C. It will be seen that the compressive strength obtained varied from 3335 to 4125 lb. per square inch, which was very satisfactory, the compressive strength of ordinary grade concrete of 1 : 2 : 4 mix after 28 days by the Code being 2700 lb. per square inch.

The floor was laid by having a shuttering of brickwork in cement (1 : 6), the surface at the ends where the vertical slabs were to be cast was left rough for good bonding. The concreting of the side slabs was



THE AMRI CULVERT

not so easy. It had been arranged to cast the side slabs upto the lower end of the haunches of the roof slab but as this would have given a drop of about 6 ft. for the mixed concrete, the masonry between the old bedstones was dismantled to a depth of about a foot below the undersides of the bedstones. In this way the drop was reduced to about 4 feet. The existing masonry was bonded to the side slabs by embedding in it a number of projecting rail pieces of 75 lb. rails. These pieces of rail also helped to keep the shuttering boards in position by means of small cleats attached to them. The roof slab and the ballast retainers were cast in one operation. The shuttering consisted of a number of brick pillars supporting a flooring of old sleepers. This was covered over by a layer of 2" cement concrete plastered over carefully immediately after it was laid. In order to prevent adhesion between this concrete and the concrete of the roof slab, ordinary paper was pasted over the surface of the plaster. Later on, when the surface of the shuttering was flooded with water to remove saw dust and fine rubbish, the paper crumpled up a bit in places and it would appear that white-washing or oiling the surface of the plaster would have been preferable to the use of paper.

For the concreting of the wing walls, a brickwork shuttering was used upto the floor level. Above the floor level a shuttering of 3" thick planks properly battened and lined by galvanized sheets was used, the shuttering boards being kept in position with respect to each other by means of cross bolts. The shuttering was kept plumb by effective shoring and props.

The shuttering of the side walls and the wing walls was struck 12 hours after casting and that of the roof slabs was struck after 3 days. As soon as the latter was struck, the roof slab was supported for a fortnight on thick timbers supported on masonry props so as to avoid any sag due to the plastic yield. At first sight this period would appear to have been too short, but it must be remembered that rapid hardening cement was used and also that the air temperature was very high. Actually, this period was found to be adequate.

The concreting of the roof slab was completed on the 7th August. Although orders had been received that train loads may be carried on the new bridge 15 days after casting of the roof, due to unforeseen circumstances it was not possible to open the bridge for unrestricted speed until the 7th September.

The Quetta Culvert.

The subordinate, who cast the Amri culvert, reached the site of this bridge by the middle of September but considerable delays occurred in the receipt of material.

This culvert has a box 12′ wide and 13′—5″ high, the side walls being 12″ thick and the roof slab 1′—5″ thick. The details of the reinforcement are shown in Plate No. IV.

During the construction of the culvert, traffic was carried on a diversion. The existing masonry was completely dismantled down to the foundation concrete before the new work was started. As second hand bricks obtained from dismantled quarters damaged by the earthquake were available for next to nothing, masonry walls with 1 : 6 cement mortar were commonly used to serve as form work for this culvert.

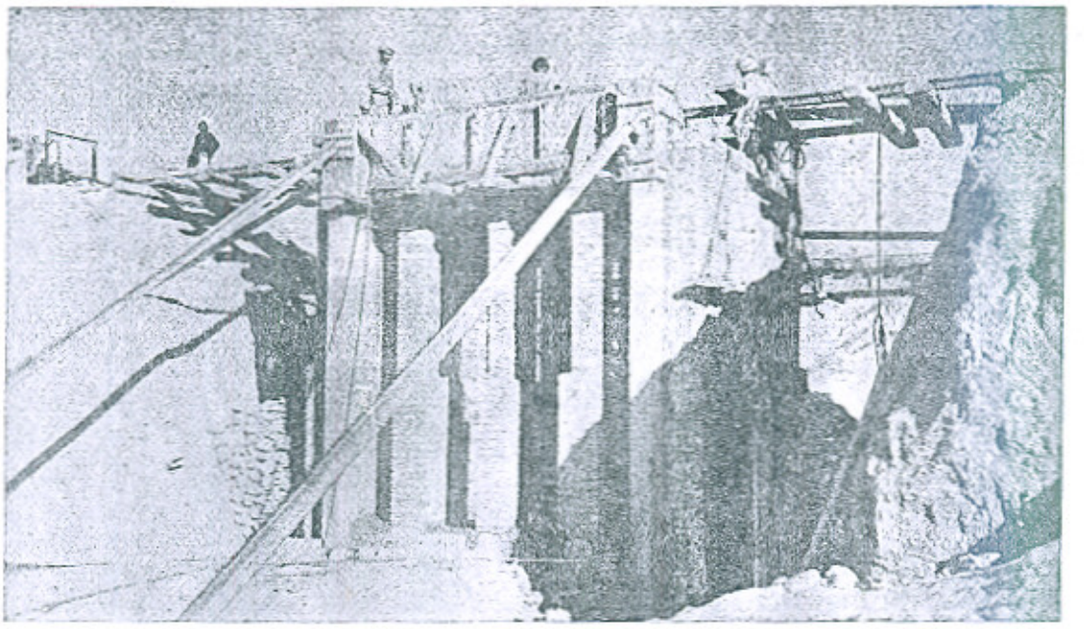
The main culvert was cast in three distinct operations. The first operation included the casting of the floor slab and the curtain and drop walls and side walls upto 3" above the haunches. It was decided not to keep the joint at the top edge of the haunch, as a fine crack, which is likely to occur at a joint, might create unnecessary alarm at the level of the haunch. The shuttering consisted mainly of cement brick walls with second hand bricks. When the floor slab had been concreted, chamfered timbers were placed in position for casting the haunches.

In the second operation the side slabs (including the extensions on the sides against which the wing walls abutted) were cast. The shuttering at the back consisted of a brick wall and in front 3" thick spruce planks lined with galvanized sheets. The shuttering in front was held in position by means of bolts cast in the masonry wall at the back. On half the number of these bolts check nuts were provided on the inner face of the shuttering to keep the planks plumb. When the shuttering was released, the bolts were cut almost flush with the front surface and covered over with a thin coat of fine cement concrete. The front shuttering was made in four lifts each about 2'—9" in height. Each successive section of the shuttering was bolted on, when the lower section had been fully concreted. About fifteen minutes were required to fit each section as the complete shuttering had been erected and the check nuts had been adjusted into correct positions before the concrete work had been started.

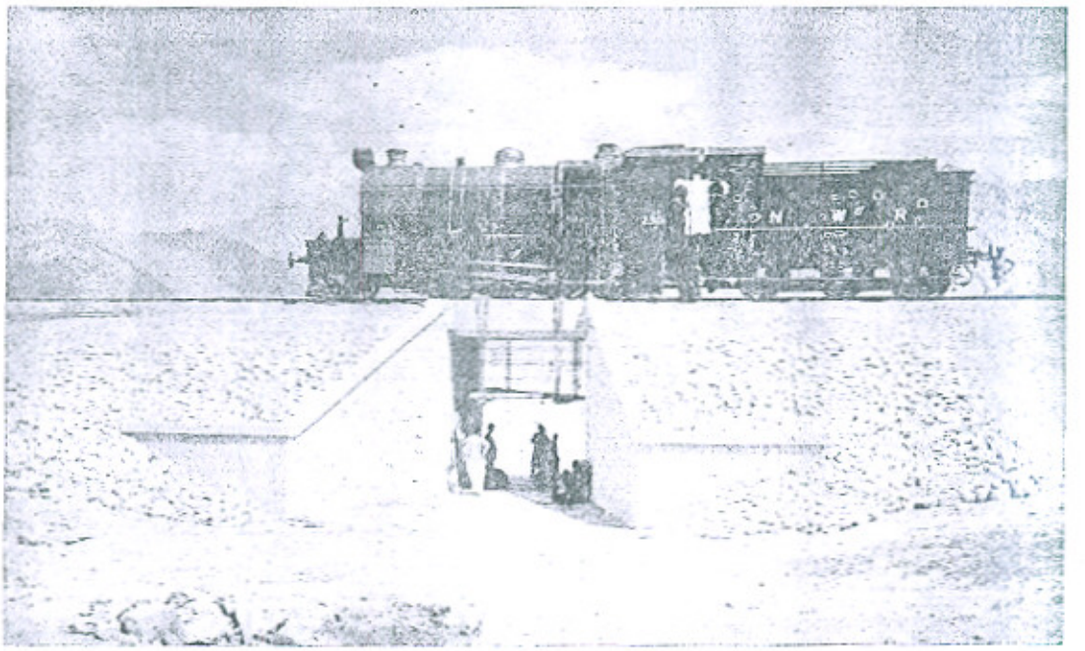
In the third operation, the roof slab was cast. The detail of the shuttering is shown in Plates No. V and VI. The wing walls and the return walls were also cast in three distinct stages—the floor and the haunches in the first stage, the return wall and the wing walls including the buttresses upto the top level of the return wall in the second stage and the sloping top portion of the wing wall in the third stage.

The concreting of the floor slab was done on the 21st October and the last portion of the concrete in the wing walls was poured on the 30th November. The culvert was opened to unrestricted speed on the 20th December.

In October and November, ground frost is to be expected at Quetta and even though there was no severe frost during these months, the work was covered over with thick tarpaulins and bonfires were kept alight on each side of the bridge at night.



THE QUETTA CULVERT-CASTING ROOF SLAB



THE TEST UNDER LOAD OF THE QUETTA CULVERT

The shuttering for the side slabs and the wing wall was struck 48 hours after pouring and for the roof slab one week after it had been concreted. As at Amri, rapid hardening cement was used at this culvert.

Testing the Quetta Culvert under load.

While casting the culvert near Quetta, pockets were left in the concrete exposing a short length of the reinforcement immediately under one of the running rails. In this way, the rods were left bare at certain pre-arranged places so that Huggenberger Tensometers could be fixed to the reinforcement and the variations in strain under a passing load read. These pockets were left at midspan points in the roof, side and floor slabs and also at the corners.

The exact arrangement at these pockets is shown in Plate No. VI. It will be observed that a small piece of a bent rod secured to the main reinforcement and running perpendicular to it was left in position before casting. At the top end of the bend had been drilled a hole $\frac{3}{8}''$ in diameter with a whitworth thread. To this was secured the special steel pillar which along with a special knife edge formed the fixing device of the Huggenberger Tensometer.

The tests were actually carried out about a month after the culvert had been opened to traffic. Unfortunately, other engineering works were in progress in the proximity and the tests could only be taken at a crawling speed and as the engine used— HG/S., 2-8-0 tender locomotive—represented only 62 per cent. of the H. M. load for which the bridge was designed, the increments of strain (or stress) were very low. Even allowing for the absence of impact effect, theoretically equal to 100 per cent. of the live load on a span of this size and the lightness of the test load, the results showed that the actual factor of safety of such a concrete structure is very much greater than the design factor.

On completion of the tests, the pockets in the concrete where the rods had been left bare, were filled with fine cement concrete.

The author is grateful to Mr. P. S. A. Berridge for his many valuable suggestions.

The paper has been presented with the kind permission of Mr. H. Wood Robinson, Deputy Chief Engineer, Bridges and of the North Western Railway Administration.

APPENDIX A.

A brief note on the design of box culverts.

The designs of the box culverts mentioned in this paper were prepared in the office of the Deputy Chief Engineer, Bridges, Lahore. It is proposed to outline briefly some important points relevant to the design of these box culverts.

Data for design.

1. Standard of loading for the design of these box culverts was H. M. standard (Broad Gauge) of 1926. The maximum axle load of the hypothetical engine of this loading is 28 tons and the spacing of the axles is 5·6 ft. This gives an equivalent uniform load of 5 tons per foot run of span.

2. Impact was worked out from the formula $\frac{65}{45+L}$ where L is the effetive span in feet subject to a maximum of 1·00 for spans below 20 feet.

3. Grade and mix of concrete—Ordinary grade concrete of 1 : 2 : 4 mix.

4. Permissible stresses :—

fc=750 lb. per sq. inch.

fs=18,000 lb. per sq. inch.

v =75 lb. per sq. inch.

u (bond stress)=100 lb. per sq. inch.

n (modular ratio)= $\frac{40{,}000}{3\times fc}$=17·8.

The formulae for determining bending moments under four types of vertical and horizontal loads on a box culvert are given in standard text books. Two points in connection with the design of box culverts may, however, be emphasized.

In the first place, it should be remembered that considerable variation in the values of positive and negative moments at different points can be obtained by altering the relative flexibility or stiffness of the horizontal and vertical slabs.

Secondly, two possible conditions of loading may ordinarily be considered for obtaining the maximum bending moments in box culverts designed for Railway loads. They are as follows:—

Condition I.—Top slab fully loaded and no lateral pressure due to earth and superload resulting from the live load over the fill. This latter condition operates sometimes with certain kinds of fills under certain conditions of moisture and temperature. The above condition of loading gives the maximum value of the positive moments in the top and bottom slabs.

Condition II.—Top slab fully loaded and the side slabs subject to full earth pressure. This condition produces the maximum negative or corner moments.

With certain class of locos such as the Garrett type, where the groups of heavy axles which govern the design, are spaced far apart, a third possible condition of loading can arise, namely—no live load on the roof slab while there is full lateral pressure due to earth and the super-load resulting from the live load. This condition of loading will result in the maximum value of the positive bending moments in the vertical slabs.

For making a preliminary design of a box culvert, it is necessary to assume a value for the ratio (I_1/I_2) of the moments of Inertia of the top (or bottom) and the side slab. With this value the positive bending moment at the centre of the roof slab and the corner moments can be determined with the help of the formulæ referred to above. If the assumed value of I_1/I_2 gives smaller moments at the corners than that at the centre of the top slab, then a smaller value of the ratio I_1/I_2 should be tried till these bending moments are as nearly equal as possible. This method will result in an economical design.

APPENDIX B.

Calculations showing the method of grading concrete by the fineness Modulus method.

The grading of concrete by the fineness modulus method is one of the recognized methods utilized in obtaining the densest and strongest concrete for any particular mix of fine and coarse aggregates with cement.

On the Amri culvert Haro sand and shingle were used and at Quetta Haro sand and Hirok shingle were used. The following calculations show the method of grading the concrete :—

A. *Determination of bulking percentage of Haro sand and Hirok Shingle.*

The sand was washed and dried. The coarse aggregate before use was screened through $\frac{3}{4}''$ and $\frac{1}{8}''$ mesh sieves.

Weight per c. ft. of loose sand after washing and drying completely. = 88 lb.

Dry rodded weight per c. ft. = 102·50 lb.

Bulking percentage $= \frac{102{\cdot}5 - 88{\cdot}0}{88} = 16{\cdot}3$ per cent.

Say, $\frac{1}{6}$th roughly.

Weight per c.ft. of dry and loosely packed Hirok aggregate. = 102 lb.

Weight per c.ft. of dry rodded Hirok aggregate. = 107·5 lb.

Bulking percentage of Hirok aggregate $= \frac{5{\cdot}5}{102} = 5{\cdot}4$ per cent.

Say $\frac{1}{20}$th roughly.

B. *Determination of fineness Moduli of Haro sand and Hirok aggregate by standard sieves.*

Representative samples weighing 5 lb. each of Haro sand and Hirok shingle were taken for this purpose.

Sieve size.	Haro Sand.			Hirok Shingle.		
	Retained.		Per cent. coarser.	*Retained.*		Per cent. coarser.
	lb.	Per cent.		lb.	Per cent.	
$\frac{3}{4}''$ ..	..	..	..	..	..	..
$\frac{3}{8}''$ ..	..	..	..	3·375	67·50	67·50
No. 4. ..	..	..	..	1·313	26·26	93·76
No. 8 ..	..	..	..	·312	6·24	100·00
No. 16 ..	·140	2·80	2·80	..	..	100·00
No. 30 ..	1·235	24·70	27·50	..	..	100·00
No. 50 ..	2·750	55·00	82·50	..	..	100·00
No. 100 ..	0·719	14·38	96·88	..	..	100·00
			209·68			661·26

M_s = fineness modulus of sand $= \frac{209{\cdot}68}{100} = 2{\cdot}10$

M_a = ,, ,, ,, aggregate $= \frac{661{\cdot}26}{100} = 6{\cdot}61$

M_c, the fineness modulus required after mixing aggregate and sand was figured at 5·3 which is quite reasonable for $\frac{3}{4}''$ shingle.

Percentage of sand in the mixture for obtaining a fineness modulus of 5·3

$$= 100 \left(\frac{M - M_c}{M_a - M_s}\right)$$

$$= 100 \left(\frac{6{\cdot}61 - 5{\cdot}3}{6{\cdot}61 - 2{\cdot}10}\right)$$

$$= 29.$$

Percentage of coarse aggregate=71.

Therefore in 1 : 2 : 4 mix *i.e.*, 1 : 6 concrete.

sand required = ·29 × 6=1·74 c.ft.

Aggregate reqd. =·71×6=4·26 c.ft.

Cement required =1 c.ft.

Therefore the field mix for one bag of cement after allowing for the bulking of sand and aggregate is as follows :—

Loose sand=1·74×1·22×$\frac{7}{6}$=2·48, say, 2$\frac{1}{2}$ c.ft.

Loose aggregate =4·26×1·22×$\frac{21}{20}$=5·46 say 5$\frac{1}{2}$ c.ft.

C. *Volume of mixing water required.*

This was worked out from the following formula :—

$$G = AK\,(2V_c + V_s + 0{\cdot}3V_a)$$

G = water required in gallons.
V_c = volume of cement in c.ft.
V_s = volume of loose sand in c.ft.
V_a = volume of aggregate in c.ft.

A taken equal to 1·0 and K equal to 1·1 for this mix.

$$\therefore\ G = 1{\cdot}1\times 1{\cdot}0\ (2\times 1{\cdot}22+2{\cdot}5+{\cdot}3\times 5{\cdot}5)$$

$$= 7{\cdot}25 \text{ gallons.}$$

In actual working less water than the above quantity was always used and found adequate.

APPENDIX C.

Compressive strengths of concrete test cylinders cast during the concreting of the box culverts.

Diameter of cylinders = 4 inches.
Height of cylinders = 8 inches.

Site.	Date of casting.	Number of cylinders cast.	Average breaking strength after 28 days.	Breaking strength in lb. per square inch.
			tons.	
Amri Culvert ..	26-7-35	3	23·13	4125
Do. ..	29-7-35	3	19·37	3454
Do. ..	7-8-35	3	18·70	3335
Quetta Culvert ..	30-11-35	6	16·73	2981
Do. ..	18-11-35	3	19·90	3549

It is thus obvious that the strength attained was much above the required strength of 1 : 2 : 4 concrete of ordinary grade, namely 2700 lb. per square inch.

PLATE I

PAPER NO.202

GENERAL ARRANGEMENTS

THE AMRI CULVERT

(BRIDGE NO:444 ON KOTRI DADU SECTION)

SCALE 1"= 8'

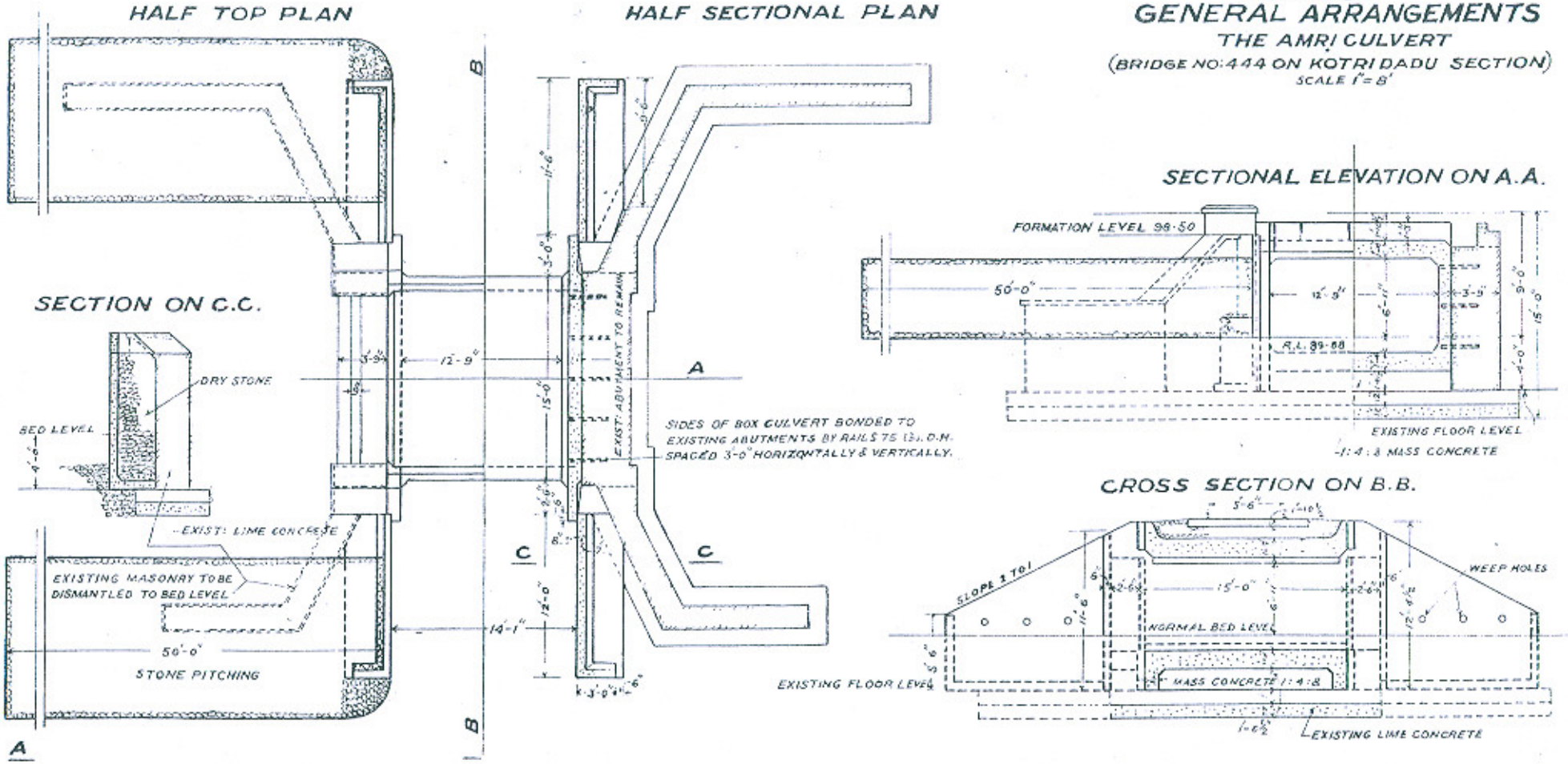
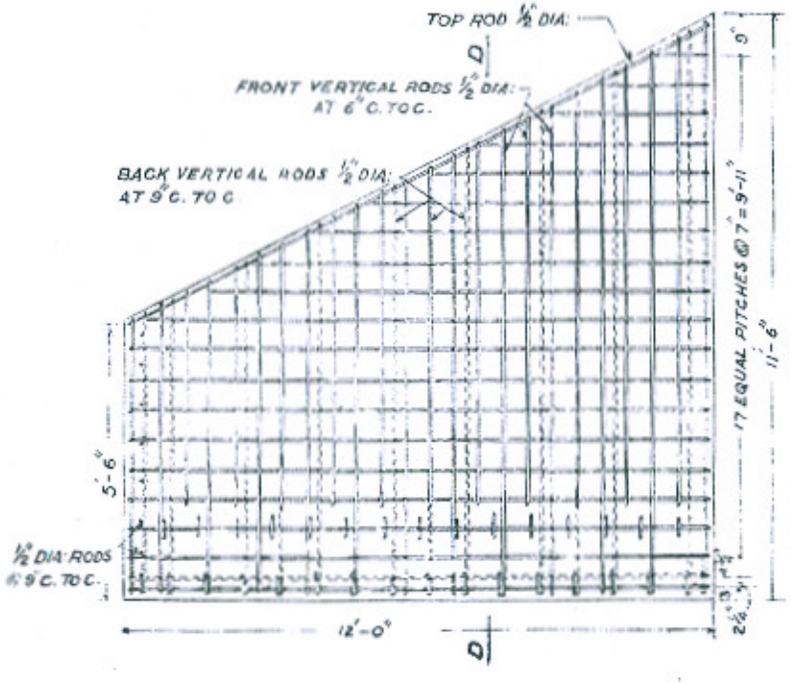


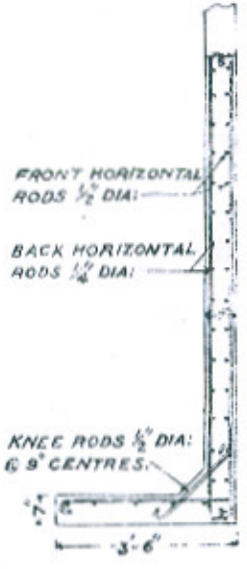
PLATE II
PAPER NO. 202

DETAILS OF REINFORCEMENT
THE AMRI CULVERT
(BRIDGE NO 444 ON KOTRI DADU SECTION)
SCALE 3/8" = 1 FT.

ELEVATION OF WING WALL.



SECTION ON D.D.



PART SECTIONAL ELEVATION OF BOX CULVERT
SHOWING ALSO BALLAST RETAINER & DROP WALL

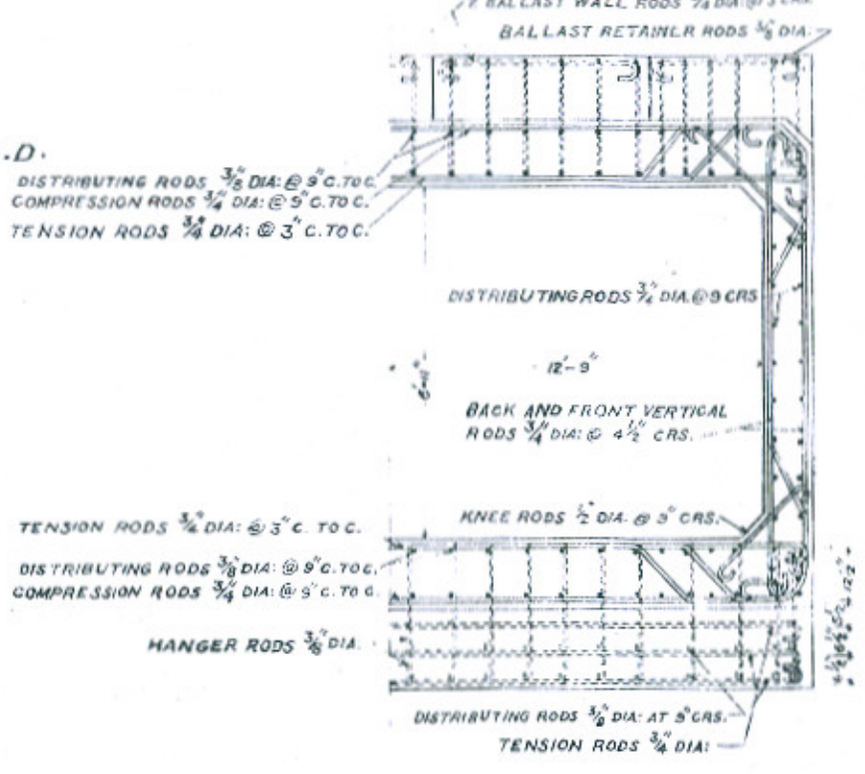


PLATE III

PAPER NO 202

GENERAL ARRANGEMENTS

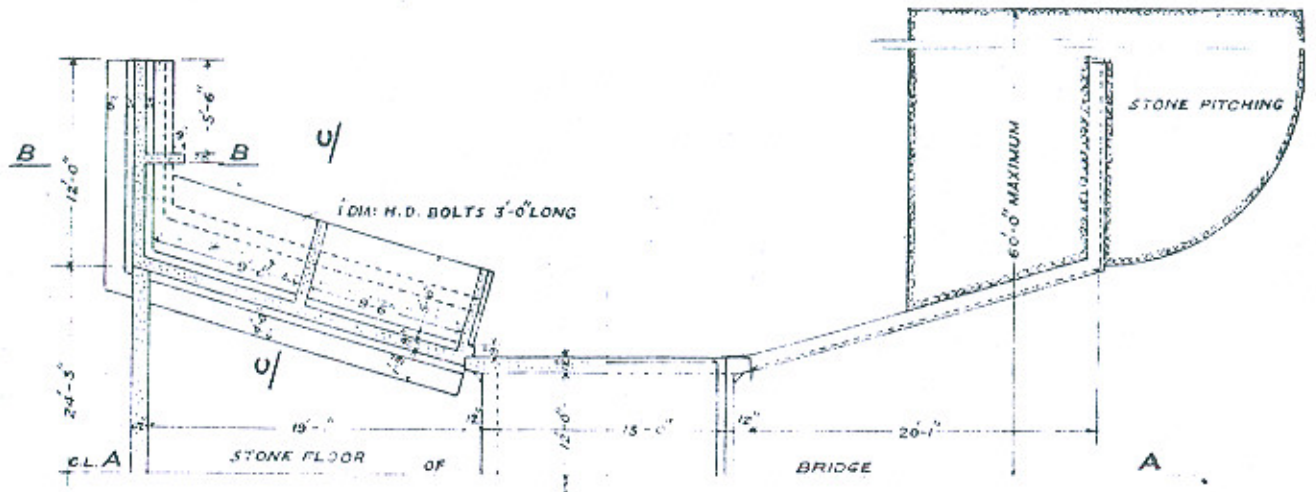
THE QUETTA CULVERT

BRIDGE NO: 363 Q ON SIBI QUETTA SECTION

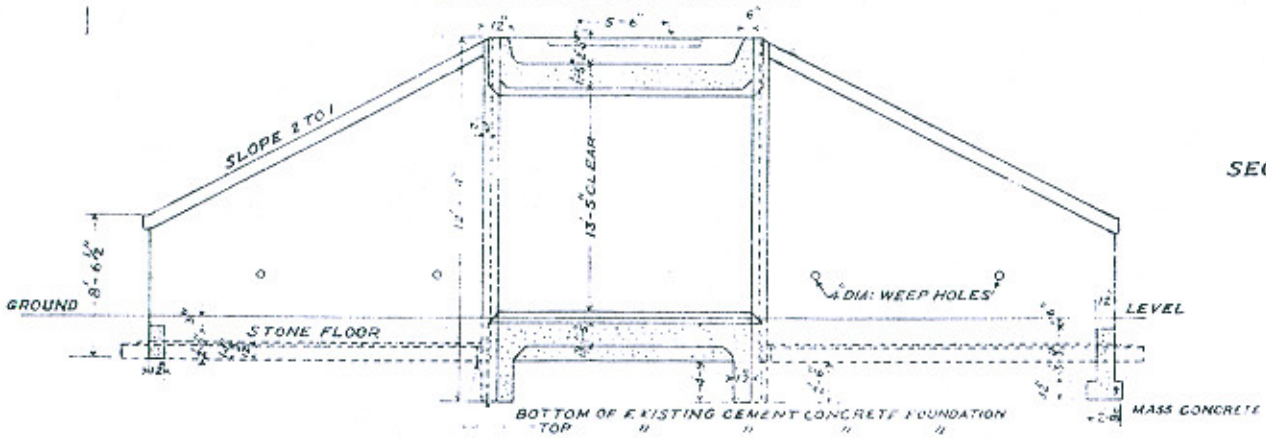
SCALE 8 FOOT = 1 INCH

QUARTER SECTIONAL PLAN

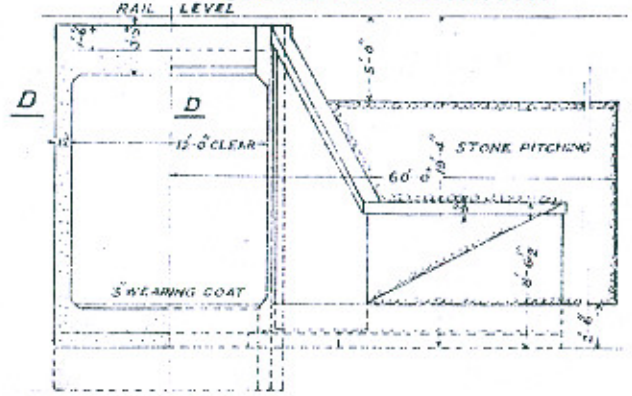
QUARTER TOP PLAN



CROSS SECTION AT A.A.

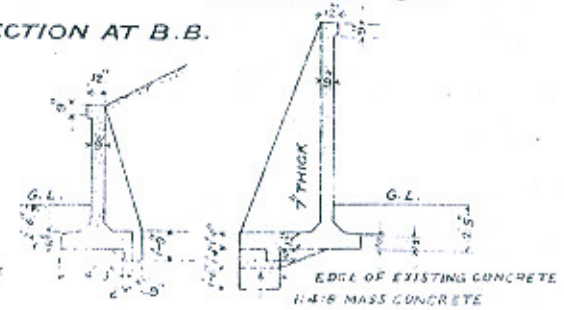


SECTIONAL ELEVATION



SECTION AT C.C.

SECTION AT B.B.

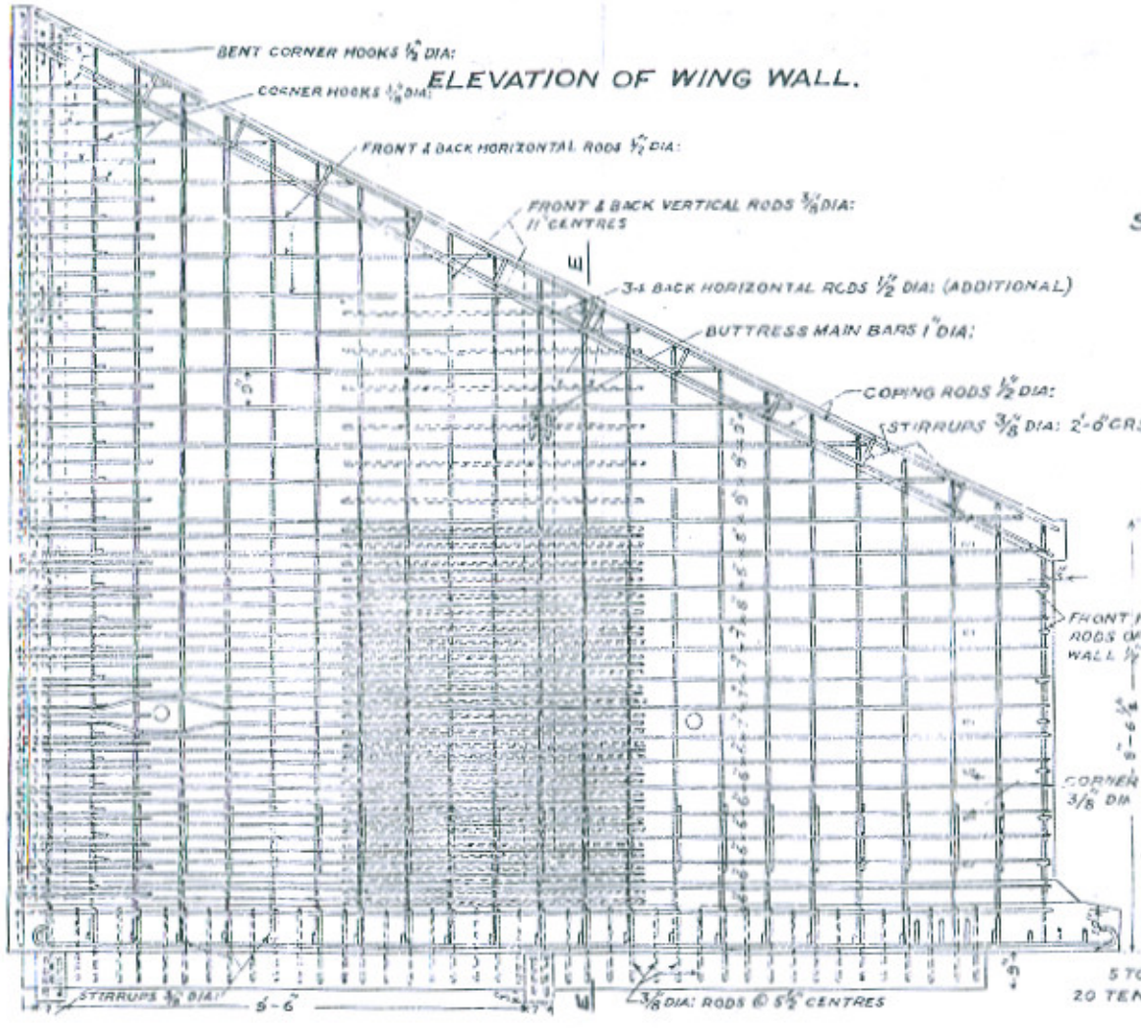


DETAILS OF REINFORCEMENT

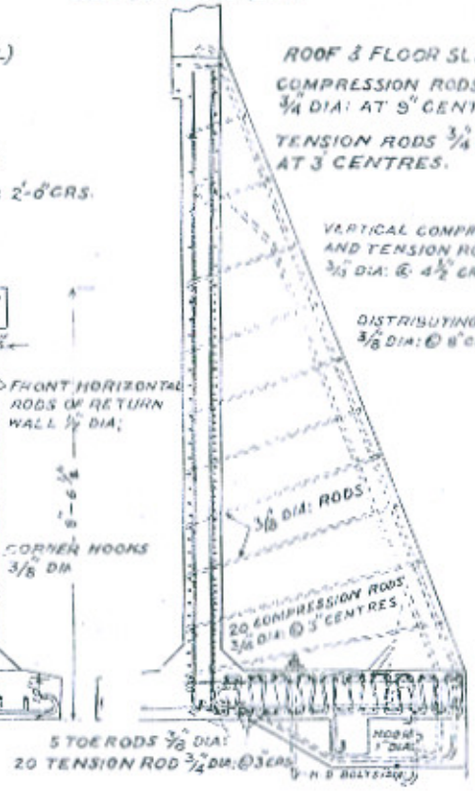
THE QUETTA CULVERT

SCALE 3/8" = 1 FOOT

ELEVATION OF WING WALL.



SECTION AT E.E.



PART SECTIONAL ELEVATION OF BOX CULVT

SHOWING ALSO BALLAST RETAINER & DROP WALL.

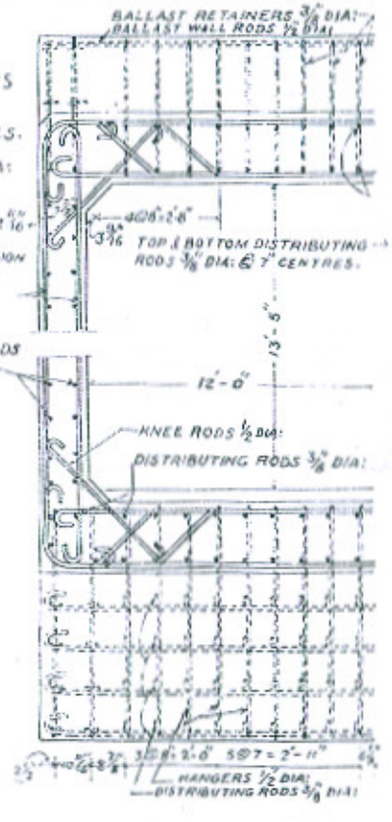


PLATE V

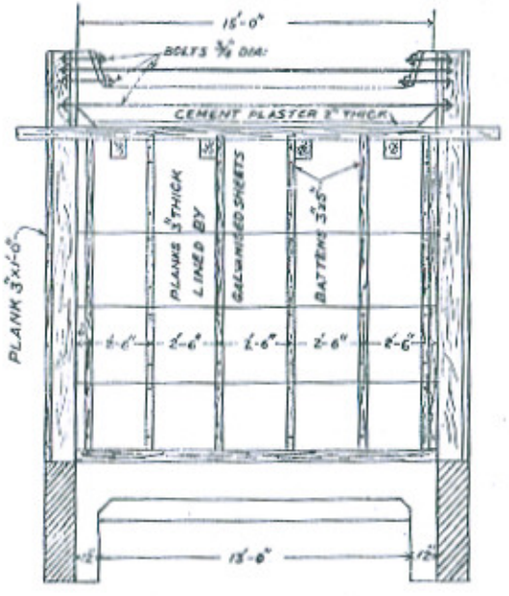
PAPER NO 202

DETAILS OF SHUTTERING

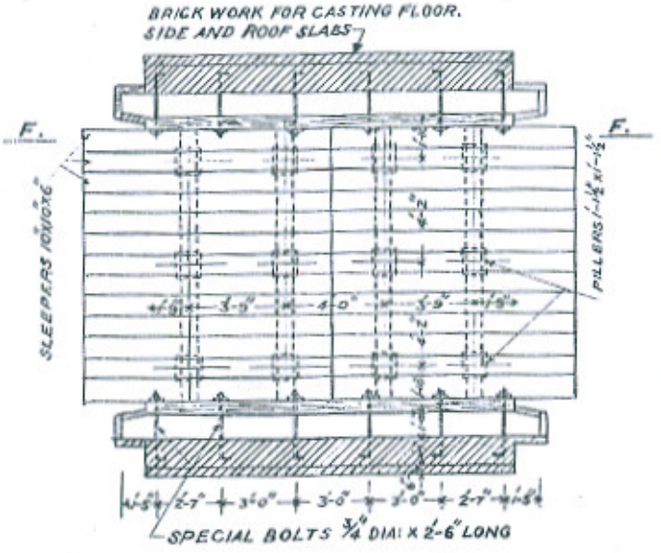
FOR THE FLOOR; SIDE & ROOF SLABS THE QUETTA CULVERT

SCALE 3/16 = 1 FOOT

CROSS SECTION AT F.F.



SECTIONAL PLAN AT D.D. (SEE PLATE III)



HALF SECTIONAL ELEVATION — HALF FRONT ELEVATION

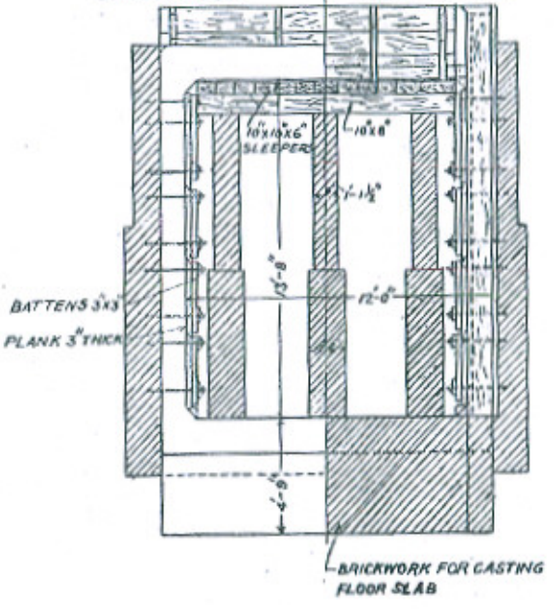


PLATE VI

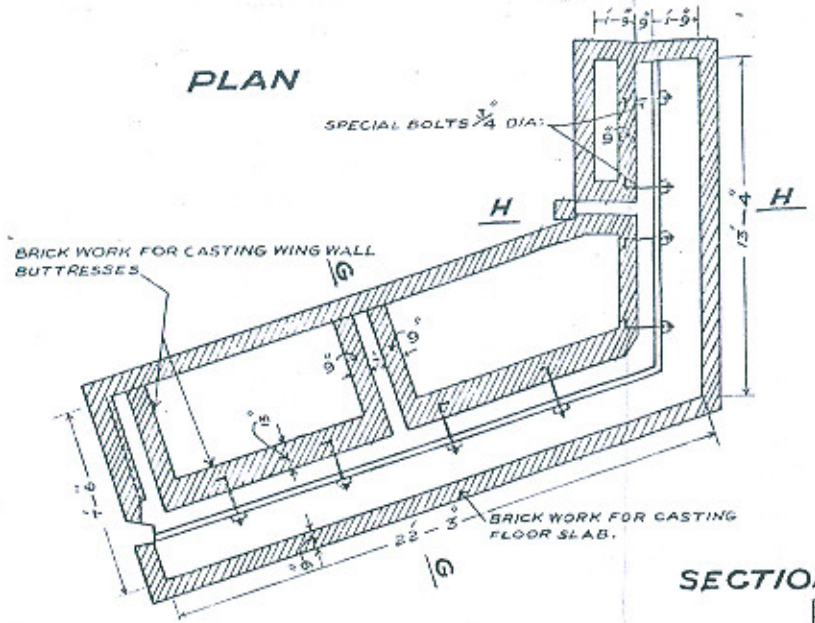
PAPER NO. 202

DETAILS OF SHUTTERING

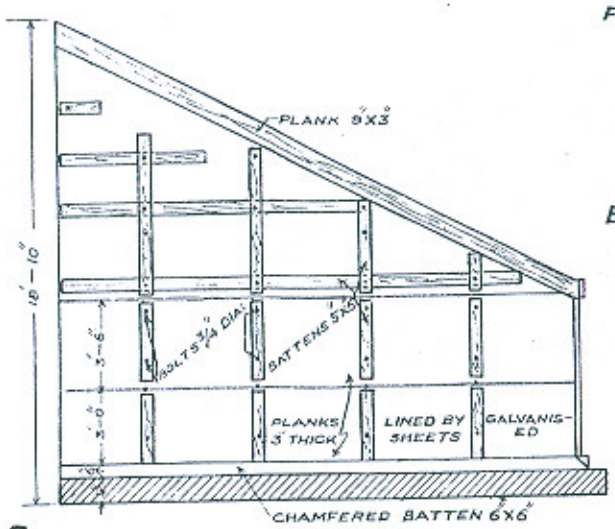
FOR THE WING WALLS OF THE QUETTA CULVERT

SCALE 3/16 = 1 FOOT

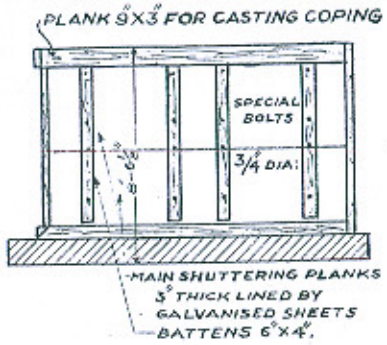
PLAN



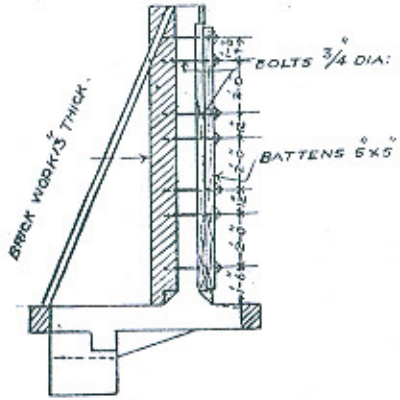
ELEVATION OF WING WALL



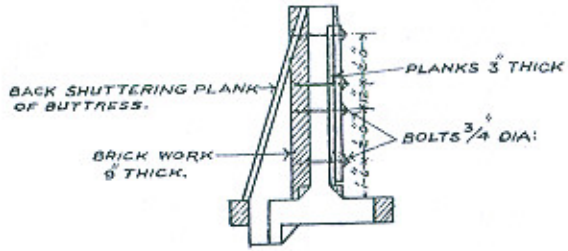
ELEVATION OF RETURN WALL



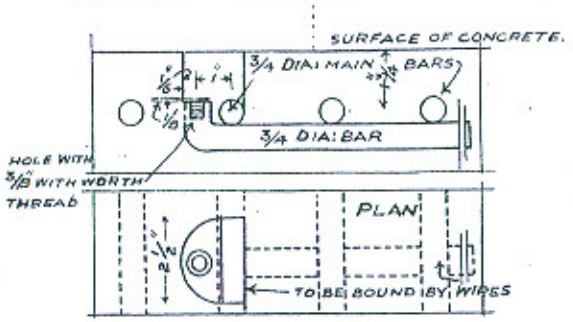
SECTION ON G.G.



SECTION ON H.H.



DETAILS OF A POCKET LEFT IN CONCRETE FOR MEASURING ACTUAL STRESSES UNDER LOAD.



DISCUSSION.

The **Author** in introducing his Paper said that Reinforced Concrete Culverts could be economically utilized for bridge work as they required no maintenance, and they could also be made earthquake proof and were eminently suitable where the carrying capacity of the soil was was very low.

The success that was attained in building the R. C. Box Culverts mentioned in the Paper was indicated by the breaking strength of concrete test cylinders cast at the time of concreting. This was entirely due to the careful controlling of concrete. Not only was the cement measured by weight but the variation in bulking which different degrees of moisture in sand cause, was completely avoided by washing and drying the sand a number of days before the concreting was started. The coarse aggregate was also in a dry condition before use. In the case of big works where it might not be possible to adopt this method, allowance had to be made from time to time for the moisture content of the sand and aggregate in computing the quantity of water required for attaining the required workability of the mix.

As a result of his experience, the Author said, he had, however, found that when washing of sand was going on simultaneously with the laying of concrete (and sand with varying degrees of moisture was bound to be used) uniformity of the mix in the concrete could only be attained either by using an apparatus recently placed on the market by Messrs. Hall & Sons, London, or by vibrating saturated sand in a vibrator for about 30 seconds. The former method automatically gave the volume of moisture required for the proper field mix, while the latter method ensured a definite percentage of moisture in sand after vibration and thereby a uniform field mix.

Mr. **H. W. Robinson** said that he would like to supplement Mr. Kumar's very interesting paper with one or two further remarks regarding the design of these culverts.

It would be noticed that both these bridges had been constructed with sliding joints between the main culverts and the wing walls. This was in accordance with usual practice on the N. W. R. of providing butt joints between the abutments and wing walls of bridges in order to allow for the possibly greater settlement of the former under the train loads.

The wing walls of the Quetta culvert being about 18 feet high it was found to be economical to design them as counterforted retaining walls with 3 counterforts, the return wall at the lower end functioning as one. In this way it was possible to reduce the thickness of the wall to 9". The Amri wing walls being much smaller, were designed as simple retaining

walls at the bottom and as beams spanning between the main culverts and the return walls at the top.

With regard to the design of the main culverts Mr. Kumar mentioned in Appendix A that formulae for the calculation of box culverts were to be found in standard text-books. As a matter of fact, calculations for these culverts were made from first principles using the general theory of three moments for continuous beams of varying moments of inertia as the vertical and horizontal sides of the culverts could be regarded as one continuous beam spanning over a series of openings. The formulae given in text-books were of course derived from this theory but the theory could be used also for special cases not covered by the formulae.

Mr. **R. R. Handa**, referring to the remarks in the second paragraph of the paper regarding high stresses used in calculations and to the remarks in para. 3, page 80, to the effect that Rapid Hardening Swastikrete or Bundi cement was used, first inquired the necessity of using Rapid Hardening cement, in place of the ordinary cement. He then said that it appeared to him that what was gained theoretically in low sections, adopted by using high stresses for steel and concrete, appeared to be counterbalanced, (if not more than counterbalanced) by the use of costly material like Rapid Hardening cement which cost about Rs. 64 per ton against Rs. 35 per ton for the ordinary cement. He requested the author to explain why ordinary cement could not serve the purpose.

He also drew the attention of the Irrigation Branch Officers to the following remarks that occurred at the conclusion of para. 5, page 80 :—

> " The country being extremely malarious, bambor oil was distributed to the labourers every night."

Referring to the remarks in the end of the first para. on page 81 that 2" cement concrete was plastered over the shuttering and that ordinary paper was pasted over the surface of the plaster, etc., he said that the use of oil was not satisfactory because unless it was washed well, it tended to start distintegration.

White washing was probably good. He said that he recommended what he had once used, *viz.*, a plaster of surkhi with a sprinkling of white lime. This was very cheap and separated very easily from the surface of the reinforced concrete. If there were no difficulties of carriage—as there were none in this case because cement had also to be carried from great distances,—surkhi could probably have been used with advantage.

Referring to para. 3, page 81, he inquired of the author the object of removing the shuttering after three days, if the slab had to be supported soon after, on masonry props.

Mr. **Kanwar Sain** said that the Paper was of special importance in view of the fact that working stresses of 750 lb. per square inch for concrete and 18,000 lb. per square inch for steel were used as against 16,000 lb. per square inch used in the Public Works Department, Punjab. The actual tests showed that in no case the strength obtained was less than assumed in the design. The use of reinforced concrete structures in the Punjab Buildings and Roads and Irrigation Departments was definitely in an elementary stage, being confined to R. C. battens and the R. C. slabs supported on R. S. Beams. Papers of the kind under discussion were bound to encourage a more free use of reinforced concrete by inspiring confidence. Reinforced concrete retaining walls in bridges must work out cheaper than masonry retaining walls and there was no reason why the reinforced concrete should not be used far more freely for this type of structure than it was used at present.

The speaker asked the author if any trouble had been felt from temperature variations. He thought that the addition of shuttering costs would have made the Paper still more useful as it was this item in reinforced concrete structures which was somewhat uncertain in cost.

Mr. **P L. Varma** said that Reinforced Concrete Box Culverts had not been used by the Public Works Department as far as was known to the speaker. Very recently a box section duct had been provided in the Legislative Council Chamber (under construction) for taking out the exhaust air from the air-conditioned rooms. A portion of the duct whose section is shown in Fig. 1,* passed immediately under the foundations and was subjected to a load of one ton per square foot and earth pressure on the sides equal to the equivalent surcharge of one ton per square foot adjoining foundations. The tunnel was designed as a frame.

Such culverts were liable to bending moments in the longitudinal direction but the speaker had not come across any method by which cross bending could be estimated and provided for when the entire area of the culvert was supported by earth which was liable to settle slightly under load. In this particular case reinforcement (5 bars, $\frac{3}{4}$" diameter) was provided for, arbitrarily both at the bottom and top to take up any longitudinal strains. Could the Author of the Paper inform the speaker as to how he provided for longitudinal bending in the culverts that he built and if he had come across any mathematical method of estimating such bending?

Did the Author notice any cracks in the culvert as a result of such conditions because in the speaker's opinion, the longitudinal reinforcement seemed to be on the small side?

* See page 89*f*.

The **Author**, in closing the discussion on his Paper, said that the figures of cost of Rapid Hardening and ordinary cements quoted by firms were likely to be misleading as the rates quoted for the ordinary cement were " f.o.r. station of despatch "and also did not include the cost of cement bags, the latter amounting to Rs. 4-6-0 for 20 bags. On the other hand the rates quoted for the Rapid Hardening cement were " f.o.r. the destination station " and also included the cost of cement bags and the protective paper covering. Further, as Rapid Hardening cement weighed 80 lb. to the cubic foot and the ordinary cement 90 lb., each bag of Rapid Hardening cement gave about $12\frac{1}{2}$ p.c. more cement by volume.

Actually on the works in question Rapid Hardening cement reached the site at Rs. 51 per ton while Ordinary cement cost Rs. 43 per ton including the cost of bags. The difference of the cost was not therefore as much as stated by Mr. Handa.

The advantages gained by the use of Rapid Hardening cement far outweighed the small additional cost. As already mentioned in the paper the Amri culvert was to be replaced as soon as possible because it was showing signs of extreme distress. In the case of the Quetta culvert, its early completion was equally essential as otherwise the concreting would have been impossible on account of extreme cold in December, in and around Quetta. The use of Rapid Hardening cement enabled the shuttering to be struck in 1/3rd to 1/4th of the time that would have been required if the ordinary cement had been used. The same shuttering material could then be re-used for the remaining portion of the work after any alterations, if necessary. Thus the additional cost on Rapid Hardening cement was compensated by the saving in the cost of the shuttering and it enabled work to be completed very much earlier.

The releasing of the shuttering after three days and then supporting the slab on props which was commented on by Mr. Handa enabled the same shuttering material to be utilized for the casting of wing walls making the necessary alterations.

In reply to Mr. Kanwar Sain the author stated that no trouble had been experienced in the structure due to temperature variations and that no cracks had appeared anywhere in the culverts.

The author regretted that the cost of shuttering had not been kept separately but drew the attention of Mr. Kanwar Sain to the useful information in this connection in Appendix V of Paper No. 204 by Mr. B. K. Kapur.

Mr. Varma had asked about the mathematical method by which the bending moment in the longitudinal direction could be determined. If the earth below the floor slab settled unequally and in an irregular

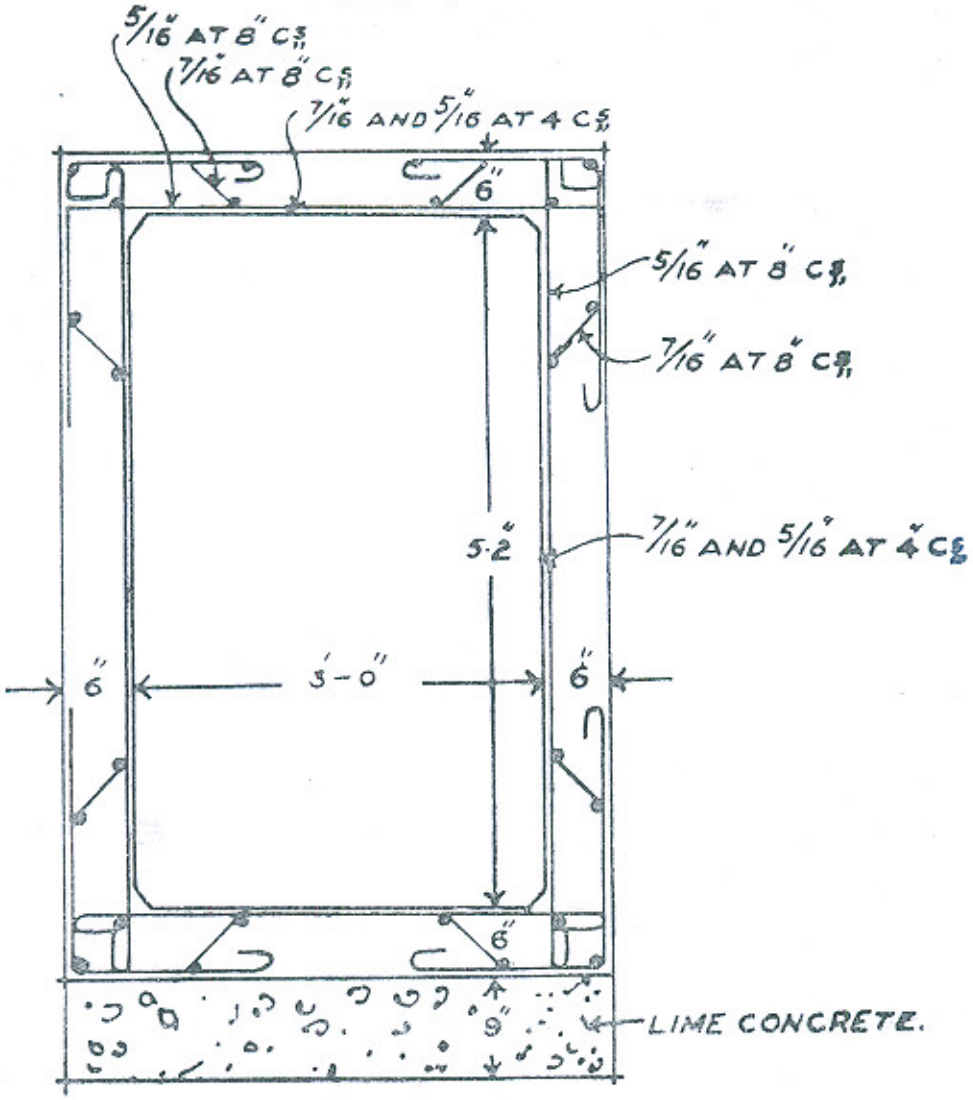
manner the whole distribution of bending moments both along and across the culvert, would be completely upset and it would not be possible to determine mathematically what bending moments in the various parts of slab would be induced.

If, however, Mr. Varma was referring to the transverse bending moments induced in R. C. slabs supported in one direction, there could be two possible conditions. If the load on the slab was a uniform one, obviously there could be no transverse bending moments provided, of course, that it could be assumed that the supports along both the abutments were absolutely level and the amount of restraint at the supports was uniform. If the slab were subjected to concentrated loads, then on account of the variation in the reactions on the supports, bending moments would be induced in the direction at right angles to the direction of these supports. Such bending moments had mathematically been determined by Pigeaud for particular forms of concentrated loads on the assumption that the slab behaved like a thin metal plate.

It would be much too cumbersome to follow such methods for ordinary design purposes. The British Code of Practice had recommended that the transverse reinforcement both top and bottom should not be less than 20 p.c. of the main tensile reinforcement.

In regard to the design of the R. C. box culverts under discussion the author informed Mr. Varma that distribution bars had been provided both at the top and bottom and that the area was more than 20 p.c. of the main tensile reinforcement even though for simplicity of calculations it had been assumed that the live load was uniformly distributed over the whole of the roof slab.

FIG 1.



SECTION OF TUNNEL
UNDER FOUNDATIONS.
SCALE = 1/2" = 1'