CHAPTER 8

TUNNEL CONSTRUCTION WORK

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8.1 TUNNEL EXCAVATION METHOD

8.1.1 Introduction

The entire length of the tunnel to be driven through the mountainous area is divided into seven sections, that is, A-B, C-B, D-E', G-F, H-I, J-I and K-L (see Fig.1), each not exceeding 2.5 km long. To complete the tunnel excavations within two years, it is necessary to ensure a monthly average excavation rate over 100 meters. This excavation speed is difficult to achieve by conventional method. The plan calls for digging many tunnels. It will also require a large number of workers including unskilled ones. The workers to be employed in the excavation of the tunnel should be given necessary training in accordance with standardized program to ensure a certain technical level. However, the excavation scheme has been so designed to avoid using any special techniques which will require an extreme high skill. When the excavation scheme has been planned, care should be taken to maintain a balance in the capacity of each excavating machines and to avoid the use of any expensive equipment which will cause a high cost of investment. Some of the presently available tunnel excavating equipment and methods require not only the extra space for the installation of launder line in the tunnel but also widened sections and tunnel branches. The use of such equipment and methods which would increase the cost of excavation and prolong the completion of the tunnel should be avoided.

In the excavation method to be employed, either the track method or the trackless method may be used as may be deemed suited. The tunnel cross section being relatively small and with the gradient of the proposed tunnel at 1.25%, the track method is well suited.

The tunnel excavation scheme was planned with 25 working days a month with three shifts a day and eight actual working hours for each shift.

The rocks in the mountainous area are metavolcanics in the vicinity of Camp 4 and conglomerate and limestone in other parts.

Table 7-1 shows the estimated timbering ratio of the tunnel and which also shows that a major portion is shotcreted and not timbered.
The mucking and drilling times, therefore, have a significant effect on the tunneling speed. In this tunneling project, emphasis has been placed in the reduction of the mucking time and the time required for the fumes to disappear after blasting.

8.1.2 Excavating Equipment and Auxiliary Machines

The following equipment should be made available for each working face of the tunnels.

(1) Mucking Equipment

- TAIKU 650 loader
- TAIKU secondary rail conveyer loader (hereafter referred to as SRC conveyer loader)
- Six Granby type mine cars and 4-ton battery locomotive
- Rails

  15 kg rail, 610 mm gauge

(2) Drilling and blasting equipment

- Leg drills of heavy type
- Compressed air and water pipes

5 inch diameter compressed air pipe:	carbon steel pipe with victaulic type joints
2 inch diameter water pipe:	carbon steel pipe with victaulic type joints

(3) Ventilating equipment

- Turboblower: 500 mm water column x 220 m^3/min. x 37 Kw
- Air ducts: 600 mm spiral steel duct, 5 m long each

(4) Diesel-driven compressors

170 HP x 17.0 m^3/min. (7 kg/cm^2)

(5) Diesel-driven generators

- For upward gradient excavation: 125 KVA x 150 HP
- For downward gradient excavation: 200 KVA x 243 HP

8.1.3 Explanation of Excavation Equipment and Reasons for Selecting Them

(1) Mucking Machine

Fig. 8-1 shows the TAIKU 650 loader combined with the SRC conveyor loader.

The specifications for the 650 loader are shown in Table 8-1. With a clean up width as great as 3,100 mm, this loader can clear the tunnel floor without leaving muck on both sides. The conventional mine car loader with a bucket capacity of 0.3 m^3 has a miximum mucking width of about 2.50 m. Therefore, it would leave some muck unloaded on the far sides of the tunnel floor and its is necessary to use manual power to clear the floor of muck completely. Another advantage of the 650 loader is that it has double-flanged wide wheels so that the working face track can be extended easily and quickly.

The 650 type loader should be used for the above reasons and also because its capacity is balanced with that of the SRC conveyor loader.

In order to set up the launder and to have a space sufficient to allow patrolling with mini-battery locomotive, the tunnel must have a cross-section of 2.8 m (wide) x 2.5 m (high). It is necessary to avoid digging a tunnel with a cross section larger than this. The same cross-section is also planned for operation. Since this is the cross-section for a single track tunnel, the SRC conveyor loader should be used to achieve a higher efficiency of mucking operations. The SRC conveyor loader varies in its sectional dimensions according to the size of the mine cars to be used. It was first suggested that mine cars with a capacity of 2.0 m^3 be used, but finally the use of the 1.6 m^3 type was decided upon because the former type necessitates a tunnel section larger than required.

Fig. 8-1 shows the SRC conveyor loader for six 1.6 m^3 mine cars. It is 21.7 m in overall length and is capable of loading the muck produced by blasting 1.2 m long onto two trains of 6 mine cars.

As seen from Fig. 8-1, the SRC conveyor loader consists of a conveyor, secondary rails to be laid on the main rails, and conveyor supports. The mine cars roll on the secondary rails. The belt conveyor is driven by a 7 HP air motor. This machine requires one operator when loading. This conveyor loader has advantages in that it is cheaper than the shuttle car loader and develops less troubles owing to its simple construction and yet has almost the same loading capacity as the shuttle car loader. Moreover, the SRC conveyor loader costs about one-fourth less than the shuttle car loader; including mine cars, the cost is about one-third of the latter. This conveyor loader is disadvantageous because its radius of curvature of 100 m (about 20 m in the shuttle car loader) is not suited for excavating a tunnel with many curves. The tunnel to be driven through the mountains will have six curves, but all can be made so that the radius of curvature is 100 m. For the above reasons, the SRC conveyor loader should be used in the tunneling project.

The car passer and cherry picker are used for interchanging the mine cars in a single-line tunnel. However, these should not be used because both require an extra excavation to ensure a space of 4 m (w) x 1.5 m (l) x 2.5 m (h) to permit interchanging of mine cars at intervals of 50 to 100 m which is a time-consuming operation.

There are two types of locomotives for drawing the mine cars, namely, the diesel locomotive and the battery locomotive. The diesel locomotive is economically advantageous but necessitates special consideration for ventilation so that the carbon monoxide in the exhaust gases may be lowered to a harmless level. In general, this type of locomotive is used in a tunnel that is short and large in cross-section. The tunnel to be developed is long and small in cross section so that the use of the diesel locomotive is not practical. The battery locomotive is recommended.

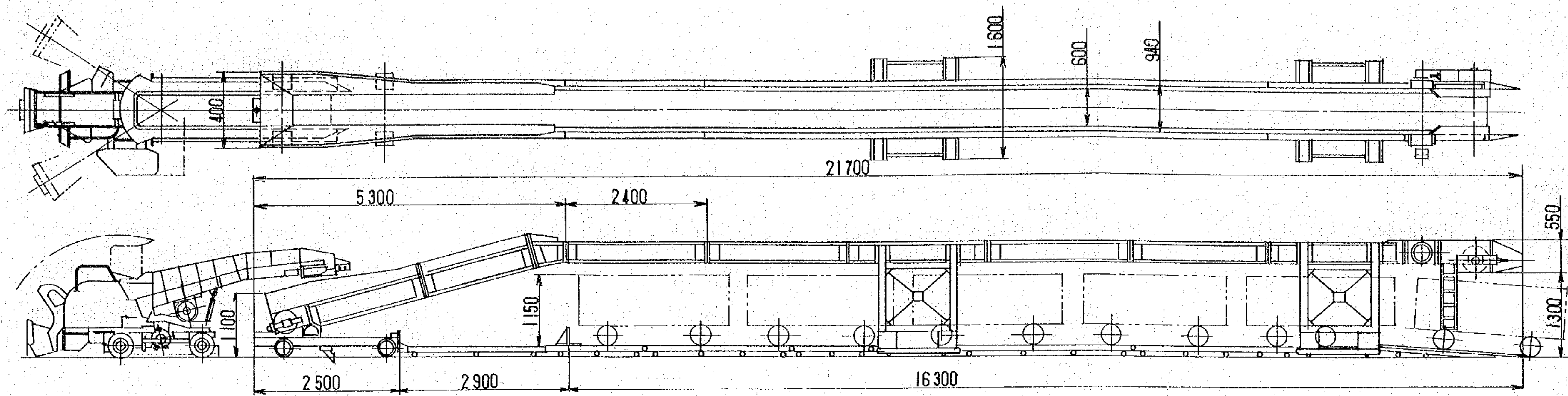
It is necessary for a battery locomotive to have a maximum tractive force to draw six 1.6 m^3 Granby type mine cars loaded with muck. Based from calculations, 4-ton battery locomotive is advisable both for upgrade and downgrade tracks.

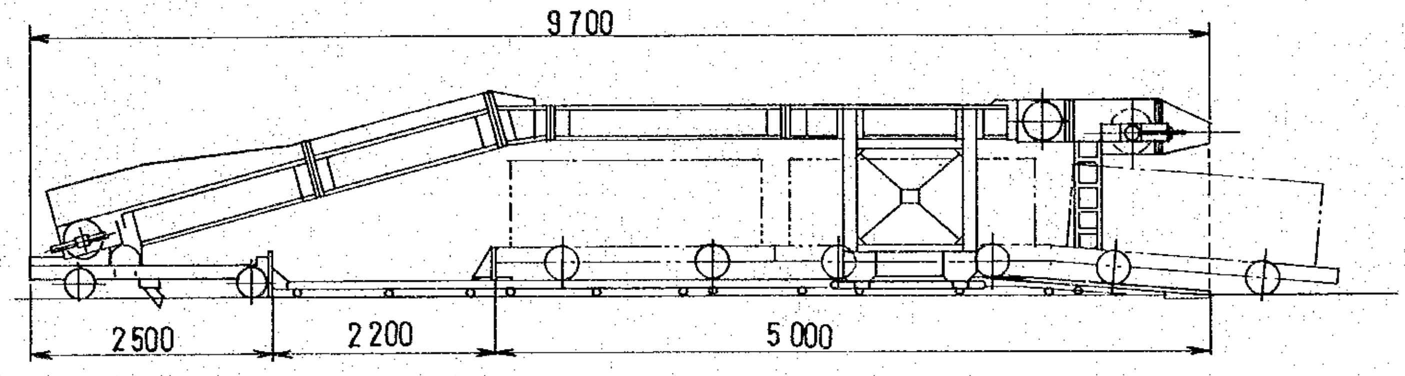
The use of 15 kg rails and a rail gauge of 610 mm is suggested to ensure safe operation of the locomotive.

After completion of the tunnel, the track will be moved at one side of the tunnel so that a mini-battery locomotive can be used to patrol the tunnel.

(2) Rock Drills and Blasting Equipment

For drilling, leg drills of heavy type are recommended. The feasibility of using the drill jumbo was considered but there are problems with regards to the use of SRC conveyor loader. It is difficult to move it out of the tunnel each time when the drill jumbo is used. If the loader is not moved out of the way in the tunnel, it is necessary to lay double tracks as long as 30 m at intervals of about 500 meters. This means an increase in the excavation cost and time.





SPECIFICATION		
UNIT	Length	21700 mm
	Width	1600 mm
	Height	1850 mm
BELT	Width	600 mm
	Air Motor	SPS Air motor
	Speed	25 M/MIN
Air Inlet P.T		PT 1½"
Used Air Press		5 KG/CM² G
Loading Capacity		100 TON/H
Used Rail		610 mm 15~22 KG
Sistem		Secondary ran
Used ore Car		1.6 M³
Noot ore Car for one train		6 Cars
Net Wt.		5000 KG

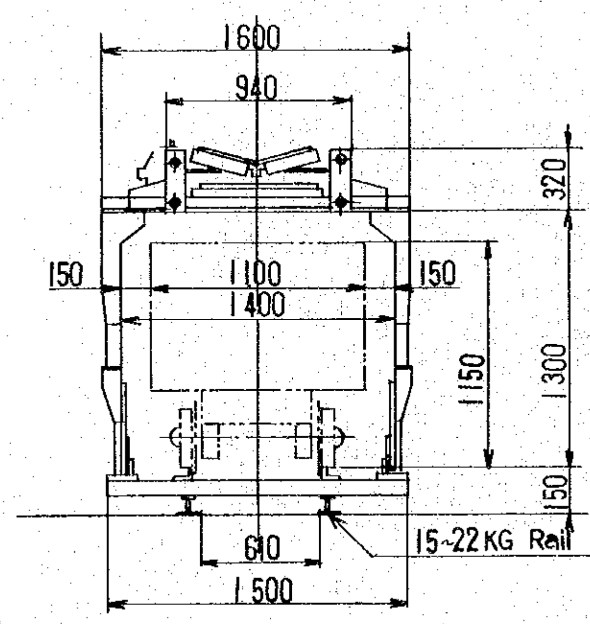


Fig. 8-1

Unit : mm

650 TYPE LOADER SRC CONVEYOR LOADER	
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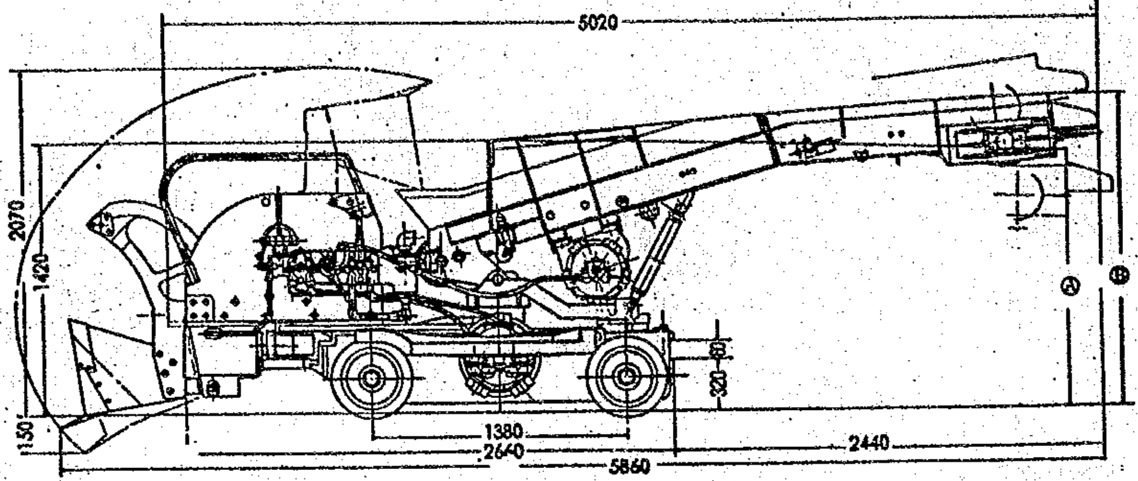
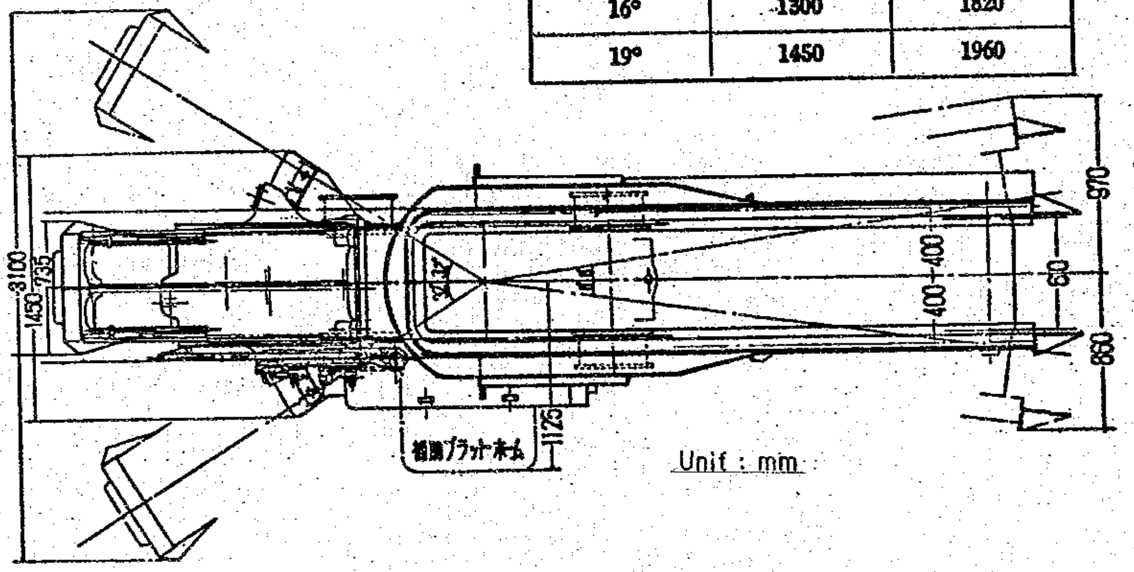
CHECKED BY K.S	DATE 6/29/'78
SCALE	

Table 8 - 1 **TAIKO LOADER, Model 650**



Conveyor angle	Ⓐ Loading height	Ⓑ Total height
14°	1200	1740
16°	1300	1820
19°	1450	1960



Unit : mm

SPECIFICATIONS

Total length mm	5860	excluding length of bucket 5100	Conveyor length mm	4080
		total length of frame body 2660	Conveyor belt width mm	610
Total height mm	1820 (Conveyor angle 16°)		Conveyor speed m/min	45~50
Total width mm	1450		Air pressure to be used kg/cm²	5
Height of headroom mm	2070		Prime motor (Air motor)	for traveling 1 unit 12 Ps
Height of loading mm	1300 (Conveyor angle 16°)			for bucket operation 1 unit 8.5 Ps
Wheel base mm	1380			for conveyor 1 unit 6 Ps
Rail gauge mm	610 (exteded rail outside 930) 508 (〃 830)			for turning 1 unit 3 Ps
Width for clean up mm	3100		Air consumption m³/min	7~12
Bucket capacity m³	0.30		Air hose size in	1~1½
Loading capacity m³/min	1.6~2.2		Total weight kg	5000

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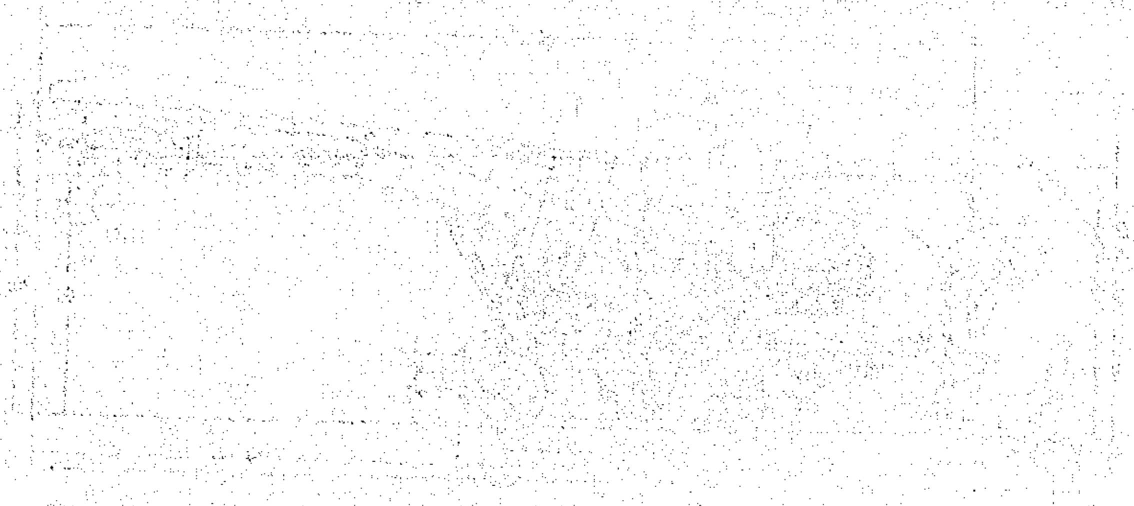
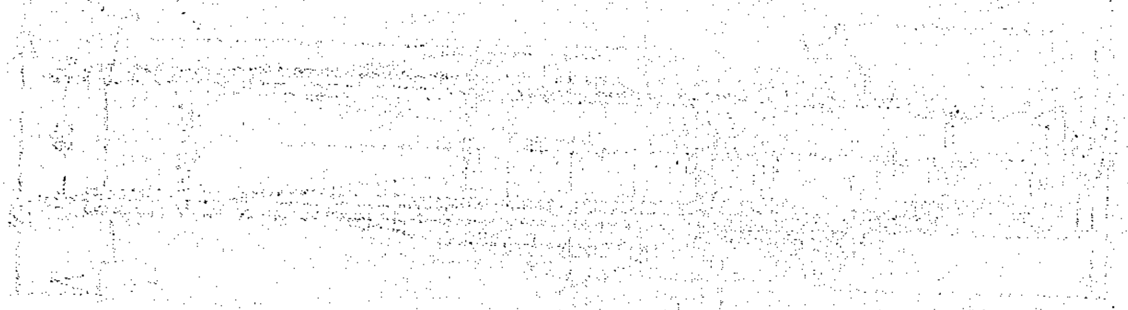




[illegible]

The two-drill type jumbo would be suitable to tunneling work of this type. However, it requires a comparatively long time for preliminary and clearing-up operations before and after drilling so that the use of the drill jumbo does not shorten the overall excavation time. An important advantage of the drill jumbo is its capability of increasing the drilling advance for each blast. However, this is not considered in the tunnel development as it is preferable to use the short step method as will be discussed later.

Dynamite and the decisecond detonator should be used in the explosive charge. A 5-inch diameter carbon steel pipe for compressed air is recommended. With this size, there will be a pressure loss of 0.2 kg/cm^2 when 7 kg/cm^2 compressed air is delivered at the rate of 20 m^3/min. over a distance of 2.5 km. In the case of 4-inch diameter pipe, the pressure loss will be as high as 0.7 kg/cm^2 under the same conditions.

As was proposed in Paragraph 7.3, after completion of the tunnel, compressed air pipe can be used to deliver water to the water tank downstream and as irrgation water pipes. The 5-inch diameter pipe is capable of delivering water at the rate of 1,000 t/day while the 4-inch diameter pipe, at 650 t/day from the intake point H to point N in Fig. 2. A 5-inch diameter carbon steel pipe is preferable because of its lower air pressure loss and greater water carrying capacity. On the other hand, a spiral steel pipe is not recommended because of doubts regarding its durability.

As for the piping joints, it is desirable to use the victualic type joints because of its advantage in quick jointing work.

(3) Ventilation Equipment

In the operation of a long tunnel, the tunneling speed is greatly influenced by how the working environment is kept in good condition and how fast the smoke is removed after blasting at the working face in the tunnel. Proper ventilation must be achieved.

There are various types of fans. The propeller type is commonly used. This type has the advantages of being compact and easy to operate. However, the disadvantage is its low ventilation pressure. It will be necessary to set up several units of the fan in series where a high ventilation pressure is required. The maximum tunneling length in the project is 2.5 km and if series of fans are set up inside the tunnel, it would be necessary to use reasonably large size electric cables to prevent voltage drop in the cables for the fans.

It is desirable to use a system in which a single fan is installed at the entrance to ventilate the tunnel through its entire length. The turboblower is the only ventilator, to meet such requirements. This is the reason why turboblower should be used in the project.

The effective airflow at the outlet of the ventilation duct set up in the tunnel should preferably be 160-180 m^3/min considering various conditions. Taking into consideration air leaks in the ventilation duct, the airflow through the fan should be about 200-250 m^3/min.

If the airflow through the duct is 200 m^3/min and the total length of ventilation duct is 2.0 km, the relations between the ventilation duct diameter and the required ventilation pressure will be as follows:

700 mmø	260 mm (water column)
600 mmø	500 mm (")
500 mmø	1,250 mm (")
450 mmø	2,200 mmø (")

The turboblower can be made to have a ventilation pressure up to more than 1,000 mm water column, but the high pressure type poses the problem of increasing air leaks in the duct. On the other hand, if the ventilation duct diameter is increased, the ventilation pressure may be greatly lowered but it will necessitate to increase the tunnel section. For the above reasons, it is advisable to use a 600 mmø ventilation duct and to use 500 mm Aq. x 220 m^3/min. turboblower.

When considering ventilation, it is necessary to study whether the blow type or the suction type is the most suitable to use. The advantage of the blow type is that the unit cost of the ventilation duct is relatively low but has the disadvantage of longer time to remove the fume produced by blasting. Moreover, the underground temperature is considered to be lower than the ambient temperature, and therefore the blow type ventilation system will possibly cause a rise in the temperature at the working place and it will result in a poor working environment in the tunnel under construction.

The suction type has merits and demerits exactly opposite those of the blow type. The suction type ventilation is recommended because a shorter time in dispersing the blasting smoke is of great importance if a speedy tunneling work is desired. Moreover, the mission found that the suction type ventilation duct can be obtained at a relatively low price. Generally speaking, the suction ventilation duct is more expensive than the blow

LIST OF CORRECTION

Page	Line	Error	Correct
48	Fig. 4-1	ANTANOK	ANTAMOK
59	Fig. 4-2	1 月	Jan.
		2 月	Feb.
		3 月	Mar.
		4 月	Apr.
		5 月	May
		6 月	Jun.
		7 月	Jul.
		8 月	Aug.
		9 月	Sep.
		10 月	Oct.
		11 月	Nov.
		12 月	Dec.
69	upper 3	oaunder	Launder
71	lower 3	BCK	BCI
91	lower 2	maintanance	maintenance
104	lower 4	transtation	transportation
113	upper 11	six ones	six spans
221	upper 3	Top box	Drop box
241	lower 3	KENSAITO	KEN SAITO
241	lower 3	JUANITOC.	JUANITO C.
256	upper 4	Lig	Liq.
258	upper 5	outdise	outside

type ventilation duct because when the duct is made of vinyl fabric, it is usually reinforced with thick piano wires with a pitch of 10 cm so that it can well withstand the vacuum induced by the effect of suction. Generally, a reinforced air duct become skinny horse under the vacuum and the resistance of ventilation increases more than 50%.

Another preferable method is the use of the spiral steel duct which is made of about 0.6 mm thick steel hoop and band. This spiral steel duct can be made to any desired length. Since the proposed tunnel is about 16.8 km. long,it will be possible to make the spiral steel duct at a relatively low unit price if a complete set of the spiral steel duct manufacturing machine costing about ₱150,000 is purchased. The unit price of the manufactured spiral steel duct is estimated to be about 60% of the cost of the piano wire reinforced vinyl fabric duct.

Because of the above reason, the spiral steel duct for ventilation is strongly recommended.

(4) Drainage

In a tunneling project, the amount of underground water is unpredictable. There is no problem in an upgrade tunnel because the water is removed by natural drainage. However, it is necessary to provide a settling pond near the portal so that any sand which the stream of water carries can settle before it is discharged out of the tunnel. The underground water in a downgrade tunnel needs be collected and pumped out. The working place will be drained by a pneumatically operated sump pump.

The largest amount of underground water to be encountered in driving a downgrade tunnel is expected to occur in section 1 where the total amount of underground water is estimated to be about 2.5 m^3/min. The next largest may be found in section 3 which passes through a limestone zone where the water will be about 1.0 m^3/min. It is expected to be less than 0.5 m^3/min. in other sections.

It is impossible at the present time to obtain a high-tension electric power in the vicinity of the proposed tunnel and there will be little need for any power supply after the completion of the tunnel. It is desirable to use diesel-driven generators to obtain the power supply required in driving the proposed tunnel. The generators should be of the same type so that their parts may be interchangeable.

However, there is reportedly a plan for building high-tension power transmission cables along the Kennon Road. If it is likely that the electric power supply is available in time for the tunnel excavation work, it is necessary to study the economic feasibility of using the high-tension power supply.

(5) Compressor

The air requirements at each stage of excavation cycle will be as follows:

(i) Mucking

TAIKU 650 loader	7 - 12 m^3/min.
Conveyor loader	3 - 4 m^3/min.
	10 - 16 m^3/min.

(ii) Rock Drilling

3.8 m^3/min. (per drill) x 3 = 11.4 m^3/min

Mucking will require the largest air supply. In view of the air consumption for mucking, an air compressor of the following specifications should be used.

Engine power output:	170 HP
Capacity:	17.0 m^3/min. (7 kg/cm^2)
Weight:	4.00 t

(6) Generator

The 37 KW turboblower consumes the largest amount of electric power. Electric power is consumed also for illumination in the tunnel, charging of storage batteries for the battery locomotive outside the tunnel and other purposes. In addition, a power supply for drainage pumping will be needed in the downgrade tunnelling section which is estimated to require about 20 KW in section 1. The following type of diesel engine-driven generator should be used in upgrade tunnelling sections:

Voltage:	220 V
Output:	125 KVA
Current capacity:	328 A
Engine power :	150 HP
Weight:	2.45 t

The following generator should be chosen for downgrade tunnelling sections including the power required for drainage.

Voltage:	220 V
Output:	200 KVA
Current capacity:	525 A
Engine power:	243 HP
Weight:	4.00 t

(7) Numbers of Compressors and Generators to be Used

Compressors and generators are equipment indispensable in driving tunnels and their failure inevitably result in the stopping of the tunneling operation. The economically usable life for diesel engine-driven compressors and generators is considered to be 8,000 hours in general. If they are used longer, the failure rate will increase sharply thus increasing repair cost.

The compressor is estimated to be operated about 7,000 hours a year and the generator, 7,000 to 8900 hours. Therefore, considering that one unit of these equipment is consumed within a year, two units of each will be required.

Due to the above reasons, two units of compressor and generator should be installed at each portal of tunnel.

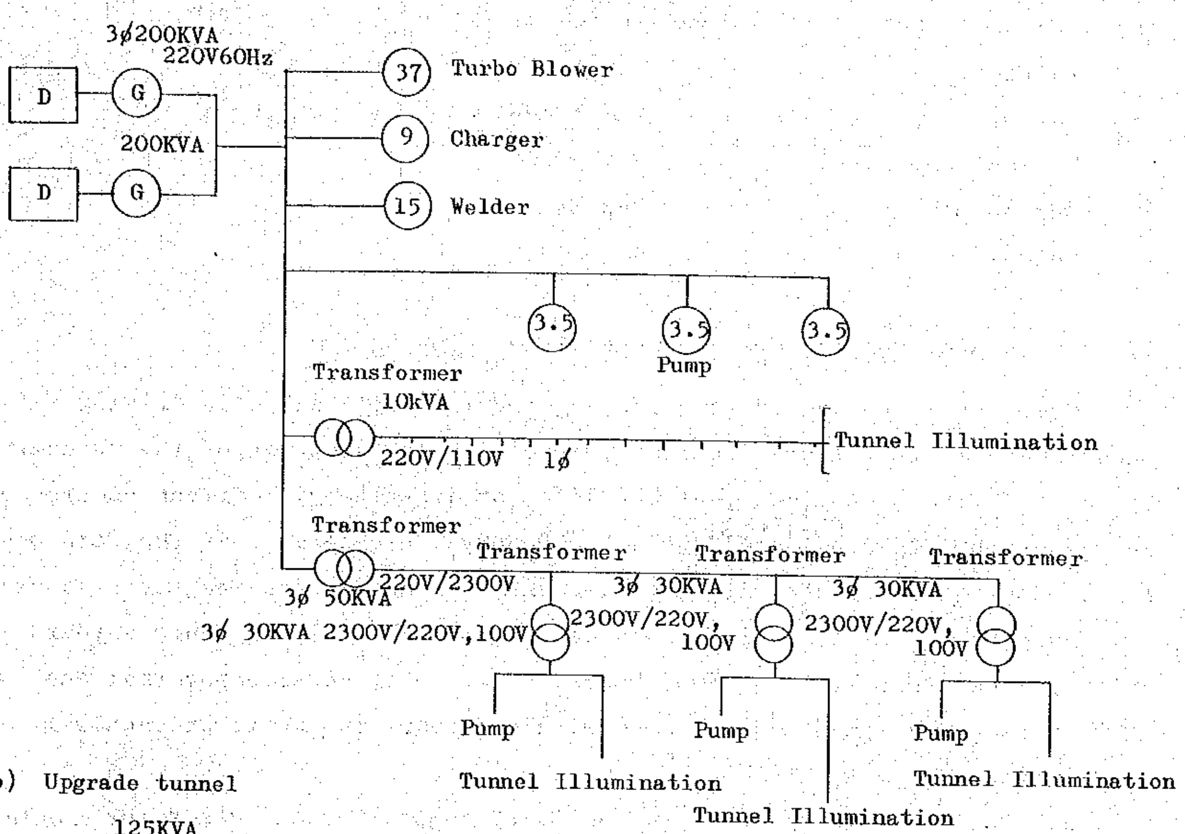
(8) Electric Power Supply Facilities in the Tunnel

a. The following voltages of power will be used.

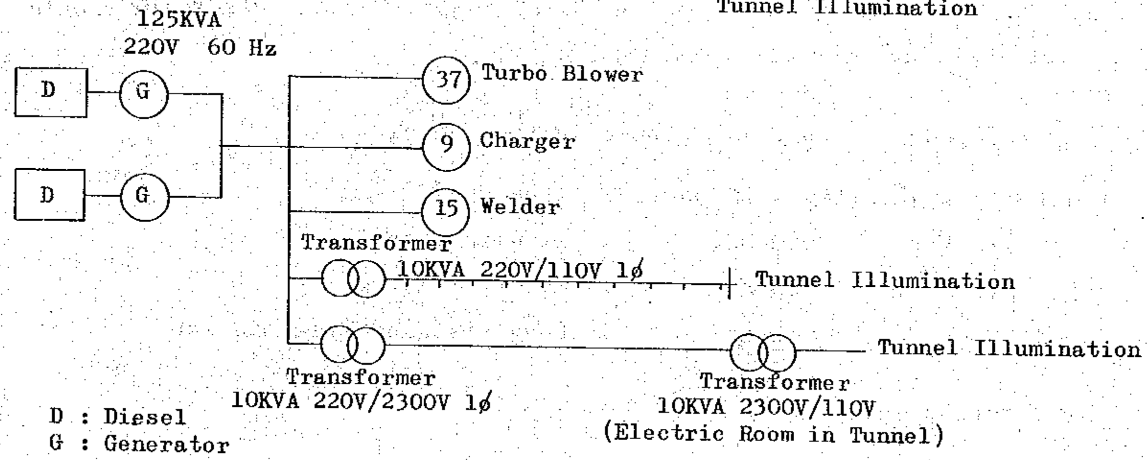
110 V	60 Hz	:	Illumination
220 V	60 Hz	:	Motor, Welding
2,300 V	60 Hz	:	Long Distance Transmission

b. Power supply system

(a) Downgrade tunnel (Next page)



(b) Upgrade tunnel



8.1.4 Timbering

(1) Shape of Tunnel Section and Timbering

Fig. 8-2 shows the tunnel sections with and without timbering. In all cases, the tunnel width is 2.80 m. The tunnel without timbering has an arched cross-section and the tunnel with either steel support or concrete lining has a cross-section which is close to an arch type consisting of straight lines.

The mountainous area through which the proposed tunnel is to be driven consists mostly of conglomerate which is sedimentary rock deposited in layers with relatively few fissures. However, joints are developed on the sedimentary plane and 15° to 25° westward. The joints are perpendicular to the tunnel. If the tunnel ceiling is made flat and such joints are encountered, a uniform thin layer can possibly appear on the ceiling along the full width of the tunnel section causing a high possibility of this layer to fall down causing injury to the workers working beneath. This can be prevented by shaping the ceiling into an arch. In the case of an arched ceiling, even if a thin layer appear in the center of the ceiling, the layer is thicker on both sides. It reduces the span of the dangerously thin layer and minimizes the danger of its falling down. This also means that the arched ceiling will reduce the area where timbering is required.

The metavolcanics in the vicinity of Camp 4 is hard but has many fissures. The arched tunnel ceiling is also effective in this section. For these reasons, it is intended to use the arched cross-section where timbering is not employed.

Timbering is required where the rock is relatively soft or faults and joints have developed. Steel supports should be used in the proposed tunnel because the tunnel will be used for a long time, and wooden timbering will be subject to decay. For the same reason, steel laggings should be used to cover the space between the steel supports.

When using steel supports, it is desirable to use arched ones. However, since large equipment and special techniques are also needed to make ordinary steel arch, the form as illustrated in Fig. 8-2 is recommended because it is easy to prepare in the work site.

Concrete lining will be required at some places such as the portal. In this case, the concrete lining should be 30 cm thick with the same cross-section as of the steel supports.

The tunnel may have some areas where no timbering is required during excavation but some protective arrangements should be necessary to prevent falling of rocks caused by weathering of exposed rock. In such areas, mortar shotcrete should be applied after excavation. The shotcrete should be 30 mm thick.

(2) Steel Supports

MI 105 (mine I-beam 105) should be used as the material for steel supports which is illustrated in Fig. 8-3. This is the smallest of the types of mine I-beams specified in Japan (105, 115, 125). MI 105 means that the I-beam is 105 mm high. This type of I-beam has thicker flanges than H-beam and therefore has the advantage of being relatively stronger for its small dimension. It has also an advantage of higher resistance to twisting than an H-beam.

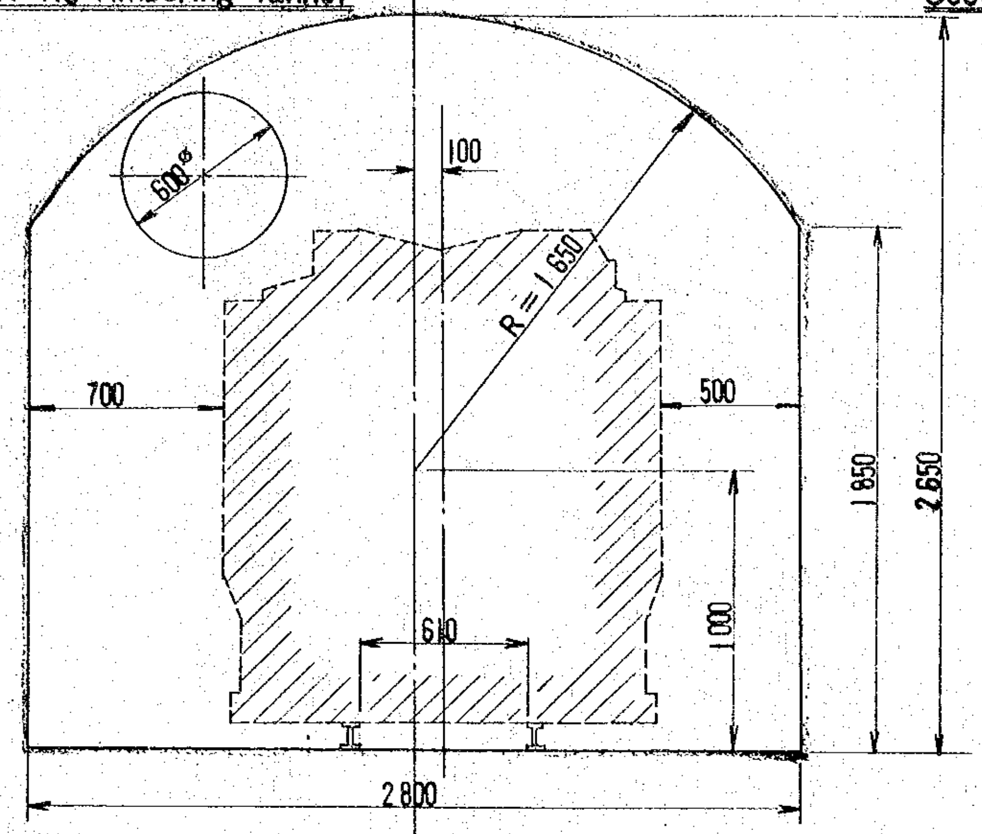
As was previously stated, steel laggings are advisable for wood is subject to decay and not suitable for use over a long period of time. The steel lagging consists of thin steels which have been corrugated to increase its strength. The strength of steel arches and that of steel laggings will be approximately in balance when the MI 105 ribs are spaced 1.0 m apart. It may seem desirable to increase the distances between the steel ribs in order to reduce the cost of excavation,but it will be necessary to increase the thickness of the steel laggings. As a result, the cost of steel laggings will increase while the cost of steel ribs would be reduced. For this reason, the overall cost of steel ribs and laggings will not be greatly lowered. The use of steel laggings will result in a considerable rise in the cost of timbering. The use of wooden plate for lagging which have been given anti-corrosion treatment should be considered as this will reduce cost considerably.

8.1.5 Rapid Tunnel Driving

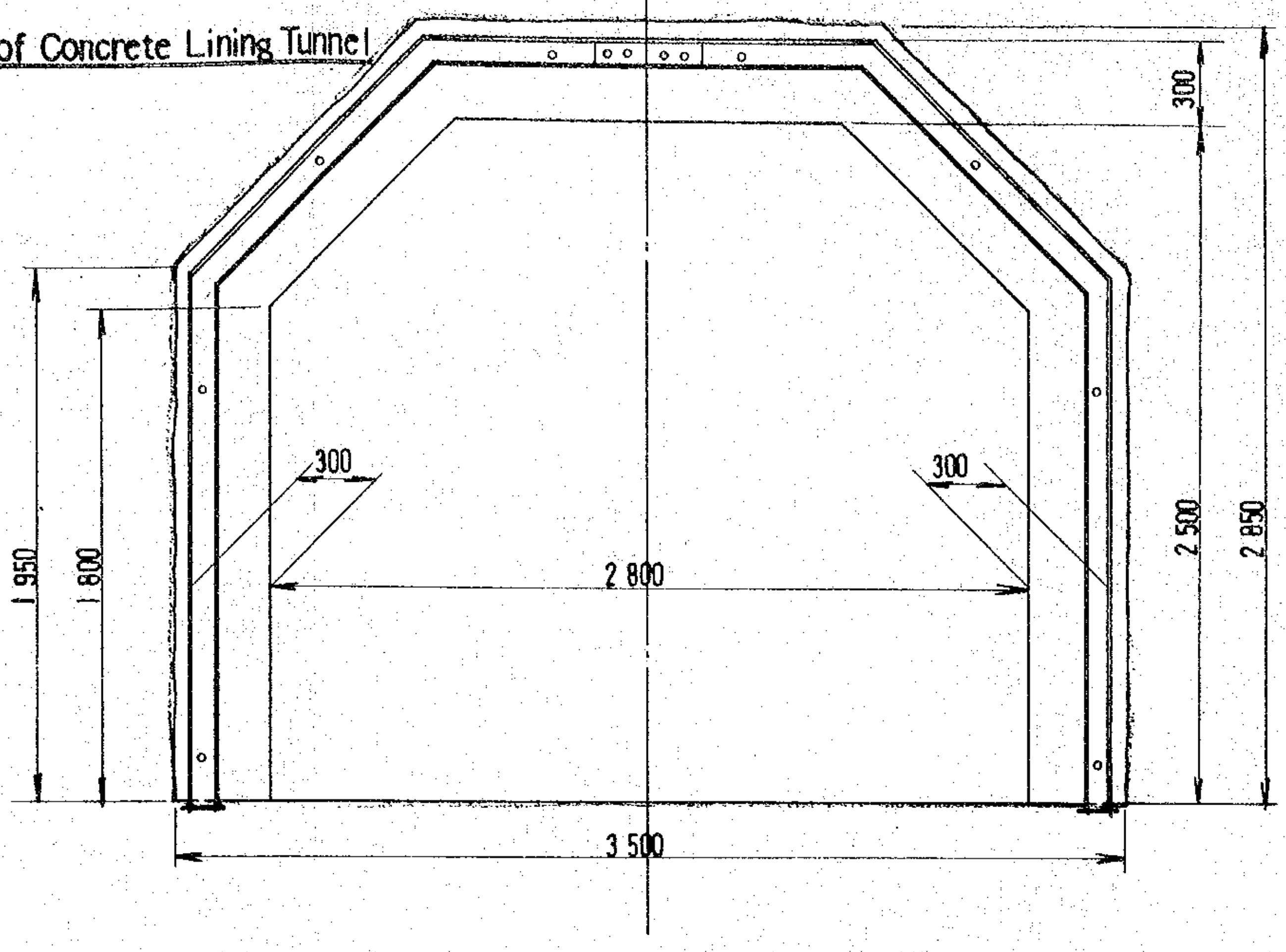
In order to speed up the driving of the tunnel, the following conditions must be satisfied:

i. Good natural conditions and tunnel specifications
ii. Well-balanced selection and arrangement of tunnelling equipment
iii. Good organization and a sufficient number of skilled workers
iv. Morale of achieving a rapid tunnel driving

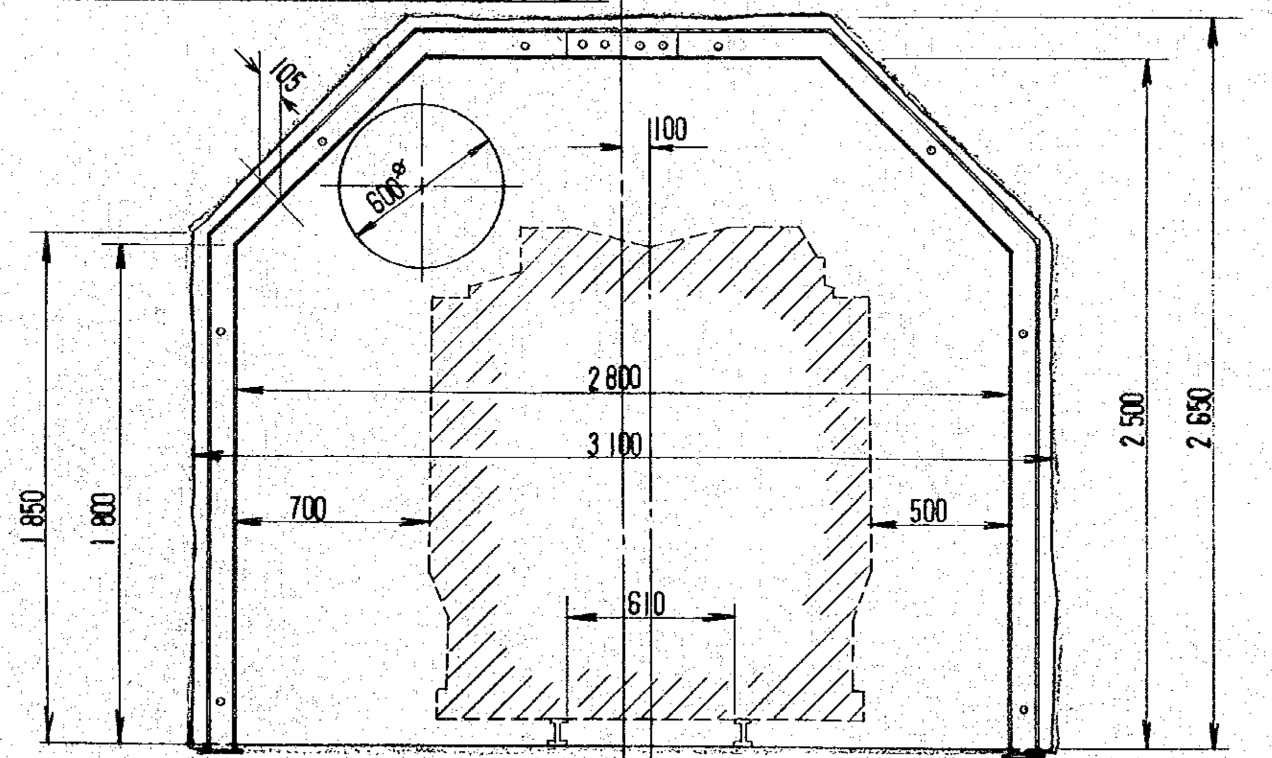
Section of No Timbering Tunnel



Section of Concrete Lining Tunnel



Section of Steel Timbering Tunnel



	No Timbering	Timbering	Concrete Lining
Planned Excavation Area	6.75 m^2	7.60 m^2	9.17 m^2
Excavation Section	7.84	8.76	10.43

Fig. 8 - 2

Unit: mm

TUNNEL SECTION

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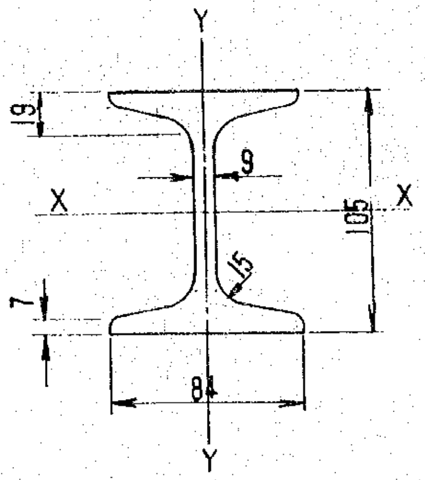
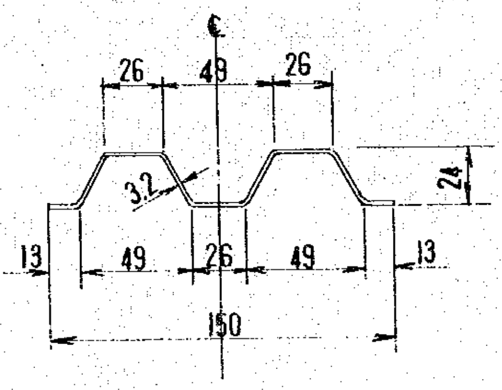
Dimension and Section Performance of MI 105



Weight	22.7 kg/m
Sectional Area	28.89 cm^2
Second Moment of Area	I_x = 490.3 cm^4
	I_y = 101.3 cm^4
Section Modulus	Z_x = 93.4 cm^3
	Z_y = 24.1 cm^3

Dimension and Section Performance of Steel Lagging (15 Type)



1 Sheet

Weight	4.9 kg/m
Sectional Area	6.23 cm^2
Second Moment of Area	4.6 cm^4
Section Modulus	3.8 cm^3

Fig. 8-3

Unit : mm

DIMENSION AND SECTION PERFORMANCE OF MI 105 AND STEEL LAGGING	
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If any of the above conditions is lacking, it would be difficult to achieve the rapid tunnel driving as desired.

The rock formation in the common line tunnel from Camp 4 to Bued River is relatively simple and moderately hard. It is considered to be favorable for tunnelling. The tunnel cross-section is so small to suit the rail track method of tunnel driving.

The tunnelling equipment to be used has been chosen to satisfy the conditions required for rapid tunnel driving work. It is essential to make effective use of 24 hours a day so that there will be no loss of time. For this purpose, there is a need for an efficient organization managed by personnel possessing high managerial capabilities to make ordinary checks to see if the work is progressing as scheduled and to make prompt remedial actions, when troubles occur so that the work would go on without interruptions.

It is also necessary to use many skilled workers who can precisely and efficiently perform any jobs invloved in the tunnel driving.

Besides the above three conditions, the morale of the supervisors and workers to achieve rapid tunnel driving will have influence on the speed of driving the tunnel. In order to achieve this objective, it is proposed to employ contract system so that wage will be paid in proportion to the speed when the excavating speed is increased. This system should, needless to say, be applied not only to the workers engaged directly in excavation but also to those who are employed in the ancillary work.

For reference, we present the data of rapid tunnel driving. The data was obtained when a rapid tunnel driving work was carried out at the Kamioka Mine in Japan, using a combination of SS conveyor loader (old model of SRC conveyor loader) and leg drills. A monthly progress of 420.1 m which was achieved in June 1965 as given below is still the highest record ever achieved in the metal mines of Japan.

i) Equipment use

SSC-22 type conveyor loader	1
Train of eight 1.6 m^3 Granby mine car	1
Rock drill ASD-317 and others	3
"TAIKU" 700B loader	1
4-ton battery locomotive	1

ii) Working conditions

Cross-section of tunnel: 2.4 x 2.6 m

Excavation system: single line rock tunnel and no timbering, 4 workers in a shift and 4 shifts a day

iii) Excavation performance records at Kamioka Mine

Item		Nov.1963	Nov.1964	June 1965
Monthly excavation length	m	324.3	356.3	420.1
Efficiency of work	cm/man.shift	162	173	179
Daily excavation length(mean)	m/day	12.5	12.7	14.0
Daily excavation length(max.)	m/day	17.0	17.0	18.0
Number of working day	day	26	28	30
Daily average number of cycle	cycle/day	10.5	11.7	13.4
Excavation length per cycle	cm/cycle	118	109	104
Number of drill holes per 1 m progress	holes/m	26.5	25.0	38.6
Number of cars per cycle	cars/cycle	8.2	9.1	8.1
Amount of explosives per 1 m progress consumption	kg/m	10.5	10.2	15.6

Time required in 1 cycle (Data achieved November 1963)

Item		Time required
Mucking	Preparations	7' 40"
	Main work	23' 20"
	Clearing up	8' 00"
	Subtotal	39' 00"
Drilling	Preparations	4' 00"
	Main work	43' 00"
	Clearing up	1' 00"
	Subtotal	48' 00"
Blasting	Preparations	9' 00"
	Main work	17' 00"
	Subtotal	26' 00"
Total		1^{o} 53' 00"

8.1.6 A Study on Tunnel Driving System and Disposition of Personnel

(1) A Study on Tunnel Driving System

The choice of the blasting hole length is important. There are two ways of driving tunnel. One is to dig holes as long as possible without considering the harmony of cycle time and time of shift. Another method is to select the appropriate blasting hole length which harmonizes the number of cycles and 8-hous shift.

These two methods have their own merits and demerits. The first method which is called the long step method has the following merits and demerits:

Merits

(i) With the designed cross-section of the proposed tunnel, it is possible to obtain an excavation length of about 2.0 m if skilled rock drilling technique is employed. This method makes it possible to reduce the time required in removing the smoke and preliminary and clearing up work.

Demerits

(i) Since the number of cycle in a work shift is not specified, the amount of work to be done within the assigned working time will not be definitely determined. It tends to slow down the tunneling work.

(ii) There will be increased overbreakage.

(iii) A skilled drilling technique is required particularly in such tough rock as conglomerate. It is difficult to bore holes accurately by a leg drill.

The aforementioned tunnel driving record at the KAMIOKA Mine in Japan was achieved by the use of the short step method with excavation lengths of about 1.0 m using leg drill.

It is desirable to employ the short step method in which the excavation length per blast is 1.2 m. where timbering is not used, 1.0 m where timbering is used with two (2) cycles/shift. The reasons to employ the short step method are described below.

(1) Leg drills will be used for drilling hole, which requires a high degree of skill to bore deep holes with accuracy.

(2) Since the proposed tunnel is to be driven simultaneously at many different sites, it will be difficult to recruit many skilled workers.

(3) The rock through which the tunnel is to be driven in the mountainous area is mostly conglomerate with few fissures and are not easy to break by blasting.

(4) The proper distances between the steel ribs to be erected inside the excavated tunnel are 1.0 m to balance the strength of the steel laggings to be used.

The length of the SRC conveyor loader to be used has a 10 to 20% margin of mucking capacity such that it is possible to extend the excavation length per blasting within the allowable limits.

To achieve speedy tunnel development, it is desirable to minimize the jobs at the working face in the tunnel and complete the jobs at the rear by the auxiliary workers. The jobs which can be done side by side at the working face in the tunnel should be done simultaneously.

The workers at the rear will undertake the following jobs:

. Extension of compressed air and water pipes
. Extension of spiral air ducts
. Drainage work
. Transportation of timbering materials and explosives
. Laggings on both sids (lagging of the roof only is made at the face)
. Installation of transformers

The jobs which can be done simultaneously side by side at the working face in the tunnel are as follows:

. Scaling and mucking
. Drilling the holes and making the primers
. Clearing work after mucking and preliminary work for drilling
. Clearing work after mucking and work of rail track extension

The operations to be performed at the warking face in the tunnel will be only rock drilling, charging dynamite, blasting, mucking, (timbering), extension of rail tracks, and preliminary and clearing operations for such jobs.

(2) Personnel Distribution:

As for the distribution of workers, there are seven (7) underground workers and 4 auxiliary workers in each shoft at each portal.
There will be a foreman in each shift at each portal.
The following number of supervisors, engineers, and others are positioned daily at each portal.

General foreman	1	
Mechanical engineer	0.5	(one engineer for two portals)
Electrical engineer	0.5	(")
Surveying engineer	1	(two engineers for two portals)
Materials procuring cleark	1	
Wage paying clerk	1	
Total	5	

8.1.7 Accuracy of Survey

Highly accurate survey work is needed in tunneling especially when a long tunnel is being driven from the two ends at the same time to meet correctly in the middle. The allowable deviation at the meeting point is 15 cm horizontal, and 10 cm vertical. The longest distance, of the 12-km. traverse is that between points H and J, (see Fig.1). This section requires a surveying accuracy of 1:100,000, horizontal, and 1:120,000, vertical. Other sections also need accuracy of somewhere around 1:100,000. Such accuracy will require a high degree of surveying skill.

8.2 CONSTRUCTION OF UNDERGROUND FALL

In order to take care of the excess head in the mountainous area, the underground fall method should be employed.

8.2.1 Excavating Machinery

Various types of raise boring machines are available in many countries and they are much in use in constructing ventilation raise, ore chutes and others.

There is a reference to such a hole of more than 400 m long and 2.4 m in diameter bored by the use of one of this type of boring machines (Sudbury Basin, Canada). There will be no technical problems about the planned use of the machine in making holes 55 cm in diameter and about 200 m long.

The construction scheme of underground fall is made by using a raise boring machine with a commercial name of "Big Man" in excavating the underground fall.

It is planned to use a medium-capacity mode of the "Big Man" series, called BM 100N, whose dimensions are shown in Fig. 8-4. This raise borer is provided with a hydraulic unit. There is need for a 135 KW, 200 V power supply facility or 175 KVA generator as power source for driving this hydraulic unit.

Tri-cone drill bit 250 mm in diameter is used for boring a pilot hole. There are two types of tri-cone bits, the tip insertion type and the tooth form type, which can be interchanged according to the character of the rock to be excavated. The drill rods to be used are 203 mm in diameter, 1,160 mm long and weigh 190 kg each. Stabilizers shall be used to prevent deviation of the borehole.

The raise drilling bit (reaming bit) consists of the bit body, rotary cutter and head roller and the standard bit diameter is 500-2,430 mm. The bit bodies are of two types, the stage type and the flat type.

8.2.2 Method of Riase Boring

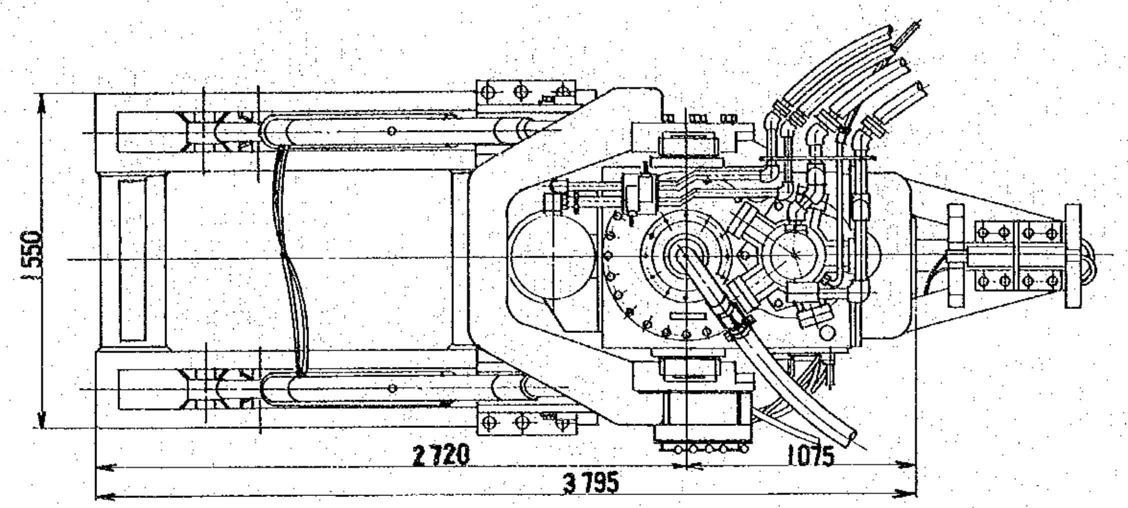
With the BM 100 N and the attached equipment situated in the upper tunnel, a pilot hole(250 mm in diameter) is drilled toward the lower tunnel by giving a thrust and rotation to the drill. The stabilizer shall be used to prevent the deviation of the hole. The deviation is estimated to be about 0.5% for a hole 200 m in length (a radial deviation of 1.0 m for every 200 m long).

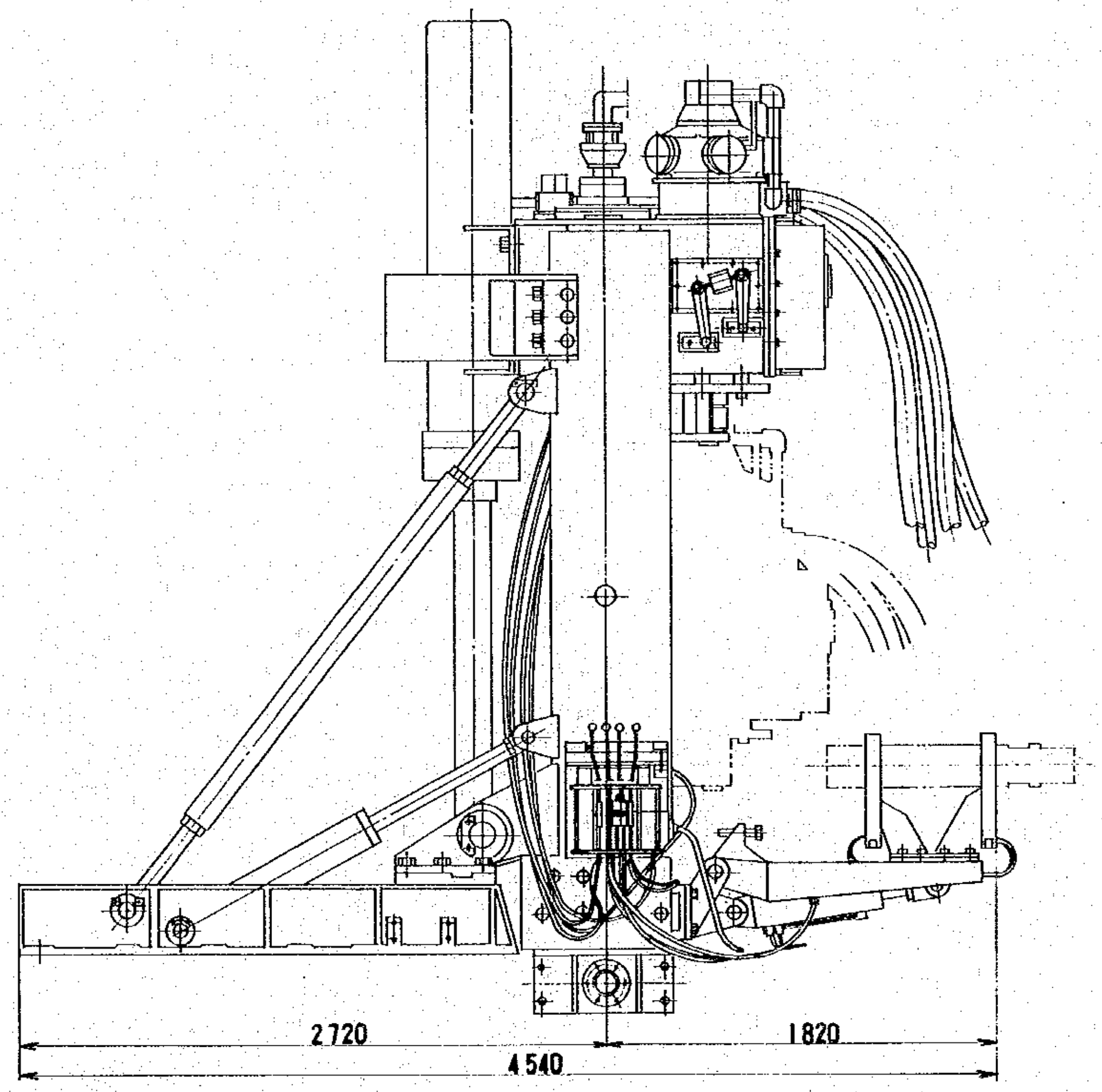
Bentonite slurry is circulated by means of a slurry pump in order to remove chippings.

When the pilot hole reached the lower tunnel, the tri-cone bit fitted to the end of the drill rod is replaced with a reaming bit of 550 mm in diameter to ream the hole by driving the drill upward.
The reaming bit is cooled by a stream of water flowing at the rate of 200 l/ min. from above. The chippings which are produced by reaming accumulate in the lower tunnel and these are removed by means of a loader. Communication facility is needed to link the upper and lower tunnels in the early stage of reaming. Two pilot holes will be drilled first where necessary and one of them is used for communication.

Specification

Type		BM-100N Rise Drill		
Diameter of Pilot Hole (mm)		250		
Diamcter of Reaming Hole (mm)		Max. 1 450		
Excavation Capacity (m)		180		
Excavation Direction		0°~ -19°		
Rotation	Change Gear	1 Speed	2 Speed	3 Speed
	Revolution (rpm)	0 ~ 1.8	0 ~ 18	0 ~ 57
	Torque (kg-m)	7 000	2 600	815
Thrust	Stroke (mm)	1 600		
		Push	Pull	
	Thrust (kg)	Max. 110 000	Max. 160 000	
Weight (kg)		About 12 000		





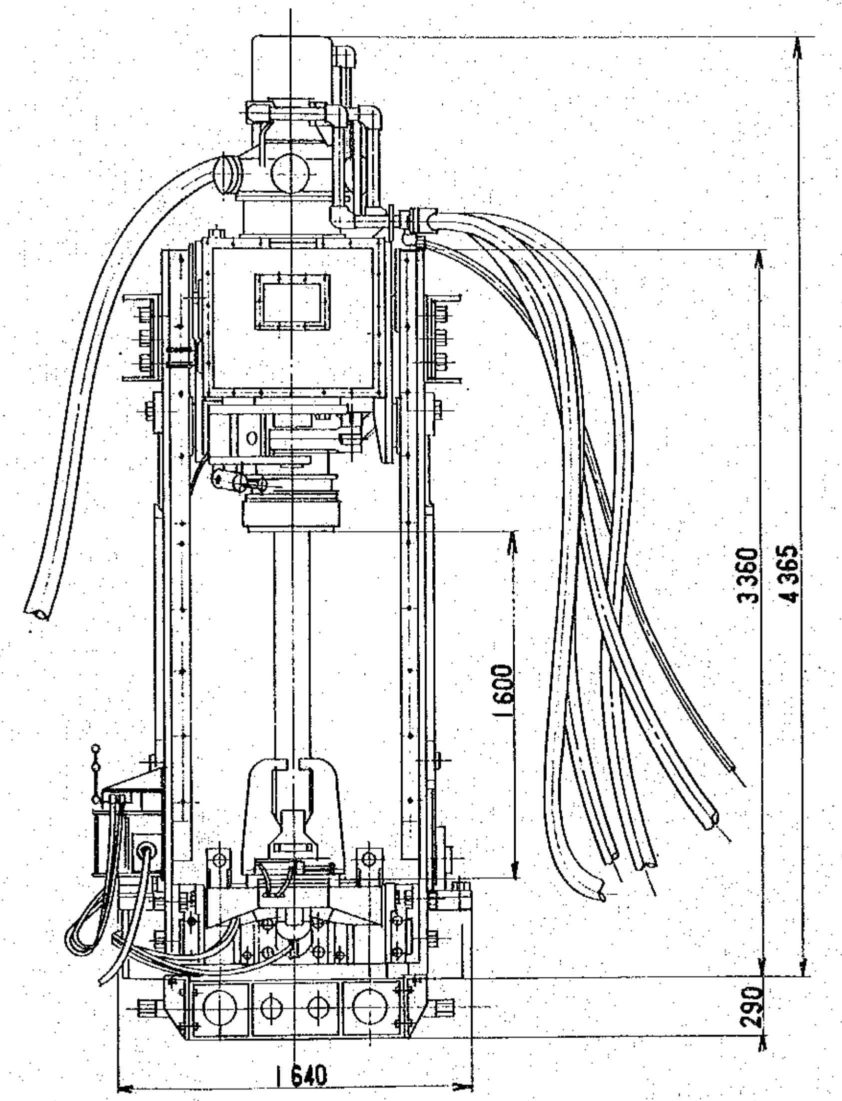


Fig 8-4

Unit : mm

BM-100N DRILL UNIT			
DRAWN BY	G	DATE	6/28/'78
CHECKED BY	K.S	DATE	6/28/'78
SCALE			

A pilot hole of 250 mm in diameter is drilled near the underground fall to provide a passage for the communication line which is required when the operation of transporting the tailings begins.

Hard rock and no spring water are the prerequisites to the underground fall. There is no need to worry about the rock strength in the project for both conglomerate and limestone are harder than concrete. If water occurs in the underground fall, the slurry volume will increase and there will be the necessity of increasing the size of the launder or pipeline subsequent to the fall. When spring water is enoucntered during the pilot drilling of the underground fall, it shall be stopped by grouting. The method is illustrated in Fig. 8-5.

After completion of the pilot hole drilling, a wooden stopper is driven into the opening of the pilot hole in the lower tunnel and properly supported from underneath.

Next, for a grout pipe, boring rods 40.5 mm in diameter and 3 m long are linked together and inserted down through the pilot hole as far as 10m above the stopper and the rods are clamped by the wooden holder.

The cement slurry, which is prepared by the grout mixer HM-250, is pumped by the grount pump MG-5h into the grout pipe formed with the boring rods. The water in the borehole is replaced with the cement slurry and flow out of the hole. When the level of cement slurry rise to the mouth of the hole, the rods are pulled up and disconnected one after another. When all the rods are withdrawn, the grout cap is fitted onto the mouth of the pipe which has been set concentric to the hole and the cement slurry is pumped again into the hole.

When the grout pumping pressure increases, pumping is stopped for a while then resume pumping. If the pressure rise immediately after pumping is resumed, it is considered that the grouting is over.

At least 24 hours is required for the grouted cement to harden after completion of the grouting, and drilling can start through the cement with the pilot bit.

8.2.3 Drilling Speed of Underground Fall

The average rate of progress in drilling is estimated to be 20 m/day for pilot drilling and 16 m/day for reaming, assuming that the work is done by two shifts a day, each shift working for 10 hours. It is estimated that the construction of two underground falls, 200 m long and 55 cm in diameter and a cable hole, 200 m long and 25 cm in diameter, will require full three months and a total of four months when the grouting work is done.

The working team formation will be as follows:

Field superintendent	1
Skilled worker (A)	2
Skilled worker (B)	2
Auxiliary worker (local labor)	6
Total	11/day

8.3 PREPARATORY WORK FOR TUNNELING

The proposed tunnel construction work will require eight portals and adequate preparatory work should be done for them before starting the tunnel driving work. The preparatory work consists mainly of the construction of access roads leadings to the portals and erection of provisional facilities at the portals.

8.3.1 Access Roads

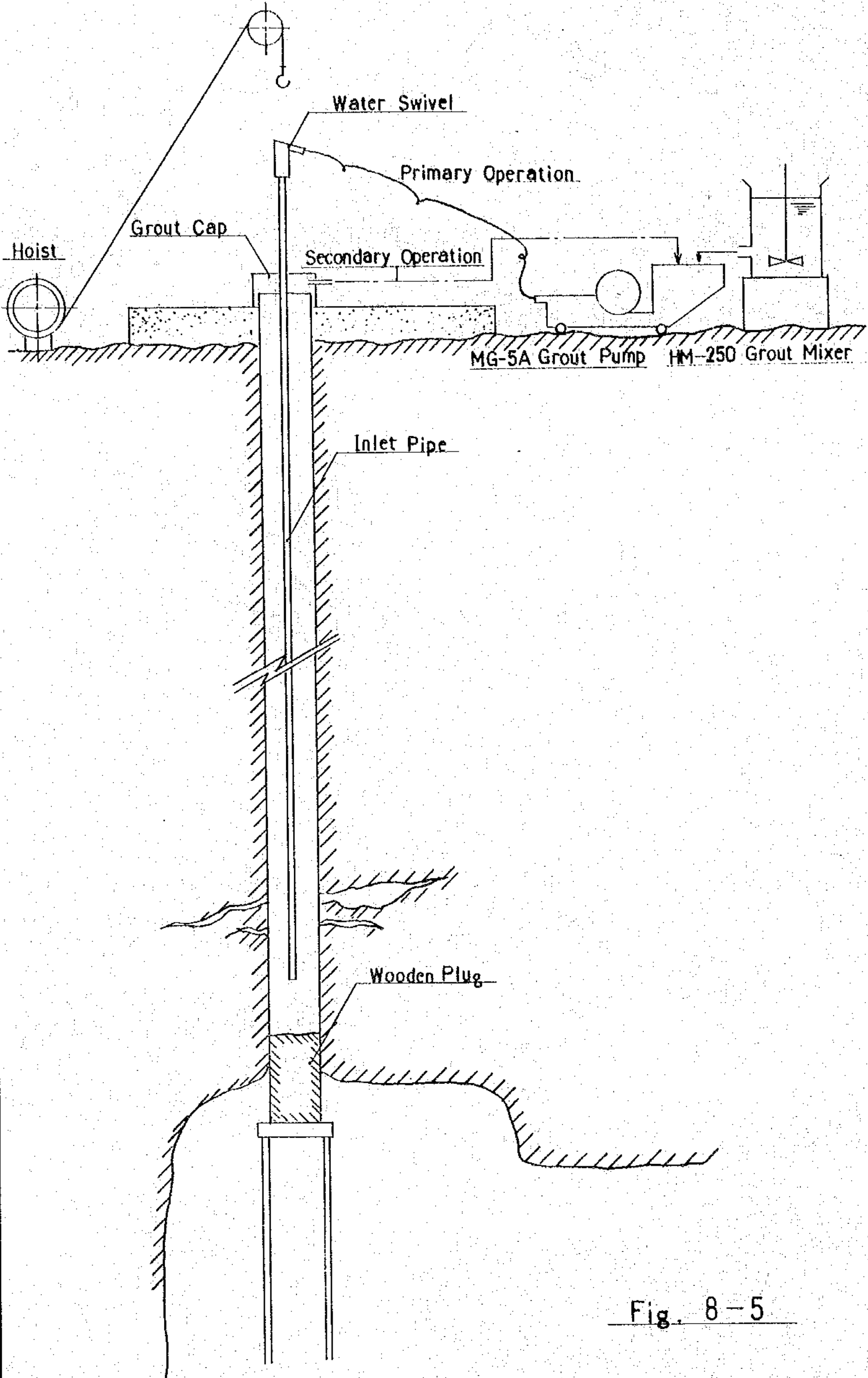
The portals of the tunnel passing through the mountainous area are all located slightly above Kennon Road and this facilitate the preparatory tunneling work. A common access road can be used for two portals located at one place, and therefore five (5) access roads will be required for the eight (8) portals.

The total length of the access roads will be 1,900 m. Besides this, there will be partial widening of the existing road amounting to 600 m.

The access road should have a width of 5.0m and a gradient less than 10%. In consideration of the fact that the terrain is relatively steep and there is a hevy rainfall and the necessity of carring heavily loaded trucks, cutting method of building the access roads should be employed limiting the filling method to a necessary minimum.

8.3.2 Provisional Facilities

The portal facilities include the field office, repair shop, materials storage yard, explosives storage place, and compreesor and generator house. They are all temporary facilities and should be prefabricated buildings. Their aggregated floor space is estimated to be 160 m^2 per portal.



Water Swivel
Primary Operation
Grout Cap
Hoist
Secondary Operation
MG-5A Grout Pump
HM-250 Grout Mixer
Inlet Pipe
Wooden Plug

Fig. 8-5

When two portals are at the same place, they will use the common facilities. Besides such buildings, the temporary facilities also include the foundations for machiery installation, fuel oil storage facilities, water supply and communications facilities. It is also necessary to lay a side track from the portal of the tunnel.

The expenses for the living quarters of supervisors, engineers and ordinary workers are included in the indirect cost and not included in the direct cost of the preparatory work for tunnel construction.

The period required for those items of preparatory work varies with different places. But all such work, including setting up of waste bins, is expected to be completed within 3 months.

8.3.3 Disposal of Waste

The tunnel driving and preparatory work produce waste and excavated soil. Each volume is respectively estimated to be 200,000 m^3 (broken) and 20,000 m^3 totalling 220,000 m^3. The plan of waste treatment is for the waste to be treated where it can be used or deposited at the work site while the rest is hauled by 10-ton dump trucks to the neighborhood of Rabon so that it may be used to construct causeway in the sea.

The waste to be produced at the point P in Fig. 1 is disposed of near the portals. Of the waste (about 45,000 m^3) to be produced at the portals J and K, about 25,000 m^3 will be used for building the embankment of an emergency pond near point J, and the rest will be transported to the coastal area.

The wastes coming out of the portals A, D, G and H are hauled by 10-ton dump trucks close to Rabon. The waste, including the surplus soil which is to be carried away by truck, is estimated at about 150,000 m^3 and the average hauling distance is 28 km. There is enough elevation at the portals A and D, such that the waste can be transferred directly to the 10-ton dump truck from the waste bins. The waste bins may be made of wood. At portals G and H, the waste which has been carried out by mine cars will be piled up on the ground and then transferred by the use of shovels onto truck.

The waste and soil may also be used on the access road construction on the level plains. In this case, the hauling distance is shorter and the cost of transportation will be much lower. This question should also be studied before making the final study.

8.4 TIME SCHEDULE OF TUNNEL CONSTRUCTION

8.4.1 Tunnel Driving Speed

Appendix A-8-1 shows the planned cycle times in the tunnel driving operations with or without timbering. According to this plan, the progress in tunnel driving will be 180 m a month when no timbering is employed and 150 m a month where steel supports are used. However, it is seldom that the work progresses as scheduled due to various unexpected troubles and difficulties arising during the tunnel driving. It is a very difficult question to determine the efficiency coefficient to be used. Taking into consideration the conditions in the Philippines, it is estimated that the coefficients 70% for the upgrade drive and 65% for the downgrade drive. In the downgrade drive, it is necessary to pump underground water out of the working place and this has been considered in determining the efficiency coefficient.

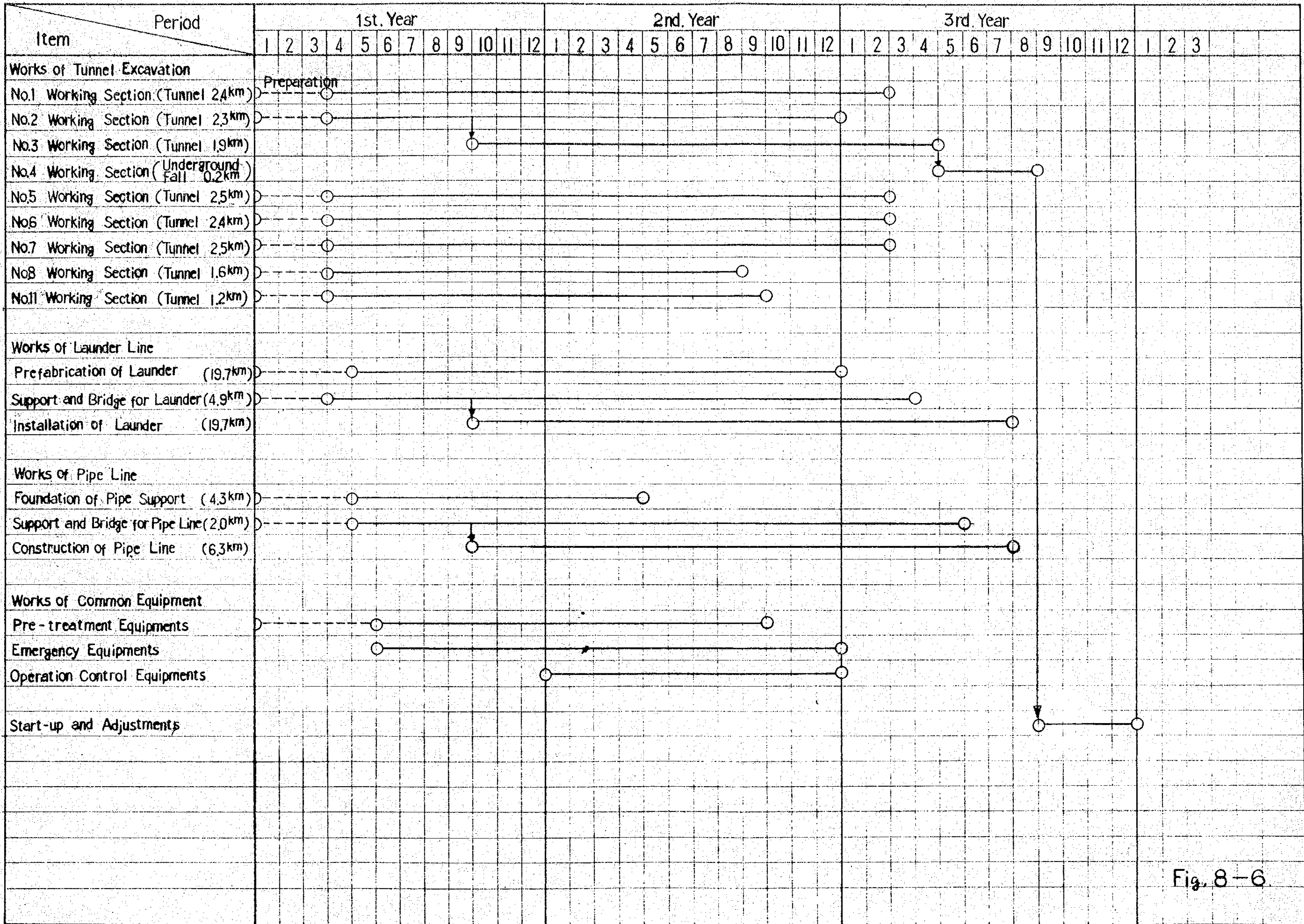
The estimated monthly length of tunnel excavation with or without timbering is as follows:

- Tunnel without timbering (including shotcrete-lined tunnel)
  - Upgrade drive: 126 m
  - Downgrade drive: 117 m
- Tunnel with steel timbering
  - Upgrade drive: 105 m
  - Downgrade drive: 98 m
- Concrete-lining tunnel (include tunnel driving and concrete lining)
  50 m

8.4.2 Time Schedule of Tunnel Construction

Fig. 8-6 shows the period required to drive the tunnel in the respective working sections, calculated on the basis of the estimated monthly excavation lengths. The preparatory work at the portals is estimated at three months. Allowance is made for one month each before and after the time required for driving the tunnel. One month before the tunnel driving is to be devoted to the training of the workers. One month is also allocated after the tunnel driving for clearing up excavation and for shotcreting the tunnel walls.

As seen from Fig. 8-6, the critical path in this tunnelling project is in Section 3 and 4. It will require two (2) years and eight (8) months. Construction of launder in the tunnel is not the critical path because the work of installing the launder can be carried out at the same time as the



Period
Item
1st. Year
2nd. Year
3rd. Year
1 2 3 4 5 6 7 8 9 10 11 12
Works of Tunnel Excavation
Preparation
No.1 Working Section (Tunnel 2.4km)
No.2 Working Section (Tunnel 2.3km)
No.3 Working Section (Tunnel 1.9km)
No.4 Working Section (Underground Fall 0.2km)
No.5 Working Section (Tunnel 2.5km)
No.6 Working Section (Tunnel 2.4km)
No.7 Working Section (Tunnel 2.5km)
No.8 Working Section (Tunnel 1.6km)
No.11 Working Section (Tunnel 1.2km)
Works of Launder Line
Prefabrication of Launder (19.7km)
Support and Bridge for Launder (4.9km)
Installation of Launder (19.7km)
Works of Pipe Line
Foundation of Pipe Support (4.3km)
Support and Bridge for Pipe Line (2.0km)
Construction of Pipe Line (6.3km)
Works of Common Equipment
Pre-treatment Equipments
Emergency Equipments
Operation Control Equipments
Start-up and Adjustments

Fig. 8-6

work on the underground fall in Section 4. The other construction works required less time than the tunneling work as seen from Fig. 8-6, and therefore the time required for the common line construction work and trial run is estimated at 3.0 years.

In making the definite study, consideration should be given to a further reduction of the time required for the critical path.

8.5 COST OF TUNNEL CONSTRUCTION

8.5.1 Basis of Cost Calculation

(1) Calculations have been made on the basis of the current unit price not considering the future price escalation. As for the laborand commodity costs, reference is made to Tables 9-3 and 9-4.

(2) The plan calls for the use of Filipino engineers and laborers to carry out the tunnel and preparatory works.

(3) The unit costs (₱/m) of driving tunnel with and without timbering are calculated from the materials and labor required to develop per meter of tunnel and each cost. The total cost of tunnel construction was calculated for the extension with or without timbering and each unit cost. For the rough breakdown of the unit costs with or without timbering, reference is made to Appendix A-8-2.

The costs of the various items have been calculated on the following assumptions:

a) Labor cost

For pesonnel distribution, reference is made to Paragraph 8.1.6 (2)

b) Commodity cost

This has been calculated from the unit requirement with or without timbering

c) Equipment cost and operational expenses of facilities

Calculations have been made on the assumption that all of the investments in the equipment used in the tunnel driving is repaid by the tunnel driving work and thus the calculated costs is evenly distributed per meter of the tunnel. The operational expenses of equipment is also distributed evenly.

d) Waste transportation cost

It is necessary to transport about 150,000 m^3 of waste (broken) produced from the driving of the tunnel which cannot be disposed of near the portals to the neighborhood of Rabon so that it can be used in building the causeway in the sea. The average hauling distance is 28 km and cost of transportation is estimated at 0.6 pesos/t-km.

e) Overhead expenses

The overhead expenses at the worksite and administrative expenses have been estimated to be 30% of the direct cost.

(4) Underground fall

The cost of the underground fall is estimated mainly by Japanese engineers using the drilling machine BM 100 N and accessory equipment to be transported from Japan.

The contents of this work are as follows:

550 mmø x 200 m 2
250 mmø x 200 m 1
Grout (cement requirements: 100 tons). . 1 unit

(5) Preparatory work for tunnel driving

The various items of preparatory work necessary to drive the tunnel have been included here. The cost of construction of the access roads to the portals accounts for about 75% of the total.

8.5.2 Costs of Tunnel Driving and Auxiliary Works

	Classification	Unit cost ₱/m	Total length m	Whole x 1000 ₱
Tunnelling cost	Without timbering (include shotcreting)	3,990	12,610	50,314
	With steel timbering	6,089	3,310	20,155
	With concrete lining	7,906	880	6,957
	Subtotal	4,609	16,800	77,426
Underground fall construction cost			200	2,519
Cost of preparatory work			1 unit	7,212
Total		5,127	17,000	87,157

The breakdown of the required funds into the funds to be raised in the Phillipines and those to be raised abroad is as follows.

Classification	To be raised in the Philippines x 1000₱	To be raised abroad x 1000₱
Tunnel driving	54,546	22,880
Underground fall construction	30	2,489
Preparatory work	7,212	-
Total	61,788	25,369