4.3.2 Existing Standard for Fire Fighting and Management of Metro

The characteristics of the fire accidents are indicated in the preceding section. According to the type of tunnels, the standard/design guideline for fire accident management is regulated by some countries taking these characteristics into consideration. On the other hand, the countries which do not have tunnels and underground stations blindly use or apply other country's standard/design guideline. As a result, the scale of the tunnel and station becomes more excessive than its requirement in some cases. In order to apply appropriate measure and method, the present conditions of standards/guidelines for metro construction/operation in the world are explained in this section and some points of these standards are studied in the following section.

(1) NFPA 130 (USA)

NFPA 130 which is the "Standard for Fixed Guideway Transit and Passenger Rail Systems" is the standard of USA for the design of the metro. It is widely used in countries which do not have their own standard/regulation and it has strong influence in other countries. So far, this standard is applied for the metro in India, Singapore, etc.

NFPA 130 is one of the strictest standards and it could not be often applied for the old metro which was constructed before NFPA 130, which was established in 1983. If this standard is applied strictly, the structure of the tunnel and station tends to be bigger and the cost of the construction also tends to be higher.

From the above reasons, NFPA 130 is applied even in North America as the guideline in some metro agencies which have underground sections. In Table 4-28, it is shown that NFPA 130 is used as the standard (law) or guideline in North America.

Table 4-28 Use of NFPA 130 in North America (USA and CANADA)

Country	City	Agency	Use of NFPA 130	
			Law	Guideline
USA	Chicago	Chicago Transit Authority (CTA)	○	
	Cleveland	Greater Cleveland RTA	○	
	Atlanta	Metropolitan Atlanta Rapid Transit Authority (MARTA)	○	
	Buffalo	Niagara Frontier Transportation Authority		○
	Pittsburgh	Port Authority of Allegheny County (PTA)	○	
	New York	Port Authority Trans-Hudson Corp.		○
	San Francisco	San Francisco Bay Area Rapid Transit District (BART)		○
	Pennsylvania	Southeastern Pennsylvania Transportation Authority (SEPTA)		○
	Los Angels	Los Angels County Metropolitan Transportation	○	
	Washington DC	Washington Metropolitan Area Transit Authority (WMATA)	○	
CANADA	Montreal	Societe de Transport dela Communaute Urbaine de Montreal	○	
	Tronto	Tronto Transit Commission		○

Application Guidelines for the Egress Element of the Fire Protection Standard for Fixed Guideway Transit Systems, 1998, Martin P. Schachenmayr

(2) Standard in Europe

In Europe, there are few national standards/guidelines or decrees for the metro. According to the report named “Fire in Tunnels (FIT)”, which was funded by the European Union, it is limited to Austria, France, Germany, Italy and Spain. In most cases, the standard and its specification are individually determined by each metro organization.

After the fatal fire accidents at tunnel in recent years, the FIT and some other reports for the management of fire in tunnel were studied in Europe. The standard and present condition of the metros of 17 cities in Europe and Russia were compared in FIT from the aspect of the infrastructure of tunnel and underground station. In the report of FIT, there are some comments for the major elements of the infrastructures but it is not concluded for the metro construction and operation in Europe. These topics will be further discussed in Europe.

(3) Japanese Standard

As described in the preceding section, many metros have been constructed since 1927 and there are 41 lines in 11 cities and the number of underground stations exceeds 560 among 724 stations of metros in Japan as of year 2009. Ridership in Tokyo City exceeds 3,200 million/year and it is biggest in the world (Moscow: 2,630 million/year, Seoul: 2,340 million/year, New York: 1,450 million/year in 2004-2006).

Under this condition, the standard for the management and countermeasure for the fire accident tunnel and underground station of metro was prepared in the early stage and it has been revised taking into consideration the recent fatal fire accidents of the world. The history of the Japanese standard is as follows:

- The fire safety management for metro station and tunnel was well reviewed and studied in Japan after the fire accident occurred at Kamiya-cho station of Hibiya Metro line in 1968, which injured 11 persons. Use of noncombustible materials for station structure and rolling stock had been considered well since this accident.
- In 1975, “the Standard of Fire Safety Management for Metro Station, etc” was issued as special appendix of the provision No. 29 of “Ministerial Ordinance of the Ministry of Land Infrastructure, Transport and Tourism (MLIT)”.
- In 2003, the fatal fire accident by arson, which killed 197 persons and injured 148 persons, occurred in the metro of Dague City, South Korea. This accident provided heavy impact to metro operators all over the world.
- The standard of fire safety management for metro station was totally reviewed and restudied in Japan taking into account the fire accident in Dague, South Korea. Different from the metro system in Dague, South Korea, the materials used for the rolling stock and other auxiliary things of the station had

been noncombustible in Japan. Therefore, the standard was not revised drastically but the fire by arson which was the reason of the fatal fire accident in Dague, South Korea was considered and added as design fire load to evaluate the evacuation of the passengers.

- In 2004, the revised "Standard of Fire Safety Management for Metro Station, etc, Ministerial Ordinance of MLIT" was issued in Japan.

As described above, the Japanese standard is updated taking into account the lessons of the latest fire accident in metro station.

4.3.3 Impact of NFPA 130 Application and Consideration

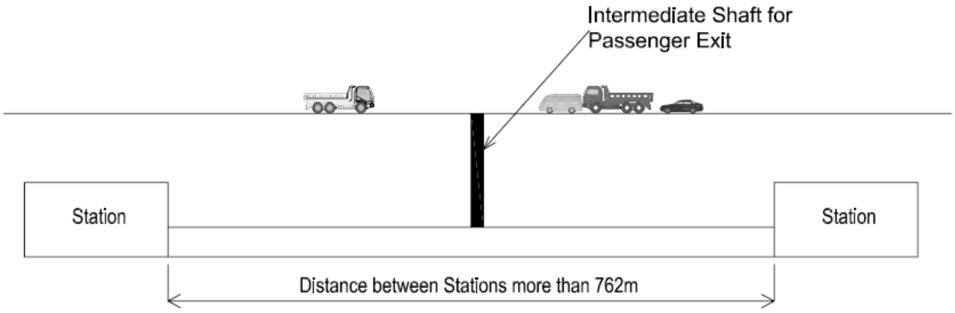
NFPA 130 is widely used in the country or city where the standard/regulation on fire fighting and management of the metro does not exist. It is also being discussed to be applied for the Cairo Metro. However, NFPA 130 is a strict standard and it will provide big impact to the design of the tunnel and stations if it is rigidly applied. Therefore, it is studied and compared with the standard and experience of Japan and Europe, taking the safety requirement and cost increase into consideration.

(1) Installation of Cross Passage

1) Intermediate Shaft and Cross Passages Regulation in NFPA 130

NFPA 130 regulates that the maximum distance between stations/accesses is 762 m. If the distance exceeds the regulation, the intermediate evacuation shaft for the access from/to the ground level or cross passages at interval of 244 m must be installed for the evacuation of passengers.

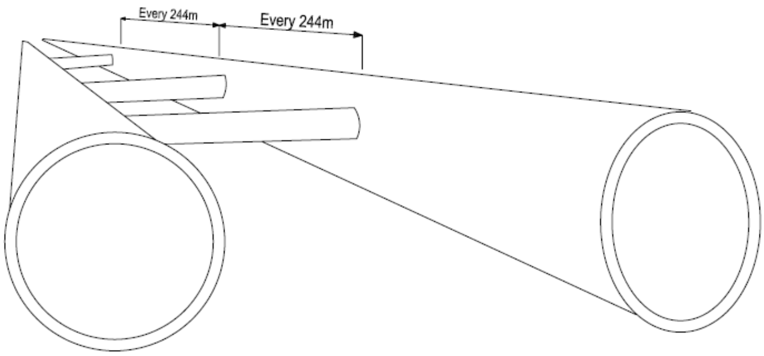
In case that the Single Track Double Tunnels (STDT) is applied, the longitudinal ventilation is applied and efficiency of the ventilation is due to the piston effect of the train running in unidirectional traffic. The ventilation shaft is constructed at the end of the station and intermediate shaft between stations is not required for the purpose of the ventilation. Taking into consideration the land acquisition and construction cost of the intermediate shaft, installation of intermediate shaft only for passenger evacuation will be very costly. Therefore, it is not realistic to make an intermediate shaft only for passenger evacuation unless the distance between stations is especially long.



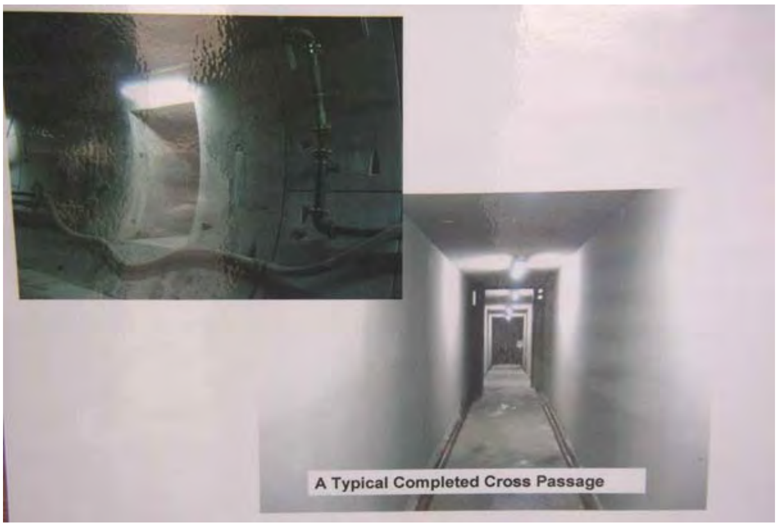
Source: JICA Study Team

Figure 4-38 Requirement of Intermediate Shaft for Passenger Evacuation by NFPA 130

NFPA 130 regulates to install the cross passages at interval of 244 m if the distance between stations exceeds 762 m and intermediate shaft/access is not installed. Image of the cross passages between tunnel and photo is shown in Figure 4-39. In order to construct cross passages, it is necessary to break the fabricated segmental lining of the main tunnel and excavate the ground and construct lining by small equipment. The installation of the cross passages will raise the cost for tunnel and enlarge the construction period.



Source: JICA Study Team



Source: JICA Study Team

Figure 4-39 Photo (Singapore) and Image of the Cross Passages between Tunnels

2) Cross Passages for Metro in Other Countries

The cross passages between tunnels for the passenger evacuation are constructed in the country/city where NFPA 130 is strictly applied (USA, India, Singapore, etc.).

The existing Metros in 17 cities of Europe and Russia were studied regarding the use of cross passages and maximum inter-distance between stations/access in the Fire in Tunnel (FIT) report. It is shown in Table 4-29. There are no cross passages in main metros of Europe and Russia. It is not common in European countries.

Table 4-29 Use of Cross Passages in Metro of 17 Cities of Europe

City, Country	Cross Passage	Max. Distance between Station/Access
Brussels, Belgium	No	750m
Copenhagen, Denmark	No	600m
Paris, France	No	800m
Rennes, France	No	600m
Helsinki, Finland	No	-
Prague, Czeck Rep.	No	2140m
Milan, Italy	No	-
Stockholm, Sweden	No	-
Hamburg, Germany	No	1000m
Berlin, Germany	No	1700m
Munich, Germany	No	1717m
Rotterdam, Netherlands	No	-
Lisborn,Portugal	No	1300m
Barcelona, Spain	No	800m
Madrid, Spain	No	1000m
Vienna, Austria	No	600m
Moscow, Russia	No	600m
London, UK	No	-
USA (NFPA130)	244m if station/access exceeds 762m	762m

Source: Technical Report 2, FIT, 2005

The cross passages are also not common in Japan. There are 13 lines in Tokyo and no cross passages are installed. Main features of the metros in Tokyo are shown in Table 4-30. In some cases, the intermediate shaft is installed for ventilation when the Double Track Single Tunnel (DTST) is applied. The average distance between underground stations (center to center of station) is approximately 1 km. In other 28 metro lines in ten cities of Japan, there are no cross passages for evacuation purposes.

Table 4-30 Main Features of Metros in Tokyo City

Line	Opening	Passengers (Thoudands/day)	Staions	Length (km)	Ave. Distance between Center of Station(km)	Distance between Stations		
						800m or less	1000m or less	Max Distance (km)
Asakusa	1960	597	20	18.3	0.96	13	16	1.4
Mita	1968	528	27	26.5	1.02	17	21	1.5
Shinjyuku	1978	609	21	23.5	1.18	11	12	2.6
(Underground)			15	12.9	0.92	11	11	1.3
Oedo	1991	720	38	40.7	1.10	21	27	1.4
Ginza	1927	1033	19	14.3	0.79	15	16	1.1
Marunouchi	1954	1076	25	24.2	1.01	15	20	1.6
(Underground)			23					
Hibiya	1961	1084	21	20.3	1.02	12	15	1.5
(Underground)			18			12	15	1.5
Tozai	1964	1245	23	30.8	1.40	7	13	1.7
(Underground)			14	15	1.15	7	11	1.7
Chiyoda	1969	1052	19	21.9	1.22	9	13	2.4
Chiyoda (Underground)			17	18.3	1.14	9	13	1.2
Yurakucho	1974	822	24	28.3	1.23	9	12	1.6
Yurakucho (Underground)			22	24.6	1.17	9	12	1.6
Hanzomon	1978	798	14	16.8	1.29	4	4	1.7
Nanboku	1991	400	19	21.3	1.18	6	10	1.4
Fukutoshin	2008	-	10	11.9	1.32	4	7	1.6

Source: JICA Study Team

3) Cross Passages for Road Tunnel

The cross passages are installed for long road tunnel or congested city road tunnel to secure the safety of tunnel users in case of fire. In many countries including European countries and Japan, it is regulated as a common use.

As described in the preceding Section 4.3.1(3), the fire accident in road tunnel is usually caused by the collision of the cars and the cars are stopped in close proximity to the fire point. It is difficult for cars to escape to the outside of the tunnel and it is thus necessary for the tunnel users to escape to the evacuation tunnel or parallel tunnel through the cross passages.

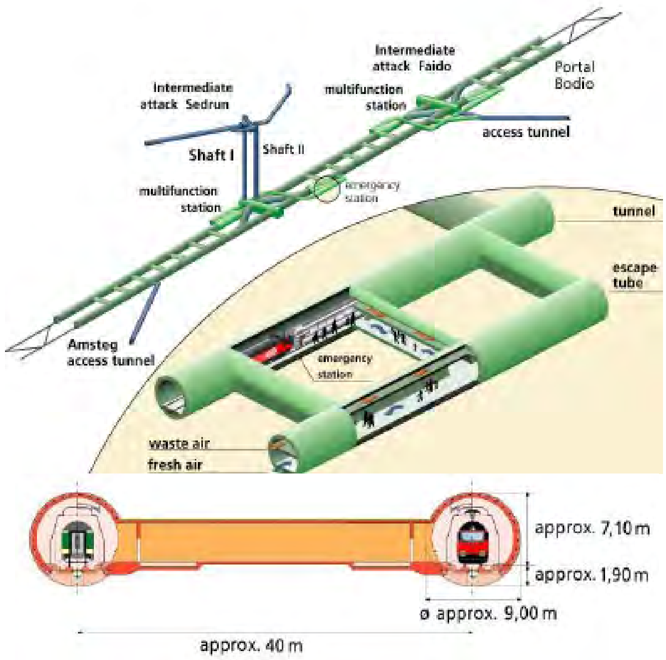
Installation of cross passages for long road tunnel or congested city road tunnel is an important consideration to save the user’s life in case of fire accidents.

4) Cross Passages for Long Railway Tunnel

The cross passages are also often installed for long railway tunnel which is used for intercity train. The cross passages are provided for the following reasons:

- The freight train with flammable material often passes in the tunnel.
- The tunnel is sometimes very long and there is the possibility that the train could not run to the exit/outside and stop in the tunnel.

Thus, there are many practices and experiences where cross passages are installed in long railway tunnels. As an example, the Gotthard Base Tunnel, which is 57 km-long tunnel under construction in Switzerland, is shown in Figure 4-40. In addition, the cross passages in long railway tunnel plays an important role to release the pressurized air in tunnel as the draft relief.



Source: AFTES International Congress, 2005

Figure 4-40 Cross Passages for Long Railway Tunnel

5) Consideration of Requirement of Cross Passages for Metro Line 4

The cross passages are frequently installed in long road tunnel and long railway tunnel and the reasons for the installation are quite obvious as described. On the other hand, as explained in the preceding section, it is rare to install the cross passages in the metro tunnel except for the metro where the NFPA 130 is strictly applied. Main reasons why the cross passages are not installed for the metro tunnel in many countries/cities are as follows:

- The distance between stations of the metro is approximately 1 km or less and the traveling time between stations is 2 minutes or less. The basic principle of operation for the train on fire is to drive the train to the next platform of the station. Therefore, there is quite low possibility that the train on fire stops in the middle of the tunnel, unlike in the case of long road and railway tunnels.
- The metro is used by commuters and other travelling passengers. The freight trains which often convey the flammable material are not allowed to pass in the metro.
- As described in the following section, the material for the rolling stocks and station should be noncombustible material in principle. Thus, the fire load of

the metro is quite small compared to the road and railway tunnels which carry fuel or flammable material/goods.

- The train is driven by professional driver and operation of the train is controlled by the CCP. On the other hand, no one controls the driving of each vehicle in a road tunnel. Therefore, the ratio of fire accident in metro tunnel is very low compared with road tunnel.

Therefore, it is not recommended to install the cross passages for the Metro Line 4 because the cross passage will raise the cost and extend the construction period but it will not enhance the safety so much.

The distance between Stations No. 12 and No. 15 would be longer than other part of the Metro Line 4 and it will exceed 1.5 km. Thus, the intermediate shaft or the cross passages should be considered and studied for this section in the next stage.

(2) Evacuation Time for Passengers in Case of Station Fire

In order to assure the safety of the passengers in the case of fire accident in the station, it is important to consider and study the evacuation time of the passengers. If the evacuation time from the dangerous point to the safe point takes too long, the fire will be enlarged and passengers will be injured by fire or smoke. The width and number of the stairs is one of the key factors to evacuate the passengers from the dangerous point. The safety of the passengers is enhanced if the wider stairs are provided in station. However, if the width of the stairs in the station is blindly widened without any consideration and study, the size of the station becomes very large and it will increase the construction cost of the station. Moreover, the safety of the passengers is not proportionally increased according to the width of the stairs. Construction becomes cost ineffective if it is blindly widened too much. There is not always a trade off relation between the safety for the passengers and cost of the construction. Therefore, the regulation of the evacuation time gives big impact and influence to the design and scale of the station.

The regulation of the evacuation time in the NFPA 130 seems very strict and the station where the NFPA 130 is strictly applied is prone to be large and excessive. Furthermore, the problem of the evacuation time in NFPA 130 is that the reason and basis of the strict regulation is not identified. Thus, in some cases for the deep station, it is difficult to apply the regulation of the NFPA 130.

Therefore, it is also studied and compared with the Japanese standard taking into account the cost reduction.

1) Evacuation Time of NFPA 130

The safety of the passengers in the station is evaluated and assessed through the evacuation time. The allowable evacuation time is defined and regulated in NFPA 130 as follows:

- Evacuation time from the platform

  There should be sufficient exit lanes to evacuate the station occupant load (passengers) from station platforms in 4 minutes or less.

  Exception: Modification of the evacuation time should be permitted based on an engineering analysis by evaluating material heat release rates, station geometrics, and emergency ventilation systems.

- Evacuation time from the platform to a point of safety

  The station should also be designed to permit evacuation from the most remote point on the platform to a point of safety in 6 minutes or less.

  Exception: Modification of the evacuation time should be permitted based on an engineering analysis by evaluating material heat release rates, station geometrics, and emergency ventilation systems.

The description of the regulation for the evacuation time is indefinite and not obvious in NFPA 130. Thus, it is necessary to consider the following points which are caused by the indefinite description in NFPA 130:

- The allowable evacuation time from the platform is defined as 4 minutes and 6 minutes to a safety point, respectively. However, the reason and basis of the allowable evacuation time for the passengers is not obvious and not described.
- The evacuation time for the passengers is deeply related to the design fire load (heat release ratio) and the density and spread speed of smoke. The passengers can safely escape if the smoke does not interfere with the evacuation. However, the design fire load for the evacuation is not defined and the characteristics in accordance with the source of fire are not mentioned. Therefore, the allowable evacuation time is uniformly applied as 4 minutes and 6 minutes to the point of safety in any fire condition.
- In order to achieve the allowable time described above, the distance to the point of safety and the width of the stairs are unique key factors for evaluation and widened very much than the actual requirement. On the other hand, the height of the ceiling of platform or concourse and the performance of the ventilation system, which are important factors for the storage and exhaust of smoke, are not considered for normal evaluation at all.
- The point of safety (safe haven) had not been defined well and it had been usually regarded as ground level (outside of underground station). In the

latest version (NFPA 130, 2007 Edition), it is revised that the concourse level is allowed to be defined as the point of safety if the safety of the concourse is confirmed by the engineering analysis. The engineering analysis is obligatory but the definition of the engineering analysis is not well defined including the fire load.

- Before the definition of the point of safety was revised in 2007, it was very difficult to apply the regulation for deep stations because it was impossible to escape from the platform to the ground level as the point of safety in 6 minutes. Consequently, it caused confusion on the design of deep stations. The definition of the point of safety was modified but it is still difficult to apply it to deep stations because the definition of the engineering analysis for concourse level is not well defined.

2) Japanese Standard on Evacuation Time

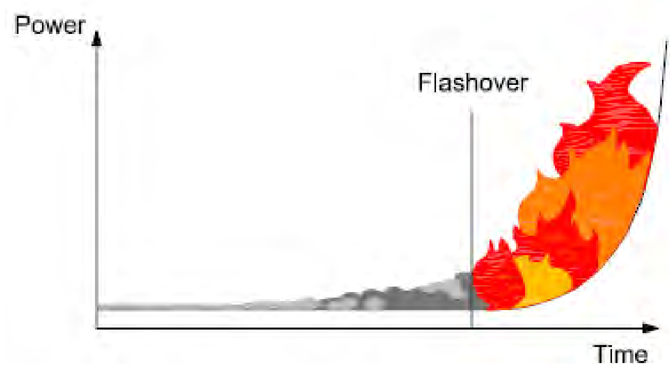
In order to compare the evaluation of the evacuation time and safety of the passengers, the evaluation of the Japanese standard is introduced as follows:

1) Fire Load and Evaluation Method of Smoke

The essential issue of fire safety management is how the passengers escape safely. The safety of the passenger is evaluated whether the passenger escapes to the point of safety without/less influence of smoke or not. The characteristics of fire are different according to origin. The fire loads are divided into two types. One is normal fire and another is fire by arson with fuel. According to the difference of the characteristics of fire, the evacuation of passenger is evaluated as follows:

2) Fire Load in case of Normal Fire

The origin of normal fire is assumed as the fire from motor or other auxiliary machine under the floor of rolling stock. Other case of normal fire is the fire from the small shop (kiosk) in the station. Usually, the power of the normal fire is quite small and its temperature is low in the beginning stage. It becomes larger after the flashover occurs. The time is relatively long until flashover takes place. The smoke of normal fire diffuses evenly and widely. Therefore, smoke inhalation is not considered and the main factor for safety evacuation is to ensure the visibility of the passengers. The image of the relationship between time and fire load is illustrated in Figure 4-41.



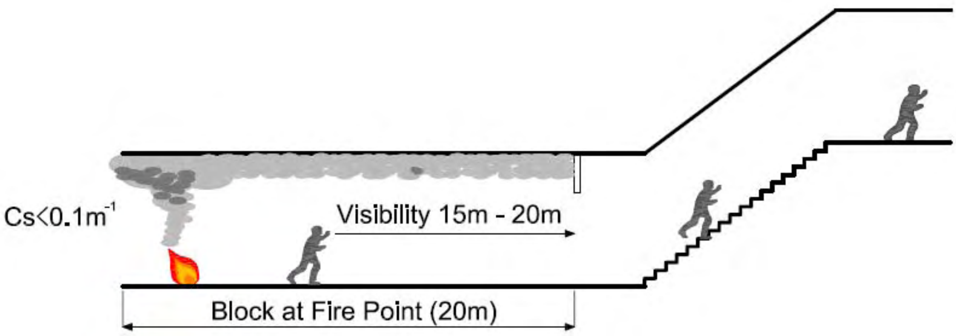
Source: JICA Study Team

Figure 4-41 Image of Normal Fire Load Model

The visibility of the passenger under smoke condition is determined by the smoke density (extinction coefficient Cs). The smoke density is defined by the following formula (Lambert-Beer Law):

$$Cs = -\frac{1}{l}\ln\left(\frac{\tau}{100}\right) \leq 0.1m^{-1}$$

where l is the required visibility (15 m to 20 m) for evacuation and τ (%) is permeability (13-22% equivalent to Cs = 0.1 m^{-1}).



Source: JICA Study Team

Figure 4-42 Smoke Density and Required Visibility for Smooth Evacuation

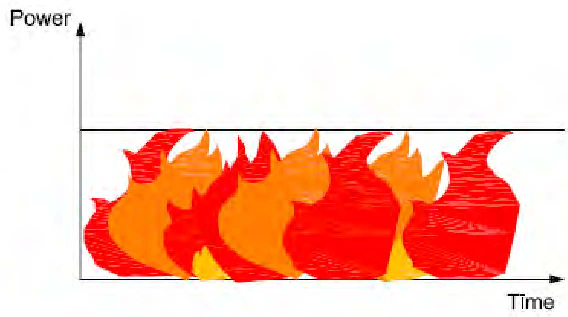
According to research and experiment in Japan, the smoke density (Cs) should be 0.1 m^{-1} or smaller to secure the visibility of 15 m to 20 m for smooth evacuation (see Figure 4-42). Under this condition, the passenger could evacuate without loosing their walking speed. Therefore, the evacuation time of passengers are evaluated according to the following procedures:

- The time (t) which is required for evacuation is calculated.
- Smoke density (Cs) at a time (t) of completion of evacuation is calculated. If Cs is 0.1 m-1 or less, the condition for the smooth evacuation is secured.

3) Fire Load in case of Fire by Arson with Fuel

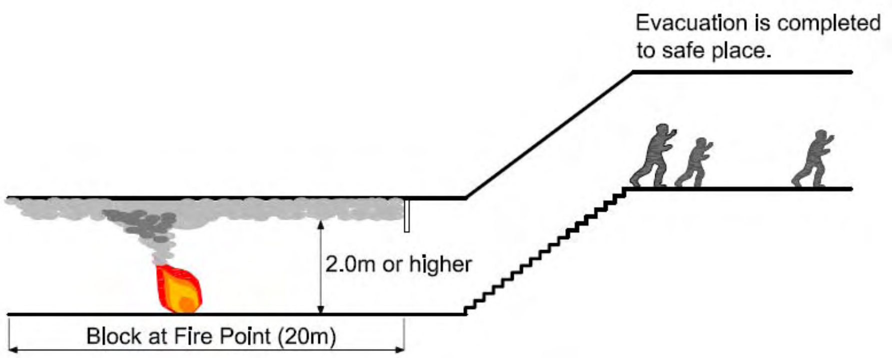
As described in Section 4.3.1(4), the fatal fire accident in Dague Metro, South Korea was triggered by arson with fuel. The fire cased by arson with fuel should be considered as the source of the fire. The fire with fuel such as gasoline or kerosene has different characteristics compared with the normal fire.

The power of the arson fire with fuel is strong and constant from beginning (see Figure 4-43). The temperature of smoke is high. Smoke will move as strata along the ceiling and it will descend to the floor. Therefore, it is evaluated by the descending speed of the smoke stratification from ceiling. For safe evacuation, the space for the evacuation should be secured. It is at least 2.0 m from the bottom of the smoke stratification to the floor.



Source: JICA Study Team

Figure 4-43 Image of Fire Load Model by Arson with Fuel



Source: JICA Study Team

Figure 4-44 Required Space for the Evacuation in case of Fire by Arson with Fuel

Therefore, the evacuation time of passengers are evaluated according to the following procedures:

- The time (t) which is required for evacuation is calculated.
- If the space from the bottom of the smoke stratification to the floor exceeds 2.0 m at a time (t) of the completion of evacuation, the condition for safe

evacuation is secured.

3) Recommendation

As described in the preceding sections, there are some abstract definitions in NFPA 130. Therefore, it is not reasonable to apply NFPA 130 strictly and blindly as it will involve excessive design and increase cost. It is recommended to use reasonable and appropriate measures taking into consideration the safety and reduction of cost.

Based on Japanese standard and other countries' experiences, the countermeasure and management for fire accident are introduced and recommended for the Metro Line 4 in the following sections.

4.3.4 Use of Non-combustible Material

The most effective measure against fire accident is the use of non-combustible materials to control and not aggravate fire. The lesson of the worst fire accident at the Dague Metro in South Korea proved the importance of the use of non-combustible materials. Therefore, it is recommended that non-combustible materials are used for the underground stations, tunnel and rolling stocks as much as possible. In the following section, the regulation of non-combustible material use for the underground stations, tunnel and rolling stocks is explained based on the Japanese standard.

(1) Use of Non-combustible Materials for Underground Stations and Tunnels

1) Materials for Structure and Interior Finish

The materials for the structure and interior finish in the station and tunnel should be non-combustible in order to prevent the occurrence and spread of fire.

Structural materials mean wall, beam, slab, column, stair, etc. Interior finish material means material which covers and finishes the surface of structural material inside stations.

Under normal fire condition, the non-combustible material should meet the following requirement for 20 minutes:

- The material shall not burn.
- The material shall not generate deformation, melting and crack which are hazardous to fire protection.
- The material shall not emit hazardous smoke and toxic gas.

The materials which meet these requirements are concrete, steel and iron, ceramic tile, aluminium, metal board, glass, mortal, brick, etc. Other materials shall be tested by Cone Calorimeter (ISO5660-1) and authorized.

Non-combustible material is not always suitable for the floor in the station office and place where the station staff or passenger stay longer, because non-combustible material is usually limited to mineral hard materials. Therefore, the use of fire-retardant material is allowed for the room and station floors, as exceptions, but it should be non-combustible as much as possible.

The parts and components which are partially used for signboard, foot guide for blind person, elevator, ticket vending machine, lighting and other electro-mechanical facilities are exempted from the regulation of non-combustible material use. However, it is preferable to use non-combustible materials for these facilities as much as possible.

2) Fittings

In order to enhance the performance of fire protection in the station, it is preferable to use non-combustible or fire-retardant materials for the fittings such as desks, chairs, benches, lockers, bookshelf, curtain, trash box, public phone, vending machine, etc. as much as possible.

Source: Ministry of Land, Infrastructure, Transportation and Tourism (MLIT)

Figure 4-45 Use of Non-combustible Material for the Chair in the Station

3) Fire Compartment for Substation, Power Distribution and Machine Room

In order to protect the spread of fire, the substation, power distribution room, machine and electric room shall be surrounded and protected by the fire compartment because there is risk of firing by the failure of machine/facility. The fire compartment is an area within a station/building which is completely surrounded with fire-resistant construction by non-combustible material, usually with features such as automated fire-resistant doors/shutters which close when a fire is detected.

- The floor and wall of these rooms shall be fireproofed by reinforced concrete, concrete block, brick or other non-combustible materials.
- The fire compartment shall be installed at the opening.
- Holes for cables, etc. in the wall and fire compartment shall be filled with mortar or other non-combustible material.

4) Shop in the Underground Station

The shops in station are divided into two categories in Japan. One is the shop where both shop man and customer can enter. This shop in the station is called "convenience store type" in Japan. This shop is relatively big and many flammable materials are stocked.

Another is the small shop called "kiosk" where only the shop man can enter.

The convenience store stock many flammable materials and it shall be protected by fire/smoke compartment. Moreover, the sprinkler shall be installed for initial fire fighting and protection of spread of fire. The fittings in the convenience store shall be fire-retardant or non-combustible material as far as possible.

Source: MLIT

Figure 4-46 Example of Convenience Store in Underground Station

Kiosk is small and difficult to protect by fire/smoke compartment. Therefore, the materials and fittings including bookshelf, etc. shall be non-flammable except materials for the floor. According to the fire test in Japan, the wooden bookshelf generated much smoke, thus, it should be forbidden.

Source: MLIT

Figure 4-47 Example of Kiosks in Underground Station

(2) Cone Calorimeter Test for Non-combustible Material (ISO5660-1)

In order to authorize the material for station and tunnel as non-combustible material, the burning test is required except for non-combustible materials such as concrete, steel and iron, ceramic tile, aluminium, metal board, glass, mortal, brick, etc. There are some methods and the cone calorimeter method which is used in Japan is introduced. The requirements and definition of non-combustible, semi non-combustible and fire-retardant material are as follows:

1) The definition of the non-combustible material, semi non-combustible material and fire-retardant material should satisfy and meet the requirement of the following conditions during test period.

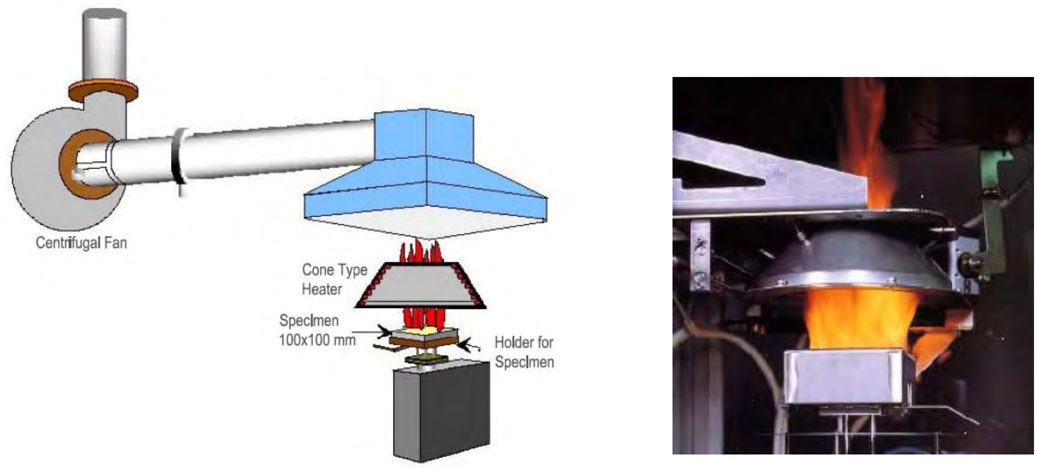
- Non-combustible Material (test period: 20 minutes)
- Semi Non-combustible Material (test period: 10 minutes)
- Fire-retardant Material (test period: 5 minutes)

2) The specimen shall be heated by the cone calorimeter with a fire power of 50 kW/m^2.

3) Accumulated total calorific value (power) for the test period shall not exceed 8 MJ/m^2.

4) The crack and hole which penetrates the specimen of the material shall not be generated.

5) The maximum speed of the calorific value shall not exceed 200 kW/m^2 for continuous 10 seconds during the test period.



Source: Ministry of Land, Infrastructure, Transportation and Tourism and JECTEC

Figure 4-48 Burning Test by Cone Calorimeter (ISO5660-1)

4.3.5 Fire Load and Evaluation of Smoke

The evacuation of the passengers is influenced by smoke diffusion. Therefore, the safety of the passengers in case of fire is evaluated and assessed by the condition of smoke in the station at the time when the evacuation is supposed to be completed.

As the reference of the evaluation of the safety of the passengers, the calculation procedure of the Japanese standard is shown as follows. The evaluation and assessment of passenger safety will be carried out for each station in the design stage.

(1) Design Fire Load and Evaluation Method for Evacuation

The assumed fire on rolling stock and station (small shop, kiosk) is defined as normal fire and fire by arson with fuel. Therefore, four cases of the origin of fire are assumed for the evaluation. The amount of the gasoline of the arson fire is 4 litters taking into consideration the examples of the arson in Dague Metro, South Korea in 2003. The evaluation for the evacuation is studied based on the basic principle that the passenger can escape to the safety place. The design fire load and its characteristic model are as follows:

Table 4-31 Design Fire

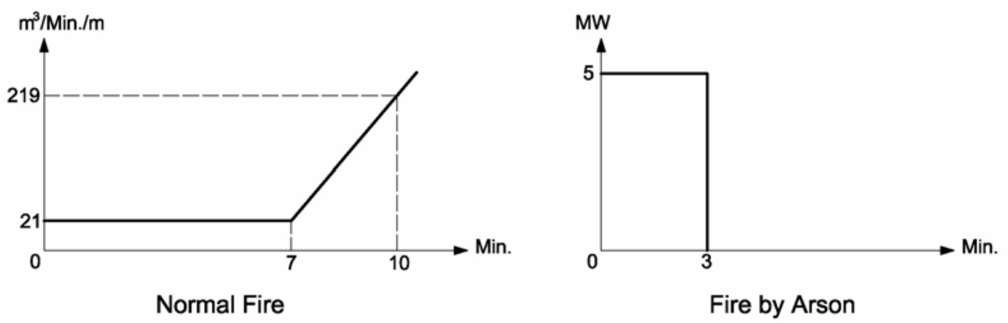
Assumed Fire	Type	Origin of Fire
Normal Fire	Rolling Stock	Fire from under the rolling stock floor
	Kiosk	Arson by lighter
Fire by Arson	Rolling Stock	Arson equivalent to 4 L gasoline
	Kiosk	Arson equivalent to 4 L gasoline

Source: Ministry of Land, Infrastructure, Transportation and Tourism (MLIT), Japan

Table 4-32 Fire Load Model for Rolling Stock

Item	Assumed Fire	
	Normal Fire	Fire by Arson
Parameter of Fire Load	Smoke Speed C (m^3/min./m)	Fire Power Q (MW)
Fire Model	C=21 (m^3/min./m), $0 \le t \le 7$ min. =21+66(t-7) (m^3/min./m), 7<t min.	Q=5 (MW), $0 \le t \le 3$ min. =0 (MW), 3<t

Source: MLIT, Japan



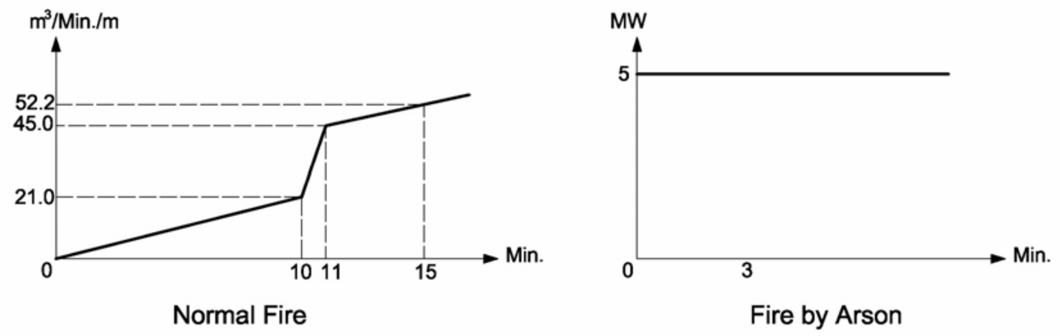
Source: MLIT, Japan

Figure 4-49 Fire Load Model of Rolling Stock

Table 4-33 Fire Load Model for Kiosk

Item	Assumed Fire	
	Normal Fire	Fire by Arsonist
Parameter of Fire Load	Smoke Speed C (m^3/min./m)	Fire Power Q (MW)
Fire Model	C=2.1 (m^3/min./m), 0≤t≤10min. =24.0t-219 (m^3/min./m), 10<t≤11 min =1.8t+25.2 (m^3/min./m),11<t min.	Q=5 (MW)

Source: MLIT, Japan



Source: MLIT, Japan

Figure 4-50 Fire Load Model of Kiosk

1) **In case of normal fire, the evaluation of evacuation is studied by smoke density (extinction coefficient Cs) of the platform.**
2) **In case of fire by arson, the time for smoke stratification which hampers the evacuation is studied.**

The allowable figure is as follows:

1) In case of Normal Fire on platform, smoke density shall be less than or equal to 0.1 m^{-1}.

Cs ≤0.1 m^{-1}

2) In case of normal fire on concourse, the smoke storage volume on concourse (V) must be bigger than the total smoke volume (Vo) until the evacuation is completed.

V ≥ Vo

3) In case of Fire by Arson, the evacuation space from floor of platform/concourse to the bottom of stratified smoke shall be more than 2.0 m before completion of evacuation.

(2) Calculation of Evacuation Time

In order to calculate the evacuation time, the queue time is calculated as follows:

T=Q/(NxB)

T: Queue Time (sec), Q: Number of Evacuator (persons),

N: Runoff Coefficient of Crowd (person/m/sec.)

B: Width of Stair (m)

In order to calculate walking time t and queue time T, the walking speed and runoff coefficient of crowd is defined as follows:

Walking Speed: Flat area 1.0 (m/s), Stair area 0.5 (m/s)

Runoff Coefficient: Flat area 1.5 (person/m/sec), Stair area 1.3 (person/m/sec)

(3) Calculation of Number of Evacuators

The number of the evacuators is calculated according to the ridership in Japan. The design number of evacuators will be assessed in the design stage.

(4) Study for the Normal Fire

1) Study of Smoke Density on Platform

The smoke density Cs shall be less than or equal to 0.1 m^{-1} when the evacuation is completed. The smoke density shall be calculated by the following formulas according to the assumed fire.

1) Fire on Rolling Stock

- a. In case the evacuation time is less than or equal to 7 minutes:

$$Cs = 21 \cdot (1 - e^{-Ve \cdot t / V}) / Ve$$

- b. In case the evacuation time exceeds 7 minutes:

$$Cs = (66 \cdot V \cdot e^{-Ve \cdot (t-7)/V} - 21 \cdot Ve \cdot e^{-Ve \cdot t / V} + 66 \cdot Ve \cdot t - 441 \cdot Ve - 66V) / Ve^2$$

2) Fire on Kiosk

- a. In case the evacuation time is less than or equal to 10 minutes:

$$Cs = 2.1 \cdot (Ve \cdot t - V + V \cdot e^{-Ve \cdot t / V}) / Ve^2$$

- b. In case the evacuation time exceeds 10 minutes but less than or equal to 11 minutes:

$$Cs = ((24 \cdot V - 21 \cdot Ve) \cdot e^{-Ve \cdot (t-10)/V} + 24 \cdot Ve \cdot t - 198 \cdot Ve - 26.1 \cdot V + 2.1 \cdot V \cdot e^{-10 \cdot Ve/V}) / Ve^2$$

- c. In case the evacuation time exceeds 11 minutes:

$$Cs = ((1.8 \cdot V - 45 \cdot Ve) \cdot e^{-Ve \cdot (t-11)/V} + 1.8 \cdot Ve \cdot t + 91.2 \cdot Ve - 27.9 \cdot V + 2.1 \cdot V \cdot e^{-10 \cdot Ve/V} + (24 \cdot V - 21 \cdot Ve) \cdot e^{-Ve/V}) / Ve^2$$

where Cs: Smoke Density (m^{-1})

V: Volume of Block at Fire Point (m^3)

t: Evacuation Time (min.)

Ve: Air Volume of Ventilation Facilities per Volume of Block at Fire Point (m^3)

If kiosk does not exist on the platform, evacuation time (t) and smoke density (Cs) are treated as "zero".

3) Volume of Block at Fire Point

In case of fire on rolling stock, volume of block at fire point is the most densely smoked section on the platform where the smoke diffuses.

Volume of block at fire point is defined as follows:

- a. Cross section area of smoke diffusion is defined in Figure 4-51. If the structure of the platform is different, cross sectional area is determined based on the concept of Figure 4-51.
- b. Cross section area of smoke diffusion is the hatched area in Figure 4-51 and cross section area of the rolling stock is deducted.
- c. Longitudinal length of volume of block at fire point is 20 m (effective length).
- d. Volume of block at fire point is calculated as follows:

V = (Ao-Av) x 20

Ao = (Va-Vm)/L

V: Volume of block at fire point (m^3)

Ao: Cross section area of block at fire point (m^2)

Av: Cross section area of rolling stock including area under the floor (m^2)

Va: Total volume of platform in effective length (m^3)

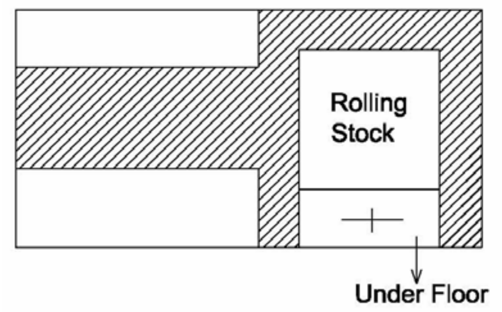
Vm: Volume of the place, such as column, stair, etc. where smoke does not diffuse

L: Effective length of platform (m)

4) Minimum Volume of Smoke Exhaust

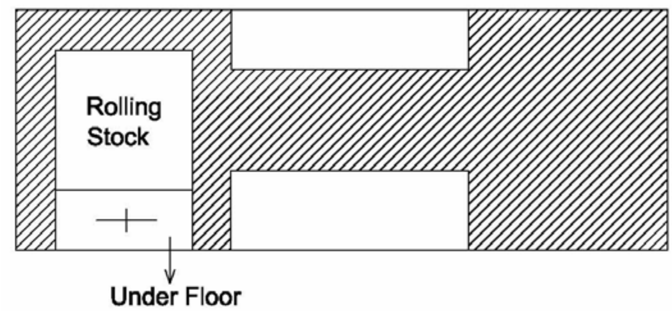
In the platform, smoke exhaust facilities with capacity of 5,000 m^3/hour or more must be installed for volume of block at fire point.

(A) One Side Platform



Smoke diffuses to all section.

(B) Island Platform



Smoke diffuses to the neighbouring platform and track due to the upward current of smoke caused by heat.

(C) Side Platform

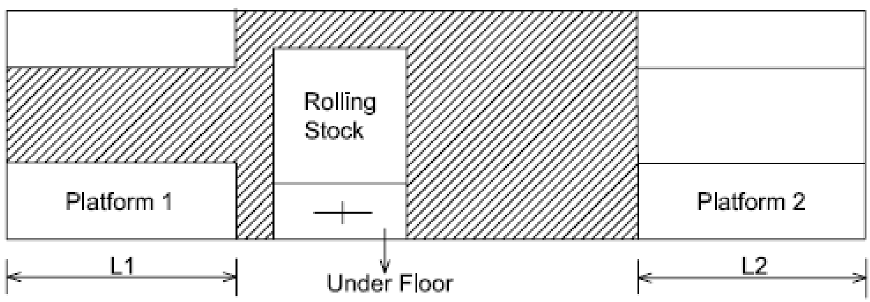


Figure 4-51 Cross Section Area for Volume of Block at Fire Point

In case the train on fire enter or stop at platform 1, the smoke does not diffuse so much to platform 2 because the height of the ceiling of the opposite platform (platform 2) is lower than the ceiling of the track. Therefore, the hatched area is used for the study as severe condition.

There are two cases when the train on fire stops at platform 1 and platform 2. The study is carried out for smaller platform as the more severe condition. For example, if platform length L1< L2, the design cross sectional area is the hatched area.

2) Study of Total Smoke Volume on Concourse until Completion of the Evacuation (Not Applied if the Concourse is Separated into Two Sections or More)

Total smoke volume on concourse (Vo) is calculated from the following formula with evacuation time “t”. Then, it must be confirmed that the smoke storage volume (V) on concourse is bigger than Vo.

- a. In case the evacuation time is less than or equal to 10 minutes.

$$Vo = 10.5 \cdot t^2$$

- b. In case the evacuation time exceeds 10 minutes but less than or equal to 11 minutes.

$$Vo = 120 \cdot t^2 - 2190 \cdot t + 10950$$

- c. In case the evacuation time exceeds 11 minutes.

$$Vo = 9 \cdot t^2 + 252 \cdot t - 2481$$

Vo: Total smoke volume until completion of evacuation (m^3)

t: Evacuation time (min.)

Smoke storage volume on concourse (V) is calculated by the following formula:

$$V = V' + t \times Ve'$$

$$V' = (Af - At) \times (H - 2)$$

$$Ve' = Ve \times (H - 2) / H$$

V’: Smoke storage volume excluding smoke volume exhausted by smoke exhaust facilities

Ve’: Effective smoke exhaust volume (m^3/min.)

Af: Area of floor of concourse (m^2)

At: Area of the place where smoke does not diffuse, such as column (m^2)

H: Height from floor to ceiling of concourse

Ve: Capacity volume of smoke exhaust facility on concourse (m^3/min.)

(5) Study for the Fire by Arson

Time (t_o) for smoke stratification up to 2.0 m from the floor is calculated by the following formula. It must be confirmed that t_o is shorter than the evacuation time (t).

1) Fire in rolling stock and kiosk on platform

$$t_o = V_E / (Vs - Ve')$$

$$V_E = (A_E - A_V') \times L$$

$$Ve' = Ve \times (A_E - Av') / (Ao - Av)$$

If VE-Ve'≤0, $t_o = \infty$

VE: Effective volume of platform above 2.0 m from the floor of platform (m^3)

Vs: Smoke volume = 300 m^3

Ve': Effective smoke exhaust volume in VE (m^3/min.)

AE: Cross section area above 2.0 m from the floor of platform excluding volume of the place where smoke does not diffuse, such as column, stair, etc. (m^2)

Av': Cross section area of rolling stock above 2.0 m from the floor of platform (m^2)

Ve: Capacity volume of smoke exhaust facility on platform (m^3/min.)

Ao: Cross section area of block at fire point (m^2)

Av: Cross section area of rolling stock including area under the floor (m^2)

2) Fire in concourse (not applied if concourse is separated into two sections or more)

$$t_o = V' / (V - Ve')$$

$$V' = (Af - At) \times (H - 2)$$

$$Ve' = Ve \times (H - 2) / H$$

If VE-Ve'≤0, $t_o = \infty$. If there is no kiosk in the concourse and t_o becomes 3 minutes or bigger, $t_o = \infty$.

V': Smoke storage volume excluding smoke volume exhausted by smoke exhaust facilities

Vs: Smoke volume = 300 m^3

Ve': Effective smoke exhaust volume (m^3/min.)

Af: Area of floor of concourse (m^2)

At: Area of the place where smoke does not diffuse, such as column (m^2)

H: Height from floor to ceiling of concourse

Ve: Capacity volume of smoke exhaust facility on concourse (m^3/min.)

(6) Measures

If the result of the study for fire by arson is not satisfied and handling by ventilation facilities is difficult, the following measures will be taken:

1) Provision of new escape way or widen walkway/stair to reduce evacuation time;

2) Enlargement of smoke storage volume;

3) Provision of fire/smoke compartment for kiosk which becomes the origin of fire and installation of sprinkler;

4) No installation of kiosk; and

5) Provision of other facility which ensures the safe evacuation of passenger.

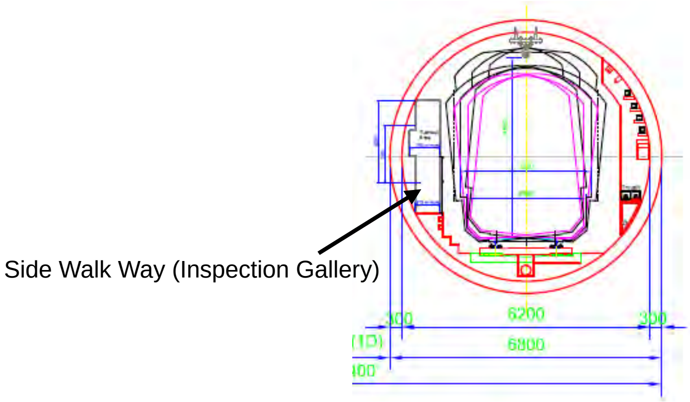
Re-study is required after the measure of 1) or 2) or 5) is taken. If the measure of 3) or 4) is taken, re-study shall be carried out under the condition without kiosk.

4.3.6 Side Walkway in Tunnel (Inspection Gallery)

When the train stops in the tunnel due to power failure or other reasons, it is sometimes necessary for the passengers to get off the train and walk to the next station. If the train on fire stops in the tunnel, though the principal operation is to drive to the next station, the prompt evacuation from the train will be required. In many countries, the egress from the train is done from the top or end of the car. However, in such emergency case, the passengers will be requested to get off the car from the side door. If there is difference in the level between the door and the track, it is dangerous to jump out of the door.

If the raised side walkway is provided and the height of the side walkway is same as that of the floor of the car, the risk of jumping out from the car will be decreased very much. The installation of such walkway usually requires enlarging the size of the tunnel and it will increase the costs. However, there is enough space to install the side walkway in the cross section of the tunnel for Metro Line 4. Therefore, it is proposed to install the side walkway. The width of the side walkway is studied to be 610 mm which enables the passengers to walk referring to the size of the walkway regulated in NFPA 130.

This walkway can also be used as the inspection gallery for the escape space of the inspector.



Source: JICA Study Team

Figure 4-52 Side Walk in Tunnel (Inspection Gallery)

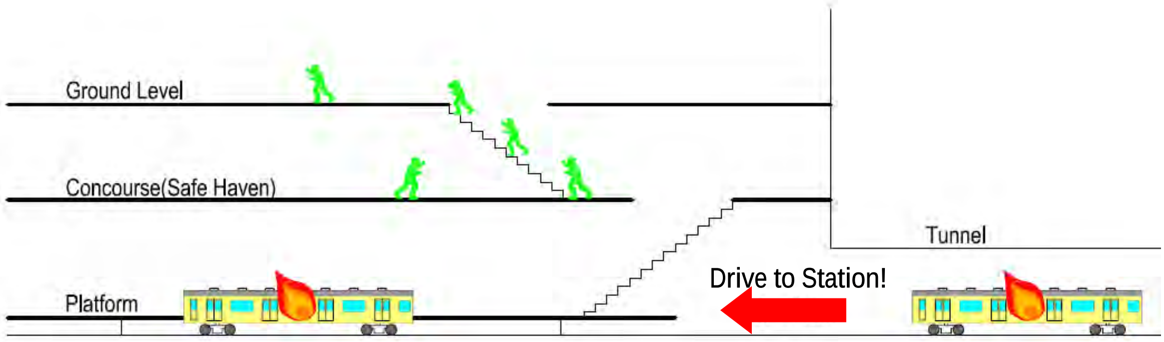
4.3.7 Train Operation in Emergency Case

(1) Principle of Train Operation in case of Fire

Several tragic fire disasters on underground railway lines have prompted railway operators and authorities in Japan to modify the train operation principle. Particularly, the incidents in the past four decades have changed regulation of the train operation principle.

Currently, the fundamental principle for train operation applied by the metro operators and railways in underground sections in the event of a fire is to drive the trains on fire to the platform of the next station without stopping at intermediate sections to evacuate the passengers and carry out fire fighting activities there. Once notified by the driver of the train on fire, the train dispatcher will direct the train in front of the train on fire to proceed to the next station and the train running behind the train on fire to stop. Trains running on the opposite track will also be directed not to access or stop at the station where the train on fire arrives.

- The basic principle of operation for the train on fire is to drive the train to the platform of the next station or outside the tunnel.
- Other train shall stop at the neighbouring station and shall not depart.
- If the train on fire stops at the station or the station is burning, the train dispatcher shall direct other trains not to approach this station.



Source: JICA Study Team

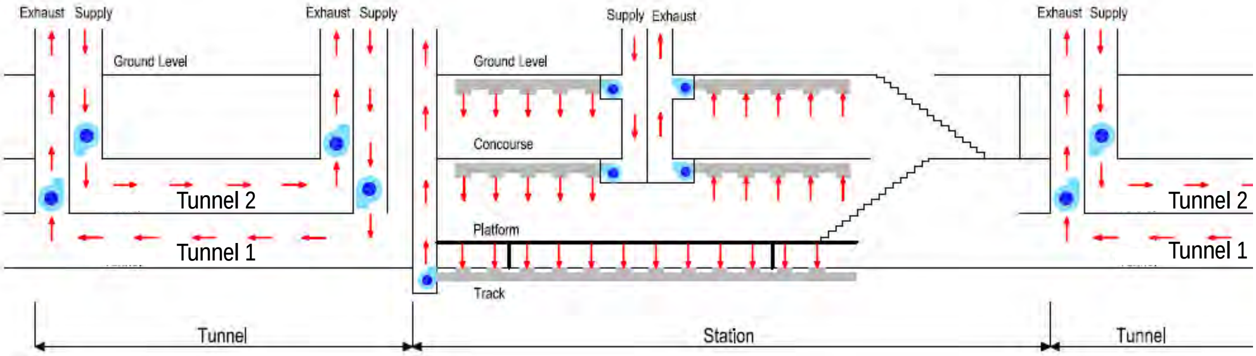
Figure 4-53 Principle of Train Operation in Case of Fire

4.3.8 Ventilation Operation in case of Fire

The platform screen door (PSD) is planned to be installed in the platform for the Metro Line 4. Therefore, the ventilation systems are separated and segregated for the concourse, platform, track at station and tunnel, respectively. Taking into account this condition, the ventilation operation in case of fire is described as follows:

(1) Normal Operation and Ventilation Fan

The tunnel is constructed as Single Track Double Tunnels. Therefore, the longitudinal ventilation system for tunnel ventilation, which is economical in terms of construction and operation costs, is applied. The normal operation of the ventilation system is illustrated in Figure 4-54.



Source: JICA Study Team

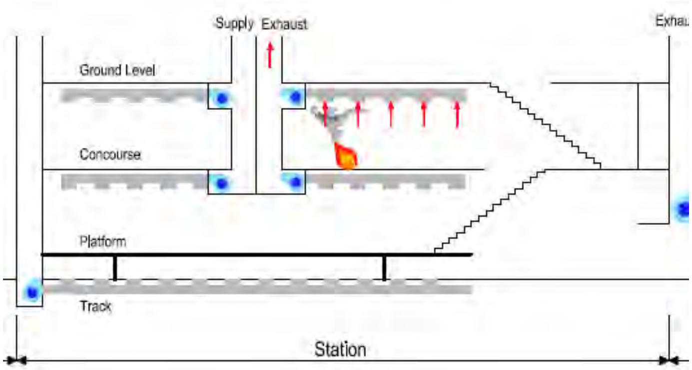
Figure 4-54 Image of Normal Operation of Ventilation System

Source: Nanakuma Line and Rinkai Likai, Japan

Figure 4-55 Centrifugal Fan for Tunnel Ventilation

(2) Smoke Exhaust in Concourse

Smoke in concourse will be exhausted by the ventilation system on the concourse.

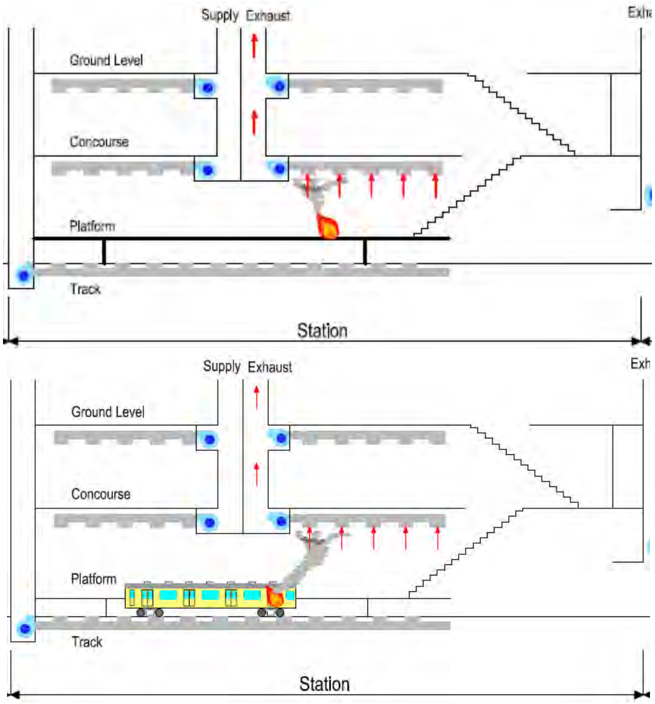


Source: JICA Study Team

Figure 4-56 Image of Smoke Exhaust for Fire on Concourse

(3) Smoke Exhaust in Platform

The PSD separates the platform and track at the station. In case of fire by arson on rolling stock, the smoke will diffuse to the platform through the opening of PSD and will not spread to the track (see Figure 4-57). Thus, the ventilation system on the platform will operate for the smoke of the fire on platform and the fire by arson on rolling stock.



Source: JICA Study Team

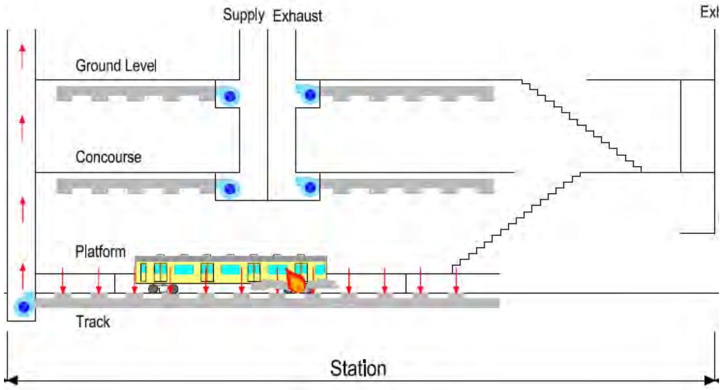
Figure 4-57 Smoke Exhaust on Platform

Source: Tokyo Metropolitan Gov. Bureau of Transportation

Figure 4-58 Exhaust Duct in Platform

(4) Smoke Exhaust in Station Track (Normal Fire on Rolling Stock)

The PSD separates the platform and track at the station. In case of normal fire on rolling stock, the fire will occur from under the floor of the rolling stock (motor or other facilities). Smoke will be protected by the PSD and diffuse only in the track at the station. Smoke will be exhausted by the ventilation system over or under the track. If the capacity of the over/under-track ventilation system is not enough, it is possible to operate the tunnel ventilation system to help the track ventilation.



Source: JICA Study Team

Figure 4-59 Ventilation Operation for Fire on Station Track (With Ducts Actually Located Over or Under the Track)

(5) Smoke Exhaust in Tunnel

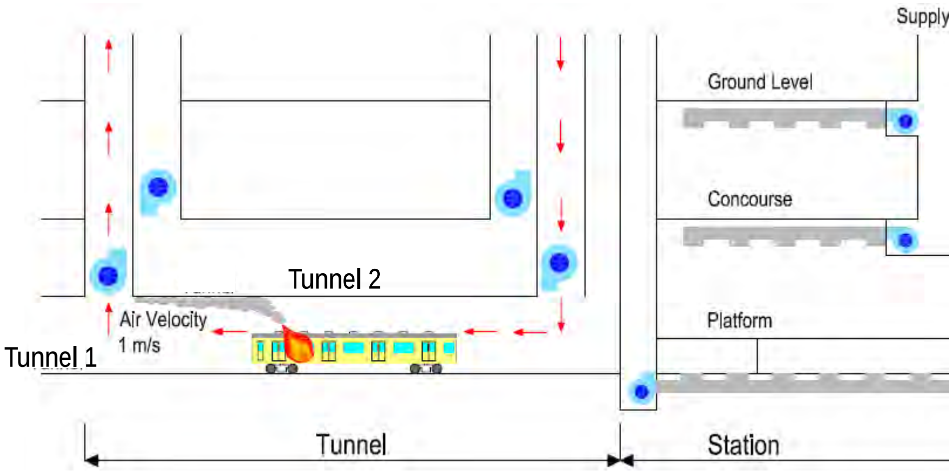
If fire occurs on the rolling stock or cable and the train stops in the tunnel, the smoke shall be exhausted by the tunnel ventilation system. According to experiments of fire test in tunnel which were mainly done for road tunnels in Japan, it is known that the fire is increased by the oxygen supply if the fire is blown by an air speed of 4-5 m/s or faster. On the other hand, if the smoke is blown by an air speed of 2-3 m/s, the smoke will be smoothly exhausted without or less back-layering of smoke. Therefore, in the design standard of road tunnel in Japan, the air flow in case of fire is regulated at 2.0 m/s by the ventilation system. According to the results of the test and regulation for road tunnel, it was recommended to use 2.0 m/s air velocity in the design guideline of metro ventilation system.

Thereafter, it has been reviewed by each train operators taking into consideration the small fire load of metro system, which is basically nonflammable material, compared to the big fire load in road tunnel. After this review and research, many metro operators have changed their design standard for the required air velocity in tunnel in case of fire from 2.0 m/s to 1.0 m/s due to the following reasons:

- The fire load of the metro is quite smaller than that of the road tunnel.
- The 1.0 m/s air velocity in the tunnel is good enough to efficiently exhaust the smoke from the rolling stock or cable and the environment for safe evacuation in the tunnel is secured.
- It will save the cost for ventilation facilities.

In accordance with the regulation and design standard of these metro operators in Japan, it is recommended that the tunnel ventilation system for Metro Line 4 should have the capacity and performance to generate longitudinal air velocity of 1.0 m/s or faster in the tunnel in order to secure a safe environment for evacuation in case of fire.

The basic principle of evacuation from the train is to walk to the next station on the windward direction. However, the safe environment for evacuation will be ensured even if the passengers evacuate to the leeward side.



Source: JICA Study Team

Figure 4-60 Exhaust of Smoke in Tunnel

Source: Sendai City Transport Bureau, Japan

Figure 4-61 Exhaust Duct in Tunnel

4.3.9 Emergency Facilities and Equipment

The emergency facilities and equipment are installed in the station for the detection and notification of fire, guidance for the passengers and fire fighting. The major emergency facilities and equipment are introduced below.

(1) Alarm Facilities

1) Automatic Fire Alarm (Fire Detector)

Automatic fire alarm (fire detector) shall be installed in the station office, power substation, power distribution station, machinery room, shop, etc. Emergency power (from emergency generator or battery) shall be supplied to the alarm facilities.

The information/data from the alarm facilities shall be transmitted to the emergency control room.

Source: MLIT

Figure 4-62 Fire Detector (Left: Smoke Type, Right: Heat Type; Source: MLIT)

2) Telephone and Push Button Alarm

If fire is detected by the passenger or station staff, the information could be transmitted to the emergency control room by telephone or push button alarm. These facilities shall be installed in proper places.

Source: Rinkai Line, Japan

Figure 4-63 Fire Detector (Left: Smoke Type, Right: Heat Type; Source: MLIT)

3) Closed Circuit Television (CCTV)

A CCTV is not an alarm facility in itself and is not regulated to be installed in stations according to the Japanese standard. However, it is effective to find fire in the early stages. Furthermore, it is also effective to monitor other accidents. A CCTV is installed at many stations in Japan and is also recommended to be installed at proper locations for the project.

Source: Rinkai Line, Japan

Figure 4-64 Closed Circuit Television

(2) Communication Facilities

The communication facilities should be installed in the emergency control room of the station in order to connect to the fire department, police station, operation control center and places in the station such as room, both edges of the platform, etc.

The public address system should be installed for the platform, concourse and passage ways in the station. It shall be controlled in the emergency control room.

Auxiliary wireless communication system should be installed in the station.

The communication system which connects to the operation control center should be installed in the tunnel at an interval of 250 m or less.

The emergency power supply/battery should be attached to the communication system and the public address system.

1) Telecommunication System

In order to contact the fire department, police station, operation control center and places in the station such as room and edges of the platform, normal telephone, internal telephone, command telephone, etc. should be installed in the emergency control room of the station.

2) Public Address System

In order to provide appropriate information and evacuation guidance in case of fire, the public address system should be installed in the emergency control room of the station.

Source: Rinkai Line, Japan

Figure 4-65 Telecommunication System and Public Address System

3) Auxiliary Wireless Communication System

In order to help the activity and communication of fire brigade, the auxiliary wireless communication system should be installed in the subway station and tunnel. The auxiliary wireless communication system is composed of connection terminal, coaxial cable, distributor, leaky coaxial cable and antenna.

4) Communication System in Tunnel

The trackside telephone should be installed as communication system in the tunnel at an interval of 250 m or less.

(3) Evacuation Guide

Different evacuation passages (at least in two directions) from platform to the ground level should be provided in the station. At least two evacuation passages should be separated and should not overlap.

The following should be provided and installed in the station:

- Evacuation Passage (two directions)

- Emergency Lighting

- Guide Lighting for Exit and Directional Sign

In addition, the following should be provided and installed in the tunnel:

- Emergency Lighting in Tunnel

- Guide Lighting for Exit and Directional Sign in Tunnel

1) Provision of Evacuation Passages (Two Directions)

Different evacuation passages (at least in two directions) from platform to the ground level should be provided in the station. At least two evacuation passages should be separated and should not overlap.

In principle, the evacuation passage from the platform to the ground level should only have ascending stairs. The evacuation passage which has a descending route is not allowed in principle.

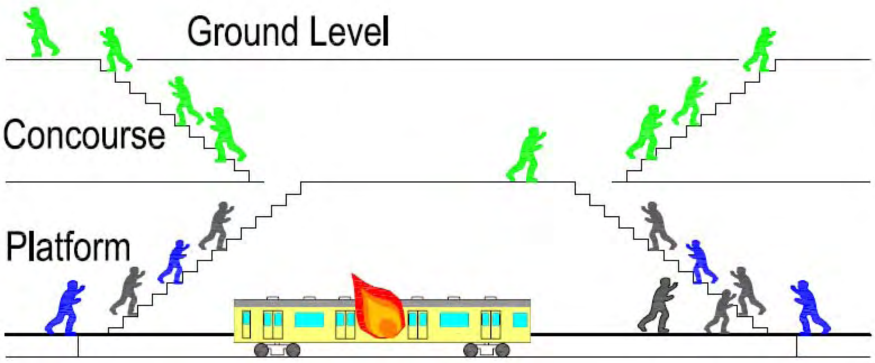


Figure 4-66 Provision of Two Separated Evacuation Passages with Ascending Stairs

The descending stair is allowed in case of the following exceptional cases:

1. Passengers escape to the neighbouring building/structure through descending stairs.
2. Descending stairs for the cross passages between the platforms of the side platform station and smoke barrier existing in the track way.

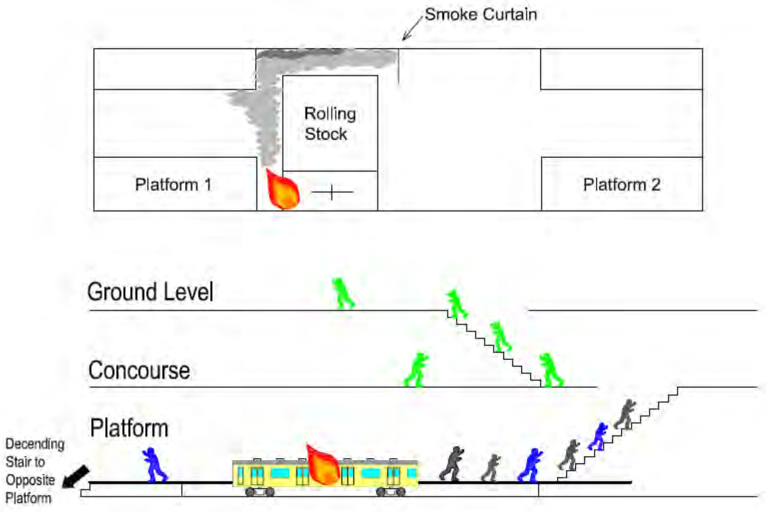
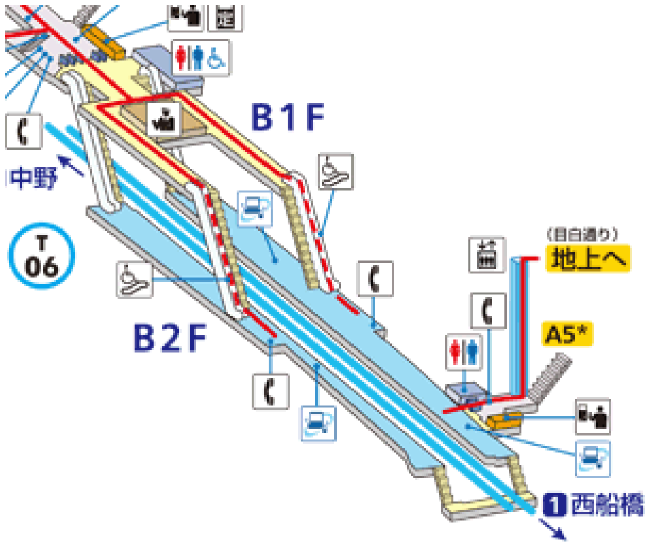


Figure 4-67 Provision of One Separated Evacuation Passages with Ascending Stairs



Source: Tokyo Metro, Iidabashi Station

Figure 4-68 Example of Evacuation Passage with Descending Stair

It is recommended that the entrances of the evacuation passages be located in both edges of the platform.

If it is difficult to put the entrance at the edge of the platform, the entrance of the evacuation passage should be located within 50 m from the edge of the platform.

The kiosk (small shop) on the platform should not be located between the edge of the platform and entrance of the evacuation passageway because it will become an obstacle for the evacuation in case of fire originating from it.

The effective width of evacuation passage should be 1.5 m or wider in principle. If required width is not provided due to constraint on private land use at ground level, etc, the width of the hand rail could be evaluated as part of the width of the evacuation passageway.

Spiral stairs should not be used for the evacuation passage because the inside of the step is narrow.

The escalator should not slide downward even if there is an overload of evacuation passengers. If the escalator has an anti-slide function, it could be evaluated as part of the evacuation passage.

The elevator should not be recognized and evaluated as part of the evacuation passageway.

2) Emergency Lighting on Evacuation Passage

In case of fire accident, there is possibility of power failure. Therefore, the emergency power supply/battery should be provided to the emergency lighting on the evacuation passage. The illumination of the floor on the evacuation passage should be 1 lux or brighter.

3) Guide Lighting for Exit and Directional Sign Board on Evacuation Passage

The guide lighting should indicate the location of exit and the direction of the evacuation. It should be a board with green color and put in a place where the passengers can identify it easily. The emergency power supply/battery should be provided.

Source: JICA Study Team

Figure 4-69 Guide Lighting for Exit

4) Emergency Lighting in Tunnel

If fire on rolling stock or cable fire occurs in the tunnel, the basic principle of the safety operation is to drive the train to the platform in the next station. However, there is the possibility and risk that the train stops in the middle of the tunnel. In this case, emergency lighting in the tunnel is required as in the evacuation passage in the station.

The power line for the emergency lighting should be separated from the power line for the train operation.

The illumination of the evacuation passage in the tunnel should be 1 lux or brighter.

5) Direction and Distance Sign Board in Tunnel

In order to identify the location for appropriate evacuation, the direction and distance sign board should be installed in the tunnel at an interval of 100 m or less. It should be installed in the vicinity of the emergency lighting and lower than 1.5 m.

Figure 4-70 Example of Direction and Distance Sign Board

(4) Smoke Control

1) Smoke Exhaust Facilities

As mentioned in the preceding section, the ventilation fans are used as exhaust facilities. Emergency power should be supplied to the smoke exhaust facilities.

2) Smoke Curtain (Shutter)

In order to protect the evacuation passage and concourse as the point of safety, the smoke curtain should be installed between the platform and concourse. If the fire protection compartment (shutter type) is used, the operation of the shutter should be carried out as indicated in the following section.

In order to prevent diffusion of smoke, the smoke curtain should be installed between the track and platform and at the foot of the stair/escalator, according to the requirement.

If installation of the fire protection compartment (shutter type) is difficult due to structural condition of station, the fixed smoke curtain/wall shall be installed at the foot of the stair of evacuation passage at the platform level.

The height of the smoke curtain should be 50 cm or more.

Source: Osaka City Transport Bureau, Japan

Figure 4-71 Smoke Curtain (Shutter)

(5) Fire Protection Compartment

1) Fire Protection Compartment

If the station is connected to other subway line or underground mall, the fire protection compartment, which can either be a fire protection screen with door (hinged or sliding) or a fire protection shutter (which should be limited roll-up type) should be installed at the connection border.

The fire protection shutter should be able to stop automatically if it hits something while moving downward, in order to prevent jamming of passengers.

Source: MLIT, Japan

Figure 4-72 Fire Protection Compartment (Screen Type with Door)

2) Operation of Fire Protection Shutter

The fire protection compartment (shutter type) should be installed at the foot of the stair/escalator between the platform and the concourse and should be installed at the required places for safe evacuation of the passengers.

The fire protection shutter should descend automatically down to a height of 2.0 m above the floor level, in accordance with the notification from the fire detector. Moreover, the fire protection shutter should be controlled from the emergency control room and descended by the station staff. The operation procedure of the shutter is as follows:

1) The fire protection shutter should automatically descend according to the notification from the fire detector or through the manipulation of the station staff down to a height of 2.0 m above the floor level.

2) The fire protection shutter should be closed by the station staff after the completion of the evacuation is confirmed. In principle, the fire protection shutter should be closed at the site by the station staff but it is preferable that the fire protection shutter could be closed from the emergency control room too.

Normal Operation

During Evacuation (Smoke Curtain)

Fire Protection Compartment

Source: Osaka City Transport Bureau, Japan

Figure 4-73 Fire Protection Shutter

(6) Fire Fighting Facilities

1) Fire Extinguisher

The fire extinguisher will be used for initial fire fighting and it will be used not only by station staffs but also by passenger. Therefore, it should be easily handled. The fire extinguisher shall be put appropriately in the station.

The specification of the fire extinguisher should comply with the Egyptian fire regulation/law.

2) Indoor Fire Hydrant Facility (with Hose Reel)

Indoor fire hydrant facility is used for initial fire fighting until the fire brigade arrives. Indoor fire hydrant facility shall be installed in the station.

The details of the location and specification of the hydrant and hose reel should comply with the Egyptian fire regulation/law and be discussed with the fire department of Greater Cairo City.

Source: Rinkai Line, Japan

Figure 4-74 Example of Indoor Fire Hydrant

3) Sprinkler (Automatic Operation)

In case of fire in station office and other rooms where passeger or station staff stay longer, it is assumed that the room is filled with smoke and is difficult for fire brigade to extinguish the fire properly. In this case, the use of sprinkler is more effective to suppress fire. Therefore, sprinkler should be installed in these rooms.

In the platform and concourse, there is little flammable material. If the sprinkler is used in the machine/electric room, there is a probability and risk of damaging the electronic device and machine due to water from the sprinkler.

It is preferable to install the inert gas fire extinguisher or dry chemical extinguisher in the substation, electric room and machinery room.

The capacity and performance of each sprinkler should be at least 1.6 m^3 (80 L x 20 minutes).

The pump and other facilities for sprinkler should be located in a place bounded by nonflammable material. The emergency power shall be supplied to the system.

4) Sprinkler (Pumped by Fire Engine through Siamese Connection)

This system resembles the abovementioned sprinkler system. The difference is that this system does not have water tank, pump and automatic operation system. Water is supplied through hydrant pipe and Siamese connection by fire engine in case of fire.

This type of sprinkler could substitute for the automatic sprinkler.

5) Gas or Dry Chemical Extinguisher

As desribed in the preceding section, it is not suitable to use normal extinguisher or sprinkler system for the room with electric or machine facilities. It is preferable to install the inert gas fire extinguisher or dry chemical extinguisher in the substation, electric room and machinery room.

6) Hydrant and Water Pipe Connection (Siamese Connection)

This hydrant for water outlet, water pipe and Siamese connection are used by fire brigade. The hydrant for water outlet should be installed in the platform, concourse and passageways. The horizontal distance from any fire point to the hydrant should be less than 50 m.

The structure of the hydrant, water pipe, etc. should comply with the Egyptian fire regulation/law and be discussed with the fire department of the Greater Cairo City.

Source: MLIT, Japan

Figure 4-75 Example of Hydrant for Water Outlet in Station (Left) and Siamese Connection for Water Supply on Ground Level (Right)

7) Hydrant and Water Pipe Connection (Siamese Connection) in Tunnel

In case of fire on the rolling stock in the tunnel, the basic principle is to drive the train to the platform of the next station. However, the hydrant and siamese connection should be installed in the tunnel in case the train on fire stops in the tunnel. If the distance between the hydrants of the adjoining stations exceeds 500 m, the hydrant and water pipe should be installed in the tunnel. The hydrant for water outlet should be installed at an interval of 500 m or less in the tunnel. In addition, it is preferable to install fire fighting equipment such as the hose near the hydrant.

Source: Sendai City Transport Bureau, Japan

Figure 4-76 Example of Hydrant for Water Outlet and Water Pipe Connection in Tunnel

8) Water Source and Water Tank in Station

The water for the hydrant is supplied by the pump of the fire engine from Siamese connection which is located on ground level. It is necessary to confirm the water source near the underground stations. If the capacity of the water source near the station is less than the requirement for fire fighting, the water tank shall be installed in the station and the water for fire fighting should be stored.

(7) Emergency Control Room

Emergency control room should be located in each underground station for gathering information and data, communication with operation control center, fire department and other agencies, public address to the passengers, monitoring and control of the fire protection compartment and other facilities, etc. Some station staff should be deployed in the emergency control room at any time during operation.

Source: Rinkai Line, Japan

Figure 4-77 Example of Emergency Control Room in Station

4.4 Design Concept or Design Criteria

4.4.1 Civil Works

(1) General

The objective of this document is to present the main design guidelines regarding the preliminary design for civil works of underground structures of Metro Line 4 Phase 1.

It is often difficult to repair, reinforce, or reconstruct a cut and cover tunnel. This is why it is important to fully study the ground conditions, state of groundwater, materials used, and the construction method to accurately predict the limit states that may occur during the design lifetime and to design a tunnel that is durable and can be easily maintained.

As for the preliminary design for Metro Line 4, international standards and Egyptian standards will be considered. The particular design specification including code and standards will be specified in the basic design stage.

(2) Civil Engineering Structures to be Designed

The civil engineering structures to be designed are subdivided as follows:

- Underground Station
- Bored Tunnel
- Cut & Cover Tunnel

(3) Design Life

The design life of a structure is that period for which it is designed to fulfil its intended function when inspected and maintained in accordance with agreed procedures. The assumption of a design life for a structure or component does not necessarily mean that the structure will no longer be fit for its purpose at the end of that period. Neither will it necessarily continue to be serviceable for that length of time without adequate and regular inspection and routine maintenance. The design life of civil structures will be considered a minimum of 100 years.

(4) Underground Station Structure

1) General Principles

The design methods for the analysis of the underground station structures shall take into account the following:

1) The method of construction, including temporary works;
2) The ground/structure interaction, including the effects of temporary works;
3) Ground pressure redistribution and bending moment redistribution;
4) Short and long term heave and settlement; and
5) Groundwater loading, backfill and other imposed loadings such as surcharge and highway loadings.

For the purpose of assessing ground pressures, the underground station shall be regarded as a rigid box structure subject to earth pressure at rest.

2) Loads

Analysis of the additional ground loadings imposed by adjacent structures on the underground structures shall be undertaken and due account shall be given to the additional stresses in the design of the underground structures.

Where the tunnels are adjacent to buildings and other structures, analysis shall be made to ensure that no loss of support can occur which endangers the stability of the buildings.

All components of underground structures shall be proportioned to withstand the applied loads and forces as follows:

1) Dead load comprises the self weight of the basic structure and secondary elements supported as well as the weight of earth cover. The depth of cover shall be the actual depth. The maximum depth to tunnel axis shall be used.

2) Traffic surcharge of a uniform 10 kPa shall be used for depths below 3.0 m when the alignment is below streets. At less than 3.0 m depth, wheel loads shall be taken into account.

3) Loads from existing or known future adjacent structures above or within the area of influence that will remain in place above the tunnels, or any specified future loading. The applicable foundation load shall be computed based on the height and type of occupancy or use.

3) Flotation

The station structures shall be designed to ensure safety against flotation due to underground water pressure.

The required safety factor is 1.10 without taking into account the friction between the diaphragm walls and the soil for permanent and high water levels.

In evaluating the design shear resistance to uplift between the walls of the structure and the ground, or lateral backfill as the case may be, a partial safety factor of 3.3 on the design shear strength of the material shall be used.

Suitable measures to counteract flotation forces shall be incorporated.

The measure(s) chosen shall suit the particular conditions and method of construction and may include the followings:

1) Toeing in of the base slab into the surrounding ground;
2) Increasing the dead weight of the structure by:
   - thickening of structural members,
   - providing an extra thickness of concrete beneath the base slab tied into the structural base slab, and
   - deepening diaphragm walls.

The value of the weight of any additional thickness of concrete shall take account of the increased volume of water displaced.

4) External Waterproofing

Where the tunnel structure is built independently with temporary earth retaining wall, external waterproofing membrane shall be provided all around the tunnel structure.

Where the temporary earth retaining diaphragm wall is used as part of the permanent structure, external membrane shall be provided over and under the tunnel structure.

Where external membrane cannot be provided, other suitable kinds of waterproofing methods shall be employed.

5) Station Structures

All stations will be reinforced concrete underground constructed within permanent diaphragm walls. Planning a station includes deciding the location, alignment, inner section, selection of the construction method, and construction period.

To plan the location of station, the plane location and depth must be decided considering location conditions, obstructions, and environmental conditions, and should be according to ground and construction conditions.

The form of the station structures is appropriately determined considering the clearance gauge, track structure, electrical equipment, ventilation equipment, drainage equipment, disaster prevention equipment, and maintenance equipment.

The profile of the structures is also predetermined by the need to minimize impact on the existing structures during construction together with constraints such as maintenance of existing public utility services which may cross the boundaries of the site.

Following the completion of the diaphragm walls, which serve as the permanent perimeter walls of the structures, the station building will be generally constructed by the top down method. The required TBM launch and retrieval access shafts and station structures will also be constructed by the top down method.

The pedestrian accesses, providing connections from the station to the surface level, will generally be constructed in diaphragm walls, except the shallow sections near the surface entrances. The transition between structures constructed in-situ in open excavation and diaphragm wall construction will depend on the location of the structure and on the proximity to moving sensitive structures and utilities.

The diaphragm walls will support lateral pressures from ground and applied surcharge loads, with strutting action provided by the internal slabs. The effects of hydrostatic uplift will be resisted by a combination of dead weight with additional restraint provided by the frictional interface between diaphragm walls and soil strata.

Structures constructed in-situ in open excavation will resist hydrostatic uplift by a combination of dead weight with additional keying action provided where required by the extension of the base slab beyond the outer face of the permanent retaining wall to form a horizontal key.

Internal floor slabs will be designed to support the applied live loads, which will include the large superimposed live loads generated by the electrical and mechanical equipment that will also be housed in the stations.

The main slabs, which will act as permanent struts to the external walls, will also be designed to resist the axial forces arising from the applied ground, surcharge and hydrostatic pressures acting on the walls.

Internal floors will generally be designed to span in one direction. Where possible, the spans will be optimized by the introduction of intermediate supports, which will maximize the transfer of dead weight to the raft slab to counter weight the effect of hydrostatic uplift.

6) Diaphragm Wall Design

The construction sequences for underground structures may be modelled by a number of steps. Soil and rocks may be modelled as two dimensional solid elements with options of soil failure criteria such as Mohr-Coulomb and Soil Hardening model for the deep excavations that interact with the structural element and groundwater. The structure force envelops enclosing the forces obtained from modelling each construction step can then be used for the design of reinforcement in the diaphragm walls and couplers required at the diaphragm wall/slabs connections.

7) Wall-Slab Connections

For roof, intermediate slabs, cut and cover tunnels and annex slabs, the joint between slab and wall is detailed as a full moment connection. The degree of fixity is indeterminate, but for the purpose of the wall analysis, the connection is assumed to provide full fixity and the wall designed accordingly to limit the risk of cracking of the external structural wall. The assumption of partial fixity would introduce risk to water tightness from any rotation and associated displacement which the waterproofing system would be unable to accommodate.

8) Design Basis for the Inside of the Diaphragm Wall

The internal part of the underground station must be performed in conjunction with the diaphragm walls calculation.

In fact, some of these slabs (completely or partially) can be used as stiffeners or struts during construction (soil excavation) in which case, the resulting forces generated by the diaphragm walls must be taken into account in the calculation.

9) TBM operations

The effect and interaction of the TBM operations will be considered integrally in the analysis of the underground structure. The design will take into consideration the various construction stages, method of breaking through diaphragm walls, loading regime on the permanent structure, support conditions, ground settlement control and water tightness.

Special diaphragm wall panels will be considered at the location for TBM opening. The area to be broken out by TBM will be designed using methods such as fibre reinforcement technology.

(5) Bored Tunnel Design

1) General

These principles shall apply to all bored tunnels:

- Tunnels between stations will be generally constructed by shield methods. A boring machine will be used between underground stations.
- The shield tunnel is composed of reinforced pre-cast concrete segmental rings placed using a tunnel boring machine.
- Segmental lining work must not only ensure safety for the service life of the tunnel but also ensure safety against temporary situations during the construction period.
- Segment materials, type, and joint shape are selected considering the ground conditions, size of the tunnel inner space section, tunnel alignment and location conditions so the tunnel will fill its stipulated functions and will comply with the construction method and related work plans.
- The limit state design method shall be used for the design of all permanent underground concrete structures.
- Due account shall be taken regarding the degree of flexibility of the linings to be used in the various soil conditions and considering the size, proximity,

timing and method of construction of adjacent excavations. The inherent lining flexibility may have to be reduced in order to maintain acceptable values for the deflection of the lining.

- The design life required shall be obtained by the use of durable materials, corrosion protection, resistance to or avoidance of wear, etc. Main structure resisting ground and groundwater loads should have a design life of 100 years.

The design shall address the following aspects, as appropriate:

1) Ring configurations may include:
   - rings with parallel circle faces,
   - tapered rings for specific curvatures,
   - tapered rings designed to suit any required curvature, and
   - matched or staggered joints.
2) Segment size and form including:
   - ring length
   - segment arc length
   - joint details
   - plane radial or longitudinal joints
   - non-plane joints
   - non-radial joints for key segments
   - wedge segments
3) Other components:
   - grout hole valves
   - gaskets
   - bedding and packing materials

2) Loads

The loads for the bored tunnel design as listed in the Design Standards for Railway Structures and Commentary (Shield Tunnel), 2002 shall be applied for the preliminary design stage.

Analysis shall be undertaken on the additional ground loadings imposed by adjacent structures on the underground structures and due account should be given to the additional stresses in the design of the underground structures.

Where the tunnels are adjacent to buildings and other structures, analysis shall be provided to ensure that no loss of support can occur which endangers the stability of the buildings and structures.

All components of underground structures shall be proportioned to withstand the applied loads and forces as follows:

1) Dead load comprises the self weight of the basic structure and secondary elements supported and the weight of earth cover. The depth of cover shall be the actual depth. The maximum depth to tunnel axis shall be used.

2) A uniform traffic surcharge of 10 kPa shall be used for depths below 3.0 m when the alignment is below the streets.

3) Loads from existing or known future adjacent structures above or within the area of influence that will remain in place above the tunnels, or any specified future loading shall be considered. The applicable foundation load shall be computed based on the height and type of occupancy or use.

3) Flotation

The bored tunnels shall be designed to ensure safety against flotation due to underground water pressure.

The required safety factor is 1.10 without taking into the account the friction in the soil for permanent and high water levels.

All tunnel designs shall be checked against flotation in accordance with the methods specified above.

4) Waterproofing

A high standard of waterproofing of the tunnel linings shall be provided.

The design shall incorporate sealing strips in the segment design. Materials for sealing strips shall be hydrophilic or elastomeric type or a combination of the two.

The design shall aim to ensure that no loss of ground occurs through any part of the completed structure.

(6) Cut and Cover Tunnel

The cut and cover tunnels may be formed within diaphragm walls and in this case it will be constructed through the top down method. The design of the retaining walls will take into consideration the effects of soil structure interaction and the varying loading conditions to which they will be subjected to during execution of the works and subsequently up to completion.

The depth of the retaining walls will be determined to satisfy the criteria for vertical and lateral stability as well as stability during excavation.

The base and roof slabs will be constructed using reinforced concrete, detailed with moment connections and designed to span transversely between external walls; the base slab supporting hydrostatic pressures, and the roof supporting the full weight of backfill and live load surcharge following surface works reinstatement.

The base slabs, which will be subjected to hydrostatic pressure, will span transversely between the embedded retaining walls, and will be detailed with a moment and shear connection to the external embedded retaining walls.

The behaviour of underground structures like cut and cover tunnels subjected to earthquake motion is strongly influenced by the behaviour of the surrounding soil.

The Seismic Deformation Method, which computes the dynamic behaviour of surrounding soil and then applies statically the outcome displacement to the structure through the sub-grade reaction, shall be used.

Method of Seismic Analysis

The member damage and stability levels are taken as indices for evaluating the seismic performance of cut and cover tunnels. The following shall be applied to the verification of the seismic performance of cut and cover tunnels:

1) Level-1 earthquake motion

The Level 1 earthquake motion has a probability of occurring several times within the service period of the structure in the vicinity of Cairo City.

2) Seismic Performance I

At this performance level, the function of the structure is retained without conducting repair after an earthquake and no excessive displacement occurs.

3) Member Damage level 1

Member damage level 1 should be satisfied for each of the structural members to ensure Seismic Performance I against Level-1 earthquakes. Set within the displacement of the longitudinal reinforcement yield point, this is a level at which no damage occur and no repair is required after an earthquake. Though the stability level need not be verified in general, the stability (settlement or uplift) of the structure should be verified when ground liquefaction is expected to occur.

On the other hand, verification of the Seismic Performance II is not required in Cairo City because of the low level of earthquake motion.

(7) Annex Structures

The annex structures will be formed in diaphragm wall construction. The permanent retaining walls will be carried to support lateral earth, hydrostatic and surcharge loads by means of waling beams and cross beams located at each floor level and between shafts. The cross connection with the bored tunnel will be constructed by tunnelling methods.

4.4.2 Architectural Works

(1) City Planning Viewpoint

Every station will have characteristics different from each other according to their location, neighbouring land use and backgrounds, future development process, volume of passengers, their transfer or other behaviours, etc.

Especially, those stations to be located near the heritage area should have a close arrangement and consensus with related authorities such as the Supreme Council of Antiquities.

(2) Main Codes and Regulations

The architectural design to be applied for Metro Line 4 stations shall be as follows:

- Egyptian codes for civil and architectural works
- Egyptian building regulation law
- NFPA 130 for safety
- Egyptian code for the handicapped
- Urban Planning or Rural Residential Planning shall be reviewed by the Governorate of Cairo/Giza
- Egyptian Civil Defence Authority shall be responsible for the fire fighting and safety regulations.
- Guideline for “The Maintenance of Tracks and Turnouts by Egyptian National Railways” (Permanent Way Department). In this guideline, the platform width and related dimension are specified.

(3) Safety Evacuation Consideration based on NFPA 130

Metro Line 4 stations are designed in conformity with NFPA 130 as a basic design guide to cover fire protection and life safety issues.

Fire safety issues for underground stations are so particularly important that the standard requirements dealing with emergency procedures are summarized herewith.

In order to confirm a safe evacuation of passengers from the most remote point of the platform to a safe zone at grade through the stairs, ticket gates and the concourse, the walking travel time is to be calculated using station geometry data and average walking speeds. The platform occupant load (the peak 15 minute traffic loads) shall be taken into account in this formula, as confirmed in the further design phase.

Table 4-34 Proposed Time Frame Set by NFPA 130

Safety time for evacuation	
Platform to safety zone	4 minutes
Most remote point on platform to safety zone at grade	6 minutes

Source: NFPA 130

The evacuation time from the platform can be calculated by dividing the station occupancy load by the exit capacity available from platform to concourse.

To calculate the total evacuation time for a station, walking travel time should first be tabulated using the longest exit route and travel speeds as given in NFPA 130. Waiting times may occur at various constriction points.

(4) Emergency Exit

The platform, concourse and ground floor levels are linked by staircases, escalators and lifts respectively during normal operational hours. Except for the lifts, these can also be used in the event of any emergency. Enclosed staircases are also proposed to be provided at both ends of the underground station to cater to safe and quick egress from the platform to the concourse level. One of the abovementioned staircases can be used by the fire brigade as an access route.

This type of staircase shall be planned in case the platform level is significantly deep and with a large number of platform occupant loads.

(5) Design for the Disabled

Stations of public transportation need to be more disabled–friendly by means of installing facilities that will provide passengers with physical and visual disabilities easier access. Design for the disabled shall basically be performed in accordance with Egyptian code for the handicapped.

The following design guideline shall be considered for disabled persons.

The principles outlined in this guideline shall be incorporated into the further design of the stations. This document sets out the background information, advisory information and mandatory standards for the overall guidance of designers relevant to various disciplines.

Approach to Station

Each station shall have at least one designated barrier free route (facilitated with elevators) leading into the station and linking to all possible passenger destinations within the station in compliance with the Code on Barrier Free Accessibility in public buildings. The approach to the elevator at the ground level should have a ramp or ramp plus stairway installed. (The ramp should comply with the guidelines listed above.)

Concourse

The concourse should not have a difference in floor level. If a level difference is unavoidable, install a ramp or a ramp plus stairways.

The floor surface of the concourse should be made of non-slip material. At places where there is a difference in levels such as stairs, it is desirable that the appearance of the surface material be changed using contrasting colours. Install guiding blocks on the concourse for persons with impaired vision.

Passenger WC

Install a toilet and washstand suitable for use by wheelchair users and other passengers.

Ticket Gates

At least one of the ticket gates should be wide enough to allow wheelchair users to pass through easily. One of the ticket gates should have a continuous line of guiding blocks for persons with impaired vision.

Ticket Vending Machines

The coin slot should be at a suitable height for easy insertion of coins by wheelchair users. A knee recess beneath the ticket vending machines should be provided. The fare buttons, cancel buttons and other information buttons should be written in Braille or in a distinct relief pattern.

Platform

The platform should have one row of dotted guiding blocks for persons with impaired vision. The paved surface of the platform must be made with a non-slip material. A bench should be installed on the appropriate location of the platform, having guiding block around it.

(6) Platform Screen Door (PSD)

A full height glass screen door which opens and closes as the train stops and departs shall be proposed. The screen installed between the platform and the track side makes the platform completely enclosed and not only prevents contamination of track dust and noise, but also encloses the air-conditioned platform, thereby enhancing passenger's comfort.

(7) Ease of Maintenance

Station shall have at least one access route for carrying maintenance materials and equipments to the machine rooms. Heavy and large size maintenance equipment can be carried from the track level to the upper floors through a maintenance hatch at the slab. Such equipments shall be brought by the maintenance train cars from outside.

(8) Basic Finish Materials

All materials used in the underground station shall comply with Egyptian codes for civil and architectural works and shall be vandal resistant, easily cleaned, maintained and non-flammable. In addition, the materials shall have low maintenance over their life span. Asbestos-containing materials shall not be used.

4.4.3 Track

(1) Basic Requirements

The track should conform to the following standards:

- It should withstand the established load.
- It should keep within the limit which will not endanger the operation of the rolling stock.
- It should be capable of being easily maintained.
- It should not impede maintenance.

As necessary, some permanent way facilities should be installed to prevent a derailment or minimize damage from sections of the main track with small curve radii which are vulnerable.

(2) Basic Stipulations

- Gauge: 1,435 mm
- Principle of driving: Left side running

(3) Basic Criteria for Track Equipment

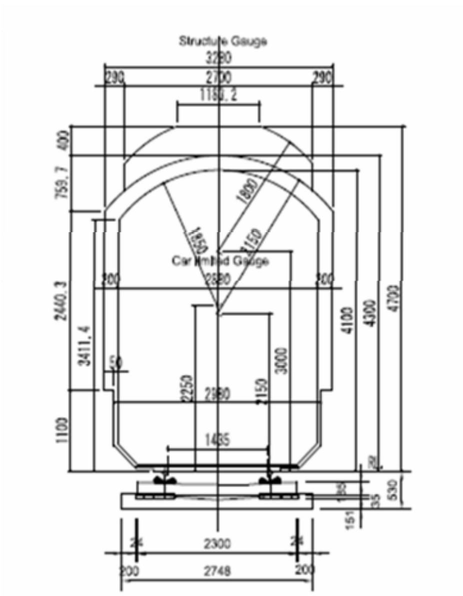
Profile of rail:	UIC60, UIC54 Grade of steel - referring to UIC-code 721 Continuous welded rail is recommended on mainline
Type of track:	underground section – solid-bed track Anti-vibration and noise reduction is required. workshop/depot – ballasted track
Type of ballast:	Grade of ballast - high quality and sufficient ballast profile Thickness of ballast - more than 150 mm on workshop/depot
Type of sleepers:	Pre-stressed concrete (mainline, workshop/depot) Plastic resin (turnout section)
Sleeper spacing:	It should be determined considering factors such as axis load, operation speed, railway sub-grade and type of sleeper, etc.
Type of fastening:	double elastic fastener (main line)

4.4.4 Rolling Stock

Main elements which decide a rolling stock plan are gauge, passenger capacity, train formation, body size and materials. The most important factors of a rolling stock plan are the demand forecast and the train operation plan.

(1) Passenger Capacity and Rolling Stock Gauge

Two types of rolling stock body size are used in Cairo Metro. One is 2.69 m wide and 16.9 m long as used in Metro Lines 2 and 3 (Type-A), and the other is 2.88 m wide and 20.0 m long as used in Metro Line 1 (Type-B). The width and length of body size is related to the train capacity. The demand forecast has shown a great demand for Metro Line 4 and the train operation plan needs greater passenger capacity than that of Metro Line 2 or Metro Line 3. To meet the passenger demand for Metro Line 4, 10 Type-A or 8 Type-B cars are required. The construction cost of underground station per meter is higher than the construction cost of two single tunnels per meter. In this respect, 8-car units are recommended because of the shorter length of station required. For the traction system, JICA Study Team proposed over head catenary (OHC) power supply system with 1,500 V/DC. Comparison study of OHC and third rail system are shown in Section 4.10.3 of Chapter 4. Figure 4-78 shows the construction gauge and rolling stock gauge of Metro Line 4.



Rolling Stock Gauge
- Track Gauge 1435mm
- Car Body Size Width: 2880mm
  Height: 4100mm
- Car Body length 20m

	Line 1	Line 2.3	Line 4
Train length (m)	190.2	140	162
Train formation	9 cars	8 cars	8 cars
Car length (m)	20.1	16.9	20.0
Car width (m)	2.88	2.69	2.88
Passenger Capacity (7persons/m2)	2600	1800	2000

Source: JICA Study Team

Figure 4-78 Construction Gauge and Rolling Stock Gauge

The rolling stock should be designed making wise use of the gauge. The car with 2.88 m width and 20 m length has been designed, and the train-set consisting of 8 cars has a 2,000 passenger capacity. This is 200 persons more than that of Metro Line 2 and 3 on the condition AW2, i.e., 7 persons/m^2.

(2) Compression Load and Body Materials

Regarding car body material, JICA Study Team proposes lightweight stainless steel. This type is usually selected for metro and commuter trains. The advantage is light weight, hard surface and maintenance reduction.

1) Compression Load

In Japan, rolling stock for Electric Multiple Unit (EMU), not locomotive, is designed based on a 50 tonnes compression load. Regarding the compression load, there have been no problems in Japan. The maximum of either traction or compression force is 24 tonnes in the case of Metro Line 4. The compression/traction load is largest when the train with exceptional load (11 passengers/m^2) is being pushed/pulled on a 40% gradient during emergency. Thus, 50 tonnes of compression load is enough for Metro Line 4. In this condition, the train weight of Metro Line 4 will be about a quarter less than that of Line 1.

Table 4-35 Comparison of Compression Load and Train Weight

	Metro Line 1	**Metro Line 2**	**Metro Line 4**
Material	Steel	Steel	Stainless steel
Train length (m)	190.2	140	162
Train weight: tare (tonnes)	408.6	281	266 (A.C. included)
Mean weight per meter (tonnes/m)	2.14 (100%)	2.01 (93.9%)	1.64 (76.6%)
Compression load at frame level (tonnes)	200	120	50
Traction load at frame level (tonnes)	90	75	35

Source: JICA Study Team

2) Car Body Material

Materials generally used for rolling stock include steel, stainless steel or aluminium alloy. Table 4-36 below shows the comparison of these body materials.

Table 4-36 Comparison of Body Materials

Material	Steel	Stainless Steel	Aluminium Alloy
Welding technology	easy	difficult	most difficult
Manufacturing delicate design	possible	impossible, use FRP if necessary	possible
Reparability in case of accident	easy	difficult	most difficult
Painting (Facility in W.S.)	needed	not needed	not needed
Train weight: tare (tonnes/train set)	290	266	258
Initial cost of a train set (Index)	100	107	120

Stainless steel is stronger than steel so the weight of the car made of it is much lighter than that made of steel body. Moreover, the surface of it is harder which contributes to damage resistance. As its name suggests, stainless steel doesn’t corrode, thus does not need painting and this contributes to maintenance reduction. The defect of stainless steel is the difficulty in manufacturing delicate design. If such a delicate design is necessary, FRP should be used.

Although aluminium alloy is lighter than stainless steel, the surface is soft and easily damaged. Moreover the welding technology of aluminium alloy is most difficult among the three materials because its melting point is low and thermal conductivity is large. It's easy to melt and flow.

These things considered, stainless steel is the best. However, the welding technology of stainless steel is fairly difficult so it is necessary that Egyptian companies should clear a high hurdle so as to acquire stainless steel welding technology.

(3) Operation Performance and Train Formation

Table 4-37 shows the operation performance. Concerning the metro area, JICA Study Team sets the same characteristic for the proposal as in Metro Line 2. The proposal has a potential ability of operation speed of 120 km/h. Thus, it will be profitable in case Metro Line 4 will be extended to the suburbs. Furthermore, it can transfer 10% more passengers than a Metro Line 2 train for the same weight, because its weight is light.

The power of the motor is up-sized to 140 kW so as to have the ability of 120km/h. If the maximum speed is designed as much as that of Metro Line 2, 80 km/h and 115 kW will be enough for the motor power of Metro Line 4.

Table 4-37 Operation Performance and Train Formation

	Metro Line 4	**Metro Line 2**
Track gauge	1,435 mm	1,435 mm
Power supply	OHC 1,500 V	3rd rail 750 V
Operation speed (Ability)	80 km/h 120 km/h	80 km/h
Initial acceleration rate Max. service deceleration	0.9 m/s^2 (ability: 1.3 m/s^2) 1.1 m/s^2	0.9 m/s^2 1.2 m/s^2
Train formation	M-N1-T-N2=N2-T-N1-M or Tc-N3-N1-N3-N1-N3-N1-Tc	M-N1-T-N2=N2-T-N1-M
Train length	162 m	140 m
Passenger capacity AW2 (7 persons/m^2)	2,000 persons	1,800 persons
Train weight : Tare : AW2	266 tonnes 406 tonnes	281 tonnes 407 tonnes

Source: JICA Study Team

The train formation can be selected from two types. One is similar to Metro Line 2, i.e., Type-1 (Figure 4-79), and the other is a typical Japanese formation, i.e., Type-2 (Figure 4-80). If it is not needed to divide a train into 2 units frequently, JICA Study Team proposes that type 2 is better. The maximum weight of a car of that type is lighter, and it is easy to increase the number of cars in a train-set by inserting trailer or motor cars.

(4) Car Body Design

The drawings of the proposed rolling stocks are shown in Figure 4-79, Figure 4-80 and Figure 4-81.

In Japan, the door size is 1300 mm wide, 1850 mm high and the seat size is 460 mm wide. However, our proposal has doors of 1500 mm wide and 1900 mm high, considering that the Egyptian morphology is bigger than that of Japanese. The width of a seat is also enlarged into 475 mm. Two wheelchair spaces are allocated in a train formation. If not needed, additional seats can be set up in these spaces.

TYPE - 1

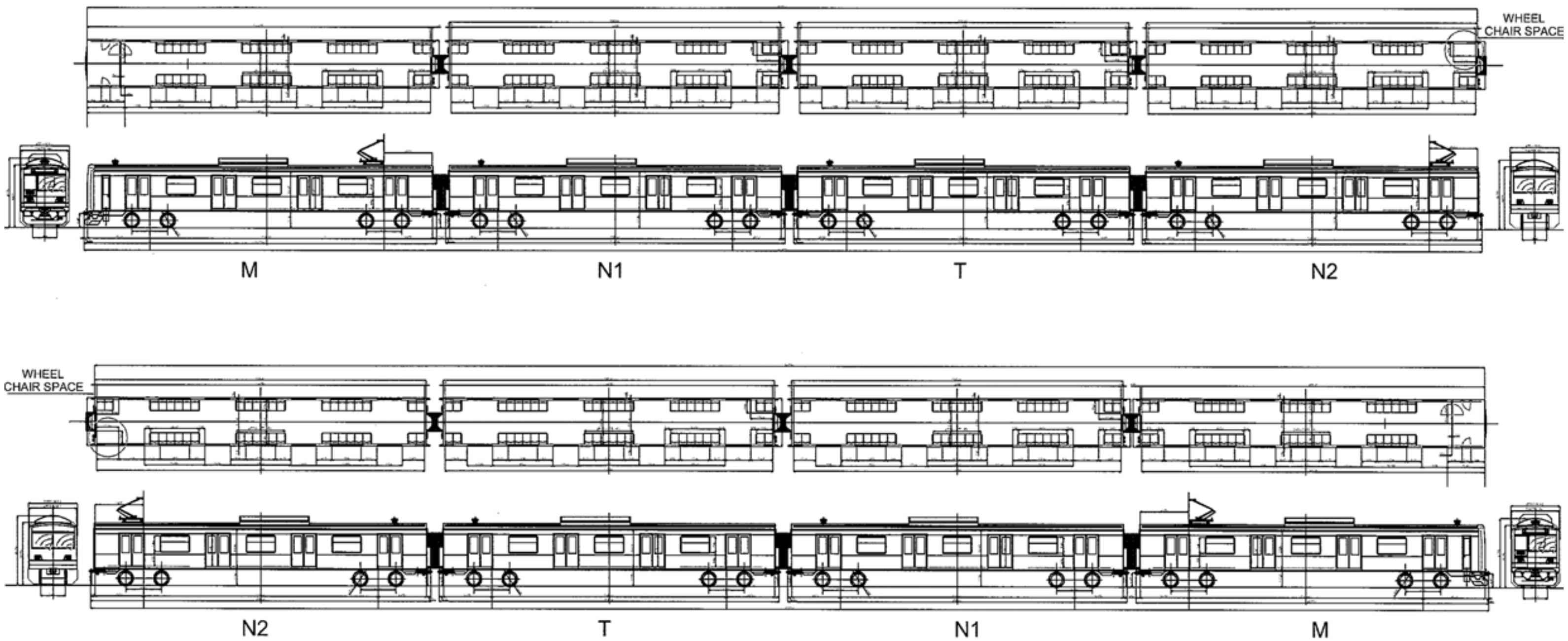


Figure 4-79 Train Formation of Type-1

TYPE - 2

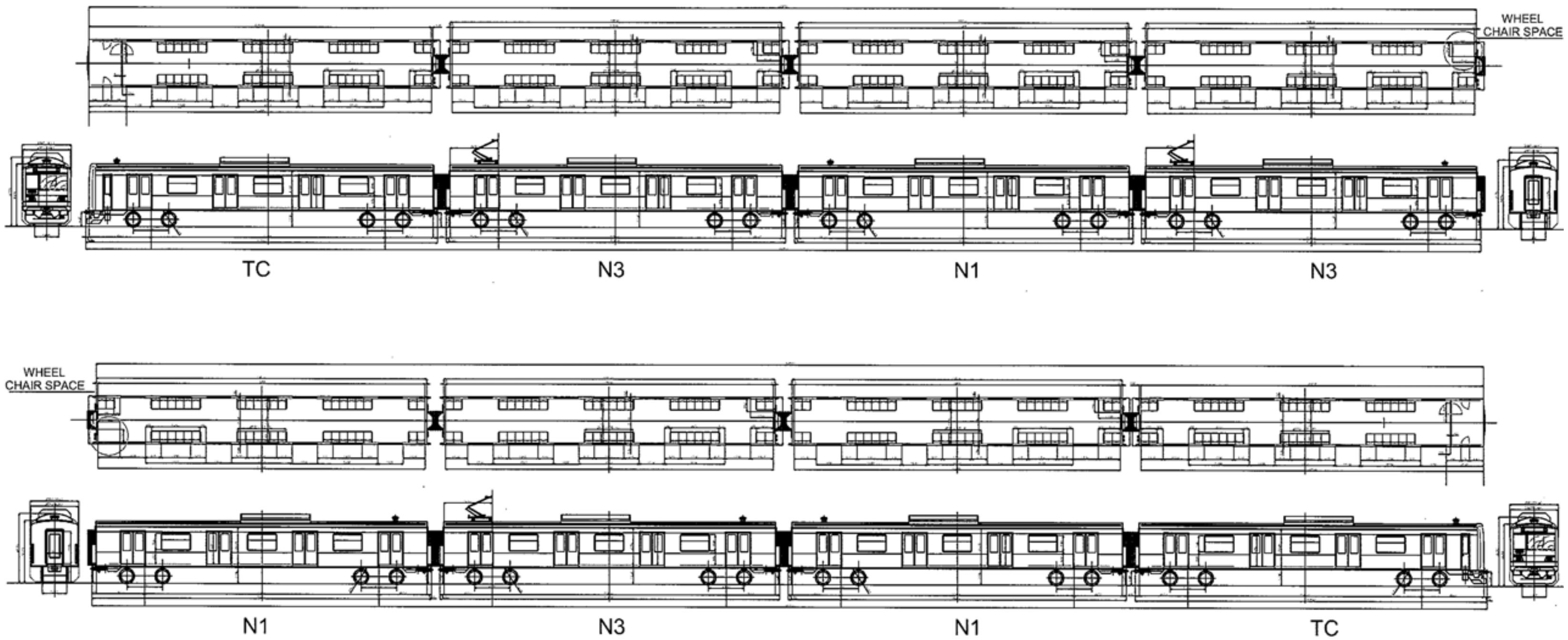


Figure 4-80 Train Formation of Type-2

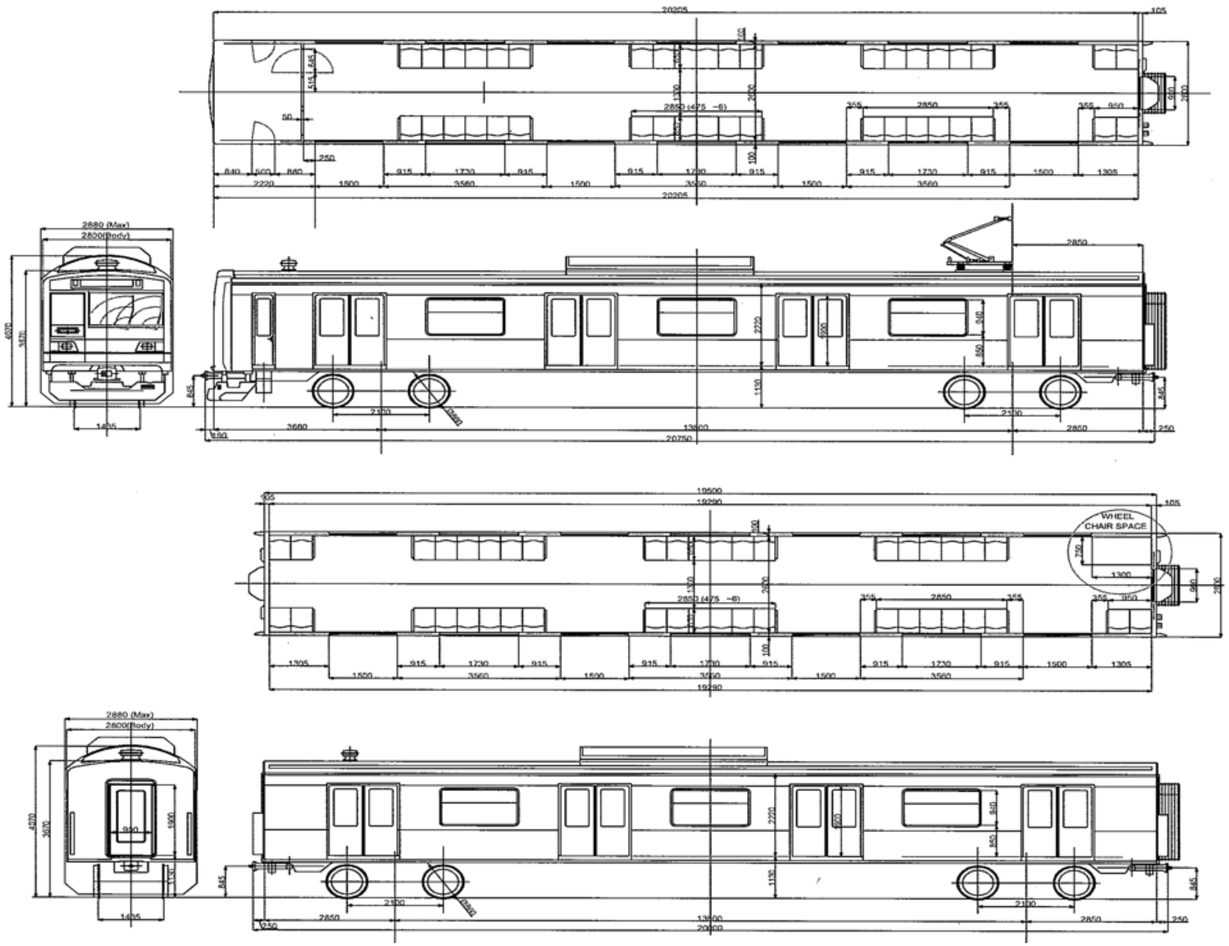


Figure 4-81 Typical Layout of Rolling Stocks

4.4.5 Signalling System

The signal system is a critical protection facility aimed at preventing trains from colliding with each other as well as preventing derailments. Furthermore, signal systems are also used to increase train operation density in order to enhance the utilization efficiency of the tracks. Therefore, signal systems must be capable of providing sufficient safety and the required reliability. Automatic train protection (ATP), which offers continuous control, requires a cab signal (CS) system in order to provide safe high-density operation. High-performance computerized interlocking equipment is installed in interlocking stations that have turnouts that can be used for turning trains around and other such functions. And there is a need to have the trains that are in operation monitored by an operating staff as well as a need to have the facilities in place to restore trains to normal operation should a disruption occur. The CCP is a command system that monitors and controls the operation of trains for the entire track system. Since the signal equipment is installed in a location where it is exposed to extremes of vibration, heat and humidity, it will need to have periodic maintenance, even for the most durable equipment, to address its inevitable aging and deterioration. Moreover, there should also be means to quickly restore proper operation should the equipment fail unexpectedly. It is also desirable to keep the number of staff workers needed for train operation and equipment maintenance in order to reduce operating expenses.

The following items comprise the wayside and onboard equipment used in the signal system:

- Interlocking devices, electric point machines that are used for controlling routes and track circuit devices that are used for train detection.
- Onboard signal equipment and wayside signal equipment for giving direction for the train about operation.
- Automatic train control (ATC), which includes both wayside and onboard ATC equipment, used for controlling the interval between trains.
- Automatic train operation (ATO), which includes both wayside and onboard ATO equipment, that provides support for operating the train.
- Programmed traffic control (PTC), which includes both centralized and individual station PTC, that can control train routes by remote control.
- Equipment that continually records the operating conditions for each piece of signal equipment. This enables information to be compiled for maintenance. This equipment also monitors the condition of the signal equipment and provides an alarm when an anomaly occurs.
- Signal routes (i.e., control cables, optical fibre cable (OFC) and conduit lines)
- Power supply equipment (emergency power generation equipment and uninterruptible power supply equipment).

Redundant fail safe (FS) systems using microcomputers are used to increase reliability in the interlocking devices and ATP that are needed for ensuring sufficient safety. In addition, MPU are used as a means of improving reliability in redundant systems even in equipment that does not have to fail safe. Redundant systems that use MPU, regardless of whether they are used for FS, offer far more added functions than previous systems while being compact and not requiring much space for installation and are easier to maintain.

4.4.6 Telecommunication

The communication system is the data transmission system used exclusively by the railway operator that enables reciprocal communication and data exchange among the various locations and sections of the track system that are involved in the smooth operation of the train, including the headquarters of the railway authority, CCP, field work organizations, stations, power substations and rooms for signal and communication equipment. There is also a train radio system that allows the CCP to communicate and handle data with both travelling and stationary trains so that commands can be given directly to the crews of those trains. Also, a video transmission system is used so that the station offices and CCP can monitor video images sent from such places as the platform on each station, ticket gates, concourses, stairs and escalators. These systems also have multiple levels in order to ensure the necessary level of reliability. Cables used for communication include OFC, city unit cable (CUC) used for direct communication phone lines, and leaky coaxial cable (LCX), which is installed along the tracks and used for the train radios. OFC and CUC are laid in fire-resistant routes, such as concrete ducts or troughs. Each cable is laid on the outside of up and down lines within sections comprised of double tracks and installed in each section comprised of single track to ensure redundancy. LCX is installed at the rail level (RL) tunnel side walls and at the sound barriers (on elevated sections). The cables in the communication system also have a level of redundancy so that even if the cable fails at one location, the communication system is still able to maintain its functionality.

4.4.7 Power Supply System

The design of the power supply system in Metro Line 4 aims to harmonize the following conflicting criteria at a high level of quality:

- High safety and reliability by proven technologies
- Cost reduction through optimization of whole railway system
- Environmental-friendly and energy-saving system by introducing state-of-the-art technologies
- Consistent system with existing lines considering easy O&M

In the transportation system development in Greater Cairo Region, Metro Line 4 is characterized as a connecting line between the central urban area and suburban developing areas. In selecting the traction system, the suitable system should be selected considering the line extension from the urban to suburban areas.

The capacity of High Voltage Station (HVS) is estimated as the summation of the total power consumption including traction power and power for station facilities on the assumptions of minimum head way, number of cars and passenger density by operation periods. The locations of HVSs have to meet the following conditions:

- Not so far from the metro route;
- Easy land acquisition;
- The area of around 3,000 m2 is necessary for HVS building;
- Grid connection from two independent substations is available; and
- Low grid connection cost.

The criteria for Rectifier Station (RS) design (for deciding the interval between RSs and the capacity of rectifiers) are as follows:

- One RS failure can be compensated by neighbouring RSs;
- The voltage of contact line should not be under 1,000 V in compliance with IEC standard;
- The distance between RSs should be as long as possible while meeting the above-mentioned requirements in order to decrease the number of RSs and reduce the construction cost of RSs; and
- RSs should be located inside the underground passenger stations.

Lighting and Power Station (LPS), which receives the 20 kV power from HVS and convert it into low voltage power to feed the station facilities, will be equipped in all passenger stations similar to the existing lines. Each LPS should have two feeders from HVS and one stand-by transformer for reliable power supply.

4.5 Rolling Stock Plan

4.5.1 Present Condition of Existing Metro Lines

The main rolling stock specifications are given in Table 4-38. The rolling stock for Metro Line 1 is a typical design for a suburban commuter train, which prioritizes passenger capacity and maximum operation speed. Those for Metro Line 2 and 3 belong to a typical metro system design, which can be operated on lines with small curve radii. Some systems, such as the propulsion system, are modernized according to the times.

The VVVF system and induction motor have contributed greatly to the reduction of system breakdown and maintenance work. The utilization of OBIS is useful to reduce inspection time.

Table 4-38 Main Specification of Rolling Stock (R.S) for Cairo Metro

Description		R.S for Metro Line 1	R.S for Metro Line 2	R.S for Metro Line 3 (under construction)
Train formation		M-T-M-M-T-M-M-T-M	M-N1-T-N2-N2-T-N1-M	M-N1-T-N2-N2-T-N1-M
Gauge		1.435 m	1.435 m	1.435 m
Power supply		OHC (1,500 V DC)	3rd rail (750 V DC)	3rd rail (750 V DC)
Train full length		190.2 m	140 m	140m
Car body	Length	21.65 m/20.1 m	17.96 m/17.31 m	17.96 m/17.31 m
	Width	2.88 m	2.69 m	2.69 m
	Height	4.3 m	3.35 m	3.35 m
Passenger Capacity AW3 (at 7 person/m^2)		2,600 passengers	1,800 passengers	1,800 passengers
Bogie	wheel base	2.5 m	2.1 m	2.1 m
	wheel diameter	1,020 mm/920 mm	860 mm	860 mm
Propulsion system		Rheostatic control + DC motor	VVVF Inverter with GTO+ Induction Motor	VVVF Inverter with IGBT + Induction Motor
Train speed (max. operating)		100 km/hr	80 km/hr	80 km/hr
Air conditioning		Not installed	In cab only	In cab and passenger car
OBIS		Not installed	9,600 bps	Over 1 Mbps

Source: JICA Study Team

4.5.2 Design Concept and Proposed System

JICA Study Team proposes the rolling stock for Metro Line 4 on the basis of the concept described in Section 4.4.4 and application of up-to-date technology. Table 4-39 shows the main specifications of rolling stock, which include some up-to-date technology.

Table 4-39 Main Specifications of the Rolling Stock

	Metro Line 4				Metro Line 2			
Car-body	M	N1	T	N2	M	N1	T	N2
・Length (m)	20.75	20.0	20.0	20.0	17.4	16.9	16.9	16.9
・Width (Max: m)	2.88 m				2.69 m			
・Weight (Tare): tonnes	37	33	30	33	37.1	34.8	26.7	34.9
・Seated Capacity	40	44	44	42	24	32	32	32
・Passenger Capacity	236	257	257	252	213	227	227	227
Floor level	1,130 mm				1,130 mm			
Door	4 doorways on each side/car				4 doorways on each side/car			
・Width	1,500 mm				1,500 mm			
・Height	1,900 mm				1,915 mm			
Bogie	Bolster-less/ Direct mount				Direct mount with Bolster			
・Wheelbase	2,100 mm				2,100 mm			
・Wheel diameter	860 mm				860 mm			
・Gear ratio	6.06				7.353			
Current collection	Single arm pantographs (4 sets/train)				Collector attached on bogie (12 sets/train)			
Propulsion system								
・Circuit control system	Inverter with IGBT				Inverter with GTO thyrister			
・Traction motor	PMSM or Induction motor 140 kW x 24 motor/train				Induction motor 115 kW x 24 motor/train			
Auxiliary power supply	Inverter Stand-by redundant type 200 kVA x 2 unit				DC/DC Converter 38kVA x 4 unit Inverter 36 kVA x 2 unit			
Air conditioning	Roof mounted with line-flow fan: 40,000 kcal/h/car				Not equipped			
Onboard information system	Train Bus 10 Mbps				Train Bus 9,600 bps			
Visual information system	100 Mbps Ethernet LCD: 2 set on each doorway				Not equipped			
Brake control system	Electric command air brake with regenerative brake				Electric command air brake with regenerative brake			

PMSM: Permanent Magnet Synchronous Motor
Source: JICA Study Team

4.5.3 Comparison and Recommendation

JICA Study Team proposes some specific items which provide customer satisfaction, efficiency, reliability, maintenance reduction and environmental friendliness.

(1) Bogie

There are two bogie types. The first type has a bolster, the centre beam that supports the body weight and can rotate around the centre pin of the bogie frame. The latter which does not have a bolster is a bolster-less type. The type used for Metro Line 2 is the one which has bolster beam and is called the direct-mount type. This type enables a car to rotate through the way the bolster rotates around the centre pin.

A bolster-less bogie supports the body weight with the air suspension directly mounted on the bogie frame. It enables a car to rotate through the way the air suspension twists. JICA Study Team proposes a bolster-less type as long as minimum curve radius in the mainline is above 150 m. Bolster-less type is simple, light and low maintenance.

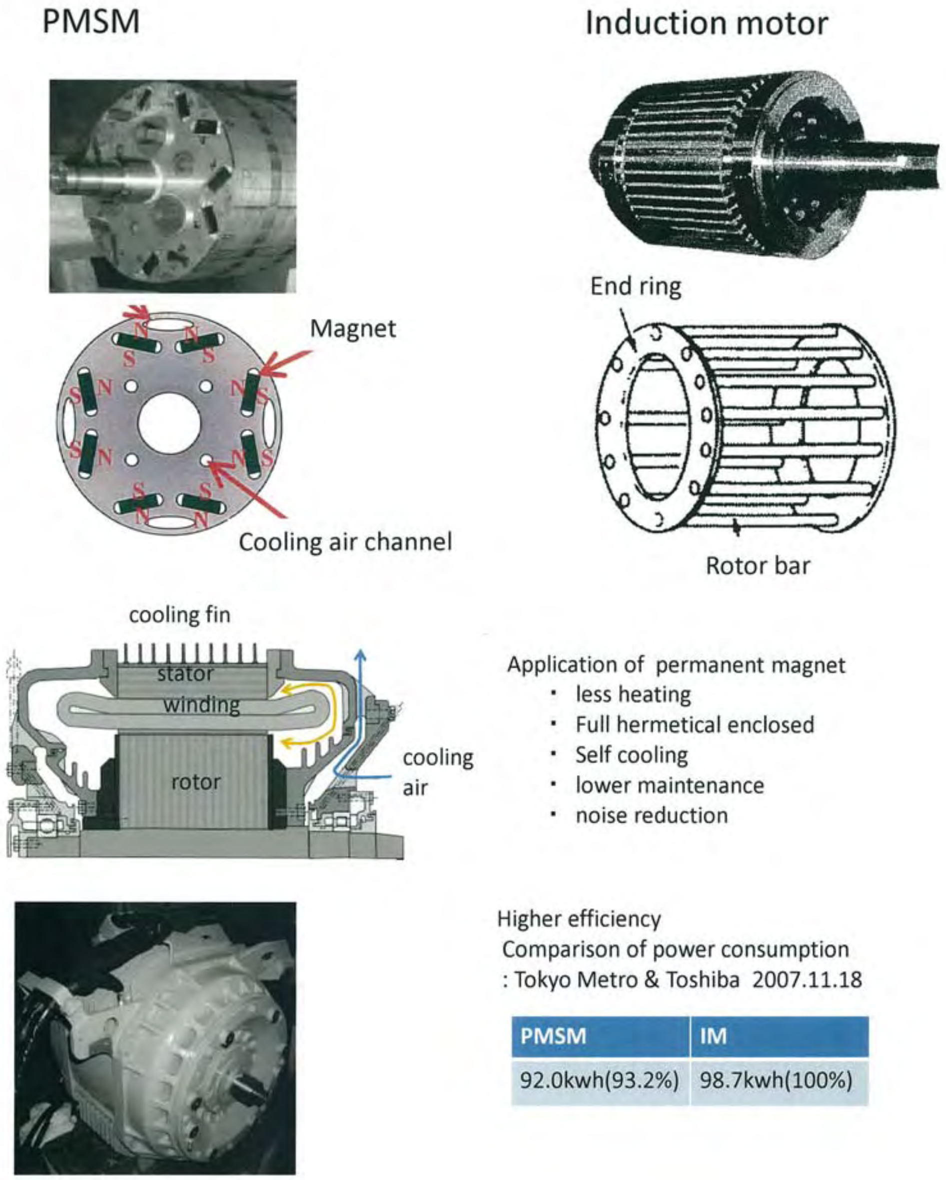
(2) Traction Motor: Permanent Magnet Synchronous Motor (PMSM)

Nowadays, induction motors are predominant for the traction motor of rolling stock. It is lighter, stronger, and requires less maintenance than a direct current motor because it does not have a commutator. For Metro Line 4, JICA Study Team will propose the cutting edge technology of the PMSM. PMSM has permanent magnets in its rotor and makes the most of the magnetic energy. Thus, the efficiency of PMSM is even higher than that of an induction motor (IM).

Since PMSM generates less heat, we can adopt self cooling and full hermetical enclosed structure. A full hermetical structure contributes to noise reduction and maintenance reduction. The test undertaken by Tokyo Metro and Toshiba shows that its efficiency is about 7% higher than that of an IM. This contributes to less energy consumption.

Usually, the maintenance of PMSM is lubrication or replacement of the bearing. PMSM is designed so that the bearing can be removed without any special tools.

The additional initial cost from IM to PMSM is about 1% of the total train-set cost. PMSM can reduce the traction power cost by approximately 5%, because that power includes some electricity for service equipments. In Japan, PMSM can save power cost much more than additional initial cost in its life time. However, the power cost in Egypt is so low that PMSM can offset less than 30% of the additional initial cost in its life time. As far as cost efficiency is concerned, IM system is superior to PMSM and the top advantage of PMSM in Egypt is that sweeping dust in the motor is unnecessary.



Source: JICA Study Team

Figure 4-82 Permanent Magnet Synchronous Motor (PMSM)

(3) Auxiliary Power Supply Stand-by Redundant Type SIV

These days, the importance of the auxiliary power supply system is increasing because its generated electricity is used by most train control systems. If it is down, all control systems using its electricity would also be down. It follows that the train cannot move, air-conditioning will stop, and lights go out in a few minutes.

In order to avoid these cases, it is necessary to consider a back-up system. Until now, parallel control systems have been usually adopted. In this system, if 1 of the 2 systems breaks down, the capacity needs to be limited and some equipment such as air-conditioning must be stopped.

JICA Study Team's proposal is a stand-by redundant type SIV. It is composed of 2 full power systems. Normally, only 1 of the 2 systems works, and the other is on stand-by at regular interval. In case 1 system is down, the switching circuit automatically changes over and the other will work. Full power will be maintained so the train can move without any trouble.

(4) Air-conditioning Equipment

Air-conditioning equipment are mounted on roofs of cars. The capacity of each unit is estimated at 40,000 kcal/h on condition that:

- Outside air-condition is 40 oC with humidity of 30%
- Air-condition in a car is 27 oC with humidity of 50%

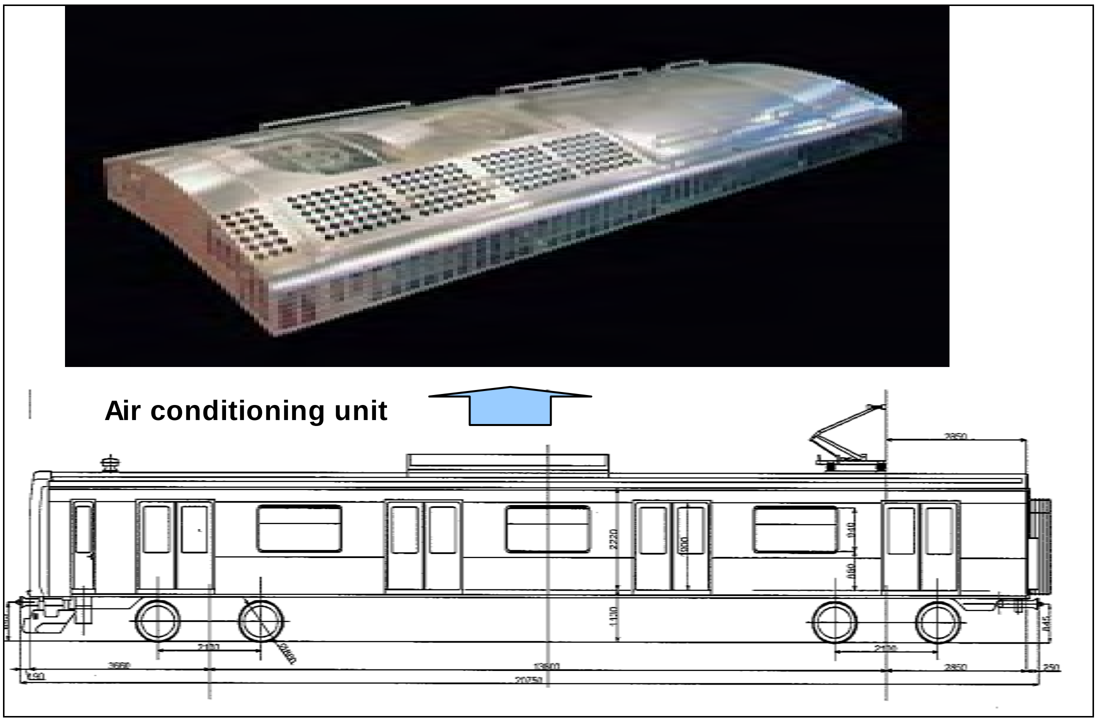
Several range of capacity larger than 40,000 kcal/h can be provided.

Some specifications are shown below as an example.

- Cooling capacity is about 40,000 kcal/h or more.
- Air supply: Fresh air is 20 m3/minute and recycled air is 120 m3/minute.
- Coolant is non-pollution type, R 407C.
- The condition is automatically controlled by on-board train information system.

The separated unit can be selected. In that case, the capacity for driver cabin will be 4,000 kcal/h approximately.

Air-conditioning system is not necessary for train operation, and some or all windows can be opened. In case of failure of air-conditioning, the passengers should open the windows to get fresh air. The troubled train-set should be changed as soon as possible.

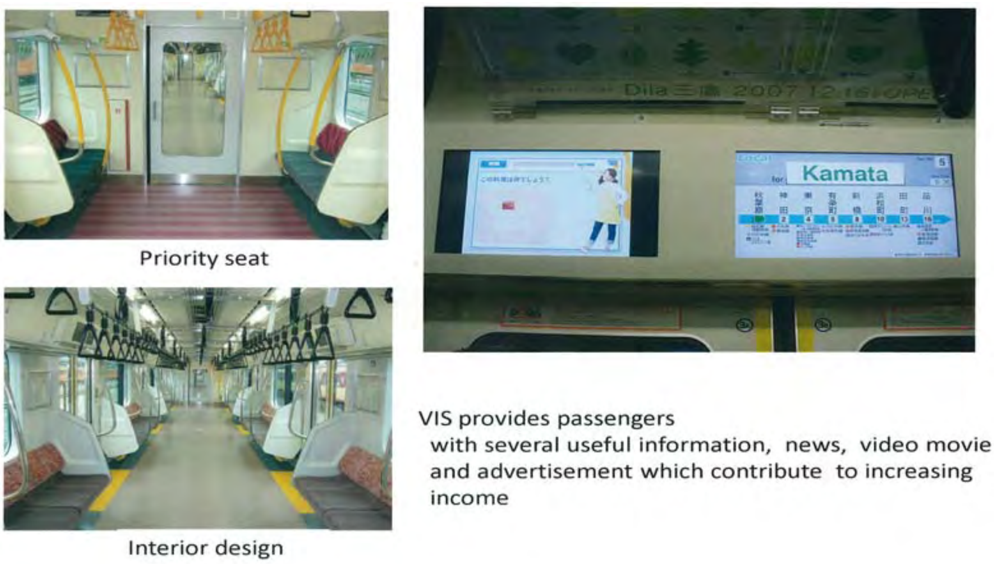


Source: JICA Study Team

Figure 4-83 Roof-mounted Air-conditioning Equipment

(5) Interior and Visual Information System (VIS)

Figure 4-84 provides images inside the car, which shows priority seat and interior design. A universal design is applied and visible colour is used. These seats are composed of fabric, but might need to be replaced with plastic seats as they are easily broken.



Source: JICA Study Team

Figure 4-84 Interior Design and VIS
(An example: JR East in JAPAN)

There are two LCD displays of VIS on each top of the door. VIS is the information system which provides passengers with several varieties of information. One display is used for the information about train operation, the name of the next stop station, time required to each station and passengers warnings. The other is used for information such as news, economics, sports, weather report and advertisement which contributes to increasing income. The data of this information is transferred to the server of a train through wireless LAN placed in some stations.

4.5.4 Rolling Stock Transport Plan

Probably, most of the rolling stocks for Metro Line 4 will be constructed overseas like those for existing lines, which were transported by cargo vessels and landed at Alexandria. Since workshops of existing lines are directly connected to ENR lines, rolling stocks for those lines are transported to their workshops by ENR from Alexandria.

However, the workshop of Metro Line 4 will not be connected directly to ENR lines and the construction gauge of Metro Line 4 is smaller than that of ENR. ENR's traction locomotive will be unable to go through Metro Line 4 to the workshop directly. Therefore, the diesel locomotive of Metro Line 4 will be substituted for ENR's locomotive in the yard which is nearest to Metro Line 4 and it will pull the rolling stocks toward the workshop.

Another way is to use trailer trucks. For example, the rolling stocks will be transported to the Shubra Workshop by ENR and carried on trailer trucks from there to the workshop of Metro Line 4. It is noted that it is possible to transport them from Alexandria to the workshop on trailer tracks.

The best way should be selected after the final decision of the location of the workshop and the connection to the ENR line.

4.6 Civil Works (Tunnel)

4.6.1 Basic Condition

(1) Geological Condition

The geological survey was carried out at stations and intermediate points between stations. The characteristics of the soil and ground based on the survey are as follows.

a) Ground Water Level

The ground water level is very high at a depth of 2.5 m from the ground level.

b) Characteristic of the Soil and Ground

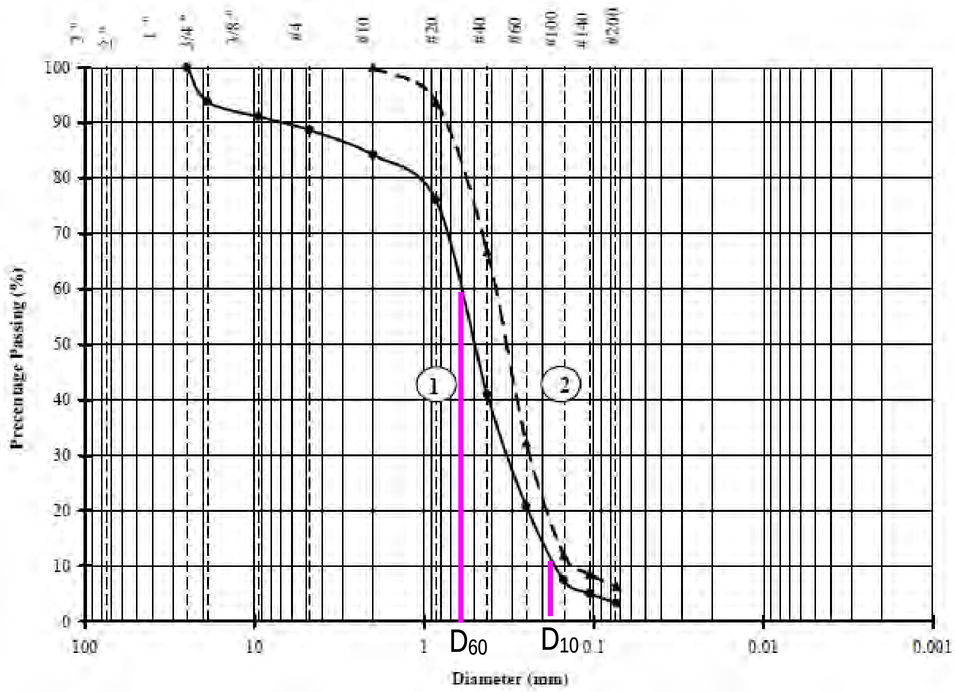
The ground of the project area is mainly composed of sandy stratum. The geotechnical soil parameter is assumed from past papers and geological surveys, as seen in Table 4-40. The shield Tunnel Boring Machine (TBM) is expected to pass mainly in the Sand (1) and Sand (2) strata. The typical particle size distribution is shown in Figure 4-85. These sand strata have small uniformity coefficients, defined as “Cu=D60/D10”. Herein, D60 corresponds to the 60% fine particle in the size distribution and D10 corresponds to the 10% fine material. The uniformity coefficient of the ground is distributed from 3 to 9 and the content of the fine material (smaller than 0.074 mm) is less than 10% (see Figure 4-88). From past experience, the cutting face in sand stratum, which has a low uniformity coefficient and less content of fine material, is unstable when excavated by the shield TBM. The cross sections of shallow overburden and deep overburden are shown in Figure 4-86 and Figure 4-87.

- The main stratum where the shield TBM is expected to pass is the sand stratum. The sand stratum is dense to very dense but it is the collapsible ground of low uniformity coefficient and low content of fine material.
- The shield TBM is expected to pass clay stratum in some areas. The clay stratum is dense and stable.
- It is expected to encounter a limestone plateau in the area from Station No.12 to No. 15.

Table 4-40 Geotechnical Soil Parameters

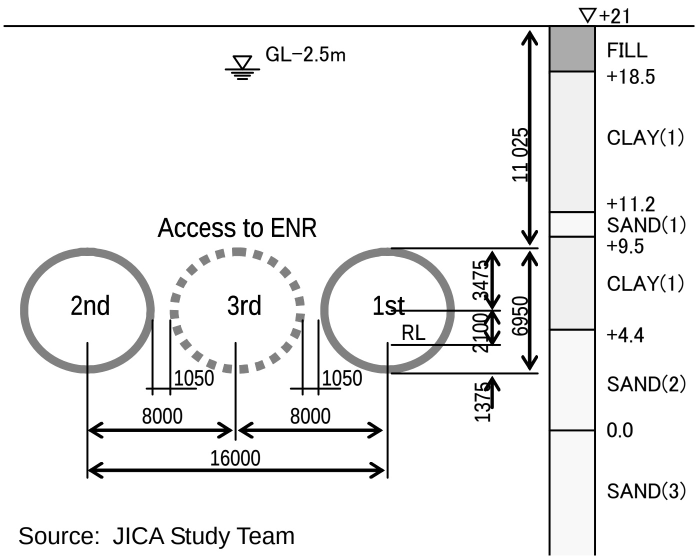
	SPT-N	γ	φ	C	Eo	ν
	-	tf/m3 (10kN/m3)	°	kgf/cm2 (100kN/m2)	kgf/cm2 (100kN/m2)	-
FILL	8	1.7	32	0.0	170	0.35
CLAY(1)	14	1.7	0	0.9	290	0.40
SAND(1)	16	1.8	33	0.0	340	0.35
SAND(2)	51	1.9	38	0.0	710	0.30
SAND(3)	100	2.0	40	0.0	980	0.30

Source: JICA Study Team



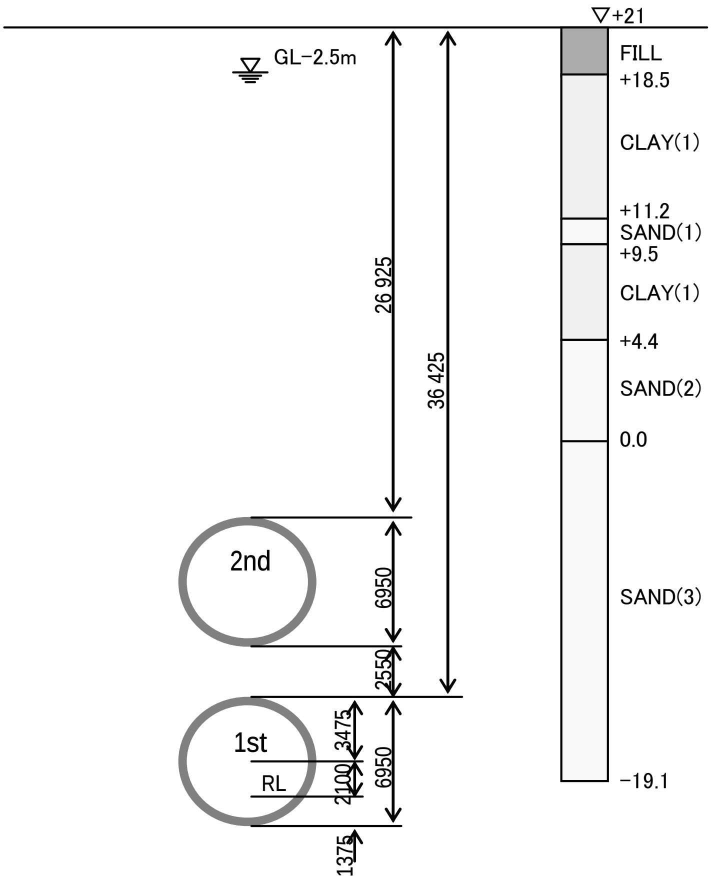
Source: JICA Study Team

Figure 4-85 Typical Particle Size Distribution (from the Data of Station No.9)



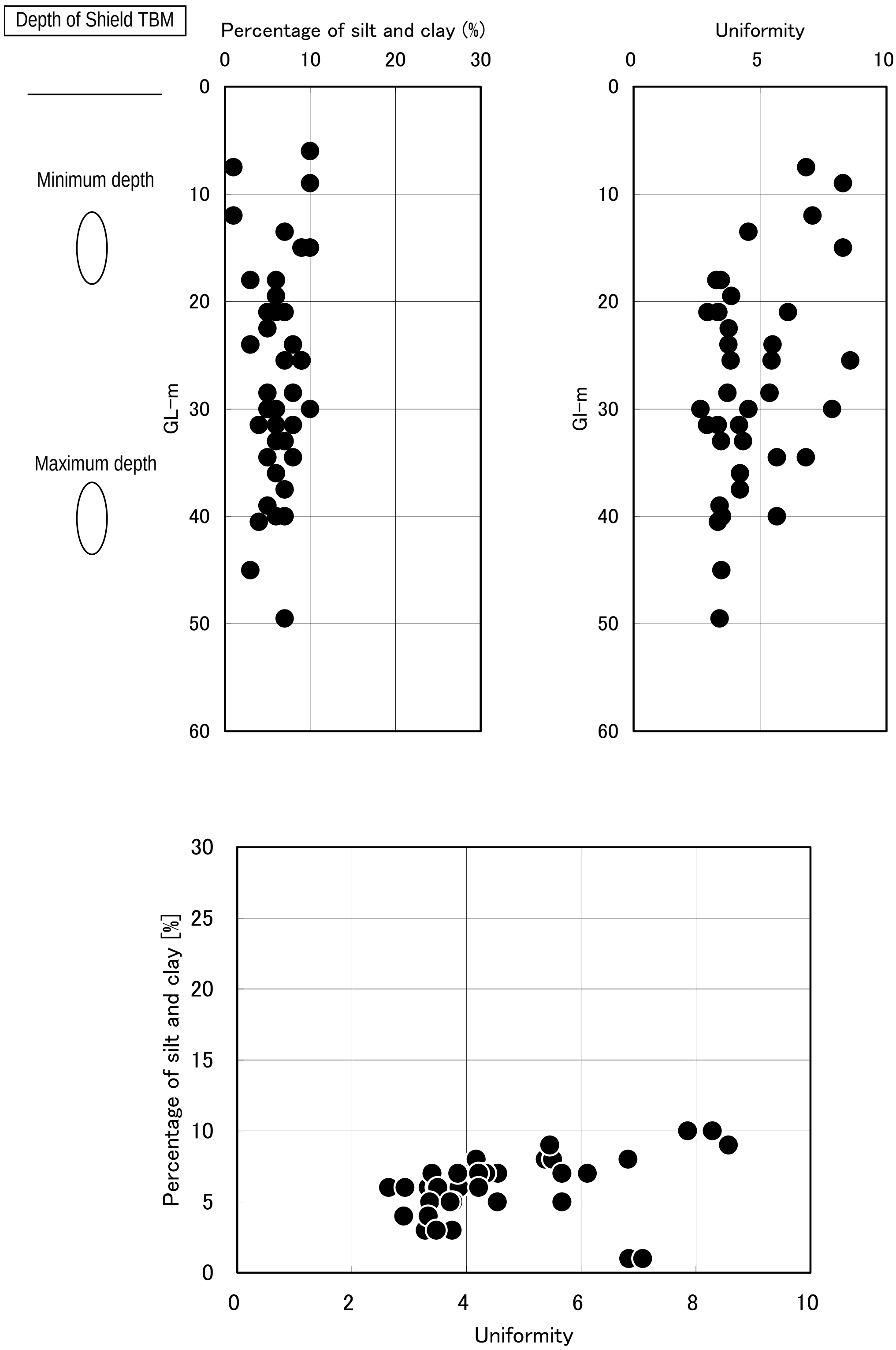
Source: JICA Study Team

Figure 4-86 Tunnel Cross Section in Shallow Overburden (adjacent to Sta. No. 5)



Source: JICA Study Team

Figure 4-87 Tunnel Cross Section in Deep Overburden (adjacent to Sta. No. 3)

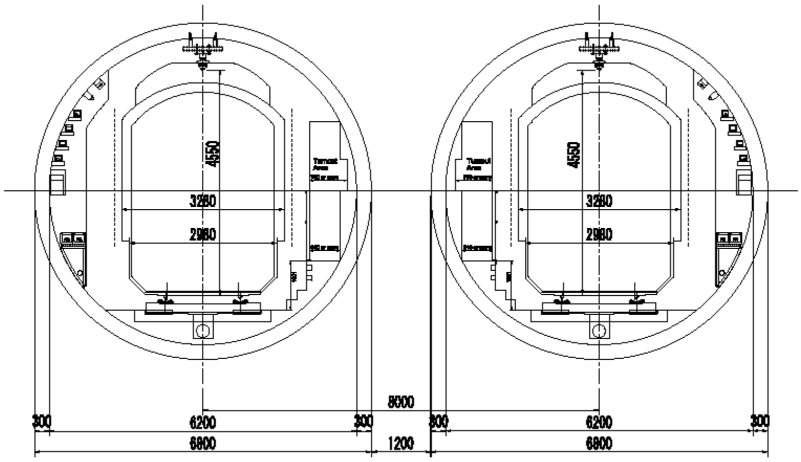


Source: JICA Study Team

Figure 4-88 Distribution of Fine Material Content and Uniformity Coefficient

(2) Cross Section of Tunnel (Construction Gauge)

The cross section of the shield tunnel is determined by the construction gauge as shown in Figure 4-89.



Source: JICA Study Team

Figure 4-89 Cross Section of the Shield Tunnel

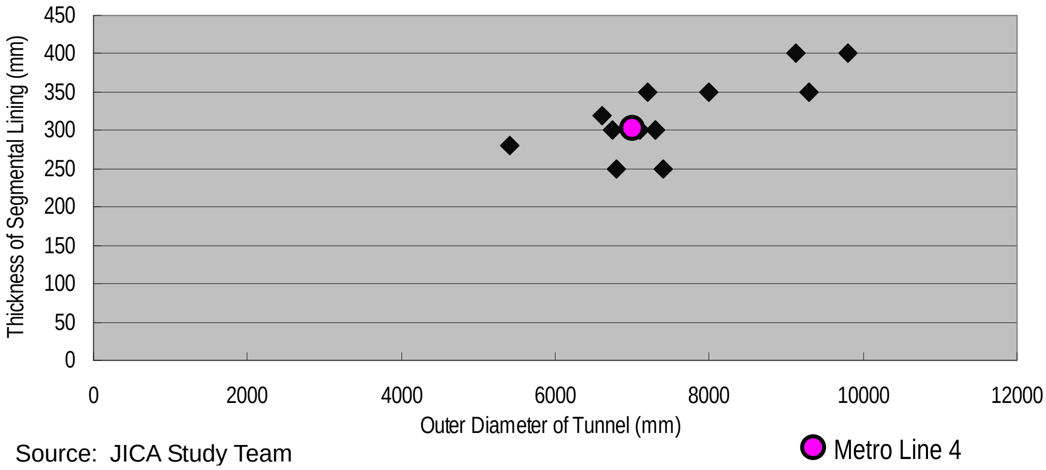
4.6.2 Study of the Tunnel Structures

(1) Study of the Segmental Lining

a) Material and Structure of the Segmental Lining

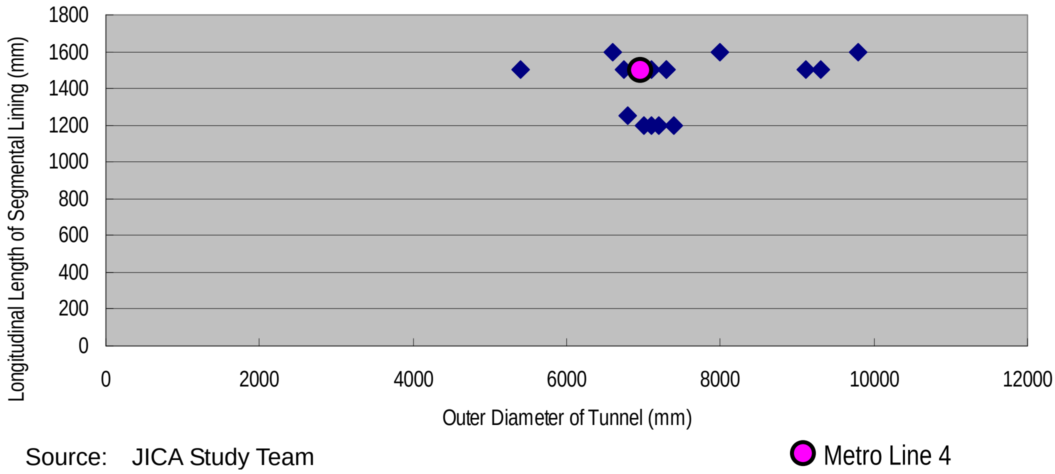
The reinforced concrete (RC) segmental lining is selected because it is the most economical and can be locally manufactured in Egypt. It is commonly used all over the world. There is the possibility that the ground of the project area contains chloride and sulphide. The use of anti sulphuric acid cement should be considered and studied carefully in the design stage.

In order to make a preliminary assessment of the size of the segment, data of the 15 metro tunnels constructed in Japan from year 2000 to 2009 were statistically analyzed and used. According to these data, the thickness and longitudinal length of the segmental lining are 300 mm and 1500 mm, respectively.



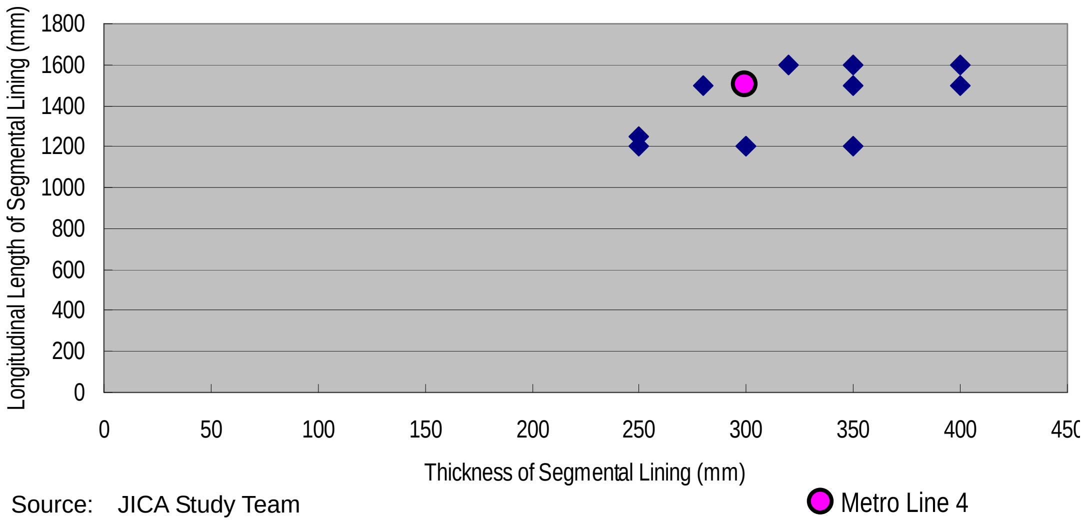
Source: JICA Study Team

Figure 4-90 Outer Diameter-Thickness Relationship of the Segmental Lining



Source: JICA Study Team

Figure 4-91 Outer Diameter-Longitudinal Length Relationship of the Segmental Lining



Source: JICA Study Team

Figure 4-92 Thickness-Longitudinal Length Relationship of the Segmental Lining

b) Application of Transmission Strip and Shear Strip

The joint part of the segmental lining has a risk of being damaged if the segments are erected and the earth and water pressure from the ground is borne. In this case, the water tightness of the tunnel is deteriorated and the risk of water leakage is increased. The water leakage to the tunnel will bring chloride and sulphide materials from the ground and cause the deterioration of the segmental lining. To prevent the damage of the segmental lining during erection, it is important to transmit the force from the hydraulic push jacks to the segments uniformly. Therefore, it is recommended to put the transmission strip for the smooth and uniform transmission of the thrust force for the shield TBM driving and install the shear strip to prevent the concentration of the shear force on the joint part of the segment.

Source: JICA Study Team

Figure 4-93 Photo of the Transmission Strip and Shear Strip

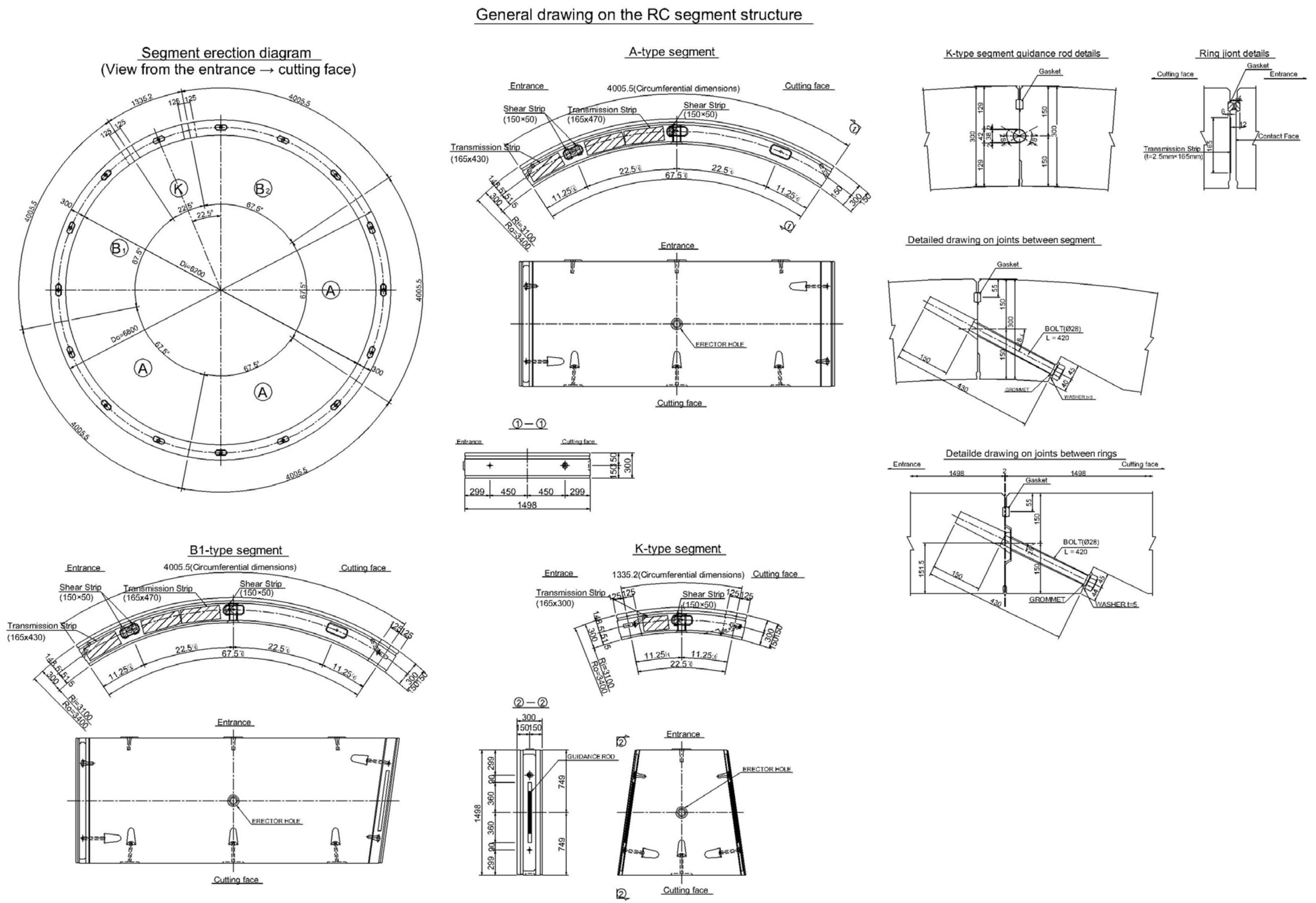
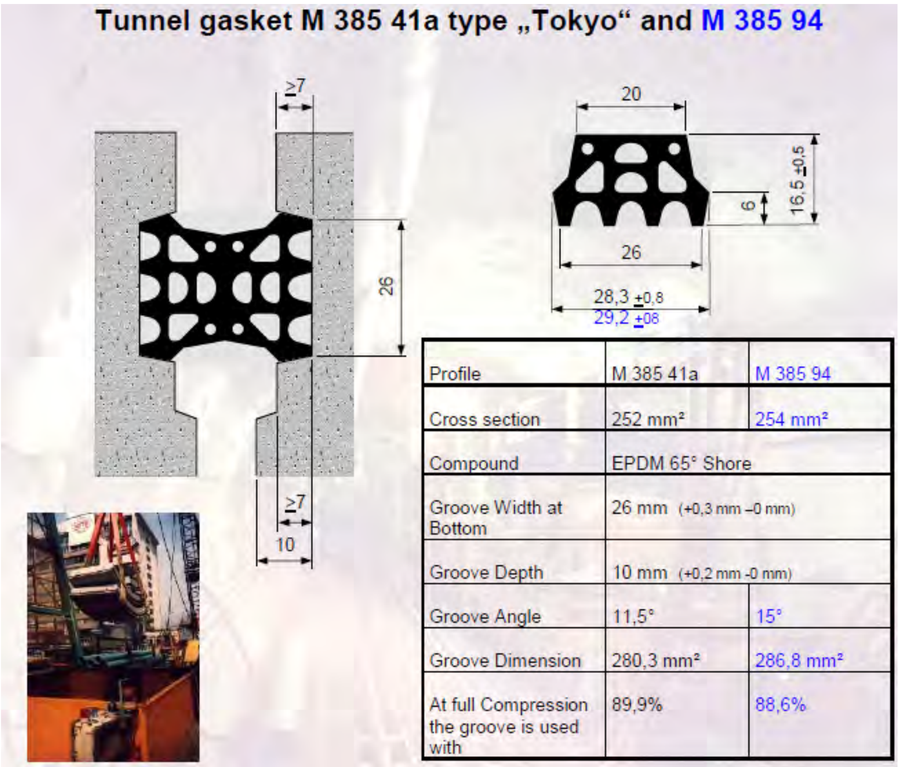


Figure 4-94 Outline of the Segmental Lining (Example)

(2) Study on Waterproofing

There are two types of water stop for the joint port of the segmental lining. One is the gasket-type and another is the water-swelling seal material. There is a possibility that the ground of the project area may contain chloride and sulphide material. Taking into consideration the long durability under this geological condition, the gasket-type water stop is selected. It has been studied to use type M386 41a or M385 94 as shown in Figure 4-95. The main features of these gaskets are as follows:

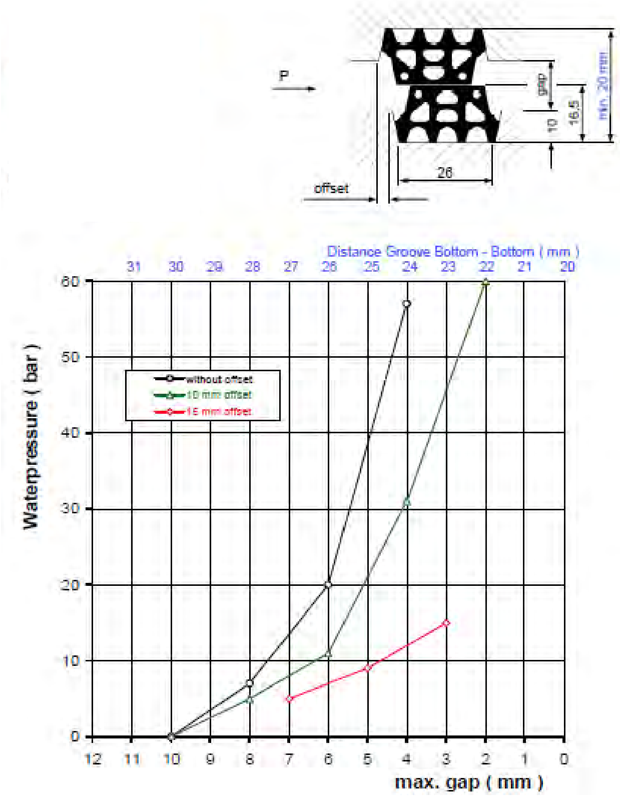
- The performance of the water proof is 20 bar under the condition that the gap between segments is 5 mm and the offset between segments is 10mm (see Figure 4-96).
- The maximum water pressure of the project is approximately 4.3 bar (4.3 kgf/cm^2). Thus, the safety factor is approximately "SF=20/4.3=4.7". In addition, the long term durability is also assured because the residual stress after 100 years will be 65% (see Figure 4-97).



Profile	M 385 41a	M 385 94
Cross section	252 mm²	254 mm²
Compound	EPDM 65° Shore	
Groove Width at Bottom	26 mm (+0,3 mm –0 mm)	
Groove Depth	10 mm (+0,2 mm -0 mm)	
Groove Angle	11,5°	15°
Groove Dimension	280,3 mm²	286,8 mm²
At full Compression the groove is used with	89,9%	88,6%

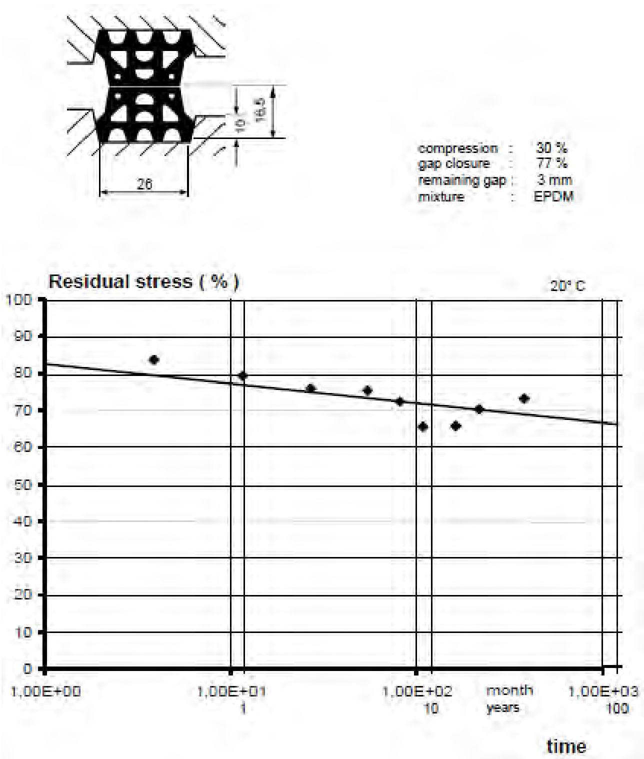
Source: PHOENIX Dichtungstechnix GmbH

Figure 4-95 Gasket Type Water Stop



Source: PHOENIX Dichtungstechnix GmbH

Figure 4-96 Performance of Water Stop under the Joint Gap and Offset Condition



Source: PHOENIX Dichtungstechnix GmbH

Figure 4-97 Residual Stress History

4.6.3 Study of the Tunnel Construction Method

(1) Risks and Considerations

The risks and considerations for the tunnel construction are as follows.

- Many buildings and structures are densely concentrated along the alignment of Cairo Metro Line 4. Therefore, it is required to control and minimize ground deformation and surface settlement caused by the metro construction.
- The shield TBM will pass under the Nile River and canals with shallow overburden.
- Driving of shield TBMs must start from the launch shaft and end at the arrival shaft in the sand stratum of small uniformity coefficient under high water pressure.
- It is necessary to control excavation and advance to prevent the deterioration of the segmental lining which would cause water leakage.

(2) Countermeasures for Tunnel Construction

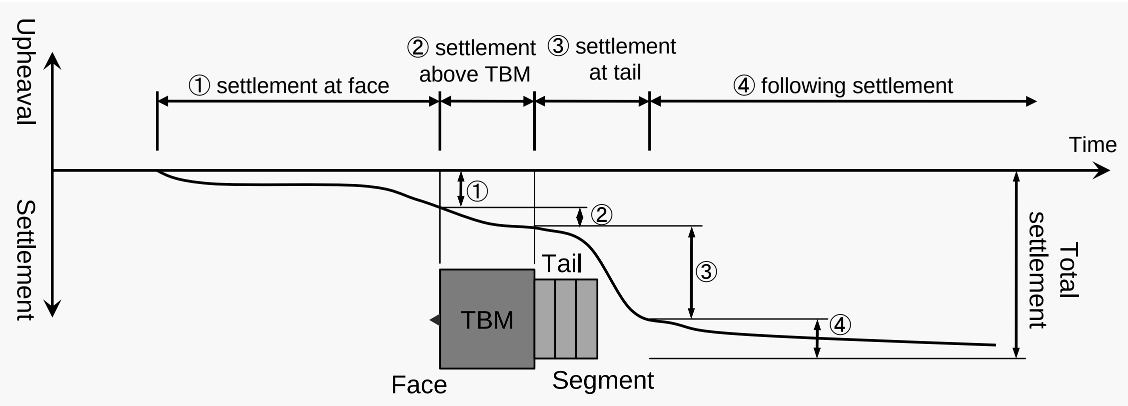
The solutions and countermeasures for the risks and consideration of tunnel construction were studied as follows:

a) Application of the Earth Pressure Balanced Shield (EPBS) TBM

Even in the sand strata with small uniformity coefficient and high water pressure, the cutting face is easier stabilized and poses fewer problems for the pressure control at bulk head against the earth and water pressure of the ground at the cutting face when the EPBS TBM is applied. Therefore, the EPBS TBM is recommended to be used for the project. The EPBS stabilizes the cutting face by the muddy soil, which has a similar unit weight with the ground. Thus, it is possible to fill the excavation chamber with muddy soil in a short period and drive safely even if the cavity is detected in the forward direction. The detail of the EPBS is described in a later section.

b) Minimization of the Tail Void

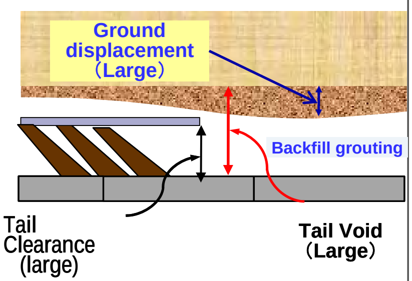
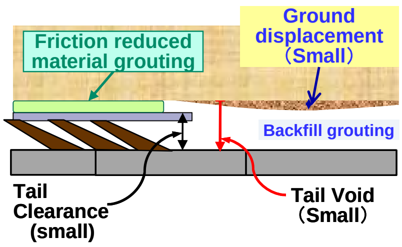
The causes of the ground surface settlement are classified into 4 stages as illustrated in Figure 4-98. Usually, the settlement at the tail is largest and most dominant. Settlement control at the tail is the most important factor in reducing the total ground settlement by the shield TBM excavation. In order to reduce the settlement at tail, it is preferable to minimize the tail void clearance, which is the gap between the excavated ground and the segmental lining. The wire brush type skin seal was made in Japan and is well developed. In addition, the back fill material was also improved in Japan and the advanced two-component type back fill material has enough fluidity for narrow spaces. Thanks to the development of the tail skin seal and backfill material, tail void was narrowed and the ground surface settlement has been decreased. The comparison between the conventional tail void and the advanced one is tabulated in Table 4-41.



Source: JICA Study Team

Figure 4-98 Ground Surface Settlement by the Shield TBM

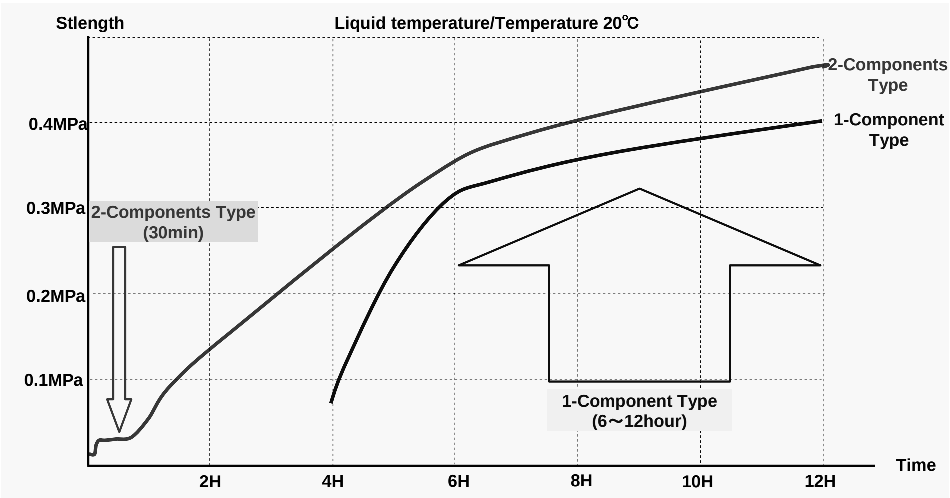
Table 4-41 Comparison of the Tail Void

	Conventional Technology	Advanced Technology (Japan)
Image D_0 = 6.8m		
Tail clearance (mm)	Approx. 120mm	Approx. 75mm
Surface settlement	large	small
Volume of backfill grouting	much	little
Friction between soil and skin plate	small	large (※It is possible to reduce friction between ground and skin plate of TBM by application of friction reduced material)

Source: JICA Study Team

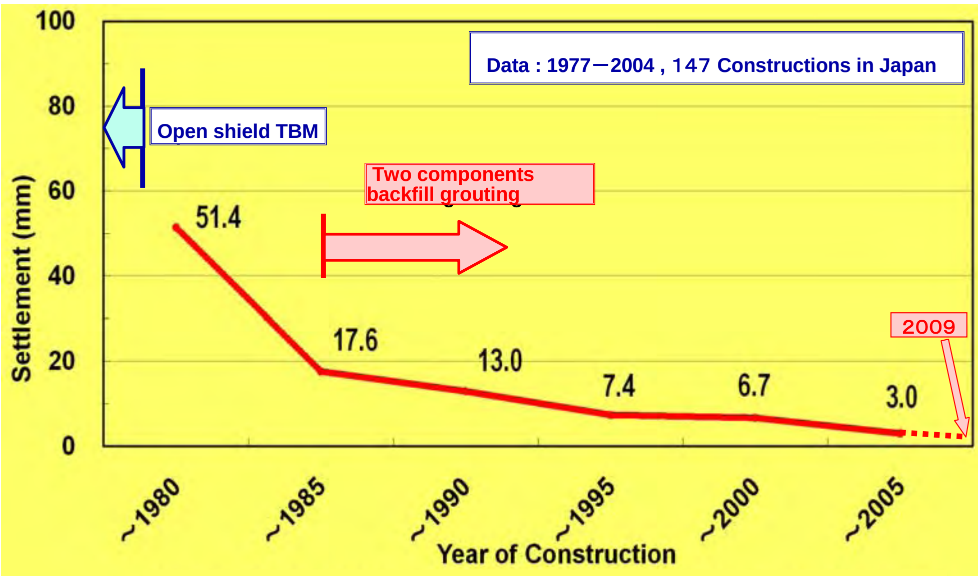
c) Application of Two-Component Type Backfill Material

The backfill material is also important in reducing ground surface settlement. It is recommended to apply the advanced two-component type back fill material for the project. The conventional one-component type backfill material has low fluidity and generates a large deformation of the ground. The conventional back fill material needs at least four hours for hardening, which gives it a minimum initial strength. On the other hand, the advanced two-component type hardens rapidly within 30 minutes after its cast at site (see Figure 4-99). The initial strength of the backfill material is most important in minimizing settlement. If it takes a long time for hardening, initial deformation and settlement of the ground will not be prevented. The advanced two-component backfill material is composed of plasticized material (thixotropy), which does not leak even in highly permeable ground. The advanced two-component back fill material was invented in Japan and the ground surface settlement has been greatly decreased since its introduction. The history of the average ground surface settlement in Japan is shown in Figure 4-100.



Source: TAC Corporation

Figure 4-99 Comparison of Hardening Time and Initial Strength (One-Component and Two-Component Types)



Source: Shield Tunnelling Association of Japan

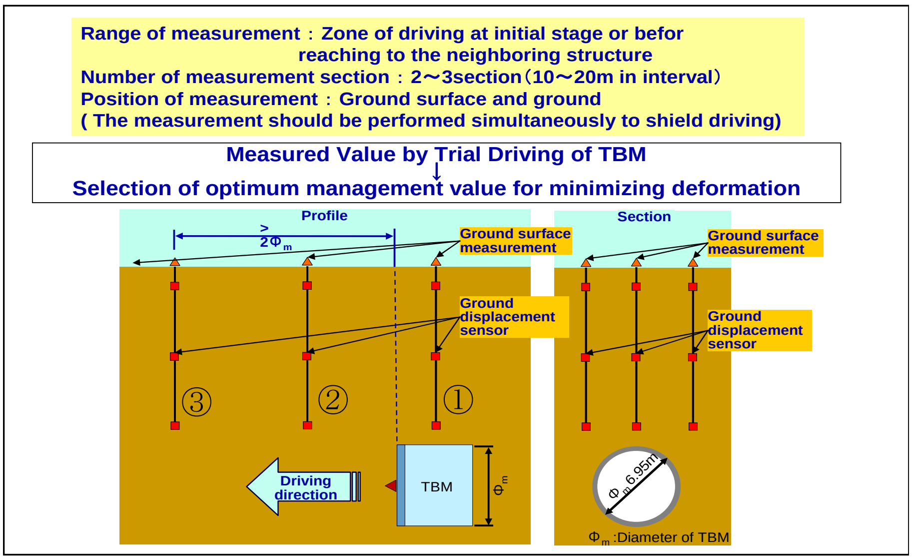
Figure 4-100 Improvement of the Ground Surface Settlement caused by the Shield TBM

d) Trial Construction and Measurement in Similar Conditions

For the optimum control of the advancement of the shield TBM, it is recommended to carry out the trial construction and measurement in the initial stage of the project. These are carried out as parts of the project in the vicinity of the launch shaft.

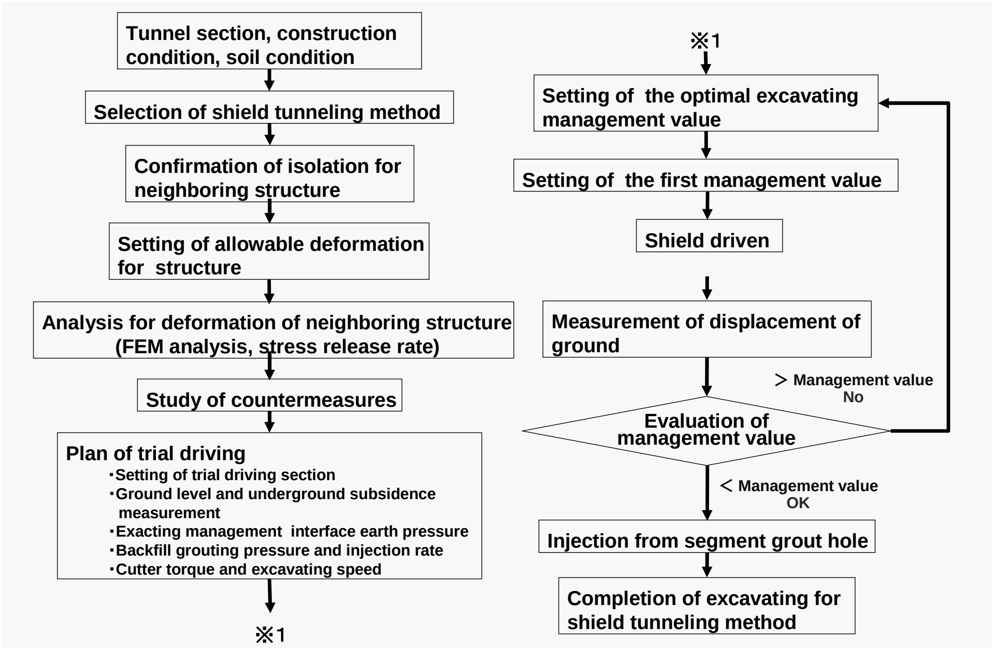
The shield TBM is planned to start from Station No.9 and No.14 as launch shafts. The ground displacement sensors are located 20-30 m apart from the launch shaft and are installed along the alignment at an interval of 10-20 m (about three cross sections). The ground surface measurement and the ground displacement sensors at depths of 2 m, 5 m and 10 m are installed in one line of measurement. Three lines of sensors are installed in one cross section as illustrated in Figure 4-101. The control factors such as earth pressure at bulkhead, injection pressure and quantity of the backfill material and drive speed are intentionally varied at the first and second cross sections. Then, the ground surface settlement and ground displacements are measured at each point and the optimum control factors are determined to minimize settlement and ground displacement. The determined control factors are applied for the third cross section and the settlement and ground displacement are measured and confirmed to be at minimum. These data are fed back to the succeeding excavation control.

In addition, there is a possibility that the trial construction has been carried out in advance of the important existing structure, which is located in the vicinity of the tunnel alignment. An example of trial construction is illustrated in Figure 4-101 and its flow chart is shown in Figure 4-102.



Source: JICA Study Team

Figure 4-101 Trial Construction Using Shield TBM

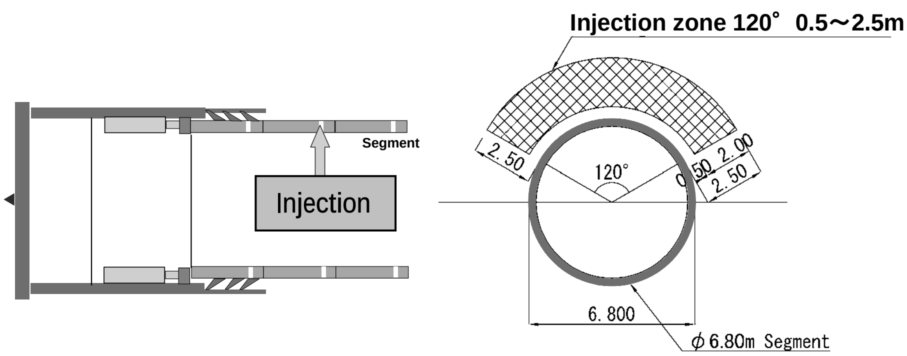


Source: JICA Study Team

Figure 4-102　Procedure for the Trial Construction Using Shield Tunnel

e)　Post Injection through the Grout Hole of the Segmental Lining

The ground around the shield tunnel is not loosened very much by the application of the narrow tail void and advanced two-component type backfill material. In normal cases, the ground improvement for the neighbouring structures is not required. However, there are cases that ground reinforcement is necessary. In the vicinity of the important existing structure, the post injection should be considered and prepared just in case.　The injection is carried out through the grout hole of the segmental lining and the ground above the crown of the tunnel is improved.

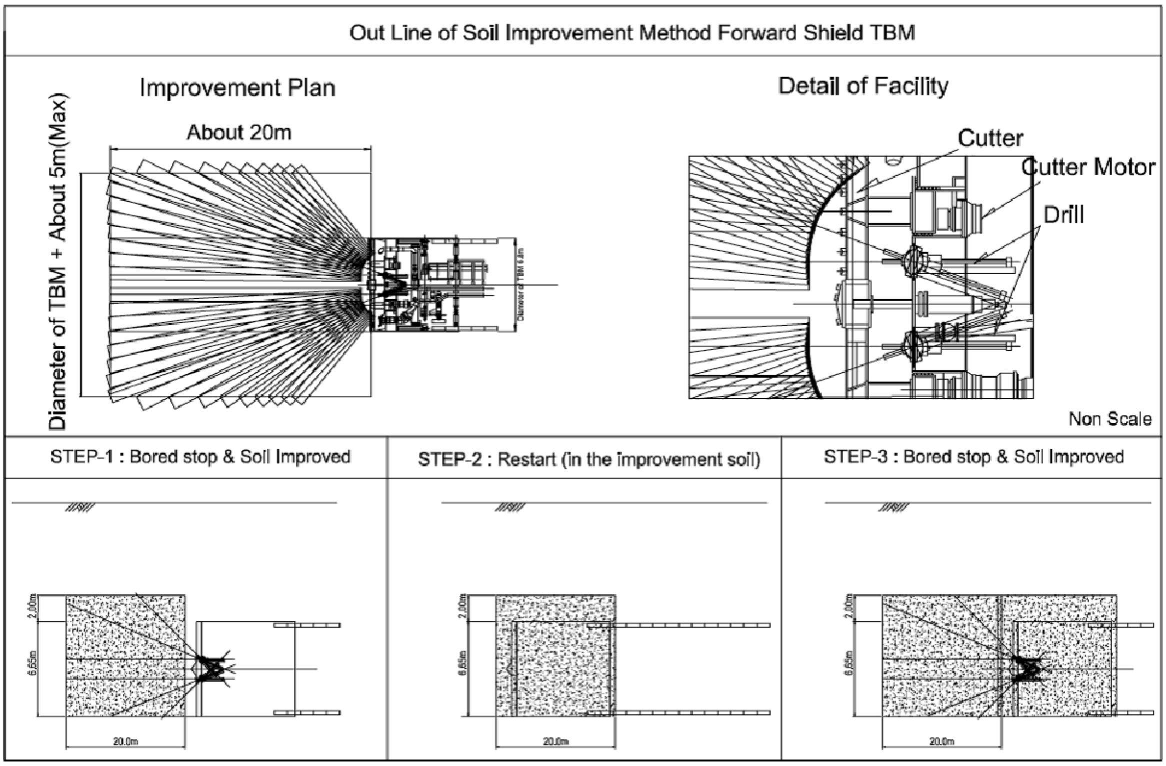


Source: JICA Study Team

Figure 4-103　Post Injection Through the Grout Hole of the Segmental Lining

f) Use of the Shield TBM with Soil Improvement Equipment at Cutting Face

The pre-injection for the soil improvement is often effective and necessary in severe conditions with other existing structures. However, it is difficult to carry out the soil improvement since the ground surface is a densely populated area with congested traffic road. Thus, the soil improvement from the cutter head of the shield TBM is effective and does not cause deterioration of the environment of the surrounding area. An example of soil improvement from the cutter head of the shield TBM is illustrated in Figure 4-104.

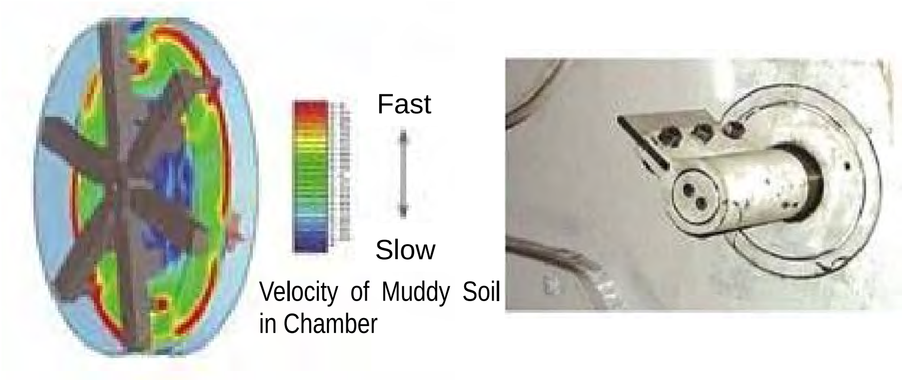


Source: JICA Study Team

Figure 4-104 Image of Soil Improvement from the Cutting Face of the Shield TBM

g) Use of the Visualization Equipment in the Excavation Chamber

The visualization equipment is installed on the bulk head of the shield TBM and the fluidity of the plasticized muddy soil in the excavation chamber is visualized and monitored. It is useful to stabilize the cutting face and control the advance of the shield TBM. The equipment and visualized excavation chamber is shown in Figure 4-105.

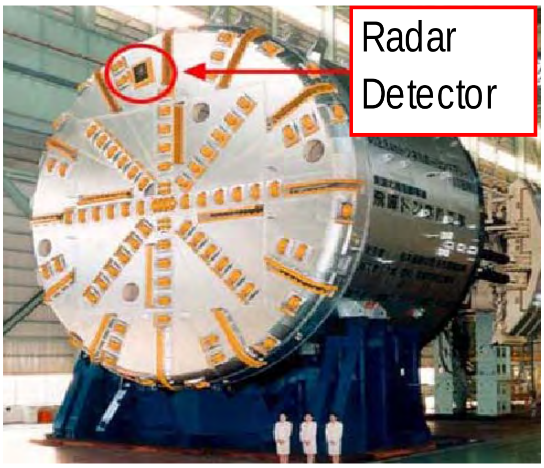


Source: Japanese Manufacturer

Figure 4-105 Visualized Fluidity in Excavation Chamber and Measurement Equipment

h) Installation of Radar Detector on the Cutter Head

The radar detector is effective for unforeseen cavity and other abnormal conditions. An example of the radar detector on the cutting head is shown in Figure 4-106.



Source: Japanese Manufacturer

Figure 4-106 Radar Detector on the Cutting Head of the Shield TBM

i) Installation of Man Lock in the Shield TBM

In case that the advance of the shield TBM is hampered by an obstruction, the air in excavation chamber is pressurized and the obstruction is removed manually through the man lock.

Source: Japanese Manufacturer

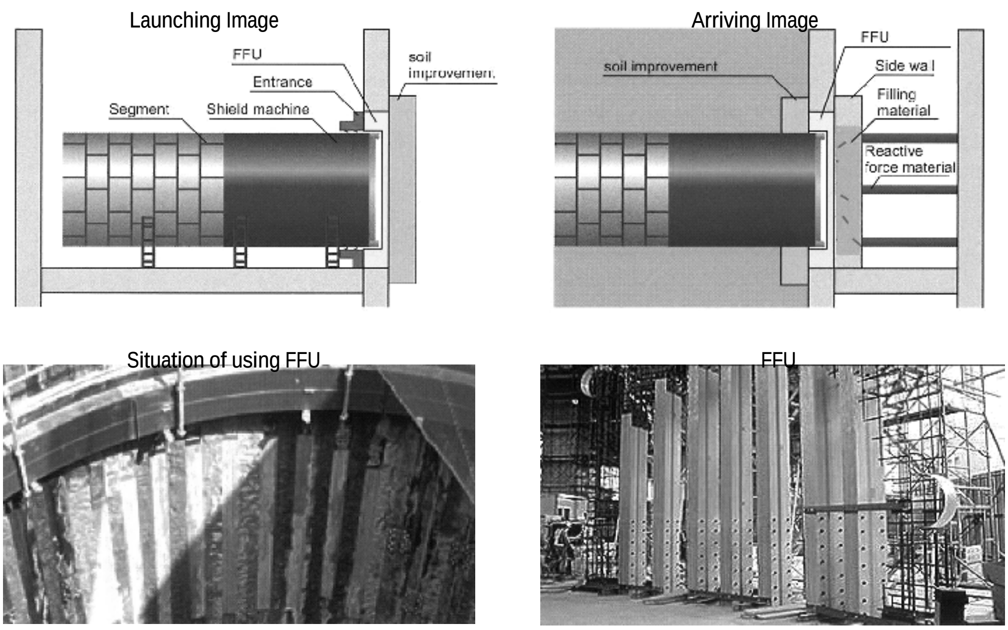
Figure 4-107 Man Lock in the Shield TBM

j) Use of the Control System of the Hydraulic Push Jacks

The hydraulic jacks push the segmental lining for the excavation and drive forward. The unbalanced forces caused by the hydraulic jacks will deteriorate the segmental lining and generate cracks. It is preferable to monitor and control the force of hydraulic jacks.

k) Use of Fibre-Reinforced Foamed Urethane (FFU) for Launch and Arrival Shaft

It is anticipated that the shield TBM will launch and arrive at the shaft which is located in sand stratum with low uniformity coefficient and high water pressure (maximum 4.3kgf/cm^2). To enhance the safety of the construction and shorten the construction period, it is recommended to apply the wall with FFU, which can be directly excavated by the shield TBM.



Source: JICA Study Team

Figure 4-108 FFU at Launching and Arrival Shafts