PAPER No. 196.

PIPE LINE PENSTOCK, PIPE TUNNELS AND SURGE SHAFT ON THE MANDI HYDRO ELECTRIC SCHEME, PUNJAB, INDIA.

By Captain N. Boddington, R.E.

The first stage of this scheme, now completed, is to obtain power from a fall of 300 cusecs, through 1768 ft. giving a total of about 36,000 KVA. Later on, by the construction of a dam, and utilizing a further drop of about 1400 feet, a total of 120,000 KVA may be developed.

This article deals only with the Penstock Pipe Track, Pipe Tunnels and Surge Shaft of the project, but a general description of the work may not be out of place.

The source of the water is the rain and snow which, flowing down the southern slope of the Dhaula Dhar Range, collect in the Uhl and Lambadag rivers, these rivers uniting at Brot, elevation 6000 feet, and eventually flowing into the Beas.

Small weirs have been placed across the two streams and the water diverted into a flume which normally feeds the tunnel direct, but when the water is in excess of requirements the excess supply collects in a diurnal reservoir of 60,00,000 cu. feet or 150 acre feet, which in turn, when the water is short, feeds the tunnel.

The tunnel is approximately three miles long, passing under a ridge which goes up to over nine thousand feet; thence the water flows through two pipe tunnels into the penstock pipe line proper, which starts at R. L. 5625, and goes down the mountain side at an average slope of one in three to R. L. 4141, the level of the power house, which contains in the first stage four pelton wheels and generators each capable of supplying 12,000 KVA. Only three of these will be in use at one time, the fourth remaining as a standby.

The work now to be described is really the connecting link between the concrete lined main tunnel and the power house machines, with in addition the Surge Shaft, or safety valve of the tunnel.

It is obvious that the junction point of the concrete and steel pipes cannot be made at the point where the tunnel issues from the hill, as a join thus situated would be weak and would inevitably leak. The distance of the join from the actual exit point depends on the ground and the

formation of the rock. In this case it was found necessary to take the steel pipes of the pipe tunnels about 1100 feet into the hill, and the same place was also suitable for the Surge Shaft, as for the second or third stage the water will rise to R. L. 6141 or to within 60 feet of the ground surface. Had a steel pipe surge tank at tunnel exit been desired it would have had to be over 500 feet, an impractical proposal.

The layout of the Pipe Tunnels and Surge Shaft is shown in drawings Nos. 1 and 2. It will be seen from these drawings that there is a drop of about 200 feet between the bottom of the surge shaft and tunnel exit. As there is in addition a drop of 88 feet between the diurnal reservoir and the bottom of the Surge Shaft, the static head at tunnel exit in the first stage is about 275 feet. There is also, however, a proposal that at some later date a high dam may be constructed as a 2nd or 3rd stage on the Brot side, which may add another 225 feet head ; in this case the total static head at the bottom of the Surge Shaft and Tunnel Exit will be 313 and 500 feet respectively—this is the equivalent of 137 and 216 pounds per square inch, which would be greater than could be conveniently withstood by reinforced concrete, particularly in bad ground. For this reason steel pipes in the last part of the tunnel are necessary.

The original design allowed for three five-foot pipes in one large open tunnel, but owing to the poor ground through which the tunnel had to be driven, it was redesigned so as to have two smaller tunnels, in each of which a six foot diameter pipe was to be embedded in concrete the whole length from tunnel portal to the Surge Shaft. During construction, however, this design was again revised as, owing to the ground being found to be even worse than anticipated, it was considered advisable to keep the first 150 feet of each pipe from the valves at the tunnel portal in an open tunnel, and to take the thrust of the blank flange pressure when the valves were closed; particularly when suddenly closed, by an anchor well within the hill, thereby relieving the concrete portal of any additional thrust beyond that for which it was designed.

Particular points to note in the layout are the grades of the tunnel and the bends which were necessary in order to prevent the tunnel going under the haulage-way, which was and is used for transporting materials all over the job, until sufficient cover had been obtained.

In view of the large quantities of cement, steel and other stores required for a work of this nature a 2" 6" gauge railway was constructed by the N. W. R. joining the existing broad gauge line at Pathankot with the work. This was ready in December, 1928.

The work described in this article falls into the following heads :—

1. The driving of the Pipe Tunnels.
2. The sinking of the Surge Shaft.
3. The lining of the pipe tunnels with pipes and concrete.
4. The lining of the Surge Shaft.
5. The construction of the concrete anchors and supports for the Penstock.
6. The erection of the Penstock.

1. Driving of the Pipe Tunnels.

This work started in January 1928, and an open cut of 90 feet into the hill was made ; this was found to be of very mixed composition-shale, earth and a little clay. The winter rains did not help matters, as during January and February about twenty inches of rain, and worse still, snow fell, and no vertical face of rock on which to start was obtained. Timber sleeper sets were then erected and strutted, and an attempt was made to push forward from these, partial success was obtained and about 100 feet progress was made up till May. The second tunnel was also started. In June 1928, however, serious cavitation having occurred above the timbering, due in a large measure to some trial pits dug in 1927, there was a serious possibility of a major slide of the hill down into the area excavated in open cut; this would have been disastrous. It was, therefore, decided to construct a reinforced concrete portal; a previous design for a temporary timber portal had been made, but owing to the impossibility of obtaining timbers of the required sizes it could not be made. The construction of a permanent portal at this stage was not desirable owing to the high cost of cement, Rs. 9 a bag, as compared with Rs. 3 when the railway was completed. The lesson learnt from this experience was that, however costly, it is both safer and cheaper to construct a suitable portal before starting tunnelling.

The tunnel as driven was, therefore, shored up with steel rails and concrete and the portal was constructed. This work took about seven months and work on tunnelling was again started in January, 1929. This time, with the danger from the hill removed, better progress was made, but in order to give some idea of the formation of the ground it may be mentioned that for the first 300 feet or more in each tunnel the timber sleeper sets were touching, and, although after this they were spaced at four foot centres, patches were encountered which necessitated reversion to the close set timbering.

This was particularly the case at R. D. 600 in A Tunnel, and to a lesser extent at R. D. 620 in B Tunnel, where these tunnels passed under a nullah and had only about 100 feet of cover. The ground here was a

decomposed phyllite, which, after the monsoon rain, was soaked with water, forming a slimy clay, and this squeezed out through the small gaps in the timber sets. In order to get through this section in A Tunnel a small heading, five by four feet was made, and this was afterwards opened out to full section, ten by ten feet approximately, but being too low, owing to the pressure of the loose ground, had again to be raised. This was done by supporting the caps on twelve inch by five inch channels on edge, and after having removed one cap, in order to give the men room to work, raising the caps and the supporting legs was carried out. Only about 12 inches height could be made at each time, and it was found necessary to do this over one short stretch no less than three times. Just when the whole had been completed and the channel beams were being fitted for the last time a coolie hammered home some wedges between the caps and the channel beam too far, and so lifting the caps off the legs some of the latter fell inwards over a stretch of about 6 feet, letting in the ground, which partially filled up the tunnel. It was also found at this time that the ground at this place was so soft that the legs were sinking, due to the pressure on the caps. A proposal was therefore made to maintain this section by means of a concrete box, and on this being accepted the tunnel was cleared, and a concrete floor 5 to 6 feet wide and 2 feet thick, suitably reinforced with one inch bars top and bottom, was poured down the centre of the tunnel, over a length of 20 feet ; this floor being two feet below the rail level. When this had set, the caps of all the sets in this stretch were supported by means of channel beams and timber struts from this solid floor, and the legs were also strutted outwards against each other. The remaining width, about 2 feet 6 inches, on each side of the floor, was then excavated and concreted in the same way, and after this the walls up to the level of the caps. The walls, however, were less thick, particularly at the top but the clearance of 7 feet 6 inches in width, and 9 feet in height, was maintained. (*See* Sketch No. 3.)

In the meantime driving was completed to the surge shaft, a short length in each tunnel having been driven from the bottom of the surge shaft, as the latter had been completed in December, 1929. B Tunnel was completed on January 29th, and A Tunnel due to the trouble at R. D. 600, on March 30th, 1930.

The organization of the parties in these tunnels consisted of one foreman in each tunnel and three assistant foremen, one in each shift of 8 hours, which consisted of about 30 men, who were employed as follows :—

Drilling and Blasting	..	6	men
Mucking	..	16	,,
Electrician	..	1	,,
Timbering	..	4	,,

Fitter	..	2
Plate layer	..	1

This organization was found suitable in bad ground where, mucking was continuous, only occasional blasting was necessary and timbering essential in every shift, but when the ground improved the following was tried with success :

1st shift.—

Timbermen	..	12	men
Drilling and blasting	..	12	,,
Electrician, fitter, etc.	..	4	,,

2nd shift.—

Mucking	..	30	,,
Fitter, etc.	..	4	,,

The above does not include winch drivers and greasers for the machines hauling the trucks.

Drilling was done with C. P. 10 wet jack hammers and blasting with 60 % gelignite, and instantaneous, 5 sec. and 10 sec. delay electric detonators fired from the lighting mains.

The jack hammers stood up to a lot of rough usage and were still in fair condition after the tunnel was complete, the gelignite was found to be difficult to detonate at times, owing to having been stored for some 18 months, but no accidents occurred in this tunnel due to explosives.

Muck was disposed of at a dump about 400 yards from the portal. The chief difficulty experienced was the haulage of trucks in the tunnel due to the steep grade of 10 and 20 %, and the horizontal and vertical bend 150 feet from the portal. This was overcome by means of two winches located outside, and ropes going into each tunnel along the roof on pulleys passing round two pulley-blocks at a point near the face, and then being attached to the trucks, the loaded truck-weight being sufficient to take it out of the tunnel, the winch acting as a brake. On the bend, the rope went to the side as the truck went past, and was allowed to run against rollers. It was kept down by means of extra rollers slightly higher and sticking out at right angles.

The winches used were 1½ ton Zenith winches, 150 ft. p.m. Light was 230 volt (one phase and neutral) and power 400 V. of a 3-phase A. C. system all over the work.

Air for use with the Jack hammers was 100 lbs. pressure, compressed in a main station one mile away, from which air was conveyed in 5 inch victaulic pipes to the tunnel. Four inch victaulic and two inch water pipes were also used. The victaulic, though heavy, was excellent, as it seldom leaked and when it did was easily repaired, whereas the water pipe leaked at many joints and was only with difficulty repaired and then seldom satisfactorily.

Air to keep the tunnel ventilated was obtained from a 20 HP motor driven Blackman fan 3000 cft. free air p.m., and was taken into the tunnel in 17 inch ventilation pipes. Owing to driving being uphill ventilation was most essential and was during the last two or three hundred feet not very good, as the vent pipes could not be taken up to the face for fear of damage when blasting. Water for the drills was taken in through a $1\frac{1}{2}$ inch pipe, sufficient head being obtained from the source of supply in a *nullah* a mile away.

The use of water for drilling was essential in the last 2 or 3 hundred feet, as the rock, though extremely shattered, was very hard, and the dust ensuing from drilling was a nuisance and danger in the confined space. In addition the drill roses lasted much longer when drilling wet.

2. Sinking of the Surge Shaft.

This work was not put in hand until April 1929, but preparation had been made prior to this, as before any sinking could be started a head gear with a winch, etc., had to be erected. As a preliminary to this an excavation 22 feet deep was made, and an $18' \times 20'$ rectangle one foot deep concrete slab having a central hole 12 feet in diameter was laid. On this a cylinder of plain concrete one foot thick and twelve feet in diameter was built up to ground level, the outside being filled in and well watered and tamped. After this a second slab was laid at ground level, two feet thick and heavily reinforced ; on this top slab the headgear was erected.

The ground, from the geological surveys, was expected to be first earth, then about 200 feet of quartzite and finally a green phyllite, similar to that in the Pipe Tunnels. Of this the quartzite was expected to be fairly sound. Actually it was found that the quartzite was a comparatively narrow band of 50 to 60 feet, and instead of being good was extremely shattered ; and the whole sinking, except for the last 50 feet or so, was in comparatively loose ground, necessitating lagging nearly all the way.

When the excavation was started, the ground was loosened with picks and jumpers and occasional blasting, and the muck removed with a two-ton winch hauling a bucket by means of a five-eighths inch rope at 50 feet per minute. At first no guides were used, but after the shaft

had been sunk some 80 feet, the whip and twist in the rope made guides essential, and these were installed.

Owing to the bad ground, timber sets, as shown in Drawing No. 2 which also shows the stretches in which the particular form of timbering was used, had to be fixed at every few feet. The procedure adopted was for the rock to be removed for 8 to 12 feet below the last timber set, then the next set was suspended by its tie rods and wedged or concreted to rock bases, which had been previously prepared for the cross beams. As soon as this was complete, struts were fixed and the timbers placed, then lagging and services fixed and the same process repeated. In this way about one foot per day average progress was made in the small sized shaft. The time occupied in filling the bucket and emptying it governed progress. Then as the shaft got deeper the raising and lowering of the bucket took more time, but on a larger motor being installed on the winch the rate of 50 feet per minute was increased to 100 feet per minute, and this brought the time occupied in mucking and haulage to an economic level.

During the sinking, the shaft was plumbed by four plumbobs of piano wire and ten pound weights, all timbers in sets being kept at a constant distance from these plumbobs. When the final correct depth of shaft was reached, a centre point was fixed from these plumbobs, and lines laid off from this point down each of the pipe tunnels and along the main tunnel. On the main tunnel heading from the adit meeting a short 130 foot heading from the surge shaft some twelve months later, it was found that the lines differed by only some five thirty seconds of an inch. This, on a distance of about one mile underground, from the adit entrance, showed extremely accurate survey, particularly as the alignment of the short heading from the surge shaft line was set off on a base of only eight feet from plumbobs 380 feet long.

Services in the shaft consisted of electric light, air and water for drills, and the winch for haulage. The ventilation remained good and although a vent pipe and an air injector were fitted they were seldom used. A ladder for the men to use was fitted the whole way down with landings at intervals on which fire extinguishers were kept on account of the large amount of timber. At most seasons, however, the shaft kept fairly damp until the tunnel broke into the bottom of the shaft, when the upward draft dried it out almost completely, except during the monsoon.

The organization of the parties was similar to that in the pipe tunnels, and although the work was started with departmental labour it was soon found economical to adopt a piece work basis as was also done in the pipe tunnels. By this method, each man of a party, from the foreman down, receives a proportion of the earnings of the whole party, based on the number of days in which he had worked, and a prearranged

percentage, based on the man's capabilities. The work done was paid for by the department at a fixed rate per foot depth. In this way the more progress made by the party the more the earnings of each man.

3. Lining of the Pipe Tunnels.

Although this work is described under one heading it can be subdivided into three distinct jobs:

(*a*) The opening out and lining of the first 150 feet of each tunnel with a two-foot concrete arch, 21 inches clear of the crown of the pipe. (*See* Drawing No. 4.)

(*b*) The transport, fixing and jointing of the pipe.

(*c*) The concreting of the space between the pipes and the rock (or timber lining) of the tunnel.

As explained in the general note at the beginning of this article the first 150 feet of each of the pipe tunnels was redesigned to allow of the pipes in this stretch being in an open tunnel and not concreted in.

The pipes are 6 feet in internal diameter and about $\frac{3}{4}$ inch thick with one and-a-half inch thick butt strap joints, so that the minimum distance from the central line of the pipes to the concrete had to be three feet plus two and-a-half inches, plus one foot six inches for the holder-up machine when rivetting. The actual design of the arch is as shown in Drawing No. 4 which also shows the first excavation timber and the timbering and method adopted for enlarging the tunnel in order to get the arch in.

In order to increase the area of the tunnel to a sufficient size to contain the arch, which was to be no less than two feet in thickness, the caps of the old sets were first supported with long horizontal timbers resting on vertical posts. This was done over a stretch of 30 feet or so. The old leg timbers were then removed one at a time and after excavation were replaced in their new position and cross struts fitted. The cross struts were then supported by short horizontal runners and posts forming a series of trestles under the cross struts and running along the tunnel. When this was done over a stretch of 10 to 20 feet the cap timbers were taken out one at a time and a three piece strutted timber arch fitted. This work was done in two or three places in B Tunnel to start with, and as soon as 50 feet of the enlarged timber section was completed the concreting was started, the base being excavated and poured first, through traffic being maintained by leaving extra cross struts at rail level. These were also necessary to prevent the footings of the legs being pushed in. The base concrete, as soon as it had set, held these footings

out and also carried the traffic. Centering was then set up at the sides and the walls on each side up to the cross strut were poured. These walls, on setting, acted as a retaining wall and held the arch timbers sufficiently to allow of the cross struts being removed for a short time while the top centering was fixed and concreted. Great care had to be taken to ensure that the concreting of the walls and arch was done evenly on both sides of the tunnel in order that the centering should not be pushed out and distorted by the extra weight of wet concrete on one side.

The base concreting was done in stretches of about 20 feet at a time, the side walls 10 feet at a time. The top arch, however, could rarely be done in stretches of more than 3 or 4 feet, as, owing to the pressure of the loose earth above the arch timbers during the period in which the struts were out, the arch timbers would tend to sink unless the work was done in very short stretches. As it was, owing to the rains, during one period of which 30 inches fell in 5 days, the timber in one stretch over about 50 feet sank and distorted more than a foot, due to earth and water pressure, and this despite the fact that struts had been fixed in every direction possible. A lesson learnt in doing the first tunnel which enabled the second to be more easily and better done, was to concrete the 5 feet centre stretch of the invert before starting opening out; this gave a sound footing for all struts, and also enabled the traffic to pass continuously without any interference. Also the leg footings were strutted against this concrete when the remainder of the base was poured.

A short stretch of about 25 feet in the mouth of B. Tunnel was concreted with pre-cast concrete Voussoirs made to exact moulds, two feet thick by 18 inches long and 6 inches high inside; this made a very sound job and with no fear of damage due to earth pressure on green concrete. They were, however, discarded later, due to the fact that (1) their weight of 240 pounds was too heavy for the labour available, and smaller blocks would not have made a satisfactory job as the joins would have been too frequent; (2) the difficulty of getting the Voussoirs on the crown into position.

Pipe Laying and Jointing.—The grade of the pipe tunnels was so steep that it would not have been possible to put in the top pipe first, and then work down, as it would have been impossible to ensure that the concrete filled all the space at the top between the timber or rock and the pipes. It was, therefore, necessary to put in the pipes nearest the open tunnel first and then work up. This meant that all pipes had to be lowered down the Surge Shaft in which the timbers had been so arranged that a clear space of 8 feet by 7 feet was obtainable. This was quite suitable for the original design of the pipes with all the joints welded, welding to be done in the tunnel, but this was altered to rivetted

bump joints, and the bend pipes and the pipes adjacent to them were made with flanges to be bolted, and these had an outside diameter of 7 feet and two and a half inches, while the distance between the chord and tangent on some of the bends was over 8 feet three inches. It was therefore impossible to take these down the shaft. The four bends for the top and near the shaft were therefore taken in first through the portal and stored in the main tunnel. The next pipes to be taken in were the B Tunnel pipes, first the third above the horizontal bend, then the next above horizontal bend, and then the bend. These had to be taken through the cross cut shown on drawing No. 1, as the opening out of B Tunnel first 150 feet, had been started, and that tunnel, due to the cross struts and bracing, had insufficient clearance. The corresponding pipes for A Tunnel were then taken in, all these through the portal. Bolts were then fixed in the flanges, the bump joints rivetted and the pipes painted outside; these pipes were then concreted in. In the meantime the next pipes had been taken up to the surge shaft on the two haulage-ways and unloaded there. As soon as the concreting in B Tunnel was completed the next pipe was rolled to the top of the shaft and attached to the three foot diameter pulley and lowered down the shaft by a two ton winch. At the bottom of the shaft by means of tackles it was pulled into a horizontal position and fixed on to a flat truck. It was then lowered down the tunnel on a 5/8 S. W. Rope by a two ton winch. This operation took about two hours, from the time the pipe was hooked to the top pulleys to the time it was unloaded off the flat truck on to its final position. It then took another one to three hours to fix it finally for rivetting. This was done by means of jacks and drift bolts. Rivetting then took about two to two and a half hours for the 160 one-inch rivets, but as the pipes became thinner and the rivets smaller it was done in one and a half hours. After the rivets were tested they were all caulked and the seams were also caulked. This took another three hours, so that fixing one pipe took from eight to ten hours. The painting of the pipes was done outside before the pipes were lowered, and the only painting done in the tunnel at this time was patching any damaged places and the painting of the joints. The firm, Ferrums of Poland, who made the pipes, also had the contract for erecting and provided besides their engineer, one foreman, one fitter, two caulkers and two rivetters, all Europeans. In addition the P. W. D. supplied a gang of about 20 unskilled coolies under an Anglo-Indian foreman to assist. After the work had been in progress for a short while it was found more economical to fit the pipes in pairs, two pipes being put into position and completed in each tunnel alternately.

The pipes in the open tunnel were fixed in position and painted, etc., after the concreting was completed. This was a comparatively simple matter as they were unloaded at tunnel exit and hauled into the tunnel on a flat truck up the 10% grade by means of a heavy gyn cordage tackle. The maximum weight of a single pipe was eight and a half tons, this was in the lower bend in B Tunnel, the rest of the upper pipes, except those

with flanges, were from four and a half tons at the lower end to three tons at the top end, and each pipe was twelve feet long. The pipes above the horizontal bend had bump joints, but those in the open tunnel had butt strap joints and were triple rivetted with one and one-eighth inch rivets. These latter pipes were twenty feet long and weighed between six and eight tons. Details of pipes and progress are given in the appendix. The last pipe below the two bends at the upper end was cut to length on the post and then rivetted to its flange so that the last pipe would come into its exact position.

Concreting the Pipes in the Tunnel.—Although the supplying firm did all erection and transport, etc., of the pipes, the P.W.D. were responsible for concreting and filling between the pipes and the tunnel walls. This work was started with daily labour as soon as the pipes were ready, the arrangement being that while the pipe erectors were in one tunnel the P. W. D. were concreting the other. It was necessary, therefore, to so arrange the services in the tunnel that a quarter yard Miller mixer could pass up and down it each time a pipe had been completely concreted.

Aggregate for the concrete was obtained from a quartzite quarry near the top of the surge shaft. As the quartzite was shattered it was only necessary to screen it to various grades and then remix it to get proper graded aggregate, as sand and all sizes of aggregate were present in the natural bed. This aggregate, ready mixed but without cement, was carried to the top of the shaft in one yard trucks, and tipped down the shaft 370 feet through a 17 inch diameter one eighth inch thick ventilation steel pipe, landing in a bin of 500 cubic feet capacity, 15 feet above the bottom of the shaft. From there it was shovelled down an inclined shoot into trucks for the tunnel as required. This shooting down the shaft created a terrible noise, and it was most unpleasant going down the shaft. The truck containing aggregate, in each of which five or six bags of cement were then loaded, was lowered down the tunnel, 20 % grade by means of the one and a half ton winch which, at other times, lowered the pipes and also lowered and pulled up the mixer. This one winch was made available for each tunnel despite the curves at the top, by means of a Y crossing and inclined pulley. This worked admirably although dust from the aggregate and cement made continuous cleaning of the pulleys essential.

A detailed programme of the work over 48 hours is given in Table C at the end. It should be noted that the Erectors only worked in the day time, but that the department worked three shifts, each of eight hours on the concreting.

It was found impracticable to take timber sets out of the tunnel except in the 250 feet nearest to the surge shaft, and even this removal necessitated at times up to 15 feet of concrete over the pipe to replace the

broken rock which fell out when timbers were removed. The specification allowed for a minimum of two feet of plain concrete all round the pipe, and if this were not possible due to closer proximity of the timber sets, reinforcement of one inch bars was put in at from 18 to 9 inch centres, closer in proportion to the nearness of the pipe to the timber sets ; these rods were taken round the pipes. In addition five-eighth bars were also put in at a slightly wider spacing. These bars made the concreting extremely difficult, especially when they were on top, as in this case they had to be put in one by one and concreted in, whereas on the sides they were made up into a net work prior to the start of concreting.

The slump of the concrete normally used was two inches, but by omitting one bag of aggregate a slump of four to five inches was obtained, and this was used for the six inches above and below the pipe invert in order to ensure that the pipe itself was well filled round this point.

4. Lining the Surge Shaft:

As mentioned earlier in this paper, the excavation of the surge shaft was completed in December, 1929, and the lining of the pipe tunnels in March, 1931. It had been intended originally to line the shaft at the same time as the pipe tunnels. With this end in view a temporary concrete and masonry ring, at the bottom of the shaft was prepared in April 1930. As, however, due to other causes there was no urgency for the shaft lining to be completed, and owing to the very restricted space in the shaft, it was decided to hold over the lining until after the pipe tunnels were completed, as a considerable amount of traffic connected with the pipes and pipe tunnels passed through the shaft.

Conversely, on the occurrence of a complete or partial closure of the pipe-line valves, the momentum of the water in the tunnel causes water to rise rapidly to the top of the riser, and the retarding effect of the back pressure due to this column is promptly brought into play. The four ports allow water to flow between the annular portion of the shaft and the lower chamber, and, by throttling such flow, produce a damping effect on the intensity of surges arising from a sharp increase or decrease of valve opening.

This section deals primarily with the main shaft. The lower 98 feet from R. L. 5841 to 5939 of the shaft is 16 feet diameter ; this tapers from R. L. 5939 to 5959 to 12-feet, which continues to R. L. 6141, at which point there is a 12 foot overflow tunnel intended for the second stage of the project. Above this overflow tunnel the shaft tapers to 9 feet at R. L. 6157 and continues 9 feet as far as the surface. In the present stage the overflow tunnel will only be excavated 10 feet as no surging in the shaft will reach above 5959 until the dam is built.

As, however, when the project is working, no alterations can be made to the bottom of the shaft, the lining for this first stage has been designed and built to withstand the maximum head of the second stage, and the reinforcement necessary is shown in Drawing No. 2.

In the 16-feet shaft up to the first taper the reinforcement is put in two layers, the first with the concreting, while the inner layer is put on later and gunited in. Above the first taper a double row of reinforcement is put in the first concreting and no guniting is done. Above R. L. 6,000 the reinforcement is reduced from two layers to one layer. The concrete used is of two kinds, a special mortar mix and an ordinary mix, the details of which are given in the appendix. The ordinary concrete is poured first over a short stretch and held away from the reinforcement by means of small sheets of galvanised iron from two feet square. The mortar mix is then poured between the galvanised iron sheet and the iron centering and well-rodded in order to cover the reinforcement completely, and then the G. I. sheet is pulled out and the concrete on both sides of the reinforcement is again well-rodded in order that they may mix intimately. This ensured a dense concrete on the face, good contact with the reinforcement and a waterproof concrete from the use of the mortar.

In addition, in order to ensure that the concrete is firmly held against the rock grouting, pipes were left at every eight-feet horizontal and one-foot rise, the grouting, when the concrete had set for over two months, being done first at 100 lbs. pressure, and afterwards, in the lower part of the shaft, at 300 lbs. pressure.

The programme of work as carried out was as follows. As none of the timber sets and lagging boards, (referred to in the excavation of the shaft) were allowed to be left in, these had first to be removed ; but, owing to the bad formation of the ground, it was not safe to remove more than 8 to 10 feet at a time, and although this timber had to be removed, staging had to be left, on which the men could work. This was easy enough for the first 60 feet as these stagings could be supported from timbers let into the temporary masonry below R. L. 5841, but as the total timber, etc., in the shaft weighed up to 90 tons this was not possible all through. Above R. L. 5900, therefore, 8 double angle irons were left in the concrete at each 30 feet in height. These stuck out up to 8 inches and held the end of cross beams which were fixed on top of them. From these the sets below were hung by tie rods and new sets above were strutted until the next set of angle irons were fixed, when in turn these strutted sets were fixed with tie bolts and the struts removed to be refitted again on the next higher set. Care was taken to ensure that after the angle iron system was adopted no connection was ever made between the original timber and the new timber fitted after the concrete was poured, as otherwise the weight of the timber at the top of the shaft, instead of hanging from the top, might have been carried on these

angle irons, in which case a collapse might have occurred. The concrete was mixed in a half yard mixer at the top of the shaft, and let down to the point at which required by means of a bucket in the bottom of which was a hole having a plug. On arrival at the required position the plug was removed and the concrete run into a box and from thence shovelled into its final position. This was preferable to shooting the concrete into its final position from the bucket, as it gave more control in pouring, and allowed of slight extra mixing to overcome any segregation which took place due to the vibration in the bucket as it was lowered down the shaft. The mixer had to be at the top of the shaft owing to the nearness of the top of the shaft to the source of supply of materials.

The reinforcement was all bent at the top of the shaft by means of a lever and a three inch pin fixed in R. S. J. All steel was tested on the layout platform to see that it conformed to its correct curvature before it was lowered into the shaft. The ends of the steel bars were bent at 30 degrees for about six inches, there being no room for complete hooks. In addition the full 40 diameter's overlap was invariably given at the joints, of which there were either three or four for each circle of reinforcement.

Services.—For this work the services were :—

Water for the concrete mixer at the top and for washing the old concrete and rock at the point of work, but as the work progressed it was found more satisfactory to brush the rock and old concrete as any washing tended to disintegrate the rock, rather than clean it.

Air required for grouting ; electricity for lighting and for a two ton winch for raising and lowering the bucket—none of these caused any particular difficulty.

Centering.—This consisted of one-eighth inch iron sheet, two feet high and about six feet long, with three by three angle irons rivetted, at all four edges, holes being drilled in the angles to allow fixing for the next piece. These segments were all made to the proper curvature and so arranged that a definite number (*i.e.*, nine in 16-foot shaft and 7 in the 12-foot shaft) were required for each 2-foot rise of concrete. It was found that the rivets were not very satisfactory, and welded centering would have been better, due to the fact that the rivets had to be countersunk on the inside in the eighth inch sheet and they continually pulled out.

Hook bolts were left in the concrete at two feet intervals. These had female threads into which half inch bolts fitted through the centering. These held the centering in position and prevented it slipping down the

shaft after the concrete was poured. For dismantling when the concrete had set these bolts were removed. One joint in each set of centering was fitted with wedges so that in order to remove the centering, the bolt through these wedges having been taken out, the wedges were knocked out and the segment on either side could be withdrawn with little difficulty. For the 16 feet 8 inches in order to allow a final guniting of four inches all round. The tapers were made with circular timber rings three feet apart in height joined by three-foot by three-inch by one-inch battens.

At each two or three centerings the shaft was plumbed from a steel bar across the top of the shaft, the plumbob being suspended in a bucket of water. In this way the only cause of incorrect line was distortion of the centering while concreting was being done. This was particularly prevented by temporary struts at the top of the centering to the rock all round; the maximum distortion which occurred was two and-a-half inches, and this was exceptional and in only one stretch of the 16-foot shaft, where the centering was worn out and slightly buckled. In the 12-foot shaft one inch was the maximum error out of the vertical.

In October 1931 when the lining had been completed to R. L. 6116 (the level at which the original timber sets and lagging changed from circular to rectangular) the upper sets started to sag on the N. E. corner and rock and earth falls occurred behind the lagging.

Owing to the possibility of this endangering the headgear, work on lining was stopped and the whole shaft above R. L. 6116 was, after being properly braced and strutted, grouted with cement and sand at 100 lbs. pressure by a special machine. In all, some 5000 cft. of grout was pushed in to consolidate the ground and this was so successful that although the ground had previously been extremely loose, after treatment it was possible to remove all the timber over stretches up to 10 feet at a time without danger.

This grouting took three weeks, and although it delayed the completion of the shaft, it made what might otherwise have been a difficult job extremely easy, and in addition by safeguarding the headgear saved what might have been a serious disaster.

The labour consisted of three shifts each of one foreman, one carpenter and 20 men, with one surface shift of 10 men for bending the reinforcement and 4 men in each shift for the services, a winch driver, a mixer driver, one fitter and one electrician. The work was started on March 14th, 1931, and was completed on January 3rd, 1932. Table B showing the progress, quantities, etc., is in the appendix.

5. Penstock Anchors and Supports.

Owing to the formation of the ground along the long section of any pipe line it is necessary, although the most favourable site may be chosen, to have a number of changes in slope, and, in most cases, a change of direction. At each of these there is at times an unbalanced force, which force, were it not counteracted, would move the penstock. The only known method of rigidly holding the penstock is by means of anchors at each bend, whether horizontal or vertical or both. These anchors are so designed that the resultant of the worst case of unbalanced forces on the pipe and the weight of the anchor, usually concrete, falls inside the middle third of the anchor base, and also is such that the anchor toe pressure does not tend to squeeze up the ground in front of the toe. Between two such anchors the pipe is held off the ground at constant grade by means of the concrete or masonry supports, on which rest steel saddles. This allows for the free movement in expansion and contraction of the pipe, and also for rivetting and caulking, both originally and in subsequent repairs. These supports have to be designed in a similar way to the anchors, except that the forces are smaller, as there is no unbalanced force due to change in slope.

During construction it was found preferable, especially on steep slopes, to have the back of the supports normal to the pipe, and not more horizontal, as stones, earth, etc., would not then tend to get between the steel saddles on the concrete and the pipe, as if this occurred there would be a tendency for the pipe to jam when contracting or expanding.

A long section and plan of the pipe track is given in Diagrams No. 6 and 7. It will be seen that anchors Nos. 14*a*, 11*a*, 10*a*, and 4*a* have no change of grade. These anchors were necessary, as, owing to the distance between the bends on either side of them, the expansion between these bends would be more than convenient to allow in one expansion joint, and also because the forces caused on both the anchors of a very long stretch by friction are so great that it would entail unnecessarily large anchors. For this reason additional anchors are provided with the pipe held firmly between the main anchor by means of the A anchors. In the case of 5*a* and 5*b* in the original design there was an anchor No. 5 at the junction of the 20 per cent. and 57 per cent. grades, but the anchor in this position would have required so much excavation that the cost would have been excessive, in addition to which it would have been necessary to partially remove a village.

The general procedure for construction was for the lower half of all supports and anchors to be poured, leaving construction joints at about six to twelve inches below the level of the bottom of the pipe, and

then when the pipe was erected to complete the concreting of the anchors and supports. The latter were done as soon as the pipe was fixed, whether or not it was rivetted, but before the anchors were poured, the pipe on each side was rivetted and caulked to the next expansion joint, as no rivetting was allowed within 14 days of the concrete being completed, owing to the vibration caused by the rivetting hammers.

In each anchor, at the actual joints, spun yarn was fixed around the pipe and a leak pipe taken from the spun yarn out to the side of the anchor, as should the pipe leak ever so slightly the high pressure of the water inside the pipe would, were there no outlet to air, produce a similar hydraulic pressure between the pipe and the anchor, which might be enough to split the anchor. A further precaution taken was for temperature and five-eighths inch rods at two feet, centre to centre, to be placed at the sides and on the top near the surface of all the concrete anchors to give strength against cracking, both when the concrete set initially and afterwards.

Plums of about 60 pounds weight were allowed except within 2 feet of the reinforcement or construction joints, but plums were placed actually sticking out of the construction joints to give a good joint in shear. No plums were used in the capping.

From the fact that over 400,000 cubic feet of concrete had to be poured at various points along the pipe track, it will be realized that one of the major problems was the supply of materials. All the coarse aggregate for the anchors came from a quarry near the surge shaft and the sand, half by rail from a village 17 miles away and the rest from the same quarry as the aggregate. Cement also came up by rail to the foot of the haulage way.

The supply of these materials was spread over two years, about one hundred thousand cubic feet being collected in the first six months of 1930, and this was used in the last months of the same year, during which time small supplies were also received. But the real beginning of progress was made in 1931, during several months of which a supply of forty thousand cubic feet per month was common. To do this the haulageways had to work twenty-four hours a day. The aggregate for the supports was ready mixed aggregate from a nearby nullah and brought up by mules or haulageway. This aggregate was, however, too inferior, owing to it being composed of poor schist, for use in the anchors.

The aggregate and sand were collected at various sites on the pipe track and half yard mixers fixed at the same points. These were usually just above an anchor, so that the concrete for that particular anchor was shot straight from the mixer for the bottom half of the anchor. In many cases the slopes were steep enough to pour the concrete to the next

lower anchor by means of half round shoots. The concrete flowed reasonably well down a slope of twenty-three or twenty-four degrees and at 20 degrees if assisted by men with shovels.

For the supports between the anchors, concrete was poured in the same way, shoots being added as required. It was found that the half yard mixer poured about 500 cubic feet a shift if working for only eight hours in the day, but would pour twelve hundred cubic feet in 16 hours, some time always being wasted at the start for getting the concrete work going.

When the capping of anchors was done one or two quarter yard mixers were brought up successively as required as the half yard mixers were too large to be conveniently moved. The quarter yard mixers were raised to a suitable height uphill of each anchor and the aggregate collected as soon as the pipe had passed the anchor. This could not be done before the pipes were fixed, as the pipes had to be rolled across the site on which the aggregate and mixers were erected. In pouring the capping, once concreting was started, it was continued throughout the twenty-four hours in order to get the work done quickly, so that the pipe would be firmly held and erecting could be continued as soon as possible. It was found that under the circumstances a quarter yard mixer could do between twelve and fourteen hundred cubic feet a day of twenty-four hours, three shifts. The quarter yard mixers could do two thousand five hundred cubic feet a day with thirty men per machine shift being employed.

Over the stretch, between anchors 5*b* and 8*a* a one and-a-half ton winch and a cubic yard truck on the two-foot gauge track was used to pour the lower half of the anchor and supports, as the slopes were not favourable to shooting, being very flat. In all cases, when shooting was employed, the concrete was hand-mixed a little in the work so as to ensure that it did not segregate.

For the capping of the supports about six cubic feet in each support was done by hand-mixing as it was not economical to use a mixer. Practically no centering was used for the lower half of the anchors as those only just came out above ground, but for the capping a large amount was required and as it was essential to fix the centering quickly. Made up shutterings 3 feet by 5 feet were prepared, and as soon as an anchor was ready for capping, reinforcement was fixed and then vertical posts five feet apart were set up and strutted and the shuttering fixed against these from the inside and lightly nailed. Any small areas in which full sized shutters would not fit were filled with cut planks and the centering was complete. This did not usually take more than 48 hours and in many cases was less than 36, so that from the time the pipes were ready to the time the anchor was concreted was seldom more than four to six days.

Bolt holes for holding down the pipe before concreting started were fixed at each anchor three to five pairs per pipe. These were about six to seven feet deep, nine inches square at the top and fifteen inches at the bottom. Table A showing the progress and other details of the work will be found at the end.

6. Laying the Penstock Pipes.

This work may be sub-divided into :—

(*a*) the transport to Jogindernaggar ;
(*b*) from rail head Jogindernaggar to the final position, and
(*c*) the pipe itself and its joints.

The Firm whose tender for the Penstocks was accepted was Ferrum & Co. of Kattowitz, Poland.

The pipes arrived in Karachi. From there to Pathankote they came in train-loads by the North Western Railway. They were then stacked in Pathankote where a special siding area to hold all the pipes and equippd by the Hydro Electric Branch with a suitable gantry had been prepared. When required at Jogindernaggar the pipes were loaded on to the narrow gauge 2′ 6″ line of the N. W. Railway. This last journey took about two days normally, but occasionally, especially during the monsoon and winter rains due to slips and other causes, no pipes were received in for two or three weeks. For this reason, as it was known beforehand that it might occur, a similar area to that of Pathankote, but to hold only 80 pipes was prepared at Jogindernaggar complete with an electrically operated gantry. All the specials such as bends, expansion joints, etc., were brought up straight from Karachi to Jogindernaggar and stored near the gantry, as owing to their shape they were difficult to move about.

From this gantry the pipes were lifted on to a small flat truck on 2′ 6″ gauge extension to the main narrow gauge line. They were then pushed to the foot of the haulageway—a distance of about 400 yards—by Sentinel Loco. On the arrival of the haulageway truck they were lifted by a 15-ton electrically operated crane and loaded on to specially prepared timber cradles on the haulageway truck. The points to note as regards this truck are as follows :

(*a*) Double flanged and roller wheels for automatically switching so as to pass the car on the other end of the rope when both cars reached the crossing place.
(*b*) Nigger head and rollers for unloading the pipes.

(*c*) Eyes for slings for holding down pipes in transit.
(*d*) Cradles for the pipe and back stop.
(*e*) Rope attachments.
(*f*) Signal and telephone arrangements.
(*g*) Rail grips.

Unloading from the Haulageway Cars.—The car was always stopped about a foot above the required position of the pipe and a heavy gyncordage tackle fixed on the back of the car to hold-fasts at various positions on the track, usually the rail. The rail grips then clamped over the track at each end of the car. This arrangement prevented the car from moving due to the diminished tension on the haulageway rope as the weight of the pipe was taken off the car. At the same time two eye plates were bolted at the extremities of the horizontal diameter of the pipe when in its final position (each pipe is drilled to fit into the lower butt strap and the corresponding rivet holes at the highest point on the pipe are marked). In these two plates a sling is fitted and to this sling through a shackle 1" steel wire rope was attached. This was connected to a 10-ton chain tackle held firmly at the next anchor upwards by means of large hold-fasts left in specially for this purpose while concreting. When the foreman in charge had seen the above all correctly fixed the chain tackle was worked so as to take up strain until the strain caused by the weight of the pipe was taken on this chain tackle and the haulageway rope became slightly slacker. This could easily be ascertained by standing on the haulageway rope and holding the tackle rope and noting the give in each by transferring one weight from one to the other, at the same time two light and very flexible ½" steel wire ropes were fixed to the eyes on the side of the haulageway cars away from the pipe track. Then under the pipe and back over the pipe with four turns round the nigger heads, the end being held by one or two men. While this was going on, 12′×10″×10″ timbers were fixed, from baulks already laid on the pipe track across the drain to the truck the whole being suitably strutted. All being ready the wedges on the pipe track side of the pipe cradle were knocked out and the flexible ½" rope gradually slackened to allow the the pipe to roll. In order to start rolling crowbars were usually used for first 6". As the pipe was rolled off it was stopped every 6′ or 7′ by means of flexible ropes while the chain tackle tightened up the holding rope. This was done as the pipe would otherwise have tended to travel on the circumference of the circle whose centre was the end of the chain tackle and consequently the pipe would have gone slightly downhill. As soon as the pipe was clear of the baulks across the drain it was wedged and the flexible rope, back gyn tackle, rail grips and timber moved off and the truck sent down for another pipe. The whole of this job at times took only 20 minutes but on an average 30 to 35 and in exceptional cases, as when a very short flanged pipe was unloaded on a rainy day, 3 hours. Normally 4 pipes were brought up between 0630 and 1300 with 2 hours

off 0730 to 0930 for a passenger truck this time including the loading, unloading and travelling up and down. The reason for these apparently elaborate precautions may not at first be realized, but as the pipes were upto 8 tons each and in several cases, when two were jointed together, up to 12 tons, the damage which might have occurred by a pipe rolling down any of the slopes would have been great not only to material but to men so that every precaution was essential. While the next pipe was being brought up, the pipe on site was rolled across the pipe track and jacked up into its final position, the rivet holes being drifted and the pipe wedged up on timber and lined on a boning rod system, from points on the anchor and supports above.

The above was the normal method used but one or two exceptions may be quoted :—

(*a*) The pipe track between 5*a* and 5*b* was for about 150′, from 5′ to 15′ above the haulageway and the pipes could not therefore be rolled off the track. To overcome this the pipes were taken to the nearest point above where they could be conveniently rolled off. They were then let down the pipe track on rough rail slides on timber cribs by means of 1½-ton winch and the 5/8″ steel wire rope throuh heavy gyn tackle.

(*b*) Between 5*a* and 4*a*. The pipe track was 3′ higher than the haulageway and the pipes could not be rolled off conveniently uphill. To overcome these difficulties three anchors of about 5 tons of concrete each were buried 8′ in the ground at the top, bottom and middle of this stretch 20′ outside the pipe track on the side away from the haulageway. These were jointed by a very heavy steel wire rope. A one and-a-half ton winch was fixed above the top of this section, and the rope from the winch passed through a snatch block lashed on to the rope between the anchors round the pipe and back again on to the heavy rope. On the winch hauling, the pipe rolled over uphill to the place. Of course the normal method of the uphill holding tackle was fixed on the pipe as well.

Lining up the Pipes.—Every alternate support was marked with a centre line point whose R. L. was known. The R. L. of the centre line of the pipe at this point was also known and so the distance between the point marked and the centre line of the pipe was calculated. On the two supports having these marks nearest above the end of the pipe batter boards were fixed at the correct level of the centre line of the pipe. In the end of the pipe a batter board was also fixed exactly on the centre line. This was done by measurement of the pipe. The correct

line was then obtained by packing and wedging the pipe until all boards were lined. The concrete line vertically was fixed by nails pressed into the batter board in the correct place and then lined. It was found best to align these batter boards by a string over all 3 and looking along the string from the side rather than sighting down in the normal way. Once a pipe had been lined the drifts were tightened, a few bolts fixed, steel saddles were placed in position wedged up from the concrete supports by means of any old piece of iron available. After this was done the supports were concreted in up to the steel saddle and when the concrete had set the timbers were removed.

Rivetting and Caulking.—All rivets were heated up in a portable forge on the pipe track and pushed in through the butt strip from the outside. The holder up was then operated by means of compressed air and the riveters from inside the pipe rivetted. The holder up was held down by means of an adjustment which fitted round the pipe. After the riveting of a joint was completed, the rivets were tested and all slack rivets cut out and replaced. The seams of the butt strip and pipe were then caulked and when this was done the rivet heads both inside and outside were also caulked. The caulking was done in order to clean the joint and ensure its being water-tight and also to reduce friction. It was not used in any way to tighten the rivets.

The joining up of the pipes was not started from the power house. The anchor at the bottom was not ready, and in any case it was more convenient to work in more than one place for most of the time, and the following was the order of work :—

A (*a*) Anchor 8 up to the expansion between 1 and 2.
B (*b*) Tunnel down the expansion between 1 and 2.
B (*c*) 10 to expansion between 9 and 8.
B (*d*) 8 to expansion between 8 and 9.
B (*e*) 15 to expansion between 10*a* and 10.
A (*f*) 10 to expansion 10a and 10
A (*g*) 15 to expansion 15×1×2, and
A & B (*h*) A^1 A^2 to expansion 15 ×1 ×2.

Two parties were at work for most of the time, " B " being the party which previously worked in the tunnel. Jointing up was done at an expansion joint. The expansion parts being slipped in, closed and then jacked open and bolted up. Any small difference in length was adjustable by cutting of the inner half of the expansion with oxyacety-

lene cutters, the expansion joints being so made that they allowed of an error upto 1′ being adjusted in this way.

The pipes themselves had all welded seams but the butt straps, flanges and bands were all inside rolled and weldless. The bends were nearly all cast steel as also were the " Y " pieces, but a few bends were welded steel sheet. Double Dutchman, (*i.e.*, two wedge washers which by turning at a flange join allowed both vertical and horizontal line being adjusted) were fitted where shown, but were only used in this job to correct very small errors as both the firms' work in the factory and in lining up were excellent. Rubber ring washers were used in all flange joints and 3 types of expansion joints were used and also 3 types of man holes. The latter were left at approximately every other section. Between anchors 1 and 2 a small hole and a cover were left for a water meter.

The main valves under separate contract were supplied by Messrs. Glenfield & Kennedy.

Tests.—For test purposes there is a blank flange to fit at the expansion between anchors 5*a* and 5*b*. The pipe was first filled with water up to 5*b*. This flange was fitted and then the remainder of the pipe above filled with water. In the blank flange there is a cock which can be adjusted from outside so that either the top half of the pipe is shut off or is hydraulically connected with the lower half. Then by means of the pump fixed at the power house and connected to the pipes by means of a special hole in the last and lowest pipe an overload of 25 % for the top half and of 45 % for the bottom half can be operated. The blank flange was essential, as if the test were carried out without it, when the 15 % over load was on the lower half, (*i.e.*, an increase of about 300 lbs.), it would mean an overload of 160 per cent on the top half, which would be excessive.

Painting.—The original specification for these pipes was,

Inside : 2 coats " Tennax " Bitumastic Paint.
1 coat " Ferroid " Enamel.

Outside : 2 coats " Tennax." Except at places where pipes were in concrete. In this place there will be in addition one coat of Ferroid Enamel outside.

Owing however, to the failure of the Enamel due to the heat in the hot weather, when the Enamel peeled off the top of the inside of the pipe in sheets rather like a black curtain, the Ferroid Enamel inside was abolished and the inside specification changed to four coats Tennax. The first coat inside and out was done at the factory. Then one coat inside was done before the pipes were taken up the haulageway. The final outside coat was done as soon as possible after the pipes were riveted and caulked. The final inside painting was done in November and December, 1931 as soon as the Enamel which had failed had been completely scraped off the pipes.

TABLE "A".

Detail of quantities and costs of various works (approx. & not final.)

Item.	Work.	Material used Earthwork Concrete.		Steel Masonry.		Turfing or stone Pitching.	Timber.	Cost.
		Cft.	Cft.	Tons.	Cft.	sq. ft.	Cft.	Rupees.
1	*Surge Shaft—*							
	Excavation	125125	2500	13	..	..	21000	120000
	Linig ..	..	66000	68	1100	..	..	151000
	Grouting ..	..	7475	..	..	..	..	39000
	Granite Mantle.	..	2500	32	..	..	..	20000
2	*Pipe Tunnels—*		..					
	Excavation	405000	500	..	..	10000	51000	263000
	Lining ..	..	186250	15	..	..	750	289000
	Pipes ..	..	..	550	..	..	100	420000
	Portal ..	60500	33200	25	600	..	5400	99135
3	*Penstock Line—*							
	Excavation	3161600	5700	..	70740	169300	2000	195140
	Anchors ..	286240	381763	83	1100	..	9155	420862
	Supports ..	60270	79863	8	..	..	636	91000
	Dressing ..	351500	5000	10	800	219000	..	60145
	Penstocks ..	..	..	3600	..	..	500	2502000
	Total ..	..	..	..	..	..	..	..

Cost of Surge Shaft	per ft. depth	..	880
Do. Pipe tunnels	per ft. run	..	974
Do. each tunnel	do. do.	..	487
Do. Penstocks	per ft. horizontal	..	747
Do. each pipe	do. do. along slope	..	373 683

TABLE "B".

Progress of various works.

Year.	Pipe Tunnels.	Surge Shaft.	Penstock Line.
1-6-28 ..	Excavation 100′ ..	..	Excavation survey.
7-12-28 ..	Const. of Portal ..	..	Excavation.
1-6-29 ..	Excavation 400′ ..	Erecting Headgear and Excavation 80′.	Do.
7-12-29 ..	Excavation 500′ ..	Excavation 300′ ..	Collection of materials.
1-6-30 ..	Completion of Excavation. Preparation for Lining.	Preparation for Lowering Pipes and Lining Pipe Tunnels.	Pouring supports and anchors 8–5 lower half.
7-12-30 ..	Opening out and lining 1st 150′ Pipe Tunnels.	..	Pouring supports and anchors 5–2 lower half.
	Fixing pipes & lining 700′ Pipe Tunnels.		Starting fixing Penstocks at 8.
1-6-31 ..	Completion of Pipe Tunnels Pipes and lining.	Lining Surge Shaft 150′.	Completion of all anchors lower half. Fixing Penstocks 1–10 and capping 1–10.
7-12-31 ..	..	Completion of lining	Completion of all pipes, anchors and supports.
1-6-32 ..	Fixing Valves ..	Constructing Surge Chamber, grouting and guniting shaft.	

TABLE "C."

Showing 48 hours' normal work while concreting the Pipe Tunnels.

Time.	"A" Tunnel.	"B" Tunnel.
0800—1600	Lowering 2 pipes down shaft and tunnels and fixing.	Concreting the pipes completed the day before.
1600—2359	....	Completing concrete under pipes.
0001—0800	....	Do. do. round sides
0800—1600	Rivetting, caulking and painting pipes fixed the day before.	Do. do. top of one pipe.
1600—2359	....	Do. do. do. second.
0001—0800	....	Moving mixer and all concrete materials into the other tunnel.

As the European erectors did not work on Sundays a hiatus would have occurred had not the concreting taken slightly longer than shown. Each time the mixer was moved therefore an increasing amount of concrete was left incomplete and on Sundays this deficiency was made up in that tunnel in which the mixer was.

TABLE " D."

Types of concrete used showing details of aggregate etc.

Purpose for which used.	Maximum size of aggregate.	Fineness modulus including sand.	Water in lbs compressed for sand moist.	Cement volume in cft. 1 Weight in lbs.	Volume of ready mix in cft.	Slump in inches.
Lining Pipe Tunnels—						
(A) Base of open tunnels ..	2½	6.25	70	1.048 98.51	5.6	2½–3
(B) Arch and walls of tunnel	2½	6.25	70	1.072 100.77	5.57	2½–3
(C) Round pipe in first 200′ of closed tunnel.	1½	5.7	70	.974 92.56	5.11	3½–4
(D) Remainder of closed tunnel	2½	6.25	70	.974 91.56	5.65	2½–3
Lining Surge Shaft—						
(A) Special mortar	⅜	4.27	70	1.72 161.0	5.46	5–8
(B) Normal concrete ..	1	5.35	70	1.072 100.77	4.72	2½–3
Anchors—						
(A) First 6 months ..	1½	5.7	70	1.048 98.51	5.18	2½–3
(B) Later concrete ..	2½	6.25	70	1.048 98.51	5.6	2½–3
Supports—						
(A) First pour	1½	5.7	70	1.048	6.13 5.86	1–1½
(B) Capping	1	5.35	70	1.048 98.51	4.56	3½–4
Cheap concrete for over-breakage in tunnel and anchors.	2½	6.25	70	.826 77.64	5.7	2½–3

Note.—Readymix was prepared by adding two parts of properly graded sand to four parts of properly graded aggregate; this gave five parts of readymix. If the sand and aggregate were not properly graded the laboratory tests showed the proportions in which they were to be mixed to get a correct fineness modulus.

Correct grading of Readymix.	Sand passing.			Aggregate passing.		
	No. 8.	No. 16.	No. 100.	1	½	No. 8.
1	More than 90%	Between 40% & 70%	Less than 10%	More than 90%	Between 40% & 75%	Less than 10%
	No. 4	No. 8	No. 100	1½	¾	No. 4
1½	More than 90%	Between 40% & 70%	Less than 10%	More than 90%	Between 40% & 75%	Less than 10%
	No. 4.	No. 8.	No. 100	2½	1¼	No. 4.
2½	More than 90%	Between 40% & 70%	Less than 10%	More than 90%	Between 40% & 75%	Less than 10%

For convenience when concreting, readymix was brought to the most suitable whole number for the particular mixer in use and the cement and water weight altered in proportion.

The cement and water were weighed in tins on a spring balance and the aggregate measured in 1 cft. wooden boxes.

PLATE I
196

LAYOUT OF PIPE TUNNELS

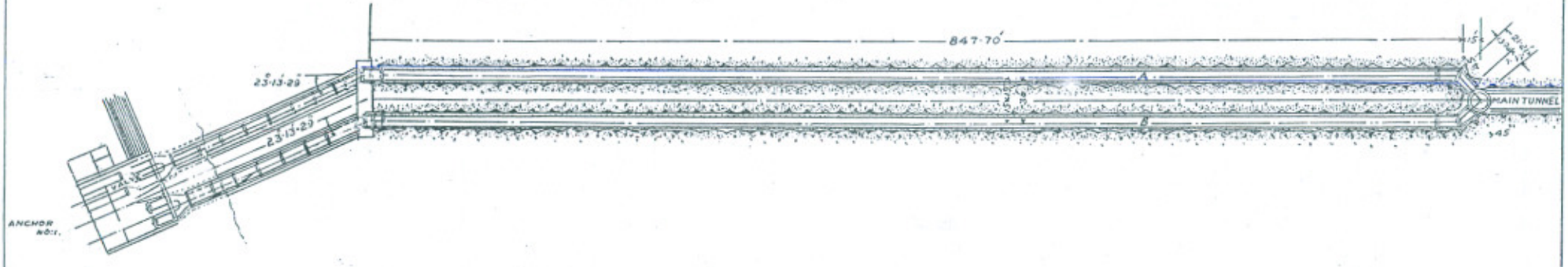
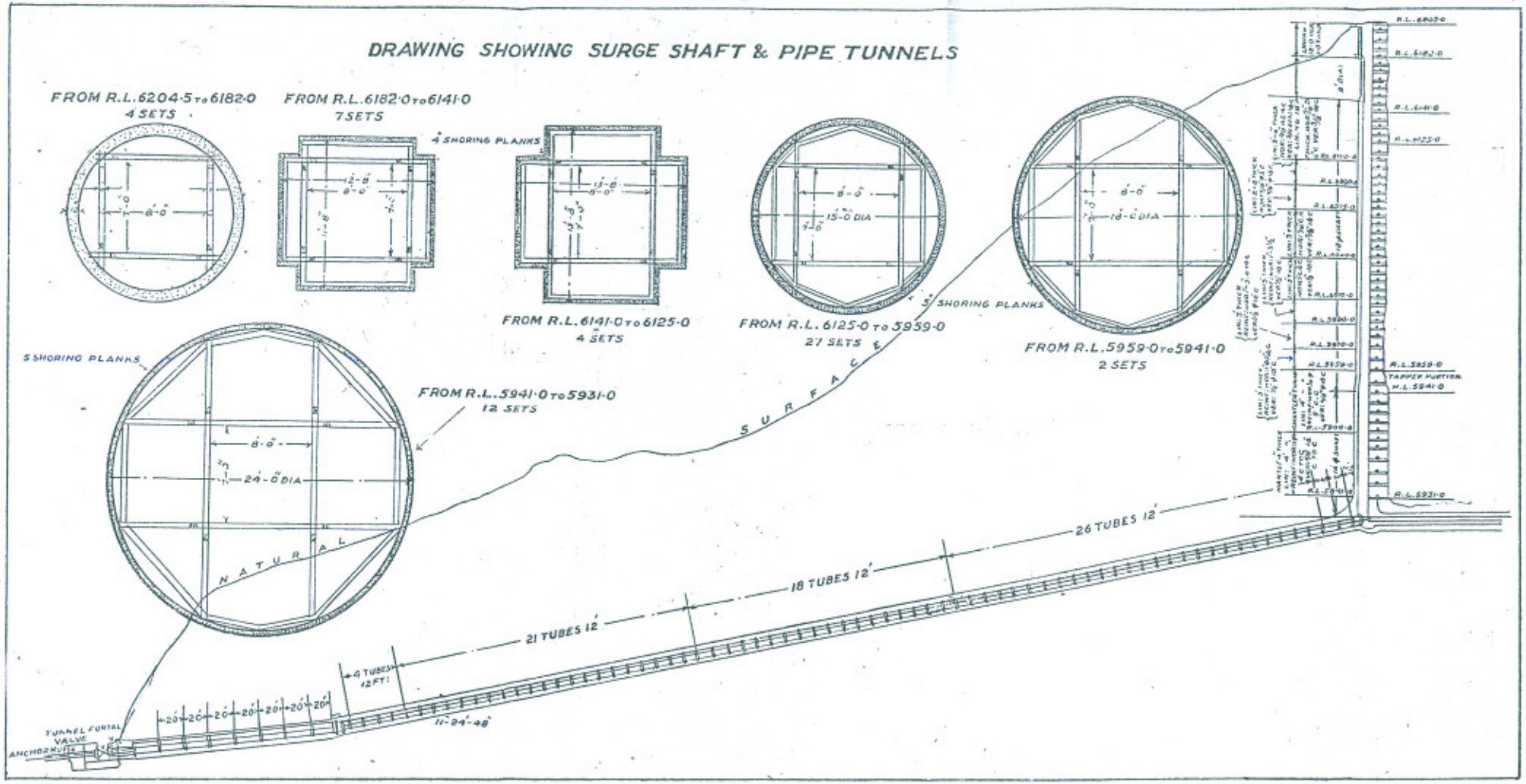


PLATE 2
196

DRAWING SHOWING SURGE SHAFT & PIPE TUNNELS



SKETCH SHOWING CONCRETE AT R.D. 600.

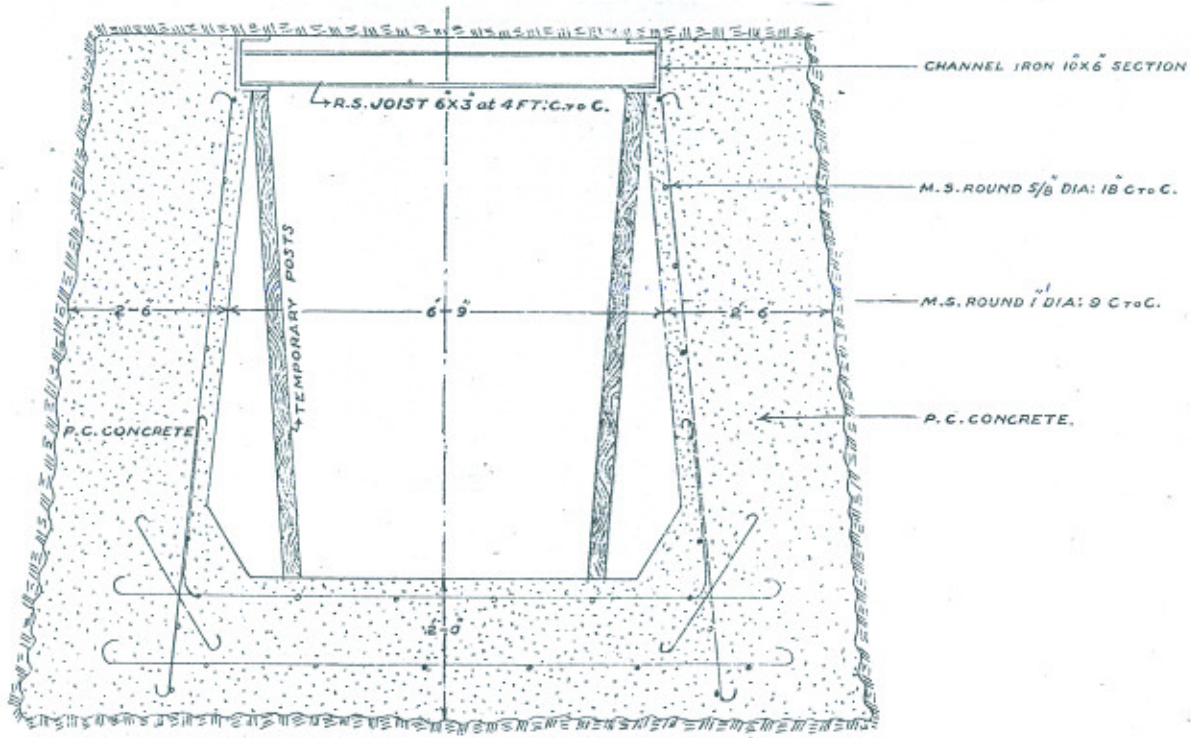
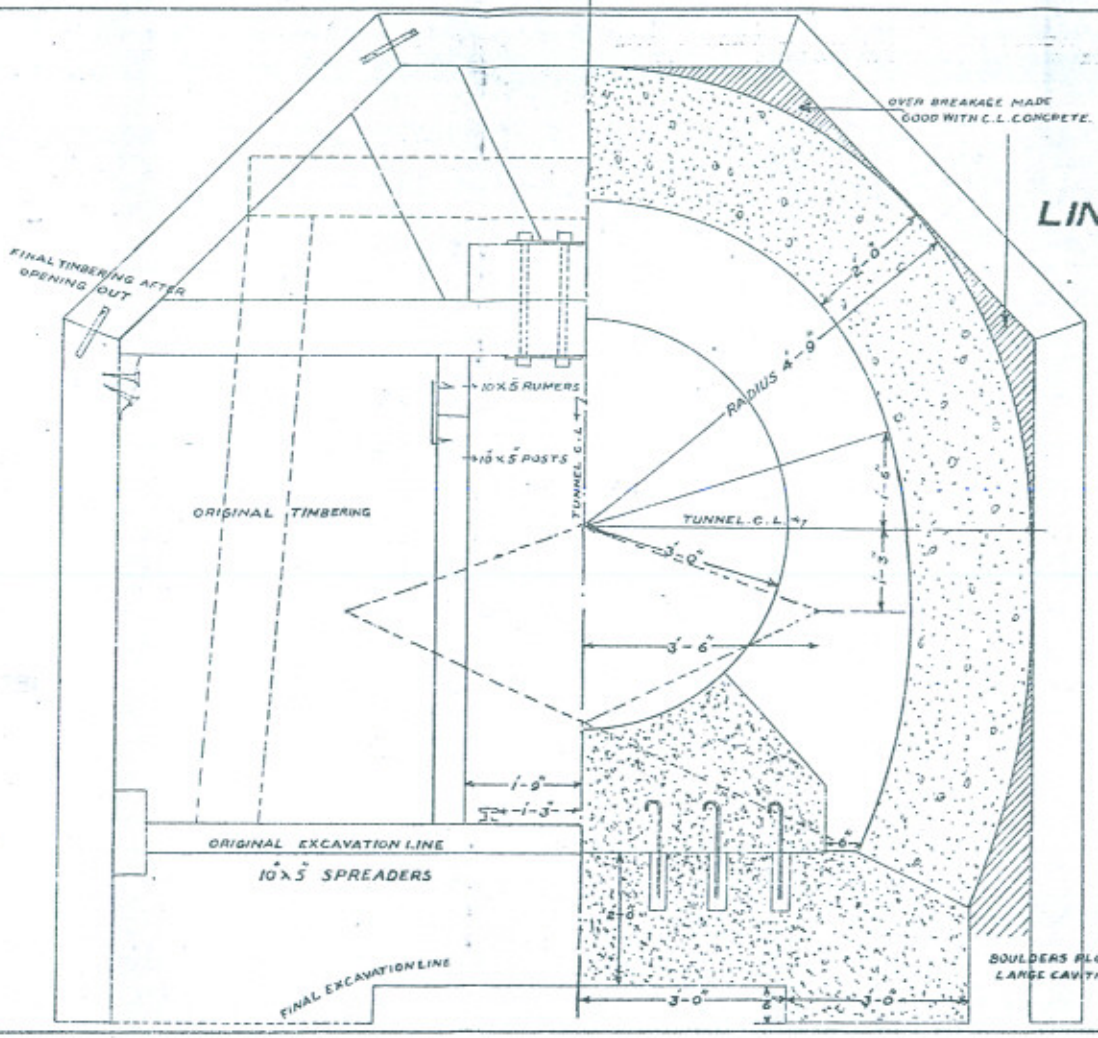


PLATE 4
196

CROSS SECTION OF LINING LOWER 150' OF PIPE TUNNELS



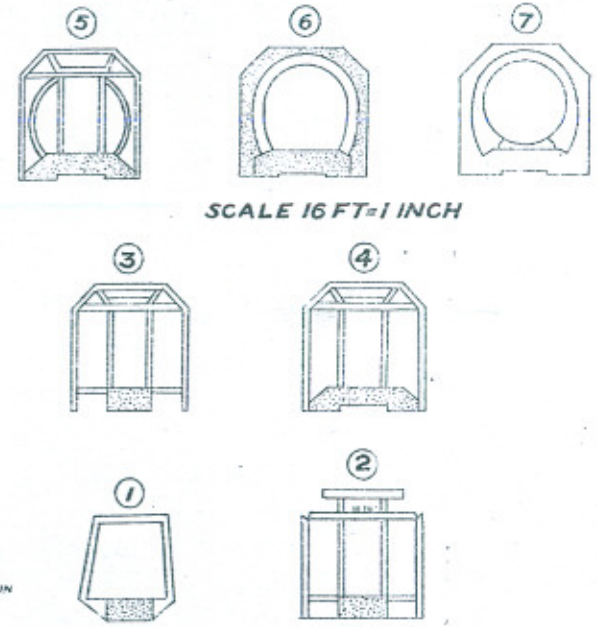
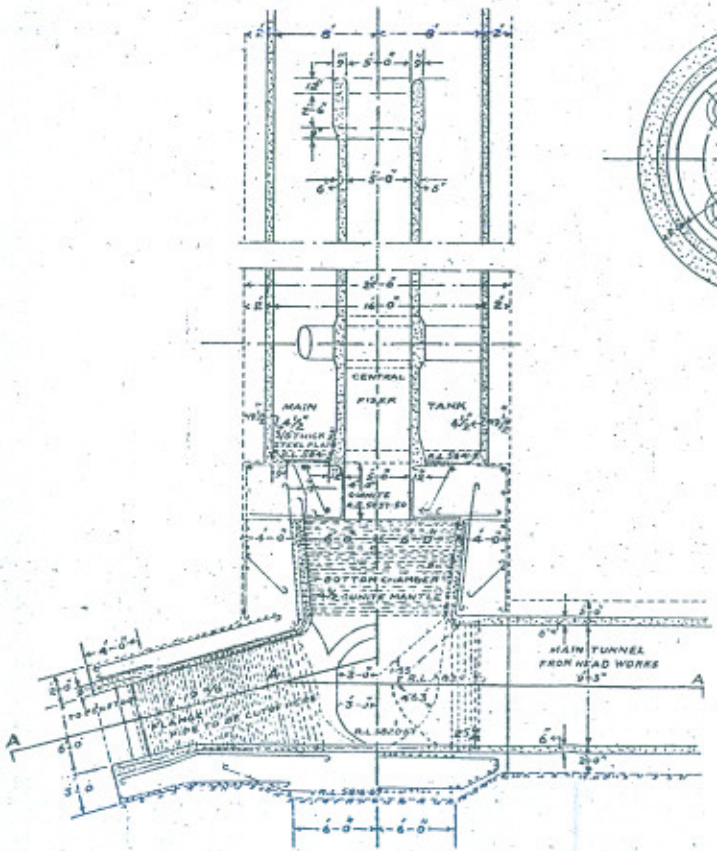
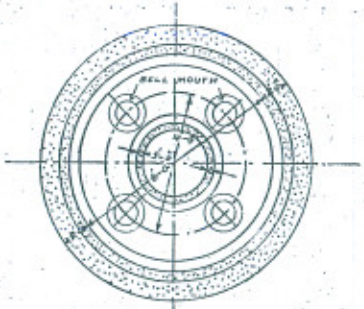


PLATE. 5
196

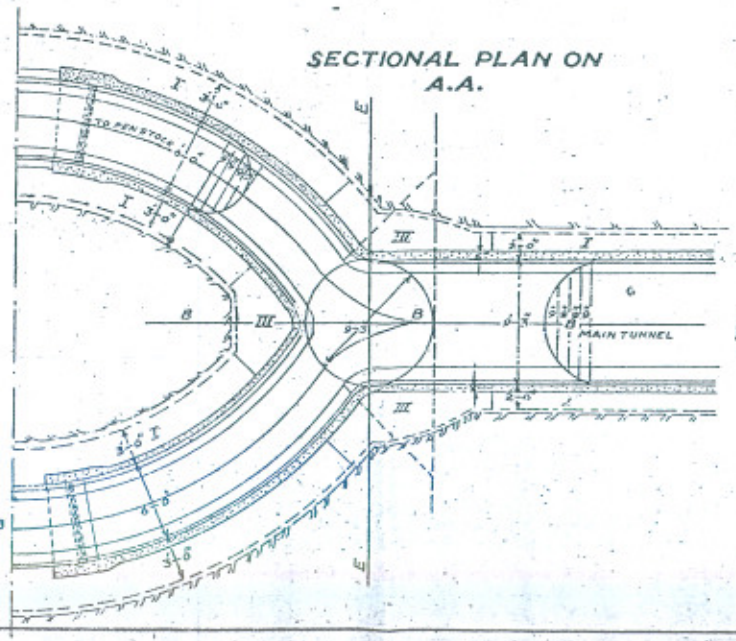
DESIGN OF SURGE SHAFT

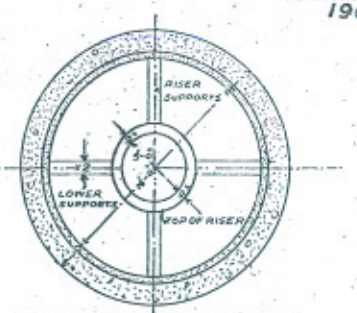




SECTIONAL PLAN ON
C.C. AND D.D

SECTIONAL PLAN ON
A.A.





SECTIONAL ELEVATION
ON E.E.

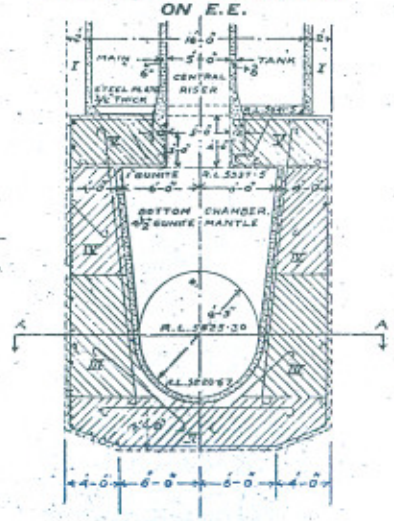
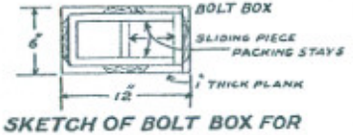
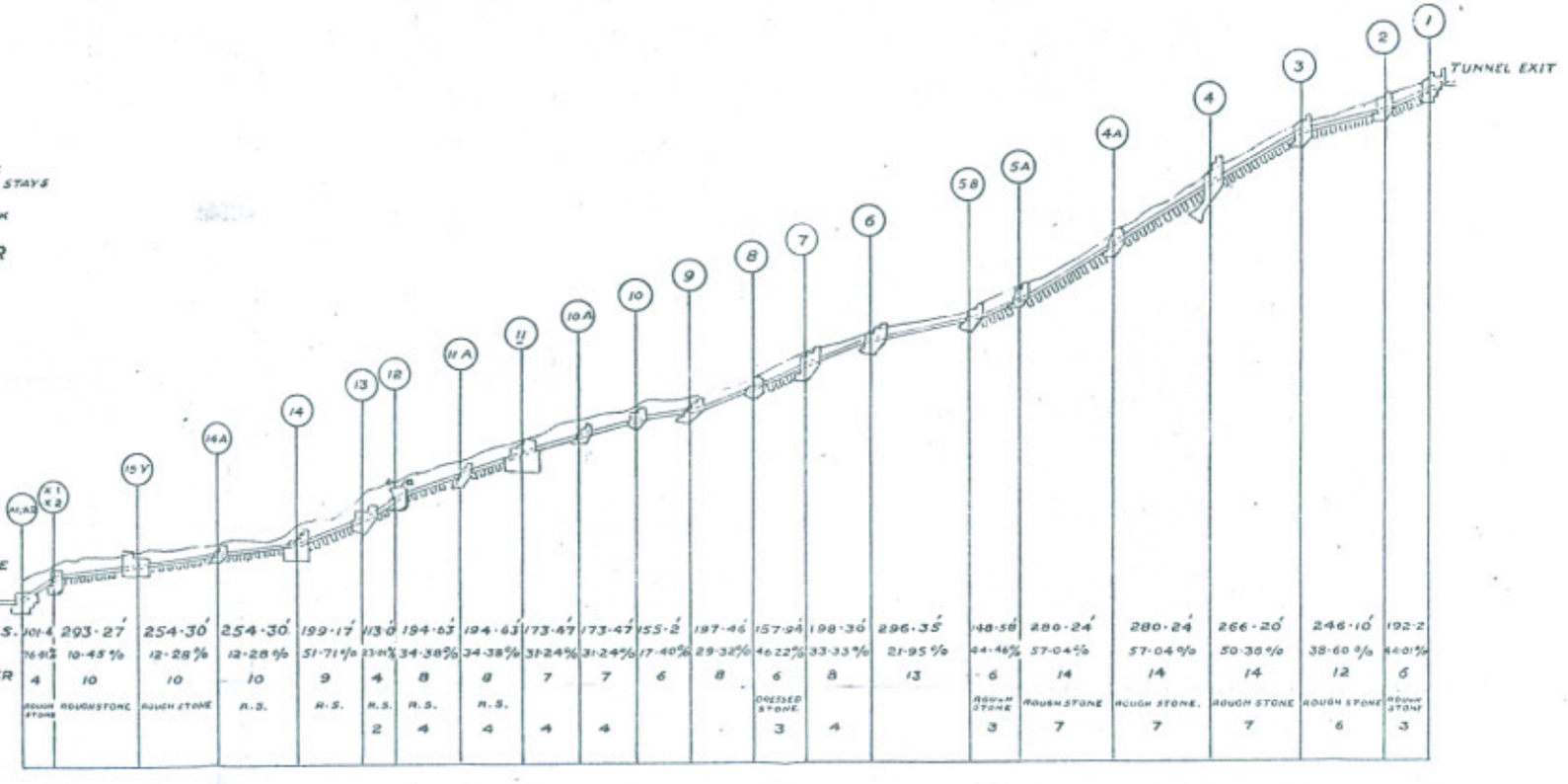


PLATE.6
196

LONGITUDINAL SECTION OF PIPE LINE FROM POWER HOUSE TO TUNNEL EXIT.



SKETCH OF BOLT BOX FOR ANCHORS



HORIZONTAL DISTANCES.	101·4'	293·27'	254·30'	254·30'	192·17'	113·0'	194·63'	194·63'	173·47'	173·47'	155·2'	197·46'	157·94'	198·30'	296·35'	148·58'	280·24'	280·24'	266·20'	246·10'	192·2'
GRADIENTS.	76·9½%	10·45%	12·28%	12·28%	51·71%	23·01%	34·38%	34·38%	31·24%	31·24%	17·40%	29·32%	46·22%	33·33%	21·95%	44·46%	57·04%	57·04%	50·38%	38·60%	44·01%
NO OF SUPPORTS UNDER EACH PIPE LINE.	4	10	10	10	9	4	8	8	7	7	6	8	6	8	13	6	14	14	14	12	6
TYPE OF PITCHING.	ROUGH STONE	ROUGHSTONE	ROUGH STONE	R.S.	R.S.	R.S.	R.S.	R.S.					DRESSED STONE			ROUGH STONE	ROUGH STONE	ROUGH STONE.	ROUGH STONE	ROUGH STONE	ROUGH STONE
CROSS WALLS BETWEEN ANCHORS.						2	4	4	4	4			3	4		3	7	7	7	6	3

DATUM LINE 3623·00.

PLATE 7
196

PLAN OF PIPE LINE FROM POWER HOUSE TO TUNNEL EXIT

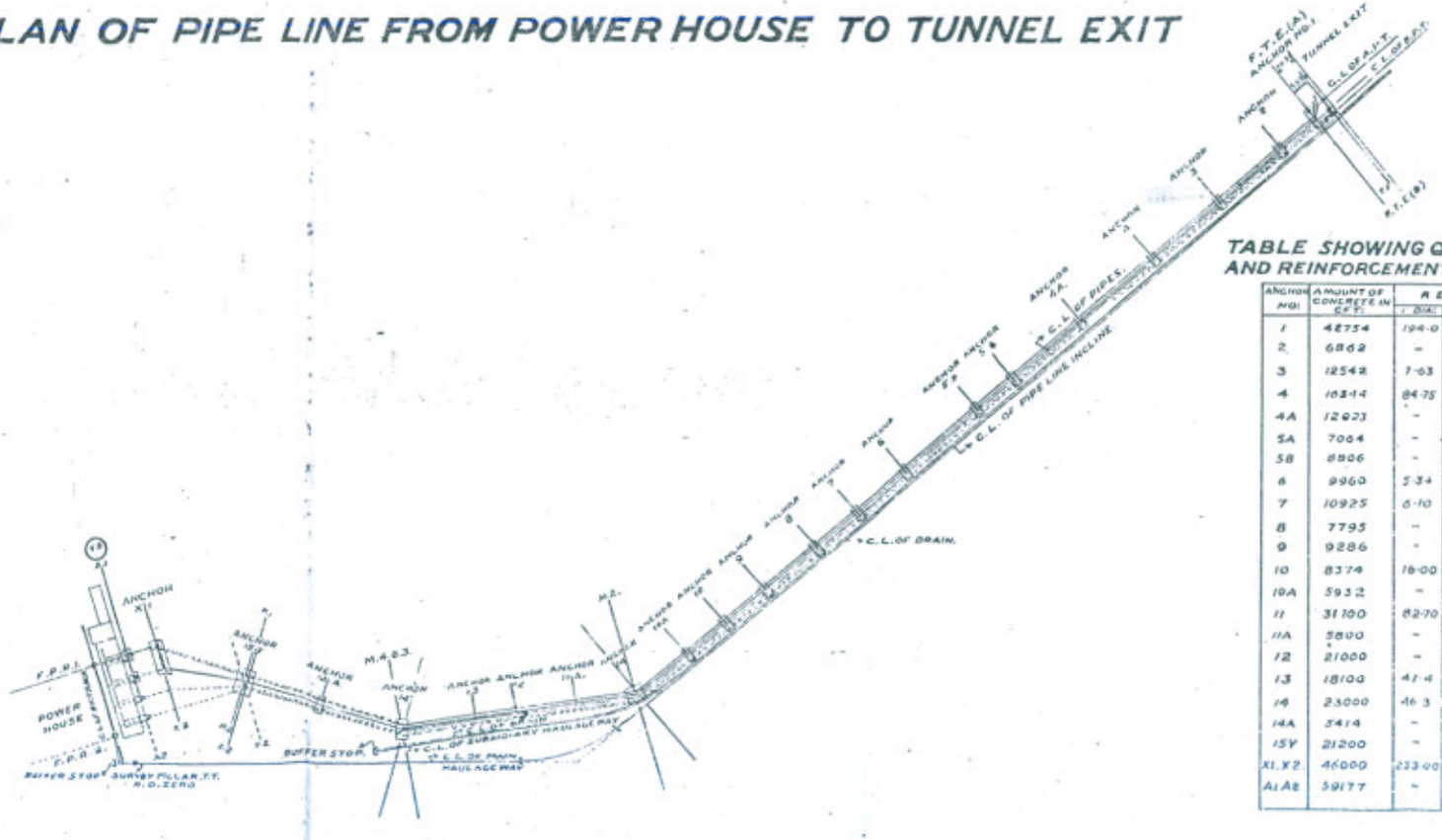


TABLE SHOWING QUANTITY OF CONCRETE AND REINFORCEMENT PUT IN EACH ANCHOR

ANCHOR NO:	AMOUNT OF CONCRETE IN C.F.T.	REINFORCEMENT				
		1" DIA.	3/4"	1/2"	1/2"	
1	48734	194·0	9·50	-	-	
2	6862	-	1·19	-	-	
3	12542	7·63	4·25	-	-	
4	16314	84·75	3·05	-	-	
4A	12923	-	3·02	-	-	
5A	7064	-	1·11	-	-	
5B	8806	-	2·79	-	-	
6	9960	5·34	3·13	-	-	
7	10925	6·10	3·65	-	-	
8	7795	-	1·00	-	-	
9	9286	-	2·72	-	-	
10	8374	16·00	3·00	-	-	
10A	5932	-	3·30	-	-	
11	31100	82·70	4·00	-	-	
11A	5800	-	4·00	-	-	
12	21000	-	2·00	51	7	
13	18100	41·4	9·30	-	-	
14	23000	46·3	4·20	-	-	
14A	5414	-	1·90	-	-	
15V	21200	-	7·00	-	-	
X1, X2	46000	233·90	-	-	-	
A1 A2	59177	-	4·40	-	-	

DISCUSSION.

Captain **Boddington** in presenting the paper apologized for its being rather out of date, since he had not had an opportunity of submitting it before, due to his being in England. Its purpose was that it might be of some assistance to other engineers, having similar work in this country, as it was concerned almost entirely with the practical side of the construction work outlined.

It would be seen from Plate VII that the shortest alignment was not adopted. The reason for this was that there were a considerable number of springs in the area and it was essential that these should be avoided. In addition it was not suitable to site the pipe line on sidelong ground as there was the possibility of slips.

The survey of the pipe line was very accurately done but it would be realized that to fit in the pipe line exactly to survey was almost impossible, particularly when the expansion of the pipe itself amounted to feet over its length. In order to ensure an agreement between the pipe line and the survey, certain expansion joints were sent out from the works 6″ to a foot too long so that in fitting, the difference in length could be made up by cutting off part of this sliding joint. Actually in only one case had this cutting to be done and it brought the pipeline length to within 1″ or so of the surveyed length.

One other point which might interest visitors to Jogendarnagar is that there was considerable erosion to the right of the pipe line when looking up the hill. This was tackled by means of wired crates filled with stones so that the nullahs could not cut away and in addition the whole area was fenced to prevent depredations of coolies in search of firewood and goats and sheep in search of food. In addition some 20 thousand trees had been planted and though he had not seen them then, he was told, the results were more than satisfactory.

Mr. **H. P. Thomas** stressed on one point in the paper which, he considered, had not received the prominence to which it was entitled. On page 149 in the last paragraph, the statement is made " as none of the timber sets and lagging boards (referred to in the excavation of the shaft) were allowed to be left in, these had first to be removed."

It would perhaps be obvious that, when it was necessary to shore up badly shattered rock, the removal of these shores was liable to cause heavy falls of the rock so shored, if not invite disaster ; yet it was necessary that no material which was not of a permanent nature be left between the concrete lining and the hill itself. For instance if wooden shores and lagging boards had been left between the concrete lining and the rock face, the disintegration of this timber would have resulted in time in the formation of cavities or in an extreme case an annular space between the lining and the rock which could only have been filled in by a further substance of the material of which the hill was

formed. It was, therefore, necessary to remove all such timber before applying the lining and at the same time avoid a collapse in the shaft due to its removal prior to the setting of the concrete lining. It was due to the necessity for doing this work that slow progress at times was unavoidable and the officers in charge were called upon to display an amount of vigilance, judgment and nerve which would not have been necessary in constructing similar works in a rock of a less shattered nature.

The **author** did not think it necessary to reply to the comments of Mr. H. P. Thomas.