PAPER No. 102.

CONCRETE LINING OF THE GANG (BIKANER) CANAL.

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Preliminary.

The " Gang " Canal is being constructed from the Ferozepore Weir to irrigate an area of approximately 755,000 acres of Bikaner State land. The Main Line Canal runs through Punjab and Faridkot State Territory for a length of approximately 73 miles before it arrives at the Bikaner State border. It extends for another eleven miles beyond the border and from there is divided into main feeder channels and distributaries. With the exception of three small distributaries which will take off from the Main Line Canal below the point where it enters Bikaner State Territory there are no other distributing channels until the Main Line Tail Regulator is reached.

The main line of this canal differs from all others at present existing in the Punjab in that it is to be concrete lined throughout its whole length of 84 miles. The primary reason for this was to prevent any chance of water-logging the land through which the canal is aligned. By preventing loss by seepage from the canal, the consequent gain of a very considerable quantity of water (about 400 cusecs) for irrigation purposes has made the concrete lining proposition financially possible.

The authorised full supply discharge is 2,144 cubic feet per second and the following data has been taken in designing the channel—Kutters " N " 0·013, bed slope 0·13 per 1,000, mean velocity 4·51 feet per second. From the above, the bed width works out to 52 feet, and the depth to 8·0 feet with side slopes of 1 to 1. The critical velocity ratio is 1·43 Vo.

The side slopes are being lined up to a height of 9 feet above bed level and the concrete is carried over a short distance at the top so as to form a ledge over which the inner slope of the dowel is dressed.

The area of lining per running foot of the canal works out to approximately 80 square feet. Thus in 84 (canal) miles there are over 33½ million square feet of lining to be done.

Materials used.

The large amount of concreting materials required to cover this enormous area was a matter of importance. At Darbari in Bikaner State, situated about 17 miles S. W. of Bikaner, there are extensive *kankar* fields. This *kankar* is different to that usually found in the Punjab in that it is really what might be termed " nodular " limestone. When burnt for the manufacture of lime it slakes just like ordinary limestone.

At the special request of the Bikaner Government it was decided to use this *kankar* for the lining, the State thereby benefitting by being able to provide the chief material required for the lining work and keeping the expenditure incurred in collecting the *kankar* and the carriage of it by railway to the canal, all within the State.

The next question to be settled was whether lime or cement was to be used. It was decided that lime manufactured from the Darbari *kankar* should be taken ; as cement would have been considerably more expensive and it was doubtful whether the local cement factories would be able to supply a sufficient quantity in addition to what they had undertaken to supply to other works in the Sutlej Valley Canals Scheme and elsewhere.

Lastly there was the question of sand. Between Ferozepore and the tail of the Main Line Canal there was no suitable grade of sand to be found. The sand *tibbas* all contained far too fine a material and the expense of railing in a good quality from places like Pathankot put sand from the higher reaches of the Punjab rivers out of the question. The use of *soorkhie* was proposed, but here again it was considered that it would probably be too fine to be really suitable. Eventually it was decided to crush up Darbari *kankar* into grit. Thus it will be seen that all the ingredients required for the concrete lining are derived from the same source, namely the Darbari *kankar*.

Preliminary Experiments.

As the intention of this paper is to describe the procedure followed for concrete lining the canal with its contingent works, it is not proposed to give the details of all the preliminary investigations that were made. It is sufficient to state here that several practical experiments were carried out to ascertain the following :—

(*a*) The percentage of voids in the *kankar* ballast and " grit."
(*b*) The thickness at which the concrete should be laid to give as watertight a lining as possible compatible with expenditure.
(*c*) The ratios for the different ingredients.
(*d*) The density of the concrete.

As a result it was decided that the concrete lining should be composed of a 1 : 1 : 6 mixture of lime, " grit " and ballast and that the thickness of it should be six inches.

Sub-heads of the work—

The concrete lining may be divided up into the following sub-heads :—

(1) Collection of *kankar* at Darbari including loading of it into wagons and railing it to the canal face.
(2) Manufacture of the concrete.
(3) Consolidating the concrete.
(4) Expansion and contraction joints.

Taking these in turn—

(1) Collection of kankar, etc.

The *kankar* at Darbari lies in beds of varying thicknesses and is generally found on the surface, though in places it is covered with a layer of 6" to 1 foot of earth. After making trial pits all over the particular area,

a plot of approximately one square mile was selected where a sufficient quantity of *kankar* (amounting to about $2\frac{1}{2}$ crores of cubic feet) was available. Over this area a net work, totalling to about 8 miles in all, of 2·0′ gauge tramway track has been layed to enable the *kankar* to be collected and brought down to the site where it is loaded into metre gauge railway wagons.

The Bikaner State Railway Branch Line from Lallgarh Junction to Kolayat runs through Darbari and just as it passes the *kankar* fields it enters a cutting of from 16 to 20 feet in depth with almost vertical sides. Advantage of this cutting has been taken to enable the railway wagons to be filled with *kankar* by gravity, and, for this purpose, a series of collecting bins (now known as " Bin-chutes ") have been constructed along the edge of the cutting.

These " bin-chutes " have been specially designed for the purpose. They are of such a size that the contents of four of them completely fill one of the 160 specially purchased metre gauge railway bogie wagons (known as " canal bogie wagons or C. B. Ws."). They are so spaced that when a full rake of C. B. Ws. is placed under them, the filing of those composing half a rake can be carried out simultaneously. The spacing was intended to be such that the whole rake could be filled at one time, but, owing to inequality in the amount of stretch and compression in the couplings of the C. B. Ws. the distance covered by a whole train varies to such an extent that it is only possible to load up half a rake at a time. Each rake can consist of as many as 28 C. B. Ws., each wagon containing 590 cubic feet or 600 maunds of *kankar*. The loading up of a whole rake can be performed in under half an hour. It may be mentioned here that the cost of the 160 bin-chutes, if spread over the whole quantity of *kankar* that has to be railed to the canal, works out at five annas per hundred cubic feet. The contractor is given Re. 1 per thousand cubic feet for supplying the necessary labour for filling and dressing off the *kankar* in the C. B. Ws., thus the cost per hundred cubic feet for loading comes to 6·6 annas as compared with a normal rate for loading up by hand of from Rs. 2 to Rs. 3 per hundred cubic feet. From this it can be easily calculated what a tremendous saving has been effected by making use of the bin-chutes for this purpose. But a more important saving still has been effected, namely that of time and labour. With the bin-chutes it is possible to despatch two trains per day containing anything up to 16,000 cubic feet of *kankar* each. Without this means of loading it would have been found difficult to despatch half this quantity.

The *kankar*, before being loaded into the 2·0 feet gauge tipping wagons to be taken to the bin-chutes, is passed over a ten meshes to the inch sieving screen in order to rid it of superfluous dust. By doing this it is estimated that there is a saving of carriage by railway of an extra 10 per cent. of the *kankar* carried. This, for the full quantity that has to be railed will amount to over 4,200 full C. B. W. loads.

The arrangements for the railing of the *kankar* up to the canal face are in the hands of the Bikaner State Railway Authorities. The distance

from Darbari to Sriganganagar, which is the station at which the Bikaner Canal Construction Railway joins the Bikaner State Railway system, is 199 miles. The Canal Construction Railway runs from Sriganganagar to Khai (within four miles of Ferozepore) and is 89 miles long. Thus the average distance to be travelled by each *kankar* train is 243 miles for a single journey or approximately 500 miles per round trip. When it is considered that two trains loaded with *kankar* are scheduled to perform this trip every day, and will continue to do so till the mid-summer of 1927, it can be realised what a considerable amount of extra work is being undertaken by the Bikaner State Railway Officials in helping towards the construction of the Gang Canal.

Two trains are normally despatched from Darbari each day—one at about 8-00 hours and the other at 15-00 hours and are timed to arrive at the Canal face during the morning of the next day, thus ensuring both the loading up at Darbari and the unloading at the canal face being carried out in day light.

2. Manufacture of the concrete.

After a considerable amount of discussion and consideration it was decided that the procedure at the canal face should be as follows :—

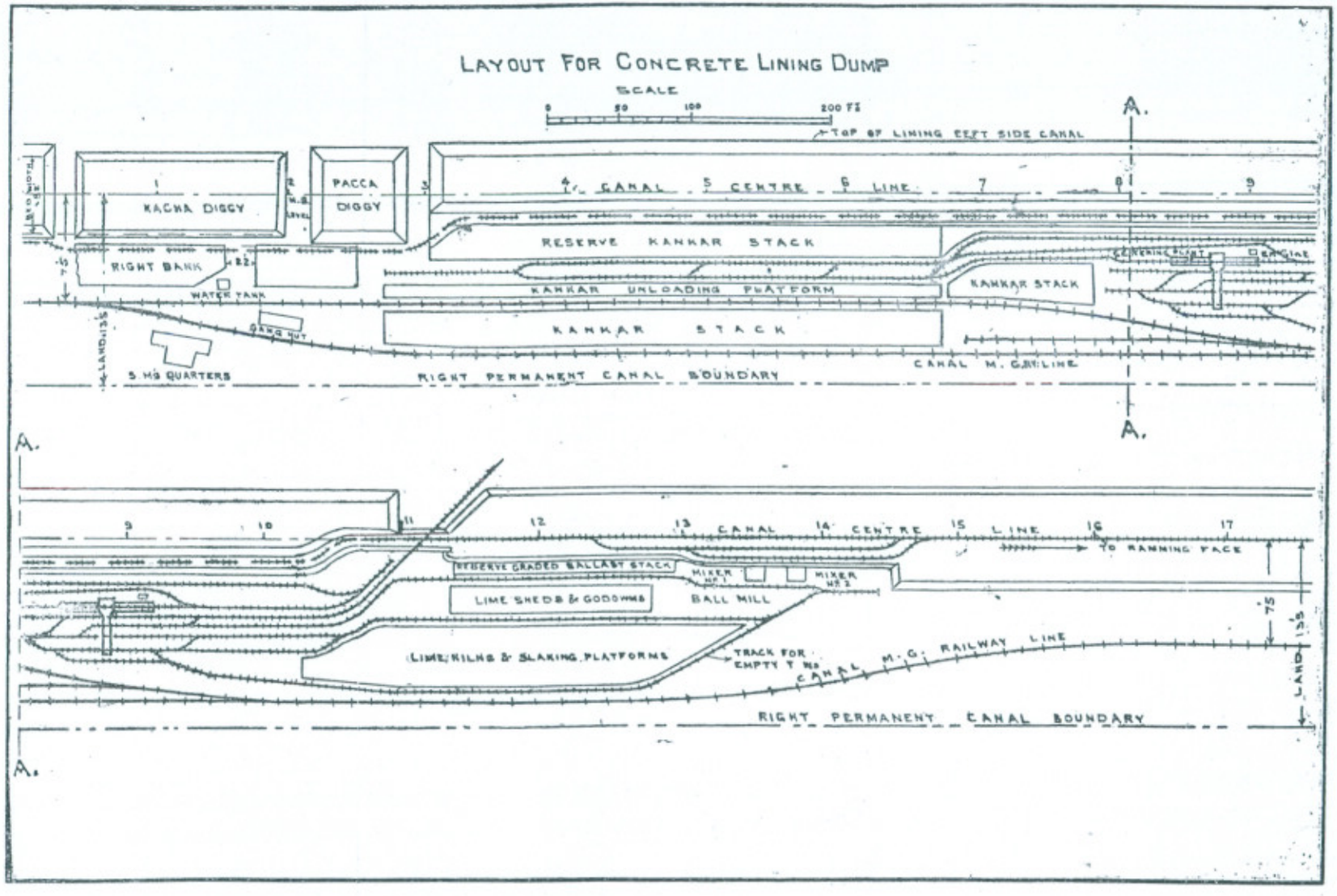
The whole length of canal was to be divided up into sections of about five miles long. In the centre of each section a " lining dump " would be erected where the concrete would be manufactured. The mixed concrete would then be railed out along the bed of the canal to the " ramming face ". Thus the furthest distance the mixed concrete would have to be railed would be about two-and-a-half miles before it was placed in position in the bed and side slopes of the canal for being consolidated.

There would be four such dumps in operation at one time.

A considerable amount of trouble was taken in designing the lay-out of the dump. What was aimed at was to arrange the machinery, lime kilns and godowns, stocks of grit, etc., in such a way as to enable the whole process of manufacture to be carried out in as limited a space as possible and to prevent any excessive carriage or handling of the materials.

Finally a lay-out which is briefly as follows (and a small scale plan of of which is attached), was arrived at :—

The *kankar* is brought in from Darbari and is unloaded at one end of the dump. From there it is loaded into 2·0 feet gauge tipping wagons and is taken to a specially designed screening plant. This plant has connected with it a creeper chain ramp. A catch on the chain engages with the front axle of the tipping wagon and draws it up to a level platform at the top of the ramp. The tipping wagon is brought to rest here and its contents are discharged on to an inclined tray from where they are fed into a rotating screen. After being emptied the tipping wagon is run down a ramp on the opposite side to the creeper chain ramp, control of it being maintained by means of a wire rope attached to a small hand operated brake drum. The screen has four hoppers fixed underneath


LAYOUT FOR CONCRETE LINING DUMP
SCALE
0 50 100 200 FT
TOP OF LINING LEFT SIDE CANAL
KACHA DIGGY
PACCA DIGGY
RESERVE KANKAR STACK
KANKAR UNLOADING PLATFORM
KANKAR STACK
KANKAR STACK
RIGHT BANK
WATER TANK
GANG HUT
S HQ QUARTERS
RIGHT PERMANENT CANAL BOUNDARY
CANAL M. G. RAILWAY LINE
CANAL CENTRE LINE
RESERVE GRADED BALLAST STACK
LIME SHEDS & GODOWNS
MIXER NO 1
MIXER NO 2
BALL MILL
LIME KILNS & SLAKING PLATFORMS
TRACK FOR EMPTY T NOS
TO RUNNING FACE
A.

it. The first hopper receives the dust which is obtained out of the *kankar*. The second receives clean material ranging in size from fine grit up to ballast of a size that will pass in any direction through a $1\frac{1}{2}''$ ring. The third hopper receives practically nothing but ballast of a uniform size such that it will just pass through a $1\frac{1}{2}''$ ring, and the fourth receives any *kankar* that is so big that it will not pass through the $1\frac{1}{2}''$ ring. A series of tram lines runs under the hoppers. The " oversize " *kankar* from the fourth hopper and the contents of the third are railed off in tipping wagons to lime kilns and Ball mills where they are converted into lime and "grit." The lime kilns and Ball mills are situated between the screener and the concrete mixers. Arrangements are made near by for storage of lime and " grit " so as to enable the tipping wagons containing the mixed-size ballast from the second hopper of the screener to receive the correct quantity of each ingredient as it travels to the concrete-mixers. The tipping wagons from under the second hopper has the quantity of ballast that is filled into it, correctly measured and, as a precaution, this is checked by a man with a gauge before the tipping wagon is permitted to pass on to the lime godown. The lime and grit are measured out in boxes of the correct capacity and as each tipping wagon containing the ballast passes by, these boxes are emptied into it. This ensures that each wagon load contains the correct proportions and quantity of ballast, lime and sand for each batch of the concrete mixer.

The concrete mixer is so placed that, after being mixed, the concrete can be discharged into a tipping wagon standing below it in the bed of the canal. Here train-loads of tipping wagons (generally 25 per train) are marshalled and are then taken off along the bed of the canal to the ramming face.

All the machinery at the dump is operated by steam. The screener with its creeper chain is driven by a 4-NHP semi-portable engine. The creeper chain does one complete revolution and the screen revolves at 16 revolutions per minute.

The Ball mills are operated by a 5 NHP semi-portable engine and each manufactures from 600 to 650 cubic feet of grit per day. The 5 NHP engine is slightly under-powered for its task and lately, when a second set has had to be purchased, a 6 NHP engine has been obtained.

The mixers are steam driven and with their boiler, engine and mixing drum, etc., each forms a complete unit. The size of the mixing drum is such that 21 cubic feet of concrete can be mixed in one batch. This is a convenient size for use when the tipping wagons used for railing the mixed concrete to the ramming face are of one cubic yard capacity as the concrete fills the tipping wagon to about 6 inches of the top and thus there is no loss on the way down as would be the case if the wagons were full to the brim.

The lime kilns used are of the usual cylindrical continuous burning type, coned at the base and with two openings at the bottom from which the burned *kankar* can be withdrawn. The original ones constructed were 12 feet high and 9 feet diameter but lately a bigger type 22 feet high

and 10 feet diameter have been constructed and these give a better outturn. From 100 cubic feet of raw *kankar* the small type of kiln would produce an average of 115 cubic feet of screened lime while the bigger type produces 135 cubic feet.

A drawing of a pair of the larger type of kilns is reproduced.

The *kankar* is burnt with railway refuse ashes ; 32 cubic feet being required to burn 100 cubic feet of raw *kankar* in the small type and 28 in the large type kilns.

At each dump there are 5 miles of 2·0 feet gauge tramway track and 150 tipping wagons. The haulage of all the wagons in the dump area is done by man-power whilst the train loads of mixed concrete are propelled by light locos of the latest approved type.

For small repairs to machinery there is a smithy's shop established at each dump but all heavy repairs are carried out at the proper workshops which are established at Orki and Khai.

3. Consolidating the concrete.

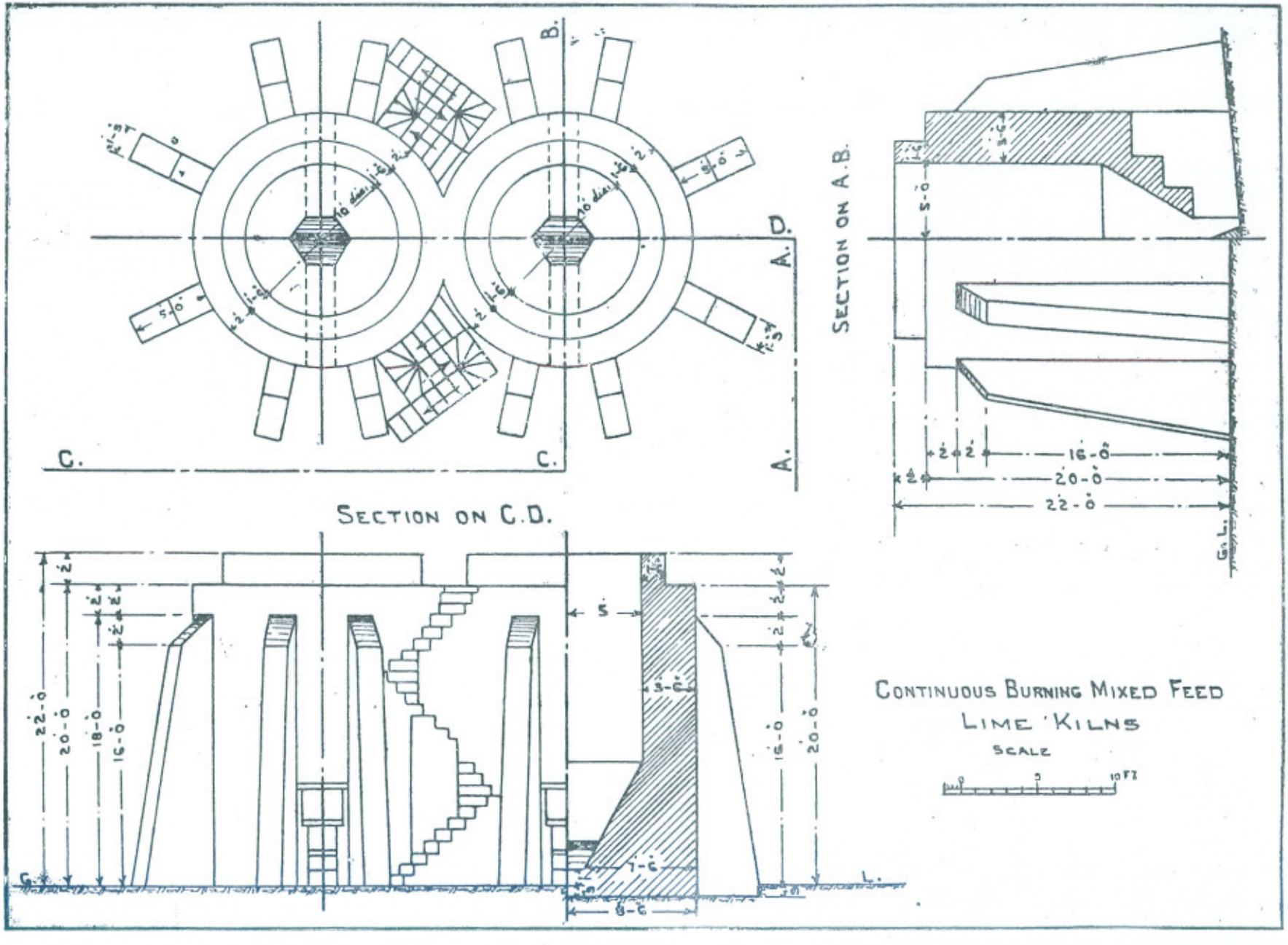
The excavation of the canal having been done several months before the concreting is taken in hand, it was decided to leave the last six inches of the bed and side slopes to be dug at the last moment so as to give a clean and true-to-level surface on which the concrete lining was to be laid.

This final dressing of the bed and side slopes prior to concreting is carried out by a special gang of labour and care has to be taken to see that it is kept sufficiently well ahead of the concrete laying work so as not to impede it. At the same time it is important not to allow the final dressing, particularly of the side slopes, to be done too far in advance of the concreting work as a downpour of rain would probably necessitate redressing, owing to ruts being formed thereby in the side slopes and heaps of washed down earth accumulating along the toe of the side slopes in the bed.

On arrival of a train at the ramming face, the concrete is turned out and is then man-handled into position and is roughly dressed off to the correct thickness for consolidating down to an average six inch thickness. It is found that the thickness required to be layed for this purpose is about $6\frac{3}{4}$".

The consolidation of the concrete is performed by means of pneumatic rammers. At each ramming face there are three portable air compressors each of which will deliver 160 cubic feet of air piston displacement per minute at a pressure of 80 lbs. per square inch. Each compressor is capable of operating up to 7 rammers comfortably and if necessary as many as 10 rammers can be attached, but then the movement of the butts is liable to become somewhat sluggish.

It has been ascertained that each pneumatic rammer when working properly will consolidate as much concrete as it would normally take


B.
D.
A.
A.
C.
C.
10' diam.
20' diam.
SECTION ON A.B.
5'-0
16'-0
20'-0
22'-0
G.L.
SECTION ON C.D.
22'-0
20'-0
18'-0
16'-0
5'
3'-0
16'-0
20'-0
7'-0
8'-0
G.L.
L.
CONTINUOUS BURNING MIXED FEED
LIME KILNS
SCALE
0
5
10 FT

6 ordinary hand rammers to do. Thus with say 20 pneumatic rammers at work at a ramming face as much concrete can be consolidated as would be done by 120 ordinary ones. Hand ramming had to be ruled out firstly, because the concrete to be consolidated was in too constricted an area and secondly, the ramming of the concrete on the side slopes would have been, to say the least, a most difficult and tedious business.

By using the pneumatic rammers, there is firstly a big saving in time and labour ; secondly, the ramming of the concrete on the side slopes is only very slightly more difficult than that on the bed ; thirdly, there are only a comparatively few men on the spot to walk over the unrammed concrete, thus enabling it to remain much cleaner than would otherwise be the case.

The labour have taken very kindly to the new mode of ramming and no difficulty is found in obtaining men to do the job. About half as many men again as there are rammers have to be employed so as to enable each man to get a short rest every now and then. It was anticipated at first that this class of work would be unpopular with the labour on account of the vibration that is caused by the rapid movement of the rammer butt, but fortunately this has not been found to be the case.

The men holding the rammers are trained to work up and down the concrete to be consolidated in the same way as is done with a gang of men using the ordinary hand rammer. Owing to the rapid movement of the butts there is a considerable amount of vibration set up in the concrete, which tends to shake it into position and drive out the air far better than could ever be done with the old fashioned rammer. Thus it is claimed that concrete consolidated in this fashion must be denser than that rammed in the ordinary way.

No extra water is allowed to be poured on the concrete until it has all been thoroughly consolidated. A little water is then sprinkled over it before a final ramming is done so as to level off any unevenness, and to give it a smooth finished off surface.

The air compressors are all driven by 4 cylinder internal combustion engines which require petrol for starting them up after which they are run on kerosine oil. It has been ascertained that one gallon of ordinary quality kerosine oil is required to consolidate 136 square feet of lining.

A normal day's output at the ramming face is now about 130 lineal feet of the canal. This is equivalent to 10,400 square feet, or 5,200 cubic feet of concrete.

As much as 168 lineal feet of the canal have been lined a day from one lining dump.

An attempt is now being made to so improve the different phases of the work as to enable 150 feet to become an average length to be covered each day from each dump.

4. Expansion and Contraction Joints.

At the commencement of operations it was taken for granted that expansion and contraction joints in the concrete lining would be necessary and the form these were to take was considered and discussed most carefully. It was realised that the most satisfactory material for sealing the joints would be some form of bitumen and consequently the cost would be appreciable. Hence the width, as well as the number or length of the joints had to be kept as small as possible.

Different forms for the joints were made and tried and the first type that appeared to be at all suitable was a " V " shaped wood form about $\frac{1}{4}$" thick at the base and 1" thick at the top, covered with G. I. sheeting. This form gave a fairly clean open " V " running from the surface to the bottom of the concrete slab. At a later date this type of form was superceded by a " Y " form (detail attached). It has been found to be just as satisfactory as the " V " type from the point of view of being able to withdraw it out of the consolidated concrete and has the advantage that the space left to be sealed is less than half that obtained from the original " V " type of form.

Spacing of Joints.

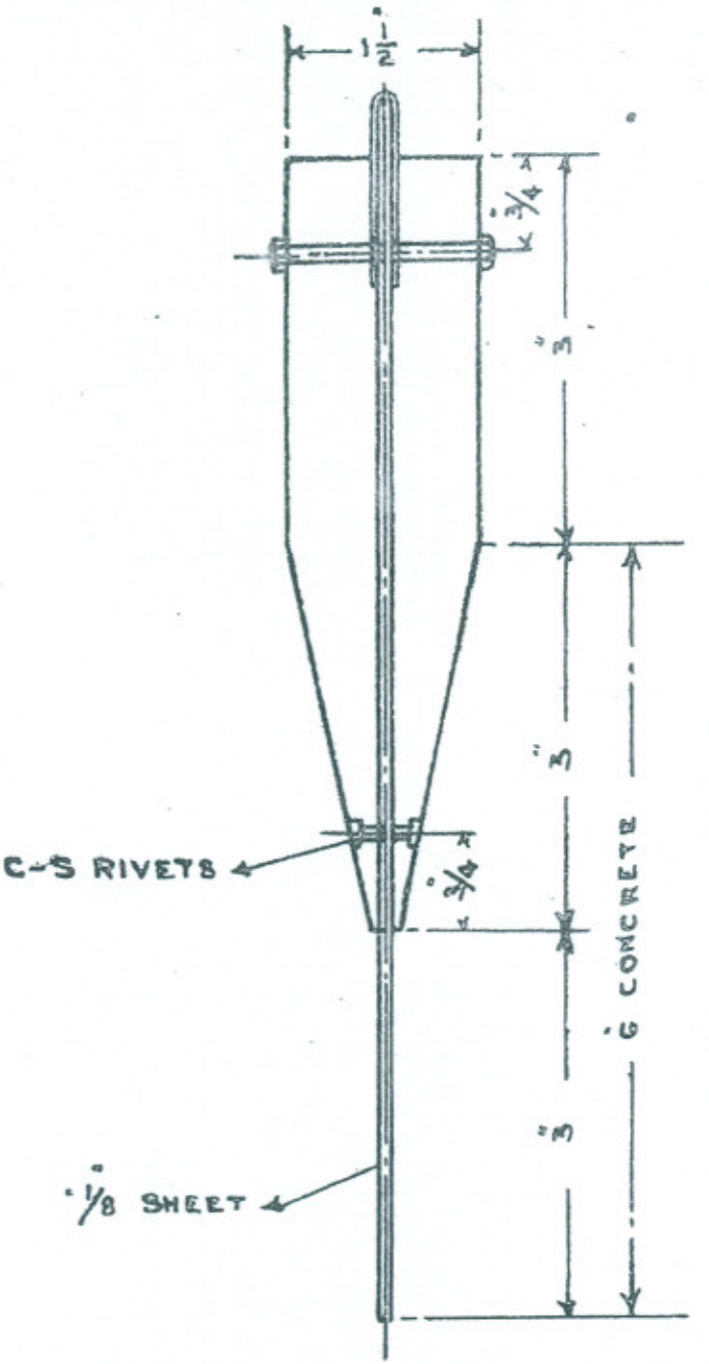
Taking into consideration the cost of both making the joints and of filling them with bitumen later on, it was realised that the spacing of them was a matter that demanded considerable care. The class of work was entirely new and there was no past experience that could be used as a guide. It was useless attempting to compare the 6" thick *lime* concrete with the 1" to 2" thick *cement* concrete flooring that is usually done in bungalows, etc., as the class of work was entirely different both as regards (1) the ingredients of the concrete and the thickness and (2) the conditions the concrete lining would have to contend with.

The first arrangement decided upon was to try spacing the joints as follows :—

In the canal bed two longitudinals to run parallel with, and at a distance of 4 feet from the toe of the side slopes, main cross joints to be spaced 44 feet apart and to run right across from the top of one side slope to the top of the other. In addition to these, an extra joint to be made in each side slope midway between the main cross joints and to connect up with the side longitudinal joints. In this way the bed was divided up into slabs of 44′ by 44′, with side slabs 22′ by 4′ wide connected to which were the side slope slabs of about 13′ width by 22′ long. Thus, in a length of 88 feet of the canal there were two centre slabs of 44′ by 44′ and on each side of these there were 4 slabs of 22′ long by about 17′ wide, or ten slabs in all for an area of approximately 7,040 square feet. The total length of joints for this area amounted to 404 feet which is equivalent to about 5·7 lineal feet per 100 square feet of lining or to approximately 4·6 lineal feet of joints per running foot of the canal.

SKETCH OF "Y" JOINT IN SECTION

SCALE HALF FULL SIZE



After some little while, when it was seen that no appreciable cracks in the concrete were visible, the making of the mid-way joints in the side slopes was discontinued and only the two main longitudinal joints with the main cross joints were made.

During the winter of 1924-25 the concrete that had been layed before and during the summer months was inspected regularly to see whether any cracks had appeared. In the bed slabs a few cracks showed in the reaches that were done first of all but these only appeared to be " hair " cracks on the surface and did not penetrate far into the concrete. After the staff and labour employed on the work had got accustomed to what had to be done, the quality improved considerably and no further cracking was visible in any of the bed slabs. In the side slopes more serious cracks were noticed, but these, generally speaking, are all situated in the lining layed at the commencement of operations. In the work done since October or November 1924, practically no cracks have appeared either in the bed or side slopes.

In the side slopes the cracks that have appeared mostly run in the same direction as the slope and only appear to extend from the top to where the " made " earth of the bank joins the natural surface. This seems to indicate that the cracks on the side slopes are not so much due to contraction of the concrete as to subsidence or other movement of the " made " earth behind the concrete lining.

The cracks in the bed slabs referred to above generally run longitudinally to the canal, but there are a few running in other directions. Some of these have appeared quite close to and running parallel with the cross joints where one would not expect them if the insertion of joints is to serve any useful purpose.

After frequent observation and discussions on the matter the conclusion was come to that owing to the peculiar nature of the concrete, it might be possible to do away with joints to take up expansion or contraction in the concrete lining. The reasons that led up to this were briefly as follows :—

(1) The relatively low tensile strength of the lime being used and its slow setting properties. (It is known that the lime is very slow setting and that it takes about 3 months to reach a tensile strength of about 80 lbs. per square inch). It is contended that the relatively slow rate of strengthening of the lime would tend to relieve a number of internal stresses set up during its first three months, and thus to a great extent prevent any severe fracture or cleavage. A three months' period covers a considerable variation in temperature whatever time of the year it occurs. For instance, during any three months in the winter, hot days with quite cold nights are experienced, and in summer time, after the grilling heat comes a downpour of rain which may cause the temperature to drop very considerably and suddenly. It would appear then, that the concrete in its early stages of setting will accom-

modate itself to the local conditions while it is in what may be termed a " plastic " state. It is probable that it does not reach its maximum strength for a very much longer period than 3 months, in fact, it is reasonable to suppose that it will continue to strengthen year by year.

(2) From observation of the work already done, which has stood both hot and cold weather seasons, and excepting for the " early stage " work, the concrete has not shewn any signs of expanding or contracting.

(3) The friction set up between the earth and the concrete. This, it is contended, is sufficient to overcome any stresses near the bottom of the concrete that are set up by variation of temperature. Since it is not feasible to divide up the concrete into small slabs like a chess board (on account of the cost of the joints) and since it has been ascertained that, generally speaking, the large 44′ by 44′ slabs do not crack from the effects of variation in temperature, it is reasonable to assume that still larger slabs could be made without fear of disaster.

(4) The relatively low heat conducting properties of the 6″ thick concrete. This means that any stresses set up in the concrete by variation in temperature must all be taken up internally and will not cause a general movement of the concrete as a whole. Thus, unless the slabs can be made so small as to reduce such stresses to a minimum (and this is not possible on account of the cost), expansion or contraction joints will serve no useful purpose.

(5) Finally, it is considered that the thickness and weight of the concrete, together with its peculiar nature (as compared with cement concrete) will make it safe from " bulging " due to expansion stresses. This has been borne out by its behaviour already, since there are no signs of any expansion strains.

The conclusions drawn, then, are that the joints, unless spaced so close together that the cost would make them prohibitive, are useless so far as prevention of cracking of the concrete due to contraction is concerned and that they are not required to overcome expansion. Spaced at reasonable distances apart, they will, however serve a useful purpose by localising any fractures in the concrete that might occur from other causes. This would be the case, particularly in the side slopes where any subsidence or other movement of the " made " earth would be liable to cause a fracture in the lining.

Following up the conclusions enumerated above, it was decided to put down two long reaches of lining without making any joints at all. These lengths were layed in April and May 1925. They have already been subjected to the rigours of a hot weather season which, as it happens,

were particularly severe owing to the intense heat of June and the early part of July having been followed by very heavy rainfall towards the end of July when, within a few minutes of being bone dry and hot, the concrete in the bed was submerged under 6" and more of water. This flowed off and dried out in time and the concrete was then subjected to more fierce heat. In addition to this one particularly heavy downpour, there were frequent showers of varying intensities followed almost immediately by bright sunshine which must have caused sudden cooling and heating up again of the concrete. In the upper reach no cracks or any sign of expansion stresses were observed at all, whilst in the lower reach, which was so situated that it received the full brunt of the downpour of July 29th, a few minor surface cracks appeared, similar to those observed in reaches where joints were left and which have been referred to already above.

In addition to these two reaches, two other 1,000′ reaches, adjoining them were lined with the two longitudinal joints only and without any cross joints. These reaches were also layed in April and May 1925 and they show no signs of any expansion or contraction stresses affecting the concrete.

Another short reach of about 250 feet long was laid in January 1925 without any joints at all. This was done in order to make a reservoir for water required for one of the dumps. Water was filled into the reservoir in April, and it has not been empty since, so the bed has not been inspected. But it holds water very satisfactorily and another interesting fact about it is as follows :—

The F. S. L. in the reservoir is about 5′ above the bed and coincides approximately with N. S. level. The concrete lining of the side slopes has been carried up to the full height of 9′ above the bed and, so far, there is not a sign of any crack at all in the concreted side slopes. All through the hot weather the temperature of the water in the reservoir was in the neighbourhood of 80° whilst the sun temperature on the exposed portion of the side slopes would have been anything from 160° to 180°, and yet there has been no sign of cracking in the side slope lining. This is considered to be fairly conclusive evidence that the concrete is not affected by variation of temperature. It is still more satisfactory when it is remembered that the level where the natural surface and the " made " earth join is probably the weakest point in the concrete lining.

The conclusions drawn from the above were that the longitudinal joints should be abolished and that cross joints should be made at the end of a half or full day's work and at such places as bridges (where cement concrete is to be used in the bridge flume).

The question of the substance with which the joints are to be sealed is still under decision and is to be settled after watching the behaviour of the concrete during the present winter months. If it is found that the cold temperatures have no deleterious effect on the long lengths of concrete lining that have been constructed without any joints at all, it will be safe to simply grout up the joints with lime mortar. Otherwise bitumen will have to be used.

Photographs.

A series of photographs illustrating the machinery, lime kilns, etc., in use are reproduced.

Cost.

Appendix I gives the detail of cost, as estimated, of concrete lining 1 (canal) mile of the canal. It has to be remembered that the figures given therein represent the cost of actual lining work only, and that in addition to these, in order to arrive at the total cost of the work, there are the cost of preparing the dumps, erection of the machinery and depreciation of the plant to be taken into consideration. This has been given in Appendix II.

Conclusion.

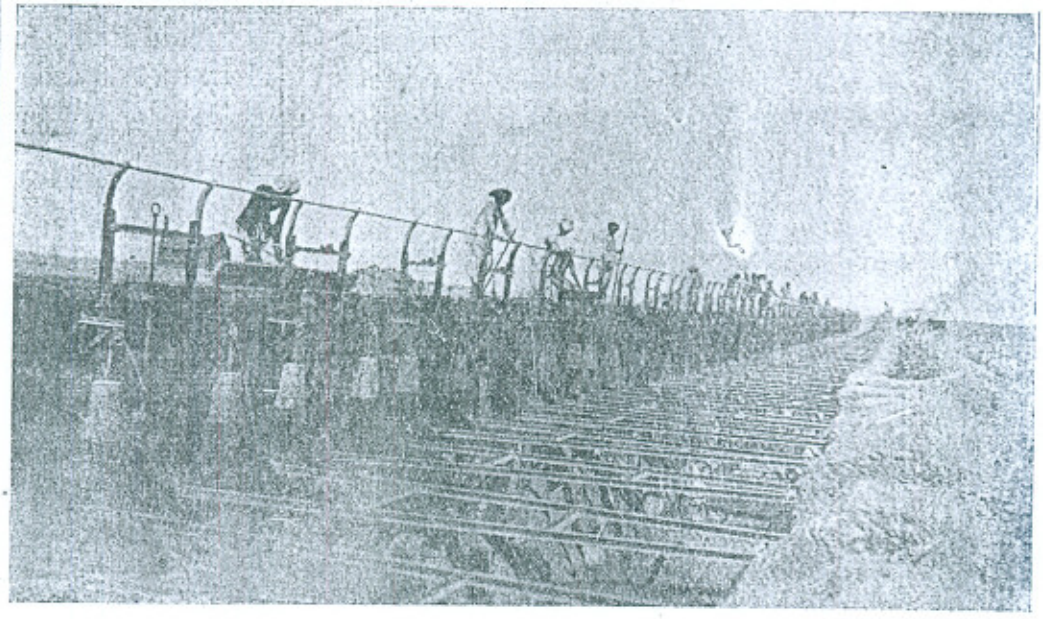
There are many novel features in the construction of the Main Line "Gang" Canal that are worthy of note. They have been touched upon above but are recapitulated here :—

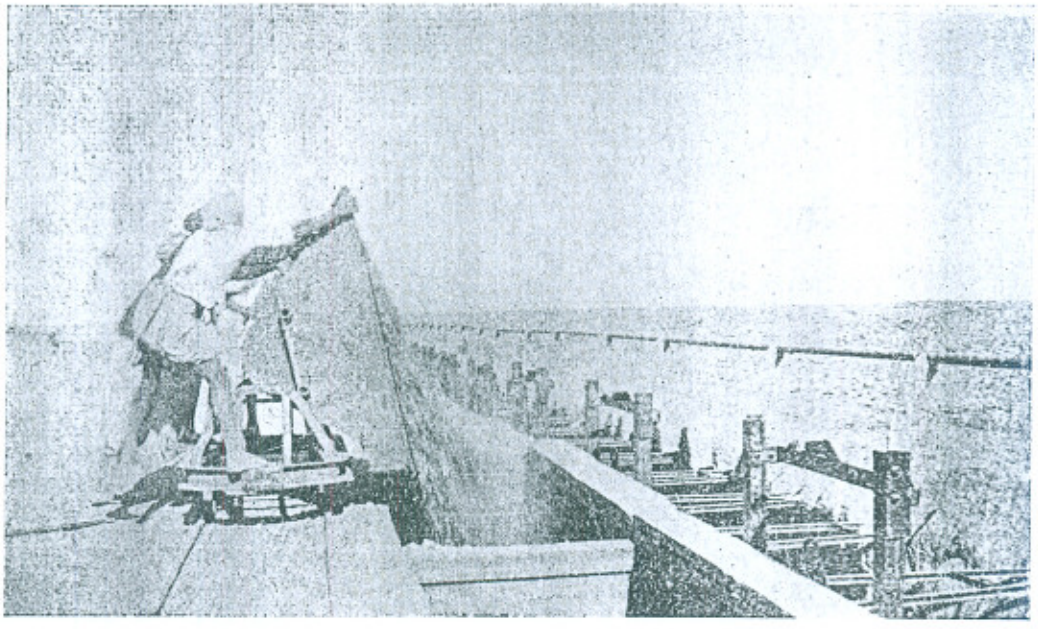
(1) The canal is over 70 miles long before any irrigation at all is done from it. It is therefore of one section throughout.

(2) It is to be concrete lined throughout and will thus be the biggest and first of its kind in India and probably the largest in the whole world.

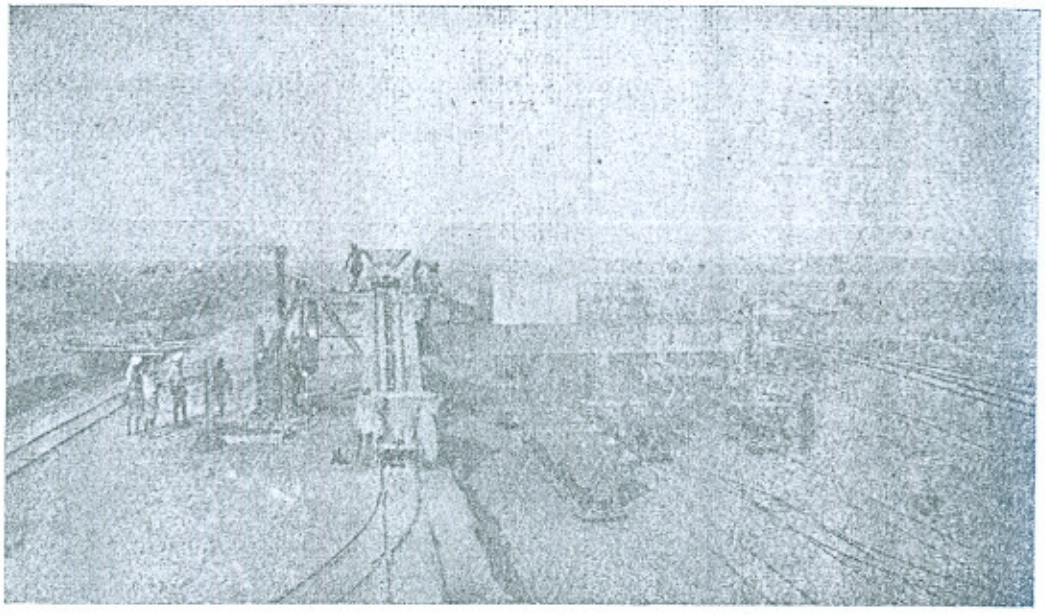
(3) Pneumatic rammers have been used for consolidating the concrete and this, it is believed, has never been done before.

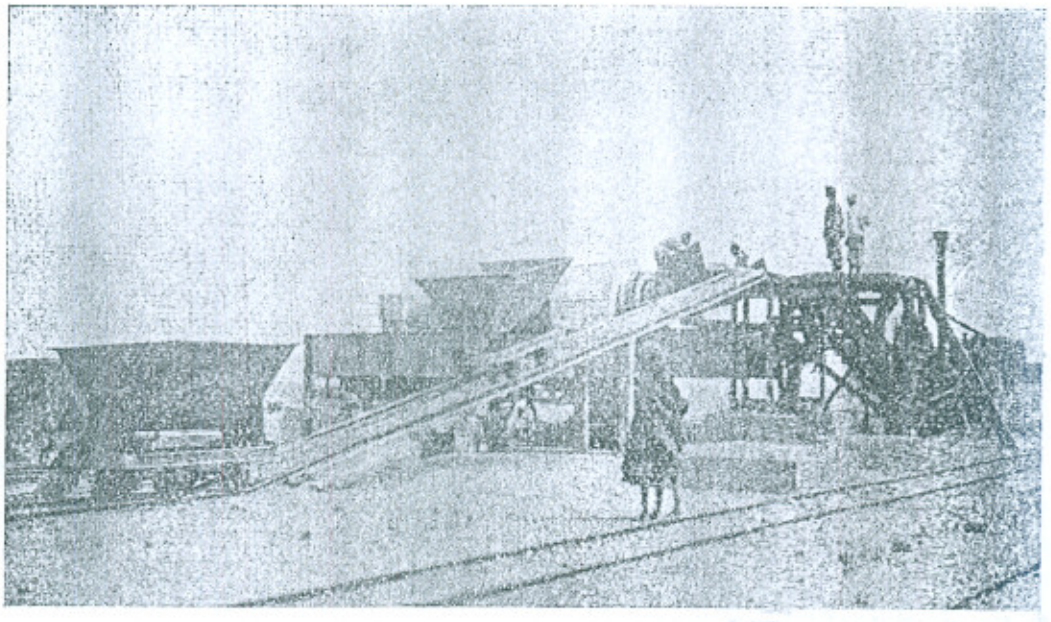
(4) All the ingredients required for the concrete are obtained from one source, namely the *kankar* fields at Darbari.





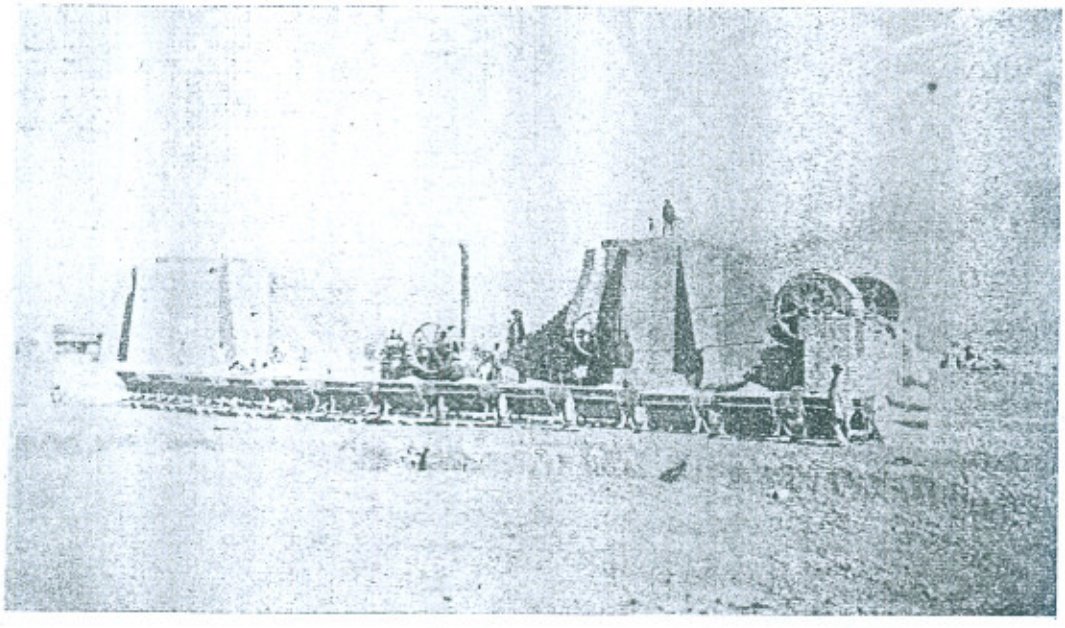
THE BIN-CHUTES AT DARBARI.
FRONT AND BACK VIEWS.



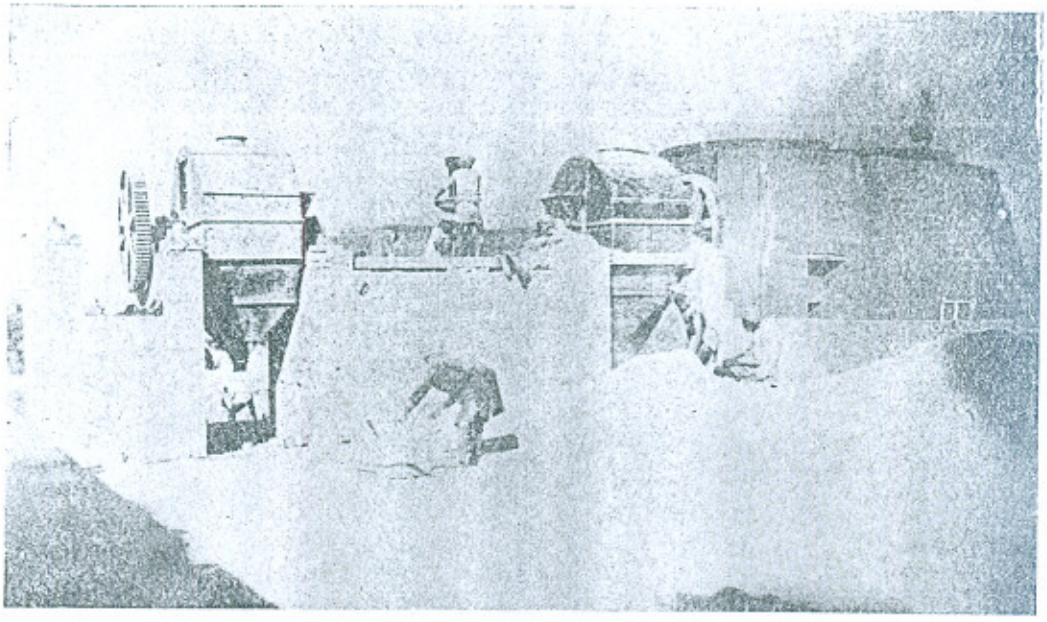


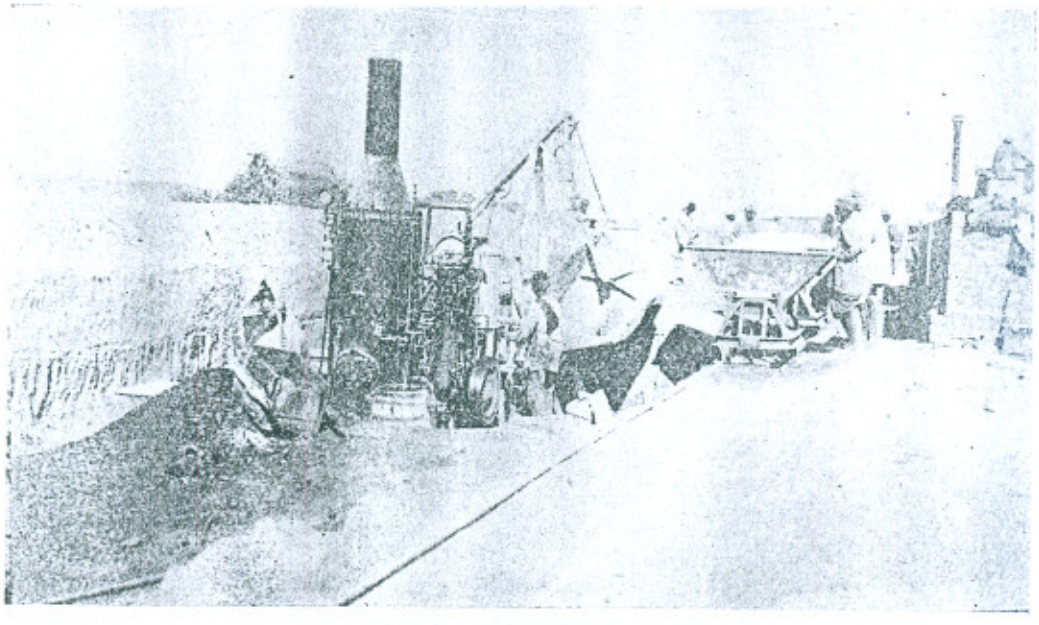
THE SCREENING PLANT.





LIME KILNS AND BALL MILLS.





BALL MILLS AND CONCRETE MIXER.





RAMMING ON BED AND SIDE SLOPES OF CANAL.





RAMMING ON BED AND SIDE SLOPES OF CANAL.



RAMMING ON BED OF CANAL AND VIEW OF COMPLETED CANAL
(EXPANSION JOINTS FILLED WITH EARTH).

APPENDIX

DETAIL OF QUANTITIES AND COST OF CONCRETE LINING 1 MILE OF THE GANG (BIKANER) MAIN LINE CANAL.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Item.	Description.	Rate per 1,000 c. ft.	Kankar.	Lime.	Sand.	Coal tons at Rs. 22 per ton.	Lubricating oil gallons at Rs. 3 per gallon	Petrol gallons at Rs. 2-4-0 per gallon.	Kerosine oil drums of 4 gallons at Rs. 3-12-0.	Other stores.	Skilled labour.	Unskilled labour.	Repairs and replacements.	Total.
		Rs. a. p.								Rs.	Rs.	Rs.	Rs.	Rs.
1	Receipt of *kankar* at dump ..	125 0 0	300,000 37,500	..	..	..	..	..	..	..	..	..	..	37,500
2	Unloading and stacking *kankar* { 1. Unloading	5 0 0	300,000	..	..	..	..	..	..	..	..	1,500	..	1,500
	{ 2. Stacking	5 0 0	75,000	..	..	..	..	..	..	..	..	375	..	375
3	Loading *kankar* into tipping wagons, taking to screens and returning empties to *kankar* stacks.	15 0 0	300,000	..	..	..	..	..	..	..	..	4,500	..	4,500
4	Screening *kankar* ..	7 0 0	300,000	..	..	45 990	55 165	..	..	50	400	375	120	2,100
5	Removing earth refuse from screens.	5 0 0	45,000	..	..	..	..	..	..	..	..	225	..	225
6	Taking ballast to mixers ..	9 6 0	216,000	40,000	38,000	..	..	..	..	..	..	2,025	..	2,025
7	Taking oversize *kankar* to lime kilns and ball mills.	7 8 0	84,000	..	..	..	..	..	..	..	..	630	..	630
8	Lime manufacture ..	120 0 0	..	40,000 4,800	..	..	..	..	..	..	..	..	..	4,800
9	Sand manufacture ..	76 0 0	..	..	38,000	38	40	..	..	..	..	..	..	
10	Mixing concrete	8 0 0	216,000	40,000	38,000	836 70	120 40	..	..	80	456	1,140	256	2,888
11	Loading and taking mixed concrete to ramming site.	7 0 0	216,000 c. ft. of mixed concrete.			830 24 528	120 40 120	..	..	80	471 408	.. 150	177 226	1,728 1,512
12	Ramming concrete ..	70 0 0				..	110 330	160 360	800 3,000	100	640	8,400	1,170	14,000
13	Watering concrete ..	2 12 0				..	..	..	..	100	..	450	..	550
14	Water-supply at dump ..	2 12 0				..	..	..	..	100	200	200	50	550
15	Picking up and removing tram track.	1 0 0	200,000 c. ft. rammed concrete.			..	..	..	..	..	..	150	50	200
16	Repairs to tipping wagons ..	1 8 0				..	..	..	..	100	100	..	100	300
17	Allowance for carriage of materials by rail coach, etc.	2 8 0				..	..	..	..	500	..	..	..	500
18	Supervision and Work-charged Establishment.	5 0 0				..	..	..	..	..	900	100	..	1,000
19		..	300,000	40,000	38,000	197	285	160	800					
20	Contingencies at 5% on Rs. 76,883—37,500=Rs. 39,383.	..	37,500 *Nil*	4,800 240	..	3,234 162	855 43	360 18	3,000 150	1,190 59	3,575 179	20,220 1,011	2,149 107	76,883 1,969
21		..	37,500	5,040	..	3,396	898	378	3,150	1,249	3,754	21,231	2,256	..

Rate % sq. ft.=Rs. 19-11-4.

Grand Total cost per mile=Rs. 78,852.

Light type figures represent quantities in cubic feet.
Heavy type figures represent cost in rupees.

APPENDIX II.

To arrive at the approximate total cost of the concrete lining inclusive of the cost of machinery, etc., installed at the lining dumps, it is necessary, at the present time to make certain assumptions. Since there are four lining dumps the plant and machinery installed at one dump can be taken as being used in the concrete lining of one quarter of the total length of the canal, *i. e.*, 21 miles. Then since approximately 5 miles of the canal is to be lined at a time, the machinery has to be erected at four different dump sites along the canal. Finally on the completion of the work, there is the salvage value of the machinery and plant to be taken into account.

Taking the initial cost of the plant and machinery and applying these assumptions, the total cost of concrete lining the canal works out to approximately Rs. 90,000 per (canal) mile or to Rs. 22-8-0 per hundred square feet as is shown below :—

(1) *Initial cost of plant and machinery—*

		Rs.
(*a*) Tramway track with necessary points and crossings, 5 miles, at Rs. 8,000 per mile		40,000
(*b*) Tipping wagons, 150 No., at Rs. 190 each ..		28,500
(*c*) 2·0 gauge locomotives, 2 No., at Rs. 16,500 each ..		33,000
(*d*) Screening plant complete with engines, 2 No., at Rs. 15,000 each		30,000
(*e*) Ball mills complete with engines, 2 No., at Rs. 12,800 each		25,000
(*f*) Concrete mixers, 2 No., at Rs. 12,600 each ..		25,200
(*g*) Portable air compressors complete with 8 pneumatic rammers each, 4 No., at Rs. 14,000 each ..		56,000
(*h*) Small plant and machines such as pumps Petter engines, etc. (allow)		12,000
		2,50,300
	(say)	2,50,000
Allow 33⅓% for salvage value at completion of the work	(say) ..	80,000
Nett cost to be charged to concrete lining	C. o. ..	1,70,000

	Rs.
B. o. ..	1,70,000
(2) *Preparing dumps and installing machinery, etc.*—	
Cost including construction of lime kilns, store sheds, quarters, for staff, etc., etc., at each dump works out to about Rs. 15,000, hence for 4 dumps cost is	60,000
Total cost to be spread over 21 miles of concrete lining	2,30,000
Cost per (canal) mile is therefore	10,952
(3) *Manufacturing and consolidating the concrete*—	
The cost as detailed in the statement for lining one (canal) mile is	78,852
Thus the total anticipated cost per (canal) mile amounts to	89,804
or (say) ..	90,000

and this is equivalent to Rs. 22-8-0 per hundred square feet of concrete lining.

DISCUSSION.

MR. JEFFERIS in introducing his paper said that when it was decided that the Concrete Lining of the Main Line Bikaner Canal was to be one of the works to be visited by members of this year's Congress, he was asked to write a paper on the work so as to give a description of what was being done. He wrote the paper in somewhat of a hurry as time was short ; since writing the paper he had not been able to visit the work again and was not, therefore, able to give any information as regards recent progress or the effect, if any, which the cold season had had on the concrete lining.

When dealing with the ramming of the concrete by means of compressed air he had asserted that concrete consolidated in this fashion must be denser than that rammed in the ordinary way. He had there some samples of the concrete consolidated with pneumatic rammers to illustrate how dense and compact it was.

With these few words he begged leave to introduce his paper.

K. S. IQBAL HUSSAIN remarked that the justification for lining this canal of 52.0′ width was (a) to prevent any chance of waterlogging and (b) to save about 400 cusecs in absorption losses. It had not been explained if there was actually any danger of waterlogging taking place. Also it had not been ascertained how much absorption loss would have created waterlogging, and also nothing was mentioned as to how much the absorption loss would now be with the lining. The figure of 400 cusecs was rather too high : a canal of 70 feet bed-width after the 3rd or 4th years of its continuous flow did not lose more than 5 cusecs per million square of surface area. This would give a loss of 180 cusecs. He said that it would be good to effect a saving of 50 per cent. of the losses by means of lining, and assuming a loss of $2\frac{1}{2}$ cusecs per million square feet of surface area, the absorption loss would be 75 cusecs, and therefore the nett gain could only be 105 cusecs and not 400. This meant that 7 million rupees were being spent to get 105 cusecs, while the complete project value of a cusec was Rs. 5,000 and therefore expenditure up to a limit of Rs. 5 lacs only was permissible.

The Khan Sahib stated that this lining work had unfortunately forced us to design the canal with a very steep slope which might prove very dangerous, when any of the lining was washed away. He considered that the material which was being used for lining did not possess hydraulic qualities, and therefore under no circumstances should its use have been agreed to when the responsibility of construction was undertaken.

No joints should have been allowed at all in the lining work and to safeguard it from expansion and contraction cracks the lining should have been roughened on the underside, to enable the bed-resistance to counteract these forces.

Bitumen should not be used for caulking the joints, as it had not a sufficiently long life.

MR. R. P. HADOW invited attention to the "lay out" of the work at the dump sites and remarked that, whilst it looked very simple on paper, it was the product of much thought and planning. This work was well repaid, as he believed that experience had led to a few minor alterations only. He emphasised the importance of spending time and thought over such matters as it paid in the end and led to smooth and economical working.

As far as he remembered, the plant was obtained with a view to a daily output of one hundred lineal feet of lining a day; Mr. Jefferis stated that a normal day's work was about 130 lineal feet, so that the plant had been designed on sound lines.

In the beginning it had always been assumed that some form of contraction joint was necessary but subsequent experience led Mr. Hadow to come to the conclusion that it would be sufficient if simple "butt-joints" were left between each day's work; if and when these opened out in the form of cracks, they could be sealed by painting with a bituminous mixture.

Mr. Hadow pointed out that the result of Mr. Jefferis' excellent analysis of the cost of the concrete lining work must be adopted with caution for other similar work, as it was very unusual to get ballast as cheap as Rs. 12-8-0 per hundred cubic feet. In this case it was possible because the initial cost of the railway track and rolling stock was excluded by the Bikaner State from the expenditure on the canal project. He further remarked that however the cost of the ramming by pneumatic rammers, *viz.*, Rs. 7 per hundred cubic feet, compared with the cost of hand ramming on a horizontal surface, the efficiency of the method in dealing with the side slopes was undoubted; besides the difficulty of keeping a gang of 500 coolies ramming continuously throughout the year was impracticable. Mr. Hadow regretted that there had been no opportunity for a visit to the Durbari quarries, where the kankar came from. It was a fine example of a well-designed lay out. Two trains containing 16,000 cubic feet of kankar each are loaded on the open line of the Bikaner State Railway in the intervals between the running of passenger trains by means of the "bin-chutes"; and every thing proceeded quietly and smoothly.

MR. MUSTO remarked that there was no lining to be done at Sukkur.

He asked what was the output of these continuous lime-kilns per 24 hours, and the cost; also if the two staircases shown, indicated that the material was carried up by hand.

MR. WILSDON said he had been interested in the properties of the concrete and regretted that Mr. Jefferis had been unable to give more information on such points, especially on absorption experiments which it was understood had been undertaken.

It appeared to him that Mr. Jefferis wished to have it both ways. If the concrete was peculiarly elastic, rendering expansion joints unnecessary, it would also be peculiarly porous. The material of which the concrete was composed, calcium carbonate, had a definite co-efficient of

expansion and elasticity. If the compressibility of the material, as laid, were greater than that of solid calcium carbonate, it could only mean that the stresses were relieved by internal deformations due to the granular or porous structure.

A calculation, using conservative estimates for the physical constants involved showed that the concrete should crack every six feet. Such calculations, it was admitted, were not free from objections, but the speaker felt that the proposal of a previous speaker to "let the concrete crack and then paint it with a bitumen cement" was not practical politics.

It was not only stresses due to temperature changes which had to be taken into account. Besides subsidence of made-earth below the side-slopes, stresses would be set up on account of the unequal expansion on wetting of a sandy or clayey bed. Comparatively insignificant cracks would render the concrete quite useless from the point of view of stopping absorption. Laboratory tests on samples were in progress which would enable some opinions to be formed on the properties of the material as actually laid in the work.

Half the samples sent had distintegrated during the railway journey. The remainder which survived appeared to be of much better quality. A few determinations had been made, but more would be available shortly. One specimen would let through roughly 7 cusecs per million square feet under an 8 feet head. Porosities range from 11 to15 per cent. It is obvious that such material will be entirely useless in stopping absorption.

Mr. Wildson subsequently communicated the following results obtained with samples of concrete cut out of the Bikaner Canal lining :—

	R. D.	Percolation in cusecs per million square feet under an 8 feet head.
1	15,000	1·47
2	133,000 (a)	13·3
3	,, (b)	4·93
4	,,	3·38

Sample No. 1 showed a fall in the rate of percolation from 3½ times the equilibrium value. The remaining samples showed a continuous *increase* in the rate of percolation during the month they were under test, and this was associated with a continuous loss of free lime, amounting

to about 10 grains of calcium carbonate per square foot per day. Such a rate of leaking would mean that one half the lime of the concrete would be leaked out in about four years.

The conclusions which these experiments force on us are that the best concrete, probably that laid at places where there was an adequate water supply, is not likely to have a percolation loss less than about $1\frac{1}{2}$ cusecs. Of the remainder, where in all probability the concrete could not be kept wet sufficiently long, the percolation loss may be anything between this and 13 cusecs. Such concrete also will rapidly deteriorate owing to the washing out of free lime. When properly cured the concrete shows a slow improvement due to hydraulic properties of the lime. When allowed to dry out no improvement takes place, but instead, a rapid deterioration.

It would be interesting to discover the proportion of the lining which corresponds in quality with the latter three samples which must be considered useless both from the point of view of stopping percolation and as a durable foundation.

MR. COLYER said it was due to Mr. Jefferis to explain that he had been asked to write this paper at the last moment in order to supply a good description of the lining work which Members would visit. He was sure Mr. Jefferis would welcome any criticism and useful opinions from them, and that they were grateful to Mr. Jefferis and congratulated him on what, in spite of the short notice, was a well-prepared paper.

MR. TINSLEY said he had been in charge of this lining work. Absorption experiments were carried out in a reservoir constructed for storing water from the Sirhind Canal instead of obtaining from a Tube-well. A length of 500 feet was lined in the ordinary way and cross-bunds were also lined with concrete. These cross-bunds were not consolidated. At first absorption was very great, *viz.*, about 5 cusecs per million square feet. The reservoir was pumped dry. The lining on the side slopes was as usual but the concrete on the cross-bunds had cracked badly. The cracks were grouted and the reservoir re-filled. The loss in absorption and evaporation immediately dropped to 1·08 cusecs per million square feet. Owing to necessity for storing water the grouted cracks were only given 3 days to set and there is reason to believe that the concrete of the end slopes might still be leaking and the loss in absorption and evaporation really under one cusec per million square feet.

This lime, being very slow setting, was ideal for the job, as sometimes several hours elapsed between mixing at the dump and ramming at site. Laboratory tests showed that this had no effect on its strength after 3 months. He said that they did not grind the lime as the material really resembled a lime from ordinary lime-stone rather than kankar, *i. e.*, it slaked. The quantity of lime had been increased a little and the mixing was now in the proportion of 3 grit (*i. e.*, ground kankar) : 4 of screened lime, 20 of ballast. The cost per mile given in the Appendix by Mr. Jefferis was Rs. 78,852. The revised figures were considerably lower and came to about Rs. 77,700 per mile.

He stated that the hair cracks which appeared in the side slopes were not vertical cracks but were shear cracks due to the sliding or slumping of concrete which was laid too wet.

Screening the kankar from dust, caused a shrinkage in volume of 4 per cent. and it was necessary to collect a correspondingly greater quantity of raw kankar.

MR. NICHOLSON said that the keynote of the design of this lining seemed to have been economy rather than efficiency. Efficiency in such a matter was all-important, and he doubted whether it was right to risk it in this case.

As ramming cost Rs. 7 per cent. he asked why some of the expenditure was not put into a waterproof skin of cement. He also asked why the local cement factories had not come forward, to make a cement lining possible; sand could have come from Suleimanke, instead of all the way from Pathankot.

Mr. Wilsdon had referred to the question of porosity; the speaker considered that lime, grit and ballast in the proportion 1 : 1 : 6 was on the lean side, and would give a low Young's Modulus, resulting in fine cracks at short- intervals.

What was required was an impervious lining, and not a hard one.

He thought that these works were an effective demonstration of the economy of mechanical handling.

He noticed the distance, $2\frac{1}{2}$ miles, of the central lining dump from the working face, precluded the use of a wet cement mixture, but considered that a cement mixture could have been fed to the face dry, on caterpillars.

He would like to know why electric power had been ruled out.

He mentioned that in carrying out tests for temperature cracks, observations must cover the whole year; at Suleimanke the cracks were seasonal, and not diurnal; they appeared for the first time in December.

When expansion joints were provided the friction between the bed and the lining was sometimes neglected; cracks appeared more frequently on this account.

Referring to Appendix I he said that even if this lining was not efficient with regard to imperviousness, yet it had resulted in economy by reducing the area of land to be acquired and the width of bridges, and by reducing the wetted-surface by 40 per cent. had effected a similar reduction in percolation.

As regards the probable life of the material and the extent of abrasion rendered likely by the dissolving of the lime, he mentioned that in Madras the percolation water was collected and analysed to ascertain this. In this way it might be possible to forecast in how many years' time the

lining would become unstable. This point was the more important as the water of the Punjab rivers was free from lime, and was therefore able to dissolve it readily.

The speaker thought that in waterlogged areas where negative pressures existed a thickness of six inches would not suffice.

MR. LYSTER asked for more information as to the lay-out of the quarry, as it was very easy to block works of this nature.

It appeared to him that the kilns were hand-fed, and that the need of mechanical appliances was indicated.

MR. TATE, who is the Superintending Engineer in charge of the work, said that the lining was in the nature of an experiment. The two aims were impermeability, and resistance to erosion. Tensile and compressive strength were of little importance; a substance to resist cracking must possess elasticity.

Preliminary experiments at Orki on different kinds of concrete, 6 inches thick, had shown that the combined absorption and evaporation losses with the concrete in use were less than half-a-cusec per million square feet of wetted surface.

Subsequent experiments in the canal itself had been vitiated by settlement of the temporary earth-bands, but further experiments were in hand.

He also stated that no experiments had yet been made regarding attrition, but that judging from the observed hardness of the mortar, there should be nothing to fear on this point. He understood that Mr. Wilsdon was going to make experiments upon the absorption of the concrete as actually laid.

Mr. Tate said that Mr. Jefferis had shown in his paper that the hair-cracks in the lining were not attributable to temperature-changes. He himself thought that they were due to the concrete having been laid too wet, and therefore not having been sufficiently consolidated.

He hoped that the assumed Kutter's N of 0·013 would materialize, but thought this value required a smoother surface than it was always possible to obtain.

MR. HAIGH, referring to paragraph (3) noted that the dimensions of the section, *viz.*, bed-width 52 feet and depth 8 feet were not the most economical ones, and enquired how they had been arrived at. Possibly the depth had been limited in consideration of future blowing-up pressure. If so, what was the intensity of uplift anticipated and how had it been calculated.

MR. LINES remarked that the samples of concrete handed round appeared porous, but would, no doubt, become less so in time.

MR. DIXON writes :—

The author might with benefit have given his personal opinion on the work, especially as he was in charge of it practically from the commencement.

He enquires whether and would, the author adopt the same materials if he had the same work to do again and methods of handling and proportioning, and of general working; and whether he considers the concrete used thoroughly satisfactory or if, while using the same materials it could be improved; also if he is quite satisfied as to the hardness, durability and impermeability of the lining, or has any suggestions to offer as to its improvement.

Beyond the proportions mentioned on (page 62) he has not given the general specification for the work, nor has he stated the crushing strength and permeability of the concrete. It is not clear whether Darbari kankar was used because it was an entirely satisfactory aggregate, or if other considerations were the deciding factor. He asks if any tests were made to ascertain the hardness of the kankar as a concrete aggregate, and if so, with what result. As mentioned by the author on page 62, it is upon this kankar as aggregate, grit and lime, that the whole of the lining depends.

He considers that this kankar is not suitable as an aggregate for lining the canal and that this concrete is considerably more porous than if ordinary broken stone had been used as the aggregate. The kankar is a limestone, more nodular than usual, and unless the mortar is unusually wet and fluid it does not get into the interstices of the nodules. Spread, as it is, in a comparatively thin layer (6 inches thick) over a large dry surface, and exposed to the sun and wind over an equally large surface on the other side, the loss of water from it is tremendous. In the case of a 10 mile dump the mixed concrete has to travel an average distance of $2\frac{1}{2}$ to 3 miles, in tip waggons before reaching the ramming face. It is then (usually after some delay) spread on bed and side-slopes and roughly dressed off to profile, before the pneumatic rammers are brought to work upon it. Allowance should be made for this at the mixer by adding say 10 per cent. more water than what is required in ordinary cases. The least quantity of water used is 18 gallons to a batch of 21 cubic feet of ballast with lime and grit; the average quantity used is 20 gallons, and sometimes 22 gallons are used. He considers the last quantity to be the best, and that in the middle of summer this might be increased to 23 or 24 gallons. If mixed with less than 20 gallons of water at dump site the final ramming cannot be satisfactorily completed until more water is sprinkled on it at the ramming face. This water serves no useful purpose beyond improving the appearance of the finished surface and it should not be used. The proper place to use all the water is the inside of the mixer, where it also assists thorough mixing, a purpose which cannot be achieved by cutting down the water in the mixer, and adding some at the ramming face. The proportion in which the concrete is actually mixed at site is :—

Lime	Grit.	Kankar.
4	3	20

The "grit" is ground in a Ball Mill from kankar ballast and unburnt stuff from the lime kilns. The objection to this grit is its unusual fineness. A sample recently taken yeilded on analysis this result :—

		Per cent.
Passed	.. No. 100 Mesh ..	= 51·8
Retained	.. No. 100 ,, ..	= 7·3
Do.	.. No. 50 ,, ..	= 7·3
Do.	.. No. 30 ,, ..	= 3·9
Do.	.. No. 20 ,, ..	= 11·3
Do.	.. No. 10 ,, ..	= 14·1
Do.	.. No. 4 ,, ..	= 4·3
	Total ..	100

It will be noticed that over half the "grit" is so fine as to pass a No. 100 mesh sieve ; and over 70 per cent. passes a No. 20 mesh sieve. He considers this grit too fine for the work, and that its use is uneconomical.

He has calculated the cost of manufacturing the lime and the grit at dump site as follows :—

Cost of 100 cubic feet Kankar Lime.

	Rs.
(a) Screened kankar, 88 cubic feet at Rs. 16 per hundred	= 14
(b) Loading into kiln and burning and slaking at Rs. 10 per hundred of lime	= 10
(c) Carriage of cinders from Orki plus petty repairs to kilns, sheds, godowns	= 2
Cost of 100 cubic feet screend lime	= 26

NOTE.—Cost of raw kankar is Rs. 12-8-0 per hundred cubic feet f. o. r. dump site.

Cost of 1,000 cubic feet Kankar Grit.

Two Ball Mills turn out an average of 1,000 cubic feet of grit per day and the cost is :—

		Rs.	A.	P.
(a) Unskilled labour, feeding mills	.. =	30	0	0
(b) Skilled labour, Drivers and stokers	.. =	12	0	0
(c) Stores (coal, oil, &c.) ..	.. =	27	0	0
(d) Repairs and replacements ..	.. =	6	8	0
(e) Screened kankar $\frac{1,000 \times 4}{3}$ = 1,334 cubic feet at Rs. 16 per hundred	.. =	213	0	0
Total cost for 1,000 cubic feet	.. =	288	8	0
Cost per 100 cubic feet	.. =	29	0	0

The grit, therefore, costs nearly Rs. 3 per hundred cubic feet more than the lime and not less as generally imagined. Were its use entirely discontinued and lime used instead, it would result in not only a cheaper, but a much superior concrete. From the author's general analysis, page 73, the cost of screening, mixing, carrying, and ramming the concrete, *i. e.*, of all labour charges, works out at Rs. 12 per hundred cubic feet of finished lining.

The cost of the concrete is then as follows :—

		Rs.	A.	P.
(a) Kankar ballast (screened) 108 cubic feet at Rs. 16 per hundred	=	17	4	0
(b) Lime, 20 cubic feet at Rs. 26 ..	=	5	4	0
(c) Grit, 18 cubic feet at Rs. 29 ..	=	5	0	0
(d) Labour charges ; (all in)	=	12	0	0
Cost of 100 cubic feet concrete ..	=	39	8	0

The cost of one mile of lining, is therefore 200,000 cubic feet at Rs. 39-8-0 per hundred=Rs. 79,000 ; as compared with Rs. 78,852 given by the author in his General Analysis Appendix 1.

Mr. Dixon does not agree with the author's opinion (on page 62) that a cement concrete would have been considerably more expensive than the kankar lime concrete now being laid, he considers that a thickness of 4 inches of cement concrete would have been ample. Darbari kankar could still have been used as the aggregate, and grit made at site as at present, only much coarser. An ordinary 1 in 8 concrete, containing 11 lbs. weight of cement per cubic foot of finished concrete, would have been an excellent lining, and superior to the one now being laid, it would have cost :—

Cost of 100 cubic feet Cement Concrete.

		Rs.	A.	P.
(a) Screened kankar 70 cubic feet at Rs. 16 per hundred	=	11·20		
(b) Fine ballast ; (kankar ground in Ball Mill to 1-8 inch) 38 cubic feet at Rs. 30 per hundred	=	11·40		
(c) Sutlej River Sand (from Weir) 50 cubic feet at Rs. 5 per hundred ..	=	2	8	0
(d) Cement ; 1,100 lbs. at Rs. 50 per ton..	=	25	0	0
(e) Ramming charges, mixing, &c. ..	=	12	0	0
Total per 100 cubic feet =		62	0	0

With lining 4 inches thick the cost per mile would have been Rs. 83·080 ; or very little more than the present lining.

Even brick flat in mud with ¾ inch cement plaster on top, and brick flat in cement on top of that again, making an excellent and durable lining, would have cost well under a lakh of rupees per mile. Either of these linings would have been more durable and impermeable than that now being laid. He considers that the present method of consolidation by means of pneumatic rammers is not altogether satisfactory; unless full compression be maintained at all times the impact of the rammers falls off noticeably. A better and much cheaper method for the bed at least would have been a suitable steam or petrol driven roller. The consolidation would have been thorough and uniform all through; it would also have been cheaper as one roller, costing Rs. 10,000 would have done the work of two compressors, costing Rs. 15,000 each.

He recommends in future work of this nature :—

(a) That no raw kankar "grit" be used in the concrete.

(b) That all coarse stuff, and unburnt or half burnt kankar from lime kilns, be ground to dust in the Ball Mills and used instead of kankar grit. (This "dust" will contain a large percentage of lime).

(c) That the concrete be mixed in the following proportions :—

Lime		Kiln Dust		Kankar.
6	:	2	:	21.

(d) that the bed lining be consolidated by means of a suitable light roller, and not by pneumatic rammers.

The author replied to some of the questions and promised to give fuller details in writing.

He writes :—

The intention of his paper was to give members of the Congress an idea of what they would see when they visited the concrete lining Works. The points raised by certain members in the discussion regarding (a) the suitability of the materials ; (b) the chemical analysis of the kankar ; (c) the comparison of the accepted type of lining with others, were matters that could well form the subject of one or more papers, and he hoped that members who were at present carrying on the lining operations would write papers on these subjects so that they might be discussed at a future Congress.

K. S. Iqbal Hussain considered that the figure of 400 cusec estimated to be the saving obtained from lining the canal was too high. The calculations arriving at this figure are given as an appendix to these remarks.

There was never any question of being "forced" to adopt a very steep slope because the canal was going to be lined. The total fall from head to tail of the canal depended entirely on local conditions ; such as the necessary full supply Level to give command at the point where the land to be irrigated was reached, and the general configuration of the

country through which the Canal was to pass, etc. If the slope of 0·13 per 1,000 had been considered to be too steep, it would have been an easy matter to have installed one or more falls or rapids along the canal and so flattened out the slope over the major portion of the total length. Again, the slope of 0·13 per 1,000 for a lined channel does not compare so very unfavourably with that of 0·125 per 1,000 which is in common use in other parts of the Sutlej Valley Project and elsewhere for ordinary unlined channels.

The author has been given to understand that the making of joints in the lining has now been stopped excepting at places such as Bridge Sites where, owing to fluming (so as to reduce the cost of the bridges as much as possible) and the consequent increase of velocity, the lining will be made of cement instead of lime concrete.

So far as the author was aware, bitumen was one of the most durable substances in existence, and he would be interested to know what better plastic material could be substituted for it.

Mr. Musto had made an enquiry regarding the output of the continuous burning lime kilns. For the larger type this varied from about 600 to 800 cubic feet and for the smaller from 400 to 500 cubic feet of slaked lime per kiln each twenty-four hours. The cost of lime burning was given in the detailed statement of quantities and cost, but the figure given had to have added to it the cost of kankar consumed. The cost of the kilns varied from Rs. 200 each for the small sized to Rs. 350 for the large ones.

Mr. Wilsdon's remarks referred almost entirely to the chemical and water proofing properties of the concerete which had not formed the subject matter of this paper. The fact that his results, obtained from samples hewn out of the lining, appeared to be poor was probably largely due to the very fact that they were cut out from the lining. Samples obtained in this way would inevitably have been interspersed with fractures due to the vibration caused in the process of cutting them out by means of chisel and hammer, and then the carriage of them from the work to the laboratory in Lahore would have subjected them to further shaking and knocking, all of which would have tended to make them very different, so far as solidity and soundness was concerned, from the original concrete in the bed of the canal. This might also have accounted for the difference in the results, as samples taken from large blocks cut out from the lining, would not have suffered so severely as those taken from smaller sized blocks. For testing purposes, special blocks should have been made out of the concrete actually being used at the time of lining, or, better still, the tests should have been made "in situ" in the canal, and until this was done and the results proved the contrary, it was incorrect to assume that the concrete was not sufficiently watertight and sound.

From the results arrived at, as stated by Mr. Tinsley, from an actual experiment on a large scale, the loss including evaporation was only 1·08 cusecs per million square feet of wetted area. This is better than was

ever anticipated when the decision to concrete line the canal was come to. At that time it was assumed that the loss would amount to two cusecs per million square feet. The author has been informed that further experiments have since been carried out in a reservior formed in the canal. These have given a combined absorption and evaporation loss of about 1·4 cusecs per million square feet.

Mr. Nicholson's remarks to the effect that economy appeared to have been taken into more account than efficiency, could not go unchallenged. Economy and efficiency ran side by side, and when working out the details of the project, both were naturally taken into account, the one not being permitted to outweigh the other.

Under the heading of " Materials used " in the paper, the reasons why kankar from Bikaner was selected for the aggregate, and why cement was not used have been given. It might be added here that before the Bikaner kankar was finally accepted, enquiries were made in Bikaner regarding the concrete made from it and the kankar lime. Tanks for the Railway and for other purposes, which had been lined with this material had been in existence for years and were reported to be in a sound and watertight condition. Since there was no valid reason for doubting the suitability of the material and since it was certainly in the interests of the Bikaner State to supply material available within the State for the construction of their canal, it was agreed to use it and, thereby, as a natural sequence, the cost of the lining became far cheaper than if other materials, obtainable from the Punjab or elsewhere in India had been used.

The chief difficulty regarding the use of cement as proposed by Mr. Nicholson and others was that it would have necessitated practically the whole of the plant being portable to permit of it being moved day by day as the work of lining progressed. Cement being so quick setting would have had to be mixed within a very short distance of the laying site and it would have been impossible to have the lining dumps fixed at different intervals along the canal. Thus, in addition to the extra expense due to the difference in cost between kankar lime and cement, there would have been the additional outlay of having most of the machinery portable. There would have also been great difficulty in supplying water all along the canal, as this was only available at certain fixed points. Adequate arrangements for this alone would have cost a very large sum.

Every one will admit that a cement concrete lining would have been more ideal than a lime one, but the difficulties of using cement in place of lime were such that it had to be ruled out. Not the least of these was that the local (Punjab) Cement Works, with their existing installation, were barely able to meet the heavy demands made upon them by other works in progress at the same time, and if cement had been procured from elsewhere in India or abroad, the cost of freight, etc., would have made the cost of the lining prohibitive. It has also to be remembered

that had cement been used, expansion joints at very short intervals would have been necessary and this would have increased the cost enormously.

Electricity instead of steam power was considered but was ruled out for the following reasons :—(1) The very dusty nature of the locality where it was of no infrequent occurrence for dust-storms to rage continuously for days together. (2) The initial cost of electrical equipment being more than that of steam. (3) The selling value of the plant at the conclusion of the work. (4) Doubt as to being able to obtain sufficient numbers of skilled electrical staff when these were in considerable demand on the Sutlej Valley Project and elsewhere.

With regard to Mr. Nicholson's final remarks, he may rest assured that the question of the thickness of the concrete in water-logged areas where negative pressures would exist had already been thoroughly considered.

Mr. Lyster asked for details of the lay-out of the kankar fields at Durbari. The whole area was sub-divided into plots 1,000 feet wide by means of two feet gauge " feeder " tramlines running more or less parallel to the metre gauge line. These lines are converged on to main double lines (one for " up " and the other for " down " traffic) running at right angles to the feeder lines and which connected in a large loop at the M. G. Railway end, thus ensuring no " return " traffic where the line was likely to be occupied by incoming wagons. The tipping of the kankar into the " bin-chutes," which were situated at the top of the main line loop, took less than half a minute and there was practically no interference with the steady stream of tipping wagons as they came up to be unloaded. On the feeder lines short cross-overs holding six or more wagons were located at intervals, thus preventing any serious blocking of traffic in either direction. The loading contractors were not permitted to load up the wagons on the feeder or main lines but were supplied with lengths of track which they laid from the feeders into the different plots. This ensured that the feeders and main lines were kept free from standing wagons.

With regard to Mr. Lyster's remarks *re* the line kilns. These were hand-fed, the reason being that the contractor who was given this part of the work, seemed to prefer this to any mechanical method. Also, keeping in view the fact that the kilns were only to be used for an average of twelve months or so and then were to be abandoned when the lining dump was moved up or down the canal, the outlay on installing and removing a mechanical means of loading did not appear to be justifiable.

The loading of the kilns was done in layers, those of kankar being from eight to ten inches and those of Railway refuse ashes two to three inches thick.

The lime did not have to be ground as it slaked. It was screened before it was used. It was unnecessary for it to be as fine as if it were

to be used in masonry work. If any unslaked particles passed through the sieves, they would get slaked when being mixed with the ballast in the concrete mixers. Any unslakeable particles formed grit.

As regards Mr. Haigh's remarks, the deciding factor as to the width and depth of the canal was one of levels. It would not have suited local conditions to have had a deep and narrow channel.

Since the canal was only being lined where there was very little fear of water-logging, the question of blowing up pressures did not arise.

Most of Mr. Dixon's remarks that are relevant to the subject of the paper have been replied to in the foregoing remarks. His remarks appeared to have been based on a somewhat brief acquaintance with the work, and an inadequate conception of the difficulties with which the originators of the project had to contend. It was quite likely that, in the light of the experience gained, they would, in a future work of the same kind, somewhat modify the methods used in the present case.

As regards his question as to whether any tests had been made to ascertain the hardness of the kanker, it had been considered unnecessary to do this, as this quality was self-evident.

The author was emphatically of the opinion that consolidation of the concrete in the bed of the canal could not be accomplished satisfactorily by means of a light roller alone. To his mind, the whole art of obtaining a really dense and solid concrete depended on shaking or "vibrating" the different ingredients together into one solid mass. He considered that this could not be achieved by merely rolling the concrete, but, on the other hand, was admirably effected by the pneumatic rammers, which, although light in themselves, worked at such a speed that the vibration set up, not only in the concrete immediately under a rammer, but also around it, caused the ingredients to become one solid homogeneous mass.

The author, in conclusion, would like to add the following :—

(1). Since the paper was written the composition of the concrete had been altered. The mixture now in use was 6 parts lime to 3 grit to 18 ballast, the higher proportion of matrix (about 50 per cent.) being used to secure greater compactness and resistance to absorption.

(2). The cost of the lining as given in Appendix I did not include the cost of erection of the dumps and the depreciation of the plant and machinery. With this added, the cost per mile would be about Rs. 82,000 with the original, and about Rs. 88,000 with the new mixture. On the other hand, a saving in cost had recently been effected by reducing the rate of quarrying the kanker by Rs. 10 per 1,000 cubic feet. Thus the inclusive cost would still remain in the neighbourhood of Rs. 82,000 per mile.

(3). Some short experimental reaches were now being lined with $1\frac{1}{2}$ inches thick cement concrete on $4\frac{1}{2}$ inches lime concrete with joints $\frac{1}{8}$ inch wide left in the cement (but not in the lime) concrete at about every ten feet. It was not proposed to fill the joints with bitumen or anything

else. A Cement Gun was also being obtained with which to make some "Gunnite" experiments. In this connection it may be added that the originators of the project had always kept in view the fact that Gunniting the lime concrete might have to be resorted to eventually, but it was anticipated that this could always be undertaken during normal closures after the canal had commenced to flow and that in this way the additional cost would be met out of "revenue" rather than out of "capital" Funds.

(4). The lay-out for future dumps had been altered slightly by taking up more land and setting the dump back so as to allow the full width of the canal to be excavated and to permit of the lining to be completed throughout before dismantling any of the machinery in the dump. The original lay-out assumed, that, after collecting sufficient material, all machinery with the exception of one concrete mixer would be removed; the balance of the excavation would then be done and the full width of the canal lined. The small space occupied by the remaining mixer was to be lined afterwards. This arrangement was not found to be satisfactory in practice, and it had now been decided that the trifling cost of hiring the small piece of extra land required for the purpose for a year or two would be far out-balanced by the saving of time and expense involved in adhering to the original lay-out.

(5). Finally, the author wished to acknowledge with many thanks the assistance that was given him in preparing the paper by other officers who were engaged on the construction of the Gang Canal with him, especially Messrs. T. B. Tate, Superintending Engineer; W. S. Tinsley, Executive Engineer; and H. F. James, Temporary Mechanical Engineer.

APPENDIX.

Calculations to arrive at probable saving in water effected by concrete lining the Bikaner Canal.

Discharge of Canal =2,144 cusecs.

Taking "n" = ·02. Slope ·13 per thousand.

Taking an unlined channel of 6 ft. depth and 120 ft. Bed Width.

W. P. = 120+16·968 = 136·968

Area of section = (120×6)+36 = 756,

$$\text{r. (H. M. D.)} = \frac{756}{136{\cdot}968} = 5{\cdot}52'.$$

$$V = C\sqrt{r.\ s.} \quad C\sqrt{r} = \frac{(a + b)\ r}{\sqrt{r} + bn}. \text{ (Parker page 1005.)}$$

a = 90·6

b = 62·7

$$V = C\sqrt{rs} = \frac{(90{\cdot}6+62{\cdot}7)\times 5{\cdot}52}{\sqrt{5{\cdot}52}+62{\cdot}7\ \times{\cdot}02} \times\sqrt{s.} = \frac{153{\cdot}3\times 5{\cdot}52}{2{\cdot}349+1{\cdot}254}\times\sqrt{s.}$$

$$= \frac{846{\cdot}216}{3{\cdot}603}\times\sqrt{{\cdot}00013} = \frac{846{\cdot}216\times{\cdot}0114}{3{\cdot}603}.$$

= 2.68 feet per sec.

Discharge = 2·68 X 756 = 2,026 cusecs.

So a somewhat larger channel would be required.

Losses on total length of 423, 000ft. at 8 cusec per million sq. ft.

$$= \frac{423{,}000 \times 137 \times 8}{1{,}000{,}000} = 464 \text{ cusecs.}$$

Losses on lined canal = 52 ft. bed width

8 ft. depth at 2 cusecs per million. = 63 cusecs.

Total saving by lining at least 400 cusecs.