4.6.4 Study of the Shield TBM (1): Comparison between Single Track Double Tunnel (STDT) and Double Track Single Tunnel (DTST)

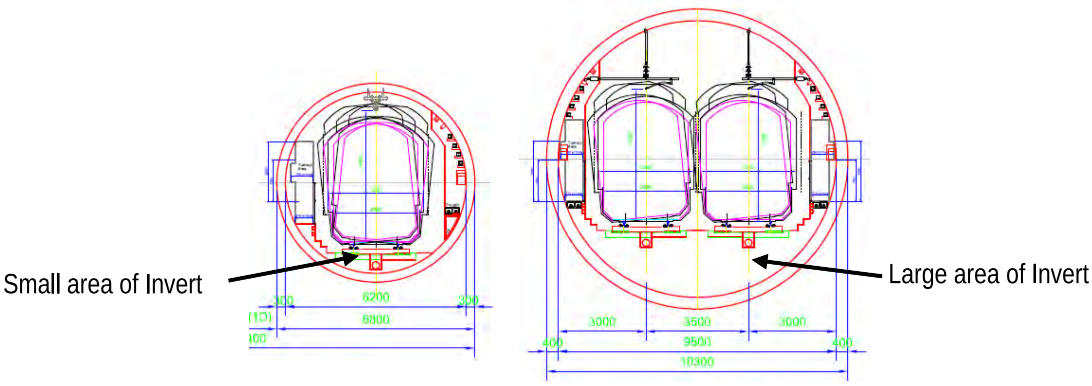
The tunnel section of the metro will be constructed by the shield TBM. For the construction with two tracks, there are two alternatives: the Single Track Double Tunnel (STDT) and the Double Track Single Tunnel (DTST). According to the condition of land use of the ground surface, the most suitable alternative has been selected in Japan. In the case of the STDT, an isolation distance between two tunnels is necessary to avoid interference of excavation between tunnels. The isolation distance between the two tunnels was basically 1.0 D (D is excavation diameter). The STDT needs a wider right of way for construction. Therefore, the DTST was well used in the past in conditions where the existing road above the metro was narrow and land use at ground level was limited. However, the required isolation distance between two tunnels has been reduced in recent years thanks to the development of tunnel excavation technology. Consequently, the right of way for construction has been narrowed and the use of the STDT is becoming dominant these days in Japan because it is more economical and convenient. In the following sections, the main methods of economical construction and convenience are indicated.

(1) Cross Sectional Area and Excavation Volume

The excavation sectional area of STDT (75.84 m^2) is smaller than that of DTST (86.55 m^2). The total excavation volume of the DTST is approximately 123,000 m^3, which is larger than that of the STDT. The excavation volume is the most important factor in the total cost.

(2) Volume of Concrete

The concrete volume for the segmental lining is almost equal in both cases. However, the volume of the lean concrete which fills the invert area under the track is different. There are many void spaces in the ceiling and under the track in DTST because the construction gauge and required space for two tracks, which are located in parallel in the tunnel, are of low profile. Thus, it is necessary to use much material to fill the invert area in the DTST. The Invert area of DTST is 5.0 times larger than that of STDT.

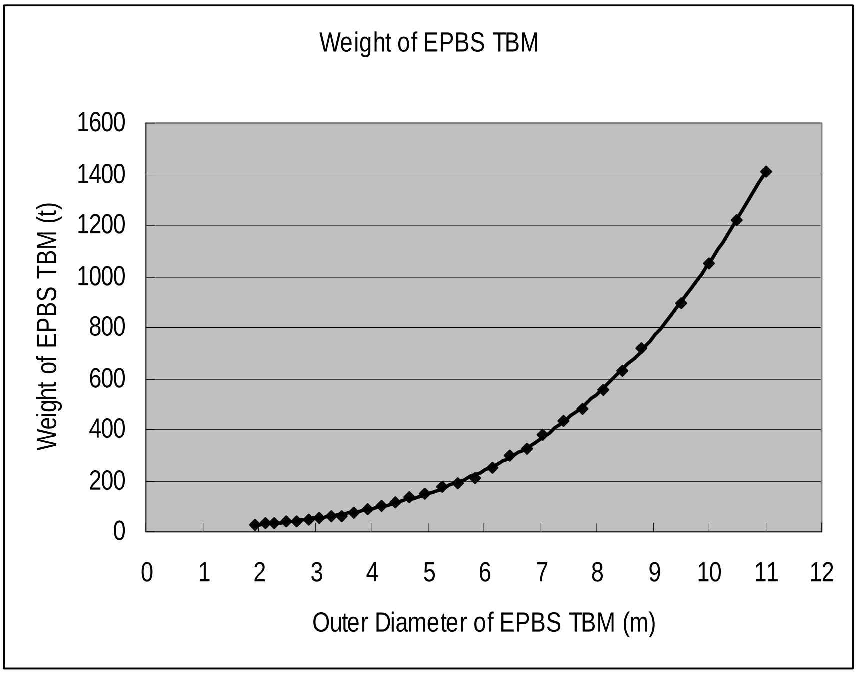


Source: JICA Study Team

Figure 4-109 Invert Area of Cross Section

(3) Cost of the Shield TBM

Material cost represents a large proportion of the total cost of the shield TBM. The cost of the shield TBM is closely related to its weight. The weight of the typical Earth Pressure Balanced Shield (EPBS) TBM is shown in Figure 4-110. The weight of each machine of STDT is approximately 400 tonnes (Outer Diameter of TBM = 6.95 m) and the total weight of the machine is about 800 tonnes. On the other hand, the weight of DTST is approximately 1200 tonnes (Outer Diameter of TBM = 10.5 m). The weight of DTST is about 1.5 times heavier than that of STDT. Therefore, the cost of DTST is consequently more expensive than that of STDT. In fact, 20-30% extra cost is usually required for the machine cost in the case of DTST.

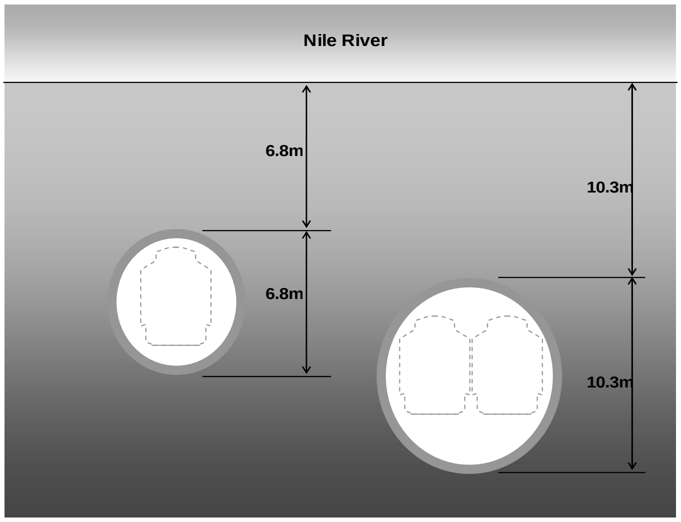


Source: Shield Tunnelling Association of Japan

Figure 4-110 Diameter-Weight Relationship of the EPBS TBM

(4) Required Overburden at Nile River Crossing

It is important to secure enough overburden under the river bed to prevent the flotation of the tunnel. The required overburden above the tunnel is basically 1.0 D (D is the excavation diameter of the tunnel). As shown in Figure 4-111, STDT can be located at shallower depths than DTST. At the passing point of the Nile River, it is anticipated that the depth of the Nile River is 6 m or deeper. Therefore, the vertical alignment becomes very deep at the Nile River crossing. This is constrained and the major control points of the vertical alignment and depth of the stations, which are located in the vicinity of the Nile River, are influenced. It is highly preferable to design the tunnel location to be as shallow as possible. STDT has many advantages for the vertical alignment design.



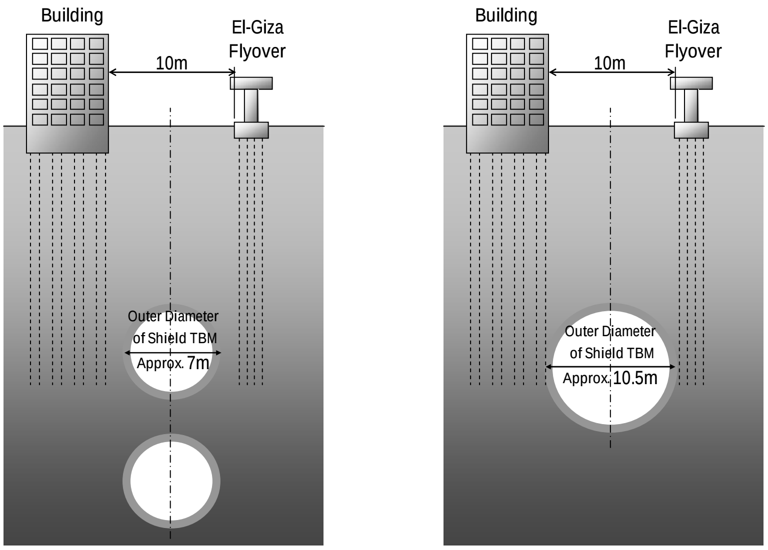
Source: JICA Study Team

Figure 4-111 Required Overburden at Nile River Crossing

(5) Ground Surface Settlement and Neighbouring Construction

The scale of ground deformation and ground surface settlement is proportional to the size of tunnel. Therefore, the impact on the ground surface settlement and existing structures in the vicinity of tunnel would be minimized if STDT is applied.

In addition, STDT can change the location of two tunnels flexibly from horizontal to vertical. It is possible for STDT to avoid existing structures and pass narrow spaces. In some areas, the foundation/piles of existing structures are closely situated and the space between them is very narrow. STDT can provide less impact to the surrounding environment.



Source: JICA Study Team

Figure 4-112 Tunnel in the Vicinity of Existing Structures (Left: STDT, Right: DTST)

(6) Station Type (Island Platform and Side Platform) and Station Depth

The island platform is more convenient and comfortable for passengers than the side platform. STDT can connect the island platform without shifting the horizontal alignment and widening the station. Therefore, the island platform is widely used for STDT.

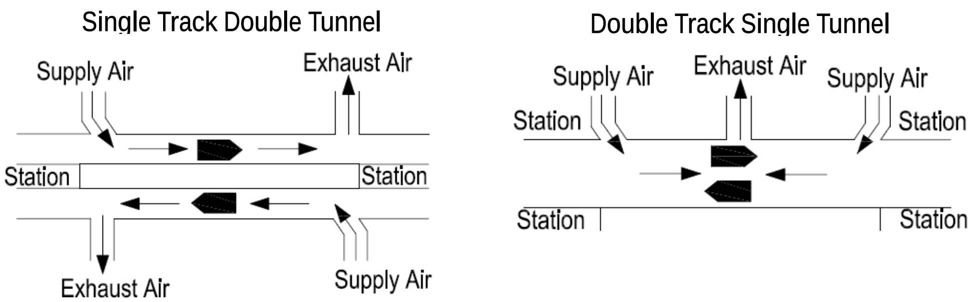
If DTST connects the island platform, the diversion of the horizontal alignment and widening of the station are required at the transition section between tunnel and station. As a result, the station tends to be more elongated and wider. Therefore, the side platform is usually used for DTST.

In addition, the track level of DTST, as well as the platform level, becomes deeper due to the large diameter of tunnel. Therefore, to enhance the service level for the passengers, the island platform with STDT is more preferable.

(7) Ventilation in Tunnel

The metro requires a ventilation system to exchange the air in the tunnel, which is heated by the train operation. The traffic flow in the STDT is unidirectional and the air always runs in same direction. In addition, the piston effect of the train operation is helpful for ventilation and the operation cost of ventilation becomes economical. Intermediate ventilation shafts are usually not needed because of the high efficiency of ventilation.

On the other hand, the traffic flow in the DTST is bidirectional and the air flow in tunnel is counterbalanced (see Figure 4-113). In addition, the intermediate ventilation shaft is required to exhaust air due to the poor efficiency of ventilation. The construction cost and operational cost will be increased very much in the case of the DTST.



Source: JICA Study Team

Figure 4-113 Air Flow and Traffic Flow in Tunnel

(8) Recommendation

As described above, the STDT has many advantages in construction, environment, cost and operation. The application of the STDT is increasing all over the world, including Europe. It is recommended to use the STDT for Metro Line 4. The comparison between the STDT and the DTST is summarized in Table 4-42.

Yurakucho Line, Tokyo, Japan
Source: JICA Study Team, 2008

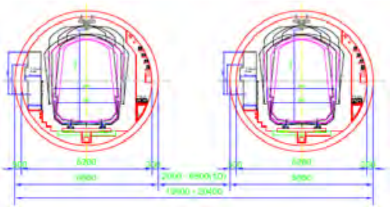
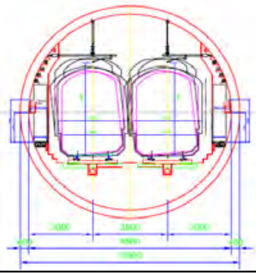
Cityringen, Copenhagen, Denmark
Source: T&T International, July, 2008

Line B1 of Rome Metro, Rome, Italy
Source: T&T International, March, 2009

Line 4, Beijing, China
Source: T&T International, May, 2009

Figure 4-114 Photo of the STDT for Metro

Table 4-42 Comparison between the Single Track Double Tunnel and the Double Track Single Tunnel

	Single Track Double Tunnel (STDT)		Double Track Single Tunnel (DTST)	
Typical Tunnel Cross Section				
Tunnel Outer Diameter	Do=6.8m x 2tube	1	Do=10.3m×1tube	1.5
Shield Outer Diameter	Ds=6.95m x 2 set	1	Ds=10.5m×1set	1.5
Width of Structure	W=6.8m(vertical) to15.9 m (horizontal)	1.0～2.3	W=10.3m	1.5
Excavation Sectional Area	A=75.84m2	1	A=86.55m2	1.14
Segment Sectional Area	A=12.25m2	1	A=12.43m2	1.01
Required Overburden at River Bed	6.8m (1.0・D)	1	10.3m (1.0・D)	1.5
Settlement of Surface	4mm(1.0・D Overburden)	1	11mm (1.0・D Overburden)	2.8
Isolation distance to Flyover structure	about 0.5m(vertical)		contact with structure	
Invert Concrete Area	2.2m2	1	12.0m2	5.5
Disposal soil volume (L＝11.5km)	872,160m3	1	995,352m3	1.14
Cost (per km)	about 20 Million USD	1	about 22 Million USD	1.14
Platform	Island Platform (High Service Level)		Side Platform	
Tunnel Ventilation	Longitudinal (Economical)		Concentrated Exhaust (Expensive)	

Source: JICA Study Team

4.6.5 Study of the Shield TBM (2): Comparison between Earth Pressure Balanced Shield (EPBS) TBM and Slurry Shield TBM

(1) Comparison and Recommendation on the Shield TBM

The Slurry Shield TBM has been used for many projects in Greater Cairo. On the other hand, as of 2009, the EPBS has never been used for any project. The comparison between EPBS TBM and Slurry Shield TBM is carried out to determine a suitable method for the project while taking into account the geological and congested city conditions in the project area. The comparison study is summarized in Table 4-43.

It is recommended to use the EPBS TBM for the project. The introduction and study of the EPBS is described in clause 4.6.6. The decisive factors in selecting the EPBS TBM are as follows:

- Safe Construction

The sand stratum of the project area is collapsible and application of the EPBS is preferable for the stability of the cutting face in that condition.

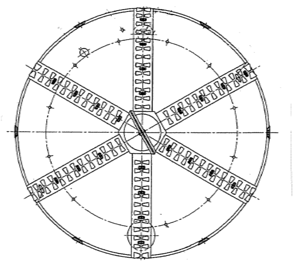
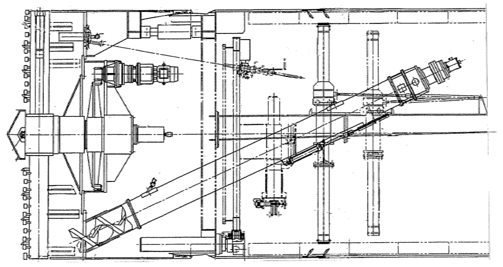
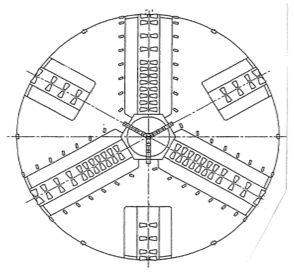
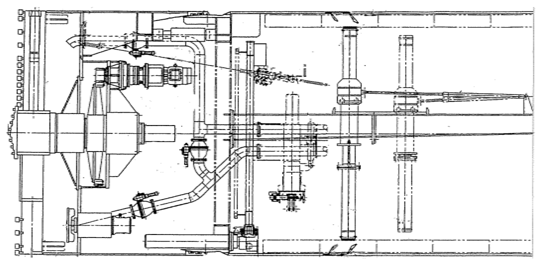
- Construction Yard

The use of Slurry Shield TBM will require a larger construction yard due to the required space for slurry and separation plants.

- Cost

The total cost for EPBS TBM is more economical than that of Slurry Shield TBM.

Table 4-43 Comparison between the EPBS TBM and the Slurry Shield TBM

Item	Earth Pressure Balanced Shield TBM		Slurry Pressure Balanced Shield TBM	
Condition	· Segment outer diameter: φ6.8m · Excavation section area: 37.9 ㎡ · Overburden:15~45m		· Shield outer diameter: φ6.95m · Segment section area: 6.12 ㎡ · Ground condition: Clay, sand, gravel, limestone	
Outline of the Machine	 		 	
Main Specification	· Shield outer diameter: φ6.95m · Jack thrust power: 2,000kN×21 pcs=42,000kN · Screw conveyer diameter: φ750mm · Cutter torque: 5,700 kN · m · Cutter rotation speed: 0.8 rpm · Cutter power: 481kw		· Shield outer diameter: φ6.95m · Shield jack thrust power: 2,000kN×21 pcs=42,000kN · Slurry removal pipe diameter: φ250 mm · Cutter torque: 4,700 kN · m · Cutter rotation speed: 0.8 rpm · Cutter power: 407 kw	
Control of Excavation	1. The Earth Pressure at Cutting Face: The amount of the discharging soil is controlled by measuring the earth pressure at bulkhead, the speed of the push jack and the rotational speed of the screw conveyer. 2. Amount of Discharging soil : The flow meter and the RI (Radio Isotope) densimeter, etc. are installed in the soil exhaust. The amount of the discharging soil is measured and managed simultaneously. 3. Properties of Muddy soil : Control of discharging soil density, water content, the slump, quality and quantity of the additive.	○	1. The Slurry Pressure at Cutting Face: The slurry pressure is measured with the water pressure gauge installed at the bulkhead and it is controlled by the slurry feed/discharge pump. 2. Amount of discharging soil: The flow meter and the densimeter are installed in slurry discharge pipeline. Flow and the density of slurry are measured and analyzed and the amount of soil as dry condition is calculated and is fed back to the control. 3. Properties of slurry : The specific gravity and the viscosity etc. of the slurry are managed.	○
Ground Condition	· Clay: In case of soft clay, the additive is not required. Even hard clayey material, it is easily transmuted to the muddy soil if water or small additive is added. Consequently, the cost for the additive is quite economical.	◎	· Clay: Large plant is required to separate the muck and slurry according to environmental law (Japan). Cost becomes expensive.	△
	·Sand: The excavated fine and midium sand could be transmuted into the muddy soil by the additive material. In case of the sand which the uniformity coefficient is under 6,the cutting face can be stabilized by muddy soil. The muddy soil can smoothly discharge and transfar to the starting base by the belt conveyer.	○	· Sand : When the uniformity coefficient is under 6,and soil particle of under 74 μ of sand is under 8 % , the stability of the cutting face is difficult in the slurry shield.The vibration screen and cyclone are required to classify the sandy muck by size and countermeasure for noise and vibration is required.	△
	· Sand and gravel: as same as sandy soil.	○	· Sand and gravel: As same as sandy soil. In addition, if the size of the gravel is 1/3 or bigger than the diameter of discharge pipe (φ250mm) , the crusher for the gravel is required.	△
	· Boulder: The boulder could be continuously discharged through the 750mm diameter screw conveyor if boulder is 450mm×250mm dimension or smaller.	○	· Boulder: It is necessary to break the boulder to size of 1/3 or less of the discharge pipe (250mm diameter) by the crasher.	△
	· Limestone: It is necessary to attach the roller cutter on the cutting head.	○	· Limestone: It is necessary to attach the roller cutter on the cutting head.	○
Shallow Overburden	· The specific gravity of the muddy soil is about 1.7 to 2.0 as same as the natural ground. Therefore, it is possible to balance both at crown and bottom between the earth pressure of ground (including water pressure) and design earth pressure at bulkhead . Consequently, it is possible to excavate under shallow overburden (0.5D D: outer diameter of the TBM).	○	· The specific gravity of slurry is 1.1 to1.2 and lighter than that of the ground. Therefore, if the slurry pressure is balanced at the bottom of TBM under the shallow overburden condition, the slurry pressure at crown is excessive to the earth pressure of the ground (including water pressure). There is possibility that the slurry is escaped and blown out in shallow overburden (0.5 D D: outer diameter of the shield)	△
High Water Pressure	· It is possible to excavate and drive with suitable control of the muddy soil condition in excavation chamber and water stoppage system of screw conveyor even under high water pressure of 0.45Mpa. Moreover, it is safer if the secondary screw conveyor is	○	· Since the slurry system is the closed circuit, the TBM could excavate and drive normally even under the high water pressure of 0.45MPa.	◎
Launch Shaft	· The plant equipment is smaller and noise from the plant is also smaller.	○	· The slurry plant equipment becomes larger and the noise and the vibration of the slurry processing equipment (vibrating screen) are also larger. Soundproofing and the vibration insulation measures are necessary.	△
Driving Speed	· It is assumed that driving speed of the shield is about 250m/month to 300m/month.	○	· It is assumed that driving speed of the shield is about 250m/month to 300m/month.	○
Cost	· Total cost of the EPBS TBM is generally more economical than that of the Slurry Shield TBM because of less additive use, smaller construction yard and smaller noise countermeasure.	○	· Total cost of the Slurry Shield TBM is generally more expensive than that of the EPBS TBM because of larger construction yard and countermeasure for large noise of plant.	△
Evaluation	The adoption of the EPBS TBM is yearly increasing all over the world. Especially, more than 70% of the shield TBM is the EPBS TBM in Japan as following reasons. ① Total cost of the EPBS TBM is lower than that of the Slurry Shield TBM. ② The EPBS TBM was invented in Japan about 35 years ago and has been developed and matured under various geological condition. Note: The EPBS TBM and Slurry Shield TBM could be both applied to the various geological condition. The selection of the machine should be totally evaluated and determined by the geological condition, situation and location of construction site.			

Note: ◎Excellent, ○Good, △Fair
Source: JICA Study Team

4.6.6 Introduction and Study of EPBS TBM

The shield TBM has been developed to construct tunnels in soft ground condition of the city area. In 1967, the first practical Slurry Shield TBM was developed in Japan. The compressed air shield, which had been widely used, was replaced by the Slurry Shield TBM and this technology spread throughout world. After the development of the Slurry Shield TBM, the first advanced EPBS TBM was invented in 1974 in Japan to reduce the total construction cost, the required space for ground level construction yard and environmental impact.

In recent years, the use of EPBS TBM has prevailed over Slurry Shied TBM in Japan because of lower construction cost and smaller construction yard at ground level. There were 1187 constructions using Shield TBM in Japan from 1998 to 2007 and 70% of them were done by the EPBS TBM (see Figure 4-115). The technology of the EPBS TBM is introduced as follows:

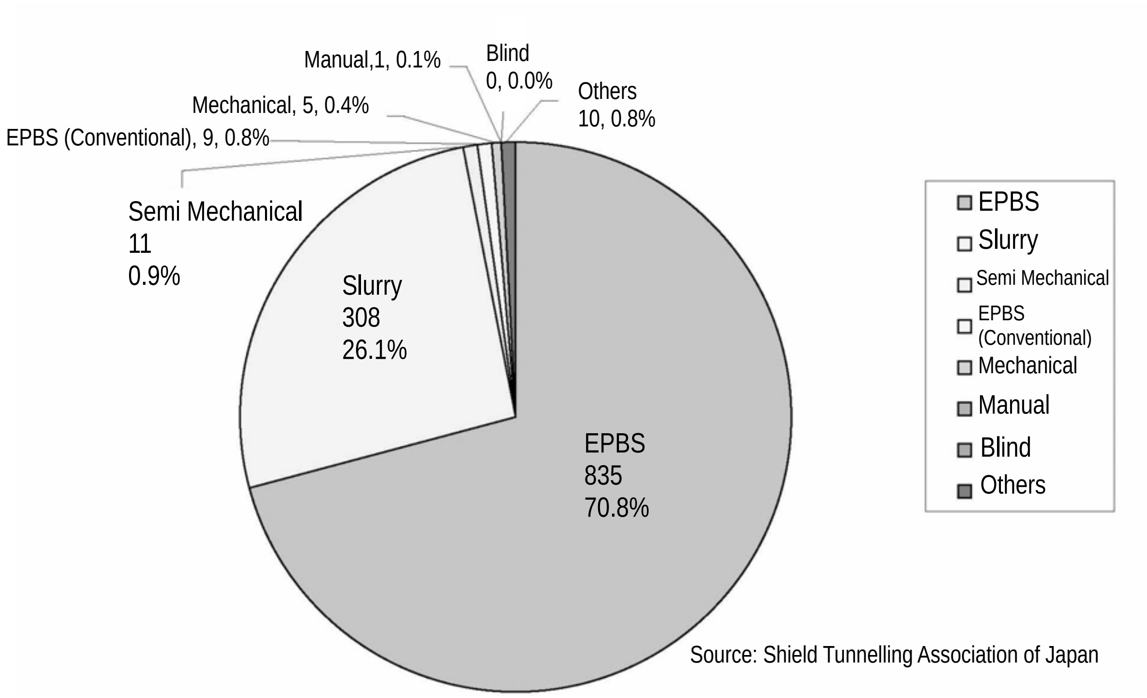


Figure 4-115 Application of Different Shield TBM Types in Japan (1998-2007)

(1) Development and Practices of EPBS TBM

The EPBS TBM was invented in 1974 and has been developed in Japan. So far, there have been more than 1400 construction practices by EPBS TBM in Japan and other countries. This method can be applied in various ground conditions, such as clay, sand, gravel, volcanic ash soil and mudstone.

The technology of the EPBS TBM has been developing and its application with large diameter projects is increasing. The largest diameter of the EPBS TBM is approximately 15m, which was used for the M30 ring road tunnel in Madrid City, Spain. The large EPBS TBM of 12 m diameter class is used for road tunnel projects in Japan and 7-10 m diameter classes are widely used for subway construction.

Source: IHI Corporation

Figure 4-116 EPBS TBM (Outer Diameter 6.24m)

(2) Principles of EPBS TBM

a) Principle of Stability at Cutting Fface

The principle of stability at the cutting face by EPBS TMB is as follows:

1) Making of Muddy Soil from Excavated Soil

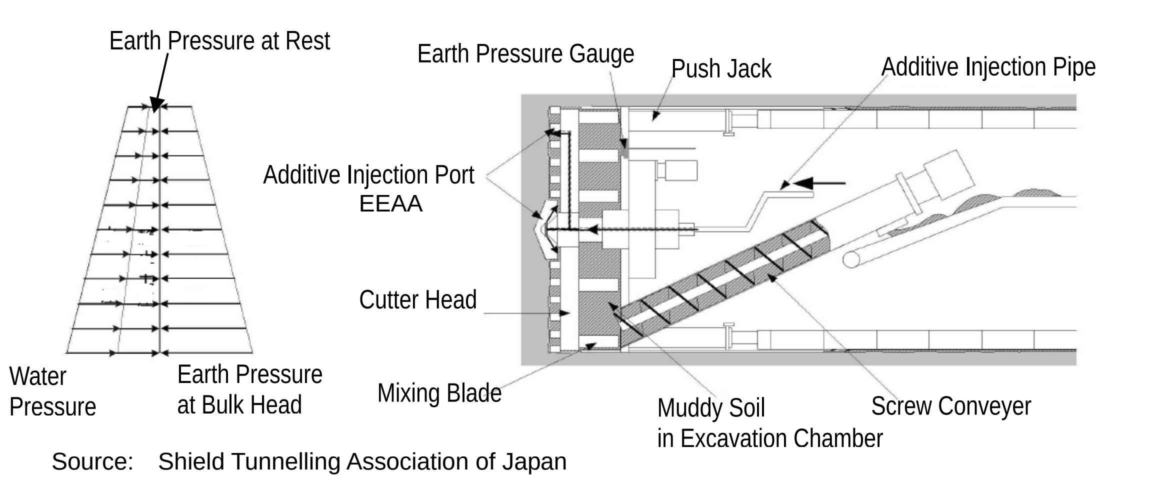
The ground is excavated by the spoke type cutting head and the excavated muck is simultaneously mixed with additive injection. The excavated soil and additive material are mixed well by the mixing blade, which is located at the rear of the cutting head. The mixed material has a unit weight equivalent to the ground and becomes muddy soil, which has a characteristic of plastic flow and low permeability.

2) Generation of Pressure at Bulk Head (in excavation chamber) and Stabilization of Cutting Face

The excavation chamber and screw conveyor are filled with muddy soil. Then, the muddy soil in the excavation chamber is pressurized by the push jack. The generated earth pressure at the bulkhead balances and resists the earth pressure at rest, as well as water pressure, thus, stabilizing the cutting face.

3) Excavation and Driving Control by Earth Pressure at Bulkhead

The cutting face is stabilized by the earth pressure at the bulkhead. The driving speed of the push jack and rotation speed of the cutting head are adjusted and controlled to stabilize the earth pressure at bulkhead.



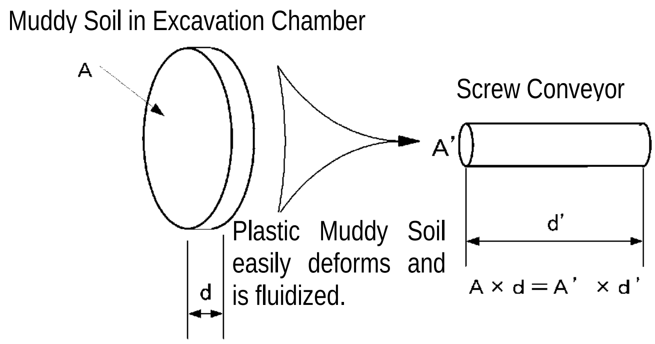
Source: Shield Tunnelling Association of Japan

Figure 4-117 Design Earth Pressure at Bulkhead and Outline of EPBS TBM

b) Plasticity Fluidizing of the Excavated Soil

As explained in the preceding section, it is necessary and important to make muddy soil which has characteristics of plastic flow and low permeability.

The muddy soil, which is filled and pressurized in the excavation chamber, is continuously fluidized in the chamber and exhausted to the screw conveyor. The diameter of the screw conveyor is about 1/10 of the shield TBM and the muddy soil is required to be deformed and be fluidized easily in the excavation chamber.

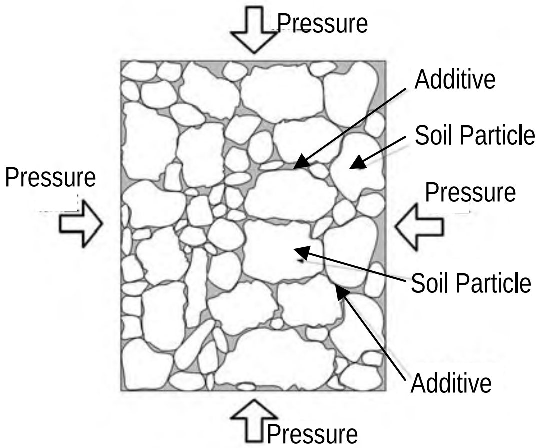


Source: JICA Study Team

Figure 4-118 Deformation and fluidization of muddy soil in excavation chamber

c) Procedure of Plasticity Fluidizing of the Excavated Soil

The soft clayey soil is easily plasticized and fluidized by the excavation. On the other hand, the sandy soil and sand with gravel would block the excavation chamber due to the angle of internal friction if there is no additive injection used. Therefore, it is important to have an additive injection and mix it well with the mixing blade.



Source: JICA Study Team

Figure 4-119 Image of Muddy soil in Excavation Chamber

(3) Study of the Application of the EPBS TBM to Metro Line 4

a) Applicable Ground Condition

The EPBS TBM can be applied not only in clayey soil but also in sandy soil and soil with gravel. Besides, it is possible to apply the EPBS TBM to the alternation of these strata if an additive injection with an appropriate quality and content is used in the excavation chamber.

1) Clayey Soil

If the water content exceeds the liquid limit in the soil, the additive injection is not required. In other cases, the amount of the additive injection is determined by the ratio of fine material (smaller than 0.074 mm).

2) Sandy Soil and Gravel

The EPBS TBM can be applied to sandy soil and gravel layer if a suitable concentration of additive injection is applied. In accordance with the ratio of fine material in sandy and gravel soil, the amount of additive injection is determined. If more than 30% of fine material is included, additive injection is not required. In case that the uniform coefficient (Cu=D60/D10*) of the ground is less than 5, the ground condition is expected to be unstable and it is therefore necessary to increase the additive injection.

The EPBS TBM can be applicable to the stratum with boulders (up to 450 mm x 250mm). Boulders can be mucked using the screw conveyor of 850mm diameter, which equips the EPBS TBM of 7 m outer diameter class.

Note: D60 corresponds to the 60% finer in the particle size distribution and D10 corresponds to the 10% finer.

3) Alternation of clay, sand and gravel strata

In the same way as for the sandy and gravel layers, the EPBS TBM can be applied to the alternation of strata and the amount of the additive injection is determined by the content of the fine material.

b) Applicability to Shallow Overburden

There are many practices and experiences involving the application of the EPBS TBMs to projects with shallow overburden. According to the application of the appropriate control of earth pressure at bulkheads and use of advanced rapid hardening backfill material for tail void, the ground surface settlement and displacement of the neighbouring construction can be controlled within a few millimetres.

c) Applicability to River Crossing

There were experiences of river crossings using the EPBS TBM in Japan. The most severe case was to cross the river in diluvium sandy strata with shallow overburden of 4.4 m (0.6D, where D is the outer diameter of the shield tunnel). The EPBS TBM can be used to cross the Nile River and other canals with suitable overburden taking into consideration the floating during construction and after completion of the tunnel.

d) Applicability to Neighboring Construction

Metro Line 4 is anticipated to pass in the vicinity of other existing structures. Therefore, it is necessary to study the neighbouring construction between existing structures and the shield TBM. There were similar and more severe experiences in Japan that were constructed by the EPBS TBM. The EPBS TBM passed under the piles of bridges and the distance between these structures was sometimes just 1.5 m (0.2D). Besides, EPBS often crossed near existing tunnels at a distance of 0.6 m or less.

e) Applicability to the Ground with High Water Pressure

As illustrated in Figure 4-117, the EPBS TBM stabilizes the cutting face by the earth pressure at bulkhead, which is a bit higher than the pressure from the ground (earth pressure at rest + water pressure) and drives forward. Even under the condition of the high water pressure of 0.4 MPa, the underground water cannot surge into the excavation chamber, enabling the EPBS TBM to drive safely. There were many practices that involve thick overburden, which is 40 m or deeper. According to these experiences and practices, the EPBS TBM can be applied to the sand or gravel layer with high water pressure conditions in Metro Line 4.

f) Applicability to Long Distance Driving and Construction

Even if the Shield TBM is continuously driven more than 5 km before completion of the intermediate vertical shaft (station), the long distance mucking from the EPBS TBM can be easier with a continuous belt conveyor or muck car than with the slurry liquid discharge from the Slurry Shield TBM, which requires more than 20 discharge pumps.

g) Disposal of Waste Soil

The mucked soil must be disposed carefully according to environmental laws/decrees, thus, it is necessary to install a plant for its treatment. In the case of the Slurry Shield TBM in Japan, it is necessary to locate a large plant which separates slurry and muck. Furthermore, this plant creates loud noises when slurry and muck are separated. On the other hand, the EPBS TBM does not need such a large plant at the construction yard.

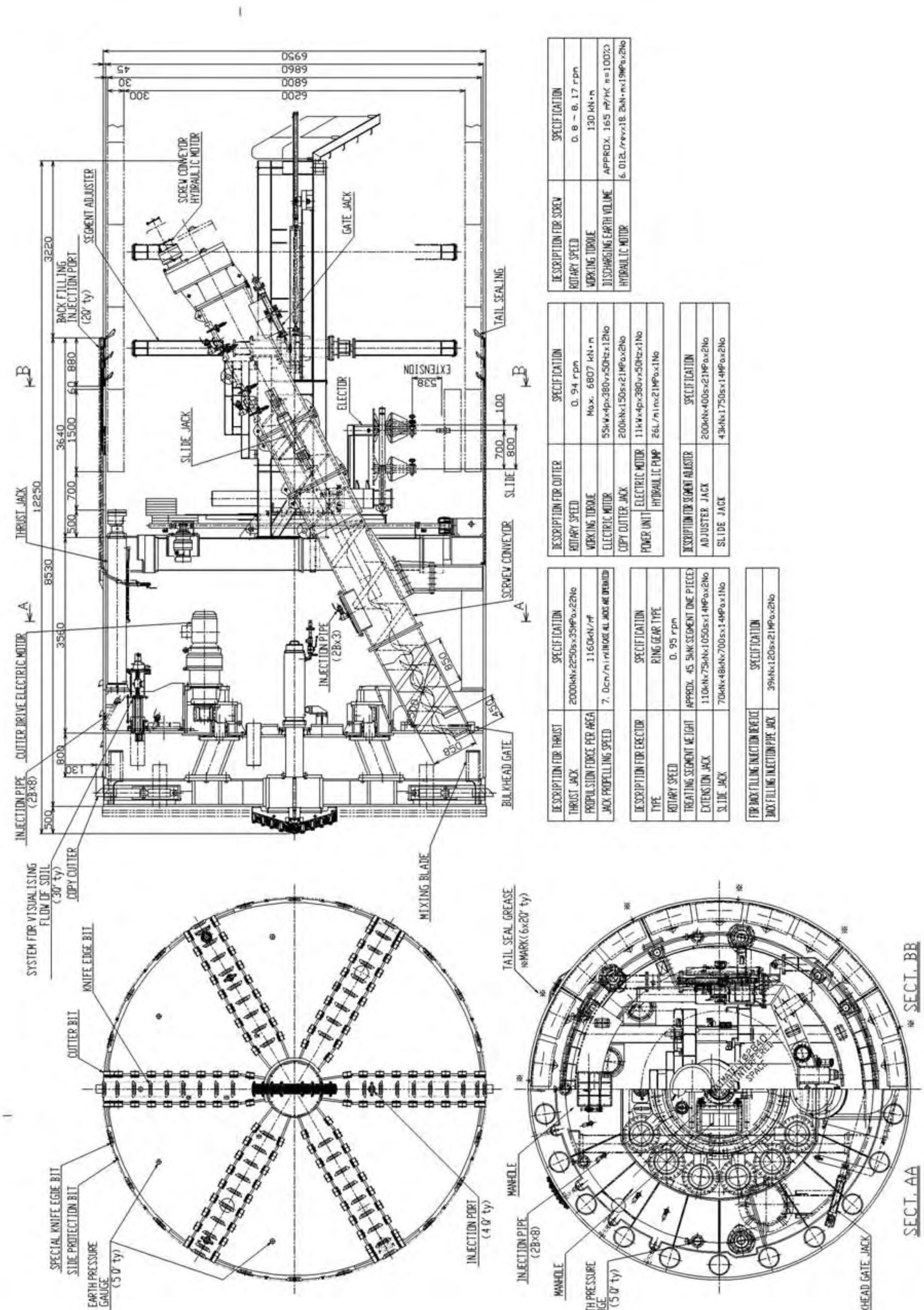
(4) Outline of EPBS TBM

The shield TBM is studied for the project. The general feature of the shield TBM is tabulated in Table 4-44 and its outline is shown in Figure 4-120.

Table 4-44 General Features of the EPBS (ϕ 6.95 m)

Item		Specification	Remarks
Shield Outer Diameter		φ6.95 m	
Stabilization of Cutting Face		EPBS Type	
Cutter Torque		6,807KN·m (max)	
Cutter rpm		0.94 rpm	
Facility Thrust Force		44,000 KN	
Advance Speed		3～3.5 cm／min.	Average monthly advance of about 300m (main driving)
Screw Conveyor		φ850 mm	
Bit	For Advance Excavation	Precutting Bit	
	For Sandy Soil	Teeth Bit	
	For limestone	Roller Bit	

Source: JICA Study Team



Source: JICA Study Team

Figure 4-120 Outline of the EPBS TBM, ϕ6.95 m (Example)

a) Excavation Mechanism for Sandy Soil and Rock

It is expected that the shield TBM will excavate and drive mainly in fine sandy to medium sandy strata in the project. It is necessary to consider this condition for the selection of cutter bits.

The cutter bits attached on the cutter head of the shield TBM are the fishtail bits as the centre bit, the pre-cutting bit as the advance bit and the teeth bits as main bits. As the combination of these bits, there are many practices in excavating FFU, which is used at the launch and arrival shaft and improved soil by the jet mixing column. Moreover, there is a practice of long drive construction which exceeds 5 km and the frequency of exchange of these bits is assumed to be once or twice in every 5 km. In the area where limestone is expected (Station 12 to 14), roller cutters will be considered.

Source: Japan Society of Civil Engineers

Figure 4-121 Example of Bits on Cutter Head (Left: Pre-Cutting and Tooth Bits, Right: Roller Cutter and Tooth Bits)

b) Torque of the Cutter Head

The torque of the cutter head is proportional to the cube of the outer diameter of the shield TBM and the empirical formula is "$T=\alpha \cdot D^3$". Based on past experiences and practices, the coefficient, α, ranges from 13 to 20 for sandy ground. Thus, 4400-5000 kN-m is prepared for normal conditions and 6800-7000 kN-m as maximum.

c) Thrust Force

The thrust force of the shield TBM is approximately 1100-1200 kN/m^2 based on past experiences and practices. Therefore, the resulting thrust force required is 42,000-45,000 kN.

d) Control System of the Earth Pressure (Pressure at Bulkhead)

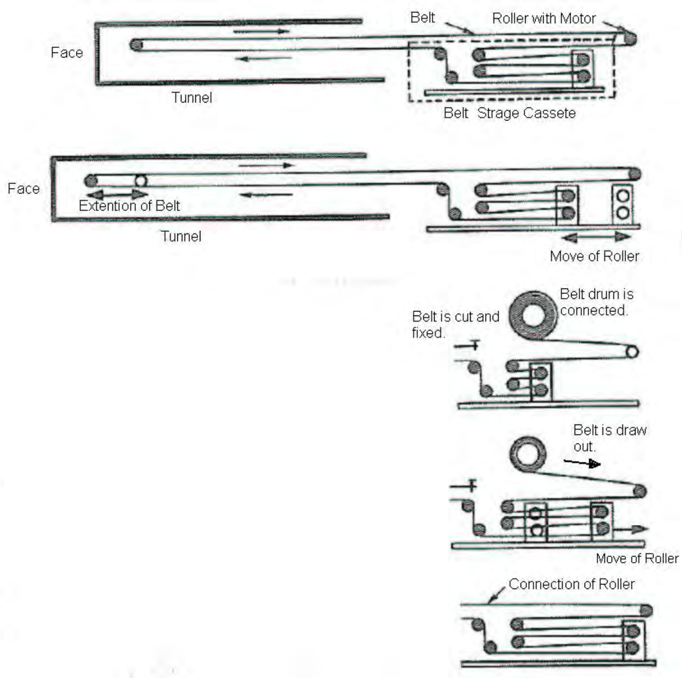
The bulkhead is equipped with about five pressure metres, and it should be possible to exchange two of them, even during excavation.

e) Backfill Grouting

The backfill grouting is simultaneously carried out with excavation through the pipe which is attached on the crown of the shield TBM. The backfill material is composed of cementitious material (liquid A) and liquid grass (liquid B). These materials are mixed just before casting to the tail void. The mixed backfill material is plastic and hardens rapidly. Most of the constructions in Japan made use of this material for shield tunnel construction, which proved to generate less settlement and be watertight. The durability for long term use was also proved.

f) Mucking of the Excavated Soil

The mucking from the shield TBM is done by continuous belt conveyer. The excavated material is carried by the belt conveyer to the shaft and lifted up to ground level by the vertical belt conveyer. The belt conveyer is extended at an interval of 300 m excavation. An image of the extension of the belt conveyer is given in Figure 4-122



Source: Kyushu Shinkansen Tagami Tunnel, Tunnel and Underground, Japan

Figure 4-122 Image of the Extension of the Continuous Belt Conveyor

g) Disposal of Excavated Soil

The excavated material is mixed with an additive and becomes mud with plastic fluidity. The mucked material is carried to the disposal area by dump truck and is dried in the yard. After that, it will be filled in at a suitable disposal area.

(5) Daily Monitoring and Control of EPBS TBM

The daily monitoring and control of the tunnel excavation is important for safe construction. As for the daily monitoring and control of the EPBS TBM, the following items will be planned and carried out:

a) Earth pressure in chamber

b) Plastic flow condition of muddy soil in chamber

c) Measurement of excavated soil and discharged soil

d) Measurement and control for injection pressure and amount of the backfill material

e) Control of mix portion and amount of additive

f) Measurement and control of the cutter torque of the shield TBM

g) Control of thrust force of push jack on the shield TBM

a) Earth Pressure in Chamber

The earth pressure at bulkhead is continuously measured by multiple earth pressure meters the bulkhead and the optimum earth pressure is obtained and controlled by adjusting the speed of push jack and revolution of screw conveyor. The earth pressure at bulkhead is controlled to be higher than the sum of active earth pressure and water pressure and to be lower than the sum of passive earth pressure and water pressure. The optimum earth pressure at bulkhead is controlled to minimize ground settlement.

b) Plastic Flow Condition of Muddy Soil in Chamber

The plastic flow of muddy soil in chamber is controlled to be in a suitable condition by adjusting the amount of additive injection and continuous monitoring of the fluctuation of cutter torque. In addition, the muddy soil condition, which is discharged through the screw conveyor, is confirmed and monitored by hand touching and material watching. The water content and unit weight of the muddy soil is frequently measured to know the change of the muddy soil condition.

c) Measurement of Excavated Soil and Discharged Soil

The volume of excavated soil is calculated as the product of cross sectional area and driven speed of the shield TBM. In addition, the discharged soil through the screw conveyor is continuously measured and compared with the amount from the calculated volume. The difference between the calculated and measured volumes is fed back to the control and adjustment of the excavation. The volume, weight and density of the discharged soil is measured and controlled by densimeter, flow-meter, number of pumping and weight scale according to the mucking delivery method (belt conveyor, pumped either through pipe or muck car).

d) Measurement and Control for Injection Pressure and Amount of the Backfill Material

The injection pressure and amount of backfill material for the tail void are continuously monitored and controlled to minimize ground settlement.

e) Control of Mix Portion and Amount of Additive

The type and consistency are determined by the mix portion test according to the actual soil condition. The amount of additive is controlled to make suitable muddy soil according to the monitoring of cutter torque of the shield TBM.

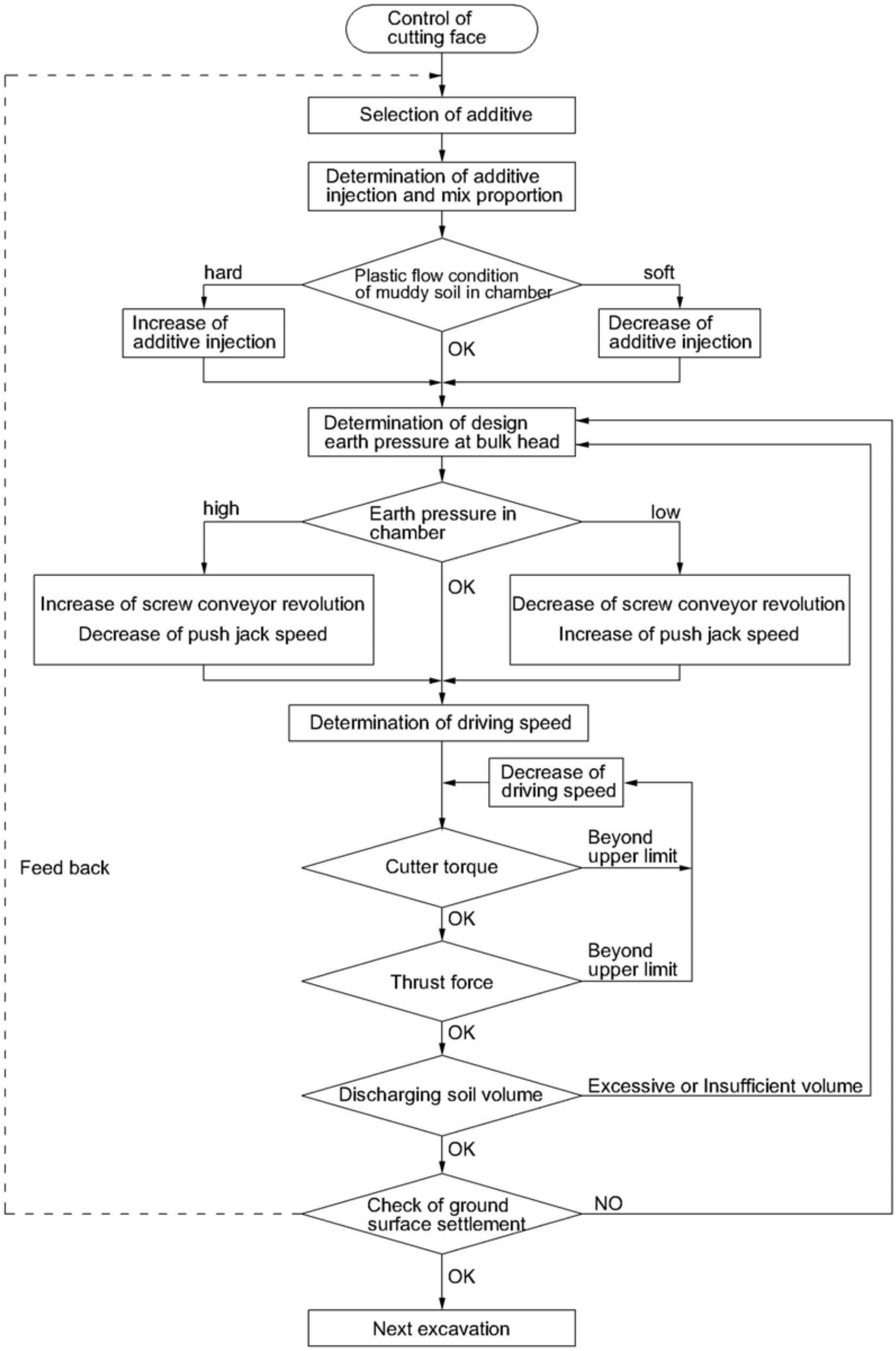
f) Measurement and Control of the Cutter Torque of the Shield TBM

The cutter torque is controlled and adjusted according to the soil condition, driven speed of the shield TBM and the amount of the additive.

g) Control of Thrust Force of Push Jack on the Shield TBM

The thrust force of the push jack on the shield TBM is controlled with accordance with the earth pressure at bulkhead, driven speed and control of the direction.

The flow chart of the daily monitoring and control of the EPBS TBM is indicated in the Figure 4-123.



Source:Japan Society of Civil Engineer

Figure 4-123 Flow chart of Control of the Cutting Face of the EPBS TBM

4.6.7 Technical Study of the Shield TBM Construction

The shield TBM will pass under the congested central area of Greater Cairo City. It is anticipated to pass in the vicinity of existing structures and their foundations/piles. Therefore, the dilapidation survey of the existing structure is carried out to confirm the deterioration of neighbouring structures. From the aspect of tunnel engineering, the required countermeasures are assessed and studied. In addition, the shield TBM will pass under the Nile River with shallow overburden and the floating of tunnel at crossing point is also studied.

(1) Study of the Neighbouring Construction

The major technical point of the neighbouring construction is illustrated in Figure 4-124. Each neighbouring construction is assessed and studied by the impact level, which is determined by ground displacement analysis of the Finite Element Method (FEM). According to the level of displacement of the ground, the impact level is classified into two levels. The impact levels are defined as follows.

- Level I_T: the ground area where 5-10 mm displacement is expected.
- Level II_T: the ground area where 5 mm or less displacement is expected.

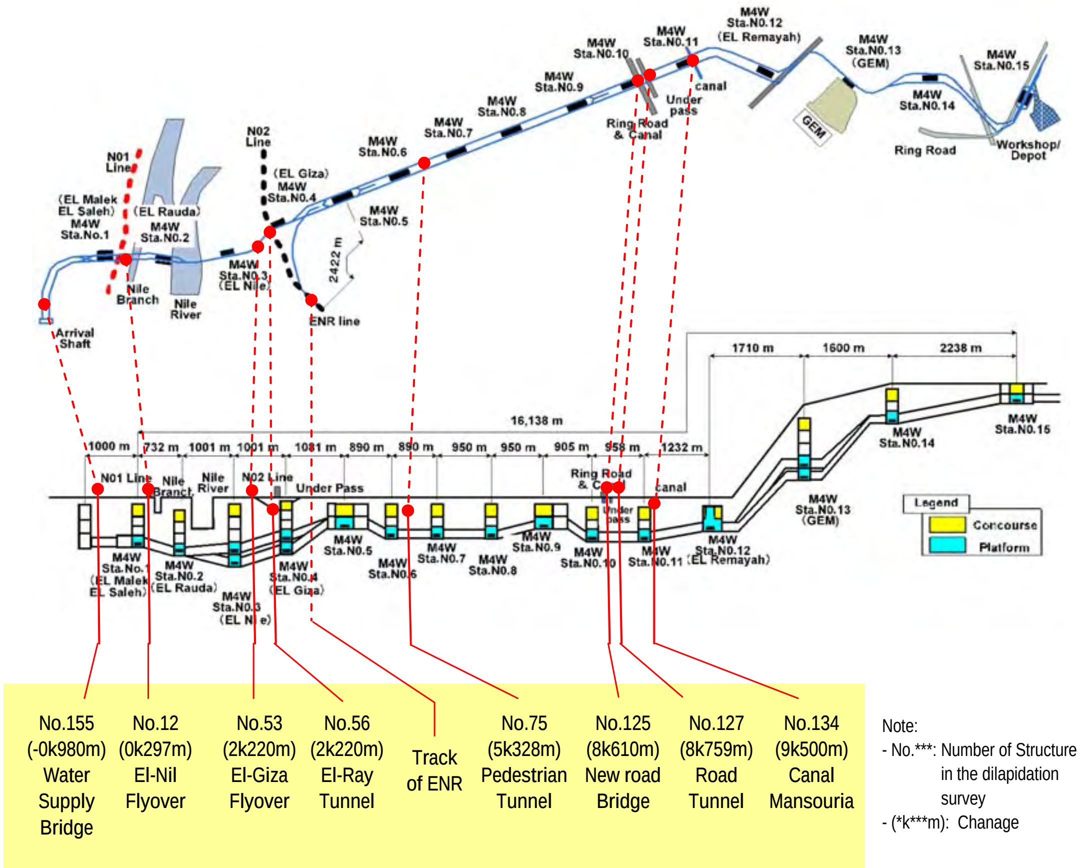
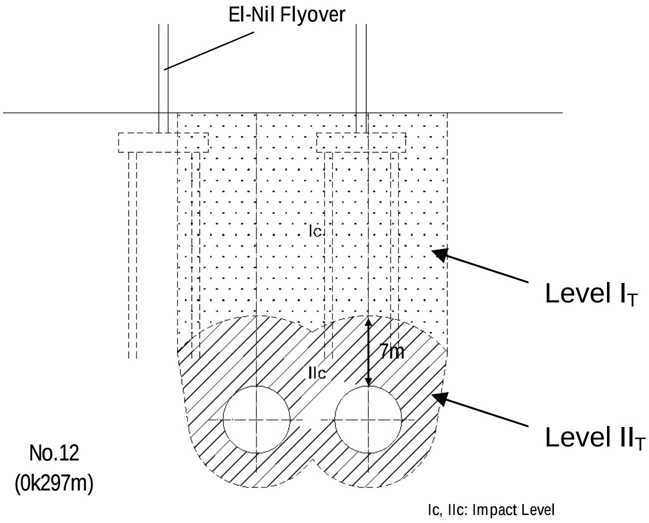


Figure 4-124 Major Neighboring Constructions

a) No.12 El-Nile Flyover

The depth of the piles is unknown. It is therefore necessary to measure the depth and confirm the isolation distance from the tunnel in the design stage. As illustrated in Figure 4-125, there are possibilities that the bottom of the pile is located in level IIT area and the pile point bearing will affect the segmental lining of the tunnel. In this case, high stiffness segmental lining will be considered and designed.

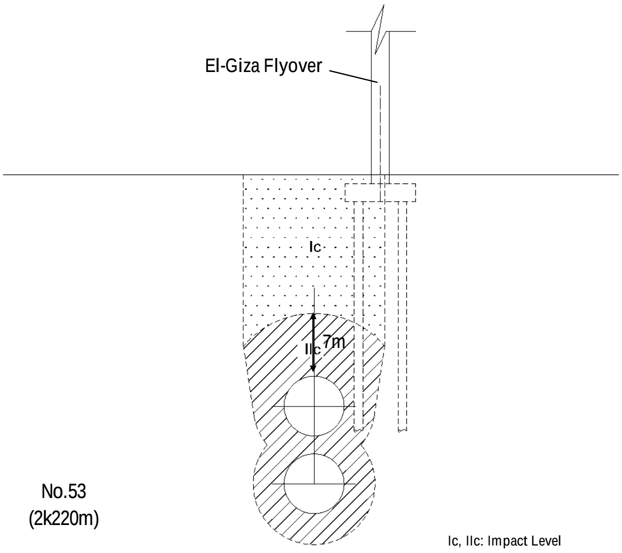


Source: JICA Study Team

Figure 4-125 No. 12 El-Nile Flyover

b) No.53 El-Giza Flyover

The piers of the El-Giza Flyover are densely located and it is inevitable to pass in the vicinity of piles of these piers. The location and depth of piles are unknown. The tunnels are located vertically to avoid the piles but there is a possibility that the isolation distance between tunnel and pile is 1.1 m. Therefore, it is necessary to measure the location and depth of the piles and design the segmental lining considering the influence of the point bearing of the pile, if the bottom of pile is situated above the crown of tunnel.

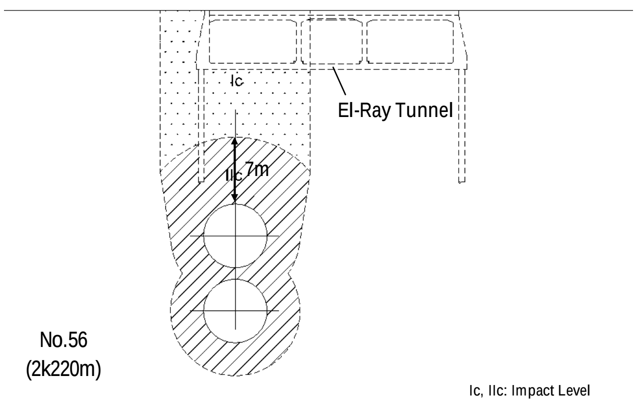


Source: JICA Study Team

Figure 4-126 No. 53 El-Giza Flyover

c) No.56 El-Ray Tunnel

The pile of the structure is not confirmed but it is assumed that the pile is relatively short or does not exist because the structure is cut and cover tunnel. Therefore, there will be no impact from tunnel excavation.

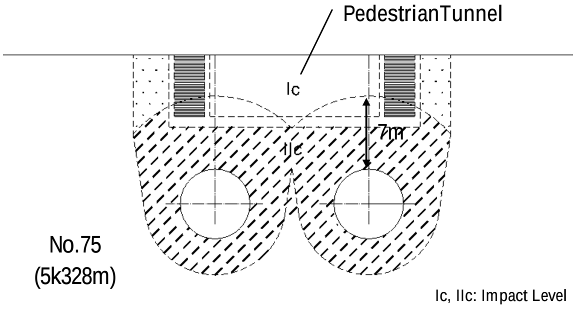


Source: JICA Study Team

Figure 4-127 No. 56 El-Rat Flyover

d) No.75 Tunnel

Judging from the structural condition, it is assumed that the piles of No.75 tunnel are non-existent. However, the overburden from the shield tunnel to No. 75 tunnel is less than 1.0D (D: Excavation diameter of the shield tunnel). The ground displacement and surface settlement will be measured and the ground will be improved by post injection after the passing of the shield TBM if necessary.

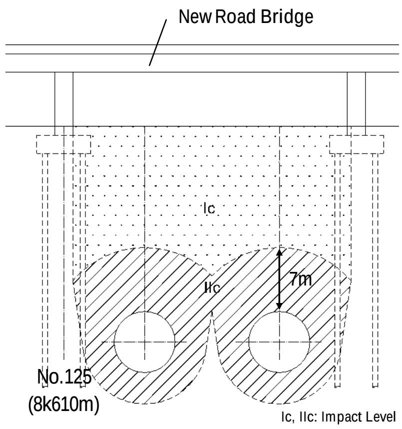


Source: JICA Study Team

Figure 4-128 No. 75 Tunnel

e) No.125 Bridge

Although the depth of the pile is not confirmed, it is anticipated that the pile is closely located in the vicinity of tunnel (about 3 m). Therefore, it is necessary to measure the location and depth of the piles and to design the segmental lining considering the influence of the point bearing of pile, if the bottom of pile is situated above the crown of tunnel.

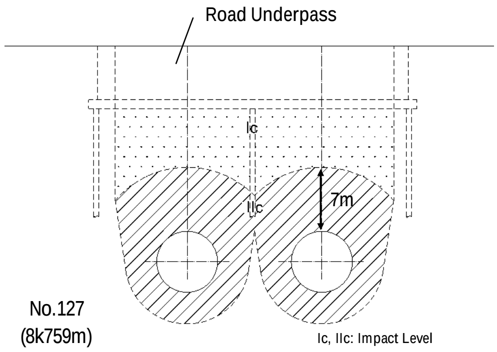


Source: JICA Study Team

Figure 4-129 No.125 Tunnel

f) No.127 Road Underpass

It is assumed that the minimum distance between the shield tunnel and the road underpass is more than 1.0D. Therefore, there is no influence from the shield TBM.

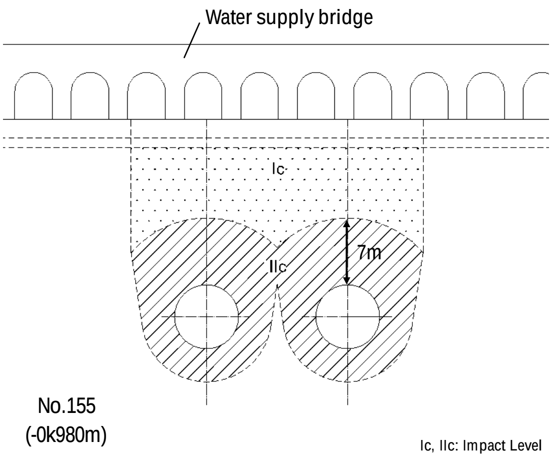


Source: JICA Study Team

Figure 4-130 No.127 Road underpass

g) No.155 Magra El-Eyoon (Water Supply Viaduct)

There is enough overburden above tunnel and the impact on the water supply bridge is negligible.



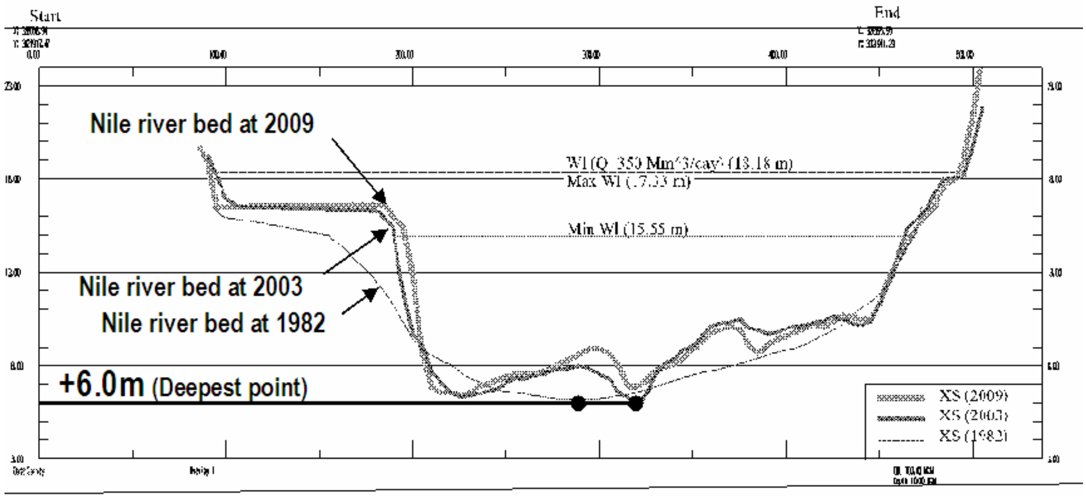
Source: JICA Study Team

Figure 4-131 No. 155 Magra El-Eyoon (Water Supply Viaduct)

(2) Nile River Crossing (Study for Floating of Tunnel)

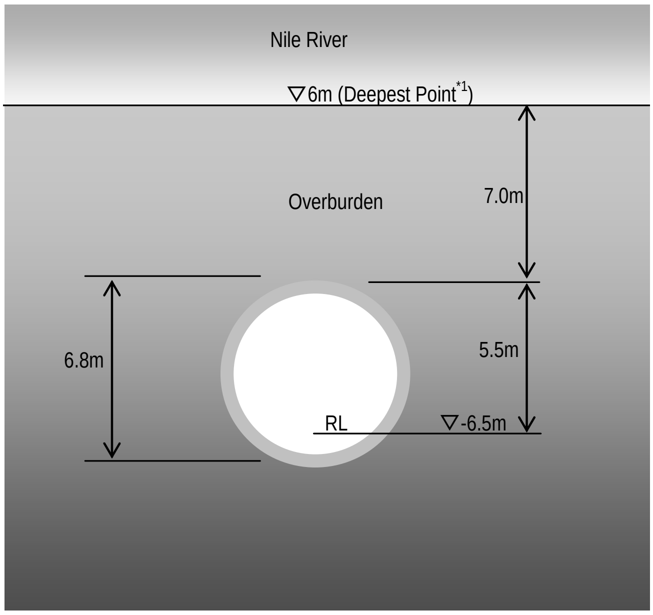
It is important to secure enough overburden under the river bed to prevent the floating of the tunnel both during construction and operation. The required overburden above the tunnel is basically 1.0D (D is the excavation diameter of the tunnel). The sounding survey at the Nile River Crossing was carried out and the cross sectional depth of the Nile River was surveyed. In addition, the historical analysis of the fluctuation of the river bed was done with the data of year 1982 and 2003. The river bed of the Nile River has the tendency of sedimentation as indicated in Figure 4-132. The deepest point of the Nile River is used for the study for the floating of the tunnel. The floating of the tunnel is studied for the condition of construction stage because the weight of the tunnel is lighter and is in a more severe condition. The safety factor for the floating should be more than 1.03 for the construction stage and the result of the study is 1.47. Therefore, the floating of the tunnel is prevented if the overburden is more than 1.0D.

As explained in the geological condition section, the uniformity coefficient of the sandy stratum is very small and it is necessary to consider and study the possibility of liquefaction in the next stage of the study.



Source: Nile River Survey Report, Nile Research Institute, 2009

Figure 4-132 Sound Survey and Historical Analysis of the River Bed at Nile River Crossing



Source: JICA Study Team

Figure 4-133 Model of the Study for the Floating of Tunnel at Nile River Crossing

Table 4-45 Comparison between the EPBS TBM and the Slurry Shield TBM

	Mark	unit	Value	note
Input	Ro	m	3.400	
	H	m	7.000	Overburden
	Hw	m	7.000	
	γ	kN/m3	17.0	
	γ'	kN/m3	7.0	
	γw	kN/m3	10.0	
	γrc	kN/m3	26.0	Segment (SG)
	t	m	0.300	thickness of SG
	g	kN/m2	7.800	γrc×t
	Po	kN/m2	0.000	
	Pi	kN/m2	0.000	
Output	Fs	―	1.472	Safety Factor
	Evaluation		OK	Fs>1.0

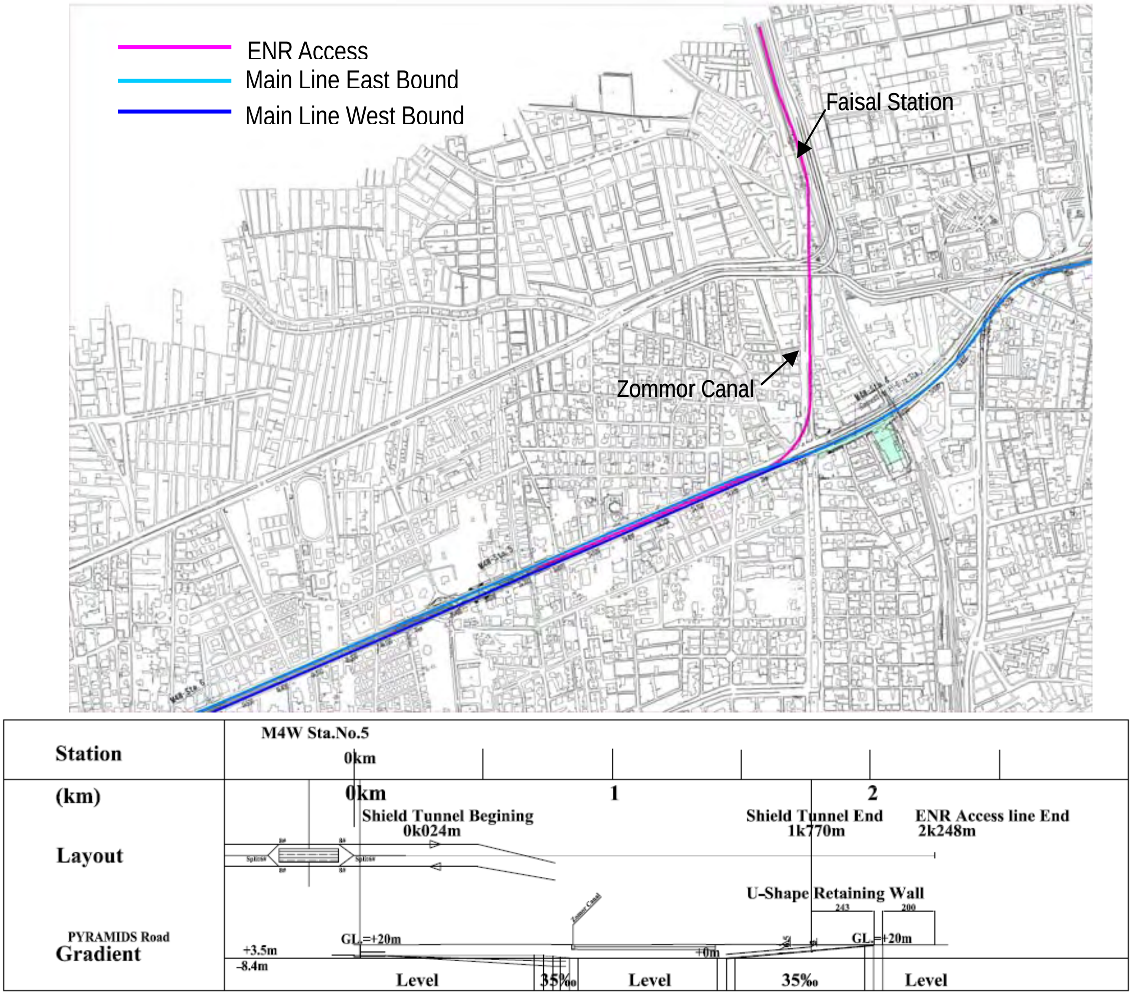
Source: JICA Study Team

4.6.8 Tunnel Construction for the ENR Access Line

The ENR access line from station No.5 of Metro Line 4 is planned to serve as a siding track to procure and bring rolling stock. It is also planned to construct this line through a tunnel. The alignment of the ENR access line is studied while taking into account the isolation distance from the mainline of Metro Line 4.

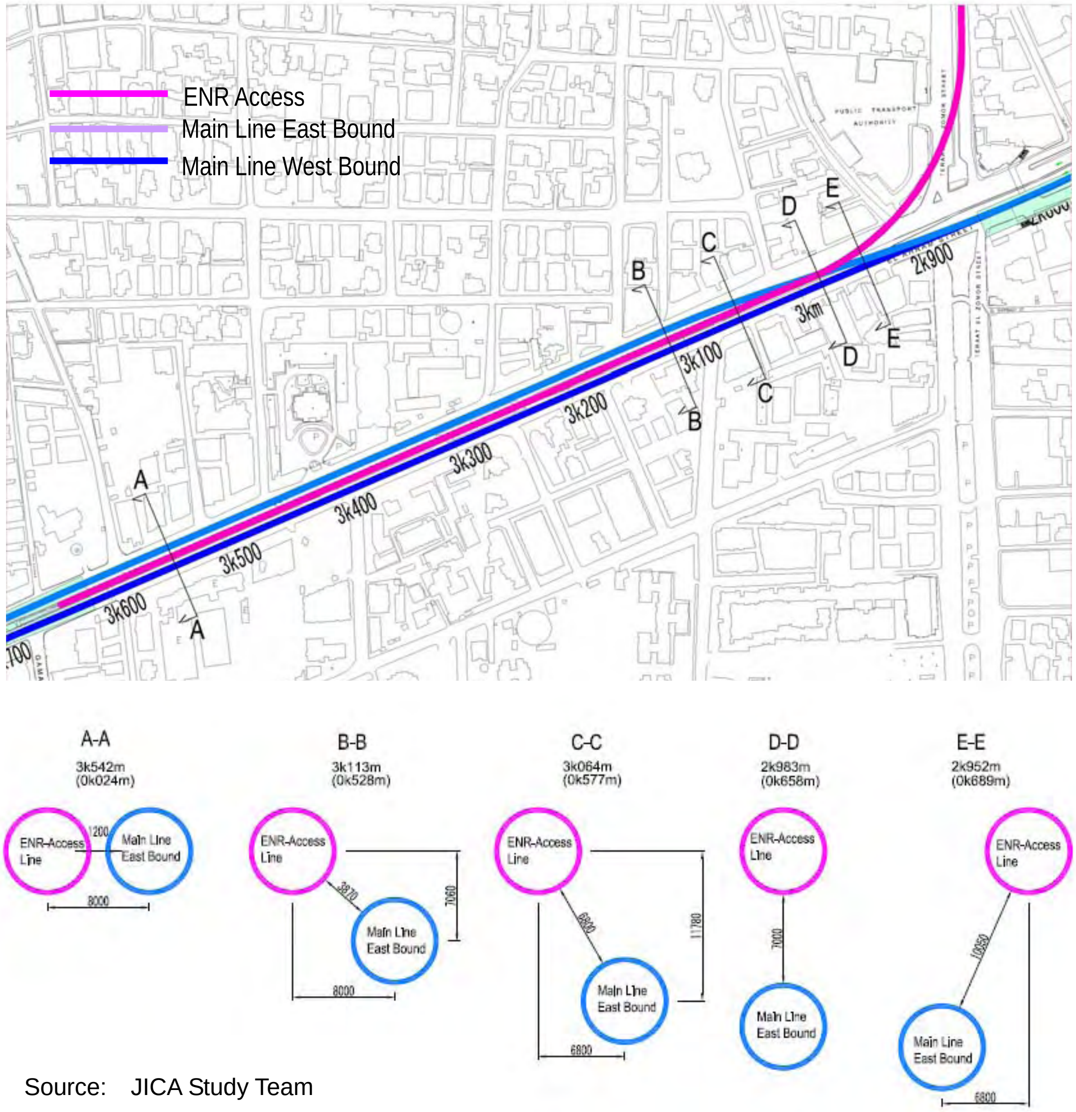
(1) Alignment of the ENR Access Line

The ENR access line will start from station No.5 and pass above the mainline east bound. Then, it will pass under the Zommor Canal and Faisal Station of Metro Line 2 and reach the arrival shaft, which will be constructed between ENR line and Metro Line 2. The length of the ENR access line is approximately 1.75 km and the diameter of the tunnel is 6.8 m, the same with that of the mainline.



Source: JICA Study Team

Figure 4-134 Plan and Profile of ENR Access Line



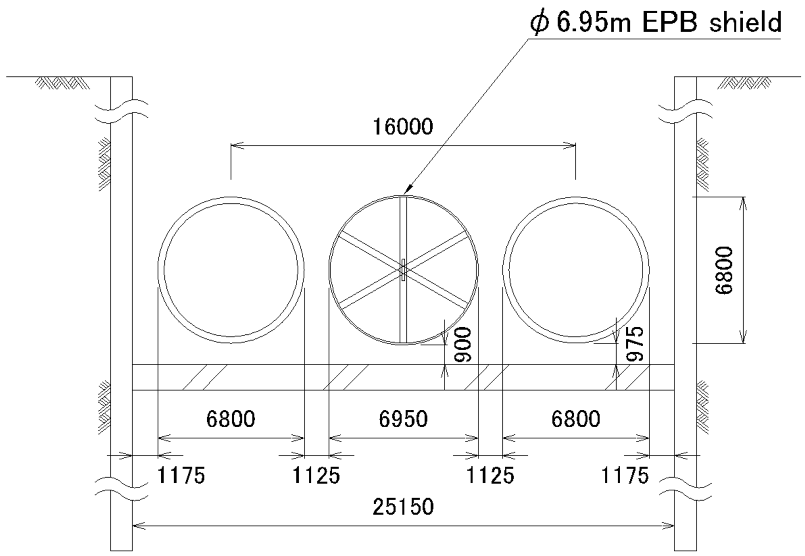
Source: JICA Study Team

Figure 4-135 Isolation Distance Between ENR Access Line and Mainline Eastbound

The isolation distance between the ENR access line and main tunnel eastbound is shown in Figure 4-135. The minimum distance is about 1.2 m at the launch shaft. The alignment of the ENR access line is diverted from the mainline eastbound and the isolation distance between two tunnels is widened accordingly. This is basically not a difficult condition and can be constructed without special countermeasures, such as pre-injection from the ground surface if an appropriate system and method of tunnel construction is applied. Ground improvement should be considered only in the proximity of the launch shaft. The shield TBM, which starts from station No.14 and arrives at station No. 9, will be removed at station No.9 and shifted to station No.5 for the ENR access line.

(2) Launch Shaft of the ENR Access Line

The distance between two tunnels of the mainline is planned to be 16 m at the launch shaft of station No.5. The ENR access tunnel is located between these tunnels and the isolation distance between each tunnel of the main line is about 1.2 m (1.125 m when excavated) as illustrated in Figure 4-136. Considering the influence to the tunnel of main line, the ground improvement would be carried out in the vicinity of the launch shaft if required with accordance with the geological condition.



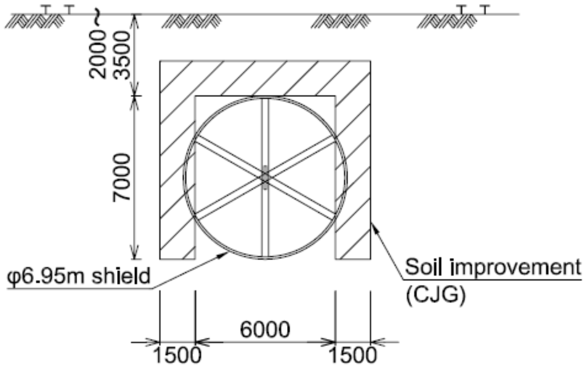
Source: JICA Study Team

Figure 4-136 Launch shaft of ENR access line

(3) Excavation and Driving of the Shield TBM

The overburden under the Zommor Canal is 1.0 D (D: outer diameter of the shield TBM) or more. Therefore, the influence to the canal caused by the tunnel excavation is minor and ground improvement will not be required if appropriate construction is used (narrow tail void, two-component backfill material, etc.).

The overburden at arrival shaft will be approximately 2 m (0.3D). The overburden above tunnel is shallower than 1.0D in the range of 140 m from the arrival shaft. The section is located in the vicinity of Metro Line 2 and ENR line. It is necessary to drive the shield TBM safely while monitoring ground displacement and surface settlement. In addition, ground improvement by the column jet grouting (CJG) should be carried out in the range of 43 m from the arrival shaft, where overburden is less than 0.5D, to intercept the influence of the tunnel excavation (see Figure 4-137).



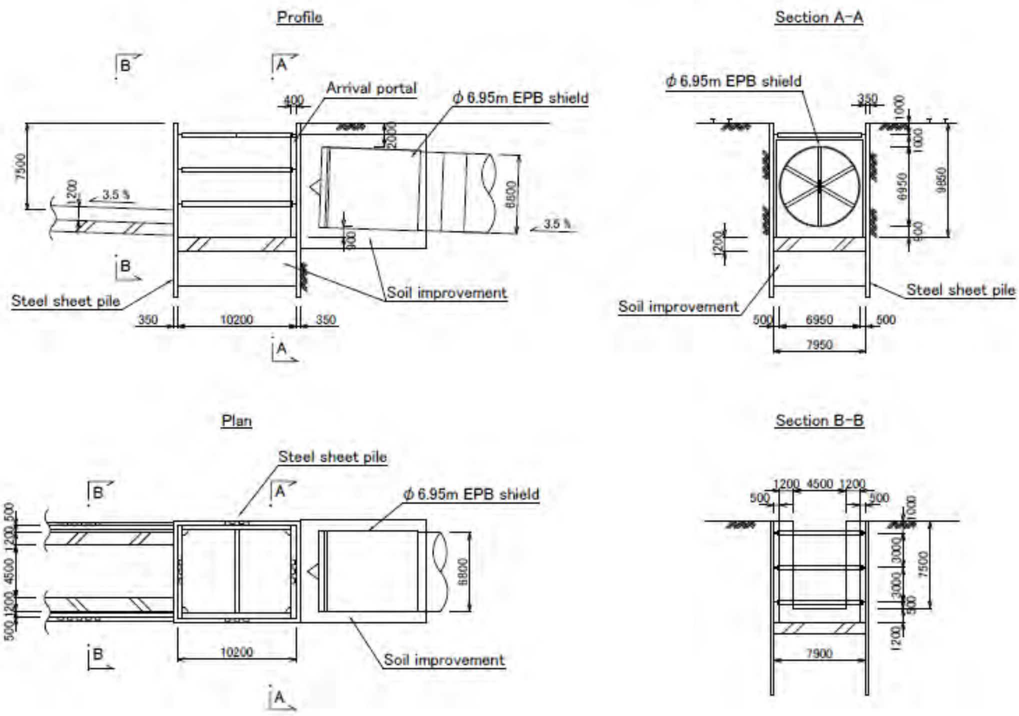
Source: JICA Study Team

Figure 4-137 Ground Improvement at Shallow Overburden

(4) Arrival Shaft of the ENR Access Line

The arrival shaft of the ENR access line will be situated between Metro Line 2 and ENR Line. Due to a very narrow space, it will be very difficult to construct a diaphragm wall, which is an in-situ RC. Steel sheet piles have been considered to be used as retaining wall in a limited space. Compared with the diaphragm wall, the required space for the arrival shaft can be narrowed.

The outside of the arrival shaft is improved within a range of 10 m by the column jet grouting as the cross sectional dimension of 9x9 m. The outline of the arrival shaft for ENR access line is indicated in Figure 4-138.



Source: JICA Study Team

Figure 4-138 Arrival Shaft of the ENR Access Line

4.6.9 Construction Plan of Tunnel

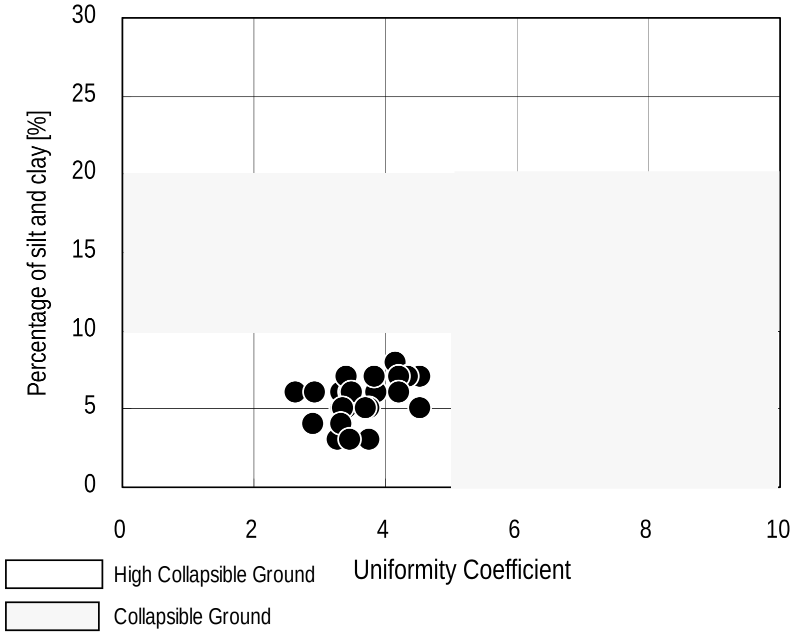
The schedule of the tunnel construction is studied. It is found from the geological survey that a risky geological stratum exists in the project area. Therefore, the construction plan is carried out considering a safe construction.

(1) Advance Speed of Shield TBM

According to the geological survey for the Phase 1A section, the stratum where the shield TBM will pass is expected to be mainly sandy. This sandy stratum is very dense with a standard penetration test (SPT) value of 50-100 or higher (converted value). However, the particle size of sand in the stratum is not widely distributed from small to large grains and the stratum is composed of similar sand particle sizes. Therefore, the uniformity coefficient of the ground is very small. In general, ground with a small uniformity coefficient (5 or less) and the content of 10% or less of fine material (silt and clay, where grains are smaller than 0.074 mm) are prone to collapse when excavated by the shield TBM. In addition, in case the water pressure is 30 kN/mm^2 or higher under that condition, the risk of collapse of the cutting face will greatly increase. The index chart of the collapsible ground is illustrated and the data of uniformity coefficients versus percentage of fine material, which was obtained from the geological survey of the project, are plotted in Figure 4-139.

If this stratum is excavated by the shield TBM with a speed faster than 500 m/mo (equivalent to 60-70 mm/min), it will be difficult to control the pressure balance at the bulkhead and measure the volume of excavated soil precisely. Therefore, the risk of the cutting face collapse will be increased by the rapid construction with shield TBM. In order to enhance the safety of excavation, it is planned to employ four shield TBMs (for Single Track Tunnel) and its average monthly advance is assumed to be 300 m/mo (30-40 mm/min).

Note: Uniformity coefficient is defined as “*Cu=D60/D10*”. Herein, D60 is corresponding to the 60% finer in the particle size distribution and D10 is corresponding to the 10% finer in the particle size.



Source: JICA Study Team, 2009 and "Practice of City Tunnel, Dr. Shunsuke Sakurai, 1988"

Figure 4-139 Risk Area of Collapsible Ground and Plotted Data of Geological Survey

(2) Procurement and Allocation of Shield TBM

The total length of the tunnel section in Metro Line 4 is about 11.3 km for main line and 1.8 km for ENR connection line from Station No. 5, as illustrated in Figure 4-140. The overall construction schedule is constrained by the construction of deep stations (No.3 El Nile and No.4 El Giza Station), which will requires more than six years. The schedule of the tunnel construction is planned to finish before completion of the station without disturbing other work and secure a safe excavation. As mentioned in the preceding section, the speed of excavation of the shield tunnel has to be controlled because collapsible sandy stratum exists in the project area and rapid excavation may lose the stability of the cutting face. The tunnel will be constructed by the shield TBM from Station No.1 to No.14. It is planned to divide the construction of this segment into two sections. Considering these conditions, it is planned to employ four shield TBMs and allocate two machines as the Single Track Double Tunnel (STDT) in each section.

There is a possibility that the cut and cover method will be applied from Station No.14 to No.15. It is planned as a cut and cover section for the study at present and it will be further discussed and studied in the design stage. The construction sections are defined as follows:

- Section 1: Station No.1-9 including turn back section from Station No.1 and access line to ENR from Station No. 5 (Shield TBM)

Launch Shaft: Station No.9

Arrival Shaft: End of turn back section which is approximately 1.0 km from Station No.1

Launch Shaft for ENR access line: Station No.5

Arrival Shaft for ENR access line: U-type retaining wall at the end of connection line

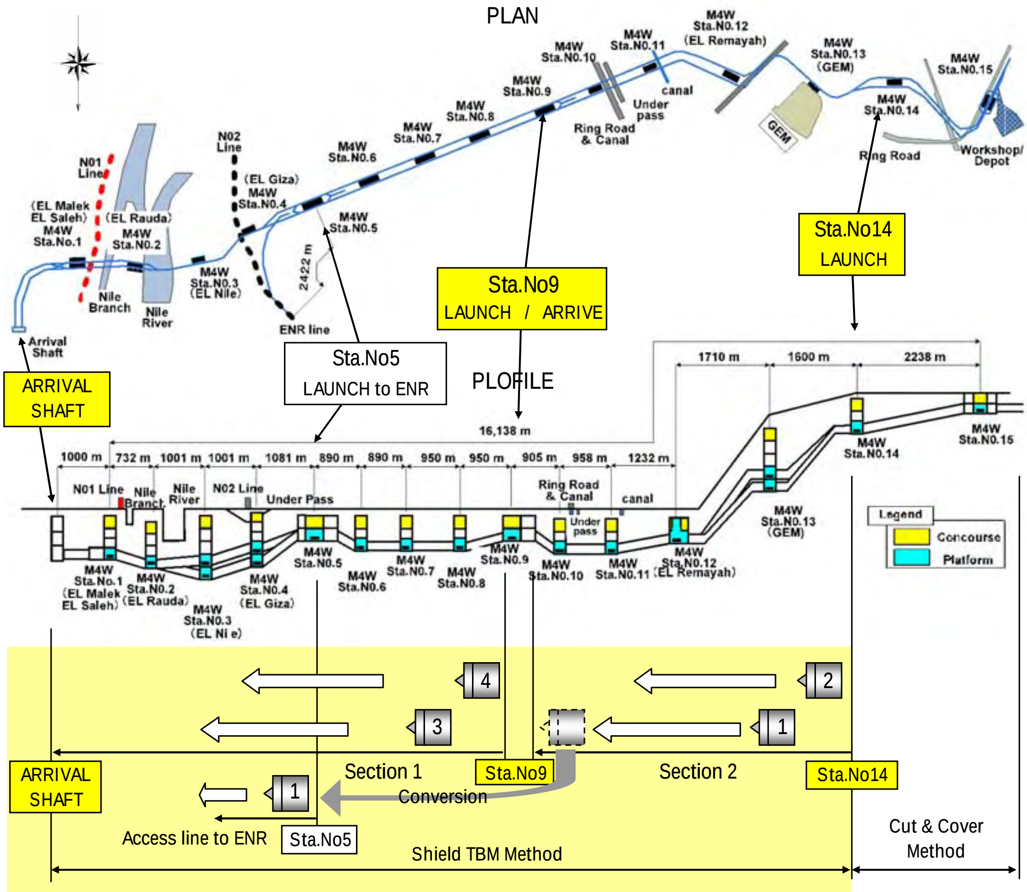
- Section 2: Station No.9- 14 (Shield TBM)

  Launch Shaft: Station No.14

  Arrival Shaft: Station No.9

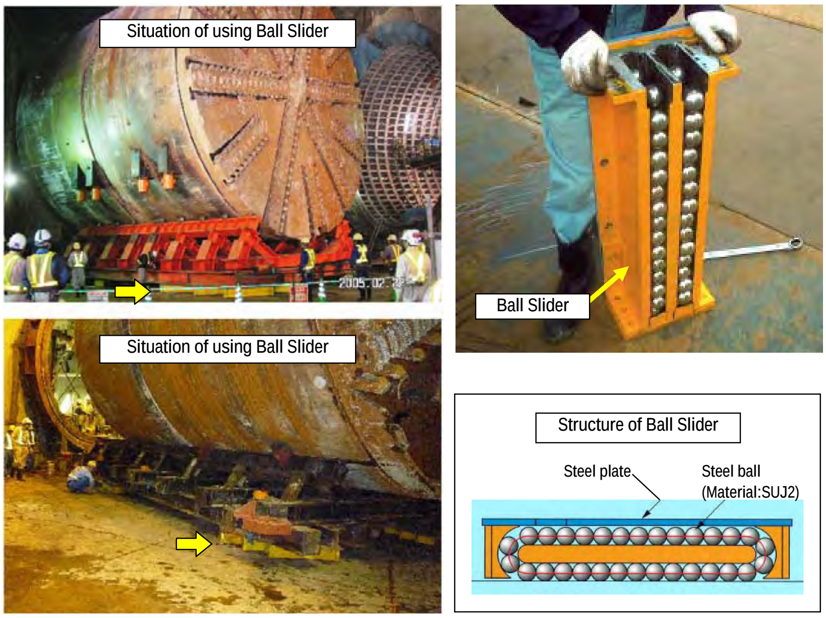
- Section 3: Station No.14-15 (Cut and Cover Method)

Each shield TBM will excavate 5-6 km. When the shield TBM arrives at the intermediate shaft (station), which is already excavated, it will be moved horizontally in the station area for the next launch by ball slider (see Figure 4-141). The ENR access line will be excavated by the shield TBM, which will complete the excavation in section 2.



Source: JICA Study Team

Figure 4-140 Allocation of the Shield TBM



Source: JICA Study Team

Figure 4-141 The Shifter for the Shield TBM in Station (Ball Slider)

(3) Study of Launch and Arrival Shaft

a) General

The maximum overburden above the shield TBM in the launch and arrival shaft is about 36.5 m and water pressure at the bottom of the shield TBM is 4.3 kgf/cm^2. Under this condition, it is suitable to use the FFU wall for safe construction and can be directly excavated by the shield TBM. The outside ground of the launch shaft is improved for crack prevention of FFU and the arrival shaft is done to lower the permeability of the ground. The ground improvement will be done by chemical or jet column grouting in accordance with the geological condition and ground water level. The image of the construction of launch and arrival shaft is indicated in Figure 4-108.

To study the space for the launch and arrival shaft, the size of the shield TBM and segmental lining is considered, as shown in Table 4-46.

Table 4-46 General Feature of the Shield TBM and Segmental Lining

Item	General Features
Shield TBM	Type: EPBS Outer diameter: 6,950 mm Machine length: 8,500 mm
Segmental Lining	Type: RC segment Outer diameter: 6,800 mm Thickness: 300 mm Longitudinal Length of each Segment: 1,500 mm

Source: JICA Study Team

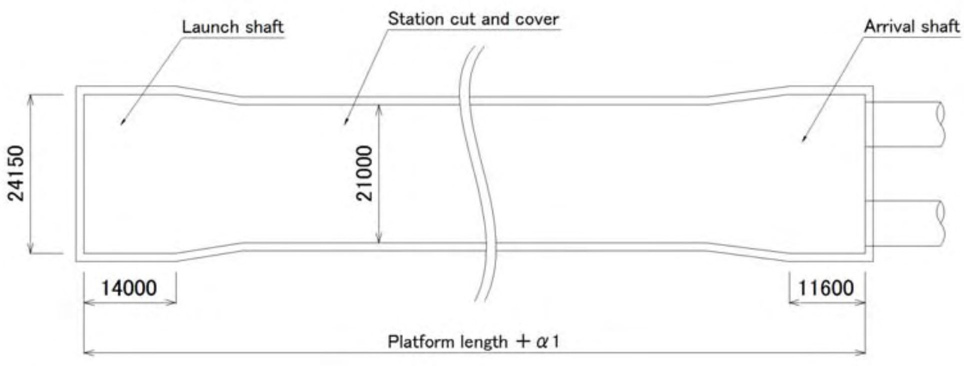
b) Required Space for Launch Shaft (Horizontally Tunnels Located)

To study the space for the launch shaft, the following items have to be considered:

- Required space for the launch of the shield TBM
- Required space for the station

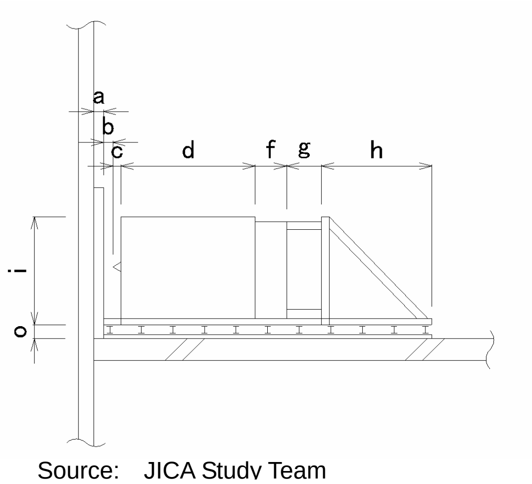
The longitudinal dimension of the launch shaft is determined by the required space for the launch of shield TBM. The arrival shaft is transversely widened and tapered from the normal part of the station (see Figure 4-142). It is necessary to calculate the allowance, l, (see Figure 4-144) for the assembly of the shield TBM to know the transverse dimension, taking the design width of the platform into consideration. The vertical dimension is determined by the requirement of the station design and overburden.

Based on past experiences, the dimension of the launch shaft is illustrated in Figure 4-142. The basis for each dimension is tabulated in Table 4-47, Table 4-48, and Table 4-49.



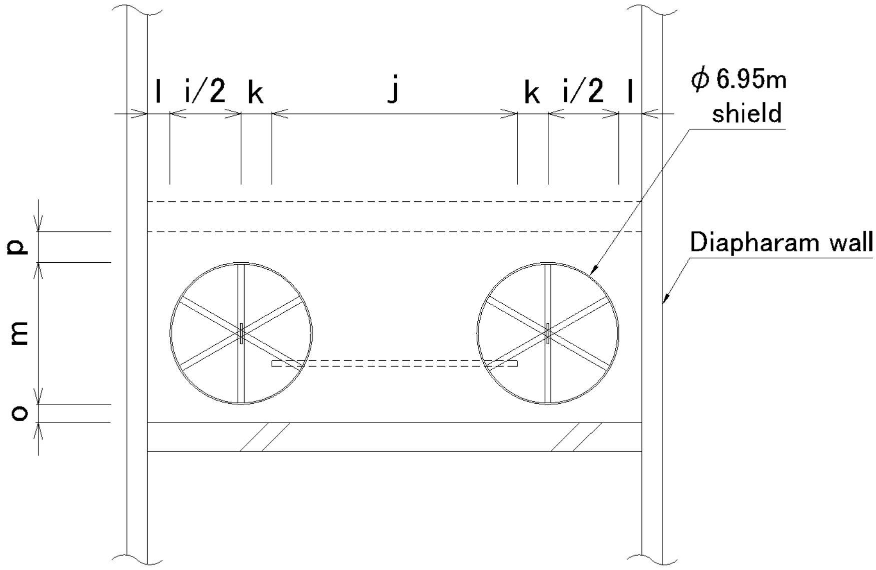
Source: JICA Study Team

Figure 4-142 Plan of Launch and Arrival Shaft



Source: JICA Study Team

Figure 4-143 Profile of Launch Shaft



Source: JICA Study Team

Figure 4-144 Cross Section of Launch Shaft

Table 4-47 Longitudinal Dimension of Launch Shaft (corresponding to Figure 4-143)

Item	Corresponding in Figure	Dimension (mm)	Remarks
1) Entrance width	a	600	
2) Allowance width for excavating	b	200	
3) Cutter length	c	500	
4) Shield machine length	d	8,500	
5) Screw conveyor length	e	(1,800)	
6) Temporary segment	f	2,000	Segment Length 1.5m
7) Supporting	g	2,200	
8) Shield thrust supporting	h	(7,000)	In the station
Total Longitudinal Dimensions, 1)-7)		14,000	

Source: JICA Study Team

Table 4-48 Transverse Dimension of Launch Shaft (corresponding to Figure 4-144)

Item	Corresponding in Figure	Dimension (mm)	Remarks
1) Shield machine outer diameter	i	6,950	
2) Platform width	j	12,000	
3) Rail center from platform edge	k	1,500×2	
4) Allowance of machine assembly	l	1,100×2	
Total Transverse Dimensions, 1)-4)		24,150	

Source: JICA Study Team

Table 4-49 Vertical Dimension of Launch Shaft (corresponding to Figure 4-144)

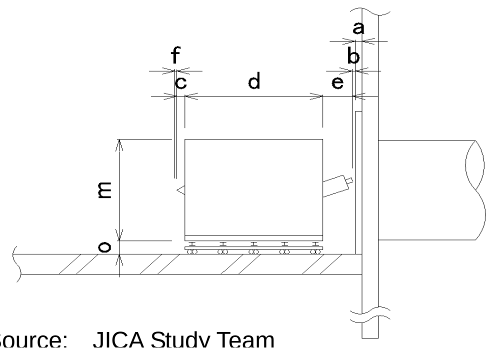
Item	Corresponding in Figure	Dimension (mm)	Remarks
1) Shield machine outer diameter	m	6,950	
2) Depth of station equipment	n	β1	
3) Bottom slab from shield bottom tip	o	725	
4) Allowance of entrance	p	425	
Total Depth 1)-4)		8,100＋β1	

Source: JICA Study Team

Therefore, the dimension of the launch shaft is 14.0 m x 24.15 m x (8.10 m +β1).

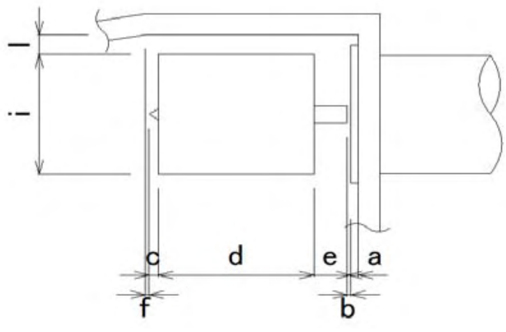
c) Required Space of Arrival Shaft (Horizontally-Located Tunnels)

The longitudinal dimension of the arrival shaft is determined by the required space for retrieval of the shield TBM. The arrival shaft is transversely widened and tapered from the normal part of the station (see Figure 4-142). It is necessary to shift the shield TBM to the centre side when it passes the shaft (station). The allowance, l, (see Figure 4-146) for the shift of the shield TBM determines the transverse dimension, taking the design width of the platform into consideration. The vertical dimension is determined by the requirement of the station design and overburden.



Source: JICA Study Team

Figure 4-145 Profile of Arrival Shaft



Source: JICA Study Team

Figure 4-146 Plan of Arrival Shaft

Table 4-50 Longitudinal Dimension of Arrival Shaft (corresponding to Figure 4-145)

Item	Corresponding in Figure	Dimension (mm)	Remarks
1) Arrival port width	a	400	
2) Allowance of draw out	b	200	
3) Cutter length	c	500	
4) Shield machine length	d	8,500	
5) Screw conveyor length	e	1,800	
6) Front allowance of shield	f	200	
Total Longitudinal Dimensions, 1)-6)		11,600	

Source: JICA Study Team

Table 4-51 Transverse Dimension of Arrival Shaft (corresponding to Figure 4-146)

Item	Corresponding in Figure	Dimension (mm)	Remarks
1) Shield machine outer diameter	i	6,950	
2) Platform width	j	12,000	
3) Rail center from platform edge	k	1,500×2	
4) Allowance of machine demolition	l	1,100×2	
Total Transverse Dimensions, 1)-4)		24,150	

Source: JICA Study Team

Table 4-52 Vertical Dimension of Arrival Shaft (corresponding to Figure 4-144)

Item	Corresponding in Figure	Dimension (mm)	Remarks
1) Shield machine outer diameter	m	6,950	
2) Depth of station equipment	n	β2	
3) Bottom slab from shield bottom tip	o	725	
4) Allowance of entrance	p	425	
Total Depth 1)-4)		8,100＋β2	

Source: JICA Study Team

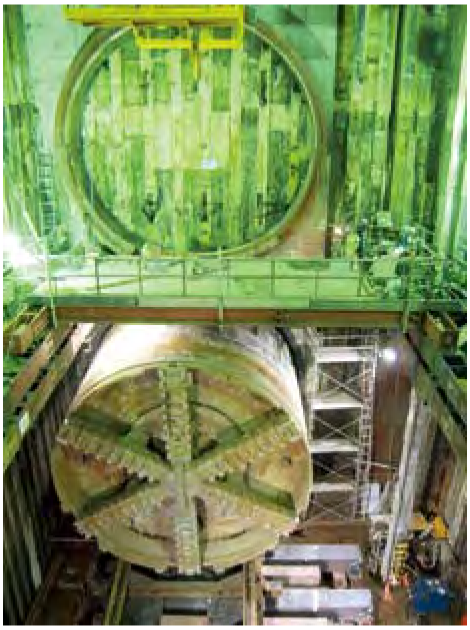
Therefore, the dimension of the arrival shaft is 11.6 m x 24.15 m x (8.10 m +β2).

d) Required Space of Final Arrival Shaft (Horizontally-Located Tunnels)

The final arrival shaft is located in the station and the required space is the same as that of other arrival shaft (horizontal).

e) Required Space of Arrival Shaft (Vertically-Located Tunnels)

Stations No.3 (El Nile) and No.4 (El Giza) are located in a congested area of central Cairo and the width of the road above station is very narrow. It is difficult to widen the station under this condition without extensive land acquisition. To minimize the width of the station, two platforms are vertically separated (located at different levels). Therefore, these stations need an arrival shaft where two tunnels arrive and locate vertically. An example of the arrival shaft with vertically located tunnels is shown in Figure 4-147.



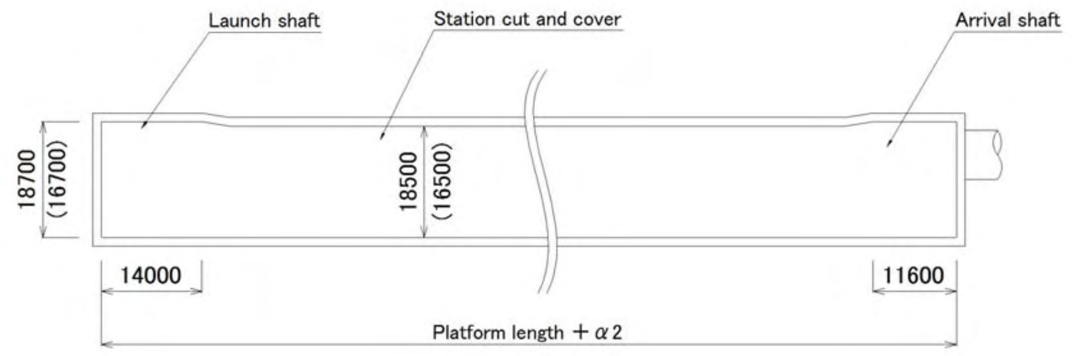
Source: Keio Corporation.

Figure 4-147 Photo of Arrival Shaft (Vertical)

The dimension of the arrival shaft is determined by the required space for the retrieval of the shield TBM in the longitudinal direction.

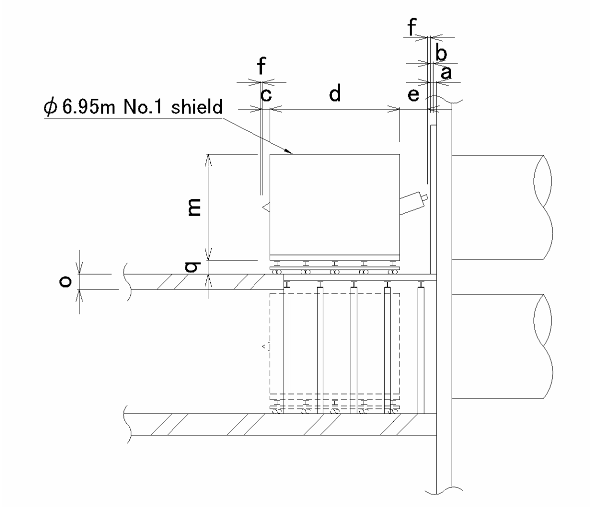
The longitudinal dimension of the arrival shaft is determined by the required space for retrieval of shield TBM. The arrival shaft is transversely widened and tapered from the normal part of the station (see Figure 4-150). It is necessary to shift to the centre when the shield TBM passes in the shaft (station). The allowance, l, (see Figure 4-150) for the shift of the shield TBM determines the transverse dimension, taking the design width of the platform into consideration. The platform width is 12 m in Station No.3 (El Nile) and 13m in Station No.4 (El Giza).

The vertical dimension is determined by the requirement of the station design and overburden.



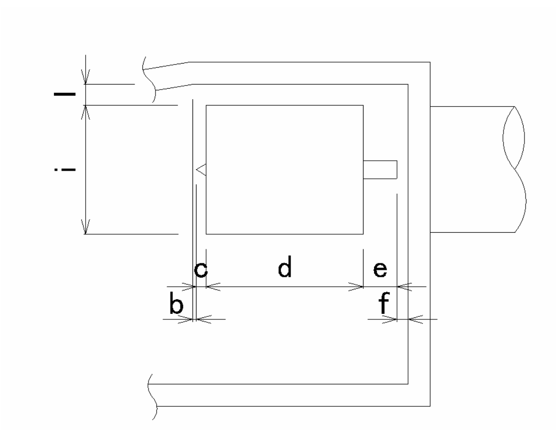
Source: JICA Study Team

Figure 4-148 Plan of Launch and Arrival Shaft (Vertically Located Tunnels)



Source: JICA Study Team

Figure 4-149 Profile of Arrival Shaft (Vertically-Located Tunnels)



Source: JICA Study Team

Figure 4-150 Plan of Arrival Shaft (Vertically-Located Tunnels)

Table 4-53 Longitudinal Dimension of Arrival Shaft (Vertical, Corresponding to Figure 4-149)

Item	Corresponding in Figure	Dimension (mm)	Remarks
1) Arrival port width	a	400	
2) Allowance of draw out	b	200	
3) Cutter length	c	500	
4) Shield machine length	d	8,500	
5) Screw conveyor length	e	1,800	
6) Front allowance of shield	f	200	
Total longitudinal dimensions 1)-6)		11,600	

Source: JICA Study Team

Table 4-54 Transverse Dimension of Arrival Shaft (vertical, corresponding to Figure 4-150)

Item	Corresponding in Figure	Dimension (mm)	Remarks
1) Shield machine outer diameter	i	3,500	6950×1/2
2) Platform width	j	12,000 (No.3 Sta.) 13,000 (No.4 Sta.)	Side Platform
3) Rail centre from platform edge	k	1,500	
4) Allowance of machine assembly	l	700	
Total Transverse Dimensions, 1)-4)		17,700 (No.3 Sta.) 18,700 (No.4 Sta.)	

Source: JICA Study Team

Table 4-55 Vertical Dimension of Arrival Shaft (vertical, corresponding to Figure 4-152)

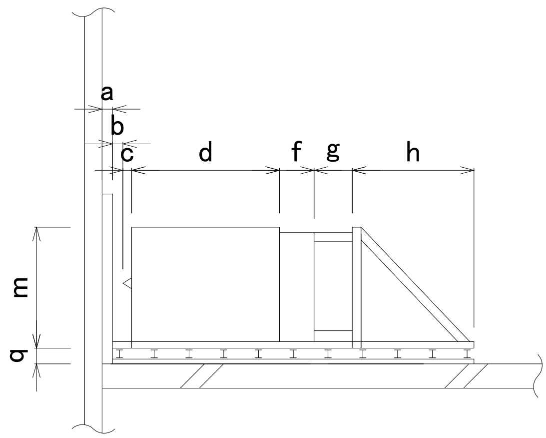
Item	Corresponding in Figure	Dimension (mm)	Remarks
1) Shield machine outer diameter	m	6,950×2	
2) Depth of station equipment	n	$\beta 3$	
3) Bottom slab	o	1,000	
4) Allowance of entrance	p1	525	
5) Allowance of entrance	p2	825	
6) Bottom slab from shield bottom tip	q	725×2	
Total Vertical Dimension 1)-5)		17,700+$\beta 3$	

Source: JICA Study Team

Therefore, the dimension of the arrival shaft is 11.6 m x 17.7 m x (17.7 m +$\beta 3$) for the Station No.3 (El Nile) and 11.6 m x 18.7 m x (17.7 m +$\beta 3$) for the Station No.4 (El Giza).

f) Required Space of Launch Shaft (Vertically Located Tunnels)

After the shield TBM arrives at the shaft, it is moved in the station and re-launched. The dimension of the launch shaft for vertical location of tunnels is determined the same as the case for horizontal location of tunnels.



Source: JICA Study Team

Figure 4-151 Profile of Launch Shaft (Vertically Located Tunnels)

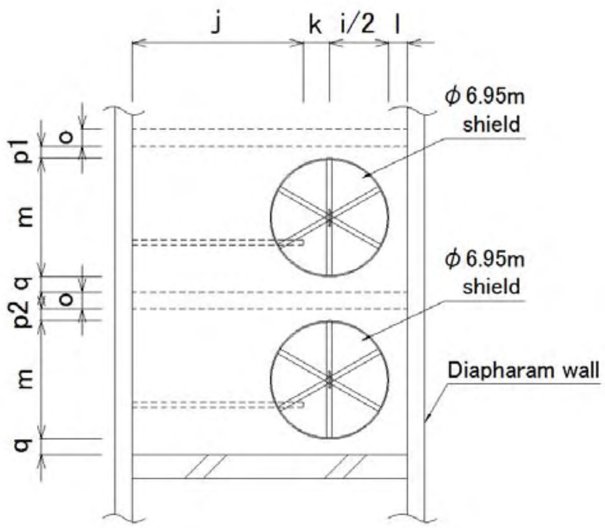


Figure 4-152 Cross Section of Launch Shaft (Vertically Located Tunnels)

Table 4-56 Longitudinal Dimension of Launch Shaft (vertical, corresponding with Figure 4-151)

Item	Corresponding in Figure	Dimension (mm)	Remarks
1) Entrance width	a	600	
2) Allowance width for excavating	b	200	
3) Cutter length	c	500	
4) Shield machine length	d	8,500	
5) Screw conveyor length	e	（1,800）	
6) Temporary segment	f	2,000	Segment Length 1.5m
7) Supporting	g	2,200	
8) Shield thrust supporting	h	（7,000）	In the station
Total Longitudinal Dimension 1)-7)		14,000	

Source: JICA Study Team

Table 4-57 Transverse Dimension of Launch Shaft (vertical, corresponding with Figure 4-152)

Item	Corresponding in Figure	Dimension (mm)	Remarks
1) Shield machine outer diameter	i	3,500	6950×1/2
2) Platform width	j	12,000 (Sta.No.3) 13,000 (Sta.No.4)	Side Platform
3) Rail center from platform edge	k	1,500	
4) Allowance of machine assembly	l	700	
Total Transverse Dimension 1)-4)		17,700 (Sta.No.3) 18,700 (Sta.No.4)	

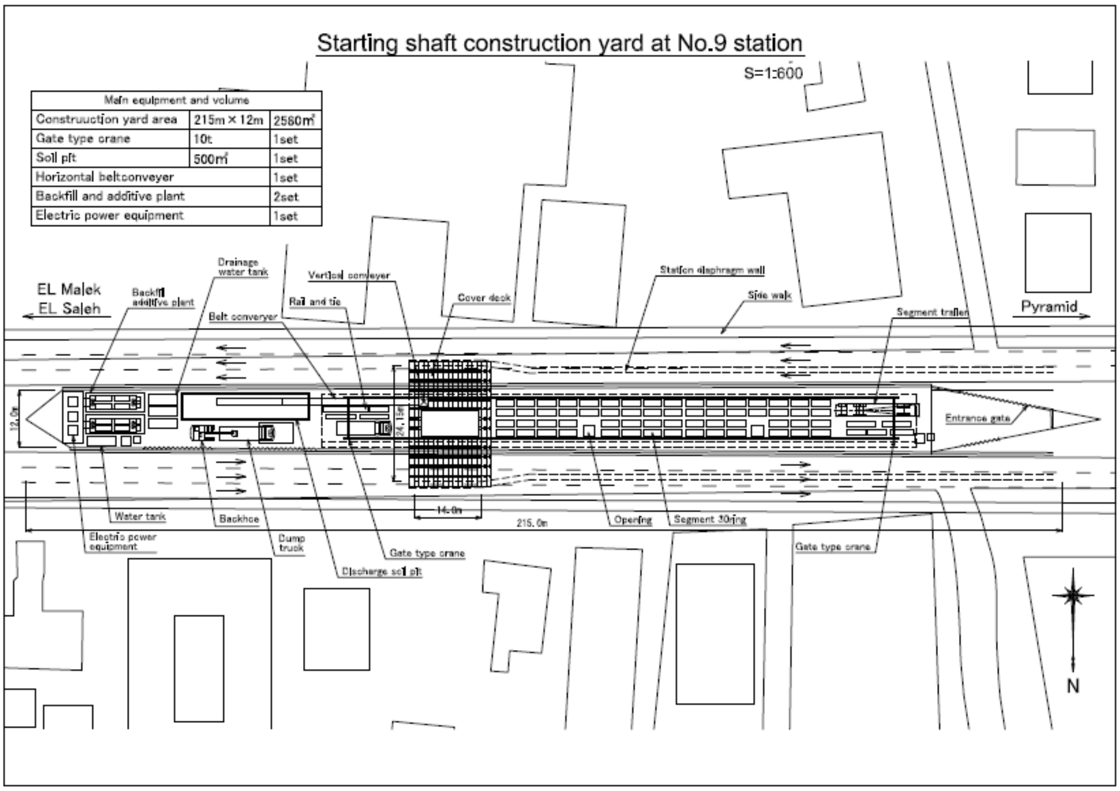
Source: JICA Study Team

(4) Study of Construction Yard of Launch Shaft

The shield TBM launches from Station No.14 and Station No. 9. The construction yard of launch is used for the supply of the construction material and power and is also used for the storage of the segmental lining. The allocation and layout of the construction yard is studied.

a) Station No.9

There is an open space of approximately 10,000 m^2 in close proximity of Station No. 9. This space can be utilized for construction site office, mess, parking and materials storage. Therefore, it is suitable to locate the launch shaft for section 1 of the Metro Line 4. The pyramid road is 40-45 m wide and the island type construction yard is planned on the median and some part the road. The construction yard is 12 m wide and approximately 2600 m^2. Dual three lane carriageway with side walk is secured during construction to prevent blockage of existing traffic on pyramid road. The major equipments include portal crane, plants for the backfill material and additive injection, pits for mucking, wastewater plant, and power substation. In addition, the space for storage of lining and rail segments has to be ensured. The outline of the construction yard is indicated in Figure 4-153.

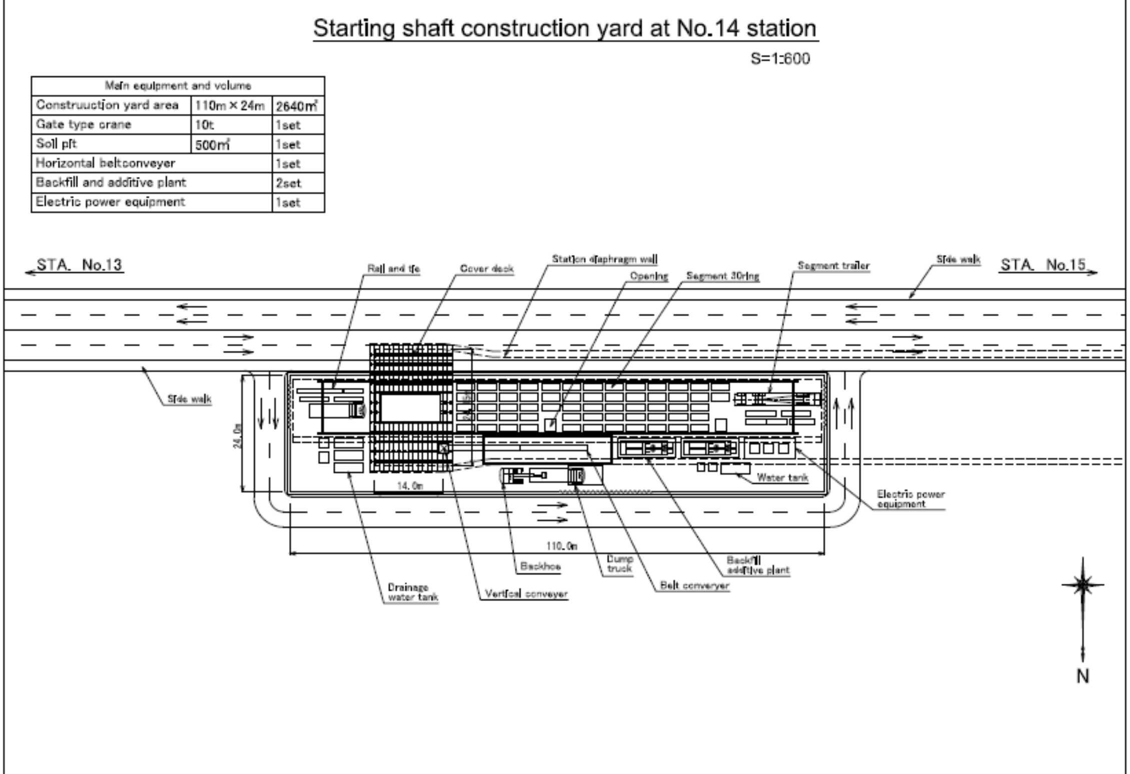


Source: JICA Study Team

Figure 4-153 Layout of the Launch Shaft Construction Yard of Station No. 9

b) Station No.14

The construction yard of launch shaft is planned to be located on the open space along the existing road. The storage space is prepared simultaneously with Station No.9. The outline of the construction yard is indicated in Figure 4-154.



Source: JICA Study Team

Figure 4-154 Layout of the Launch Shaft Construction Yard of Station No.14

4.7 Civil Works (Station)

4.7.1 Basic Condition

(1) Geological Condition

Geological survey was carried out at stations and intermediate points between stations. Typical geological dada and corresponding analysis are presented and summarised in section 4.6.1, Basic Condition of Civil Works (Tunnel).

(2) Basic Design Condition and Requirement

The basic design condition and requirement for the alignment, station, arrangement of station facilities, etc are considered for the planning of the station. A summary of these requirements is shown in Table 4-58.

Table 4-58 Basic Requirement for the Structural Planning

item	contents
Railway alignment	See Section 4.1
Station location	See Section 4.1, 4.9
Arrangement of Station facilities	See Section 4.9
Platform width of island type	12.0 m
Platform length	170.0 m
Minimum width of passenger corridor between platform screen door (PSD) and stairway and escalator	2.5 m
Tunnel type between stations	single track double tunnel

Source: JICA Study Team

Taking into consideration the congested condition of central Greater Cairo City, neighbouring structures, convenience and economical advantages, the main features of the Metro Line 4 are studied and determined. The difference in major features between the Metro Line 4 and other lines are as follows.

- All stations of the Metro Line 4 (Phase 1) are underground.
- Tunnel structure type of the Metro Line 4 is single track double tunnels. On the other hand, that of the existing lines is double track single tunnel.
- The platform of Metro Line 4 is mainly island type except for the two-storey platform stations, namely, El Nile station and El Giza station. On the other hand, those of the existing lines are side platform.
- PSD is installed at all stations of Metro Line 4.

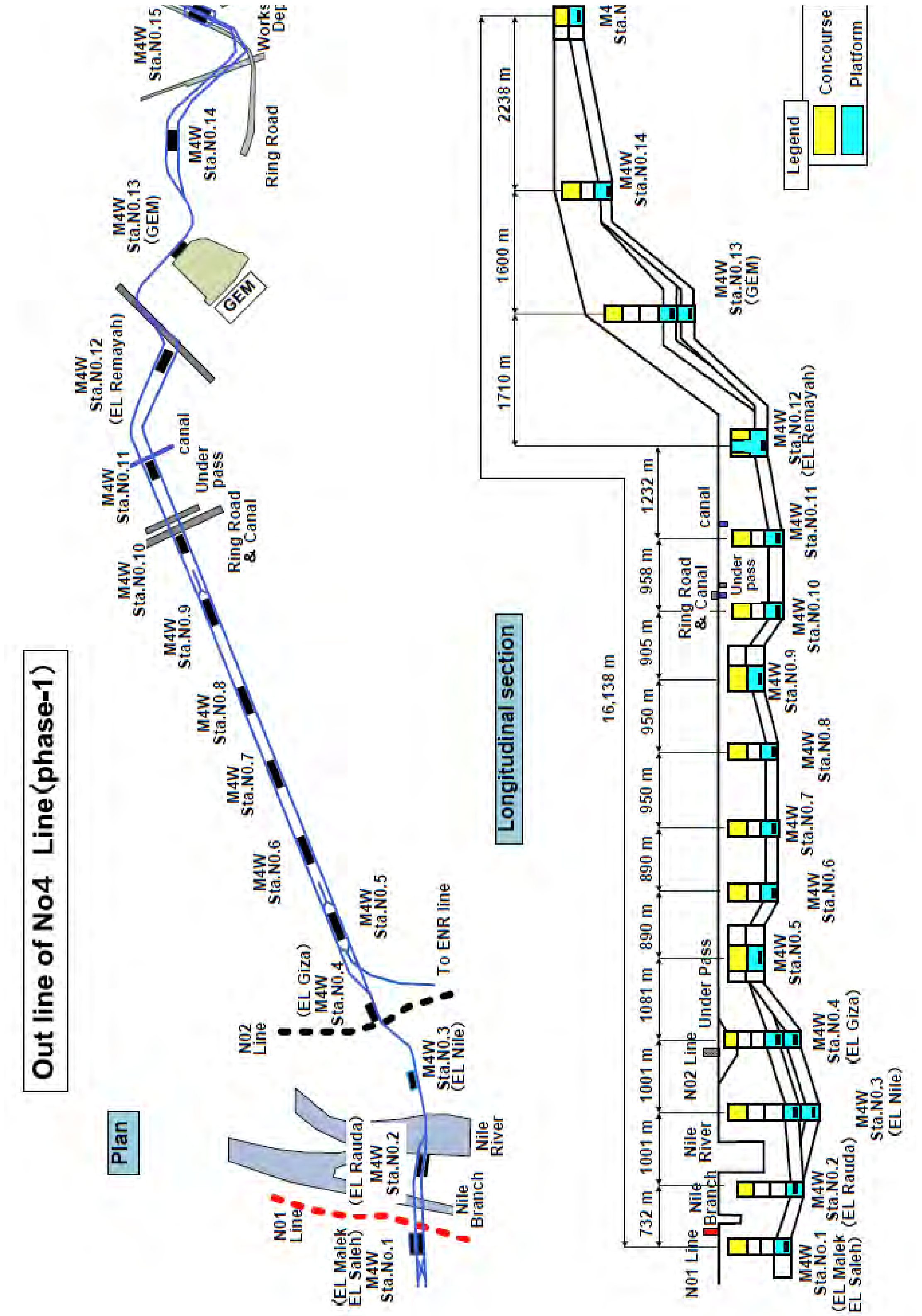
Table 4-59 Comparison of Typical Features of Standard Stations

	Metro Line 3	Metro Line 4
Name of standard station	Abdou Pasha Station	M4W Station No.6
Number of story	3	3
Platform type	side	island
Platform widths	7.015 m	12.0 m with PSD
Platform length	150 m	170 m
Station inner width	20.0 m	21.0 m
Station length	150 m	190 m
Structure type	1 span rigid frame	3 spans rigid frame
Retaining wall	Diaphragm wall	Diaphragm wall
Minimum stairway width at platform	1.2 m	1.5 m
Tunnel type between stations	Double track single tunnel	Single track double tunnel
Remarks	Under construction	Under planning

Source: JICA Study Team

(3) Outline Feature of Stations

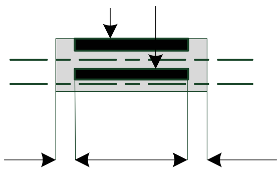
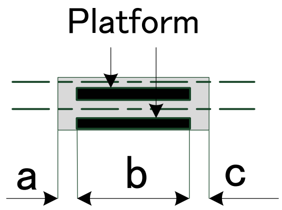
The outline of the stations and major features are shown in Table 4-60 and Figure 4-155.



Source: JICA Study Team

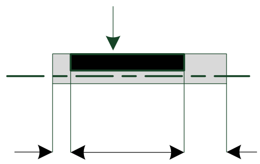
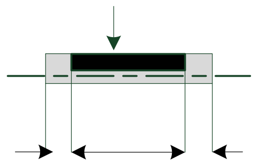
Figure 4-155　Outline of Stations of Metro Line 4 (Phase 1)

Table 4-60 Outline of Station of Metro Line 4 (1/7)

		M4W Station No.1	M4W Station No.2
		El Malek El Saleh	El Rauda
Outline of plane			
Platform	Type	Island and side	2 side
	Width	8.0 m + 10.5 m	12.0 m
	length	170 m	170 m
Scale	Structural type	2 span rigid frame with 4 storeys	2 span rigid frame with 4 storeys
	Inner width	26.0 m	24.0 m
	Outer width	29.0 m	27.0 m
	Bottom depth	32.1 m	35.6 m
Length	Addition (a)	10 m	10 m
	Platform (b)	170 m	170 m
	Addition (c)	10 m	10 m
	Total (a+b+c)	190 m	190 m
Facility arrangement	B1 level	Entrance square, Concourse, Station office	Entrance square, Concourse, Station office, Environmental control System, Electric room
	B2 level	Passenger corridor, Air handling unit, Environmental control System, Electric room	Passenger corridor, Air handling unit
	B3 level	Stair, escalator and elevator, Air handling unit, Tunnel ventilation fans, Tunnel exhaust fans	Stair, escalator and elevator, Tunnel ventilation fans, Tunnel exhaust fans, Spare space for facility room
	B4 level	Platform, Drainage equipment (both ends)	Platform, Drainage equipment (both ends)

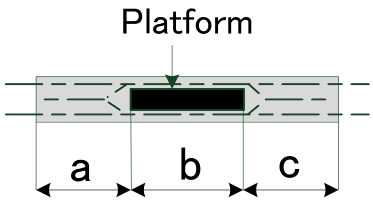
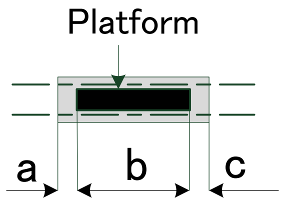
Source: JICA Study Team

Table 4-61 Outline of Station of Metro Line 4 (2/7)

		M4W Station No.3	M4W Station No.4
		El Nile	El Giza
Outline of plane			
Platform	Type	2 side (2 storeys)	2 side (2 storeys)
	Width	12.0 m	13.0 m
	length	170 m	170 m
Scale	Structural type	1 span rigid frame with 5 storeys	1 span rigid frame with 5 storeys
	Inner width	16.5 m	18.5 m
	Outer width	19.5 m	21.5 m
	Bottom depth	44.6 m	36.6 m
Length	Addition (a)	25 m	25 m
	Platform (b)	170 m	170 m
	Addition (c)	40 m	25 m
	Total (a+b+c)	235 m	220 m
Facility arrangement	B1 level	Entrance square, Concourse, Station office, Environmental control System, Electric room	Entrance square, Concourse, Station office, Air handling unit
	B2 level	Passenger corridor, Electric room, Sub station	Passenger corridor, Environmental control System Electric room Spare space for E/M room
	B3 level	Passenger corridor, Air handling unit, Electrical supply station, Tunnel ventilation fans, Tunnel exhaust fans	Passenger corridor, Air handling unit, Tunnel ventilation fans, Tunnel exhaust fans, Spare space for E/M room
	B4 level	Platform, Tunnel ventilation fans	Platform, Tunnel ventilation fans
	B5 level	Platform, Drainage equipment	Platform, Drainage equipment

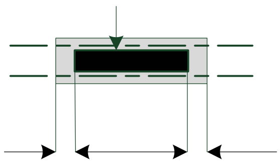
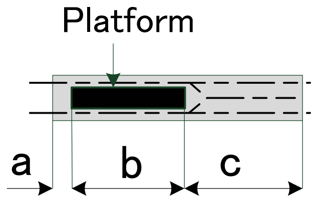
Source: JICA Study Team

Table 4-62 Outline of Station of Metro Line 4 (3/7)

		M4W Station No.5	M4W Station No.6
		El Mesaha Square	Madkour
Outline of plane			
Platform	Type	Island	Island
	Width	12.0 m	12.0 m
	length	170 m	170 m
Scale	Structural type	3 span rigid frame with 2 storeys	3 span rigid frame with 3 storeys
	Inner width	21.0 m	21.0 m
	Outer width	23.4 m	23.4 m
	Bottom depth	20.1 m	27.1 m
Length	Addition (a)	115 m for ENR access line	10 m
	Platform (b)	170 m	170 m
	Addition (c)	290 m for head shunting line	10 m
	Total (a+b+c)	575 m	190 m
Facility arrangement	B1 level	Entrance square, Concourse, Station office, Environmental control System, Electric room, Air handling unit, Tunnel ventilation fans, Tunnel exhaust fans, Sub station	Entrance square, Concourse, Station office, Environmental control System, Electric room
	B2 level	Platform, Drainage equipment, Air handling unit, ENR access line, head shunting line	Passenger corridor, Air handling unit, Tunnel ventilation fans, Tunnel exhaust fans
	B3 level	—	Platform, Drainage equipment

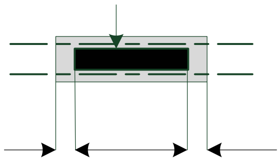
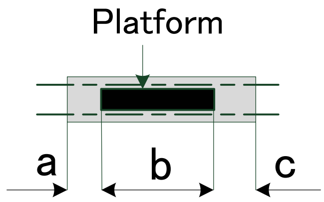
Source: JICA Study Team

Table 4-63 Outline of Station of Metro Line 4 (4/7)

		M4W Station No.7, 8	M4W Station No.9
		El Talbeya and El Matabaa	Hassan Mohammed
Outline of plane			
Platform	Type	island	Island
	Width	12.0 m	12.0 m
	length	170 m	170 m
Scale	Structural type	3 span rigid frame with 3 storeys	3 span rigid frame with 2 storeys
	Inner width	21.0 m	21.0 m
	Outer width	23.4 m	23.4 m
	Bottom depth	27.1 m	20.1 m
Length	Addition (a)	10 m	10 m
	Platform (b)	170 m	170 m
	Addition (c)	10 m	290 m for head shunting line
	Total (a+b+c)	190 m	470 m
Facility arrangement	B1 level	Entrance square, Concourse, Station office, Environmental control System, Electric room	Entrance square, Concourse, Station office, Environmental control System, Electric room, Air handling unit, Tunnel ventilation fans, Tunnel exhaust fans, Sub station
	B2 level	Passenger corridor, Air handling unit, Tunnel ventilation fans, Tunnel exhaust fans	Platform, Drainage equipment, Air handling unit, head shunting line
	B3 level	Platform, Drainage equipment	—

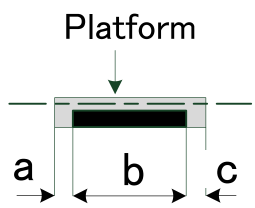
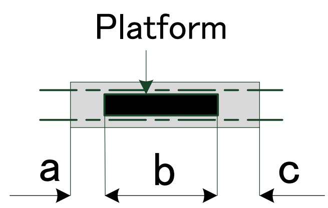
Source: JICA Study Team

Table 4-64 Outline of Station of Metro Line 4 (5/7)

		M4W Station No.10, 11 Maryoutia and Al Ahramat	M4W Station No.12 El Remayah
Outline of plane			
Platform	Type	island	Island
	Width	12.0 m	14.0 m
	length	170 m	170 m
Scale	Structural type	3 span rigid frame with 3 storeys	1 span rigid frame with 2 storeys
	Inner width	21.0 m	23.0 m
	Outer width	23.4 m	26.0 m
	Bottom depth	29.6 m	22.6 m
Length	Addition (a)	10 m	35 m
	Platform (b)	170 m	170 m
	Addition (c)	10 m	40 m
	Total (a+b+c)	190 m	245 m
Facility arrangement	B1 level	Entrance square, Concourse, Passenger corridor, Station office, Environmental control System, Electric room,, Air handling unit	Entrance square, Concourse, Station office, Air handling unit, Environmental control System, Electric room,
	B2 level	Passenger corridor, Air handling unit, Tunnel ventilation fans, Tunnel exhaust fans	Platform, Drainage equipment, Air handling unit, Tunnel ventilation fans, Tnnel exhaust fans, Electric room, Sub station
	B3 level	Platform, Drainage equipment	—

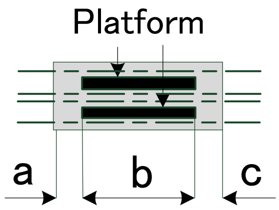
Source: JICA Study Team

Table 4-65 Outline of Station of Metro Line 4 (6/7)

		M4W Station No.13	M4W Station No.14
		GEM	—
Outline of plane			
Platform	Type	2 side (2 storeys)	Island
	Width	12.0 m	12.0 m
	length	170 m	170 m
Scale	Structural type	1 span rigid frame with 5 storeys	3 span rigid frame with 3 storeys
	Inner width	16.5 m	21.0 m
	Outer width	19.5 m	23.4 m
	Bottom depth	40.1 m	25.6 m
Length	Addition (a)	10 m	25 m
	Platform (b)	170 m	170 m
	Addition (c)	10 m	35 m
	Total (a+b+c)	190 m	230 m
Facility arrangement	B1 level	Entrance square, Concourse, Station office, Environmental control System, Electric room	Entrance square, Concourse, Station office, Electric room, Sub station
	B2 level	Passenger corridor, Electric room, Sub station	Passenger corridor, Environmental control System, Air handling unit, Tunnel ventilation fans, Tunnel exhaust fans
	B3 level	Passenger corridor, Air handling unit, Tunnel ventilation fans, Tunnel exhaust fans	Platform, Tunnel ventilation fans, Air handling unit, Drainage equipment
	B4 level	Platform, Tunnel ventilation fans	—
	B5 level	Platform, Drainage equipment	—

Source: JICA Study Team

Table 4-66 Outline of Station of Metro Line 4 (7/7)

		M4W Station No.15 —
Outline of plane		
Platform	Type	2 Islands
	Width	12.0 m + 12.0 m
	length	170 m
Scale	Structural type	3 span rigid frame with 2 storeys
	Inner width	40.0 m
	Outer width	42.4 m
	Bottom depth	20.6 m
Length	Addition (a)	10 m
	Platform (b)	170 m
	Addition (c)	40 m
	Total (a+b+c)	220 m
Facility arrangement	B1 level	Entrance square, Concourse, Station office, Environmental control System, Electric room, Air handling unit, Tunnel ventilation fans, Tunnel exhaust fans, Sub station
	B2 level	Platform, Drainage equipment, Air handling unit

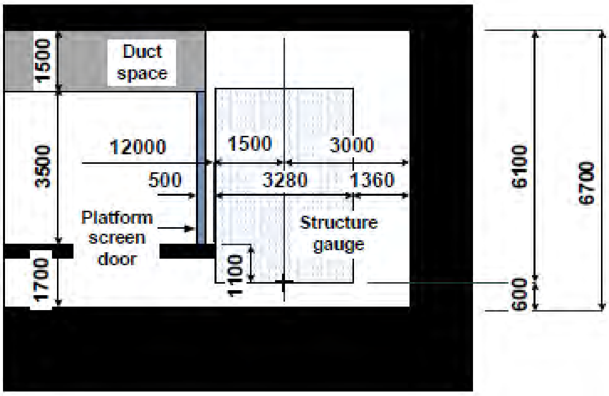
Source: JICA Study Team

4.7.2 Required Clearance and Space

(1) Structural Gauge and Inner Cross Section of Station

The inner cross section of the platform level is shown in Figure 4-156. The major feature of the clearance is as follows:

- Clearance between the rolling stock gauge and the column of PSD is 200 mm. Therefore, distance between track centre and edge of platform is 1500 mm.
- Distance between the edge of the track and wall is planned to be 1360 mm taking into consideration the clearance for the maintenance work.



Source: JICA Study Team

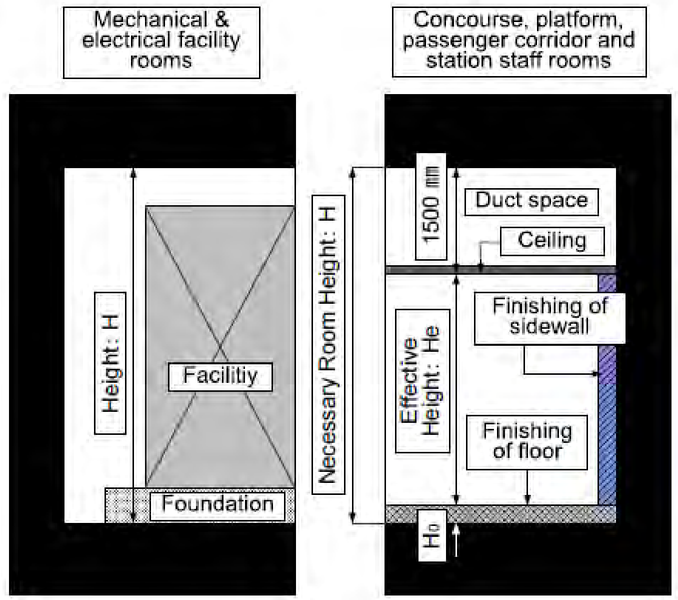
Figure 4-156 Structural Gauge and Inner Cross Section of Station

The station is composed of the spaces for the platform, concourse, entrance square, electrical and mechanical rooms and station office. In order to provide appropriate space for each facility and rooms, the required heights are planned as follows.

Table 4-67 Planned Height of Facilities and Rooms in Station

	Finishing of floor H0 (mm)	Required Height (mm)	Duct space on ceiling (mm)	Standard height H (mm)	Minimum height H mm)
Platform	100	2700-3400	1500	5000	4300
Concourse	200	2700-3300		5000	4400
Station office					
E&M room	－	4000-5000	－	5000	4000
Sub-station	－	6000	－	6000	6000

Source: JICA Study Team

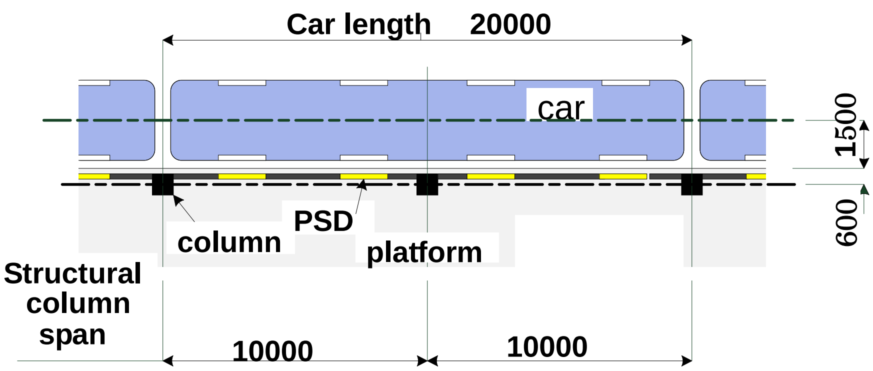


Source: JICA Study Team

Figure 4-157 Height of Spaces and Rooms in Station

(2) Distribution of Structural Column at Platform

PSD is planned to be installed in Metro Line 4. Taking into account the array of the PSD, spacing between columns is proposed to be 10.0 m as shown in Figure 4-158.

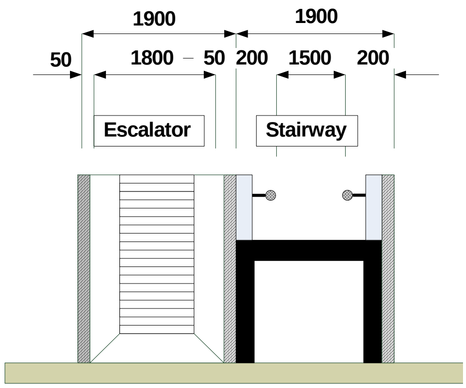


Source: JICA Study Team

Figure 4-158 Distribution of Structural Columns and Array of the PSD

(3) Width of Escalator and Stairway at Platform

Minimum width of escalator and stairway is shown in Figure 4-159. The provision for escalator and stairway includes the space for the interior finish on wall and column. Effective width of stairway should be more than 1500 mm.



Source: JICA Study Team

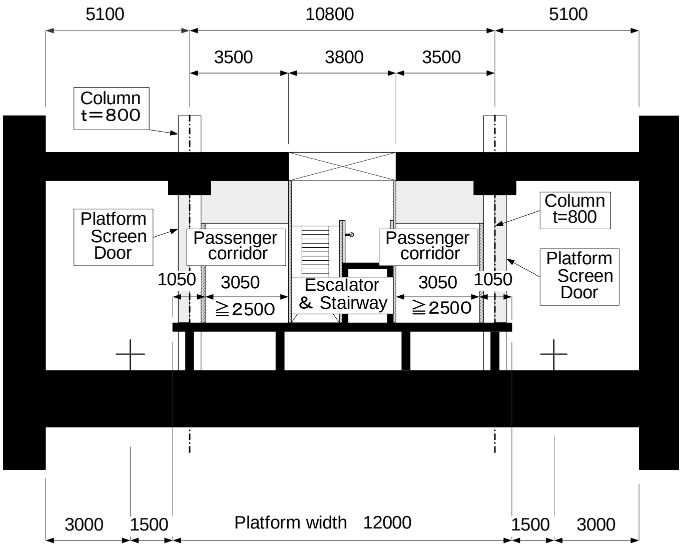
Figure 4-159 Minimum Width of Escalator and Stairway

4.7.3 Study of Structure for Standard Station

The structure of the standard station is studied taking into account size of the station, construction cost and service level for the passengers. The possible structural types for the standard station are the three-storey type, two-storey type and the two-storey type with atrium. Since each structural type has advantage and disadvantage, a comparative study is carried out.

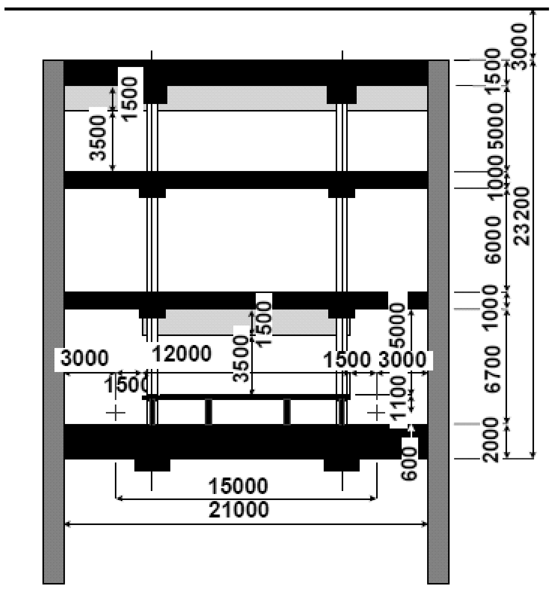
(1) Cross-Sectional Structure of the Standard Station

The platform structure for the standard station is studied. The passenger corridors at platform are important space for the safety and smooth operation of station. The minimum width of the passenger corridors is 2500 mm. In order to assure this space on the platform, the location of structural columns, escalators, stairway, PSD are arranged as illustrated in Figure 4-160. The structural columns are used to support both the station structure and the PSD. The structural section of each station type is shown in Figure 4-161 to Figure 4-163.



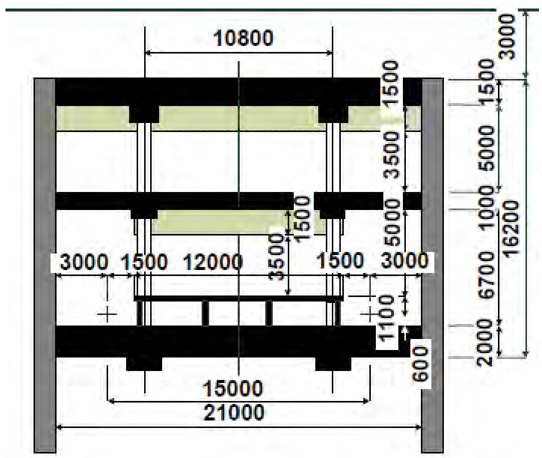
Source: JICA Study Team

Figure 4-160 Platform Structure Plan of a Standard Station



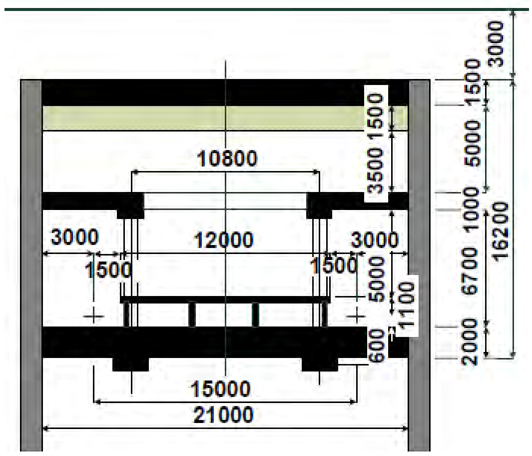
Source: JICA Study Team

Figure 4-161 Section of Standard Three-storey Station



Source: JICA Study Team

Figure 4-162 Section of Standard Two-storey Station

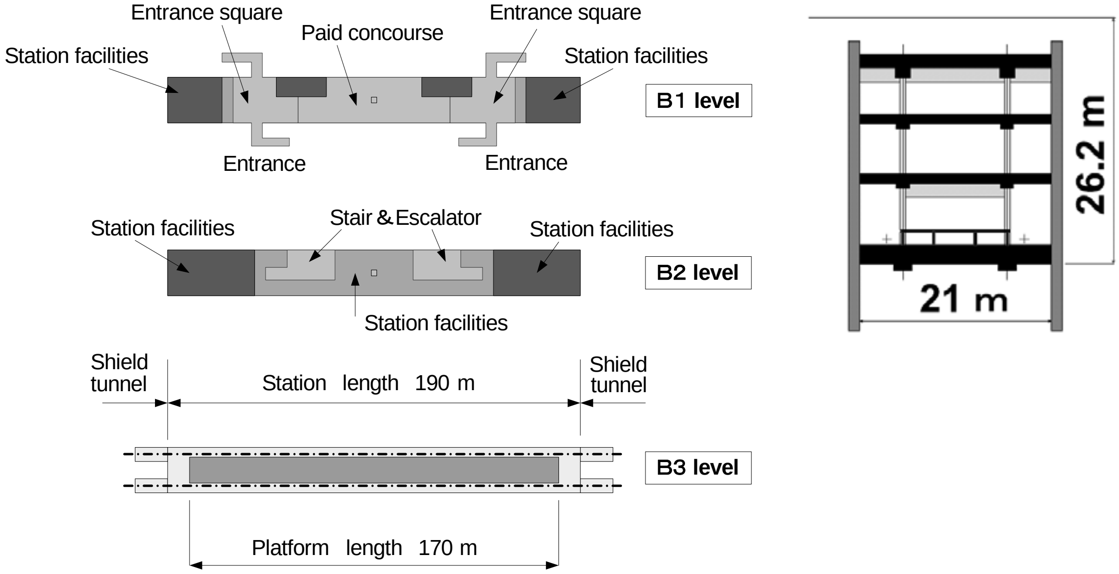


Source: JICA Study Team

Figure 4-163 Section of Standard Two-storey Station with Atrium

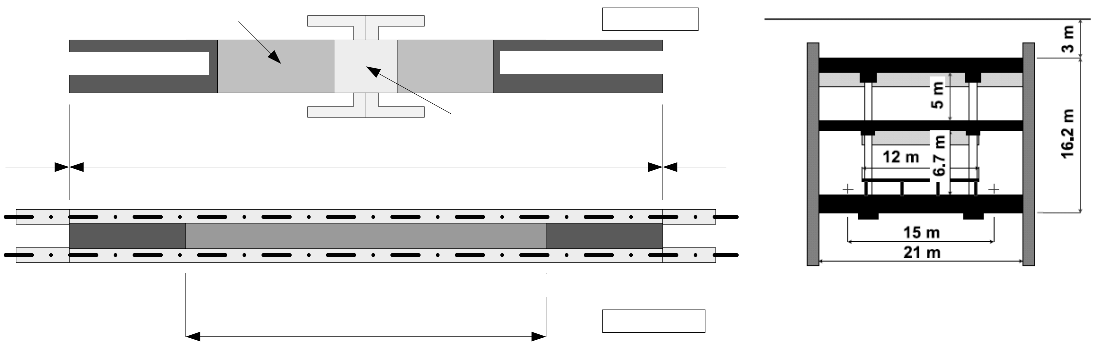
(2) Plan of the Standard Station

The station length is determined by the required space and arrangement of platform, stairway, electrical and mechanical rooms, station office and entrance square. Plan for each type of station is illustrated as follows.



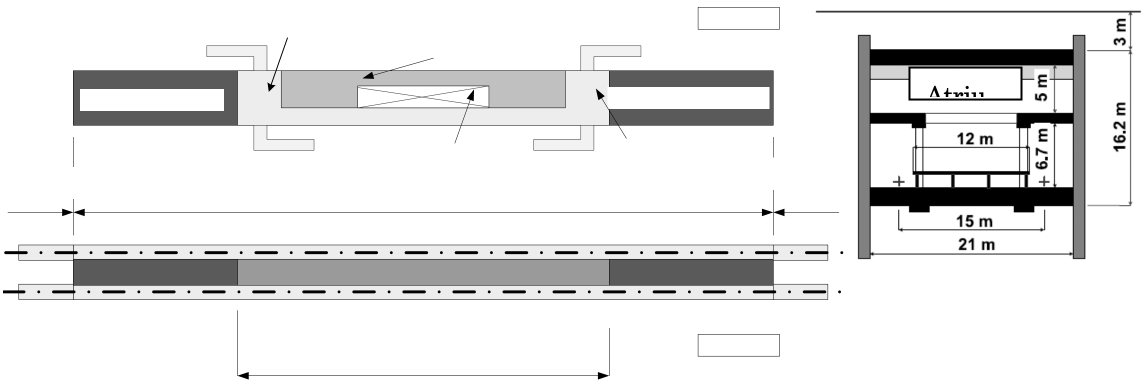
Source: JICA Study Team

Figure 4-164 Plan of Standard Three-storey Station



Source: JICA Study Team

Figure 4-165 Plan of Standard Two-storey Station



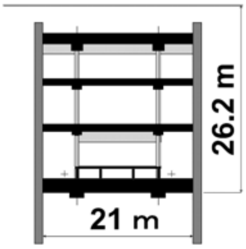
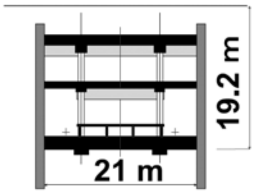
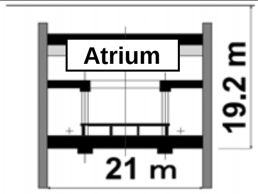
Source: JICA Study Team

Figure 4-166 Plan of Standard Two-storey Station with Atrium

(3) Comparison of the Three Types of Structure as Standard Station

Comparison among the three types of structure is carried out taking into account the service level for the passengers and construction cost. The service level and construction cost are compared in terms of trade off. In order to determine the structure of the standard station, the construction cost is mainly focused for comparison. The comparison is summarised in Table 4-68.

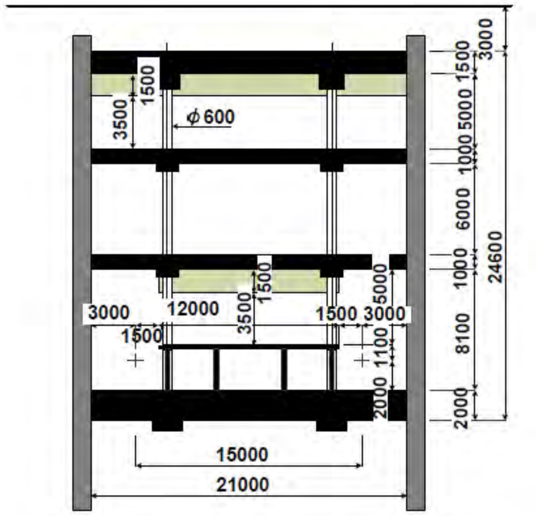
Table 4-68 Comparison of Structures for the Standard Station

	Three-storey type	Two-storey type	
		Without atrium	With atrium
Outline (cross section)			
Inner width of Station	21.0 m	21.0 m	21.0 m
Station length	190.0 m	280.0 m	320.0 m
Accessibility from concourse to platform	Vertical distance: 13 m use of stairway: 2 times	Vertical distance: 6.0 m use of stairway: 1 time	Vertical distance: 6.0 m use of stairway: 1 time
Volume of Excavation	About 104,500 m^3	About 113,000 m^3	About 129,000 m^3
Concourse (B1 level)	Area: 2,730 m^2 Entrance square: 2 places	Area: 2,310 m^2 Entrance square: 1 place	Area: 3,570 m^2 Entrance square: 2 places
Construction costs ratio	1.0	1.08	1.23
Construction Period ratio	1.0	1.2	1.4
Characteristic	Most economical for construction cost, and similar to Metro Line 3 under construction	Most convenient for passengers, but expensive for construction	Most Convenient and comfortable for passengers, but most expensive for Construction
Recommendation	For typical standard Station of Metro Line 4	For long length station required by another reason like turn-back track	For only special station of Metro Line 4
Applicable station	No.6, 7,8,10,11,14	No.5, 9	inapplicable

Source: JICA Study Team

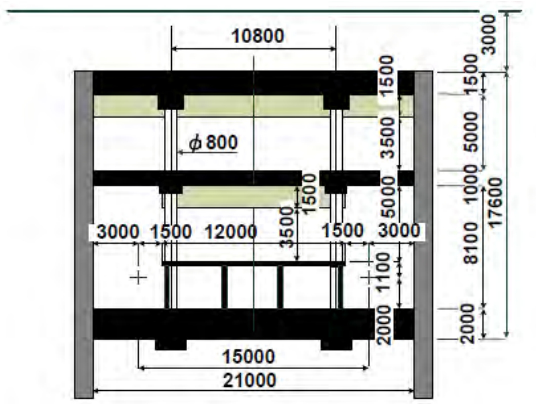
(4) Consideration of the Shield TBM Passing for the Standard Station

According to the overall construction schedule, it is necessary for the shield TBM to pass through some stations. In that case, the height of the platform level should be increased to allow for the passage of the shield TBM. The vertically elongated stations are illustrated in Figure 4-167 and Figure 4-168.



Source: JICA Study Team

Figure 4-167 Elongated Standard Three-storey Station



Source: JICA Study Team

Figure 4-168 Elongated Standard Two-storey Station

(5) Consideration of the Location for Structural Column on the Platform

With regard to the installation of structural columns at platform edge, further study will be required and carried out considering the following aspects.

a) Installation of the PSD

The PSDs should be installed at appropriate positions.

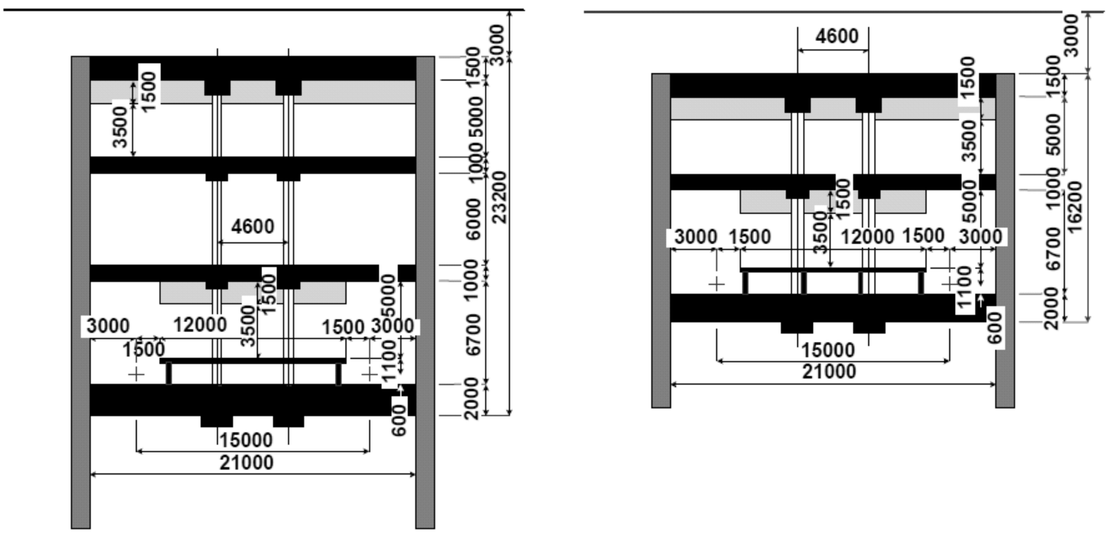
b) Operation

Columns on the platform should not hamper any operation of train service and safety of the passengers.

c) Visibility

The clear visibility of the driver/station staffs on the platform should be ensured without any invisible spaces.

In case the columns at the edge of the platform hamper the operation of train services and installation of the PSD at appropriate position, consequently affecting the visibility of the driver/station staffs on the platform, relocation of said columns further inside the platform will be considered and studied. Cross sections of the standard stations are shown in Figure 4-169



Three storeys **Two storeys**

Figure 4-169 Relocation of Columns for Standard Stations

4.7.4 Study of Structure for Other Stations

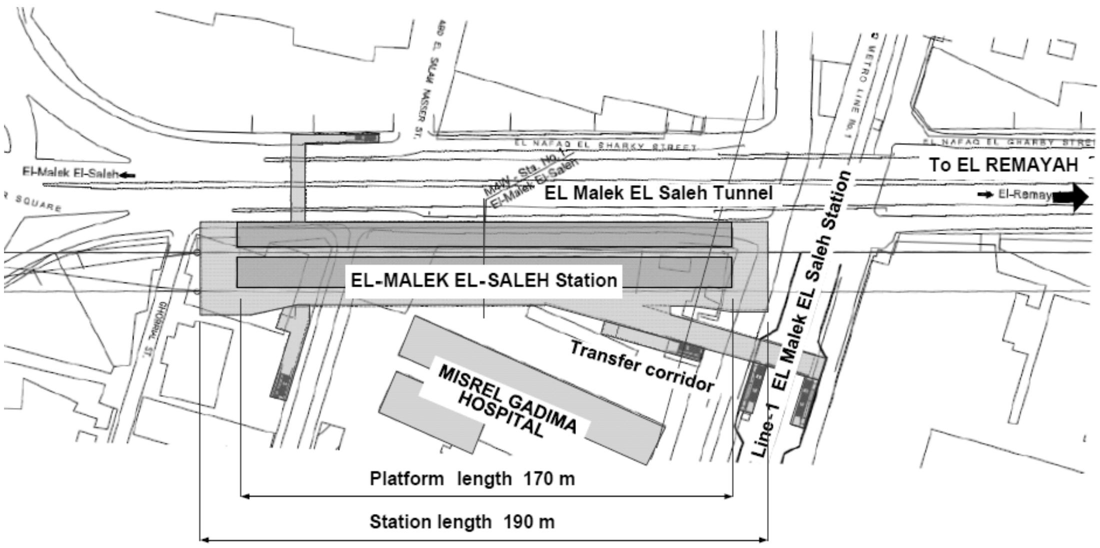
Some stations are located in densely populated and congested areas where there are constrains on land use at the ground level. In order to avoid some structures or minimize land acquisition, the alignment and station structures are significantly affected. Besides, the alignment is vertically deepened at the Nile River crossing and the depth of the station in its vicinity is also considerably affected. The station structures in said area are different from that of the standard stations which are located under Pyramid Street. The structures of such stations are studied in this section.

(1) M4W Station No.1（El Malek El Saleh Station）

a) Control Points and Important Factors

The El Malek El Saleh Station is located in the proximity of hospital, mosque and existing El Malek El Saleh Station of Metro Line 1. Furthermore, the turn back track is installed behind said station. Therefore, the control points and important factors for the station planning are summarised as follows.

- Avoid Misrel Gadima Hospital as much as possible
- Minimize land acquisition
- Facilitate the passenger’s transfer between Metro Line 1 and 4
- Minimize the damage and influence to El Malek El Saleh Tunnel
- Shorten the turn back track section as much as possible



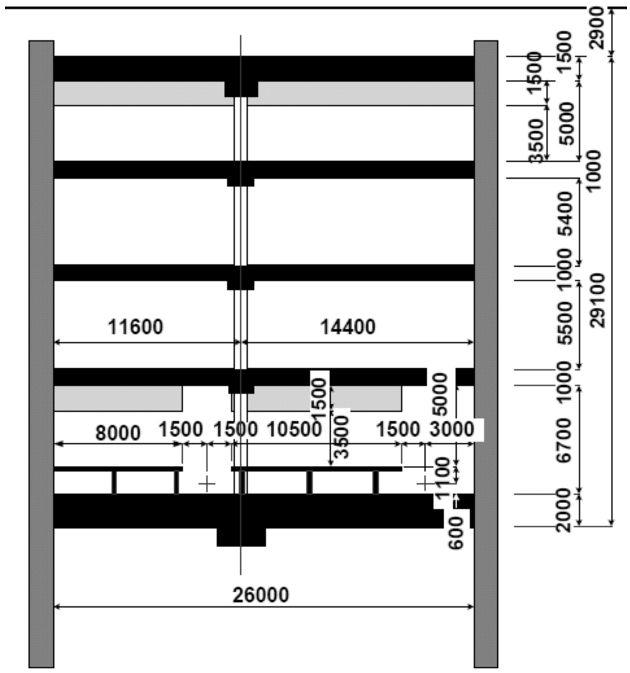
Source: JICA Study Team

Figure 4-170 Plan of El Malek El Saleh Station

b) Structure of Station

The structure of the El Malek El Saleh Station is studied taking into account control points and important factors. The characteristics of the structure of station are as follows.

- Station is composed of four storeys and two-span rigid frame structure.
- The structural column is used to support both the station structure and PSD to ensure appropriate space for the passenger corridor.
- Two platforms (side and island) are irregularly positioned to maintain the capacity of platform and shorten the turn back section as much as possible.
- The excavation depth is 32 m.

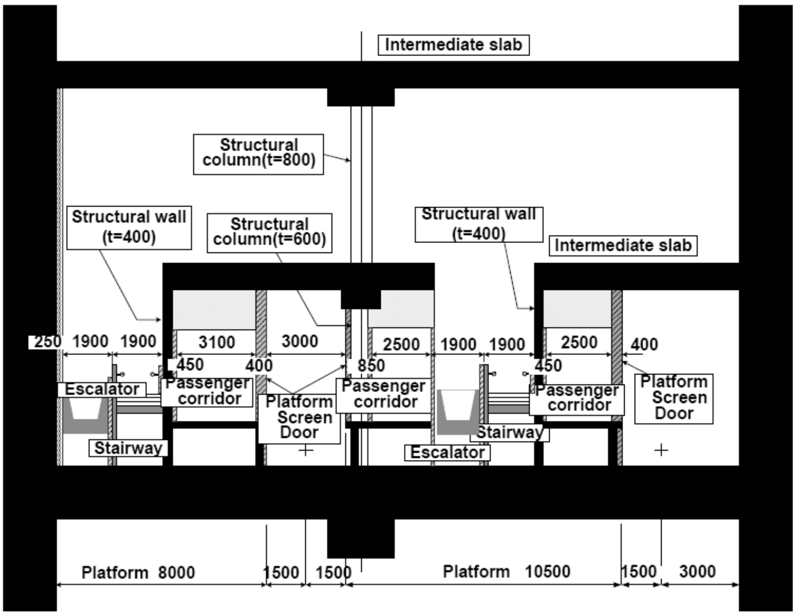


Source: JICA Study Team

Figure 4-171 Structure of El Malek El Saleh Station

c) Consideration for the Opening of Intermediate Slab

In order to install the stairway and escalator, a large opening is provided on the intermediate slab. In that case, the structural study for the influence of the opening is necessary. The opening gives impact on the vertical support mechanism of the slab and lateral support mechanism of the diaphragm wall. The large opening and other required spaces is illustrated in Figure 4-172.

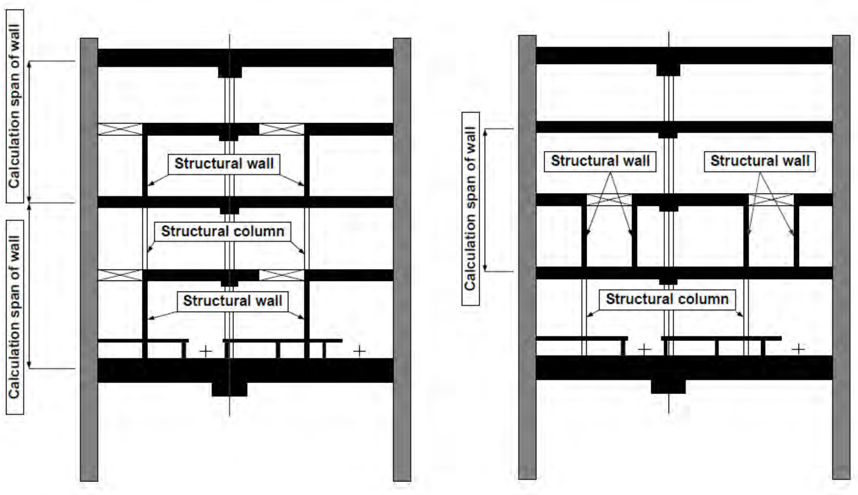


Source: JICA Study Team

Figure 4-172 Large Opening for the Stairway and Escalator

The vertical support mechanism of the slab and lateral support mechanism of the diaphragm wall are illustrated in Figure 4-173.

- In case that large opening is provided on the intermediate slab, the diaphragm wall will be supported by the top slab and the slab of B2 floor against the lateral load.
- In order to reinforce the vertical support which weakened by the opening on the slab, supplemental structural walls and columns are installed as indicated in Figure 4-173.

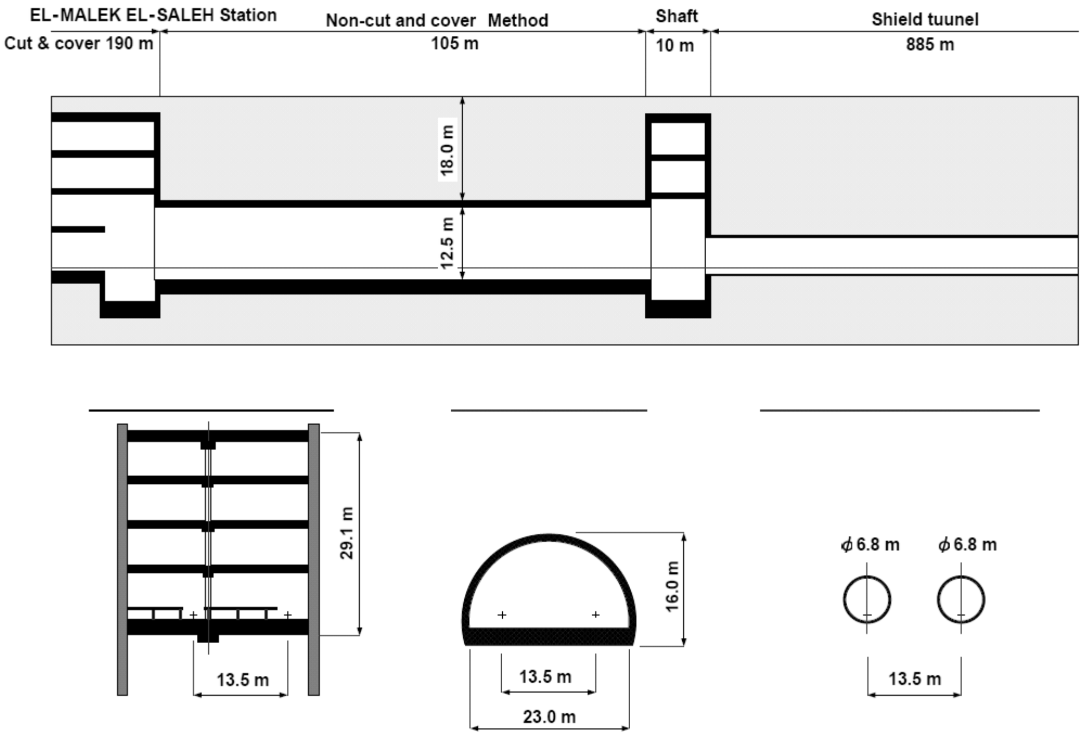


Source: JICA Study Team

Figure 4-173 Arrangement of the Supplemental Structural Wall and Column to Support Large Opening on Slabs

d) Consideration for the Turn Back Track Section

Provision of one scissor crossing beyond the platform for shuttling operation until Phase 2 opens is required. However, it will not be able to place the scissor crossing by adopting cut-and-cover method since a mosque obstructs the section. Therefore, a special method is required which will protect the mosque during and after the construction as well as avoid land acquisition as shown in Figure 4-174.



Source: JICA Study Team

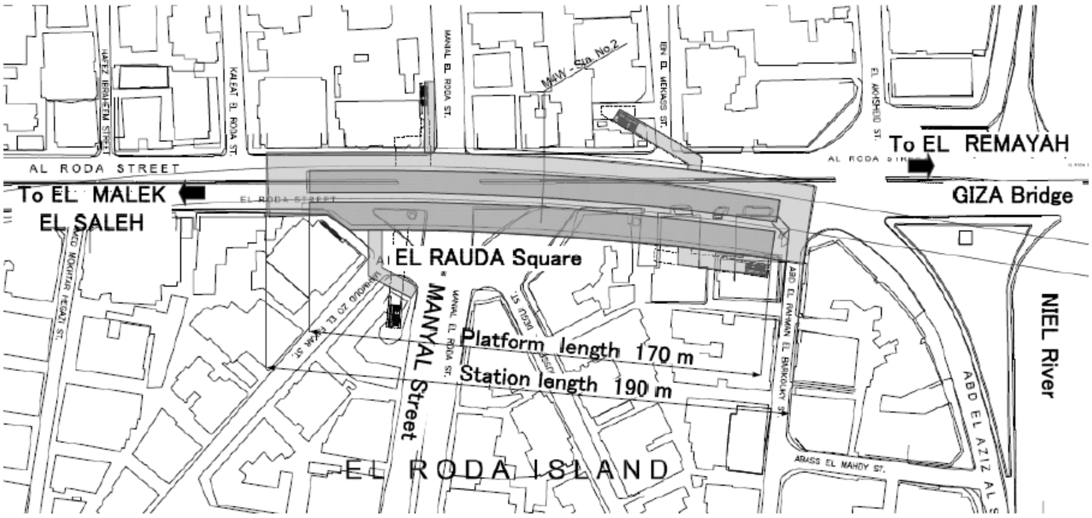
Figure 4-174 Turn Back Track Section (Scissors Crossing)

(2) M4W Station No.2（El Rauda Station）

a) Control Points and Important Factors

El Rauda station is located in El Rauda Island surrounded by seven to eight storey buildings. The station will be located in a curve section and separate type of platform is then proposed. The control points and important factors for the station planning are summarised as follows.

- Minimize land acquisition
- Avoid a mosque
- Avoid the foundation of the El Giza Bridge



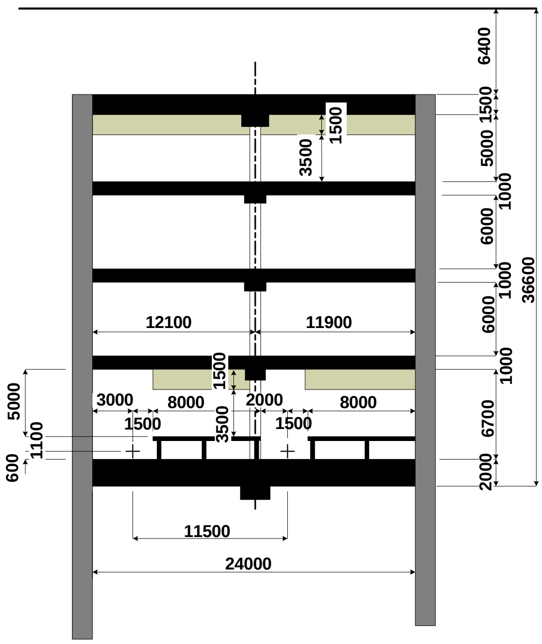
Source: JICA Study Team

Figure 4-175 Plan of El Rauda Station

b) Structure of Station

The structure of the El Rauda Station is studied taking into account the control points and important factors. The characteristics of the structure of the station are as follows:

- Station is composed of four storeys and two-span rigid frame structure.
- The structural column is used to support both the station structure and the PSD to ensure appropriate space for the passenger corridor.
- Two platforms (side and island) are irregularly installed to maintain the capacity of the platform.
- The excavation depth is about 36.6 m.

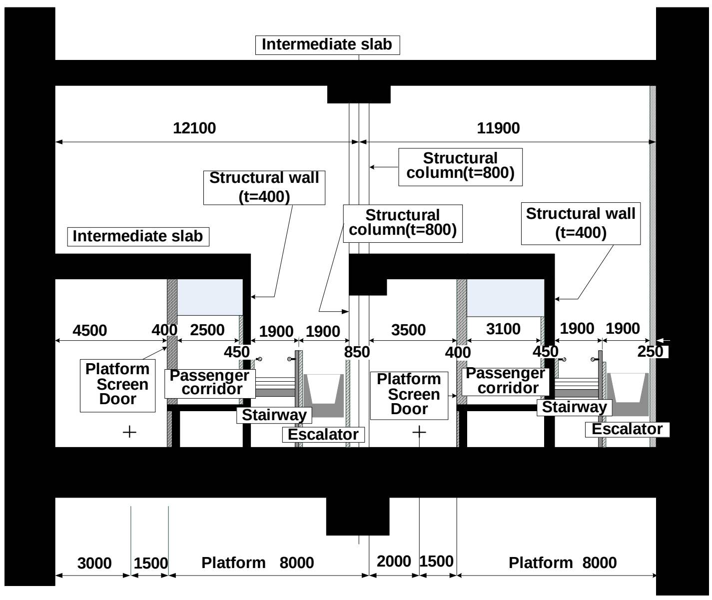


Source: JICA Study Team

Figure 4-176   Structure of El Rauda Station

c)   Consideration for the Opening of Intermediate Slab

In order to install the stairway and escalator, a large opening is provided on the intermediate slab. In that case, the structural study for the influence of the opening is necessary. The opening gives impact on the vertical support mechanism of the slab and lateral support mechanism of the diaphragm wall. The large opening and other required spaces is illustrated in Figure 4-177.



Source: JICA Study Team

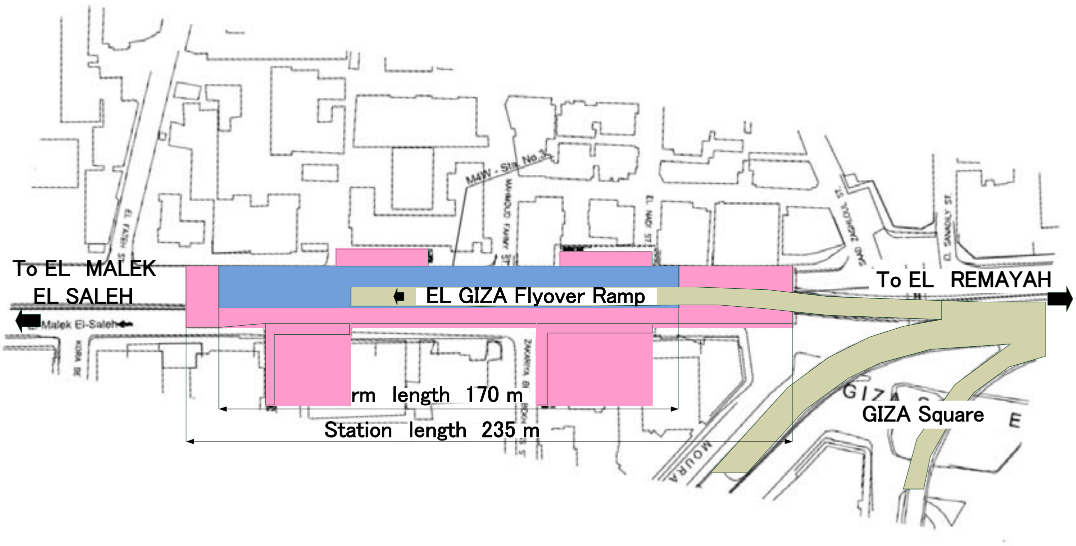
Figure 4-177   Large Opening for the Stairway and Escalator

(3) M4W Station No.3（El Nile Station）

a) Control Points and Important Factors

El Nile station is located under the Giza Flyover. A new pedestrian underpass which crosses this flyover is under construction to connect with an existing bus terminal and other sidewalk. Control points and important factors for the station planning are summarised as follows:

- Minimize land acquisition
- Facilitate a safe and efficient station access route for passengers
- Minimize the damage and demolishment of Giza Flyover



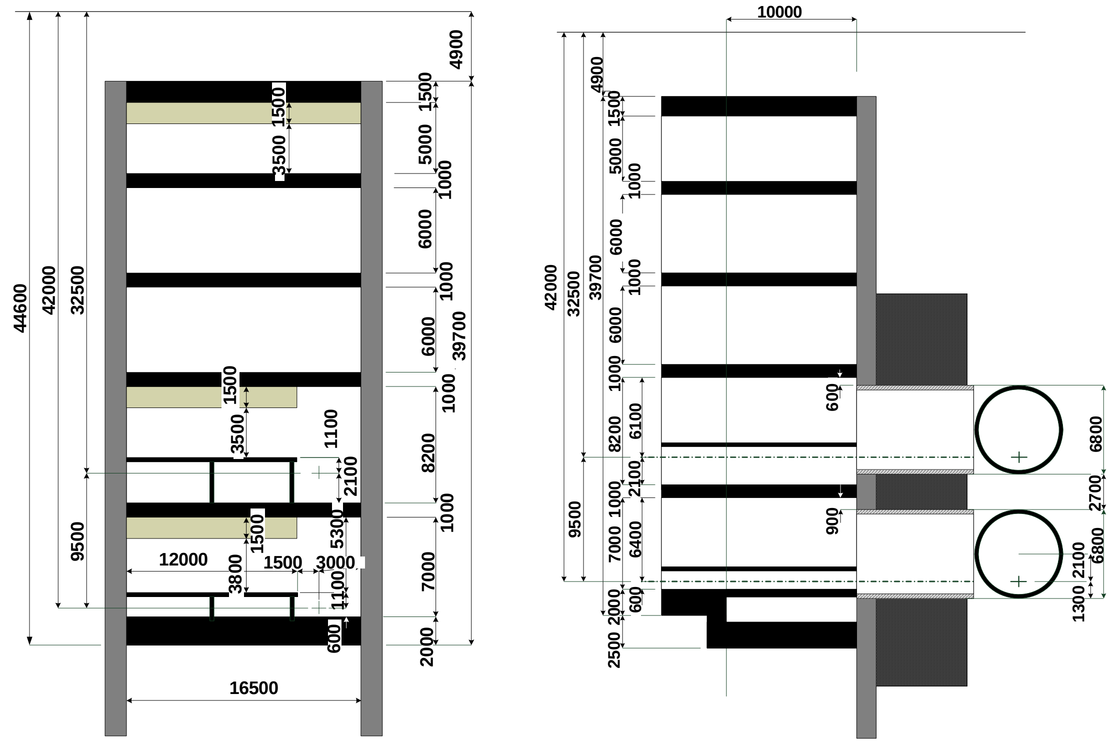
Source: JICA Study Team

Figure 4-178 Plan of El Nile Station

b) Structure of Station

The structure of El Nile Station is studied taking into account control points and important factors. The station is deepest among Metro Line 4 stations. The characteristics of the structure of station are as follows:

- It is composed of five storeys and one span rigid frame structure.
- Two storeys platform is provided to minimize land acquisition.
- Roof slab of station must be able to support the foundation of flyover bridges
- Excavation depth is about 43.6 m.

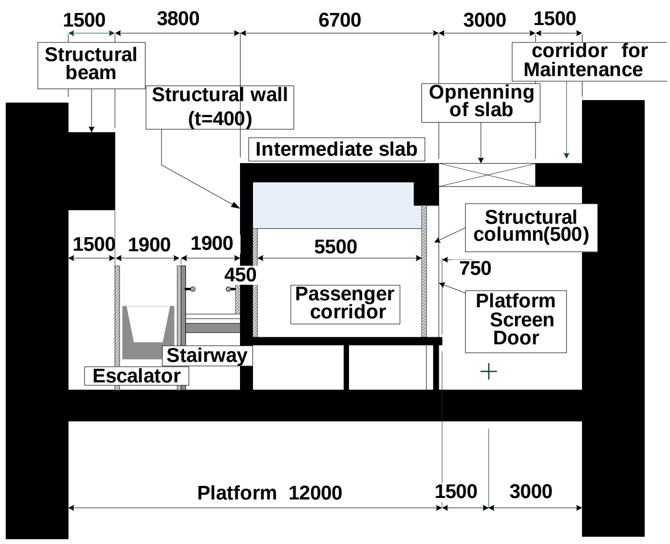


Source: JICA Study Team

Figure 4-179　Structure of El Nile Station

c)　Consideration for the Opening of Intermediate Slab

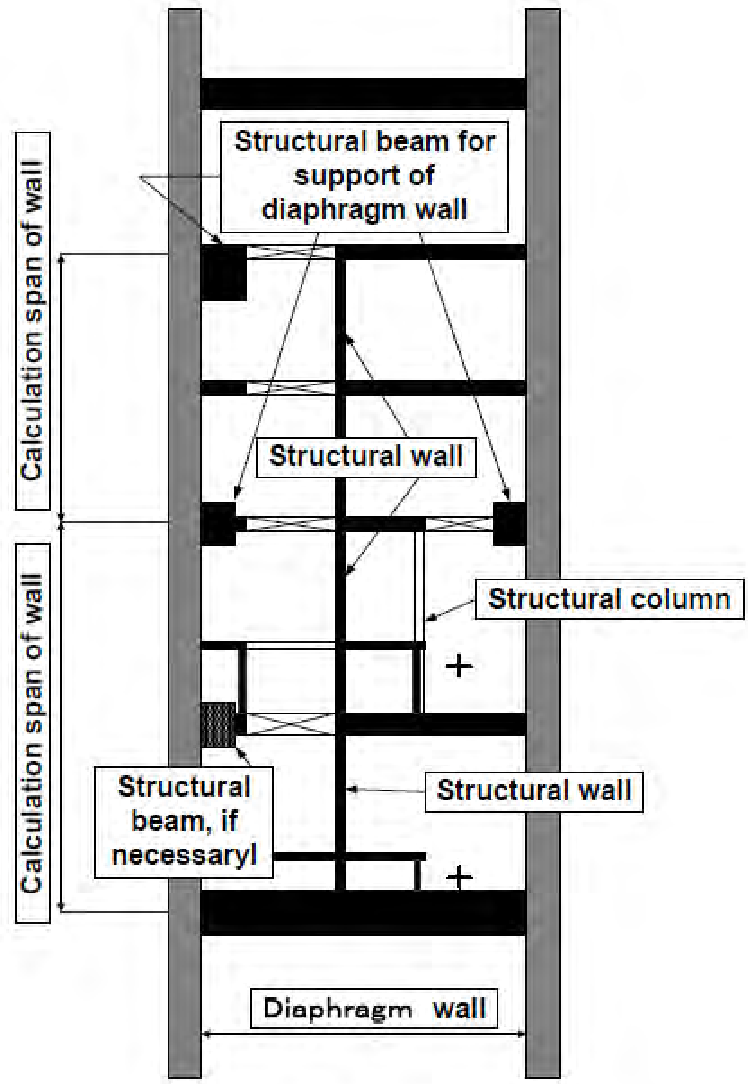
In order to install the stairway and escalator, a large opening is arranged on the intermediate slab. In such case, the structural study for the influence of the opening is necessary. The opening gives impact on the vertical support mechanism of the slab and lateral support mechanism of the diaphragm wall. The large opening and other required spaces are illustrated in Figure 4-180.



Source: JICA Study Team

Figure 4-180　Large Opening for the Stairway and Escalator

In this station, support mechanism of diaphragm wall poses a serious problem, because the openings of the four slabs are at the same location of the stairway arrangement. Structural beams should be constructed for the purpose of ensuring the stability of the diaphragm wall.



Source: JICA Study Team

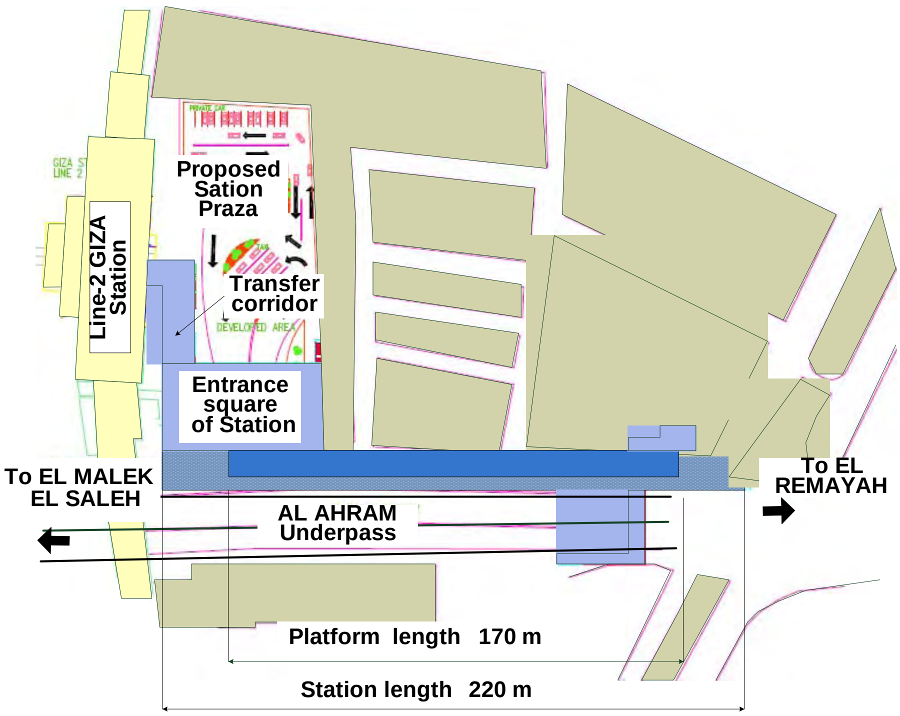
Figure 4-181 Support Mechanism in case of Open Slab

(4) M4W Station No.4（El Giza Station）

a) Control Points and Important Factors

El Giza station is located near the Al Ahram underpass and crosses under the ENR line and a Metro Line 2 viaduct station. The control points and important factors for the station planning are summarised as follows.

- Minimize land acquisition
- Facilitate the passenger's transfer between Metro Line 2 and 4
- Minimize the damage and demolishment to Pyramids Road underpass
- Reduce influence on traffic of Al Aharam underpass during the construction
- It is inevitable to demolish some part of Al Aharam underpass (see Figure 4-183). In order to minimize the influence and restore Al Aharam underpass, dividing the station construction may possibly be adopted. In this case, the construction period will be longer and TBM will be driven before the station excavation. Therefore, this possibility is also considered for the study of station structure.



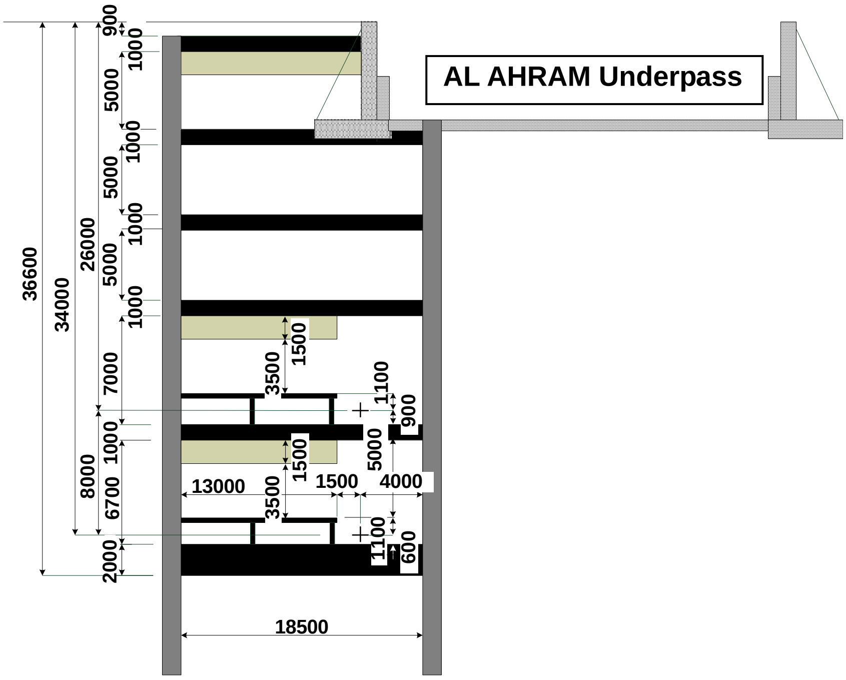
Source: JICA Study Team

Figure 4-182 Plan of El Giza Station

b) Structure of Station

The structure of El Giza Station is studied taking into account the control points and important factors. The characteristics of the structure of station are as follows.

- Station is composed of five storeys and one span rigid frame.
- Two-storey platform is installed to minimize land acquisition.
- The excavation depth is about 36.6m.



Source: JICA Study Team

Figure 4-183 Cross Section of El Giza Station

c) Consideration for the Opening of Intermediate Slab

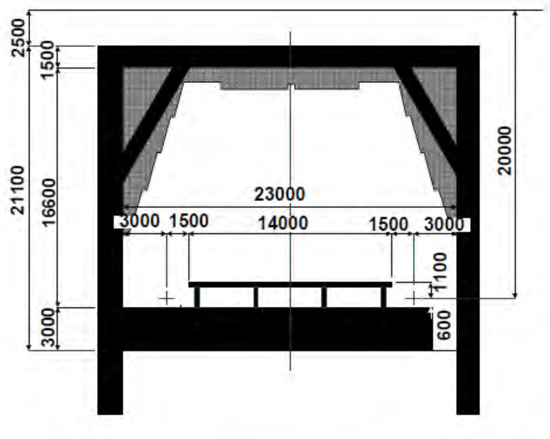
The large opening affects the vertical support mechanism of the slab and lateral support mechanism of the diaphragm wall, same as El Nile station.

(5) M4W Station No.12（El Remayah Station）

a) Structure of Station

The structure of El Remayah Station is studied taking into account control points and important factors. The characteristics of the structure of the station are as follows:

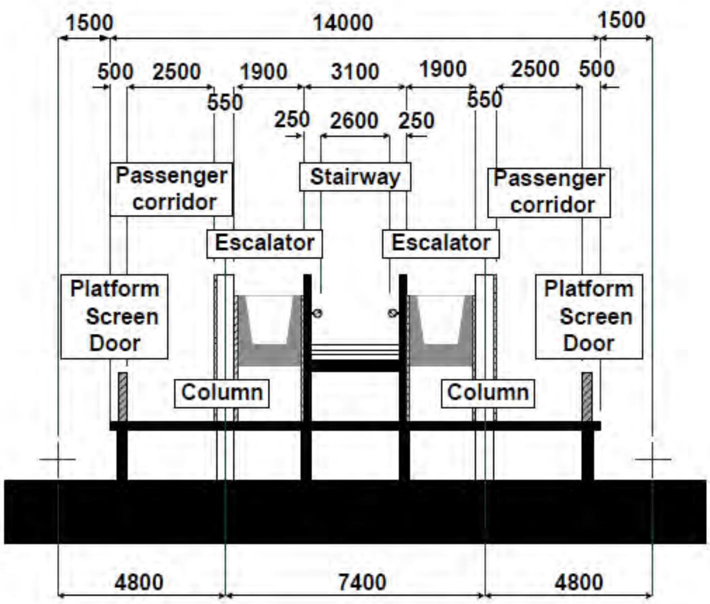
- Station is composed of one storey and one span rigid frame structure.
- The excavation depth is about 22.6 m



Source: JICA Study Team

Figure 4-184 Cross Section of El Remayah Station

The location of structural columns, escalators, stairway, and PSD are arranged as illustrated in Figure 4-185.



Source: JICA Study Team

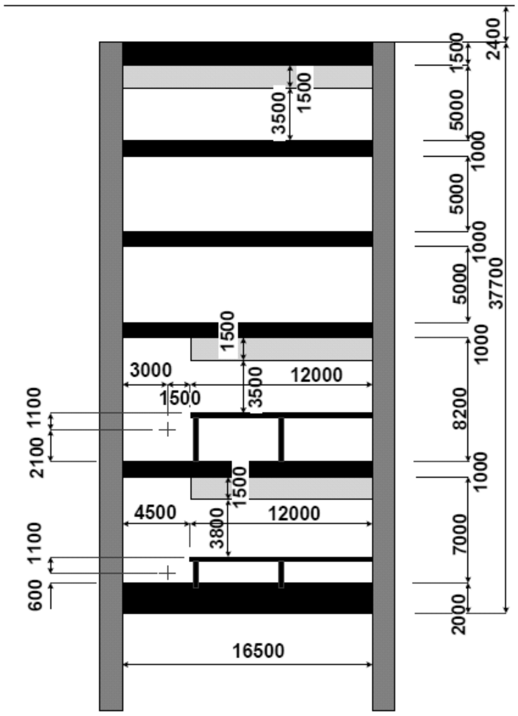
Figure 4-185 Section of Platform Structure of El Remayah Station

(6) N4W Station No.13 (GEM)

a) Structure of Station

The structure of GEM Station is studied taking into account control points and important factors. The characteristics of the structure of station are as follows.

- Station is composed of one span rigid frame with five storeys.
- Two-storey platform is installed to minimize land acquisition
- The excavation depth is about 40.1 m
- Structural type is same as El Nile Station.



Source: JICA Study Team

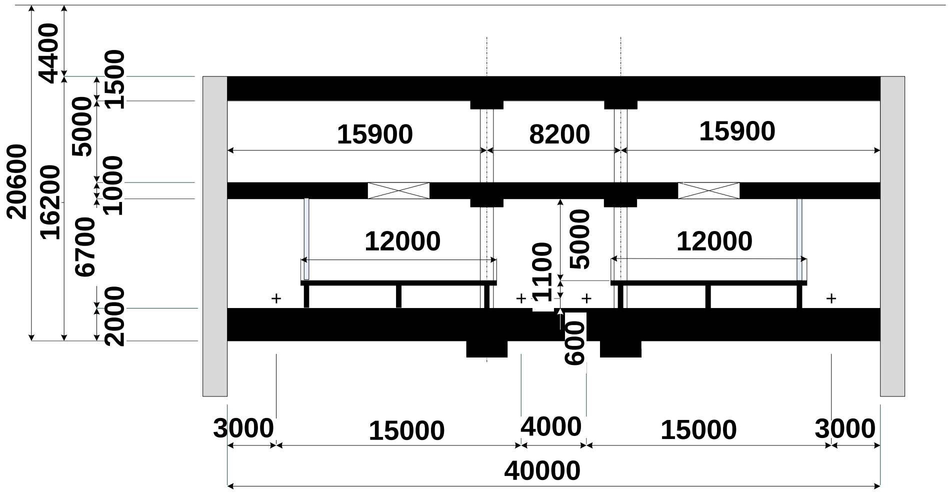
Figure 4-186 Cross Section of Station No. 13

(7) N4W Station No.15

a) Structure of Station

The structure of No.15 Station is studied taking into account control points and important factors. The characteristics of the structure of station are as follows:

- Station is composed of three-span rigid frame with two storeys.
- Inner width of the station is the widest among the Metro Line 4 stations as the terminal consist of two platforms.
- The excavation depth is about 20.6 m



Source: JICA Study Team

Figure 4-187 Cross Section of Station No. 15