ADDITIONAL WORKING FACES THROUGH SHAFT NO.2, HSUEHSHAN TUNNEL

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ABSTRACT

The Hsuehshan Tunnel composes of two main tunnels and one pilot tunnel, each hole has a length of over 12.9 Km. the geological conditions along the alignment are very complicated and heterogeneous. In addition, the anticipated excavation rate of the tunnel boring machines (TBMs) was not realized; therefore, the progress of the project was behind schedule from the beginning of construction. In order to shorten the construction period, the Engineers decided to create additional working faces for the horizontal tunnel excavation through ventilation shaft No.2. Through the helps of the connection tunnels and detour adit, a total of 10 additional working faces were excavated for the main tunnels and pilot tunnel. This effectively increased the excavation rate of construction. The construction layout, including mucking, ventilation, drainage, and emergency measurements for the additional working faces through the shaft are quite different to ordinary tunnel excavations. In this paper, the constructions of working faces through the shaft are introduced. Hopefully, it provides help in any similar subsequent constructions in the future.

Keywords: shaft, horizontal tunnel, working face, connection tunnel, detour adit

INTRODUCTION

The Hsuehshan Tunnel is situated in the northern end of Hsuehshan range; it is the longest traffic tunnel in Taiwan. The geological conditions along the route are rather complicated. Also, there was an influx of a large amount of groundwater along the tunnel alignment. During the construction, numerous collapses and tremendous groundwater were encountered. The most serious mishap was the cave-in located at the station of 38k + 902 of the northbound main tunnel. The tunnel boring machine was buried in this accident, and the excavation method was forced to change from TBM to drill and blast in this tube. This led to the progress of the whole project being far behind schedule. Due to the topographical situations of construction site, the moderate access adit along the tunnel route is uneasy to find. In order to expedite the construction, the Engineers decided to arrange the additional working faces through shaft No.2 for the main tunnels and pilot tunnel. In total, 10 additional working faces were arranged. The excavated length was 5,599 m, about 14.4% of the total length of three holes (38,801 m). This had a substantial improvement to the project's total progress.

The depth of shaft No.2 is nearly 250 m. Not only did the workers, material and mucking use this shaft as transportation, but also the piping of ventilation, air and water passed through this shaft for the connection between working face and the ground surface. The deck platform at the bottom of the shaft was also unusual on the tunnel construction. Owing to the fact that the people worked in the nearly enclosed space beneath the ground surface, the emergency measurements were important for safety. The issues mentioned above will be introduced in this paper.

GENERAL LAYOUT OF HSUEHSHAN TUNNEL

The Hsuehshan Tunnel is 12.93 km in length. The northern portal is located at Pinglin in Taipei County, and the southern portal is located at Toucheng in Ilan. The Hsuehshan Tunnel composes of two main tunnels and one pilot tunnel, the excavation radius of the main tunnel and the pilot tunnel are around 12 m and 4.8 m respectively. In a normal section, the centerline distance

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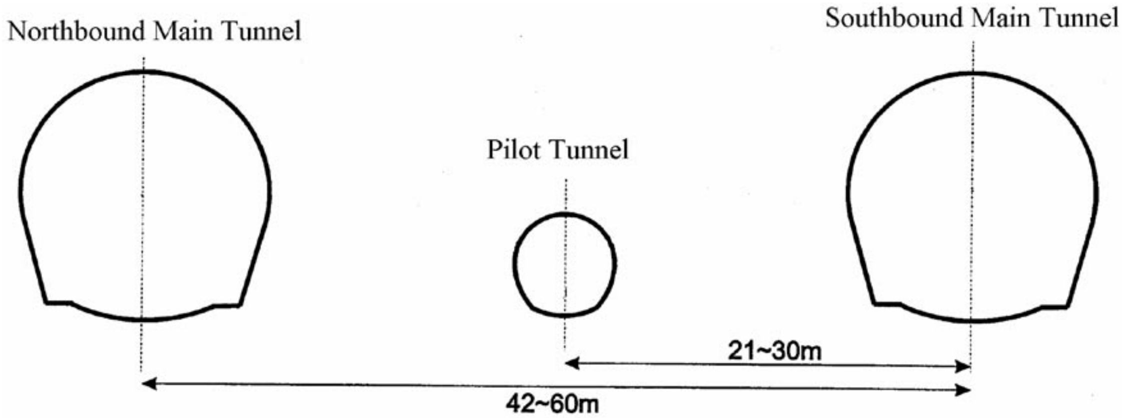

Fig.1 The Cross-section Layout of Hsuehshan Tunnel

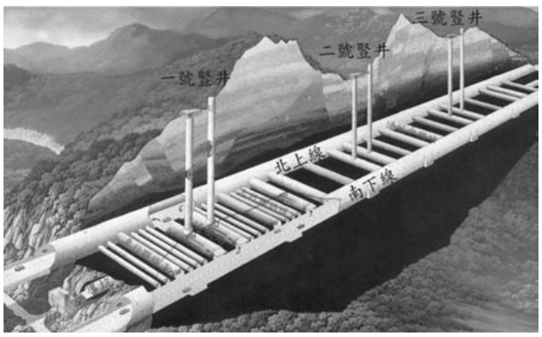

Fig.2 The Perspective Drawing of Hsuehshan Tunnel

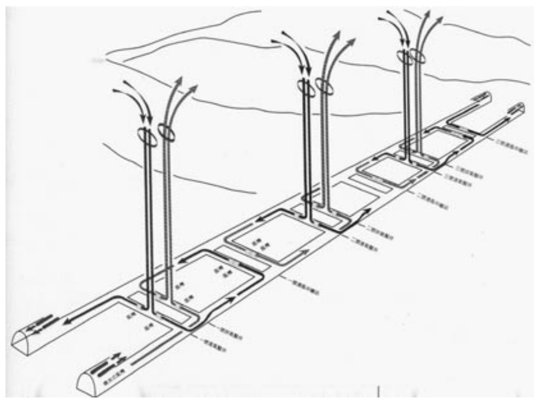

Fig.3 The Schematic Drawing of Ventilation System

Table 1 The Construction Data of Ventilation Shafts of Hsuehshan Tunnel

Shafts	Shaft No.1		Shaft No.2		Shaft No.3	
	Fresh Air	Exhau. Air	Fresh Air	Exhau. Air	Fresh Air	Exhau. Air
Depths (m)	480.22	500.94	237.94	248.66	438.21	458.94
Exca. Diameters (m)	7.0	7.0	7.5	7.5	7.0	7.0
Final Diameters (m)	6.0	6.0	6.5	6.5	6.0	6.0
Excavation Methods	Raise boring & Sinking	Raise boring & Sinking	Sinking	Sinking	Sinking	Sinking
Excavation Period (Year/Month)	2003/07 ~ 2004/10	2003/06 ~ 2004/09	1998/03 ~ 1999/11	1998/03 ~ 2000/01	1996/02 ~ 2002/09	1996/01 ~ 2001/08

between the main tunnel and the pilot tunnel is 30 m, which gradually reduces to 21 m at both portal sections, as shown in Figure1. Considering the transportation and the ventilation, there are 28 pedestrian connection tunnels, 8 vehicle connection tunnels, 3 sets of shafts, 6 ventilation caverns and 6 interchange caverns along the tunnel route, the perspective drawing of this is shown in Figure 2.

The longitudinal ventilation system was adopted for the Hsuehshan Tunnel (the schematic drawing of which is shown in Figure 3). Each set of shafts consists of one fresh air and one exhaust air shaft. The centerline distance between the fresh and exhaust shaft is 50 m. The depths of the shafts are from 238 m to 501 m, and the inner diameters of the shaft after concrete lining are 6 m and 6.5 m. The dimensions and construction methods of each shaft are listed in Table.1.

THE CONSTRUCTION ARRANGEMENTS

Working Faces Layout

According to the original design, only 800 m of the south portal section were planned to be excavated by the drill and blast method, the other sections of the tunnel were to be excavated by the tunnel boring machines (TBMs). When the TBM in the northbound tube was driven to the sta. 38k + 902 in December 1997, it was stopped and buried by the cave-in of tunnel due to the horrendous ground conditions (the maximum influx of groundwater was 750 liter/second). After discussions with the consulting members, it was decided to change the excavation method from TBM to D&B. As the excavation rate of D&B is far less than that of TBM, the Engineers decided to arrange the additional working faces for northbound main tunnel through shaft No.2. The procedures were opened the ventilation cavern form the bottom of shaft toward the northbound tube. Two working faces were excavated subsequently toward the north and south portals respectively, as shown in WF1 and WF2 in Figure 4.

The construction of the pilot tunnel was started on July of 1991, but till the end of 2001, the excavated length was 6,918 m, which is only 53.5% of the total length of 12,942 m. According to the geological investigation, there were still 16 shear zones and one big fault in the unexcavated section. With reference to the proceeding experience, it would be difficult to complete the construction on scheduler if follow the original plan. Therefore, two additional working faces through shaft No.2 also arranged for the pilot tunnel. A detour adit 62 m long was excavated from the northbound main tunnel, when it reached to the pilot tunnel, two working faces were excavated toward the north and south portals respectively, as shown in WF3 and WF4 in Figure 4.

Owing to the fact that the TBM in southbound tube was stopped at the station 36K + 440 on December of 2002 due to the adverse geological conditions, the progress of the project was significantly delayed. For the sake of reaching the target of operation for traffic at the end of 2005, the additional working faces through shaft No.2 were also considered for the southbound main tunnel. Through the help of pedestrian and vehicle connection tunnels, six additional working faces were excavated for the southbound tube, as shown in WF5~WF10 in Figure 4.

Mucking Layout and Treatment

The original aim of the additional working faces through shaft No.2 was to expedite the excavation progress of northbound main tunnel. In fact, the accumulated excavation length of the northbound tube through shaft No.2 was 3,023 m, about 23.4 % of the total length of northbound tube (12,942 m), and it led to a substantial

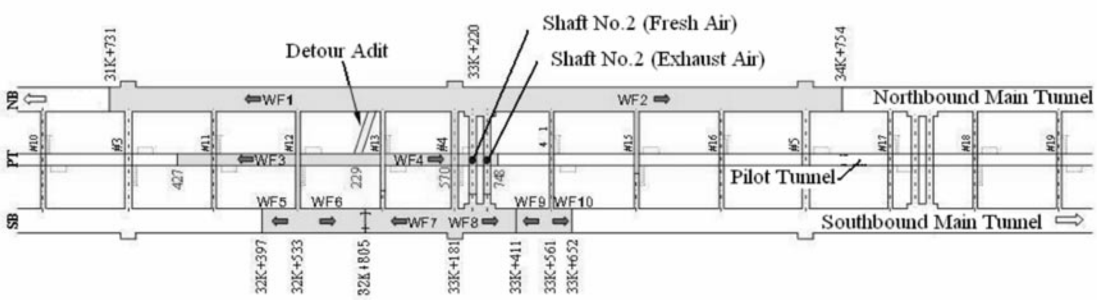

Fig.4 The Layout of Additional Working Faces through Shaft No.2

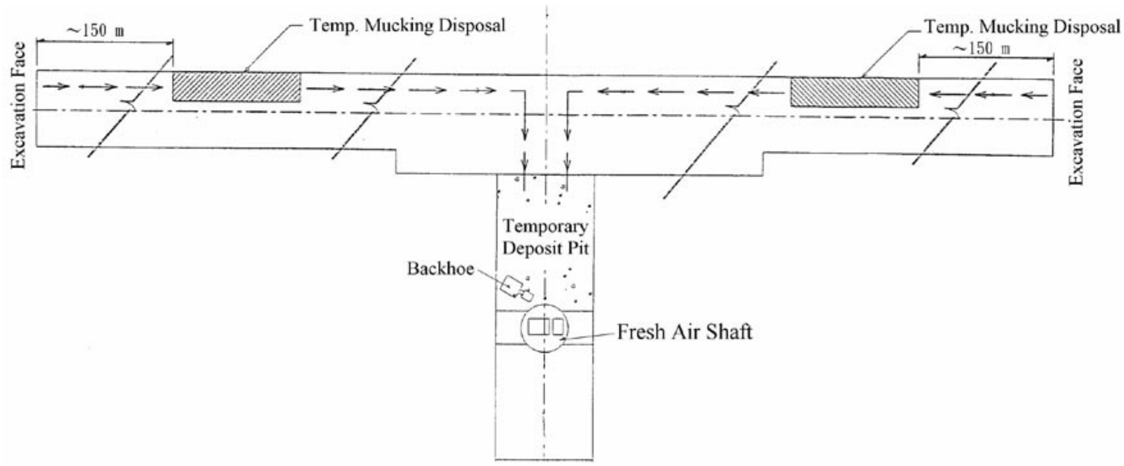

Fig.5 The Mucking Layout of Northbound Main Tunnel

improvement to the project's progress. Therefore, the descriptions of the construction arrangements in this paper are focused on the northbound main tunnel.

The layout of mucking operation in the northbound main tunnel is shown in Figure 5. After the blasting, the mucking was transported by the wheel loader to the temporary mucking disposal about 150 m behind the excavation face. When the mucking in front of the excavation face had been cleaned out, the mucking on the temporary mucking disposal was transported again by the wheel loader and dumping trucks to the temporary deposit pit located at the fresh air ventilation cavern, in which the mucking was shoved to the mucking tank by the backhoe. With the help of raising equipment, the mucking in the tank slid into the skip. Then the mucking with the skip was hoisted by the high speed winch to the ground surface. The wheel loader and the dumping trucks waited on the ground surface and carried the mucking to the open road section for the embankment construction.

Wastewater Treatment and Drainage System

In the period of construction, the groundwater and wastewater would be treated and pumped out through shaft No.2. According to the estimation of original design, the accumulated quantity of groundwater in this section was almost 600 liter/second. Considering the burden of wastewater treatment and drainage system, the capacity of the facilities was designed for 300 liter/sec. During the construction, for the sake of emergency and safety, the influx of quantities should be controlled to less than 120 liter/sec by the grouting

The working face heading to the north portal is up gradient (+1.254%). The gravity drainage system was adopted for this working face. The wastewater flowed into the primary settling tank first, and was then pumped to the wastewater treatment devices. After treatment, the water flowed into the settling tanks and final settling tanks. In order to lower the burden of water treatment devices, the groundwater of excavation face flowed into the settling tanks directly, followed by the final settling tanks. The working face heading to the southern portal is down gradient (-1.254%). The groundwater and wastewater were compulsorily pumped to the primary settling tank and settling tanks, and the other procedures were similar to that of working face heading to the northern portal. All the systems are shown in Figure 6. The treated water in the final settling tanks was pumped out through 2 ϕ-12″ high pressured steel pipes by 4 turbine pumps. Each turbine pump was 8″ ϕ, 5 m3 of discharge capacity, and 270 m in raising height. The sludge after water treatment was dehydrated and pressed into dried soil which was transported out with the mucking.

Considering the requirements of repairing and maintenance the main dewatering system, the original 24-4″ ϕ relay pumps for the excavation of shaft No.2 were reserved as the function of auxiliary use. Meanwhile, for the sake of repairing and maintaining the ϕ-12″ high pressured dewatering steel pipe, one additional steel pipe with the same dimension was installed and connected to the other two pipes. In order to avoid the damage caused by the abrupt large groundwater, the turbine pumps were placed on the deck platform, with a height about 1 m above the spring line of ventilation cavern, as shown in Figure 7.

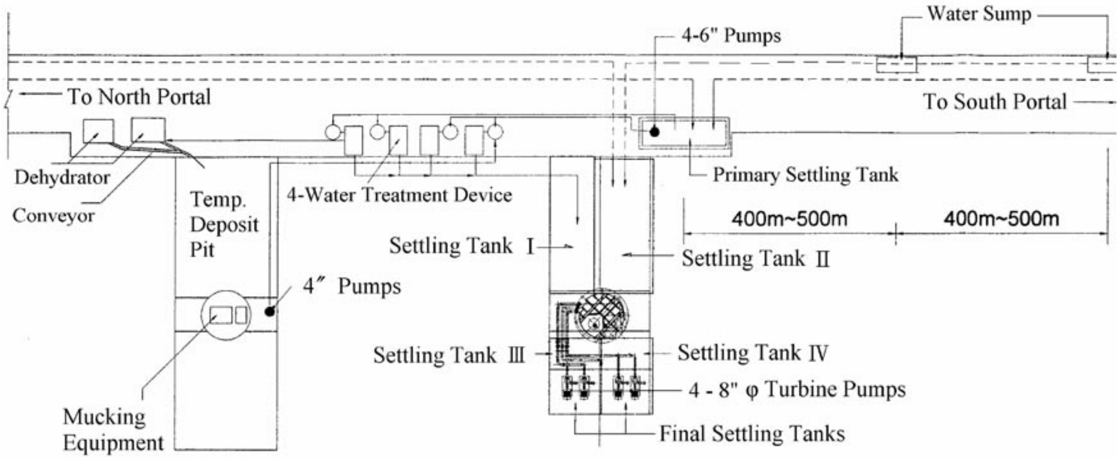

Fig.6 The Layout of Wastewater Treatment and Drainage System

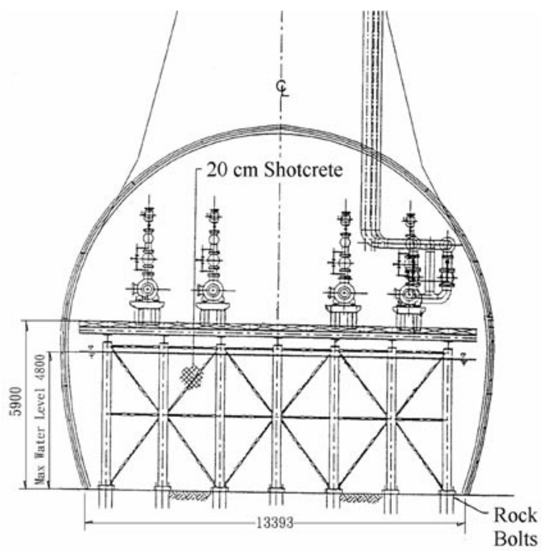

Fig.7 The Installation of Turbine Pumps on the Deck Platform

The Ventilation and Air Convey System

In the period of constructions, the additional working faces had not yet broken through with the faces driven from both portals; therefore, all of the ventilation and air ducts were passed through shaft No.2. According to the related specifications and designing, 2 sets of ϕ1.4 m ventilation ducts were installed for the northbound main tunnel, one set was toward the northern working face, and the other was toward southern working face. The airflow quantity for each set was 1500 m3/min, which was enough for the needs of workers and equipment in the normal situations. Because the mucking operation in the fresh air shaft was busy, the two sets of ventilation ducts were installed in the exhaust air shaft. The material of ventilation duct was poly-vinyl-chloride, but the bents were ϕ1.4 m steel pipe. Two sets of air compressors were also installed near the shaft portal. The ventilation layout is shown in Figure 8.

The drill and blast method was adopted for the additional working faces, and the shotcrete was the main support of tunnel excavation in this project; therefore, the enough pressured air afforded by the air compressors was necessary for the construction. The air compressors were placed on the ground surface near the shaft, and the pressured air was supplied by two 4″ ϕ steel air pipes to the working faces for the construction.

The Transportation of Mucking, Material and Workers

There were two additional working faces in the northbound main tunnel; the estimate of loose mucking volume was about 650 m3 per day. Considering the frequency of the mucking operation, the fresh air shaft was considered for the mucking transportation only, and occasionally as the traffic for people moving cage. While the exhaust air shaft was considered for the transportation of workers, material and the mechanism devices. The ventilation, water and air pipes were also installed along exhaust air shaft.

1. Mucking equipment (Installed in the fresh air shaft)

The mucking at the temporary mucking disposal was transported by the wheel loader to the temporary deposit pit at the fresh air ventilation cavern. The mucking at

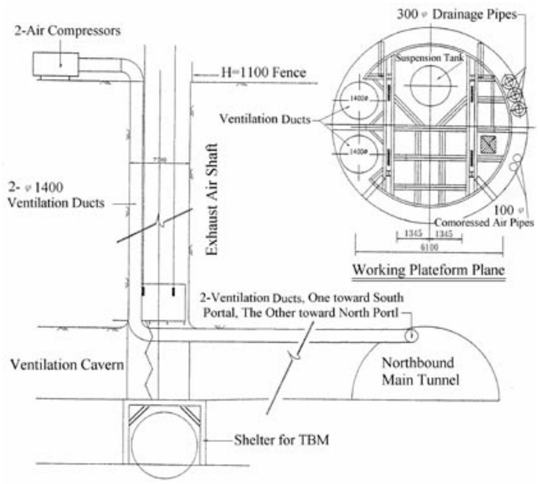

Fig.8 The Ventilation System Layout

the deposit pit was loaded to the mucking tank and skip, as shown in Figure 9. The mucking with the skip was hoisted to the ground surface by the winch equipment. When the skip reached the surface, it was overturned and the mucking slid into the chute, as shown in Figure 10. After dumping the mucking, the skip was sunk to the shaft bottom for loading mucking again. One cycle took about 516 seconds (8 minutes and 36 seconds).

2. The Transportation of Material (In the Exhaust Air Shaft)

As a result of the busy mucking work in the fresh air shaft, all of the material and most of the employees in this project used the exhaust air shaft for transportation. In addition, the ventilation, water and air pipes were also fixed to the exhaust air shaft. To utilize the limited space efficiently, the facilities arrangement in the working platform at the exhaust air shaft is shown in the right-up corner of Figure 8.

The shotcrete batching plant was located on the ground surface in the vicinity of fresh air shaft portal. The dry mix shotcrete was transported by the conveyor to a 2 m3 suspension tank. This suspension tank was carried by the carriage car to the shaft portal. The shotcrete material with the suspension tank was sunk down the shaft bottom by the winch and then dumped into the trucks. The shotcrete material was carried by the trucks to the working faces for tunnel support.

3. People Moving Cages

There were two vertical suspension cages for people in this project. One was installed in the fresh air shaft; the other one was in the exhaust air shaft. These two cages were specialized for the transportation of people. Each cage had a load of 450 kg, which could carry 5 people at a time. The average speed of the suspension cable was 45

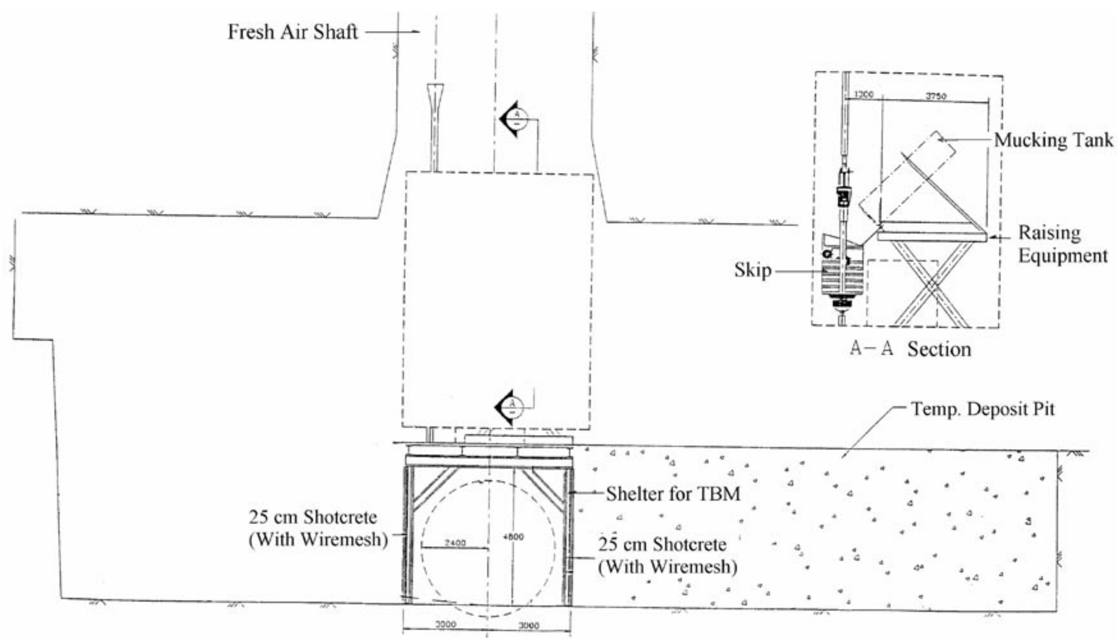

Fig.9 The Mucking Operation at the Bottom of Fresh Air Shaft

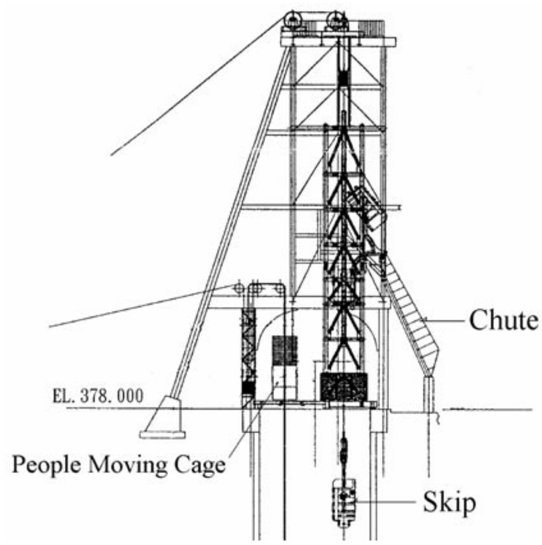

Fig.10 The Mucking Equipment at the Fresh Air Shaft Portal

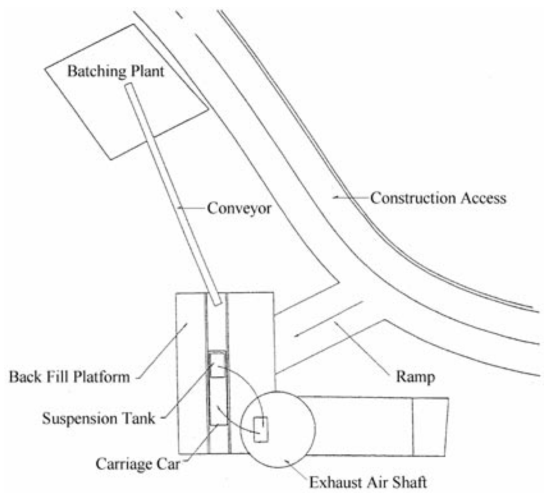

Fig.11 The Transportation Layout for Shotcrete and Material

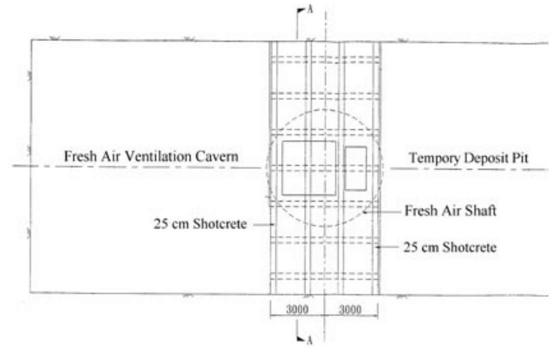

Fig.12 The Plane of Deck Platform in the Fresh Air Ventilation Cavern

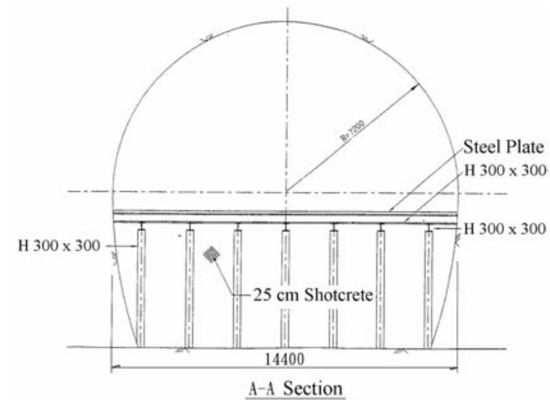

Fig.13 The Cross-Section of Deck Platform in the Fresh Air Ventilation Cavern

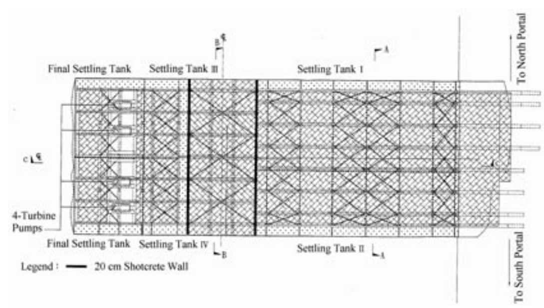

Fig.14 The Plane of Deck Platform in the Exhaust Air Ventilation Cavern

m/min, the average travel time for one round trip was around 14 minutes. The two cages could carry 50 people within 70 minutes.

The Deck Platforms in the Cavern

For the sake of the TBM driven in pilot tunnel and the facilities of water treatment, the deck platforms were erected in the fresh air cavern and the exhaust air cavern respectively. The deck platforms were built by steel trusses. The top of trusses was covered by the steel plates. The height of each truss was 5~6 m, and the plane dimension were 6 m x 14 m in the fresh air cavern, and 35 m x 14 m in the exhaust air cavern respectively. The side walls of the shelter for the pilot tunnel were constructed out of 20~25 cm thickness

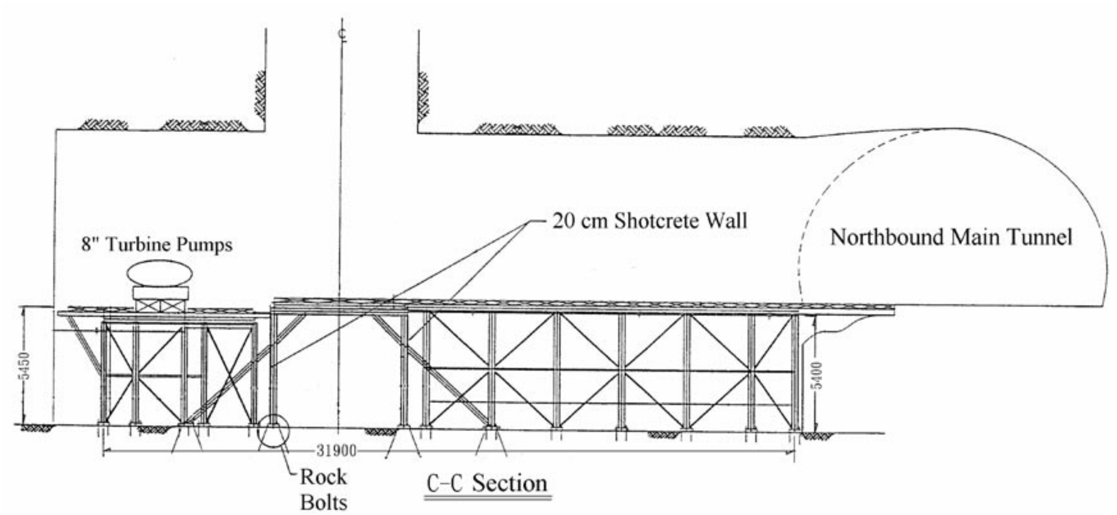

Fig.15 The Longitudinal Section of Deck Platform in the Exhaust Air Ventilation Cavern

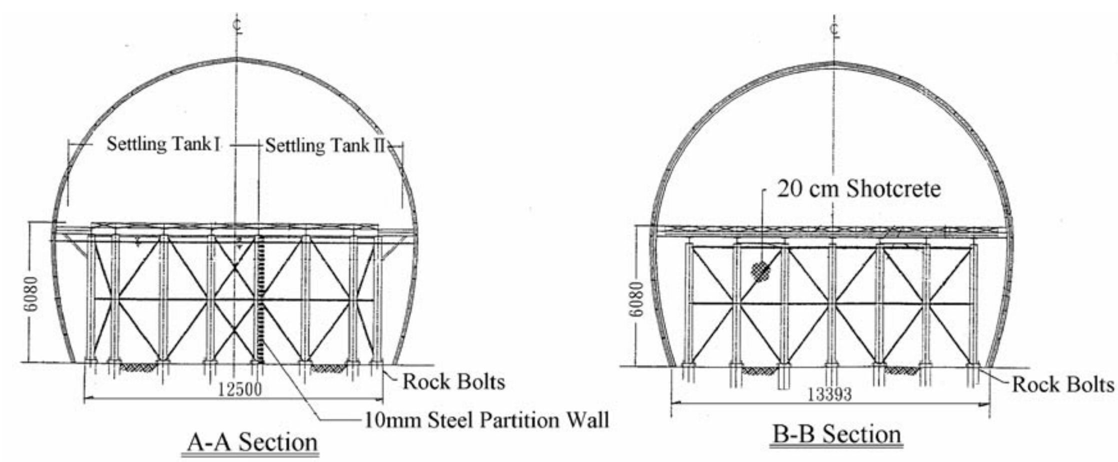

Fig.16 The Cross-Section of Deck Platform in the Exhaust Air Ventilation Cavern

shotcrete. The planes and cross-sections of the deck platform are shown in Figure 12~Figure 16.

TUNNEL EXCAVATION AND THE TREATMENT OF VAST AMOUNT GROUNDWATER

The "drill and blast" method was adopted for the excavation of the additional working faces. The drilling holes were drilled by the hydraulic drifter, and ammonium gelatin dynamites and non-electric MS detonators were used for the blasting. The mucking after blasting was transported to the temporary deposit pit which was located at the fresh air cavern; the mucking was then hoisted out by the winch. The tunnel was first excavated by topheading, and subsequently by the bench and invert excavation. Most of the rock classification belonged to No.Ⅲ and No.Ⅳ. The main tunnel supports are shotcretes, wire- meshes, rock bolts and steel ribs. Occasionally, auxiliary supports such as fore-pilings were adopted to account for the adverse geological condition.

To avoid the influx of abundance of groundwater and out of consideration for the capacity of the drainage system, the inflow quantity of groundwater should be controlled within the amount of 120 liter/sec by grouting. The chemic grouting of "water-glass"series was selected for this project. The pressure for grouting should not exceed 20 kg/cm2, and the setting time was set to the range of 2~300 seconds, this could adjust in accordance with the water flow and geological conditions. The grouting was

Fig.17 The Vast Amount of Groundwater in front of the Excavation Face

MONITORING AND EMERGENCY EVACUATION SYSTEMS

The construction site of the additional working faces was 250 m below the ground surface, and shaft No.2 provided the only access outside the tunnel; therefore, the emergency measures were very important in this project. The emergency measures included the monitoring and emergency evacuation systems. The monitoring also included the closed circuit television (CCTV) system. The fire monitoring in the tunnel and the water level monitoring in front of the excavation face can be inspected through the control panel (CP-1)

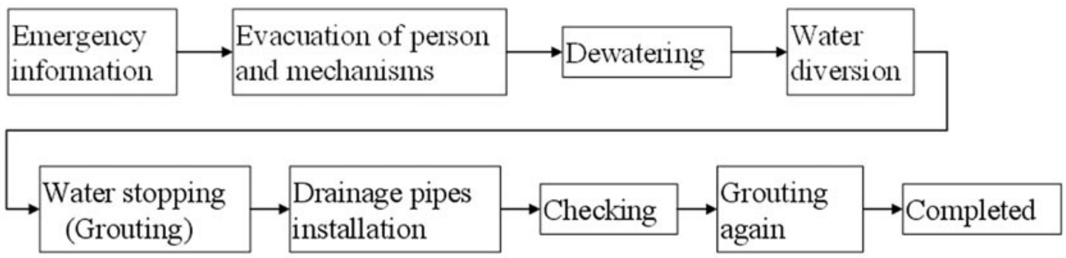

Fig.18 The Treatment Procedure for Large Amount of Groundwater on Excavation Face

injected form the bottom of the hole and was packed outside every one meter.

When the southern working face reached the Daudieutze syncline (Sta.33k+614), an 80 liter/sec quantity of pressurized groundwater was encountered, and a 100 m3 cave-in also occurred. Since the heading is down gradient, a vast amount of water accumulated at the front of excavation face (Figure 17). This caused an unexpected stop to construction. The contractor then increased the pumps for dewatering and implemented the grouting for stopping the water. The shorter round length and heavier tunnel supports were adopted in this adverse section. Finally, it was past through successfully.

In order to avoid the influx of large quantities of groundwater, the water drainage holes with a length of 20 m were necessary before the excavation. During the construction, the engineers should watch out for water seepage conditions on the drilling holes of rock bolts and forepilings. Moreover, the geological mapping for the excavation faces should also be implemented carefully for every round. If the tremendous groundwater influx is encountered during construction, the treatment procedure is shown in Figure 18.

in the morning control center. In addition, there was a second control panel (CP-2) installed in the site office; the engineers could inspect the construction situations from the office by the second control panel. The schematic illustration of monitoring and emergency evacuation systems are shown in Figure 19.

Water Level Monitoring System

The water level monitor was installed around 50 m behind the excavation face; the monitoring data was consistently transferred to the control panel located at the monitoring control center. According to the monitoring data, the control panel gave command to the 4-6″ ϕ drainage pipes system (8-6″ ϕ pumps), and controlled the operation of drainage pumps. In addition, one monitor was installed at the crown of tunnel – at a suitable distance to the excavation face - to survey the situations around the working face. If a vast quantity of groundwater or unusual water level was detected by the monitoring system, the emergency evacuation system would get the commands, and the alarm siren and turning lights along the tunnel also became active. In such a situation, the workers would evacuate immediately.

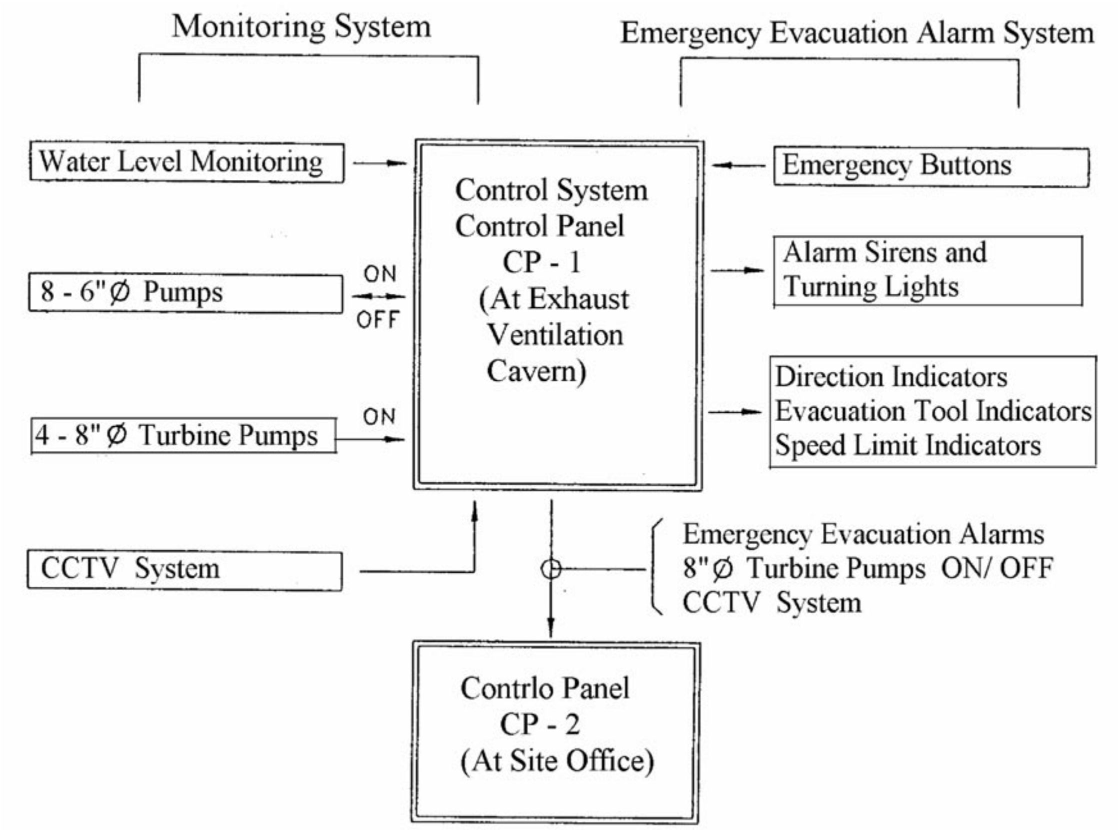

Fig.19 The Schematic Illustration of Monitoring and Emergency Evacuation Systems

Table 2 The Monitor Location and the Monitoring Range

Location	No.	Monitoring Ranges
Fresh air shaft bottom	No.1	To monitor the people arriving and entering into the people moving cage.
Exhaust air shaft bottom	No.2	To monitor the loading of materials and the people arriving and entering into the people moving cage.
Exhaust air shaft bottom	No.3	To monitor the operation of 8″ ϕ turbine pumps.
Northbound working face	No.4	To monitor the construction at the front of the working face.
Southbound working face	No.5	To monitor the construction at the front of the working face.

Emergency Evacuation System

In order to let the workers in the tunnel evacuate immediately if accidents happened, there were emergency buttons with a red indicator light every 100 m along the tunnel. Similarly, there were alarm sirens and turning lights every 200 m along the tunnel. In the case of fire, the workers ought to press the emergency button immediately, and then the message was transferred to the control panel (CP-1). Subsequently, the siren and turning light were initiated in order to urge the workers to evacuate. In addition, there was a direction indicator and evacuation tool indicator every 100 m along the tunnel to help the workers leave the site promptly. The electric power of emergency evacuation system was supplied by the substation at the bottom of the exhaust air shaft. In the case of power outage, the electric power was supplied by the emergency generator (3ψ1500KVA/ 3.3KV).

Table 3 The Excavation Length and Schedule of Additional Working Faces

Tunnels	Working faces	Length (m)	Station		Excavation period (Year / Month)	Remarks
			Begin	End		
Northbound main tunnel	North driving	1,489	33K+220	31K+731	2000/05→2003/06	
	South driving	1,534	33K+220	34K+754	2000/05→2004/03	
	(Subtotal)	3,023				
Pilot tunnel	North driving	802	33K+229	32K+427	2002/05→2003/05	Through detour adit.
	South driving	519	33K+229	33K+748	2002/06→2003/10	
	(Subtotal)	1,321				
Southbound main tunnel	# 12 North driving	136	32K+533	32K+397	2003/12→2004/09	Through # 12 pedestrian tunnel
	# 12 South driving	272	32K+533	32K+805	2003/12→2004/08	
	# 4 North driving	376	33K+181	32K+805	2003/11→2004/08	Through # 4 vehicle tunnel
	# 4 South driving	230	33K+181	33K+411	2003/11→2004/06	
	# 14 North driving	150	33K+561	33K+411	2004/01→2004/06	Through # 14 pedestrian tunnel
	# 14 South driving	91	33K+561	33K+652	2004/01→2004/05	
	(Subtotal)	1,255				
	(Total)	5,599				

Gas Detection System

A gas detector was installed for each excavation face. Before the excavation, the engineer would carry the detector to the construction face to check the content of gas in the air. When the engineer went to the working face for the detection of gas content, he would carry a mobile emergency button which was connected to a wire of about 100 m in length. If an accident happened, the inspecting engineer could press the button immediately and the message would promptly be transferred to the control panel and site office.

Closed Circuit Television System

For the sake of ensuring the labors' safety and in order to monitor the operation situation, the closed circuit televisions (CCTVs) were set up around the construction site. There were 5 sets of CCTV systems in the northbound main tunnel, whose locations and monitoring range are listed in Table 2.

THE PROGRESS OF TUNNEL EXCAVATION

The additional working faces through shaft No.2 for the northbound main tunnel were started in May, 2000. There were two working faces in this tube. The construction site was 250 m below the ground surface, the transportation of workers and materials would pass through the shaft, all of the pipes and ducts also used this shaft as a connection between the working site and ground surface. At the beginning of the construction, the progress was low due to the unfamiliar operations. After the improvements were made to the equipment and environment, the progress gradually improved. The accumulated excavation length of the northbound working face was 1,489 m, in the period of 37.5 months construction. The best excavation rate was 87 m/month, and the average rate was 40 m/month. If the time lost due to accident treatment and the replacement of equipment are neglected, the average excavation rate was 50 m/month. The total excavation length of the southbound working face was1,534 m, and the construction period was 46.5 months. The best rate during construction for this face was 97.5 m/month, and the average rate was 33 m/month; but, if exclude the time taken for accident treatment and the replacement for equipment, the average rate was 45 m/month.

In order to expedite the construction, there were also two additional working faces through shaft No.2 for the pilot tunnel, as shown the WF3 and WF4 in Figure 4. The excavations started in May 2002. The accumulated excavation length of northbound working face was 802 m, this face had broken through with the working face from the northern portal on May 31, 2003. The accumulate excavation length of the southbound working face was 519 m, and this had broken through with the face from south portal on October 12, 2003; therefore, the entire route of the pilot tunnel had broken through on that day.

The excavation rate of TBM in the southbound main tunnel was not as fast as expected. In order to reach the target of operation for traffic at the end of 2005, additional working faces were also taken for the southbound main tunnel. From the passing through of pedestrian connection tunnels # 12, #1 4 and vehicle connection tunnel # 4, a total of six working faces were created in the southbound main tunnel, as shown in WF5~WF10 in Figure 4. From January 2004 to May 2004, the excavation length driven form the # 14 pedestrian connection tunnel was 241 m; from November 2003 to August 2004, the excavation length driven form the # 4 vehicle connection tunnel was 606 m; from December 2003 to September 2004, the excavation length driven from the # 12 pedestrian connection tunnel was 408 m. The excavation lengths and schedules of the additional working faces through shaft No.2 are listed in Table 3.

CONCLUSION AND SUGGESTION

Owing to the advanced excavation methods and excellent equipment performance, the present shaft construction is faster and safer than before. With the helps of the high speed winch operation, the transportation time of mucking and materials is shortened significantly. The environment of construction sites can also be improved effectively by the advanced ventilation and drainage systems. For the sake of accelerating construction and improving both the ventilation and the drainage capacity for the long tunnel construction, besides the excavation of horizontal access adits, the shaft excavation in a suitable location also can be considered. Still, the people who work in a nearly enclosed space below the ground surface have substantial risks; hence, the drainage of groundwater should be planed carefully, and the emergency evacuation and monitoring measures also should be planned thoroughly.

REFERENCE

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