the sumps was accelerated by intermittently pumping the water out of the sumps. This resulted in a heavy inflow of sand and water under the curb of the sumps which went down quickly. A dredger pump was tried on one of the wells but did not prove very successful and, therefore, all the wells were sunk by open dredging. After they were sunk completely, the bottoms were plugged by skipping concrete with skips. In a few cases a steam hoist was employed to work the dredgers and the skips. The wells were then filled up with sand and again plugged at the top with concrete. The *jharies* between the wells have been blocked up by driving piles at an angle so that an exact number could be driven. The well foundation has been provided under the noses of the divide walls upstream and the divide wall extensions below the tails of the fish ladders downstream.

Road Bridge

Loading.—The arterial road Jhang to Bhakkar crosses the river at Trimmu and the traffic was carried by a ferry service. The opportunity for constructing a road bridge to take this arterial road was, therefore, not to be lost. The probability of the N. W. R. taking a railway line across the river being remote, there was no object in locking up money unnecessarily by making the bridge strong enough for railway traffic. To meet with the requirements of future developments, the bridge was, however, designed for Indian Road Congress Heavy Loading which corresponds to about 13 B. S. Units of loading and is equal to .58 tons per linear foot of each traffic lane plus a knife-edge load of 7 tons for computing shears with the limitation that for computing bending moments the total distributed load on loaded length of 20 ft. and under shall never be less than 11.6 tons per lane of traffic over the whole loaded length.

This permitted the working of an erection gantry for the steel-work of the gates and would accommodate narrow gauge traffic or broad gauge track with restriction on the axle load of the traction engine.

The road has a clear 20-ft. roadway with two sidewalks of 2 ft. 7 inches on each side.

Type.—The previous practice has been to erect steel girder bridges but with the object of economising various alternative designs were considered and finally a concrete bridge was decided upon which would cost Rs. 5,62,000 only. The steel bridge would not only have been expensive but it would not have been possible to procure material and erect it within the time available.

Of the concrete types for spans of 24 ft. and 30 ft. over the regulator and undersluices respectively, ordinary T-beam bridges were found to be most economical and were adopted but for weir spans of 60 ft. clear with 7-ft. thick piers in between several alternatives were considered. Arches or continuous structures were not to be preferred because the design could not provide against the unequal settlement of any individual pier.

A cantilever-*cum*-continuous form was finally evolved which gave an arch effect to the structure by varying the depth of the beams as shown in Plate VII. This consists of simply supported span on one bay with arms cantilevering out into the adjoining bays up to ¼th span on either side. These cantilevers at the ends supported another span which bridged the gap.

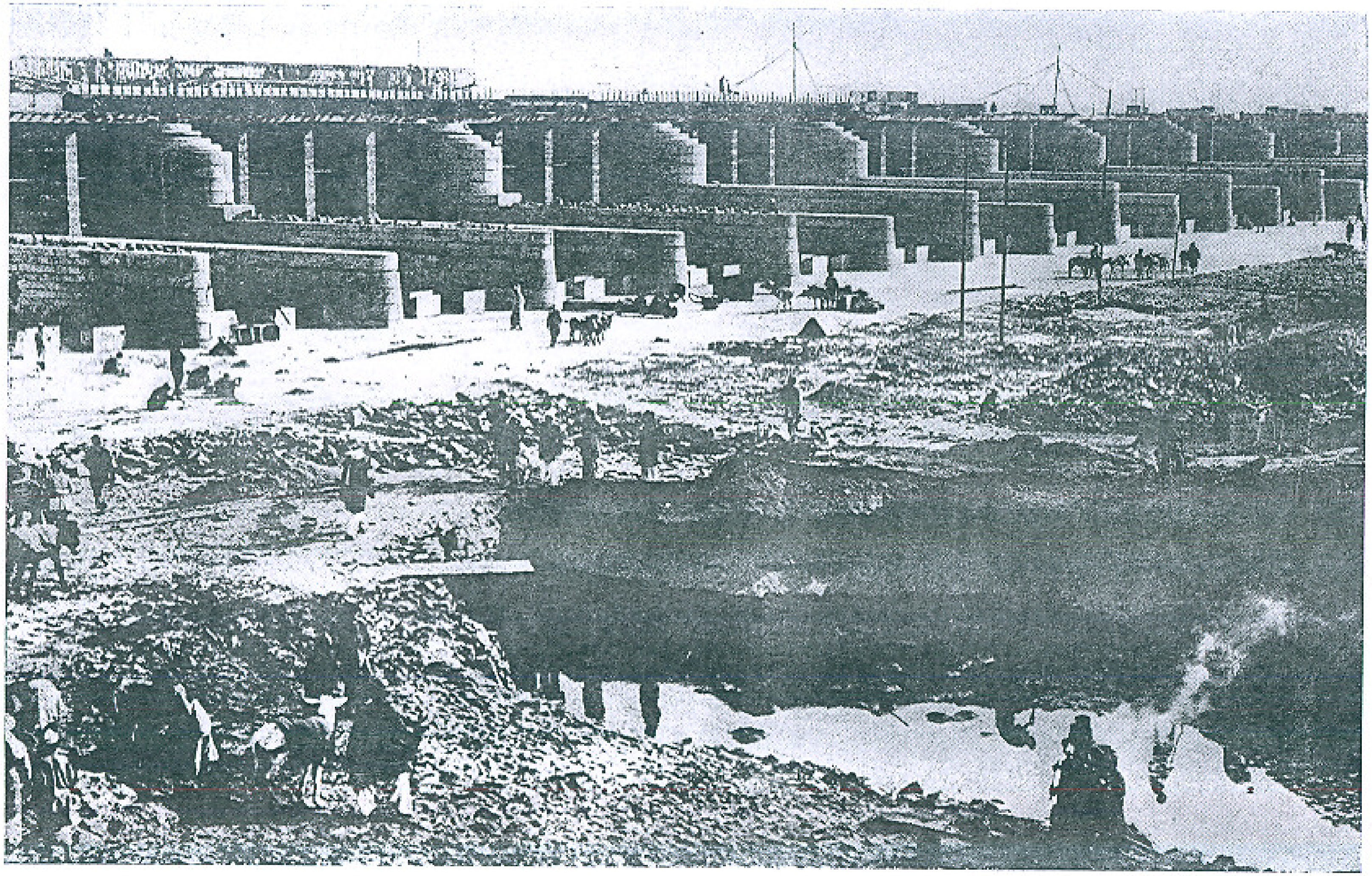
Design.—The design of these suspended and continuous units consists of T-beams, suitably stiffened by cross-beams at the bearings and quarter points. The most economical depth of T-beams was worked out as from cost considerations. A parabolic transverse camber to give an average slope of 1 in 80 has been provided but as surfacing has been kept of uniform thickness the camber has been effected by slightly reducing the depth of the outside beams. The bearings at piers have been specially designed and consist of curved half-inch thick steel plates. Lest the progressive creep, as a result of temperature effects, should materialise, the movement is restrained at every alternate bearing by means of a rivet-head fitting a hollow made in the bottom of the bearing plate. Expansion joints, the detail of which is shown in Plate VII, are provided between adjacent beams. The suspended span bearings placed at the middle of the section are inclined as shown in Plate VII and consist of two half-inch thick steel plates with hooks to bond in their respective beams. Graphite was applied between these plates to give free sliding action.

The cross members at the ends transmit the load to the T-beams and are designed accordingly and, further, the load is transmitted from the beam to the cantilever slab which has also been provided with enough reinforcement. The details of this point are shown in Plate VII.

The cantilevered portion of the continuous span would be subjected to the maximum stresses when the suspended span is fully loaded and so is the cantilevered portion which has been designed accordingly. The central spanning portion will be subjected to both positive and negative moments and the design takes into account the following two cases which give the worst cases of each type :

Firstly, the whole of the central span will be fully loaded with live load and, secondly, the adjoining span with the suspended cantilevered portion is fully loaded.

Adjoining the fish ladders the cantilevering will only be on one side and the beam has been designed independently though for the same conditions of loading as above.



Road bridge shuttering on various stages. Note T-beams. Reinforcement being tied outside and downstream floor clean-sweeped.

The fish-ladder portion of the bridge had a span of 11 ft. only; hence an ordinary simply supported 12-inch thick slab was proposed.

The work on the road bridge started on the 25th September, 1938, and the last span was poured on the 11th February, 1939.

Staging.—The formwork for the T-beams had to be laid about 25 to 31 ft. above the floor level and a different type of staging was proposed. In the undersluice, sleeper cribs were erected. Fifteen-foot steel girders could thus span the gap which enabled the formwork to be placed. Some amount of warping and unevenness exists in each sleeper and thus the settlement in the crib as a result of the load of the formwork concrete and labour could not be accurately anticipated. This mode of staging was therefore given up and in the weir bays three intermediate *kachcha-pacca* masonry pillars were erected (see photograph). This gave spans of 15 ft. and steel girders 15″ × 15″ spanned these and in turn supported the wooden formwork.

Formwork.—Various types of formwork were suggested. It was apparent that each set of formwork, after pouring one span, would not be available for use for at least 20 days even if rapid-hardening cement was used. In actual practice, the side-shuttering was removed after four days and the main supports removed after 10 days of pouring the span when the full load was allowed.

To complete the work in time, six sets of shuttering for the weir spans and four for the undersluice spans were necessary. Steel shuttering was out of question because there was neither the time nor the labour available even if importation charges were to be accepted. Besides, after pouring the bridge the shuttering would be of no use and hence a cheap type of wooden shuttering was the only thing to be evolved.

This consisted of *kail* wood planks, well stiffened with rafters and angle iron pieces to avoid warping and lined with galvanized iron sheeting inside. These could easily be assembled at site and were fitted with movable parts which enabled easy dismantling. All this shuttering was designed and manufactured in Trimmu Workshops at a cost of Rs. 83,029 and about 130 carpenters and an equal number of fitters and blacksmiths were employed for four months in manufacturing shuttering alone. For the continued shifting, erection and dismantling of the shuttering about 150 fitters and 400 skilled gangmen were employed.

Reinforcement.—About 650 tons of steel bars varying in diameter from $\frac{3}{8}$-inch to $1\frac{1}{2}$-inch and 30,000 bags of rapid-hardening cement were used in the construction of the bridge. The reinforcement of T-beams had to be tied outside on the shuttering between the beams and subsequently lowered into position (see photograph). To ensure correct thickness at bottom and side cast-iron distance pieces were used. Small concrete pieces were tried but got crushed under the load of the beam reinforcement. The dirt and dust on the formwork was cleaned by compressed air jets worked by the compressor from the weir floor.

Aggregate and Concreting.—The minimum spacing between the reinforcement was ⅜-inch and to ensure complete enveloping in concrete the aggregate used consisted of 33 per cent. ordinary 1½-inch stone ballast, 33 per cent. crushed and graded ballast and 33 per cent. ¾-inch *bajri*. The concrete was thoroughly wriggled both by manual labour and mechanical vibrators run by compressed air and was made to flow so as to completely cover the reinforcement. The bigger span of weir required about 4,000 c.ft. of concrete which had necessarily to be poured in one day as a joint, being a source of weakness, would not be permissible. The work could not be done from the top of the bridge already poured because the space for material and labour required would not be available; besides it would restrict the work of steel erection. Two mixers used to work a ¼ cubic yard from the top of the bridge and a cubic yard at the level of the weir floor. The mixed concrete was partly taken to the road level by inclined gangways temporarily erected and partly hoisted. The tub of one cubic yard N. G. track filled with concrete from the mixer was lifted bodily with hooks and slings by dragline excavators and was placed at the road level either on the finished bridge portion or a place specially prepared and was carried to the site by baskets (see photographs).

Other Details.—As N. G. track had to be laid on the bridge permanently, hooks threaded at the straight end were embedded in the slab at the time of concreting to take the N. G. sleepers later. Drainage holes were also left through the slab. The side walks consist of precast concrete hollow blocks raised 10 inches above the road level. The wearing coat consists of 3½-inch 1 : 2 : 4 cement concrete separated from the slab by a coat of *colas*.

Parapets and Pylons.—The parapets along the bridge and on the flank formed a subject of great controversy. Various types of concrete parapets and steel railings were suggested. The concrete parapets on the main bridge were finally given up because they would provide intolerably hot tunnels in the long length of 3,000 feet, would mar the river view, would be difficult to repair in case of damage and would entail long and difficult construction. In the case of the bridge, steel railing as shown in photograph on first page was decided upon, the channels were to be bolted to the slab by hooks, deep enough to ensure sufficient anchorage. These hooks were left at the time of pouring of concrete. On the regulators and flanks, concrete parapets of the section shown on Plate VII were proposed. In the case of flanks the parapets were cast outside and placed at site before pouring

Concreting of road bridge. Note gangways and hoisting with excavator, copings of flanks but in the case of regulators they were cast at site. A set of pylons as shown in photograph on the first page was erected at each end. To erect these, three-inch shells in 2-foot heights were cast outside, hoisted in position and concrete-filled inside at site.

Regulators

Design of Haveli Regulator.—The F. S. discharge of the lined canal on the left is 5,249 cusecs for irrigation purposes plus 2,200 cusecs for silt ejectors.

To enable the pond to be drained to the maximum during the winter and also to reduce pond absorption losses to the minimum the regulator has been designed with the object of causing the minimum ponding for the low supply discharge of 1,000 cusecs which corresponds to a water level of 482.7 in the canal. A waterway of five bays of 24-ft. span each was proposed which meant 1,000/120 cusecs per foot run requiring an H of 2.0 and, allowing an afflux of .3, the crest level worked out to 481.0.

The bed-level of the Haveli Canal was to be 479.0 at the lined section and 477.0 at the regulator to accommodate the discharge through silt-ejectors and also to give depth to the ejector tunnels without interfering with the bed of the canal.

The cistern depth from standing wave considerations was tested with three discharges: the free capacity of a bay, the F. S. winter discharge of 2,750 cusecs and the low supply discharge of 1,000 cusecs, and was found to be satisfactory. A double row of staggered blocks was, however, put in on the downstream floor in case the discharge was at any time concentrated through only two bays (Plate VIII).

Rangpur Regulator.—The Rangpur Regulator has been designed for 3,708 cusecs which allows for 1,000 cusecs through the silt ejector. Since Rangpur Canal is non-perennial with downstream F. S. level of 489.0, a crest level of 483.5 was required with three bays of 24-ft. to pass the F. S. discharge of 3,708 cusecs with a pond level of 490.0. Downstream floor level was kept the same as for the lined canal. The cistern depth was tested as above and found to be low enough to support the standing wave under all conditions. One row of staggered blocks was, however, provided on the floor of the regulator (see Plate VIII).

Section and Profile.—On the upstream side the regulator face is cut off from the pockets by a deep pile line going 23 feet below the pocket floor. This would protect the floor from being undermined in case the pocket floor failed and also reduce subsoil pressures from under the regulator floor. At the end of the regulator floor a 10-foot deep curtain wall is provided. The length of the floor has been worked out to give an exit gradient of 1 in 4 with the maximum head of 93.5—77.0=16.5 and is in accordance with Plate VII/5 of C. B. I. Publication No. 12. The subsoil pressures were then worked out and a gravity section allowed. The floor has, however, been covered with a 9-inch slab of 1 : 2 : 4 concrete reinforced against temperature stresses.

Beyond the *pacca* floor a 10-foot wide inverted filter is provided which consists of 3′×2.5′×2′ deep blocks with *jharies* $1\frac{1}{2}$-inch wide separating adjacent blocks and filled with *bajri* overlaying 18-inch ordinary stone ballast and 6-inch crushed graded ballast. A stone apron 30′×2′ is provided beyond it.

The downstream crest of the regulators has a parabolic profile, the object being to get a high discharge co-efficient for highly submerged conditions and a sharply inclined jet entry into the cistern under the maximum head which would give the minimum turbulence and quicker dissipation of energy. Various conditions were tested to get the maximum velocity which could be obtained at the crest. The profile dimensions were then worked out from $X = \frac{U\sqrt{4Y}}{g} + Y$ where U is the maximum velocity and X & Y the profile co-ordinates.

Bridge.—The arterial road Jhang to Bhakar crosses both the regulators and the bridge design, which is the same as for the weir, is carried on 5-foot wide piers with deep foundations. On the upstream side, the regulator piers have been curved to give streamlined approaches and minimum loss of head at entry. The abutments go down to a level of 464.0, thus obviating the necessity of piles. At the floor-level the abutments have, however, been stepped out to give a base width of 9 feet which gives an exit gradient of 1 in 3.5 and is thus safe.

Breast Walls and their Design.—Both regulators are worked with vertical gates and a breast-wall is provided with the bottom of diaphragm at 489.0, the section being shown in Plate VIII.

The top of this is kept at 499.25, the same as the top of the flank wall, to provide for concentrated flow and impact from rolling logs of wood and wave action. The maximum water-level for purposes of design is assumed at 495.0 although the high flood level is 493.5 and the wind load is assumed at 40 lbs. per square foot.

The vertical stem has been designed as a cantilever fixed into the diaphragm slab under the above conditions.

Again it may be possible that the river be low and the vertical stem be subjected to wind pressure from the canal to the river side. To provide for this contingency, vertical stem has been considered as a cantilever. Steel has been provided to take up a wind pressure of

20 lbs. per square foot above pier level and 40 lbs. per square foot below.

To take into account the temperature and shrinkage stresses, steel equivalent to ·4 per cent. of the volume of the concrete has been used up to R. L. 495.0 and ·2 per cent. above. This steel has been divided half and half on both faces. Steel reinforcement has also been provided to enable the breast-wall to support itself under its own load.

Although it has been constructed as a continuous beam, moments are taken for partially fixed conditions due to its being sandwiched between the concrete masonry of piers and to allow for temperature and shrinkage stresses in the longitudinal direction, steel stresses have been limited to 12,000 lbs. per square inch.

The diaphragm has been designed as a continuous beam subjected to wind load and water pressure from the river side. Reinforcement has also been provided to enable it to withstand wind pressure from the canal side as a continuous beam in case the river water level falls below its bottom. It has further been designed as a continuous slab and reinforcement provided to enable the diaphragm to withstand its own load and to be strong enough against the maximum uplift pressure from the bottom when the river water level is 495.0.

The breast wall functioning as a cantilever and fixed to the diaphragm is likely to cause torsion in it. These stresses were worked out (Taylor & Thompson, Vol. 1, page 95) and found to be within safe limits.

Constructional Details.—The construction of the regulators presented no difficulties ; the deep foundations were all laid with local pumping. The concrete floor was tied with the top 1 : 2 : 4 skin with steel hooks embedded in the lower mass.

The superstructure was done with precast concrete blocks—the entry portion having been done with K. P. brickwork shuttering plastered from inside and wooden *chapties* nailed to give the effects of joint work.

The construction of breast walls in the past has necessitated very heavy and expensive shuttering. It was designed from architectural considerations to give this wall the finished look of precast block masonry.

The breast-wall was to be only 8 inches thick and about 8 feet high and as it was to be continuous across the full face of the regulator, the design of a suitable type of shuttering to give a surface in one vertical plane was a serious problem. This was, however, overcome by manufacturing precast blocks with two faces 8 inches apart and with lugs joining the faces spaced 6 inches vertically and 12 inches horizontally (see Fig. 3A). The reinforcement was recalculated to give this spacing in the two directions and put in. The blocks had to be slung through the vertical reinforcement and the horizontal reinforcement had to be pushed in from one side. Where reinforcement did not suit the spacing of the lugs it was hung from the lugs at the proper level by galvanised iron wire.

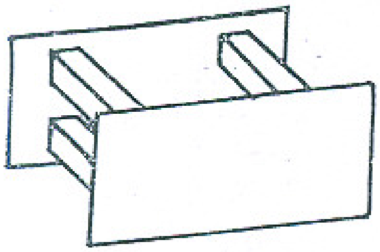


FIG. 3A

As the breast-wall was to be constructed as a single through beam it was intended to have no connection with piers through which it passed and to keep the two separated, the breast-wall was first constructed between the piers, then oiled and paper-lined and the pier concrete was dumped afterwards.

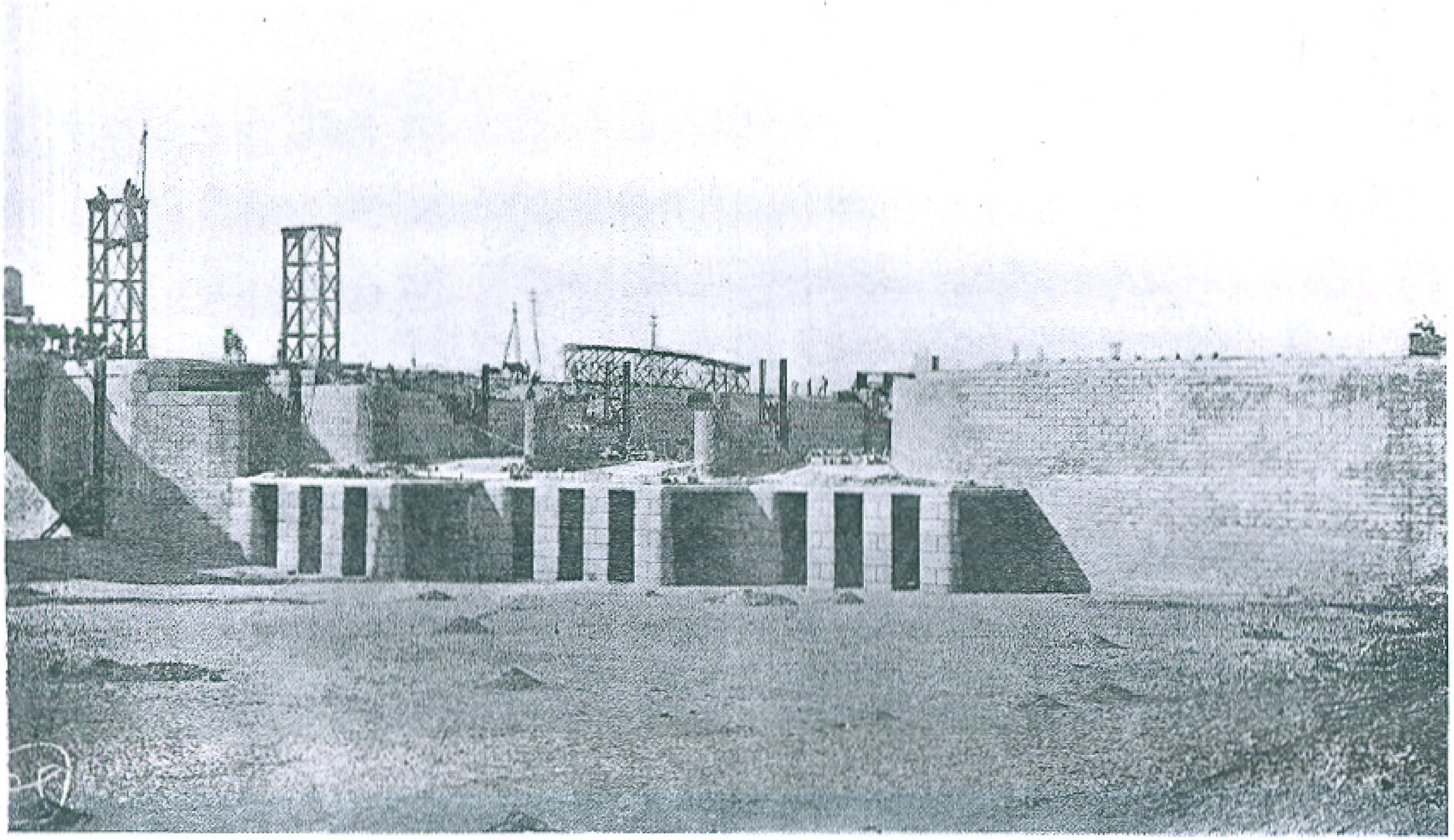
The diaphragm was constructed with sand-filling done under it and supported by masonry walls. The clearance between the regulator gate and the diaphragm edge was kept at 1/32-inch and to ensure its accuracy a channel iron was fixed to the end of the diaphragm being tied down to it by passing the reinforcement through hooks in the channel iron. This channel iron was also bolted to the grooves to ensure proper spacing between the gate and the diaphragm.

Silt Exclusion

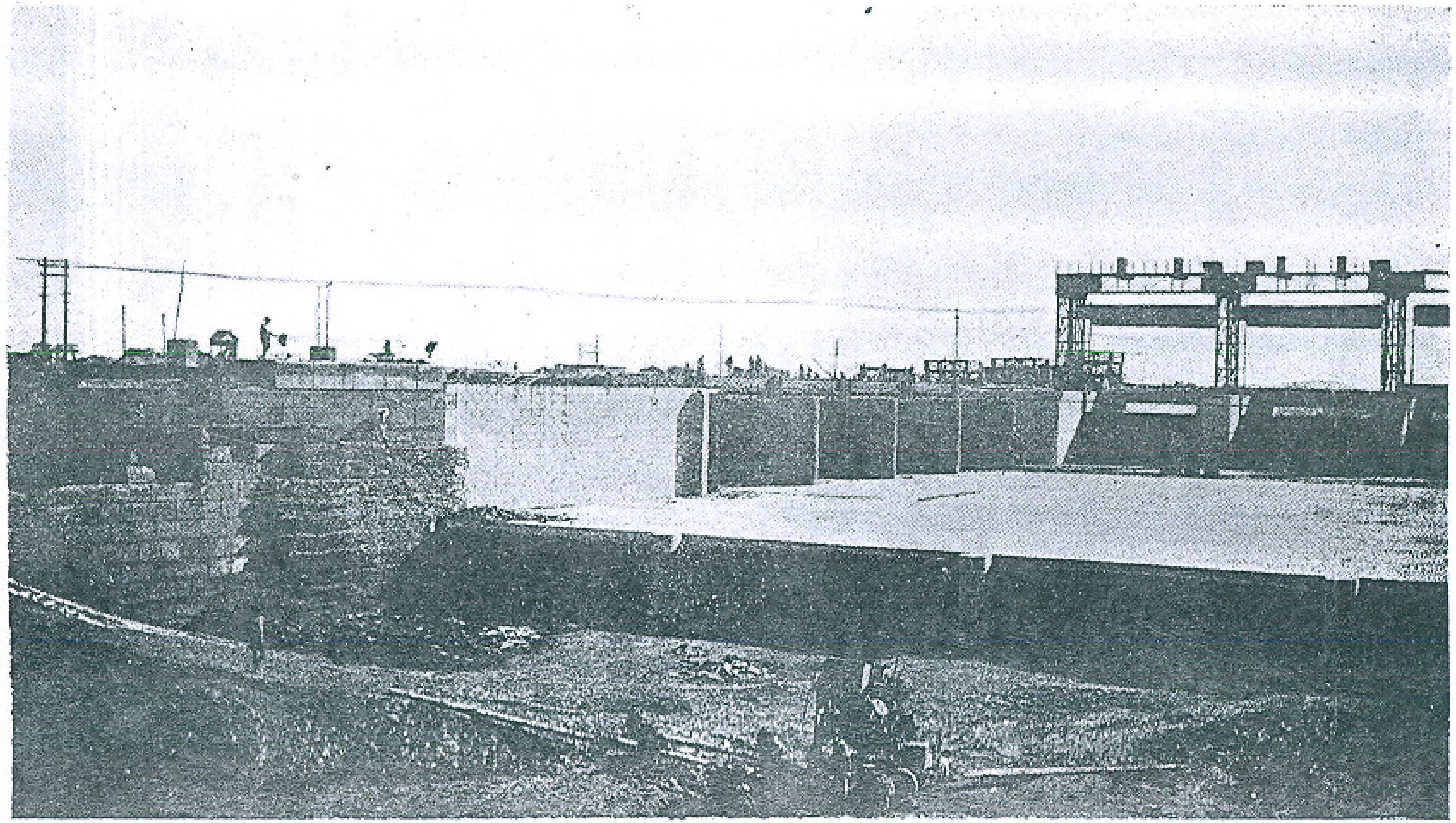
The Haveli Canal, which drops into the river above Sidhnai, has no fall in its length of 45 miles and is designed with a slope of 1 in 10,500. In low supplies flatter slopes would be obtained as a result of the heading up required at the regulator sites. This would give rise to silt deposits which would be scoured with the rise of supply. It was, therefore, essential to provide means to control the grade of silt entering the canal.

Of late a great advance has been made towards silt exclusion and full advantage of the knowledge and experience gained was taken at Trimmu by putting two silt-excluders, one opposite each regulator, in the undersluices. In addition to the above, two silt-ejectors have been constructed in the Haveli Canal and provision for one made in the Rangpur Canal.

The silt-exclusion in the Rangpur Canal was not so great a problem because the canal had a number of falls and any steepening of the slope could be adjusted and even if the trouble did arise, provision had been made for the construction of a silt ejector in the canal. This was, therefore, provided with a cheap type of excluder which is identical to the one constructed at Khanki. The undersluice bay adjacent to the regulator was used for the construction of this excluder in which three tunnels running parallel to the regulator face were provided.



SILT EXCLUDER IN RIGHT UNDERSLUICES.
Note the architectural effect.



SILT EXCLUDER TUNNELS IN LEFT UNDERSLUICES, VIEW FROM UPSTREAM.
Note the regulator taking off above the excluder slab.

They were covered with a reinforced cement slab at a level of 481.0 against 483.0 crest level of the regulator. This excluder is shown in photograph opposite and in Plate VIII. Each tunnel stepped out from the one next to it but farther from the regulator face and had openings both on the upstream and towards the pocket formed by columns supporting the slab.

Design of Left Excluder.—The silt excluder in the left undersluice (see photograph opposite) has been designed to give greater efficiency. The left undersluices, which have eight bays, have been divided into two portions by a divide wall going far out to give a smooth approach. The four bays adjacent to the regulator are covered with a slab at R. L. 481.0, the same as the crest level of the Haveli Regulator with its upstream edge normal to the river axis and extending beyond the regulator face, which ensured the separation of the escape water before turning into the regulators.

A silt-excluder covering half the width of the undersluices which formed an altogether separate pocket was bound to be very efficient, the efficiency being the maximum if the disturbance at the upstream end was the least, which would be done by keeping the width of the tunnels as great as possible.

The alternatives of keeping two tunnels and one tunnel in each bay were considered and although the larger spans would cost 25 per cent. extra, the consideration of the blockage of tunnels by jungle resulting in a reduced waterway brought about the decision in favour of the larger span and thus each undersluice bay under the slab is kept separate from the adjoining one and functions as an independent tunnel.

Slab Loading.—The slab of the excluder has been designed for various flow conditions. The maximum downward loading would occur when there is no flow on the top of the tunnel, the pond is at the maximum and the tunnels are discharging full bore freely. Under these conditions the discharge was first worked out by equating the total energy at the entry of the tunnels to the energy at the exit as:

$$7.25 + (q/7.25)^2 \times 1/2g + h_f + h_e = 20$$

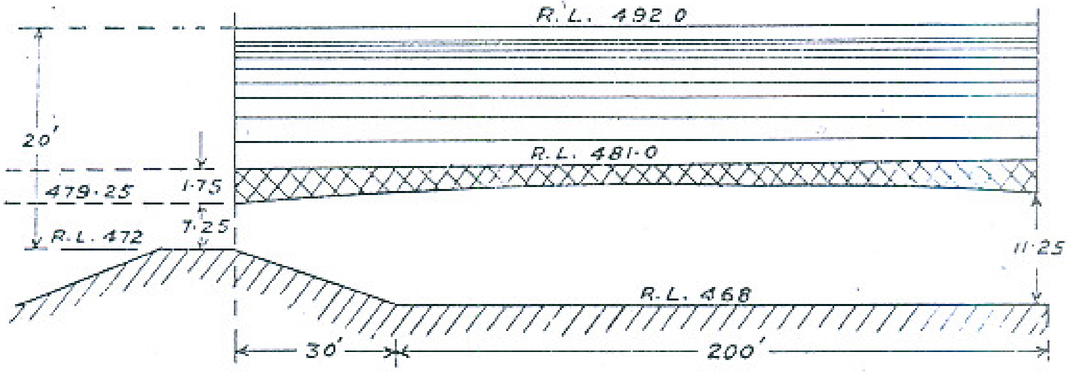


FIG. 4

h_f is the loss of head through friction and can be found out by Manning's formula $V = 100\,R^{\frac{2}{3}} \times S^{\frac{1}{2}}$ h_e is the loss of head at exit and is $\cdot 3\,\frac{V^2}{2g}$

The energy line under the tunnel is given by the total energy at entry less the loss at entry and loss due to friction up to each point as shown below:

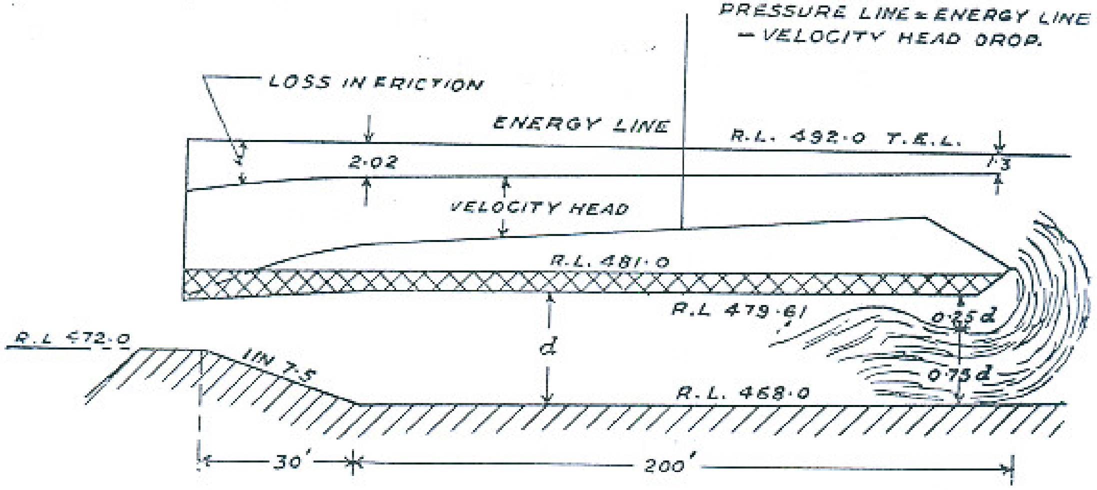


FIG. 5

The velocity head at each point is then worked out; at entry the section will be constricted and may be taken as $\frac{3}{4}$th of the normal. The velocity energy will be greater here but as the tunnel resumes full-bore running, this will decrease to a uniform figure and would again increase at the exit due to constriction in section. The velocity head and loss of head due to friction at various points is thus plotted and the total of these accounts for the difference between the pressure from above and below the slab. The slab is thus designed for a downward water pressure obtained as above plus the submerged load of the slab. In order to reduce the load of the slab a mixture of 1 : 1, $\frac{1}{2}$: 3 was used and concrete stresses were assumed at 100 lbs. per square inch, those for steel being 16,000 lbs. per square inch.

The pressures in the case of the water hammer were investigated but, as the gates would take at least three seconds to block the tunnel which was 230 feet long and had a section of 34′ × 11.67′ the pressures were negligible and were ignored.

The maximum uplift pressure on the tunnels would, however, occur when these are completely closed but water is flowing above and the uplift pressure would be the velocity head less submerged weight of slab as the friction loss would be too small to be considered.

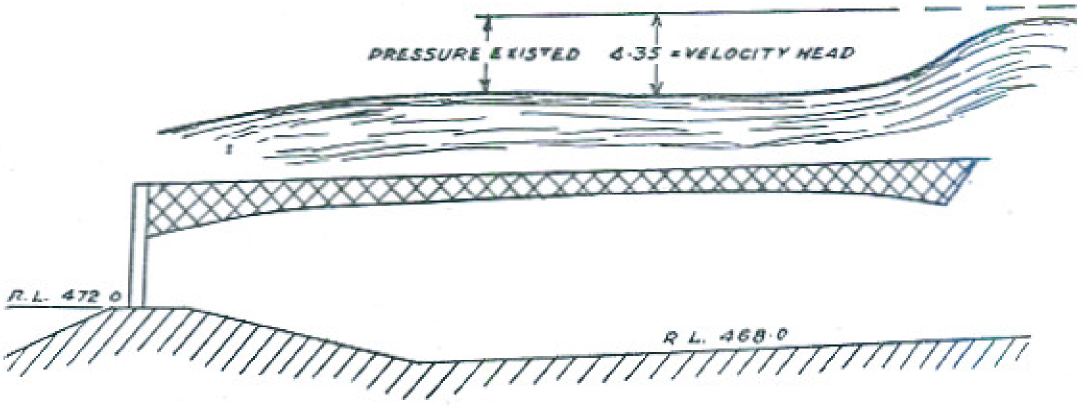


FIG 6

To obtain this the relative potential discharging capacity of the two tight points A & B was considered. $Q_A = 2.5\ B \times H^{3}/_{2}$ and $Q_B = 3.09\ B_2 \times H^{3}/_{2}$.

The pier width was such that $\frac{B_2}{B_1}$ was $2.\frac{5}{3}$ .08 and hence critical velocities occurred at both points simultaneously.

The first downward loading condition of flow would never be permitted in practice as the standing wave would shoot beyond the glacis, but the design was worked out independently as fool-proof; nor would the second condition be permitted as it could only occur in floods when tunnels must function, but since the uplift pressure due to the surging action in the case of simultaneous flow above and below the excluder slab could not be correctly estimated, the slab was designed to fully account for this condition.

Anchorage and Foundations.—The ends of the silt-excluder are fixed by the divide wall on one side and by the flank wall on the other except the opposite regulator face where it is tied down into the flank wall by steel; hence the slab is designed as a continuous one, partially fixed over a number of supports and ends rigidly fixed. As the design was to be strong enough both against the loading and upward lift, the section was doubly reinforced and thus slab thickness reduced.

The foundations for the tunnel walls beyond the floor of undersluices were worked out in accordance with Rankin's formulæ but, in the case of the floor portion of the undersluice which was to function as a raft, the pressure and the weight of the tunnel were accounted for in the design of the raft.

Silt Ejectors.—As a further precautionary measure against the silting of the canal, silt ejectors were constructed in the Haveli Main Line. It is well known that the efficiency of silt extraction is increased by multiplying the number of extractors and dividing the available discharge between them. Since a straight length of at least 1,000 feet is needed to permit silt to concentrate near the bed after it has crossed an obstruction resulting in turbulence and since escapage could not be economically arranged below R. D. 2,000 of the canal, only two silt ejectors could be put in. In each case it was arranged to utilise about 16 per cent. of the discharge available and hence the first extractor was to run with 1,200 cusecs and the second with 1,000 cusecs.

The approach channel has been designed with a very low value for "*f*" to permit the maximum concentration possible. The sides of the approach channel have further been pitched with dry brickwork.

Design of Silt Ejectors.—The ejectors consist (see Plate VIII) of triangular concrete slabs two feet above the bed-level and cover four tunnels running across the canal and discharging into the outfall channels over the broad-crested weir. Each of these tunnels is fed by eight orifices two feet high permitting the canal water to enter from the upstream side and intercept $\frac{1}{4}$th of the canal waterway. The discharging tunnels of the two ejectors are five feet and four feet wide respectively and are designed to run with a head of five feet and a velocity of 12.5 feet per square inch. The discharge through each orifice is kept the same. The total loss of head through each tunnel is first worked out by taking Kutter's $N = .01480$, the total drop being five feet, the head available for generating the velocity through each tunnel is thus worked out. The width of each orifice is then found out by $Q = 5\ b\ d\sqrt{H}$.

At the control weir the depth on crest to pass the designed discharge of 1,200 cusecs is given by $1{,}200 = 4 \times 6 \times 3.1\ H^{3/2}$. This gives $H = 6.5$.

The T. E. L. being 5.0 feet below canal F. S. L. the crest level= Canal F. S. L.—5.0—6.5.

The control on escapage at the crest is obtained by the provision of gates. The limit within which the ejectors would work correspond to the downstream water-level (475.0 to 484.0).

The downstream floor level of the ejectors has been kept sufficiently low to retain the standing wave under all conditions which may occur in practice. The subsoil flow into the outfall required careful consideration as the work would be subjected to converging flow from the general water table on three sides and parallel flow from the canal. The worst condition would occur when the canal would be in flow and the river downstream the minimum, *i.e.*, 468.0. A minimum head of 12—15 feet would be exerted as the spring-level would be about 480—483 and to meet these conditions a line of sheet piling is provided on three sides under the wings and a system of pressure relief consisting of a filter discharging through pipes and silt traps is provided under the floor (Plate VIII). The object of the silt-trap is to prevent the filter from being choked by reverse flow when downstream water-level is above spring-level. Both the silt ejectors have been fitted with sets of pressure pipes.

The construction of the excluders presented no serious difficulty; the excluder tunnel walls were constructed with precast concrete blocks serving as shuttering. For laying the slabs the tunnels were filled with sand and plastered over with a mortar 1 in 8 on which the slab was laid.

Special pumping had to be resorted to for the construction of ejectors, which then proceeded on the same lines as the main weir work.

The outfall channels which connect the ejectors to the river were dug to the level possible at the time of construction and it was left to the ejector discharge to work its own way later.

Guide Banks (Type and Alignment)

There has been a considerable controversy in the past as to the relative merits of various types of guide banks—the Bell's Straight and Bottle-necked. All these types have been tried on the S. V. P. and the Bell's Type was found to be the most satisfactory. This type suits a canal headworks better than the others from the point of view of ease in regulation and silt entry into the canals.

The exact alignment of the guide banks is shown on Plate IX which is a slight modification of Bell's Type.

Sections (Plate IX)

The protection was designed in accordance with the principles enunciated in Chapter IX of Spring's book on River Training and C. B. I. Publication No. 12. The banks which have a free board of 6.5 feet are 30 feet wide at the shank, widening out 60 feet, in the curved portion with 2 : 1 inner slope and 3 : 1 outer slope. It is protected at the back to a length of 500 feet where it has a slope of 2 : 1 on both sides. Banks have been given a covering of 2.0 *pacca* earth except under pitching, where it is 1.0 foot, and the protection consists of 1.3-foot uncoursed stone pitching lying over 0.7-foot spawls top of protection being 3 feet above H. F. L. The design of the apron is governed by scour considerations as below:

Maximum discharge=6,45,000 cusecs.

$\text{WP}=2.67\ Q^{\frac{1}{2}}$ therefore $\text{WP}-\frac{800\times 8}{3}$

$q=\text{discharge per foot run}=\frac{645000\times 3}{800\times 8}=300$ cusecs.

$V.=1.17\sqrt{R}$ if $f=1$ $q=300=1.17\ R^{3/2}$
therefore, R=41 feet.

From construction considerations it was decided that aprons would be laid at a level of 475.0, *viz.*, 18.5 below flood level. At nose the deepest scour was taken as 2.25R=92 feet or 73.5 feet below apron bed. In order to cover the scoured slope which would stand at 2 to 1 with stone 2 feet thick a total of 331 cubic feet of stone was required in the apron at nose. In the shank portion as the flow would be normal, scour would be nearly equal to R, *i.e.*, 41 feet or 22.5 feet below the apron and hence in shank apron stone worked out to 101 cubic feet.

The quantity of the stone in aprons, however, was kept the same as for Panjnad which provided 300 cubic feet at nose and 113 cubic feet along the shank with a transition length of 500 feet. As the curved portion of the right upstream guide bank was to be subjected to severer river action as compared with the left guide bank, 25 per cent. extra stone was allowed in the apron of the former.

Downstream Guide Banks.—The downstream guide banks are 30 feet wide and side slopes of 2 to 1 on the apron side and 3 to 1 on *bela* side, have a free board of 6.5 feet and splay out at 1 in 5. The river concentration being on the right, the length of the downstream right guide bank was kept at 800 feet, while the left was to be 600 feet long. Similarly, the apron on the right was to have 25 per cent. extra stone. The aprons were designed on the same lines as the upstream and the noses are protected with aprons going back to a width of 100 feet.

Constructional Details.—In accordance with the programme the right upstream guide bank was to be ready for action in summer, 1938. The work was started in October, 1937. The earth from the excavation of the apron was used in the banks, the surplus having been dumped behind to give extra strength in floods. As a result of general pumping in the weir area, the subsoil was low and in the shank portion aprons could be laid dry but near the nose pumping had to be resorted to. Work on the stone aprons was started in December 1937, and within the next three months this guide bank was completed. The material was carried to site by B. G. Track which ran parallel to the guide banks and the back portion was fed by N. G. track.

The work on the left guide bank was started in the winter of 1937-38 and, although the excavation was practically done, there was no stone available for the aprons. The excavated bed of the apron was, therefore, suitably protected from floods by surplus earth from excavation and this guide bank was completed in March, 1939.

The downstream guide banks and the portions of the upstream guide banks adjacent to the pockets were completed along with the pockets, and their construction was facilitated by the pumping done in the pockets.

Protection Works

Plate IX shows the various protective bunds put in during the floods of 1938. A main ring bund was constructed round the work with earth excavated out of the weir area.

In addition to the weir area, the excavated apron of the left guide bank had to be protected and a small ring bund was put round it for the purpose. A bund connecting R. D. 3,000 of guide banks was put in further up to protect the railway line which served the upstream weir area and also to preserve the creek portion on the right side which later was to be used for purposes of diversion. Incidentally, it gave an opportunity to excavate diversion cuts during the hot weather. Another bund was put in to preserve this creek higher up which encircled the creek and connected the right guide bank at 4,200 with the bund connecting R. D. 3,000 of both guide banks.

Thus three lines of defence as shown on the plan were put in and this ensured complete safety within the working area. The construction of the right guide bank would keep the main river beyond its nose but there was nothing to protect the ring bund on the river side from the river attack and, in order to keep the main current further away to the right, a spur (Item 6, Plate IX) pitched with stone was constructed as shown in the plan. The outer portions of the ring bund, which were exposed to river attack, were pitched with *pilchhi*.

Diversion and Other River Works

A complete description of river diversion has been given in Paper No. 229, presented by the author to the Punjab Engineering Congress in 1939, and as such this subject will not be dealt with here. The river was finally diverted in December as per programme. The construction of the Rangpur Canal and the Right Marginal Bund in the river reach were taken in hand early in October on *belas* and as the creeks were diverted or closed, work was advanced through them.

The Rangpur Canal in the river portion has only one bank on the left side. After allowing wide berms, the right marginal bund forms the second bank. The marginal bund is 20 feet at the top end of the sections as shown in Plate VI. It is pitched with stone against wave action on the upstream side in the river portion. A slope of 1 in 10 has been assumed for work under water and on the downstream side it is designed for a hydraulic gradient of 1 in 7. The canal bank is also designed for a similar hydraulic gradient of 1 in 7. There was no *pacca* earth available in these two miles of the canal and, therefore, the embankments were covered with *pacca* earth covering brought from a distance of two miles which was partly done by donkeys and mostly by running N. G. rakes. The work was completed by March, 1939.

Pumping

As stated previously, sumps were generally located about 300 feet apart. In addition to these, additional sumps were necessary in pockets upstream and downstream and at other places whence drains to existing sumps were either not desirable or were not possible. Plate V shows the sites of the various sumps.

At each of these sumps about 4 to 5 pumps on an avarage were installed. The pumped water had to be discharged outside into the open drains which all joined in a main drain leading to the old river creek outside the ring bund enclosing the weir area. The open drains were all on the unexcavated *bela* and as such delivery lines were generally 100—200 feet long. A pipe delivery of this length would have resulted in excessive friction rendering most pumps inefficient when the water level had reached about 25 feet below the delivery level.

To guard against this, semi-circular sheet iron troughs were manufactured in the workshops at Trimmu and the pumps delivered into these open troughs which replaced the delivery pipes and led water to the drains on the *bela* by gravity. These troughs were supported by vertical *balli* staging which, to ensure stability, was driven deep by a high pressure water jet from a positive pump. The spacing of these *ballies* was just enough to permit the troughs to take their own weight and that of water and they were strutted to withstand wind action against the troughs.

A total of 3,000 l.ft. of troughs were manufactured and 5,000 l.ft. of piping used.

Two-Stage Pumping Plan.—Plate V shows the scheme of pumping. Water was led to the open drain by the pump deliveries and thus discharged outside the ring bund in three groups—right, left and centre. The general water-level in the drains was 86.0 and, at the site of the ring bund, 85.0. It was thus apparent that, during floods, if the downstream river water-level rose above 85.0, the pumps would cease functioning, resulting in flooding, which could not be permitted. As this could only happen during floods, it would have been uneconomical to keep on discharging at high levels continuously. Provision was, therefore, made for double-stage pumping as per arrangement shown in Plate V. The drains dropped into a cistern which was connected with a masonry shaft through an opening at the bottom and operated by gates. This shaft was constructed sufficiently high above flood level and discharged outside the ring bund by 20-inch pipes in the case of the right and left and by a R. C. syphon in the case of the central drain. Pumps were installed which would work during floods when the opening between the shaft and the cistern was to be closed by gates. The pumps would pump from the cistern and discharge into the shaft against the flood water. As there would be a paucity of power at such times, the chances of double-stage pumping were further decreased by constructing a three-mile long embankment parallel to the creek on the *bela* with the top above the H. F. L. This ensured that the downstream water level would be the backwater from the flood level three miles down.

As a result of this embankment, the necessity of double-stage pumping arose on one occasion, only for a few hours. In addition to the pumping plant required to work on these sumps to keep the general subsoil water low, a number of small pumps were used on open pumping where the laying of deep foundations required local concentration. A number of high-pressure pumps were required for (*a*) washing and cleaning the 9-inch slab before the laying in of the reinforced concrete; (*b*) for washing the ballast; and (*c*) for curing the masonry and concrete. Pumps were also required to pump out the water of the floor washings when it could not be freely drained.

Plant and Power Generation

Power was required for pumping as above for driving the concrete mixers and compressors which, in turn, either worked the vibrators or air jets to do the cleaning under reinforcement. The machinery available could be divided up into three kinds of prime movers. The steam engines, the oil engines and the electric power. A list of the total plant and machinery used on the works is printed as Appendix "B."

The Power House, which started working on the 4th January, 1938, consisted of two No. 125 K. W. sets and 3 No. 140 K. W. sets. It was proposed to instal one more power set and an order was placed for the same as previously stated but it could not arrive in time and, although one of these sets ought to have been kept as a standbye, the demand after June, 1938, became so keen that all these sets had to work continuously to cope with the demand. The efficiency of the three old Peter sets went down considerably with the rise of temperature in the hot weather. The result was frequent breakdowns and a time came when the demand on power increased to such an extent that it could not be met. High river caused an increase in seepage and pumping discharge rose to 60 cusecs against a head of 32 feet.

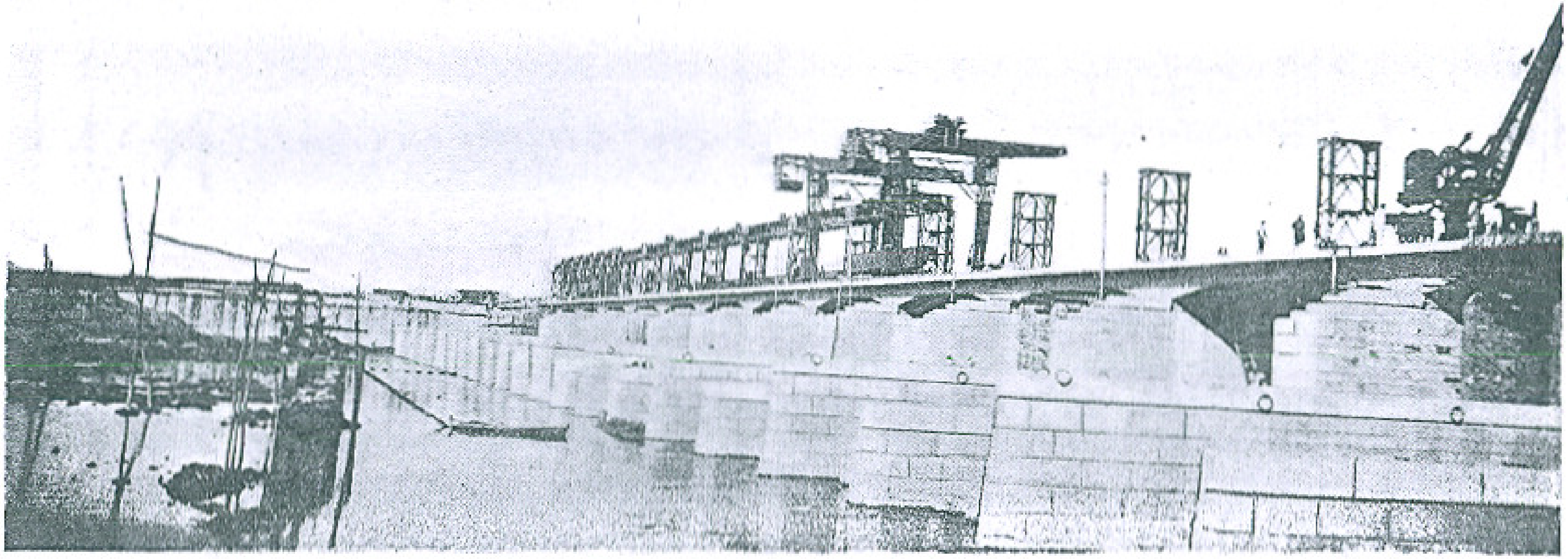
As more and more area became available for concreting, a greater number of mixers were required to run. All available plant in the Department had been collected and was in use at Trimmu but was found to be insufficient. Consequently, four second-hand portable steam engines were purchased from the open market and were put into action and five N. G. Locos after suitable alterations were used to drive the concrete mixers. This solved the problem. A number of electric-driven mixers were converted to be driven by steam engines. Further, the oil engines which used to drive the crusher were requisitioned and put on driving mixers. At one time even the rationing of power had to be done. With, however, the purchase of extra portables from the open market and the covering of a considerable area the strain on pumping decreased and consequently the power situation was solved. The total H. P. available in the steam engines was 576 excluding B. G. and N. G. Locos and in oil engines 398. The Power House used to transmit energy at 3,300 volts and three substations were erected on the works for stepping it down to 440 volts. The total quantity of copper used in transmission lines was 12.5 tons.

Workshops

In the earlies, a temporary workshop was erected along the railway line which shifted as the railhead proceeded. Later, a temporary workshop in the station area was erected, the machinery of which was run by Peter engines. The permanent workshops consisted of lathes 20 ft., 15 ft., 8 ft. and 6 ft., one radial drill, one pillar drilling machine, shaping machine, saw-sharpener, sensitive drill, tool-grinder, two band-saws, cupola, two blowers, riveter, shearing and punching machine, hacksaw, boring lathe and mechanical hammer in addition to a large number of temporary presses.

Steel Erection

Description.—Tenders were called for the gates and gearing of the Emerson Barrage and the Regulators and the tender of the Central Workshops was accepted at Rs. 18 lacs. The gates working on the "Stoney" principle are 15.5 feet high for the weir. The undersluices have two gates, one vertically over the other with a height of 9 feet and 12 feet respectively. They consist of ⅜-inch thick steel skin plate supported at suitable intervals on horizontal bowstring girders of the lattice type rigidly connected to vertical end posts of steel and have a self-adjusting staunching bar bearing on the gate face and groove on the upstream attached to them. Fixed roller paths are provided in the gate ends and grooves and between these roller paths stoney rollers operate which, made from high tensile copper bearing steel, are of the trunnion type. The gates are suspended by steel ropes which pass



ERECTION IN ALL STAGES
Note gantries lifting counterbalances.

round the spirally-grooved steel drums and carry counterbalance boxes on the other end. These drums, located in the framework of the superstructure, have completely enclosed roller bearings running in oil baths and are operated by spur-wheeled gearing from centrally located winches. The weir gates are 24½ tons each, whereas the undersluice gates are 11½ and 22 tons respectively. Both the undersluice gates operate in the same groove but on different roller paths and each gate has its own gearing and counter-balance box. The winches have reduction gears 80 to 1 and the total lifting time for the weir and undersluice gates is nearly 14 and 18 minutes respectively. The superstructure is 27 feet above the road level of the bridge. Grooves are provided with scouring ducts at the bottom.

Execution.—The cill girders were first accurately grouted in the crest. These were in three pieces for weir bays and two for undersluices and a gap of ¼ inch was left between the adjacent sections to take temperature effects during erection. To ensure absolute accuracy in span length and horizontal alignment of grooves the ends of cill girders had holes which received locating pins fitted to the bottom of the grooves. Special jigs were fitted on these holes to ensure correct spacing between the adjacent cill girders. Grooves were then bolted to these cill girders which, when erected, formed their own shuttering and concrete was poured at the back. In order to fix the position of superstructure columns, 6 feet deep foundation bolts, rigidly fixed at the bottom in the pier concrete, were provided.

The setting of these foundation bolts was done by means of a jig from the groove which in turn had been rigidly fixed to the cill girders. Three-inch diameter holes were, however, left round the foundation bolts to permit slight adjustments in the column position at the time of final bolting after which these were grouted.

It was arranged that the road bridge would be available for steel erection. The laying of cill girders started on 9th May, 1938, and the road bridge was available for steel erection on 28th November, 1938. Ninety-five per cent. of the steel came from Tatas and the steelwork was manufactured at the Central Workshops and railed to Trimmu.

Slipways and Erection.—Everything came in complete units except the weir gates which came in two halves and were rivetted at site. Steel erection was proposed to be started from both ends and, in order to carry the heavy parts from B. G. trucks on which these were loaded at Amritsar to the road bridge, two sets of slipways, one on either flank, were erected. These slipways consisted of five pairs of 250-foot long inclined tracks with 60-lb. rails fixed to firewood sleepers which, in turn, were supported on masonry pillars 15 feet apart of increasing height. The rail level of the lowest pillar was the same as that of the platform of a standard railway bogie truck and of the highest the same as the top of the special platform trolley resting on a track at the road bridge level.

The trucks were parked at the foot of the slipway and the unloading of the heavy parts was done by their haulage on the slipway by means of a crab-winch fixed at the upper end. With the same winch later these heavy parts were hauled up onto the material trollies at bridge level which carried them to the site. In order to effect speedy erection, two sets of gantries costing Rs. 62,000 were used. These consisted essentially of 8-ton capacity electrically operated travelling hoists mounted on a track fixed to the top gantry frame, which was cantilevered out beyond the bridge to such an extent that a gate would be lifted by the hoists which would then travel out so as to plumb the grooves and then lower the gate in position.

In addition, a 10-ton crane was used to erect columns in advance. Two small gantries fitted with three-ton capacity wormgear travelling pulley blocks were used to erect the small parts of superstructure from the top of the overbridge.

The erection with the gantries took one day per bay against one month taken to erect the steel of six bays of the right undersluices by means of a crane and was completed on 25th March, 1939, the total steel used in erection being 3,000 tons.

Layout

As soon as the weir line was fixed and excavation started, it was essential to fix the centre line of the weir which would form a permanent baseline for future layout. Two observation towers (see photograph) were constructed on either end on the weir line and theodolites were permanently mounted and fixed on to masonry pillars on the top of the tower. The weir line could always be relaid with the help of these and permanent vertical lines were painted on the theodolite base columns for sighting from the other side. The distance between these two points was obtained by checked triangulation. As the pier under the foundation stone was the first one to be constructed, its position was determined by ordinary steel tape measurements and all further measurements done from that. As steelwork was being manufactured and assembled at Amritsar, a site different from where building work was being done, it was absolutely essential to work on standard units of measurements so that the steelwork and building work fit each other in all dimensions. It was noticed that, although steel tapes were supposed to give standard measurements at 68°F., even when new no two steel tapes would agree in their length. Invar metal is least affected with change of temperature ; hence two invar tapes, marked 100 and 50 feet, were used. The cill girder length was marked on both and all steelwork manufactured on that basis and the other invar tape dictated the measurements in the field. All measurements were generally done during morning hours in summer and with the spring balance exerting a certain fixed pull on the tape. The two invar tapes were occasionally checked with each other and the value of the spring balance pulls adjusted to confirm to the standard on which steelwork manufacture had been based (a specific steel tape with 12-lb. pull at 95° F.).

General Organisation

Except for the quarry and portions of the marginal bunds outside the river area, the entire work in the Headworks was done by the Trimmu Division which had six sub-divisions, *viz.*, Headworks Left, Headworks Right, Weir, Power, Materials and Executive ; the officer in charge of the latter also acted as Personal Assistant to the Executive Engineer and had charge of the Station Area and welfare work and land acquisition.

Contractors and Labour.—A departure from the past on this construction had been the employment of a large number of contractors. This ensured a large capital to be utilised in the work and, at the same time, a greater and larger organisation interested in the successful completion of it. The programme of work took into account the continued employment of all types of labour, for example, in the beginning the donkeys were needed the most and certain works involving excavation, carriage of materials, etc., were started to collect them.

A large number of coolies would be required for the concreting and construction of buildings ; tramming of earth and stone dumping were, therefore, started to collect sufficient labour in advance. Similarly, full account was taken of the number of masons, artificers, carpenters, etc., required at various stages of the work and enough work was reserved for slack periods so as to keep the labour busy and available for the work to be completed in time. In spite of this, there were times when labour shortage was acutely felt and special concessions in the form of railway freight and extra rates were allowed on various items. These special rates were given in the harvest period and also in the months of August and September during the hot weather. For the diversion work it was realised that about 3,000 donkeys would be required continuously for about four months and if they were not to come in time, the operations were likely to be delayed, involving greater cost and delays and lesser possibilities of success. Consequently, importation charges were sanctioned for donkey labour for this work and the success of diversion operations is mainly due to the sanction of such allowances.

Another feature of the organisation was a number of reserve works and their distribution according to labour to be employed at specific periods. These reserve works were also useful at times of dislocation of work due to the failure of power, which was a very rare occurrence, or other causes. The supply of material was also controlled in accordance with labour requirements.

Field Offices.—The site of work was situated at about two miles from the residential quarters and, therefore, field offices for officers and subordinates were constructed at the site of works. This ensured a very high efficiency as it enabled the officers to be on the works at all hours of the day, thus ensuring very close supervision.

Materials.—The despatch, receipt and distribution of materials at their proper site and at the right time was most essential for successful completion. The stone rakes were run according to a definite time-table from quarry to work sidings and back. The organisation and time-table for local shunting was different from the organisation and time-table of running of stone rakes. Most of the local shunting and shifting of machinery, unloading at site, etc., was done during the night to facilitate which extensive lighting arrangements were made on the works which, in addition to a large number of lighting points, also consisted of 11 flood lights of 1,500 watts. The establishment for night duty was different from that employed during the day and was entrusted with definite jobs to be completed during the night.

In general concrete mixers, N. G. trucks and concrete dumps were cleaned up and the working area tidied.

General.—Generally one overseer was deputed for each concreting face although there were some exceptions at times and each operation was under direct supervision of a *mistri*. Payments to contractors were made at least twice a month. Odd jobs were generally done through departmental labour which also formed enough reserve in case of emergencies. A schedule of rates having been drawn up on the basis of tenders, works were distributed to contractors according to their capacity. 500 B. G. Trucks, seven B. G. Locos, three Weighbridges and 36 miles of B. G. Track were laid for the internal traffic at the headworks and quarries. About 70,000 cubic feet of material was handled per day although on many occasions figures reached over a lakh. The Traffic Staff consisted of four Station Masters, five Railway Guards, three Train Examiners assisted by about a dozen material *mistries* and a material surveyor.

Contracts and Concessions

The alternative of using lime instead of cement was contemplated at one time because lime would be cheaper in some places. The total quantity of cement was worked out if the use of lime was to be avoided altogether and the Associated Cement Companies of India, in order to encourage the use of cement on the work, allowed a concession rate of Rs. 25 per ton for cement used on the Barrage and Rs. 20 per ton on the lining of canals. The North Western Railway had allowed a concession in the form of reduced railway freight on cement during the construction of the Sutlej Valley Project. This was again granted and amounted to six annas per maund against 11 annas per maund from Wah.

In view of the large requirements, negotiations were carried out with the Tata Iron and Steel Co. for the supply of reinforcement and other structural steel and concession rates obtained.

All cement bags were returned to the manufacturers to be refilled with cement and, although it was thought that each bag would make four trips, it could not make more than two on account of the reduced time of construction.

General

The accompanying Appendices give some useful information and Statement I gives the total quantities of the various works executed; Statement II also gives the total quantities of the material obtained. Statement III gives labour figures by months. Statement IV gives the approximate cost of the works.

Opening of Barrage

The river was completely diverted on to the right undersluice on the 17th December, 1938. A flood came in the third week of February when the entire right half, segregated from the left by heavy protected embankment, came into action. Before this flood subsided, there was another big rise which reached Trimmu on the 1st March. The river rose 180,000 to 200,000 cusecs on 3rd March. The work on the left had just been completed and although the right half had cleared away considerably, yet, due to enormous *belas* downstream which had still to be scoured, the water-level rose considerably and was 1.8 foot above the maximum flood-level ever recorded. The river seemed to be rising still further and was causing considerable panic in the villages upstream. The left side was opened to the river and the entire barrage came under action. The gates had not yet been fixed in the regulators and temporary walls had been erected to prevent the water entering the canals. On the right side, there were leakages and on the left the wall collapsed on the 5th evening, letting flood water into the canal. Luckily a bund across the canal existed at R. D. 8,000 which was immediately strengthened and the canal saved from flooding. The water escaped into the station area and outflanked the two silt ejectors under construction on the Haveli Canal. Bunds round the station area and close to the ejectors were cut to relieve the station area of flood water. Some damage occurred to temporary buildings and material but the flood subsided and the water drained back by next morning.

This caused a setback in the work on the ejectors which were, however, pushed with great vigour and the barrage was officially opened on the appointed date, the 2nd of April, by His Excellency Sir Henry Duffield Craik, the Governor of the Punjab.

During the following years the barrage has worked quite satisfactorily. Pressures below the floor are less than those anticipated and *belas* have been mostly washed away.

Conclusions for Speeding the Work

Generally the preliminaries in the past have taken considerable time and it is here that a considerable amount of time can be cut down.

The work must be started in the spring and the preliminaries should be completed by the end of the hot weather. About three to four officers would be necessary in the beginning for the collection of materials and machinery, placing orders for stores, preparing estimates and working out the programme and the quantities. The burning of the kiln should start before the monsoons set in. In order to get the work going in full swing in the following cold weather, the work on the buildings should be completed by December at the latest so as to house all establishment and the order of preference should be meanials upwards.

Preferably the whole of the weir area should be opened out and the far side of the weir through which the river can be diverted prior to the full completion should be completed by the end of the next hot weather and the diversion must take place the following winter at a time when the river is most tame and has the least discharge. The rest of the work can then be completed in due course.

The greater the number of contractors, the better. The number should, however, be limited by the consideration that they are all kept continuously employed.

There should be an ample reserve of power if possible because the secret of successful work rests with the prime movers for mixers and the pumping capacity.

There should be a certain amount of reserve work such as construction of marginal bunds, carriage of materials, excavation of canals where both basket labour and donkey labour can be kept busy when not required on works and there should be no hurry to execute these.

There should be a liberal provision of railway sidings at the site of work so that unnecessary lead is avoided and works are expedited. There should be a liberal provision for stacking ground on the work for which reason the ring bund round the weir work should be well set back which will incidentally help to reduce seepage during floods.

Mechanical jobs should be done departmentally as it is generally very uncertain when they would arise and no contractor can afford to keep labour idle. It is desirable to execute all odd jobs departmentally as this would ensure maintaining labour for emergent jobs which contractors may not be able to undertake efficiently and economically.

Acknowledgements

Rai Bahadur A. N. Khosla was responsible for the entire organisation, planning and construction of the Barrage. The work was carried out in Mr. J. D. H. Bedford's administration and the superintendence of Mr. F. F. Haigh. The designs, excepting the Canal silt-ejectors, were all prepared in the Central Design Office under the Directorship of R. S. Kanwar Sain. The silt-ejectors on the Haveli Canal were designed by Mr. F. F. Haigh. The steelwork was designed by Mr. W. G. Wheatley who was also responsible for the erection organisation. The following Officers held charge of the various Sub-Divisions between 1st April, 1937 and 1st April, 1939, the period of construction :

Headworks Left	.. Mr. A. R. Khanna (also Messrs. B. S. Talwani and S. N. Kapur).
Weir	.. Mr. M. R. Chopra.
Headworks Right	.. Mr. S. N. Kapur (also Mr. C. P. Malik.)
Personal Assistant	.. Mr. C. L. Handa, Mr. A. N. Malhotra (also Mr. M. L. Aggarwal).
Power	.. Mr. B. L. Sakuja.
Materials	.. Mr. S. M. Saeed (also Messrs. S. N. Kapur and B. S. Talwani).
Steelwork	.. Mr. F. E. J. Connolly was the Sub-Divisional Officer of the Central Workshops in charge of steel erection.

APPENDIX "A"

STATEMENT OF BUILDINGS CONSTRUCTED AT TRIMMU

	Permanent	*Temporary*
Divisional Office	1	2
Sub-Divisional Office and Field Office	1	7
Compounder's and Dai's Quarters	..	2
S. D. O.s' Bungalows	1	6
Executive Engineers' Bungalows	1	1
Subordinate Quarters	4	22
Junior Clerks' Quarters	11	58
Senior Clerks' Quarters	5	13
Menials' Quarters	20	54
Mistris' Quarters	6	90
Cement Godown	2	1
Coolies' Quarters	..	108
Sub-Stations	..	3
Teachers' Quarters	..	12
Bazar Shops	..	10
Regulation Beldars' Quarters	35	..

S. A. S.'s quarter and Dispensary, Post and Telegraph Office, Canal Telegraph and Exchange Office, Segregation Hut, Power House, Weigh-bridge, Oil Godown, two Pump Houses, Rest-house and subsidiary buildings were the additional permanent and indoor ward, Recreation Hall, Cholera Block, Boys' School, Girls' School, Police Post and Workshop were the additional temporary buildings.

APPENDIX "B"

STATEMENT OF PLANT AND MACHINERY USED

18 Portable Steam Engines, two Fowler Tractor Steam Engines, seven 35 H. P. Ruston Oil Engines, three Peter Oil Engines, seven B. G. Locos, five N. G. Locos, one Steam Hoist, four Excavators, four Pile-drivers, four Air Compressors, two Steam Cranes, two Bernard Pumping sets 4-inch and 6-inch, one Crossley Pumping Set 5-inch, three $\frac{1}{4}$-cubic-yard Concrete Mixers Fowler's, one Parker $\frac{1}{4}$-cubic-yard Concrete Mixer, two one-cubic-yard-capacity Rex Engine-driven Mixers, one $\frac{1}{2}$-cubic-yard-capacity Peter Engine-driven Concrete Mixer, one $\frac{1}{8}$-cubic-yard Peter Engine-driven Mixer, two Granulators, three Small Hand-operated Concrete Mixers, two Oxyacetylene Cutting Plants, three 140-K. W. Generating Sets and two 125-K. W. Generating Sets, eight Transformers, one Electric Welding Plant, one Dredger Pump, 18 8-inch Electric Pumps, seven $^{10}/_{12}$-inch Electric Pumps, three 6-inch Electric Pumps, $12\frac{3}{4}$-inch Electric Pumps, 23 2-inch Electric Pumps, 10 16/14 and 12/10 Centrifugal Pumps, seven 10/8-inch Centrifugal Pumps and two 6-inch Centrifugal Pumps, 14 one-cubic-yard Concrete Mixers with Electric Motors, two $\frac{1}{4}$-cubic-yard Electric-driven Concrete Mixers, one Grouting Machine, two Merryweather Pumps, one Evinrude Pump, four Stone-crushers, four Electric Hoists, 15 Crab-winches, one Coaling Crane, two Portable Cranes, one Overhead Crane, one Turntable, one Weighbridge, 38 Bull's Dredgers of different capacities, eight Skips, 506 N. G. Trucks, 500 B. G. Trucks, seven miles N. G. Track, 36 miles B. G. Track, and seven Vibrators.

TELEPHONES

Telephones at Trimmu

Bungalows for Officers	9	Sub-stations	3	Mudduki Canal and Railway Station	2
Offices for Officers	9	Rest-house	1	Trimmu Railway Station	1
Power House	1	Kiln	1	Dispensary	1
Overseer, Supply, Office	1	Jhang	1	Right Pocket	1
		General	1	Right Guide Bank	1

STATEMENT I

QUANTITIES OF MATERIALS USED AND WORK EXECUTED

Cement	36,340 Tons.	Spawls	15,75,189 C.ft.
Ballast	41,01,604 C.ft.	Bricks	1,86,04,518 No.
Empty Cement Bags	2,70,516 No.	M. S. Angles	161 Tons.
M. S. Flat	40 Tons.	Other iron of sorts	40 Tons.
Channel Iron	51 Tons.	Fuel Oil	2,88,083 Glns.
Lubricating Oil	43,554 Glns.	K. Oil	2,200 Tons.
Cotton Waste	11 Tons.	Deodar Logs	5,653 C.ft.
Kail Logs	22,790 C.ft.	Sal *Ballies*	7,685 No.
Sal *Tor*	5,426 No.	Coir Rope	7 Tons.
G. I. Wire	66 Tons.	Copper Cable	3 Tons.
Copper Wire	9.5 Tons.	Carbide	1 Ton.
Stone	76,40,177 C.ft.	Earthwork	14.7 Crore C.ft.
Crushed Ballast	6,77,423 C.ft.	Stone filling and pitching	67.03 Lakh C.ft.
M. S. Bars	3,562 Tons.	Concreting	54.79 Lakh C.ft.
M. S. Sheet	95 Tons.	Reinforcement	3,562 Tons.
Steam Coal	2,000 Tons.	Masonry	13.79 Lakh C.ft.
Sheet Steel Piling	3,213 Tons.	B. G. Rails	28.88 Miles.
Transformer Oil	1,000 Glns.	Sheet Piling	2.53 Lakh S.ft.
Fir Logs	1,688 C.ft.	Precast Faceblocks	1.71 Lakh No.
Manilla Rope	6 Tons.	Precast Troughs	2,401 No.
Grease	3 Tons.	Precast Battens	9,534 No.
Oxygen Gas	30 Cylinders	K. Masonry	9,00,000 C.ft.

STATEMENT II

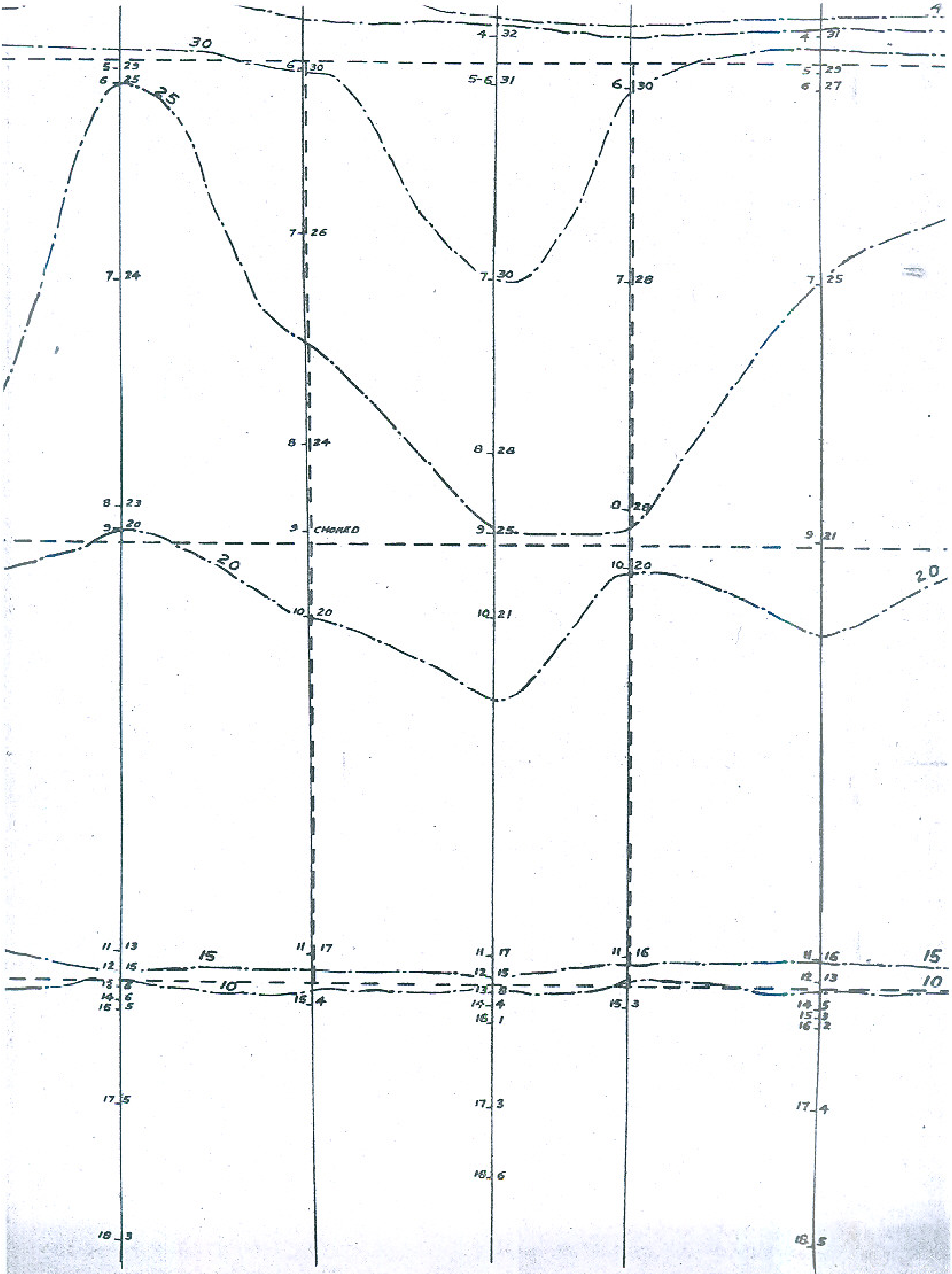
LABOUR EMPLOYED DURING THE CONSTRUCTION OF THE EMERSON BARRAGE

Months		YEAR 1937-38				YEAR 1938-39			
		Donkeys	*Unskilled Labour*	*Skilled Labour*	*Total Labour*	*Donkeys*	*Unskilled Labour*	*Skilled Labour*	*Total Labour*
		Average Per Day.				Average Per day			
April	..	..	..	..	..	794	2,691	1,899	5,384
May	..	..	..	..	..	714	2,447	2,040	5,201
June	..	..	..	..	..	507	2,427	1,624	4,558
July	..	..	..	..	..	580	2,354	1,646	4,580
August	..	310	1,210	..	1,520	571	2,579	1,725	4,875
September	..	414	527	182	1,123	1,074	2,628	1,666	5,368
October	..	1,696	1,707	362	3,765	1,825	2,724	1,399	5,968
November	..	2,703	2,804	1,056	6,563	2,119	3,143	1,594	6,856
December	..	2,602	3,320	1,362	7,284	2,467	4,718	2,227	9,412
January	..	2,746	4,212	1,942	8,900	2,417	3,839	2,064	8,320
February	..	1,753	3,157	2,067	6,977	1,873	3,110	1,919	6,902
March	..	1,414	3,227	2,215	6,856	996	1,627	777	3,400

STATEMENT III

ABSTRACT OF COST

	Rs.
Buildings	3,77,098
Weir	22,39,166
Undersluices	17,98,680
Road Bridge	4,96,975
Regulators	1,46,389
Guide Banks	7,06,837
Marginal Bunds	3,87,786
Gates and Gearings	18,58,221
Diversion Cuts	2,85,120
River Diversion	69,417
Protection Works	1,29,079
Pumping	6,87,958
Piling	6,41,426
Excavation	5,74,154
Railways	8,29,671
Ejectors	1,28,317
Lands	25,01,151
Miscellaneous	11,00,537
Total Cost ..	1,49,56,982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9_CHOKED
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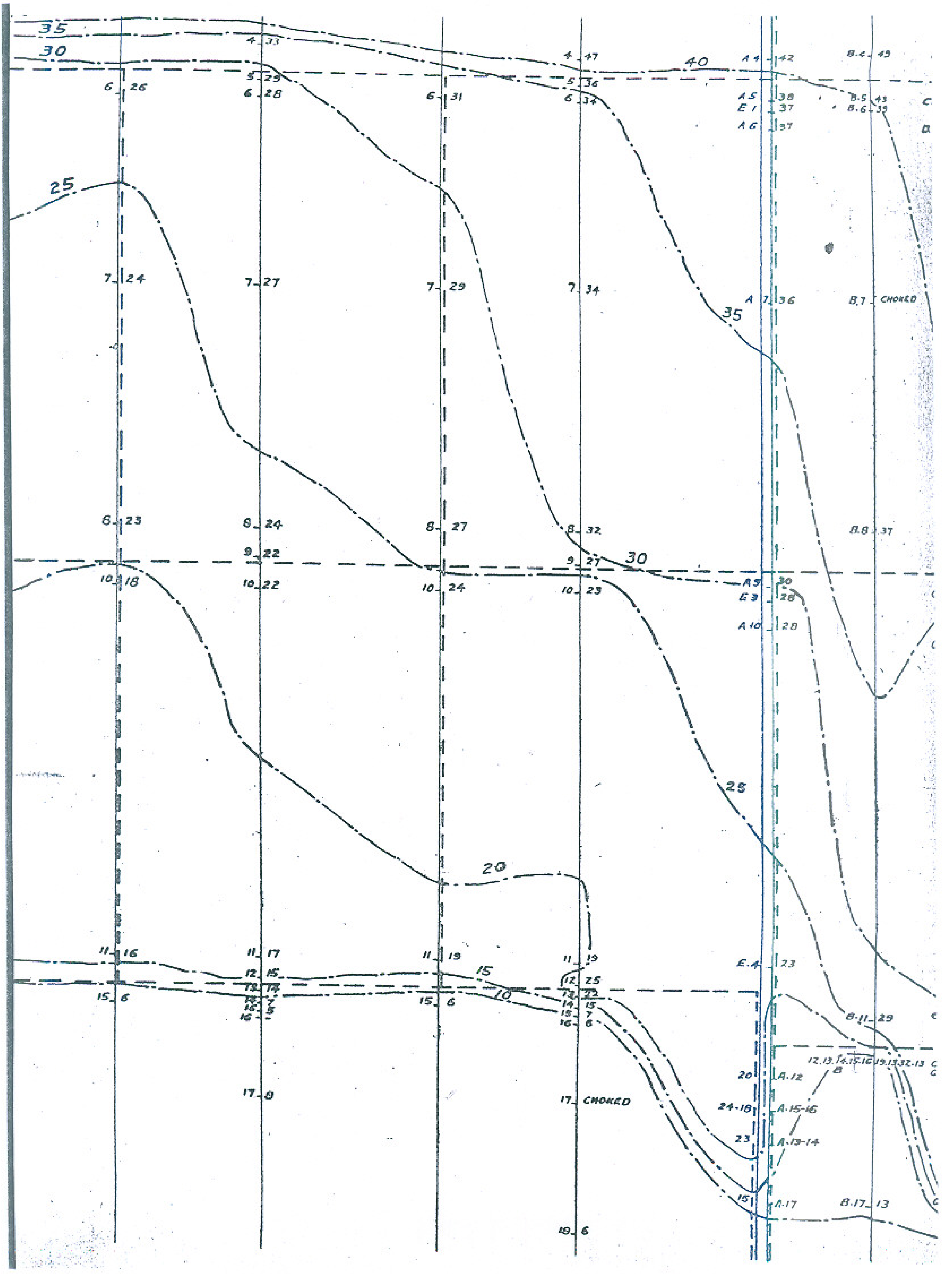
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4 33
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A 4 42
B.4 43
5 29
6 28
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6 34
6 26
6 31
A 5 38
E 1 37
A 6 37
B.5 43
B.6 39
7 24
7 27
7 29
7 34
A 7 36
B.7 CHOKED
8 23
8 24
8 27
8 32
B.8 37
9 22
9 27
10 18
10 22
10 24
10 23
A 9 30
E 3 28
A 10 28
11 16
11 17
11 19
11 19
12 15
12 25
13 14
13 22
14 7
14 15
15 6
15 6
15 7
16 3
16 6
16
E.4 23
B.11 29
12.13.14.15.16 19.13.32.13
B
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A.13-14
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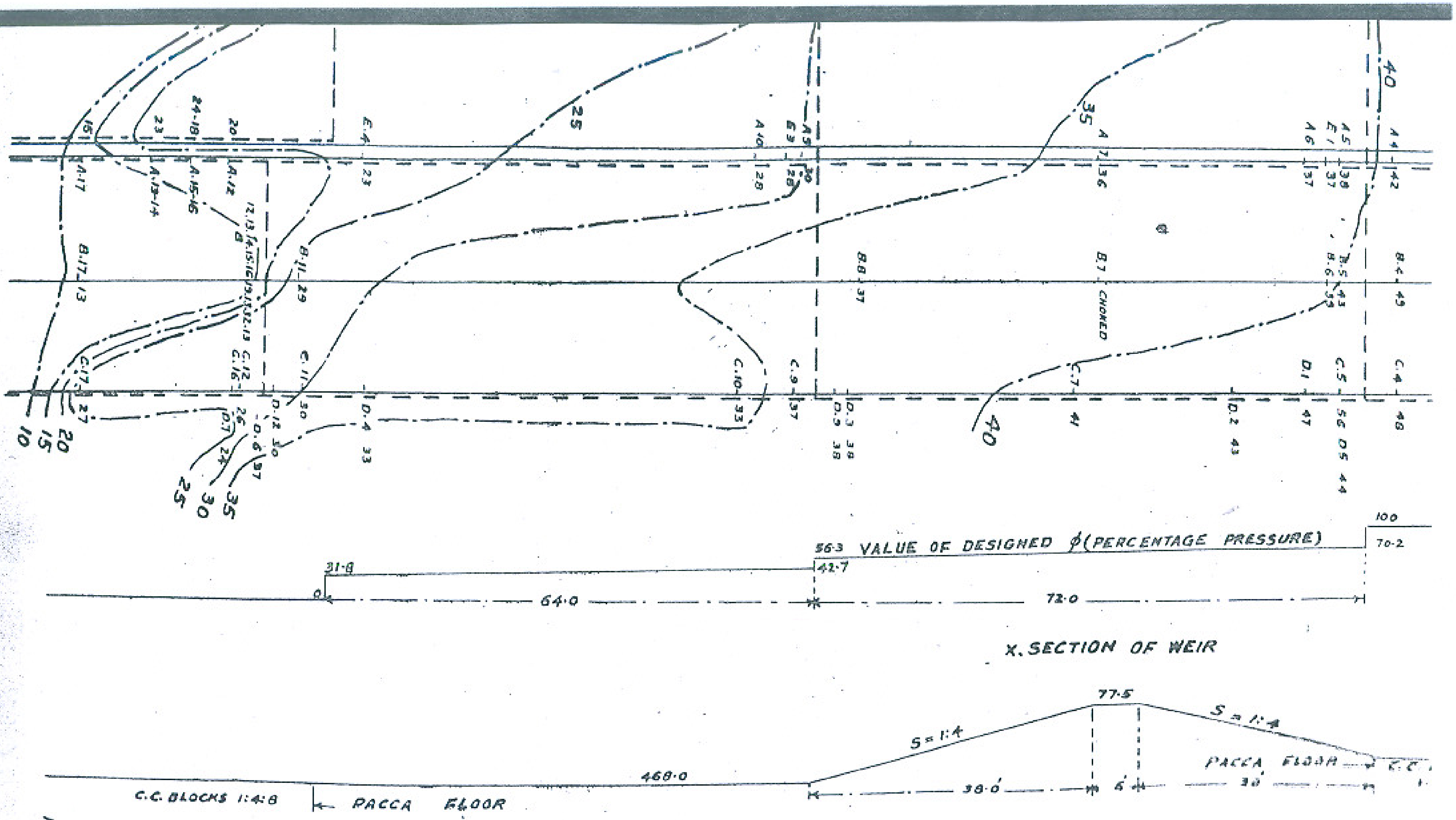
A.17
B.17 13
17 8
17 CHOKED
18 6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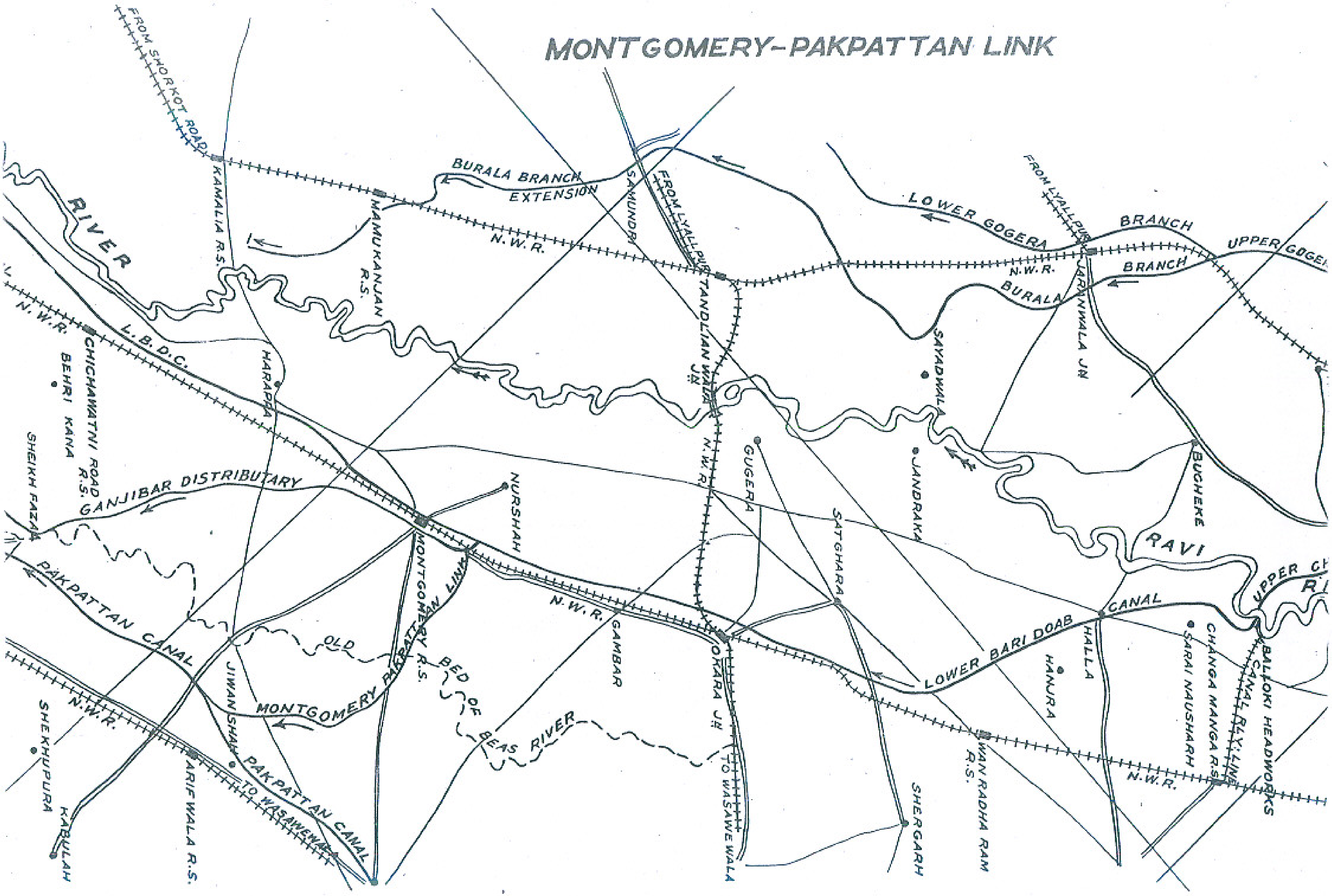
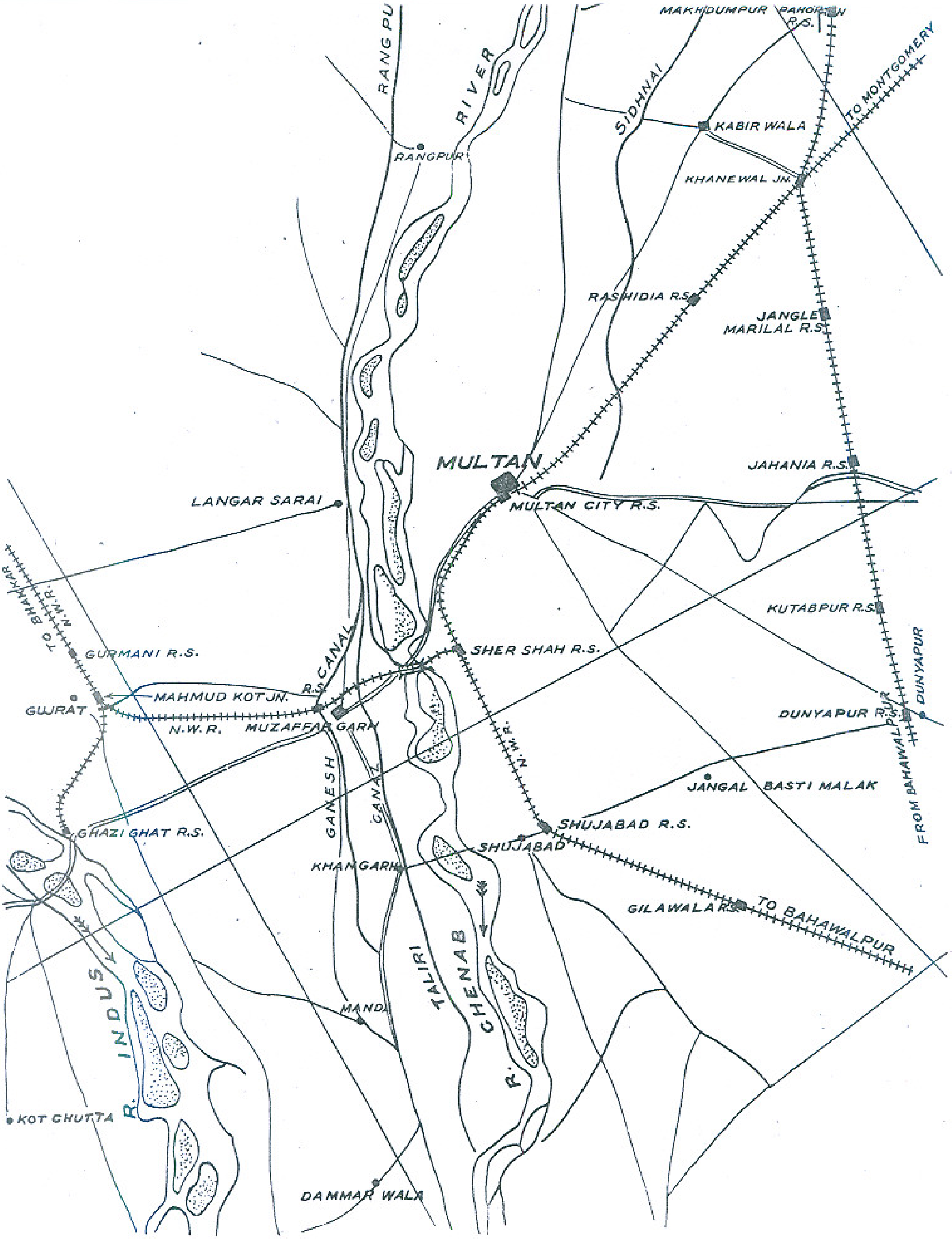
A.5 38
E.1 37
A.6 37
A.7 36
A.9 30
E.3 28
A.10 28
E.4 23
20 A.12
24-18 A.15-16
23 A.13-14
15 A.17
B.4 49
B.5 43
B.6 39
B.7 CHOKED
B.8 37
B.11 29
12.13.14.15.16.19.13.32.13 B
B.17 13
C.4 48
C.5 56
D.5 44
D.1 47
D.2 43
C.7 41
D.3 38
D.9 38
C.9 37
C.10 33
D.4 33
C.11 30
D.12 30
D.6 37
C.12 26
C.16
D.7 24
C.17 27
100
70.2
56.3
42.7
31.8
0
VALUE OF DESIGNED ϕ (PERCENTAGE PRESSURE)
64.0
72.0
X. SECTION OF WEIR
77.5
S = 1:4
S = 1:4
468.0
38.0′
6′
30′
PACCA FLOOR
C.C.
C.C. BLOCKS 1:4:8
PACCA FLOOR

MONTGOMERY-PAKPATTAN LINK




MAKHDUMPUR PAHORAN R.S.
RANG PU
RIVER
SIDHNAI
KABIR WALA
TO MONTGOMERY
RANGPUR
KHANEWAL JN.
RASHIDIA R.S.
JANGLE MARILAL R.S.
MULTAN
JAHANIA R.S.
LANGAR SARAI
MULTAN CITY R.S.
TO BHAKKAR
N.W.R.
KUTABPUR R.S.
GURMANI R.S.
CANAL
SHER SHAH R.S.
R.S.
MAHMUD KOT JN.
DUNYAPUR
GUJRAT
N.W.R.
MUZAFFAR GARH
DUNYAPUR R.S.
N.W.R.
FROM BAHAWALPUR
JANGAL BASTI MALAK
GANESH
CANAL
SHUJABAD R.S.
GHAZI GHAT R.S.
SHUJABAD
KHAN GARH
GILAWALA R.S.
TO BAHAWALPUR
TALIRI
CHENAB
MANDA
R. INDUS
R. CHENAB
KOT CHUTTA
DAMMAR WALA


HORE
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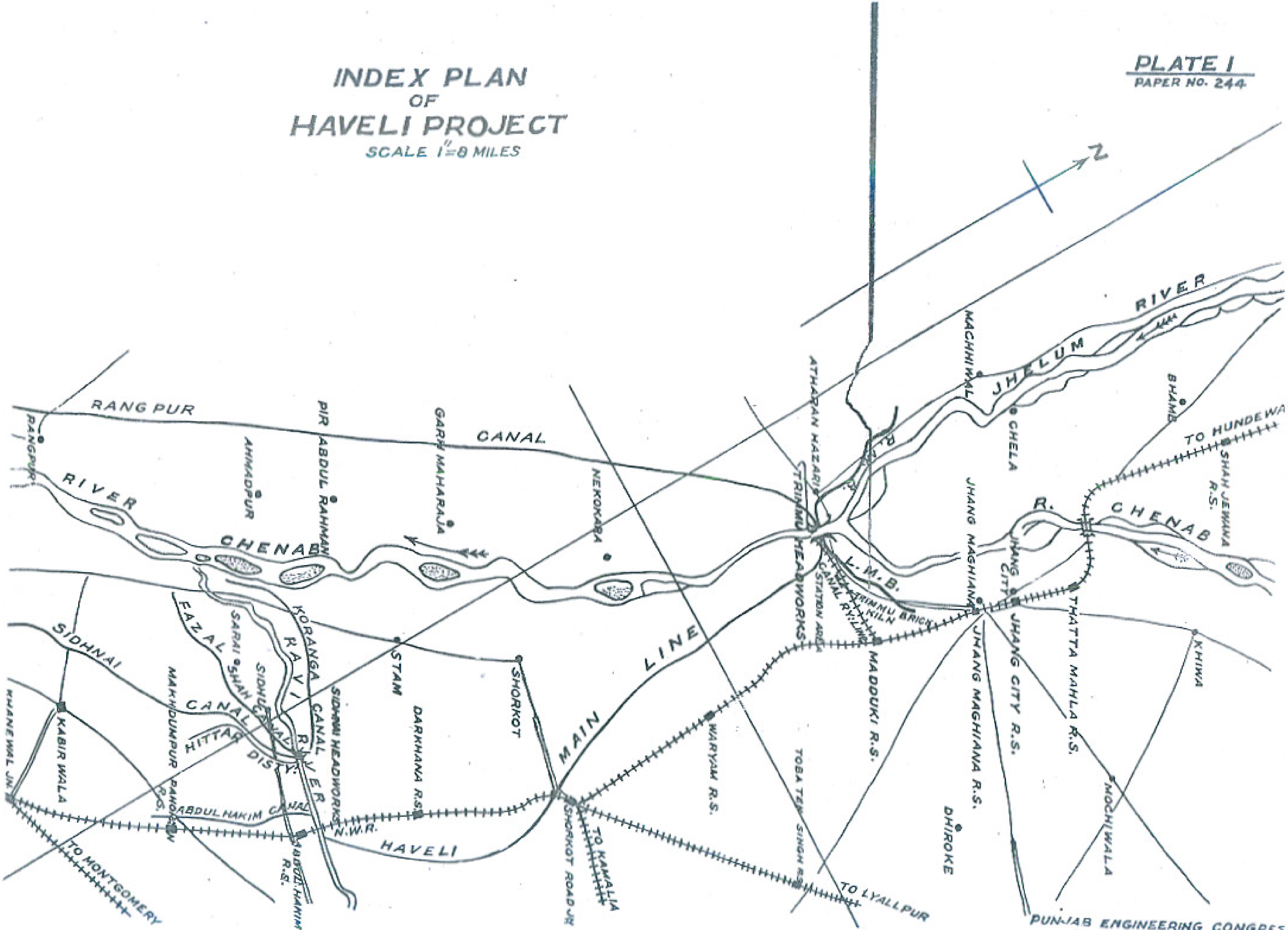
PLATE I
PAPER NO. 244

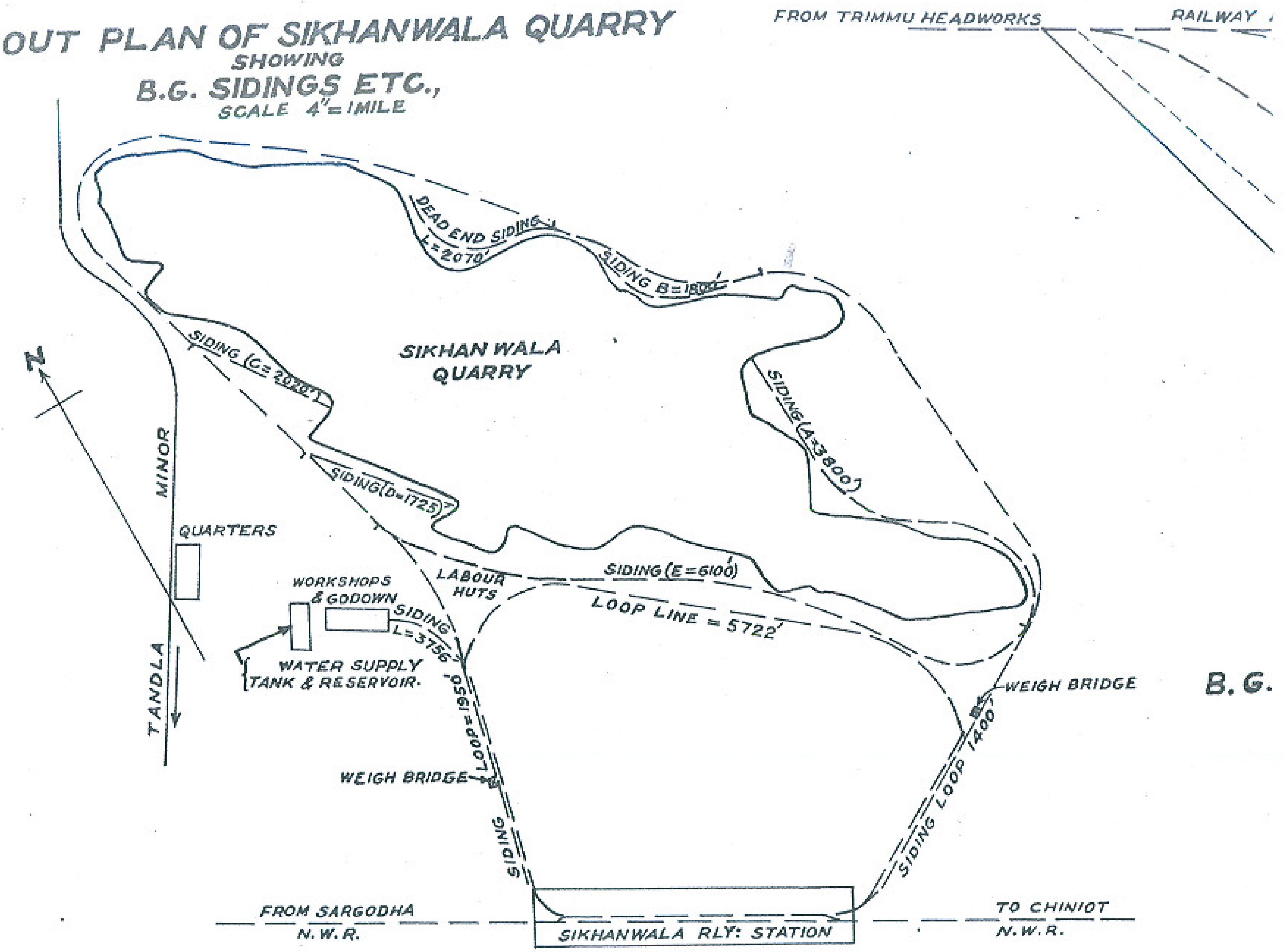
INDEX PLAN
OF
HAVELI PROJECT

SCALE 1"=8 MILES

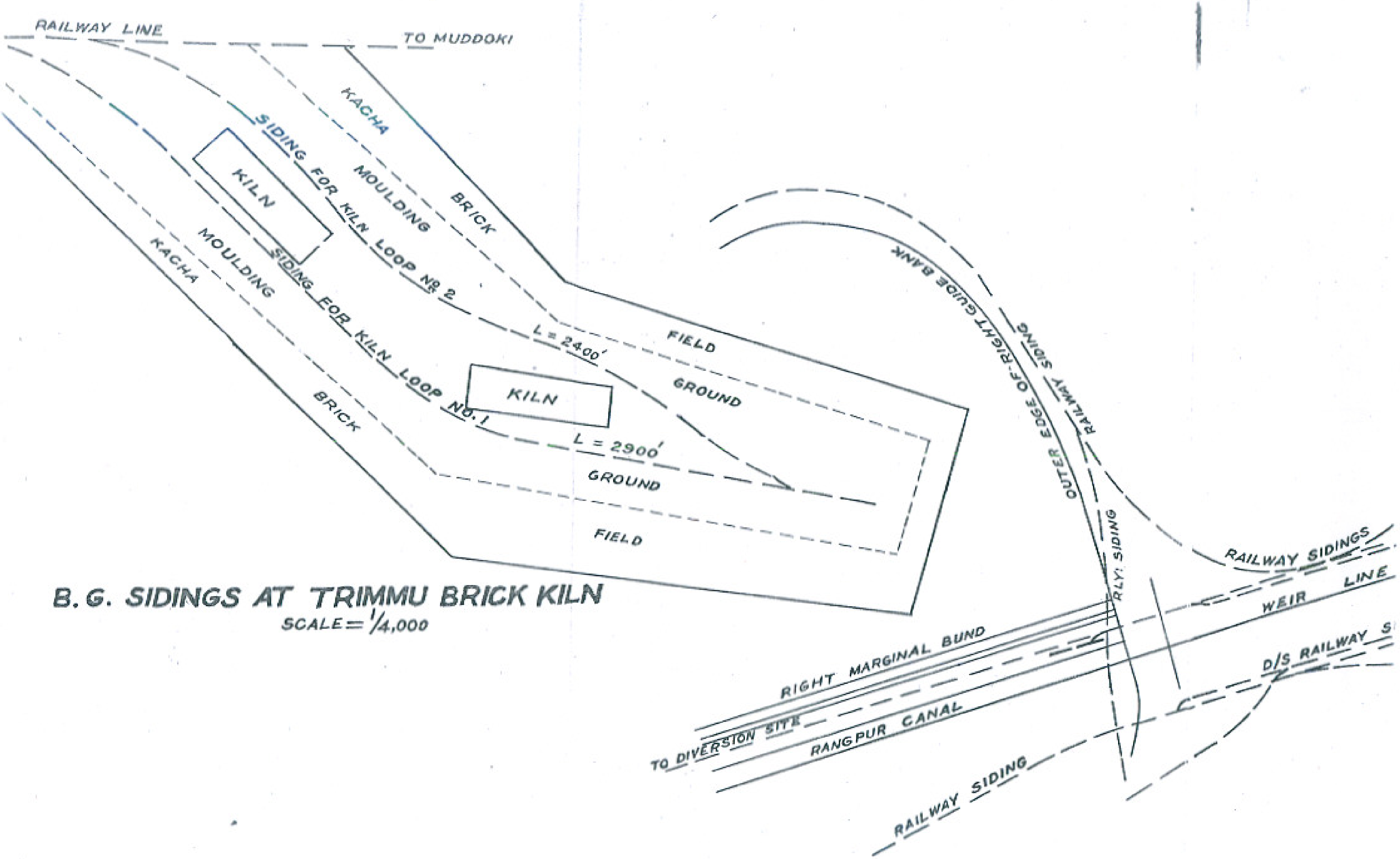


PUNJAB ENGINEERING CONGRESS
1941.

LAY-OUT PLAN OF SIKHANWALA QUARRY
SHOWING
B.G. SIDINGS ETC.,
SCALE 4" = 1 MILE

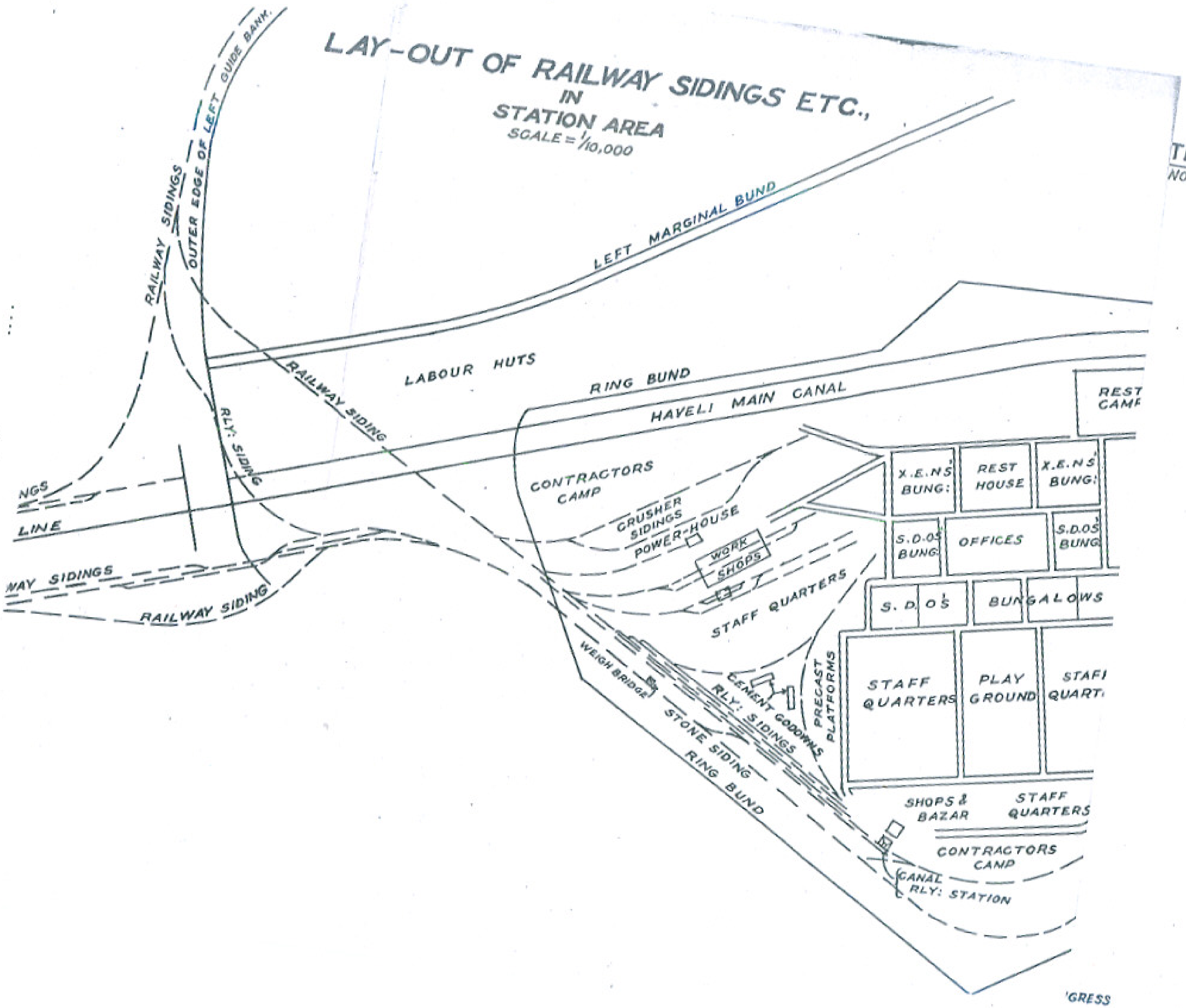


B.G.



B. G. SIDINGS AT TRIMMU BRICK KILN

SCALE = 1/4,000



LAY-OUT OF RAILWAY SIDINGS ETC., IN STATION AREA

SCALE = 1/10,000

TE II
NO.244

'GRESS

PLAN
OF
TRIMMU HEADV

SCALE 1/200