necessity arisen. In fact, in the south headings, with the aid of additional centring, over 400 ft. was done in one heading in a month.

The cost of the lining through the granite gneiss, which work has only recently started, is estimated to amount to Rs. 48 per ft. run.

The cost of the complete lining, excluding the mantle, of the surge shaft heading was Rs. 157 and of the mid-point heading was Rs. 162 per ft. run.

The cost of the mantle in the southern headings amounted to Rs. 160 per ft. run.

Grouting.

Grouting or injection into the rock by means of compressed air of liquid mixtures of cement, sand and water in varying proportions has been extensively applied throughout the tunnel.

Reference has already been made to the employment of this process as an aid in excavation through loose rock. Its main application however is in connection with lining.

In all except the most solid rock there is always a disturbed area surrounding the excavated section more particularly over the upper portions. As a tunnel is excavated the existing stresses in the rock have to adjust themselves to the new conditions and a natural arch of varying stability is formed. If the rock is of a disintegrated or highly jointed nature falls from the roof will tend to take place and this is especially liable to happen where the rock is charged with water and is of a rapidly weathering nature. The construction of a concrete arched lining will go far tc give stability but if any hollows are left above the lining it is obvious that rock movement is possible and hence the development of heavy pressure may not be entirely prevented. The roof of a tunnel is always more or less uneven and it is not possible to ensure that the concrete lining at the crown invariably makes close contact with the rock. Even where the concrete is packed tight the shrinkage while setting leaves a small space between the upper portion of the ring and the rock. It is here that grouting is indispensable and affords a simple means of filling voids.

Grouting through the lining is carried out in two stages : (1) low pressure grouting, and (2) high pressure grouting. Low pressure grouting is carried out with air up to 100 lbs./sq. in. which is piped direct from the compressors. Its object is to fill all voids behind the lining, to render the concrete waterproof and to consolidate loose stone packing and also the surrounding rock so far as this is possible with the low pressure

High pressure grouting is carried out by means of the same plant with the addition of a small Worthington booster compressor which takes air from the main at 100 lbs/sq. in. and delivers it to the grouting tank at 300 lbs. The object is to continue the work of the low pressure grouting and to fill up the smaller crevices in the surrounding rock and so render it stable and water tight. At the time of writing this work is only at its commencement so that it cannot be further described.

Proportions of water, sand, and cement for the low pressure grouting have varied considerably from neat cement at half a bag to ten gallons of water for the finest voids up to a mixture consisting of one cu.ft. of cement and three of sand with seven to ten gallons of water for consolidating stone packing and filling larger voids. One and a half or two inch pipes for grouting are fixed in the concrete at the time of lining at regular intervals and the number is subsequently increased as required by drilling the lining. Pipes are also fixed as water vents in wet stretches and the inflow of water is concentrated into these by grouting others in the vicinity.

In order that grouting may proceed without interruption to traffic, recesses are left in the lining every 200′ to accommodate the grouting tanks and from these points grout is delivered to pipes located up to 100′ away on either side. As a rule grout is forced into a pipe until it will take no more. If grout leaks from adjoining pipes, the latter are plugged. Grout will often travel considerable distances behind the lining. Any imperfect joint in the lining is almost immediately detected by grout leakage which however always ceases as grouting continues illustrating the waterproofing effect achieved. After a stretch of tunnel has been grouted so that no more can be taken the grout is left to set and later on the pipes are all drilled through 6′—8′ in depth and the grouting is repeated.

The quantity taken naturally varies considerably being large in the neighbourhood of stone packed cavities and small in good rock.

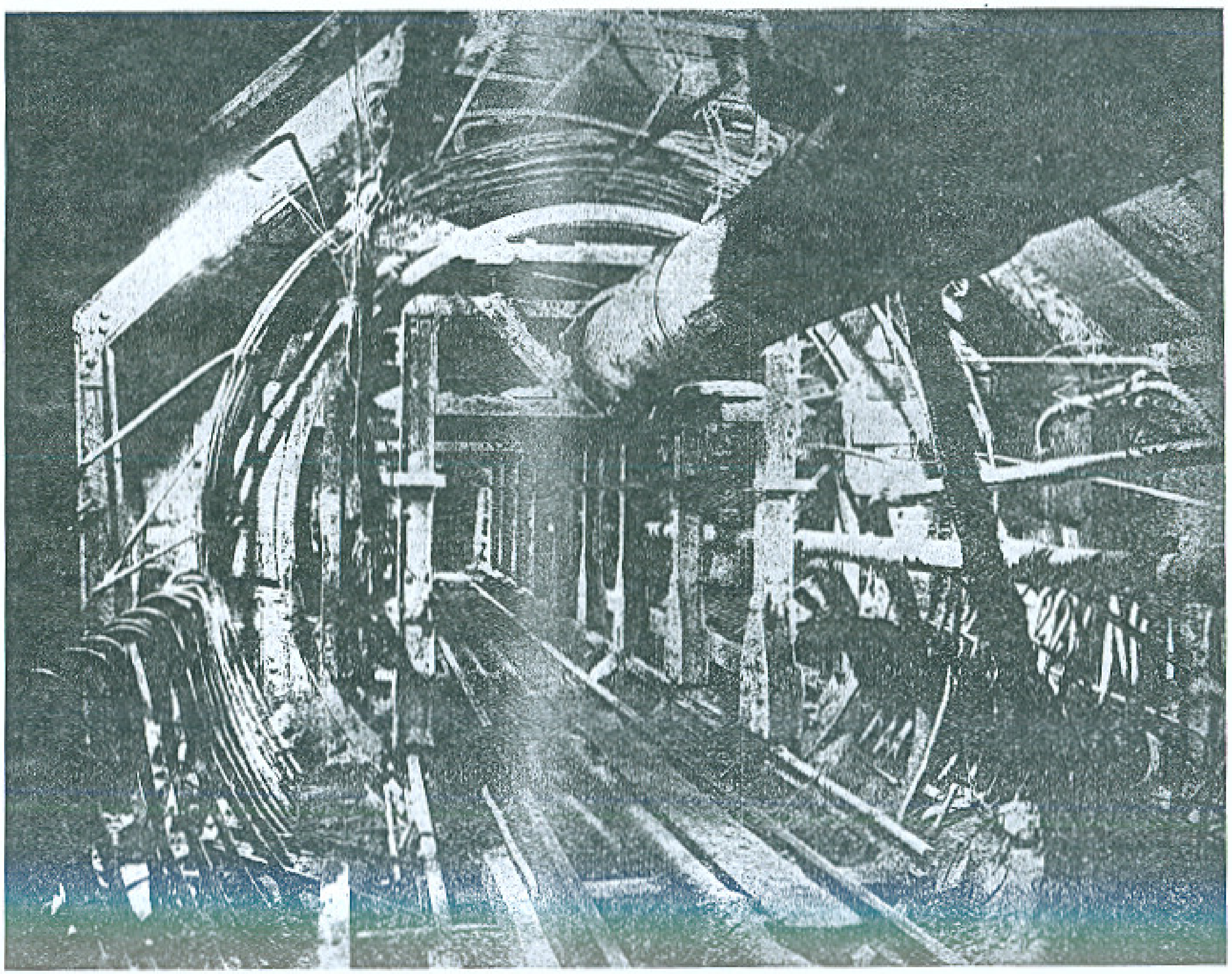
Upto the end of October, 1931, the average quantities were as follows :—

	Grout injected per foot of tunnel grouted.	Cost per foot of tunnel.
		Rs.
North heading	4 Cu. ft.	5
Midpoint heading	7 Cu. ft.	15
Surge shaft heading	11 Cu. ft.	14

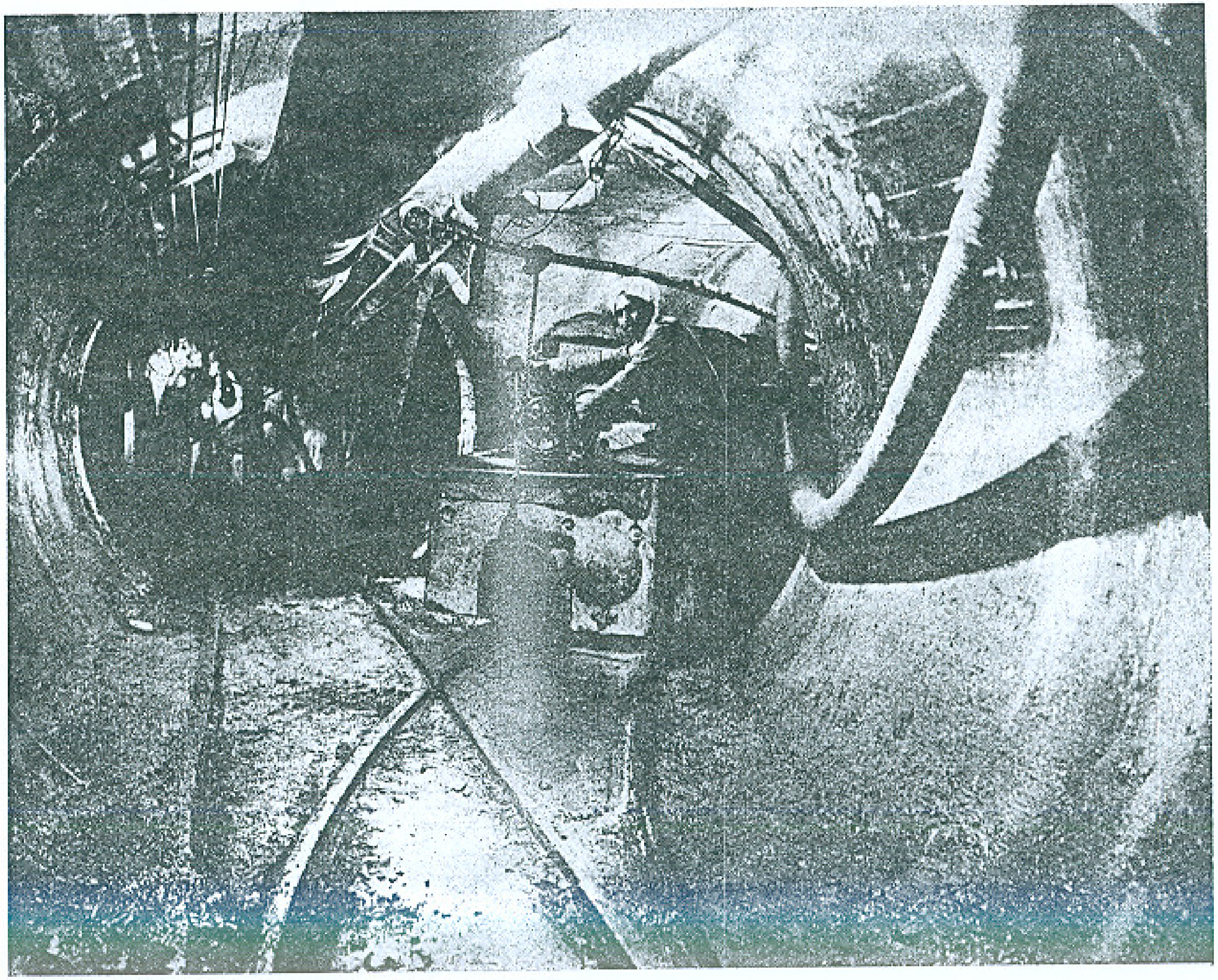
Conclusion.

At the beginning of December there still remained some 1300 ft. of tunnel to be driven to connect up the two headings, and it is hoped to complete this work in March 1932, after which date the lining and mantling will have to be finished off, ready for testing out some four months later. The testing out of the penstock, power house machinery, and transmission lines will then follow, and it is hoped to start the supply of power by the spring of 1933.

The writers desire to thank Messrs. McPhail and Brickman for certain data they have kindly supplied, regarding the surveys and work in the northern heading.

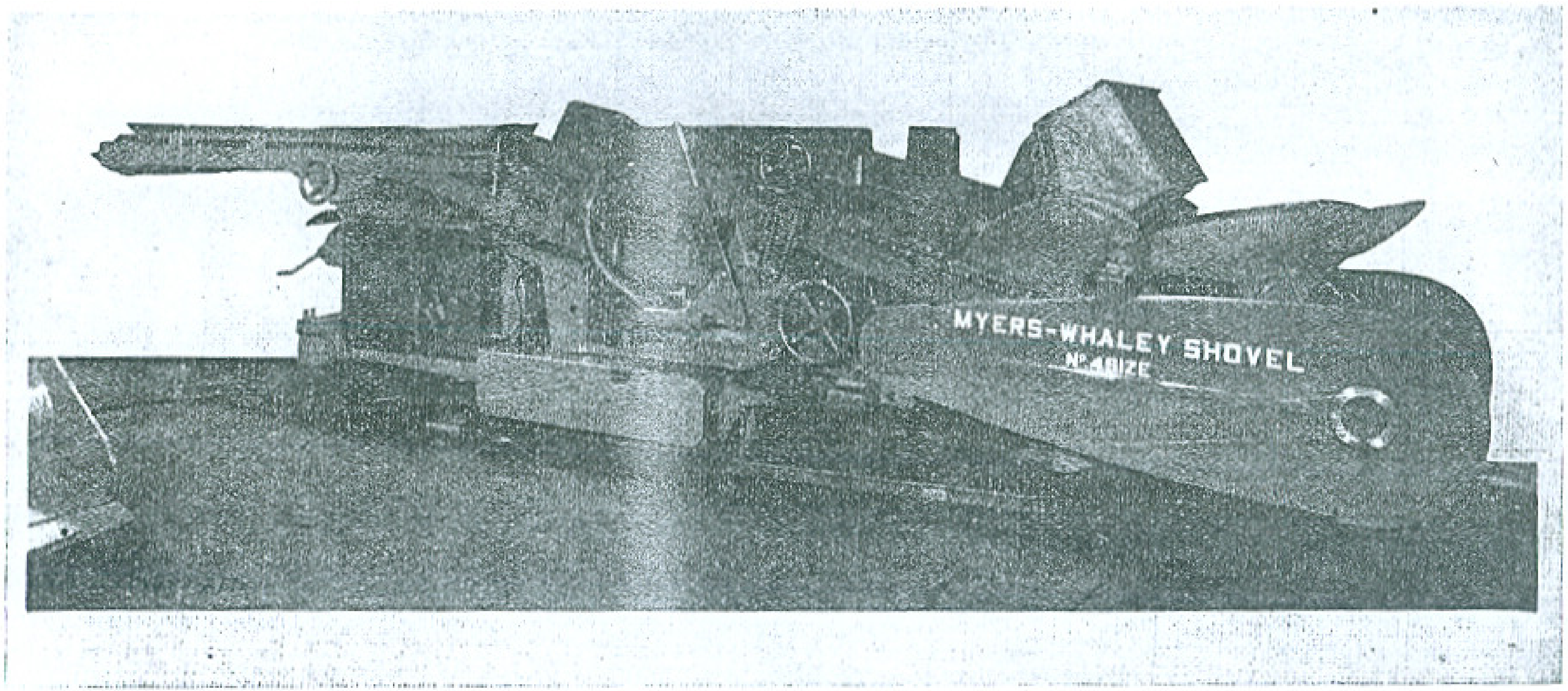


Centring Car.



Valve Adit Junction, North Heading.

Drilling in Granite.

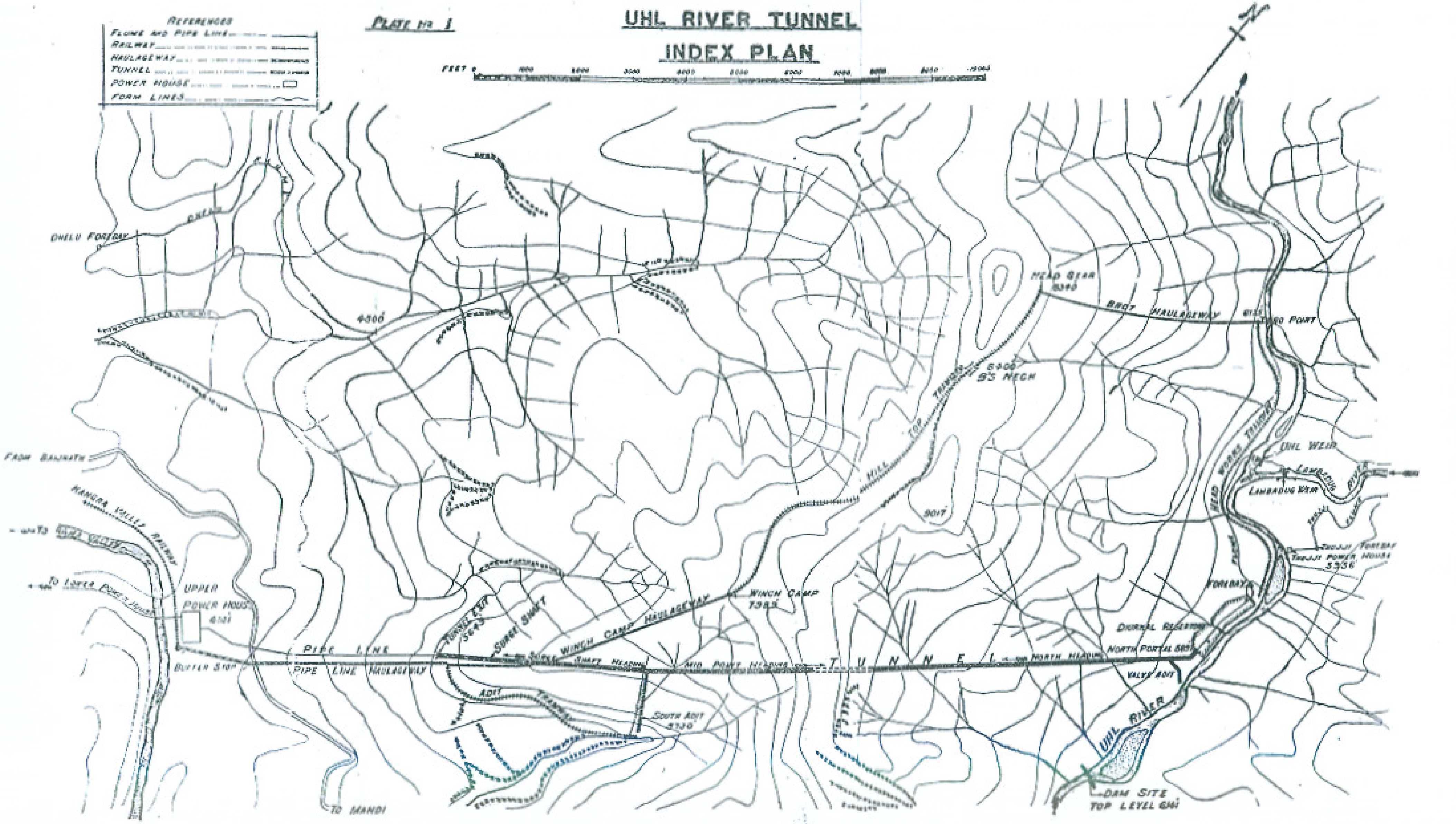


Mucking Machine.

PLATE No 1

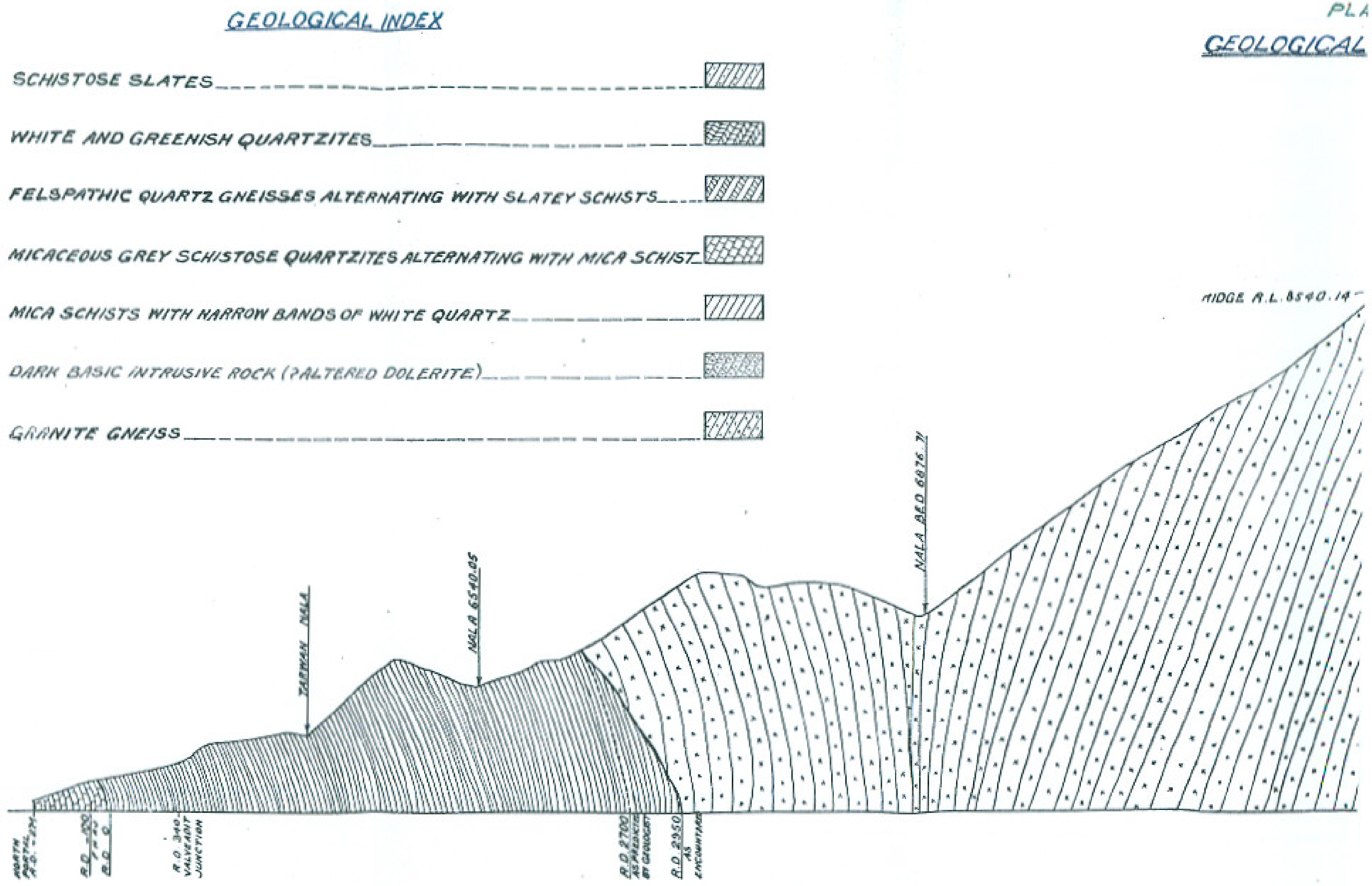
UHL RIVER TUNNEL

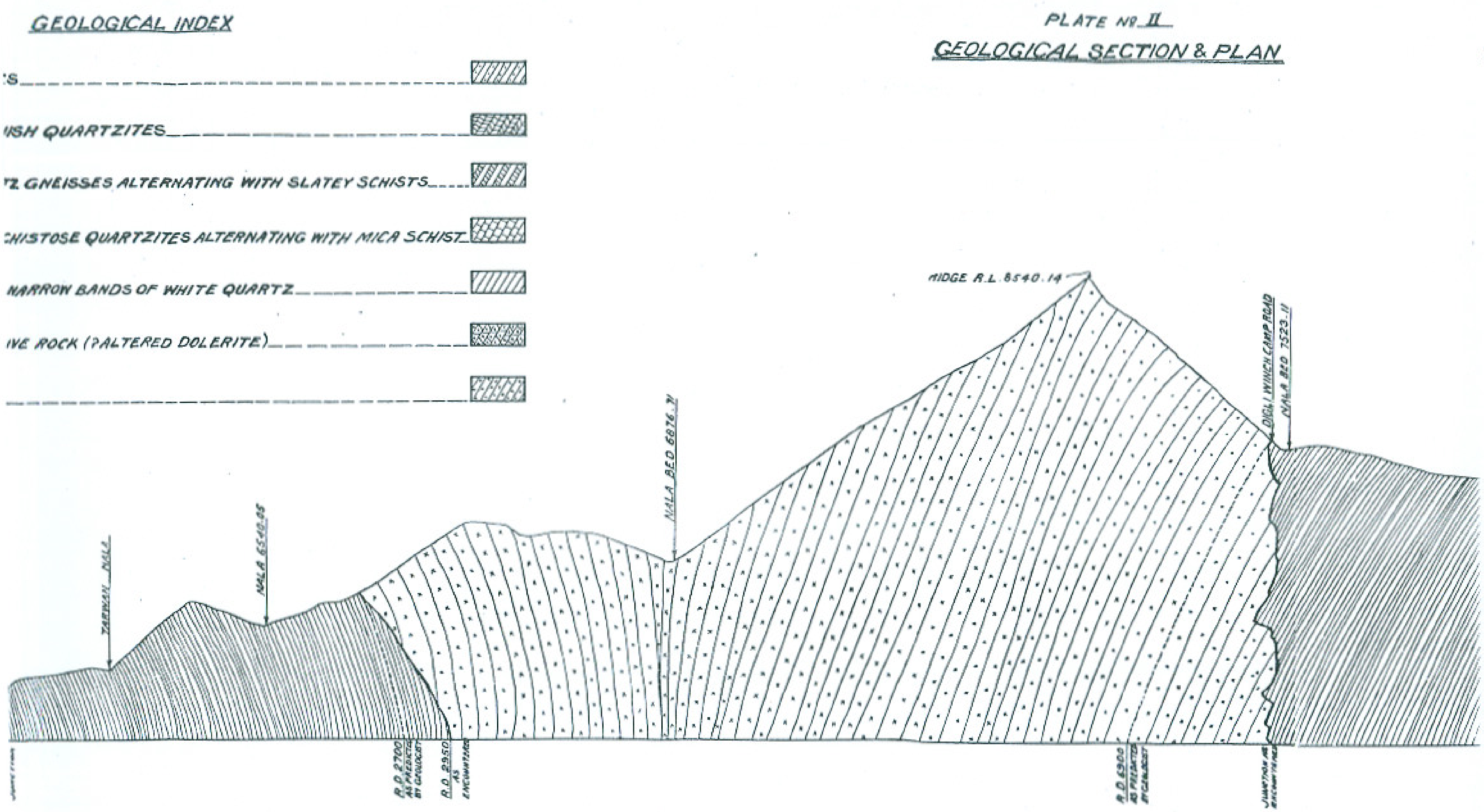
INDEX PLAN



PLA

GEOLOGICAL




GEOLOGICAL INDEX
:S
ISH QUARTZITES
TZ GNEISSES ALTERNATING WITH SLATEY SCHISTS
CHISTOSE QUARTZITES ALTERNATING WITH MICA SCHIST
NARROW BANDS OF WHITE QUARTZ
IVE ROCK (?ALTERED DOLERITE)
PLATE No II
GEOLOGICAL SECTION & PLAN
RIDGE R.L. 8540.14
DIGLI WINCH CAMP ROAD
NALA BED 7523.11
NALA BED 6876.71
NALA 6540.05
TARWAN NALA
R.D 2700 AS PREDICTED BY GEOLOGIST
R.D 2950 AS ENCOUNTERED
R.D 6900 AS PREDICTED BY GEOLOGIST
JUNCTION AS ENCOUNTERED

II

TION & PLAN

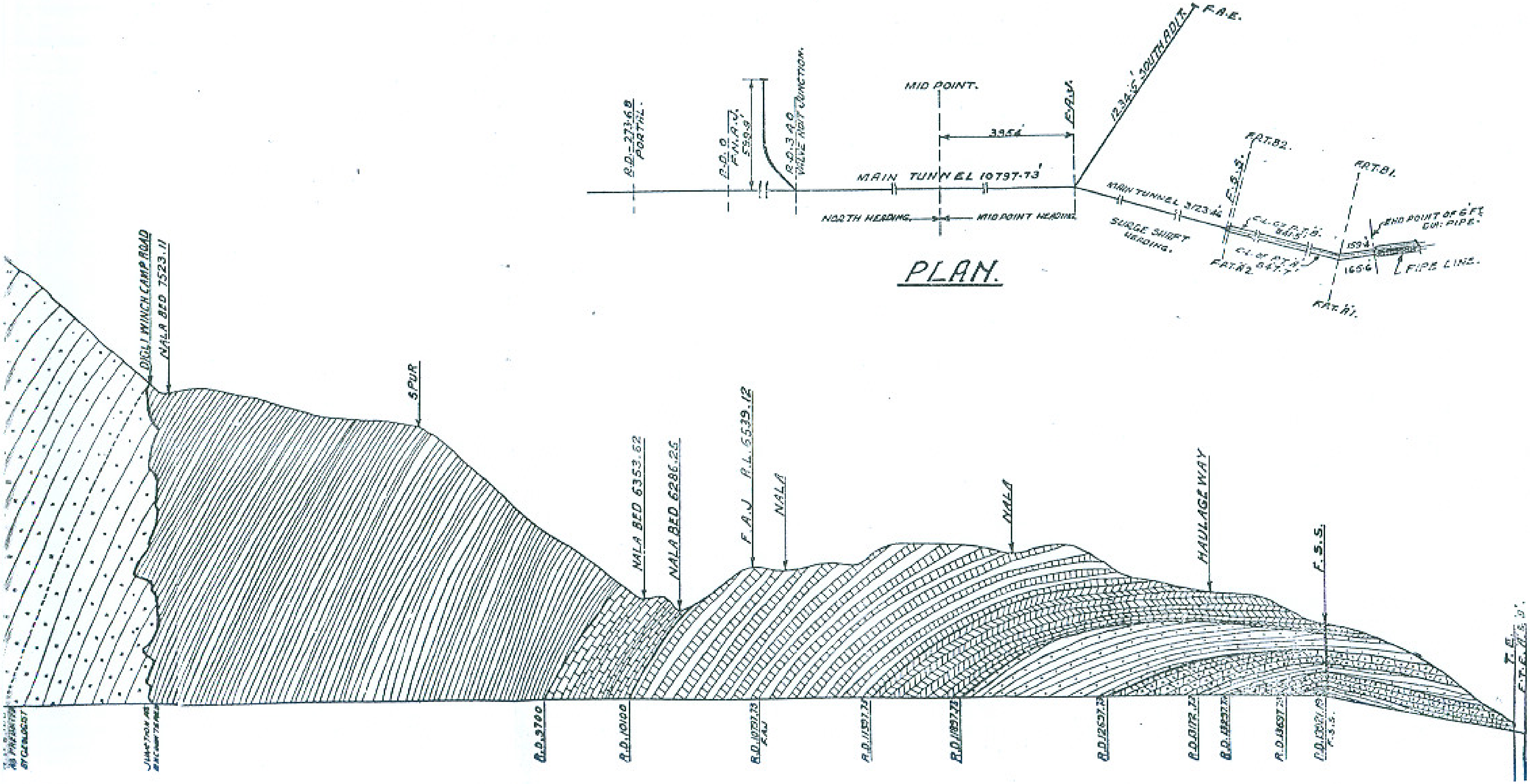
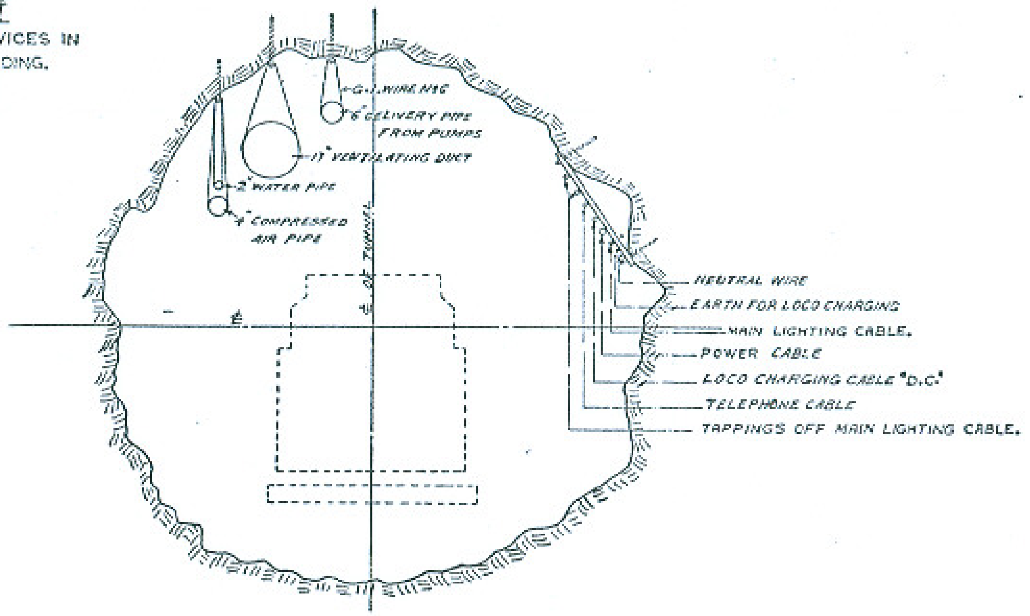

PLAN.
MAIN TUNNEL 10797-73'
MID POINT.
3954'
F.A.J.
1234.5' SOUTH ADIT.
F.A.E.
R.D.-273.68 PORTAL.
R.D. 0 F.N.A.J.
599.9'
R.D.340 VALVE ADIT JUNCTION.
NORTH HEADING.
MID POINT HEADING.
MAIN TUNNEL 3123.46'
SURGE SHAFT HEADING.
E.S.S.
F.AT.B2.
F.AT.B1.
END POINT OF 6 FT. DIA. PIPE.
PIPE LINE.
159.4'
165.6'
DIGLI WINCH CAMP ROAD
NALA BED 7523.11
SPUR
NALA BED 6353.62
NALA BED 6286.25
F.A.J. R.L. 6539.12
NALA
NALA
HAULAGE WAY
F.S.S.
R.D. 9700
R.D. 10100
R.D. 10797.73 F.A.J.
R.D. 11537.73
R.D. 11897.73
R.D. 12657.73
F.S.S.
T.E.

PLATE No III
ARRANGEMENT OF SERVICES IN
NORTHERN HEADING.



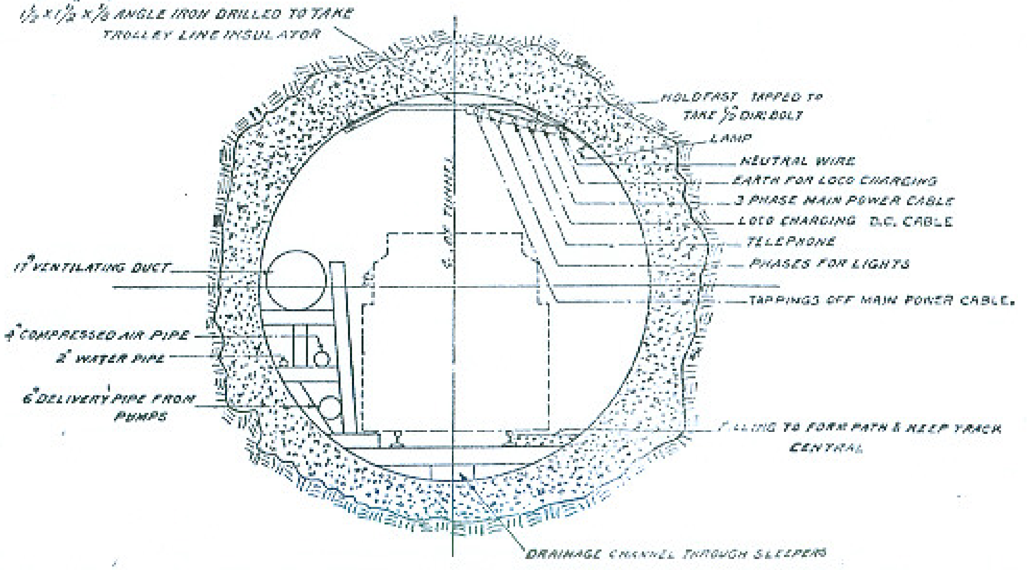
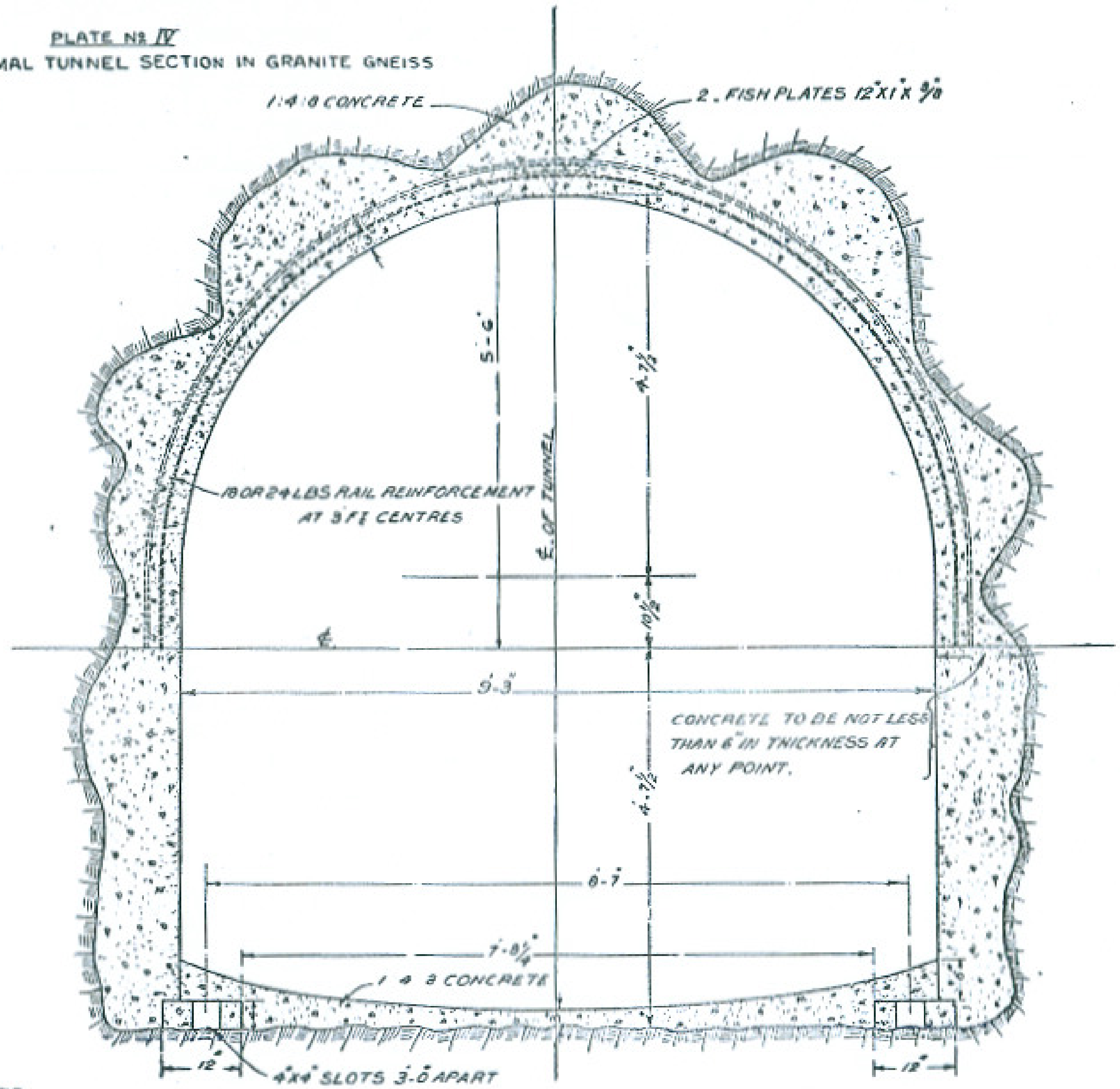


PLATE No IV

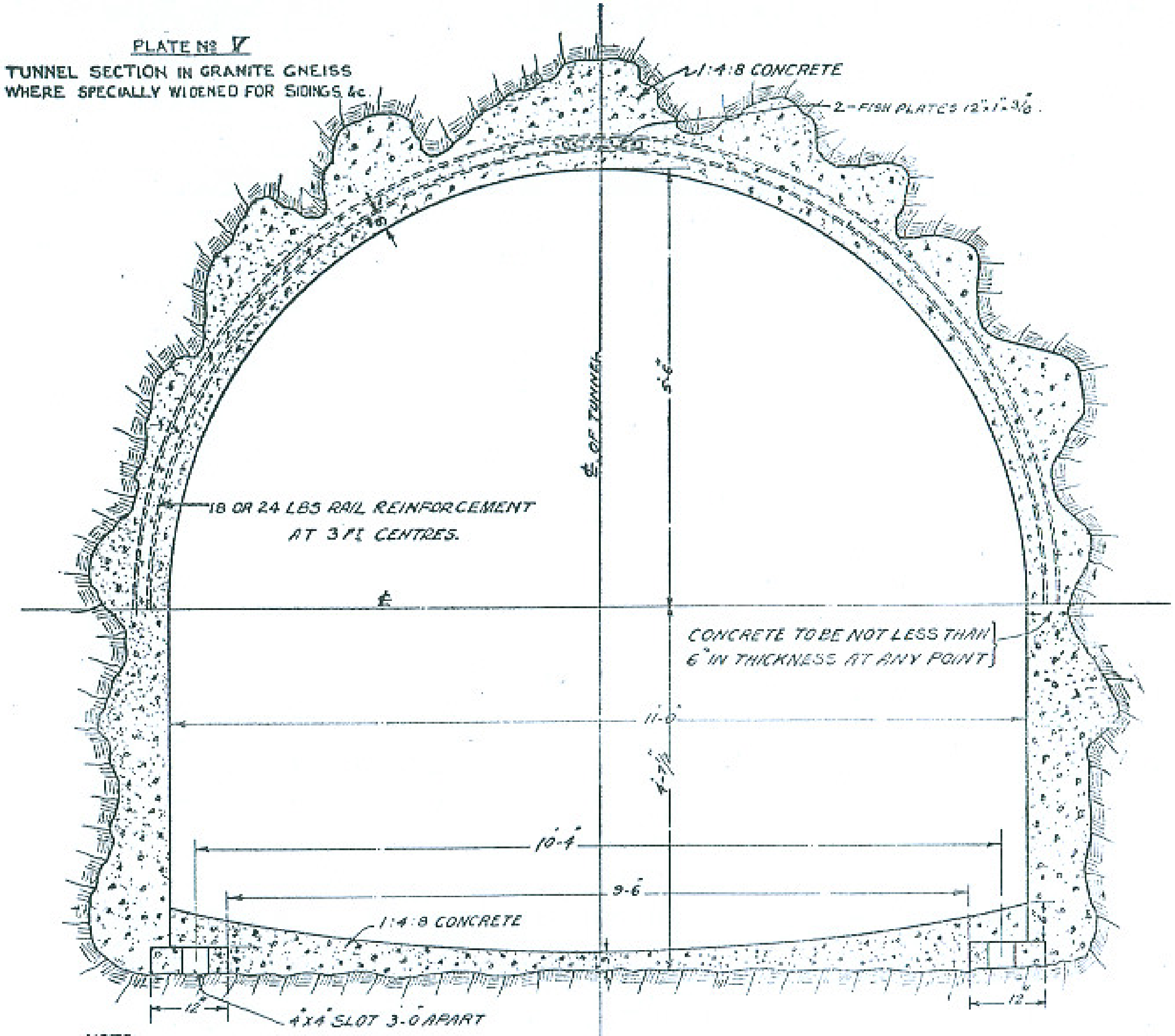
NORMAL TUNNEL SECTION IN GRANITE GNEISS



NOTE:- WHERE THICKNESS OF CONCRETE AT CROWN EXCEEDS 2 FEET AND THICKNESS OF WALLS AND ABUTMENTS IS LESS THAN 2 FEET, REINFORCEMENT IS TO BE PROVIDED

PLATE No V

TUNNEL SECTION IN GRANITE GNEISS WHERE SPECIALLY WIDENED FOR SIDINGS &c.

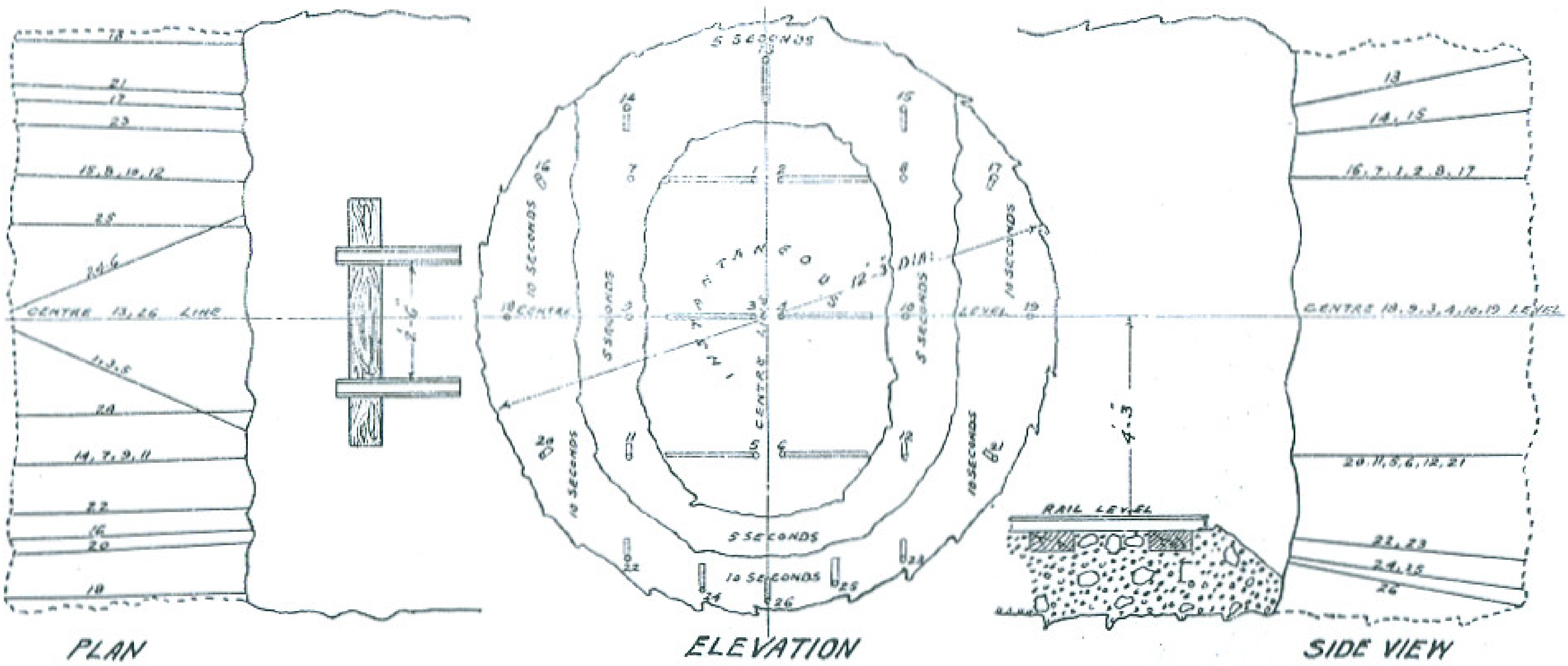


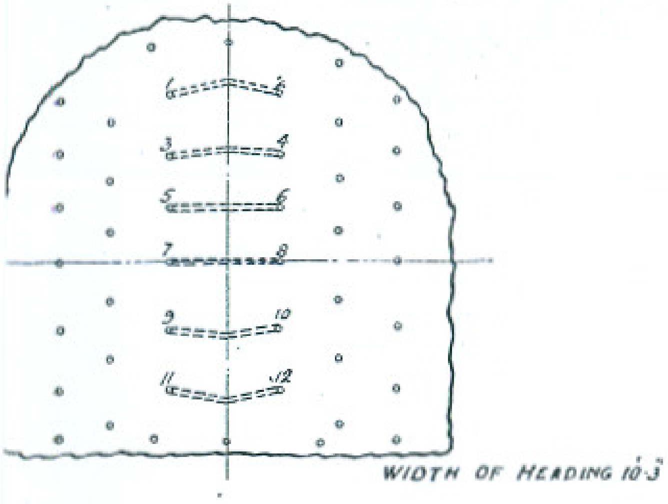
NOTE:- WHERE THICKNESS OF CONCRETE AT CROWN EXCEEDS 2 FEET AND THICKNESS OF WALLS AND ABUTMENT IS LESS THAN 2 FEET, REINFORCEMENT IS TO BE PROVIDED.

PLATE No. VI a

TYPICAL DRILLING DIAGRAM SOUTH HEADING

USING DELAY ACTION DETONATORS





FULL FACE BLAST IN GRANITE GNEISS

ARCH SECTION TUNNEL

RILLED 5'-6" DEEP

LED 4'-6" DEEP

F HOLES = 43 (12 CUTS & 31 OTHERS)

ITH 1¾ LBS GELIGNITE EACH............21 LBS

WITH 1¼ LBS GELIGNITE EACH............39 LBS

TOTAL.....= 60 LBS

GE PROGRESS PER ROUND = 3 FEET

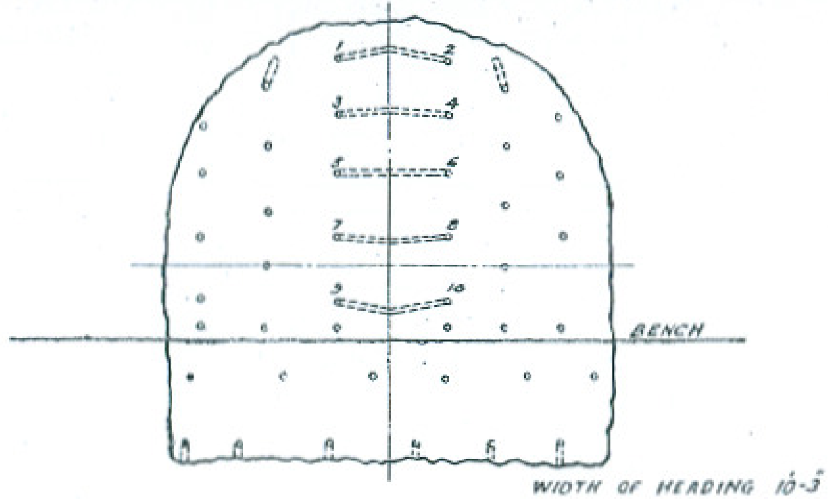


DIAGRAM FOR FACE & BENCH BLAST IN GRANITE GNEISS

FACE IN ADVANCE OF BENCH BY ABOUT 20 FT.

1-10 CUT HOLES DRILLED 5'-6" DEEP

ALL OTHER HOLES DRILLED 4'-6" DEEP INCLUDING BENCH HOLES

TOTAL NUMBER OF HOLES AT FACE 31 (10 CUTS & 21 OTHERS)

№ OF HOLES IN BENCH 12

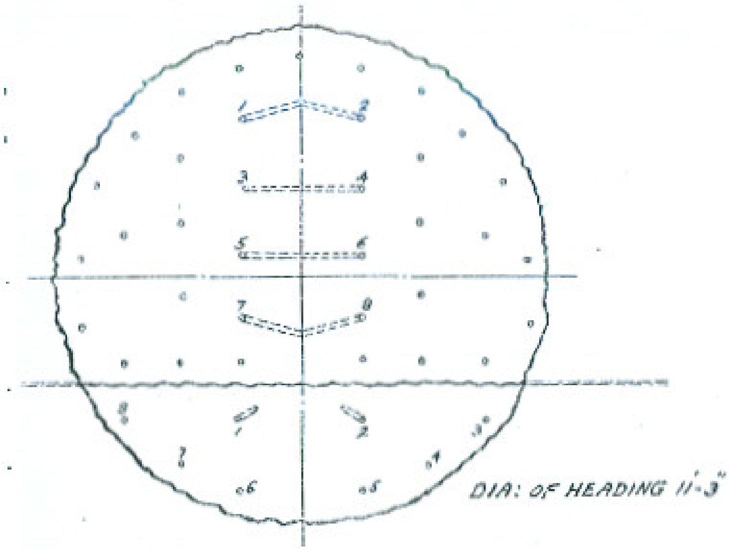
CUT HOLES 10 LOADED WITH 1¾ LBS GELIGNITE PER HOLE = 17 LBS

OTHER FACE HOLES 21 1¼ LBS GELIGNITE PER HOLE......= 26 LBS

BENCH HOLES 12 1½ LBS GELIGNITE PER HOLE............= 18 LBS

AVERAGE ADVANCE OF BOTH FACE & BENCH = 61 LBS

PER ROUND 3 FEET.



' OF FACE & BENCH BLASTS IN GRANITE

WHEN BENCH IS 10'-20' BEHIND HEADING

LLY 10-20' BEHIND FACE

DRILLED 5'-6" DEEP

HOLES DRILLED 4'-6" DEEP EXCEPT BENCH HOLES Nº 1-2

5'-6" DEEP

ER OF HOLES AT FACE 35 (8 CUTS & 27 OTHERS)

HOLES IN BENCH 8

LOADED WITH 1¾ LBS GELIGNITE IN EACH HOLE = 14 LBS

HOLES 27 Nos 1¼ LBS GELIGNITE IN EACH HOLE = 34 LBS

2 IN BENCH LOADED WITH 1¾ LBS GELIGNITE EACH = 3½ LBS

S 3-8 LOADED WITH 1½ LBS GELIGNITE EACH ---- = 9 LBS

ANCE OF BOTH FACE & BENCH 60½ LBS

UND 3 FEET

IME AVERAGES 5 HOURS

TION DETONATORS USED

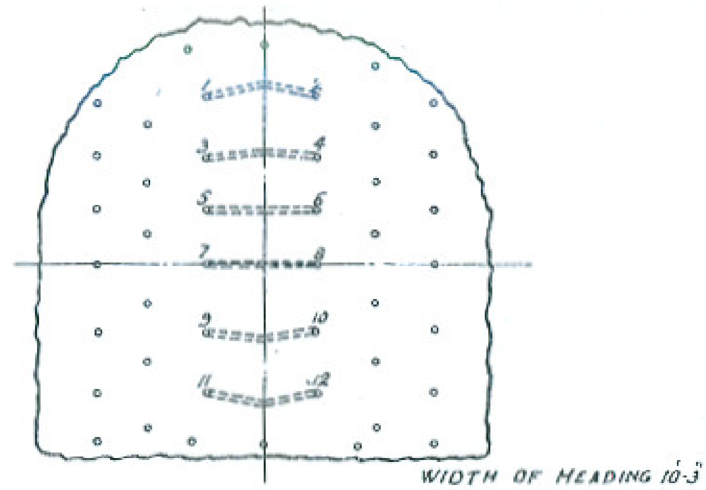


DIAGRAM FOR FULL FACE BLAST IN GRANITE GNEISS

ARCH SECTION TUNNEL

1-12 CUTHOLES DRILLED 5'-6" DEEP

ALL OTHERS DRILLED 4'-6" DEEP

TOTAL NUMBER OF HOLES = 43 (12 CUTS & 31 OTHERS)

CUTS LOADED WITH 1¾ LBS GELIGNITE EACH---------- 21 LBS

OTHERS LOADED WITH 1¼ LBS GELIGNITE EACH---------- 39 LBS

TOTAL ---- = 60 LBS

AVERAGE PROGRESS PER ROUND = 3 FEET

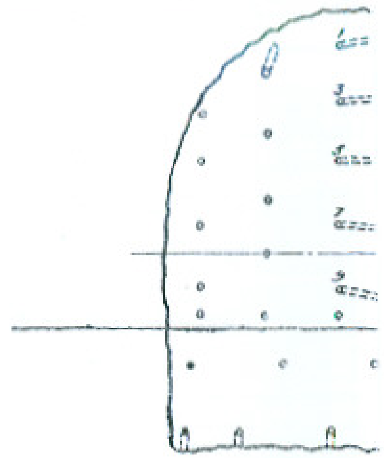


DIAGRAM FOR FACE & BE

FACE IN ADVANCE OF

1-10 CUT HOLES DRILLED 5'-6" DE

ALL OTHER HOLES DRILLED 4'-6" DE

TOTAL NUMBER OF HOLES AT FA

Nº OF HOLES IN BENCH 12

CUT HOLES 10 LOADED WITH 1¾

OTHER FACE HOLES 21 1¼ LBS G

BENCH HOLES 12 1½ LBS GELIGN

AVERAGE ADVANCE OF BOTH FACE

PER ROUND 3 FEET

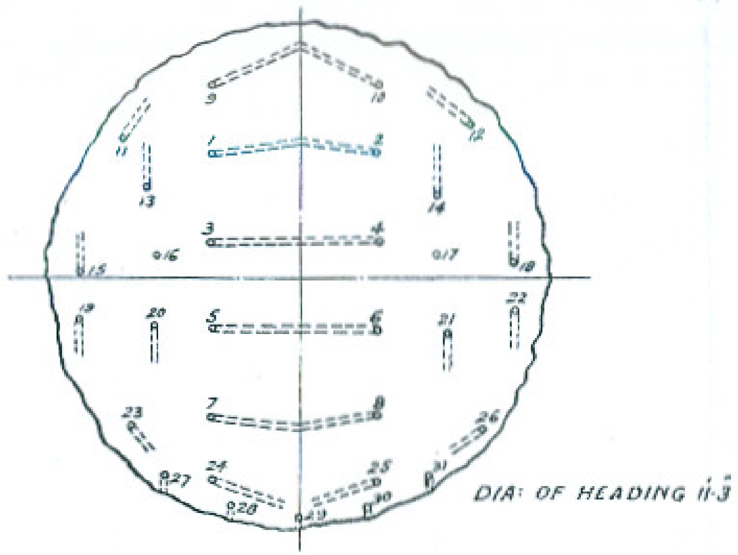


DIAGRAM FOR FULL FACE BLAST IN MICA SCHIST

Nos 1–8 CUT HOLES 6' DEEP LOADED 1½ LBS GELIGNITE EACH
Nos 9–26 EASERS 5' DEEP LOADED 1¼ LBS GELIGNITE EACH
Nos 27–31 LIFTERS 5' DEEP LOADED 1½ LBS GELIGNITE EACH
TOTAL 42 LBS GELIGNITE
AVERAGE PROGRESS PER 1 ROUND = 4 FEET

PLATE No VI b

"YPICAL DRILLING DIAGRAM FOR DIFFERENT CLASSES OF ROCK

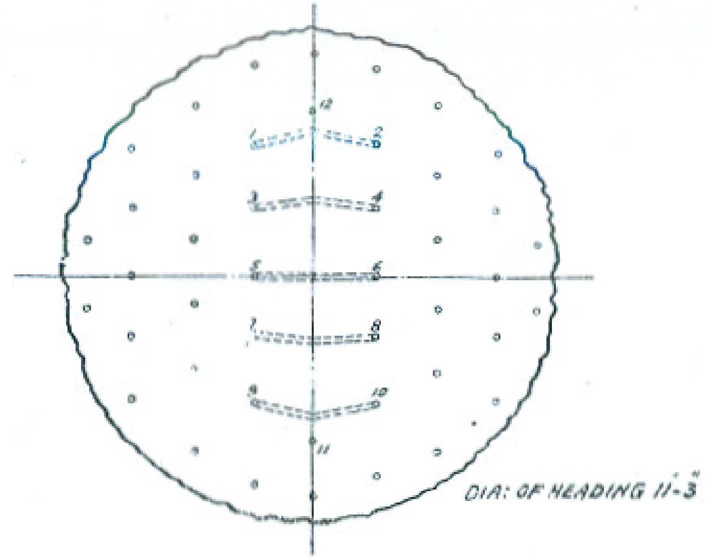


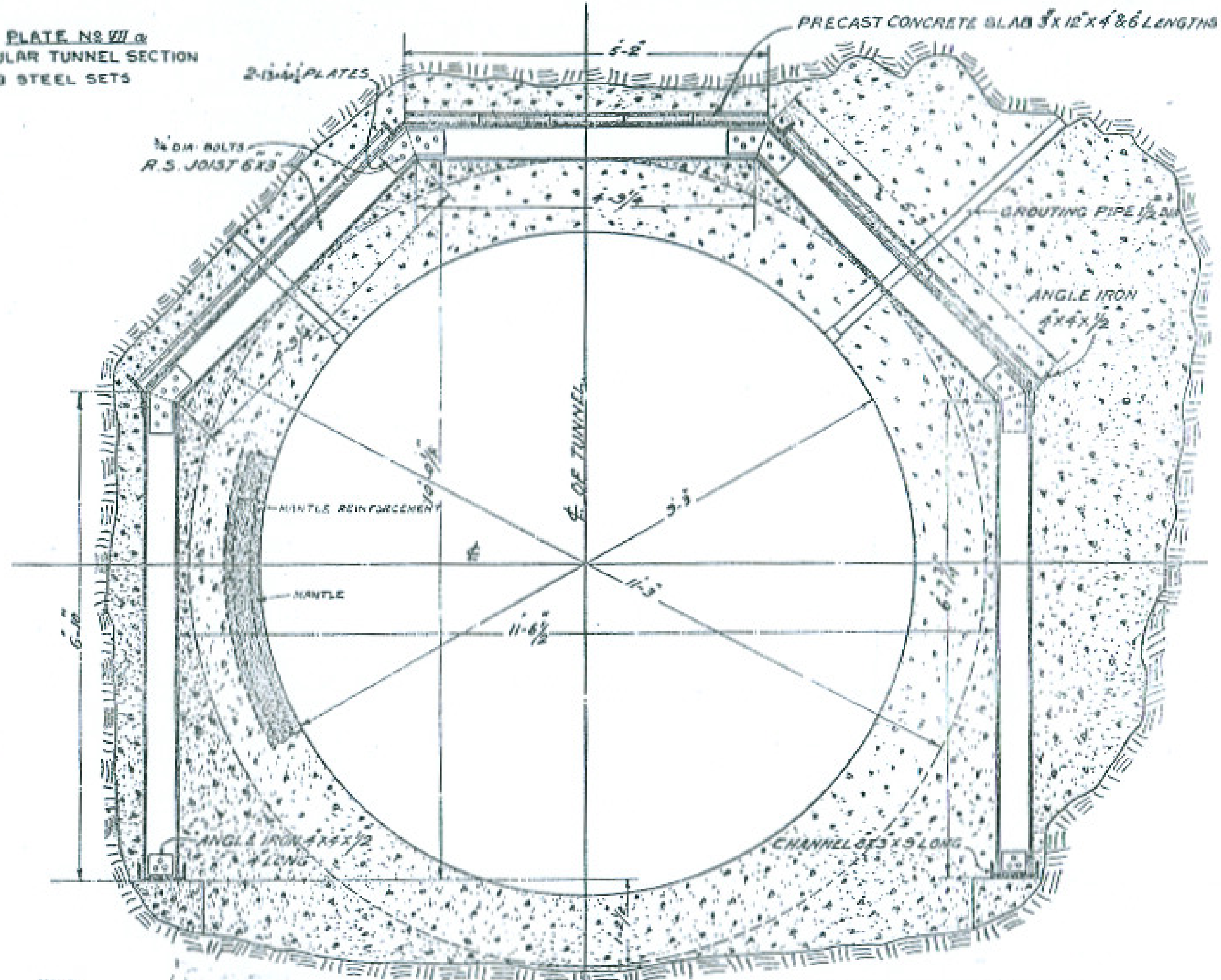
DIAGRAM OF FULL FACE BLAST IN GRANITE GNEISS

CUT HOLES No 1–12 DRILLED 5'-6" DEEP
ALL OTHER HOLES DRILLED 4'-6" DEEP
TOTAL NUMBER OF HOLES = 43 (12 CUTS & 31 OTHERS)
CUT HOLES LOADED WITH 1¾ LBS GELIGNITE IN EACH HOLE ------ = 21 LBS
ALL OTHER HOLES LOADED WITH 1¼ LBS GELIGNITE IN EACH HOLES = 39 LBS
AVERAGE PROGRESS OBTAINED WITH ONE ROUND 3' FEET 60 LBS
NATURE OF ROCK – HARD GRANITE GNEISS
HOLES ARE SPACED FAIRLY CLOSE TOGETHER IN ORDER TO GET THE NECES-SARY CHARGE OF EXPLOSIVES OFF IN ONE ROUND USING THE ⅞" DIA: CARTRIDGE REQUIRED WITH THE DRILLS IN USE
DRILLING TIME AVERAGES 5 HOURS – USUALLY THREE JACKHAMMERS IN USE
12 CUT HOLES 5'-6" DEEP = 66 FEET
31 EASERS 4'-6" DEEP = 140 FEET
TOTAL = 206 FEET, 69 PER MACHINE IN 5 HOURS
= 1 FOOT IN 4½ MINUTES (APPROXIMATELY)
NO DELAY ACTION DETONATORS USED

DIAGRAM OF
GNEISS WHE

BENCH USUALLY 10
CUT HOLES DRILLE
ALL OTHER HOLES
WHICH ARE 5'-6" D
TOTAL NUMBER OF
NUMBER OF HOLES
CUT HOLES 8 LOA
OTHER FACE HOLES
HOLES No 1–2 IN BE
BENCH HOLES 3–8 L
AVERAGE ADVANCE
WITH ONE ROUND
DRILLING TIME AV
NO DELAY ACTION

PLATE No VII a
CIRCULAR TUNNEL SECTION
USING STEEL SETS



NOTE:-
1 GROUTING PIPES PLACED IN PAIRS AS SHOWN AT 12' CENTRES LONGITUDINALLY, WITH AN INTERMEDIATE PIPE PLACED VERTICALLY AT CROWN.
2. WHERE SIDE PRESSURE EXISTS REINFORCED CONCRETE SLABS ARE ALSO TO BE USED OUTSIDE THE VERTICAL JOISTS

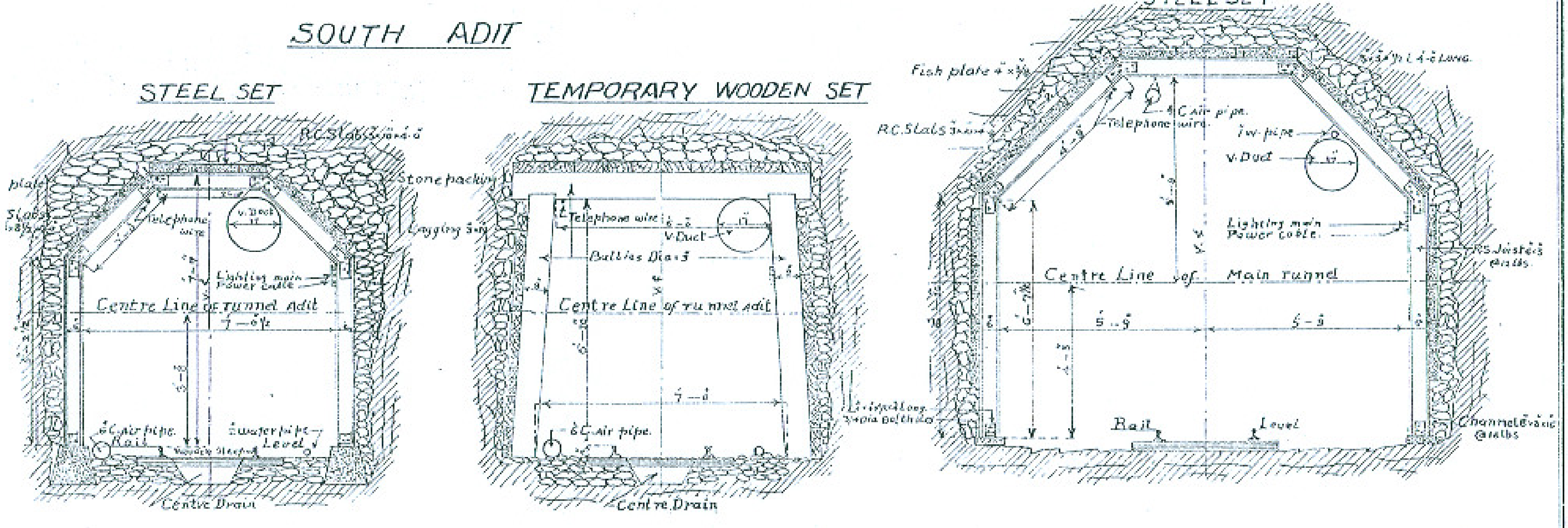
PLATE NO VII b

SOUTH HEADING

TYPICAL CROSS SECTIONS

SCALE:- 1" = 3'-0"

SOUTH ADIT



GAVITY FILLING

PLATE No. VIII

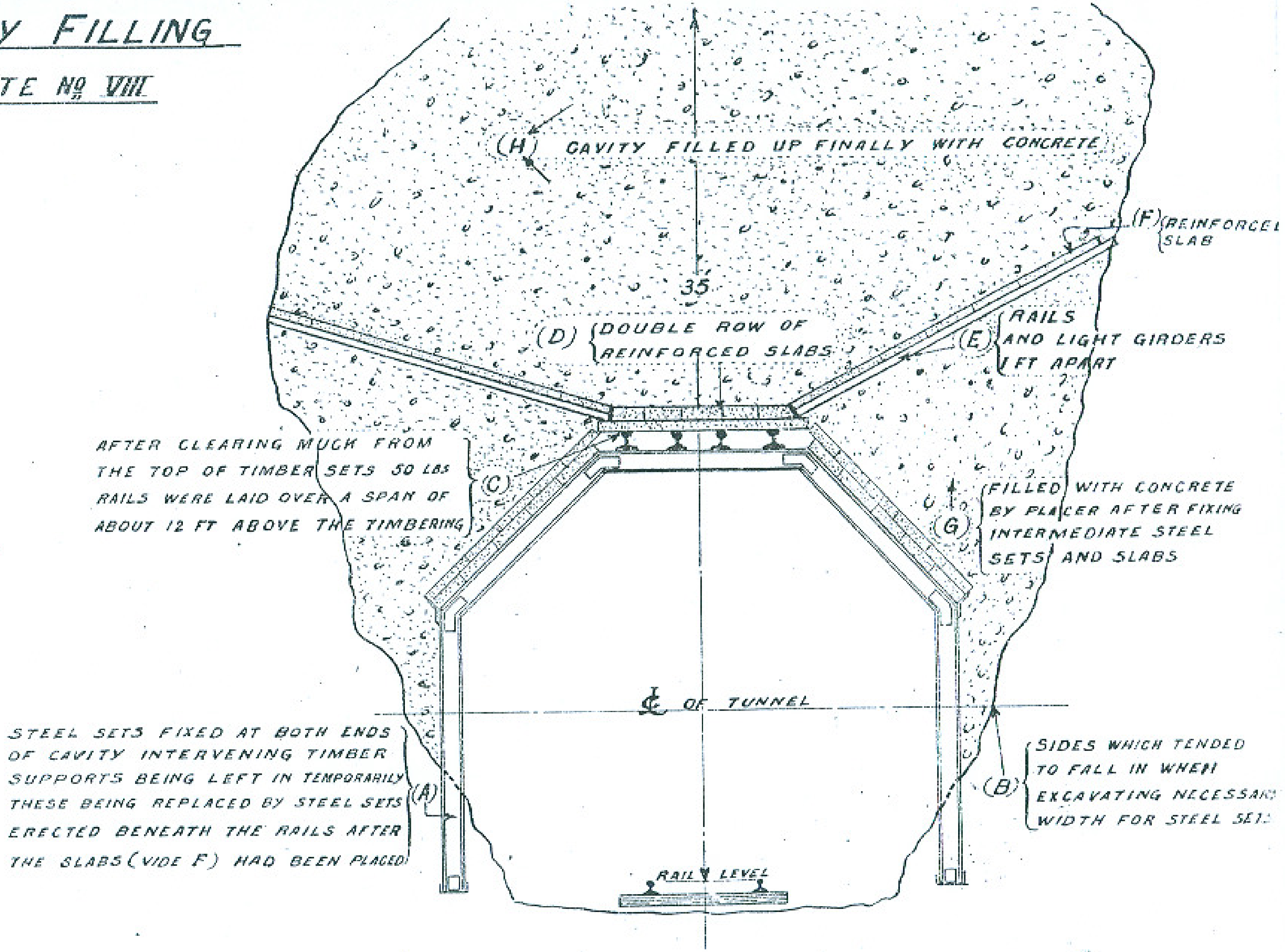
.ETELY
AND PACKED
OUTED.

E OVER SLAB.

SLAB

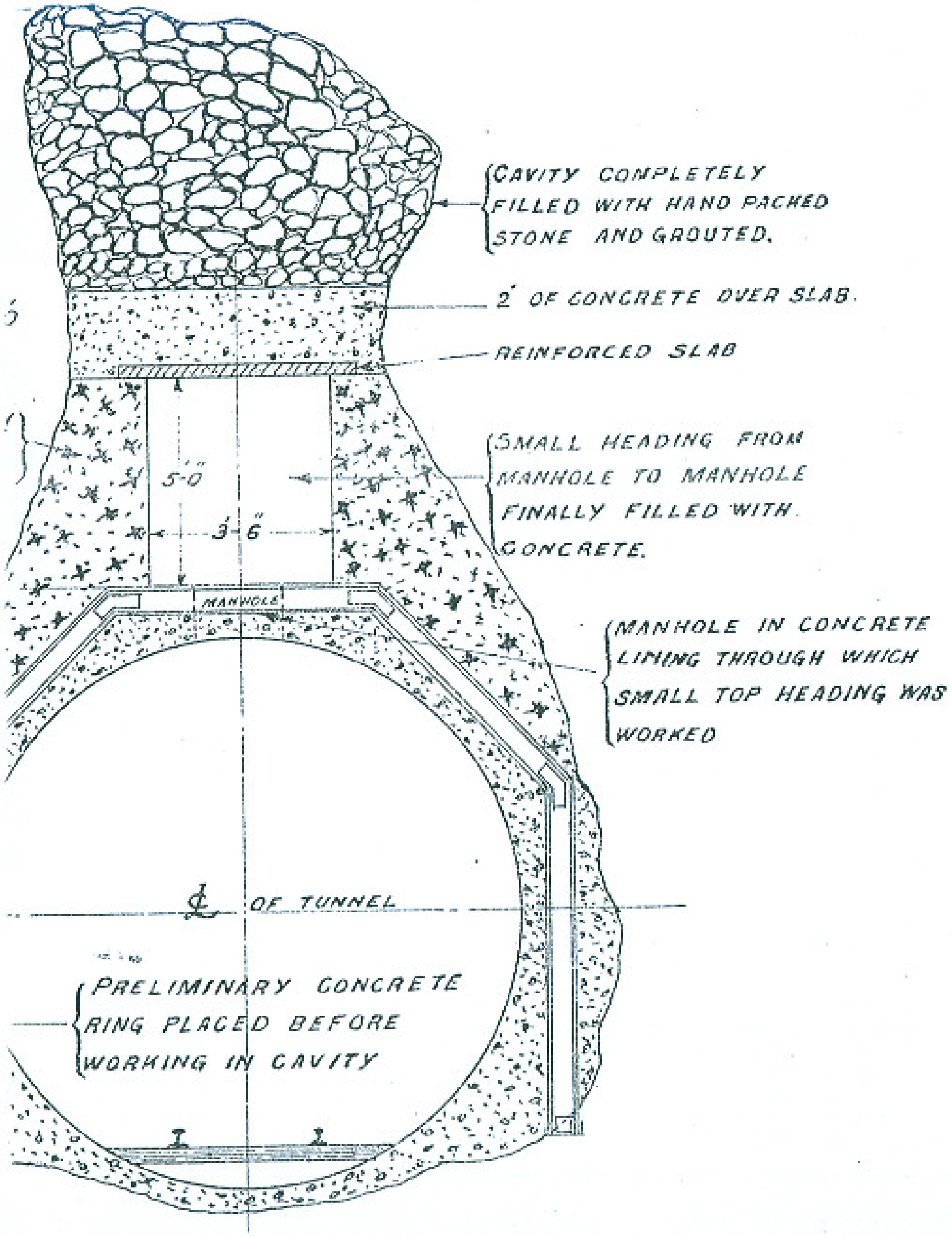
NG FROM
MANHOLE
ED WITH.

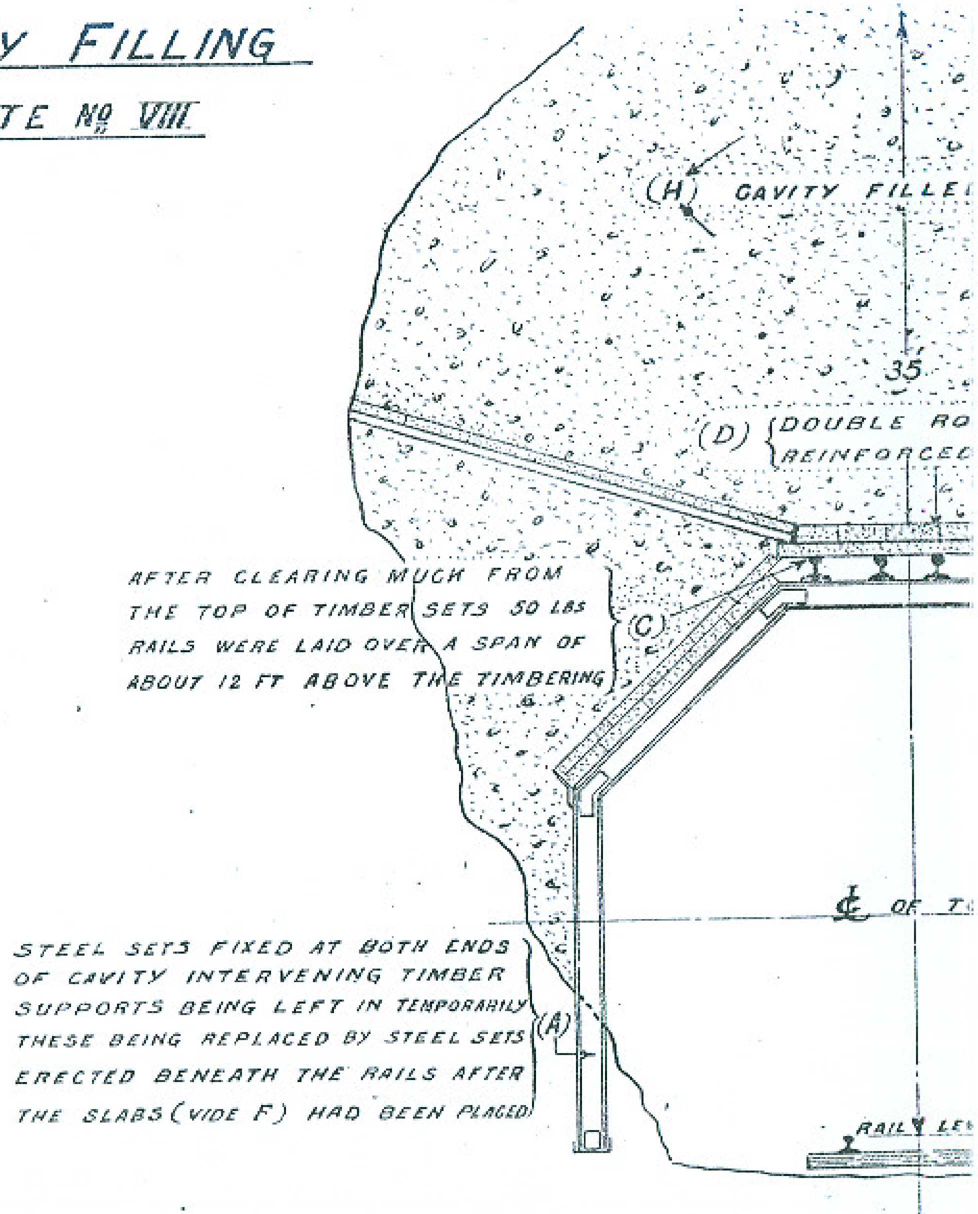
HOLE IN CONCRETE
G THROUGH WHICH
L TOP HEADING WAS
ED



GAVITY FILLING

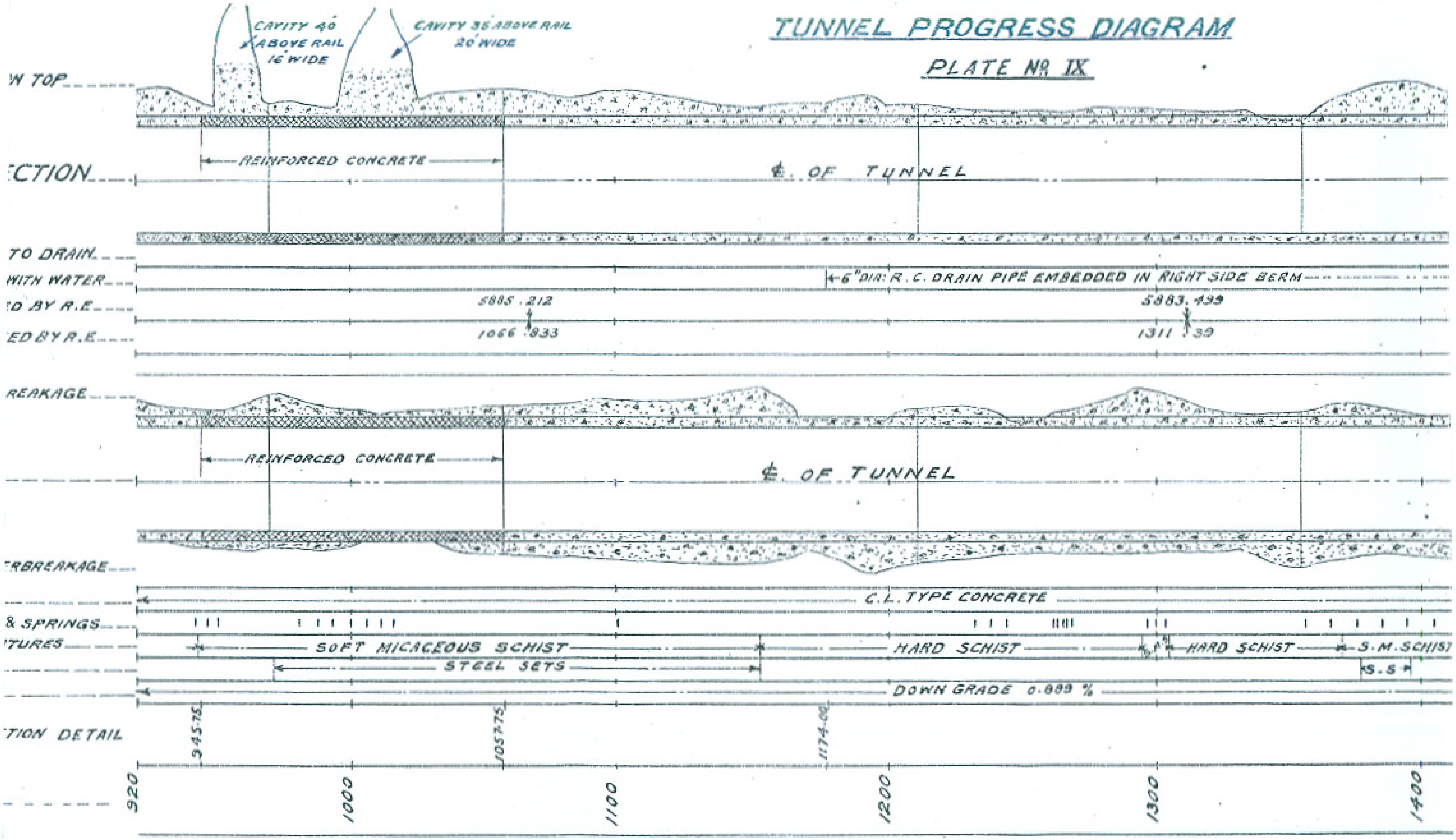
PLATE No VIII





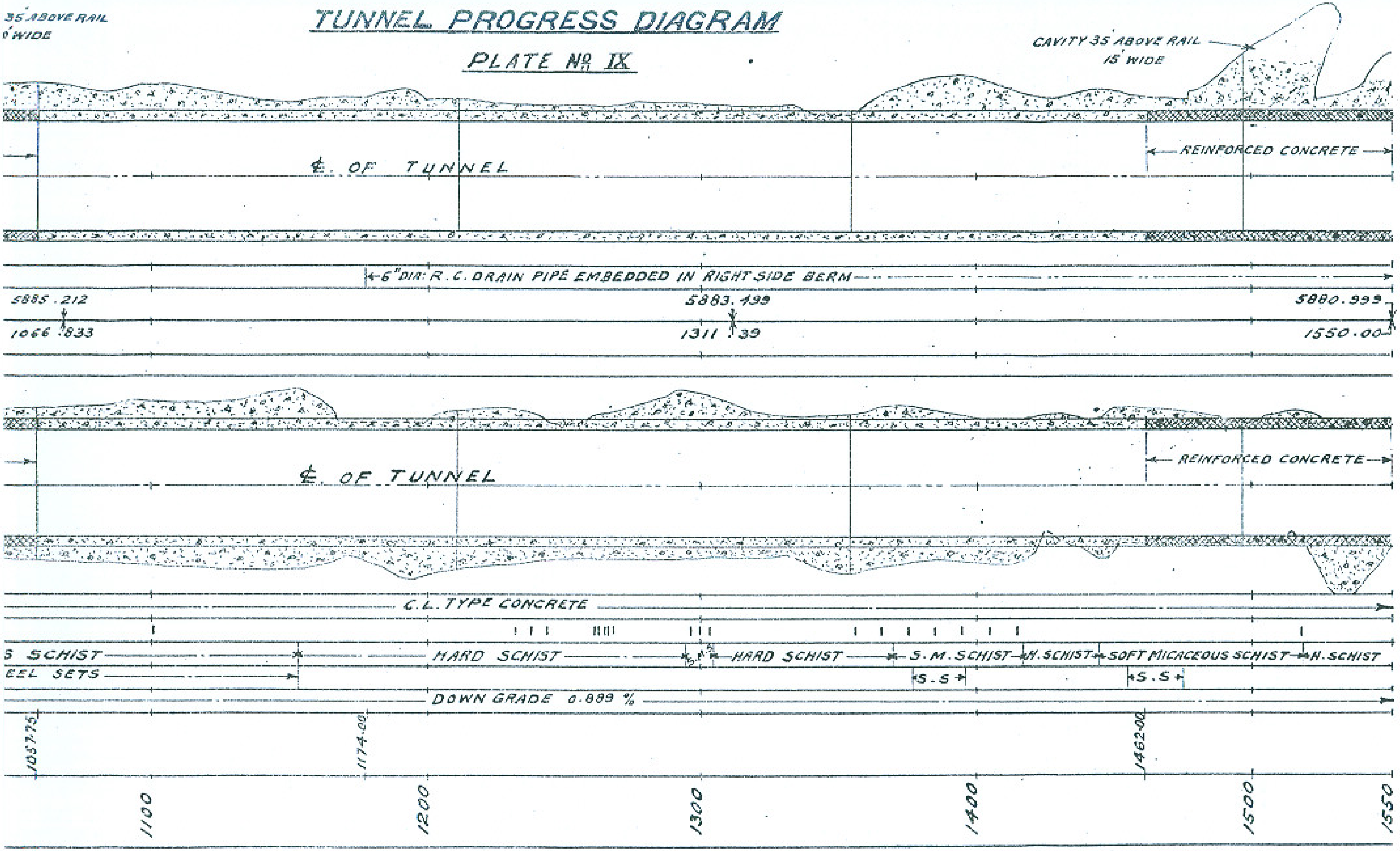
TUNNEL PROGRESS DIAGRAM

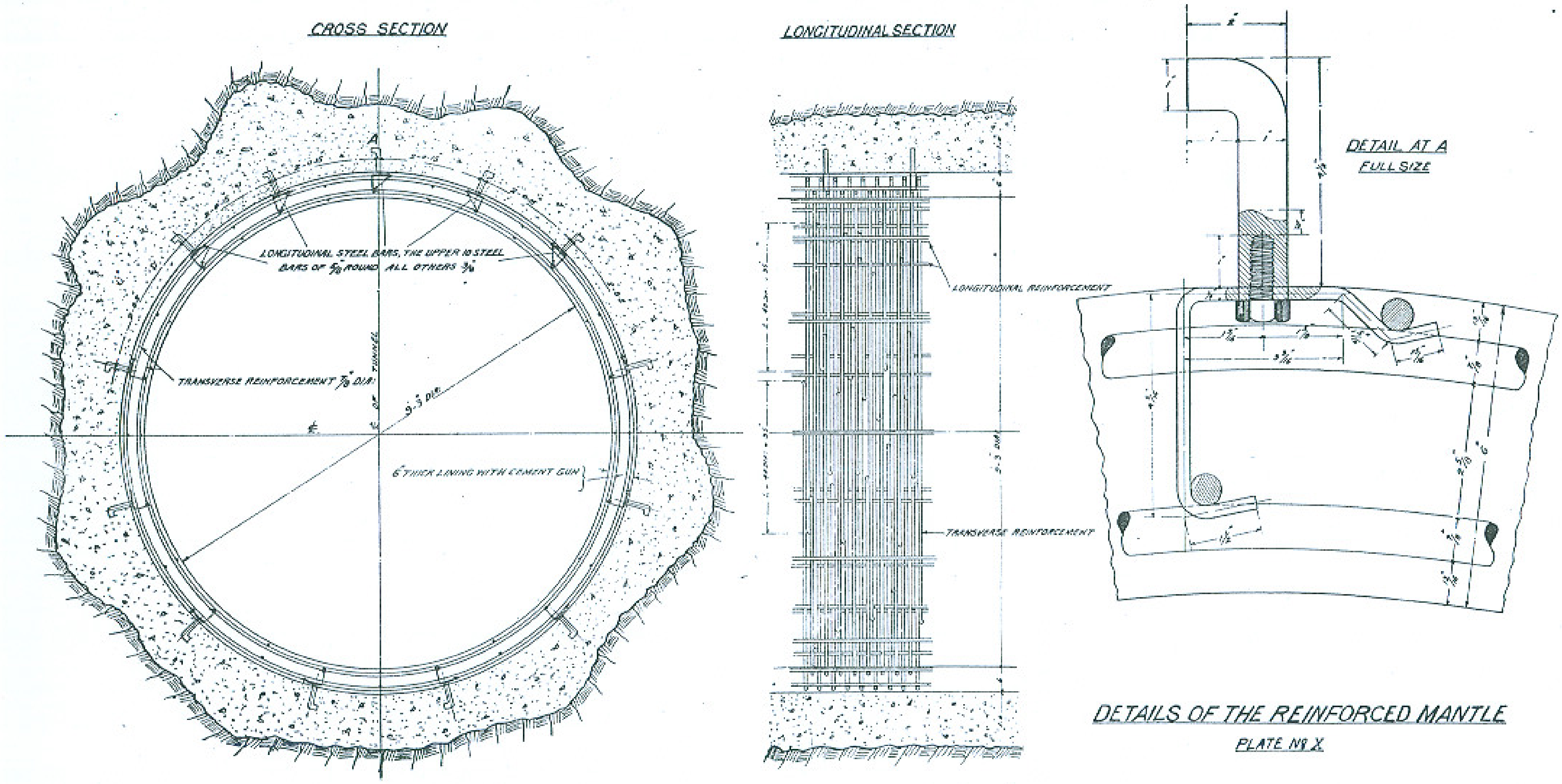
PLATE No. IX



TUNNEL PROGRESS DIAGRAM

PLATE No. IX

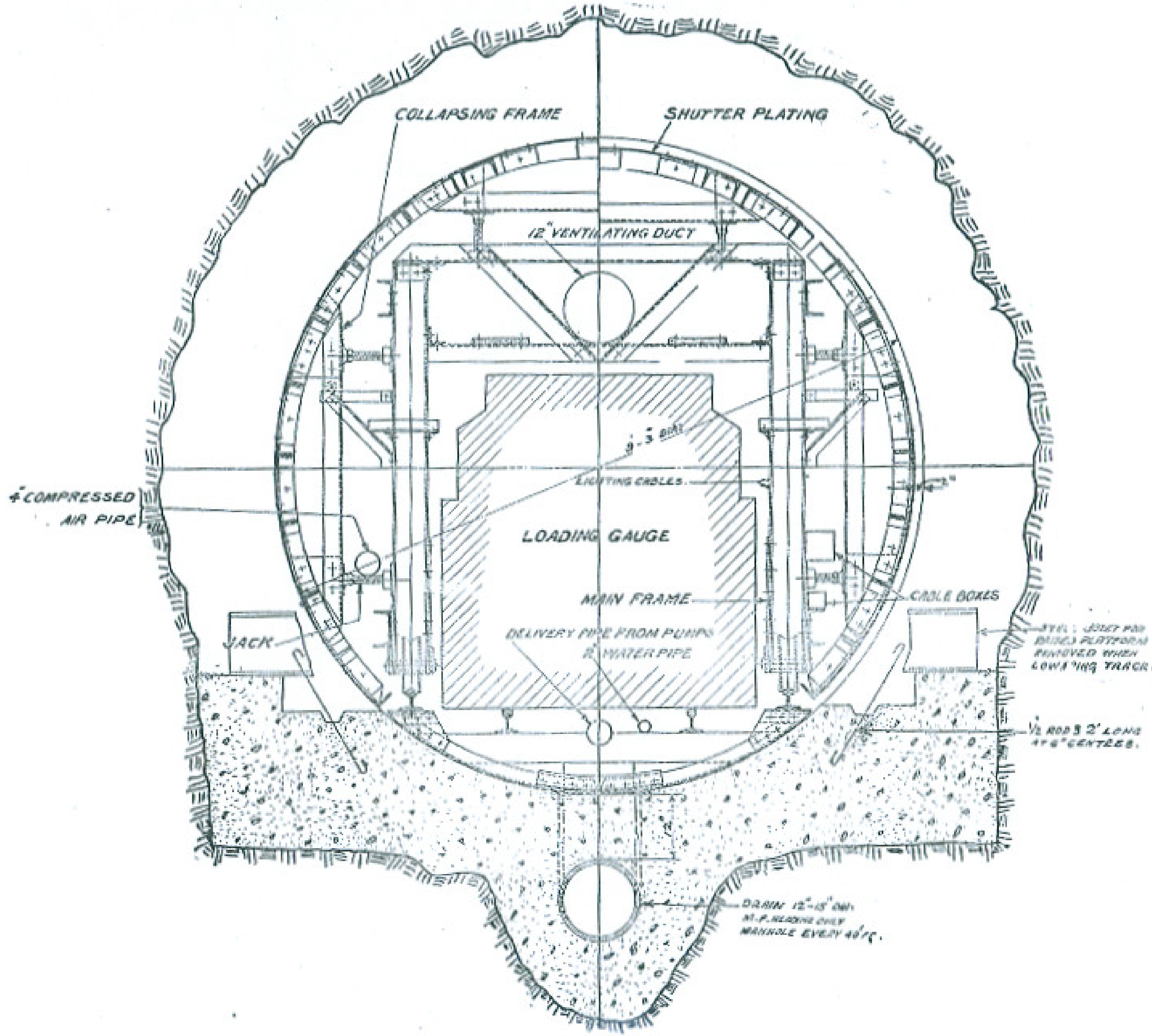


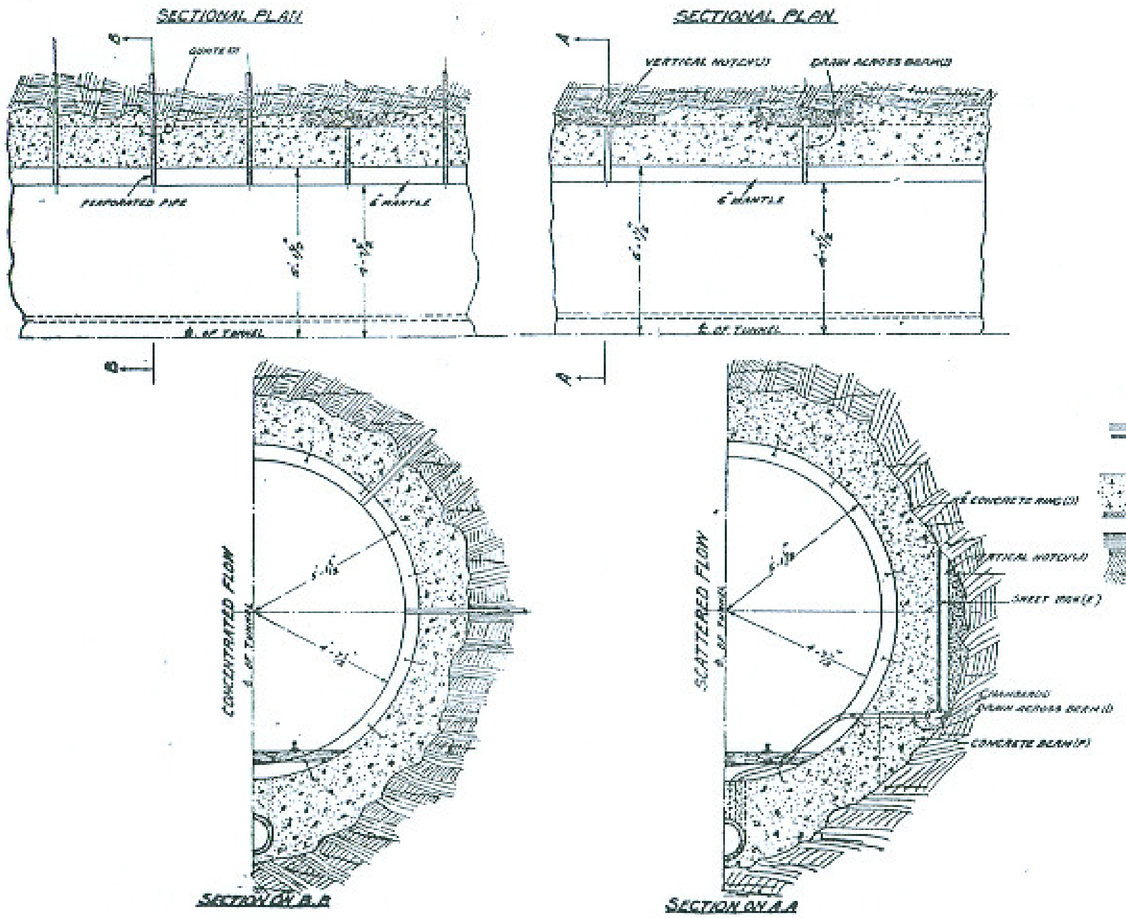


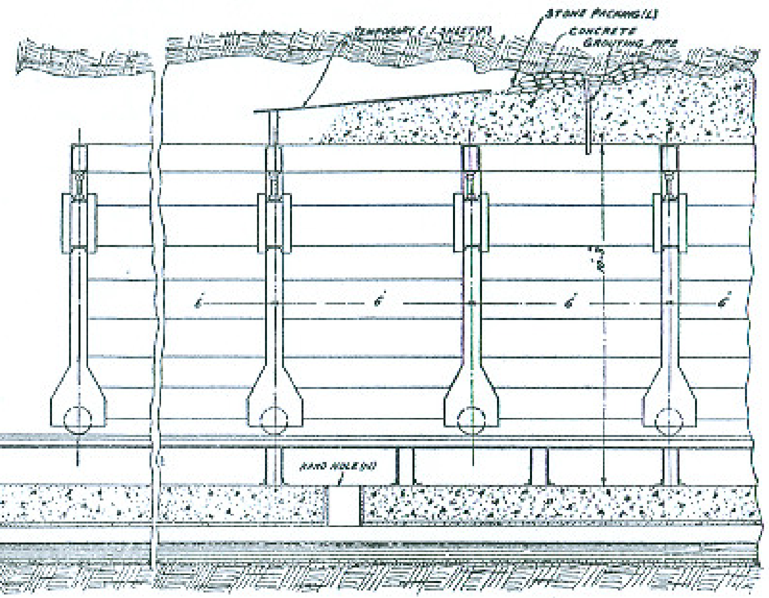
DETAILS OF THE REINFORCED MANTLE

PLATE Nº X.

PLATE No XI
TUNNEL CENTRING CAR.







LONGITUDINAL SECTION SHOWING ARRANGEMENT TO PROTECT CONCRETE FROM WATER FLOWING IN FROM THE ROOF

MAIN TUNNEL

METHODS OF CONTROLLING WATER

PLATE No XII

Mr. G. H. Hunt, introducing the paper said that first of all he wished to apologise for the unavoidable absence of Captain Kean, one of the writers of the paper.

He said that the paper followed on the one written by Colonel Battye (the Chief Engineer of the Hydro-Electric Project) for the 1930 Congress, in which he described in detail much of the plant, which had been used in driving the Uhl River Tunnel. For the data regarding the general features governing the design of pressure tunnels he acknowledged much indebtedness to the writings of Dr. Walch and to the advice of Dr. Gruner of Basle (Switzerland).

He added that an endeavour had been made in the paper, to show the special features governing the design of pressure tunnels, which differ so considerably from ordinary tunnels, and to indicate the serious consequences of faulty design with its resultant leakage of water, which must be avoided at all costs in mountainous country of the type through which the tunnel had been driven.

He pointed out that so far as the Northern Heading was concerned one of the most important problems had been to get rid of the water, and that this had necessitated over-cutting in the pavement, so that the water could be drained back by gravity from the face, over short lengths, particularly where heavy water was encountered. He added that since the paper was written several fresh gushers had been struck, with the result that the rising main could not cope with the discharge; this had been anticipated and although there did not appear to be justification for the purpose of a second 6" main, arrangements had been made for some 4" and 5" victualic piping which was available from another part up in the heading, and this was dealt with by coupling up the standby pumps to the 4" victaulic compressed air main. This kept the water down during the few days necessary for duplicating the rising main. It was then found that the discharge of any one pump was increased very materially, by fitting a special cross connection to enable one pump to deliver into both rising mains simultaneously, enabling the second pump to remain as a standby. These connections were made up locally and consisted of two parallel short lengths of pipes, of the same size as the rising main, to which at least two cross pieces of the same diameter were welded.

He stated that one of the factors which controlled progress in the Northern Heading was mucking, particularly when driving on a heavy down grade and that during the last few months, progress would have been improved to some extent if a third elec: loco had been available. It was found later, that the 700 odd feet, of $3\frac{1}{2}\%$ grade, have tended to run down the loco batteries very rapidly, even though only 8 tubs were being hauled up at a time. An overhead trolley line was not favoured owing to the danger to men carrying tools, drill steels, etc., and hence about 350 ft. of trailing cable was run out from a switch, fitted at the middle of the grade, and this was plugged into the elec : loco during the time it was on the grade. This arrangement proved very satisfactory and speeded up haulage materially. He added that on several occasions when the labour was experiencing much trouble in marshalling the full tubs in the heading siding, a small air hoist carrying 330 ft. of 3′ 8⅜″ wire rope and capable of a vertical lift of 1,000 lbs. at 160 ft. per minute and consuming 200 cft. of free air per minute was installed to one side of the track, and this, with suitable guide-pulleys was used for pulling out the heavy tubs. It was also used once or twice with a slip scraper, for pulling muck back from the face over the bench, when the mucking machine was under repairs, but this did not prove as economical as hand-mucking.

With the consumption of some 400 drill steels per day in each heading, a figure which varied with the hardness of the rock, the sharpening arrangements required special attention. The oil furnaces proved satisfactory, but were more costly to run than charcoal furnaces (charcoal being manufactured locally) and they suffered certain disadvantages ; one being, that with one side open the fire-clay would only stand up to the work for about 48 burning hours, and with both sides of the furnace open, though it was possible to work with two shifts instead of three per day, nevertheless the fire-clay would only stand up for about 24 burning hours. Another difficulty encountered was that fuel oil would not flow freely, owing to the low temperature of Brot, but this was got over by electrically heating the oil tank.

He referred to the description of the lining work, it had been mentioned, that it is frequently specified that reinforcing steel in concrete should only be lightly stressed, and he showed that in the case of the gunite mantle however, the governing factors are different and with favourable conditions, the theoretical maximum stress in the steel can be allowed to approach closely to the elastic limit, neglecting any effect produced by back pressure from the rock. This is a variable factor but even in the worst conditions to be met with in the tunnel, it may be assumed to have considerable effect in reducing the actual stress.

He said that there had been some places in the tunnel where, notwithstanding the 100 lbs. pressure grouting, there had still been a tendency for leaks to occur. These were being treated by grouting with a 1 : 5 solution of Silicate of Soda, this being followed immediately by a cement injection. This had only recently been tried but appeared to give satisfactory results, as the Sodium Silicate solution penetrates further than the cement would do, and the cement, which followed this solution was rendered quick setting thereby, and hence was not nearly so liable to be washed out of any voids there might be in the concrete, under the influence of external water pressure.

The work of driving the Northern Heading started on the 1st of July 1926 and during the six months that followed, 280 ft. were driven at an average of 46·6 ft. per month, the total, over-all cost per ft. run to the end of the year being Rs. 83. During 1929, 1,615 ft. were driven at an average of 134·6 ft. per month, the cost at the end of the year having risen to Rs. 99. During 1930, 1,963 ft. were driven at an average speed of 163·6 ft. per month, the cost at the end of the year being Rs. 131. During the 13 months ending January 1923, 2,610 ft. were driven at an average of 200·75 ft. per month, the total over-all cost at the end of January being Rs. 140 per ft. run.

In conclusion, he stated that the work was approaching completion and out of a total of some 18,000 ft. of tunnelling (including North and South adits and Pipe tunnels) which had to be driven, there remained about 60 feet between the two headings which, it was hoped, will meet within the next week.

Mr. Dorofeeff added some remarks to the information given in the paper concerning mainly the Southern Section.

For construction purpose the whole tunnel has been divided into the following three sections :—

1. *Northern Section* :—T/N which includes excavation of Main Tunnel from the North Portal upto the Mid Point and the excavation of the Valve Adit and Valve Chamber.

2. *Southern Section* :—T/S which includes the excavation of the South Adit and the two headings of the Main Tunnel from the head of the Adit, one towards Mid Point and the other to the Surge Shaft.

3. *Pipe Tunnels*:—T/P which includes the sinking of the Surge Shaft and the excavation of both the Pipe Tunnels.

The total footage of tunnel driven in connection with the Project is 18,441 feet :—

Main Tunnel	14,202 feet.
Pipe Tunnel A	1,106 ,,
Pipe Tunnel B	1,094 ,,
Valve Adit	363 ,,
Surge Shaft	386 ,,
South Adit	1,235 ,,
Total	18,586 feet.

Out of 18,586 feet 2,586 feet was done by the Pipe Section 7,254 feet by the Northern Section, and 8,746 feet by the Southern Section.

The ideal condition for tunnel driving is when there is no necessity of changing the method of working. It does not matter much if the rock is soft or hard so long as the routine of the work does not require frequent alteration. The Southern Section of the Tunnel particularly could not be classed as ideal in the above sense.

On this section we encountered thirteen changes in the kind of rock. The details of each kind of rock encountered are given below :—

Adit :—

R. D.	R. D.	
0	—500	Quartzite.
500	—920	Schistose slate.
920	—1235	Felsphatic quartzite gneiss.

Surge Shaft Heading :—

0	—600	Felsphatic quartzite gneiss alternating with Schistose slate.
600	—1600	White and greenish quartzite.
1600	—1640	Schistose slate.
1640	—2375	Dark basic intrusive rock altered dolerite.
2375	—2500	Schistose slate.
2500	—3124	Dark basic intrusive rock altered dolerite.

Mid Point Heading :—

0	—1000	Felsphatic quartzite gneiss alternating with schistose slate.
1000	—3260	Mica schists with narrow bands of quartzite.
3260	—3640	Gneiss.
3640	—3820	Mica schists with narrow bands of quartzite.
3820	—4223	Granite Gneiss.
4223	—Mid Point	Mica schists.

The rock practically throughout the whole of this section was of a poor texture and heavily charged with water and on the contact zones the rock was particularly bad being broken, loose or soft. In addition to this many patches of shattered and disintegrated material were encountered amidst sound rock.

Tunnelling under such conditions necessiated the greatest care and involved a complex organization and was of necessity slow. Loose rock and water rendered work unsafe and difficult.

From an academic point of view variety in the methods applied in getting the rock out, made the work of great interest by constantly providing new problems to be solved and this now portrays a unique example of tunnelling, which cannot fail to interest any one who is a student of this class of engineering.

Amongst methods applied in tunnel driving, one of them used in the southern section is not very common in tunnelling practice. The method consist of solidification of loose or soft rock by means of injection of cement or a thin mortar of cement and sand under pressure and then tunnelling through the solidified ground.

The smallest bit of steel drill used for 7/8" gelignite or gelatine was 1¼". While drilling the bit gets smaller and so in order to get holes of 7/8" diameter at the bottom, the drill bit for the last 6"-24" of hole (depending on the hardness of the rock) should be 1" and not 7/8" as mentioned in the paper.

On the Southern Section where particular care was required in blasting to avoid shattering of the adjacent strata, already badly shattered, use of the delay action detonators was inevitable. In hard rock blasting with all instantaneous detonators would not always give good results. Some holes would fire back and not blast the rock out.

Having to deal in this section with water from the bore holes reaching often considerable pressure, several unusual methods of loading explosives were applied such as attaching primers to reeds or thin bamboos which were jammed to the side of the holes with a wooden plug, or loading the required charge into specially made pipes and inserting them into the holes and then plugging them solid with wood to obviate the charge being pushed out by water pressure.

The best continuous progress obtained in the Southern Section was on the Mid Point Heading during year 1931 when 2,058 feet were driven and 355 steel sets erected.

Factors which demanded particular care in the execution of the lining on the Southern Section of the tunnel were underground springs, spouting from crevices in the rock on the whole length of the Mid Point Heading and on the length of 700 ft. in the Surge Shaft Heading, poor quality of rock in general, rapid decrease of cover over the tunnel and increase of internal pressure as the tunnel outlet is approached.

The methods of dealing with underground water in case of scattered and concentrated flow, page 68, adopted on the Southern Section gave very satisfactory results. A detailed description of these is given in my paper sent to the Institution of Engineers India.

There were 22 cavities in Surge Shaft Heading and 4 in Mid Point Heading, attended to through windows in the lining ring. One of them is shown on the plate.

Work over the lining ring was slow and risky. With the method applied, we were sure that there were no hollows left between rock and tunnel lining, which is so important on the Southern Section of the tunnel where the over-burden over the tunnel, running under a comparatively narrow spur, is small.

I am glad to say that in spite of the risk we were exposed to, when working in the cavities over the lining ring having only a small opening (referred to in the paper as a window), through which we were connected with the rest of the world, not a single man was permanently disabled in the Surge Shaft Heading neither during excavation nor lining. Ten men injured during four years of risky work, have seen this heading completed in all respect including the installation of the mantle.

During the month of January inflow at the Tunnel Face alone reached 5 cusecs. The water was spouting in the form of jets $2\frac{1}{2}''$ in diameter some of them 25 ft. long. In order to proceed with the blasting, the number of holes was doubled, longer holes were drilled to take water and shorter ones for blasting, but it was not always possible to find dry holes and therefore special arrangements were introduced in order to charge the holes with explosives, as mentioned bove.

The tunnel was flooded, as the drain pipes in the lined portion could not take all the water and soon some of them were blocked with silt. Water flowing in from the top of the tunnel washed away the stuff holding big blocks of rock together which then being shattered by proceeding blasts in the heading, begun to fall down. The effect of the rock fall can be judged by plates, joining the members of steel sets being torn like pieces of paper on one occasion. Still an average progress $4\frac{1}{2}$ feet per day was maintained throughout the month.

The meeting of North and South Headings will take place at the most desirable point. Had the north heading advanced a couple hundred feet more towards the Surge Shaft Heading, it would have again entered the water region with the consequence that the pumps would be unable to cope with the total inflow and the work would be seriously affected.

By the end of January the rush of water subsided and by the 14th February was reduced to practically nothing ; on this date we entered well compressed mica schists, but there is only 127 feet to do which will be completed in a two days.

Col. Battye stated he intended to divide his remarks into two parts, those dealing with equipment and those concerning designs.

As regards the former he wished to emphasize how well the electric locos had stood up to the work, though trouble was experienced early on, due to the wearing out of the wheels. The Davis wheels originally specified could not be obtained, but the difficulty was got over by purchasing manganese steel wheels from Calcutta. Another point worthy of note was that the trolley arm supplied, was too long for it to be reversed inside the normal section of tunnel ; though this was not a matter of great importance in this case, as no overhead line was installed for the reasons given in the paper.

Fifty pounds rails had been provided underground and in his opinion had amply justified their adoption owing to the freedom from derailments and track difficulties.

He would like to enquire whether the authors could give further reasons justifying the running of the ventilation fans so that they were exhausting continually, he also considered that further details regarding the pumping plant and difficulties encountered would be of interest to the meeting.

He referred to the methods adopted to obtain a scientifically graded aggregate and a fixed water cement ratio, due allowance being made for the moisture in the aggregate, and he emphasised the value of the testing laboratory and of having a special survey staff responsible for the co-ordination of work in the different divisions and for the initial lay-out of important works.

He felt that further information regarding sanitation in connection with underground work, drying rooms, clothing, and the methods adopted for dealing with epidemics would be of interest.

He pointed out that it was quite impossible to apply a gunite mantle inside a wet tunnel and that it was therefore necessary to control any inflow of water in pipes and that these pipes were generally fixed in cement plaster containing Sika to render it quick-setting.

After commenting on the principles governing the design of linings for pressure tunnels, he referred to the failure of the Ritom Pressure Tunnel, where from the very beginning many cracks and loss of water showed. Finally, when subjected to full head, the tunnel cracked so badly that landslips occurred and the pressure had to be reduced until it functioned as a non-pressure tunnel. Since the placing of a circular mantle inside the tunnel in 1925, it has worked under full head without giving any trouble. He then referred to the valuable information on the subject contained in Dr. Walch's book and stated that the maximum head on the tunnel during the first stage would amount to about 150 ft. and in the second stage, after the construction of the dam, to 300 ft. From this it followed that the safety factor for the first stage would be considerable and furthermore as the dam was not likely to be built for upwards of 10 years, conditions would improve still further due to the ageing of the concrete.

He then referred to Dr. Gruner's original recommendations regarding the tunnel mantle in which it was stated that in view of the fact that part of the water pressure is carried by the reinforced concrete lining and part by the rock, it is usual to stress the steel up to 22,750 lbs. per sq. inch and that in the case of the Uhl River Tunnel the stress might, with safety, be increased to within a small margin of the elastic limit, say up to 28,400 lbs. per sq. inch, which would be within 5 to 10% of the elastic limit. It was decided, however, not to adopt such a high stress and 24,100 lbs. per sq. inch was selected for normal structural steels. As steel of intermediate grade has been used with a yield point of 40,000 lbs. per sq. inch. an increased factor of safety on the yield point has been obtained.

He then referred to the success which of recent years had attended the construction of pressure tunnels lined with a gunite mantle and mentioned the practical reasons for its adoption in preference to reinforced concrete, which, under bad conditions is extremely difficult to lay to a uniform standard of quality, owing to the large amount of steel which has to be fixed in a comparatively small area, to the difficulty of water control, and the probability of dirt from the sides of the tunnel falling on to the concrete while being laid. With regard to the arch section lining through the granite gneiss, he referred to the fact that for certain short lengths where the rock encountered had proved to be very hard, the thickness of lining might have been reduced to a matter of an inch or two and here it had originally been intended to gunite the surface of the rock, merely in order to smooth it off. There was a possibility, however, of air being imprisoned in the resultant pockets during the filling of the tunnel and this air at times of sudden draw on the tunnel, might have been carried along and released with explosive force at the surge shaft, with the consequent risk of damage to the riser and its supports. It was, therefore, decided to make the gunite conform to the standard section instead of following, and merely smoothing off the corners of the excavation line.

MR. L. A. FREAK, remarked that no mention had been made of the slipping hillside below the adit tramway. Could this have been prevented if more care had been taken with the disposal of drainage from the tunnel? Is this slipping likely to endanger the portal or the tunnel in anyway; and a description of any steps taken to stop the slipping would be of considerable interest?

The authors referred to delay caused by gelignite which had deteriorated from storage under local conditions but on a later page they explained that the number of misfires due to delay action detonators were surprisingly high. After nearly four years experience of road work in the same neighbourhood as the Hydro-Electric work using a fair quantity of gelignite for rock cutting, the speaker had never known of a single case of a gelignite cartridge being at fault; in some cases his gelignite had been in stock for over three years. The speaker said he would question whether on the Hydro-Electric work it was really the gelignite which had deteriorated. It would be interesting to hear whether the suppliers were referred to about this alleged deterioration and what their reply was.

On pages 71 and 72 for the concrete, ideal proportions according to sieve analysis had been described whilst the mixing water used was varied to suit the moisture content of the aggregate. No doubt these were correct scientific methods but does the quality of the resulting concrete justify the cost of the additional supervising staff required to determine these sieve-analysis and moisture contents. It is stated that the aggregate was measured by volume so that a variation in the sieve-analysis would require a variation in the measuring boxes. The mixtures mentioned are practically the same as 1 : 2 : 4 and 1 : 3 : 6 respectively and would it not have been cheaper, quicker and simpler to use such ratios as 1 : 2 : 4. The speaker understood that American practice had now reverted from the ultra scientific proportions back to simpler mixes such as 1 : 2 : 4, as it had been found that the supervising staff had to devote so much attention to sieve analysis and water content that the other part of the work suffered from lack of adequate supervision. Experienced hands by eye can vary the quantity of mixing water to suit varying moisture in the aggregate without any determination of the exact moisture content.

On page 68 the use of precast concrete pipes for drainage is described and the speaker would ask why concrete was chosen as the material for these pipes, what is their advantage, is it cheapness ?

The speaker put forward a suggestion that some member of the Hydro-Electric staff lays a paper before the Congress on the types of earthquake-proof construction adapted for staff quarters and other buildings together with details of cost. In Kangra district numerous buildings had been built with *dhajji* walls, which is a timber framing with stone in mud filling in the panels ; but up to an elevation of 4,500 ft. this type of construction is positively dangerous due to white-ants riddling the whole of the timber. Many houses in Lower Dharamsala are white ant eaten right up to the roof, in some cases roof timbers have had to be renewed and in his opinion such houses with *dhajji* walls instead of being a protection against moderate earthquake shocks are absolute death-traps and it was therefore necessary to change to some other methods of earthquake proof construction which will not be so subject to damage by white-ant.

Mr. W. T. Everall congratulated the authors on their very excellent paper and particularly on the methods which were adopted for overcoming the unusual difficulties they encountered in the work.

The method of grouting under 100 lbs. pressure ahead of the face when driving through loose ground struck him as very ingenious indeed. This process was employed for founding the trestle legs of the original Attock Bridge. The rock in this case was badly fissured and treacherous. As a preliminary to cutting the pits to form sockets for these trestle legs, cement grout was injected into the rock and the actual cutting away was then done in material which had been thus made perfectly sound.

A good deal of grouting will have to be done on the North Western Railway in the near future. In particular there are some masonry piers of a railway bridge which are about 100 ft. high. The mortar joints are no longer intact and it is thought that the hearting may be unsound. The piers are rectangular in sectional plan, being 10 feet thick by 20 feet wide. It is the present intention to drill a number of holes into the heart of the pier and then to cement in 2" bore pipes at intervals of 4 feet apart. Water is then to be injected followed by the grout forced in at a suitable pressure.

Mr. Everall wished to know the measures adopted by the authors to determine how far the grout had penetrated in any particular direction and whether it has been found possible to apply the grout without de-watering.

The results obtained from the high pressure grouting for a final consolidation of the tunnel mantle will be of considerable interest and Mr. Everall hoped that the Congress will hear fuller particulars of the work later on, as it struck him as being a bold method and very effective if it could be carried out.

It would be interesting to know whether any shrinkage effects have been noticed since the tunnels have been finished.

It is further noted that a rotary air compressor was installed to cope with increasing demands for air. It would be interesting to know the approximate efficiency of this machine when supplying air at 150 lbs. per square inch.

MR. NICHOLSON enquired if there was any abnormal amount of pneumonia amongst the labour working in the tunnel in the absence of an elaborate system of drying rooms for use at the tunnel exits.

He also asked if in view of the unsoundness of the hillside down which the pipe-line ran the alternative was considered of taking the supply before reaching the tunnel exit down a vertical shaft and continuing in tunnel at a low level to near the power house thus avoiding the danger of the unstable hillside.

MR. STOKES enquired what was the opinion of the engineers about the use of friction clutches on the mucking machines and whether separate motors would have been preferable.

CAPTAIN N. BODDINGTON, discussing some of the questions asked by Mr. Freak, said he would like to mention that they were not entirely covered by the paper, but concerned rather work with which he had been personally connected in the construction of the shaft and pipe tunnels mentioned in the paper.

The slips on the hillside were probably there before work started, but were accentuated by the excavation of the adit tramway and haulageways; they had no connection with the tunnel drainage. As soon as the danger was apparent the matter was taken up on the lines of repairing damage done and preventing further damage by the application of the principles of Mr. Glover's paper written for the 1930 Congress.

The result was that in 1931 the rains did no damag eto the hillside and at the present time the area is, owing to its being closed to grazing, fast becoming afforested.

Mr. Everall wished to know the effect of grouting and how far it travelled, as he was interested in its application on bridge piers. One case rather similar to bridge piers, in that the grout had to travel vertically, occurred during the grouting of the shaft, when grout travelled 120′ down and 40 to 50 feet away from the point of application, but this was with 80—100 lbs. pressure, which would probably be dangerous in a bridge pier.

Mr. Nicholson's suggestion that, in order to avoid the possibility of damage by earthquake, the pipe-line might have been in a tunnel as far as the Power House, would not in practice have been possible, as owing to the pressure (up to 1,760 feet) on the whole pipe-line, steel pipes of the same size and thickness as now used at the bottom end only, would have had to be used throughout, and in addition, there would have been the prohibitive cost of excavating a wide low tunnel at an average grade of 1 : 3 in bad ground. In this it would have been most difficult to lay the pipes owing to their weight and size and which, in addition, would have had to be concreted up completely.

The whole, when finished, would have been impossible to inspect, except when the pipe was empty and so the result of any damage would not be immediately apparent and would, therefore, probably be far more serious. In addition, when damage had been located tremendous difficulty would be encountered in carrying out repairs, owing to the earth and concrete cover.

Capt. Boddington with reference to another question remarked that many earthquake-proof buildings had been put up by the Department and a paper on the subject could no doubt be arranged for the next year's meeting.

The President remarked that he was struck by the organization of the big scheme. The organization must be tremendous. It was particularly of note that the scheme had been executed with practically no loss of life, and the officers in charge might well be proud of that fact.

The President was much impressed by Mr. Everall's remarks regarding the adoption of pressure grouting. If this method proves satisfactory, there will be justification for adopting it elsewhere. His congratulations were due to the writers of this paper on behalf of the whole Congress.

Mr. Hunt in replying to the points raised by Col. Battye, stated that a reversal of the ventilation frequently caused joints in the ventilating duct to blow and furthermore the foul gases in the heading did not clear nearly so fast when blowing, as the compressed air escaping at the end of the air main and from the drills, appeared to be insufficient to counteract the effect of the blowers ; it was therefore found advisable to run the ventilating plant exhausting as the general practice.

In connection with the pumping there are a few points, which may be of interest. Firstly, makers often provide branches on their pumps, which are made as small as possible to keep down the size of the casing. We found that it paid to fit taper pipes and to increase the size of the delivery mains above that of the branches ; and it is obviously cheaper to fit these taper pipes than to ask the pump manufacturers to make their branches and consequently their casings larger. Secondly, all the pumps in use in the Northern Heading were driven by alternating current with 4 pole induction motors at a 50 cycle supply and hence the speed of 1,450 revs per minute could not be altered and no alteration in the output of the pump could be made by varying the speed. The maximum pressure in the casing being fixed by the impeller diameter and its speed, it is clear why it is impossible to use a turbine pump on a total head appreciably greater than that for which it is designed. The most general cause of failure of the pumps occurred on the suction side and as the water is forced up a suction pipe and into the impeller by atmospheric pressure, it is clear that the more water that is taken, the more of this atmospheric pressure is used up in friction in the foot-valve and at the eye of the impeller and the less is available for suction lift, hence the advisability of keeping the suction lift to the minimum when maximum discharge is required, and we found that suction pipes should, therefore, be of ample area, tipping slightly towards the sump to avoid air locks ; special care being taken to ensure that an air pocket was not formed, if the suction pipe were reduced in size at the point of connection to the pump suction. Owing to the possibility of pumps stopping with their valves open or to the necessity of having to prime a pump by opening the valve on the rising main, the suction pipes had to be capable of withstanding the delivery head with an additional margin of about 50%.

The provision of drying rooms was not appreciated by the tunnel labour apparently owing to the presence of an instinctive fear that their clothes would be stolen. Water-proof tunics and other articles of clothing and equipment were, however, obtained and were much appreciated. To avoid loss of time it was necessary to provide for latrines in the tunnel, which were kept fairly fresh by the use of ample quantities of disinfectants. As regards epidemics we were troubled with influenza and mumps, which persisted off and on in the Northern Heading for over a year, being kept under control by the isolation of all patients and the spraying of the whole tunnel periodically with disinfectants. A small dispensary was fitted up inside the tunnel, where minor injuries and ailments received attention, thereby saving the delay consequent upon the attendance of the labour as out-patients at the hospital.

Mr. Hunt stated that Col. Battye had remarked on the increase of strength, which would take place in the concrete lining during the years which would elapse before it would be subject to the full head due to the construction of the dam. This is particularly the case when concrete is cured under such ideal conditions as regards dampness, as in the tunnel. A further point worthy of note is that during the passage of time before the dam is built, the rock surrounding the tunnel will adjust itself to the new stresses.

As regards the question of earthquake-proof construction raised by Mr. Freak, Mr. Hunt remarked that the specification for temporary buildings laid down that roof covering should consist of corrugated iron sheets, the roof trusses being carried by ballies buried some 2 ft. into the ground that the walls should be constructed of sundried bricks and that barbed wire securely fixed to the ballies should be laid at every 2 ft. vertically in the sun-dried brickwork. The same principles were adopted for the permanent buildings, the asbestos cement sheet roofs being carried on rolled steel joists embedded in cement concrete some $2\frac{1}{2}$ ft. deep, the walls being of hollow brickwork reinforced with flat iron laid in cement mortar at every 4th course.

As regards Mr. Everall's remarks, Mr. Hunt stated that the 100 lbs. per sq. inch grouting would frequently penetrate along the tunnel for a distance of about 40 ft. and the distance the grout penetrated longitudinally, could easily be checked from the adjacent grouting pipes, as the work was, in general, started from the lowest pipe and proceeded with until grout appeared at another pipe, which would then be plugged up, grouting continuing up to refusal, Mr. Hunt remarked that it had been found possible to grout in the presence of water and that Sodium Silicate was being found to give considerable assistance in this work. No shrinkage effects had been noticed during the course of the work, and this was probably largely due to the almost ideal conditions under which the concrete was cured and to the lack of any appreciable temperature variation.

In reply to Mr. Nicholson's question, Mr, Hunt remarked that the number of cases of tunnel labour suffering from pneumonia was not serious, though the tunnel labour suffered more than the labour employed on works above ground.

In reply to Mr. Stokes, Mr. Hunt stated that he considered that the separate motor controls on the Marion Excavator were more reliable than the friction clutches on the mucking machines used in the tunnel, but it was very doubtful whether the former type of control could be adopted on the mucking machnes, which had to pass through the centring cars and where space was such a vital factor.

Mr. Hunt then stated that he would endeavour to answer in writing at a later date any questions, which had not been dealt with.

Mr. N. V. Dorofeeff, in reply to the point raised by Mr. Freak, stated that time and condition under which explosives are stored have certainly great influence on the detonation power. In our case explosives were affected by the time they were kept before use and variation of the temperature in the magazine, this varied between 25° and 80° F., whereas temperatures below 40° are not desirable.

Some of the tests showed very poor detonation of the gelignite. The space between two cartridges had to be reduced to ¼" against 8", which is normal. Such gelignite could not give a satisfactory blast, particularly when the holes could not be kept absolutely clean so that each cartridge could touch the other.

As regards detonators, the failure amongst the delay-action ones was due to the detonator bridge being covered with the waterproof compound, which melted by the passing current before the lighting powder could ignite and also due to defective detonator bridges. This was ascertained by a detailed examination of the detonators by opening them up. The matter was referred to the manufacturers and in the new consignment considerable improvement was observed. Some misfires were also due to extraction of the detonator being blasted out of the rock from the action of the instantaneous detonators before the delay-action were fired.

Mr. Freak asked why we did not use steel pipes instead of concrete ones. There was no objection to using them, but the cost of concrete pipes in our case was less and therefore they were used.

In reply to Mr. Nicholson regarding the specification for the sand used in gunite.

The sand used for gunite was of crushed quartzite and granite gneiss only, and of the following grading :—

Passing not less than 100% through sieve size 3/8"

Passing not more than 70% through sieve size No. 4.

Passing not less than 40% through sieve size No. 4.

Passing not more than 10% through sieve No. 1.

Weight removed by decantation not more than 30%.

Col. Battye asked for information regarding control of water when applying gunite.

Plaster was then applied to the damp patch around the pipes and to speed up the setting, this plaster was made up with a mixture of cement and silicate of soda or ordinary washing soda.

In reply to certain questions left unanswered Mr. Hunt writes as follows :—

I think that there is no question regarding the deterioration of gelignite, which is kept in store for considerable periods, as the Government Inspector of Explosives visited the works in 1929 and reported that he found deterioration and exudation of nitro-glycerine, in consequence of which a number of cases had to be destroyed. On another occasion a representative of Messrs. Nobels, expressed the opinion that the gelignite was becoming inert, and tests were carried out showing that if the gap between the cartridges was not less than ¼", the detonation was not transmitted.

My experience of works above ground and using some 10 lbs. of gelignite per day on this type of work, is much the same as Mr. Freak, mis-fires being for all practicable purposes non-existent. The conditions under which this work was carried out using safety fuse and commercial caps, were, however, very different from those in the tunnel where electrically fired detonators had to be used under very bad conditions and some 30 to 40 holes had to be fired in an area of about 100 sq. ft.

Mr. Freak has criticised the specifications adopted for concrete work, possibly owing to a misapprehension of the methods adopted. There was no question of variations in the sieve-analysis affecting the size of the measuring boxes. Considerable quantities of different sized aggregates both coarse and fine were collected ; sieve-analysis were then taken and "mixed aggregate" suitable for any type of concrete was prepared by taking a certain quantity of aggregate from each stock-pile. Measuring boxes were then made up to measure the correct quantity of "mixed aggregate" for the types of concrete in use in the tunnel and no difficulty at all was experienced in doing this. The fundamental principle governing the use of scientifically graded aggregate is missed when such proportions as 1 : 2 : 4 are adopted. The conventional proportions given on page 72 of the paper are merely for estimating purposes, the aggregate being mixed in the proportions given as the result of sieve-analyses, with the aid of two measuring, boxes one of 50 c. ft. and one of 10 c. ft. capacity. The supervising staff did not have to devote their time to sieve-analyses and water content determination, all of which work was done by the personnel employed in the testing laboratory.

During the years 1930-31 and 1931-32 some 12½ lacs of c.ft. of concrete was placed in the Brot area, at a cost on account of laboratory staff of just over ten annas % c. ft. of concrete. During this time some 1,800 tests were carried out and in addition the staff was responsible for all river gauging work and temperature and rainfall records at Brot.

With reference to Mr. Everall's query regarding the efficiency of the Rotary Air Compressor 22-3 B. H. P. were required % c. ft. of free air at R. L. 6,000 compressed to 120 lbs. per sq. inch at an inlet temperature of 90° F., at sea level the corresponding figure was specified to be 24-4 B. H. P.

Since the discussion on the paper, the two main headings met on February the 29th, 1932, the discrepancy in levels between the two, being 1/10th of an inch and in alignment 11/16th of an inch. Finally, the tunnel was tested out at the end of September and found to be water-tight against internal pressure ; in fact, due to the high external water pressure at places, there was an in flow into the filled tunnel of nearly one cusec, which overflowed at the Forebay.