Technical Assistance for Improvement of Capacity for Planning of Road Tunnels

Japan Sri Lanka

Guideline for Design of Road Tunnel

February 2018

Road Development Authority (RDA)

Japan International Cooperation Agency (JICA)

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1 Outline of Tunnel

1.1 Tunnel Definition

Tunnels are civil engineering structures that are constructed for the purpose of securing space in the ground. Depending on the purpose of use, tunnels are classified into road tunnel, railway tunnel and water way tunnel. In addition, in the case of Japan, tunnels are classified as mountain tunnels and city tunnels depending on the location conditions.

Tunnels generally refer to on-line structures in which a predetermined cross section is continuous in the longitudinal direction. Definition of the tunnel was given by the OECD (Economic Cooperation and Development Organization) Tunnel Recommendation Conference, OECD Advisory Conference on Tunneling in Washington 1970. The definition of tunnels is a cavity which is located below the ground surface and is used in some way and made into a prescribed geometry and has a size of two square meters or more.

1.2 Construction Method of Tunnels

In Japan, there are three kinds of general-purpose specifications for building tunnels.

These are rock tunnel, shield tunnel, cut and cover tunnel. These construction methods are closely related to tunnel location conditions. For this reason, there is a tendency that the rock tunnel is selected for tunnels constructed in mountainous areas, and the shield tunnel or cut and cover tunnel is selected for city tunnels built on flat ground. However, depending on the topography and geological conditions, there are cases where the cut and cover method is adopted in portal of the mountain tunnel, and the rock tunnel is adopted in the urban tunnel. Hence, the boundary is not necessarily clear.

The Standard Specification for Tunneling for rock tunnel, shield tunnel, cut and cover tunnel is respectively developed by Japan Society of Civil Engineers. The target of this guideline is the rock tunnel.

Table 1-1 Construction Method of Tunnels (1)

Condition		Mountain Tunnel	Shield Tunnel	Cut and Cover Tunnel
Applicable condition	Geology	・Suitable for consolidated bedrock, excavation is possible even in unconsolidated grounds by using ・Basics of excavation surface independence	・Suitable for unconsolidated mountains / low consolidated mountains ・In the case of the closed type, it is possible to construct even if the excavation surface is not self-sustaining	・Mainly suitable for unconsolidated land, but it can be applied to any land
	Earth Covering	・Earth Covering more than 2D (tunnel outer diameter) is necessary. It is possible to construct even a few meters by using auxiliary method	・Earth Covering more than 1D (tunnel outer diameter) is necessary. ・	・Suitable for small earth covering (roughly 20 m or less)
	Ground Water	・If the amount of spring water is large or the autonomy of the excavated surface can not be secured, an auxiliary construction method is necessary. It is necessary to consider the influence to the surroundings	・In the open type, countermeasures such as pressure method and underground water reduction method are required, but in the case of sealed type almost no auxiliary method is required	・It is necessary to take countermeasures such as groundwaterreduction method and soil improvement
	Location	・It is used in the mountains, but depending on ground conditions it is also used in urban areas	・It is also used in urban areas	・It is used in urban areas. Sometimes it is constructed as a start / arrival base of the shield Tunnel

(Source: JICA project)

Table 1-2 Construction Method of Tunnels (2)

Condition		Mountain Tunnel	Shield Tunnel	Cut and Cover Tunnel
Design Condition	Cross Section	・horseshoe shaped cross section is used. An arbitrary sectional shape is possible to some extent, but an arch shape is desirable for the upper half	・determined by the cross sectional shape of the shield machine, but a circular cross section is used ・With the exception of special excavating machinery, it is impossible to change the cross sectional shape ・With special excavating machines, cross sections such as multi-circle and rectangle are also possible	・Generally, a rectangular cross section is used, but an arbitrary cross sectional shape is possible
	Structure of Support and Lining	・Use steel support, rock bolts, shotcrete as support. ・The lining is basically based on plain concrete by striking the place, but in the case where the ground pressure acts it may be a reinforced concrete structure ・Portal zone is generally arranged with reinforcing bars to prevent cracking due to shrinkage	・Assemble a reinforced concrete made from a factory or a steel segment in the rear of the machine to make it the primary lining ・In some cases lining is carried out with plain or reinforced concrete secondary lining	・Rigid structure by steel frame or reinforced concrete is basic

(Source: JICA project)

2 NATM in JAPAN

2.1 Difference between Conventional and NATM Method

NATM (New Austrian Tunneling Method) is one of the construction methods of tunnel proposed by the Austrian geologist Dr. Rabcewicz in 1964. NATM was introduced to Japan in 1977 in a railway tunnel, and since 1978 it became a standard construction method in railway tunnels. Also in the road tunnel, NATM was introduced in 1978 and became the standard construction method in Japan like the railroad tunnel.

NATM is quite different from the conventional method and it can be said that the construction method to make maximum use of the tolerance possessed by the ground because the support is in close contact with the ground. Figure 2-1 and Figure 2-2 show the difference between NATM and conventional method.

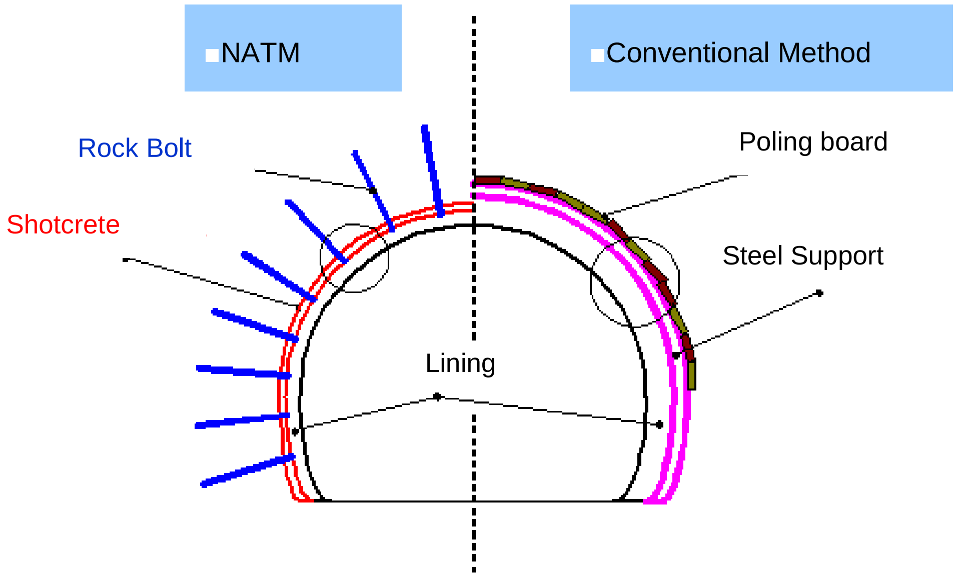

Figure 2-1 Comparison between NATM and Conventional Method (1)

(Source: JICA project)

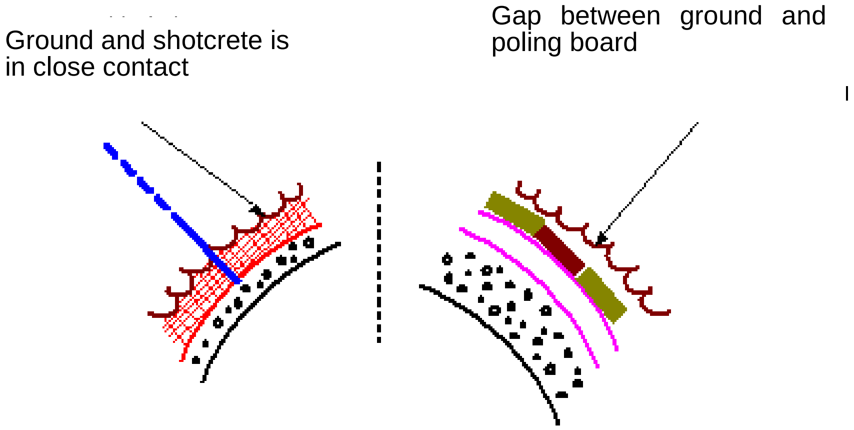

Figure 2-2 Comparison between NATM and Conventional Method (2)

(Source: JICA project)

2.2 Concept of NATM in JAPAN

The fundamental difference of NATM from the conventional construction method is that NATM shows the concept and necessary methods for tunnel design and construction by using the strength of the ground as much as possible. Its basic philosophy is "to make the tunnel as much as possible in the ground". In other words, it is the idea that the tunnel should be retained as much as possible by the shear strength of the ground and the support is an auxiliary structure aiming at reinforcing the ground.

2.3 Features of NATM in JAPAN

Characteristics of NATM in Japan are shown below.

a. The main support structure is the combination of shotcrete, rock bolt and steel support. The support structure is relatively thin and allows little displacement. This “soft” structure utilizes the strength of the ground to support the tunnel.

b. Quantitatively design is conducted based on statistical measurements such as ground pressure, supporting stress and deformation of the ground and support.

c. Since it is a relatively thin-walled support structure, resource-saving lining can be performed, which is advantageous for economy.

d. Since the support structure is flexible, it is possible to deal with even unstable rocks, and the degree of freedom of correspondence of the ground is high.

e. The surface of the support is smooth, the installation of the waterproof sheet becomes easy, and the structure with high waterer toughness can be constructed

f. Since the inner space section is wide and can be effectively used, safety and work efficiency are improved. Also, it is easy to change the cross section.

3 Design of Tunnel (NATM in JAPAN)

3.1 Features of the Design of NATM

Since tunnels are on-line structures built underground, their design differs greatly from other structures. In general design of a structure, safety is evaluated according to the stress calculated by the structural calculation and the characteristics possessed by the material with assumption of an external force acting on the structure. In general, the construction method is examined to construct structures based on the design. On the other hand, in case of underground structures such as tunnels, it is difficult to correctly estimate the load acting on the tunnel in the design stage. Since the interaction between the ground and the support is complicated, the structural calculation is limited. Furthermore, it is difficult to provide sufficient information on geological survey methods and their accuracy to design; it is also difficult to design accurately over the entire length of the tunnel. Also, in the case of a tunnel, the behavior of the tunnel and the surrounding ground during excavation is different depending on the construction method. Therefore, the design of the support work must be done with due consideration of the construction method.

From technical background mentioned above, tunnel design and construction are usually carried out in the following procedure. In the initial design, designers make the best use of geological information and make an appropriate basic design. During the construction process, constructors collect and analyze the data of observation and measurement, and review the design to change to the support structure more suitable for the ground against the basic design.

In this way, it is vital to pursue the optimum construction method during constructing process.

3.2 Outline of Design Methods

3.2.1 Choice of Design Methods

The design of the tunnel is based on initial design (basic design) and tunnel design (basic design), which designs support structural members such as shotcrete, rock bolt, steel support and lining, based on limited ground survey results in advance. In the construction stage, modification of design is made to change the support structures based on the observation of the facing surface to be carried out at the time of excavation and measurement results and the like.

There are the following three types of design methods used in the initial design.

a. Application of standard design

b. Application of the design based on similar conditions

c. Application of analytical design

However, in consideration of the design process and economic efficiency, each mountain grade, which distinguishes the ground mountain condition into several types, is set and the standard support pattern corresponding to it is often adopted in many cases.

3.2.2 Application of Standard Design

When standard cross sections are decided like roads and railway tunnels, general standard designs are used except for special conditions. In this method, representative support patterns for shotcrete, rock bolts, steel support, lining, etc. are set in advance for each class of grade and applied. The ground mountain grades are based on the geotechnical classification table evaluated by classifying the generation era of the mountain, the geological structure, the weathering / deterioration situation, the state of the discontinuous surface, the influence of the groundwater and the other geological conditions.

The geotechnical classification table and the standard support pattern are independently developed for each order because there is a close relationship with the each order size of the excavated cross section along with the construction method. In other words, a lot of construction result and observation data and also rock type, elastic wave exploration, rock quality condition, core condition, RQD (Rock Quality Designation), ground strength intensity ratio and situation at tunnel excavation are analyzed; then, the geotechnical classification tables and standard support patterns have been evaluated and set up.

Two examples of standard support patterns of road tunnels in Japan are shown in Table 3-1, Table 3-2 and Table 3-3. The first table is for general roads and the others are for expressways.

Table 3-1 A typical Example of Standard Support Pattern for Road Tunnels (Medium Section)

(ordinary section tunnels,inner width:about 8.5m to 12.5m)

Class of ground	Support pattern	Standard round length(m)	Rock bolt				Steel Support			Thickness of shotcrete (cm)	Thickness of lining		The amount of allowable deformation (cm)	Excavation method
			Length(m)	Spacing		Area of installation	Top heading	Bench	Spacing (m)		Arch,side wall(cm)	Invert(cm)		
				Circumferetilal direction	Longitudial direction									
B	B	2.0	3.0	1.5	2.0	Top heading 120°	–	–	–	5	30	0	0	Full face metod with auxiliary bench cut , or bench cut method
C I	C I	1.5	3.0	1.5	1.5	Top heading	–	–	–	10	30	(40)	0	
C II	C II -a	1.2	3.0	1.5	1.2	Top heading, bench	–	–	–	10	30	(40)	0	
	C II -b						H-125	–	1.2					
D I	D I -a	1.0	3.0	1.2	1.0	Top heading, bench	H-125	H-125	1.0	15	30	45	0	
	D I -b		4.0											
D II	D II	1.0 or less	4.0	1.2	1.0 or less	Top heading,bench	H-150	H-150	1.0 or less	20	30	50	10	

Notes 1) As a general rule, the support pattern "b" is applied for class CII and DI ground, whereas application of support pattern "a" is considered when it is anticipated that the displacement induced by tunnel excavation is small and the face is stabilized.

2) On invert concrete

i) When the geology categorized as class CI and CII ground is Tertiary mudstone, tuff, serpentinite or other rocks prone to argillization, or weathered crystalline schist, or solfataric clay, invert concrete, the thickness of which is given in parentheses, should be placed.

ii) When early closure of excavation cross section is necessary, shotcrete is applied to the invert. The thickness of shotcrete in the invert should be determined, individually, referring to that in the top heading and bench. Although the thickness of shotcrete in the invert can be included in the thickness of invert concrete, the thickness of cast-in-place concrete in the invert should not be lower than the thickness of lining in the arch and side wall.

iii) Even if the class of ground is DI, the placement of invert concrete can be omitted in case the long-term bearing capacity of the ground is expected to be sufficient as a result of the appearance of sound rock in the bench, and squeezing due to lateral pressure is not anticipated.

3) On wire fabric

i) For class DI ground, wire fabric is generally placed in the top heading. For class DII ground, wire fabric is usually placed in both top heading and bench.

ii) The placement of wire fabric can be omitted when steel fiber reinforced shotcrete (SFRC) is adopted.

4) On the amount of allowable deformation

For class DII ground, the amount of allowable deformation usually provided in the design is about 10 cm. The amount of allowable deformation is provided in the top heading for the bench cut method, whereas it is provided in both top heading and bench for full face method with auxiliary bench cut. The amount of allowable deformation should be modified from time to time based on the measurement results during construction.

5) For class A and E ground, specifications should be determined based on the actual ground conditions.

6) Even in the case where the design of ordinary section tunnels is applicable, the application of the support pattern for large section tunnels should be considered when the flattened cross section such as three centered arch is adopted in the boundary region to large section.

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-65)

Table 3-2 A typical Example of Standard Support Pattern for Expressway Tunnels (Medium Section)

(ordinary section tunnels,inner width:about 9.4m to 13.2m)

Class of ground	Support pattern	Standard round length(m)	Rock bolt					Steel Support		Thickness of shotcrete (cm)	Thickness of lining		The amount of allowable deformation (cm)	Excavation method
			Length(m)	strength (kN)	Spacing		Area of installation	Top heading	Bench		Arch,side wall(cm)	Invert(cm)		
					Circumferetilal direction	Longitudial direction								
B	B-a(H)	2.0	3.0	170.0	2.0	2.0	Top heading 120°	–	–	5	30	0	0	Full face metod with auxiliary bench cut , or bench cut method
C Ⅰ	C Ⅰ -a(H)	1.5	3.0	170.0	2.0	1.5	Top heading	–	–	7	30	(40)	0	
C Ⅱ	C Ⅱ -a(H)	1.2	3.0	170.0	1.8	1.2	Top heading, bench	–	–	7	30	(40)	0	
	C Ⅱ -b(H)				1.8	1.2		HH-100	–					
D Ⅰ	D Ⅰ -a(H)	1.0	3.0	290.0	1.8	1.0	Top heading, bench	HH-100	HH-100	10	30	45	0	
	D Ⅰ -b(H)	1.0	4.0											
D Ⅱ	D Ⅱ -a(H)	1.0	4.0	290.0	1.2	1.0	Top heading,bench	HH-108	HH-108	15	30	50	10	

The classification of a and b of the support pattern is as follows
a: Basic support pattern applied to all basic rock types
b: Applicable only in cases where it is expected that the displacements due to tunnel excavation are expected to increase in the initial design such as slate, black schist,
Invert's ( ) is applied to viscous rock such as Tertiary mudstone, tuff, serpentinite, weathered crystal schist, hot spring soil etc.

(Source: Design Procedure 3rd Collection for Tunnel Conservation-Tunnel Construction, 2017, NEXCO RI (in Japanese))

Table 3-3 Former Typical Example of Standard Support Pattern for Expressway Tunnels (Medium Section)

(ordinary section tunnels,inner width:about 8.5m to 12.5m)

Class of ground	Support pattern	Standard round length(m)	Rock bolt				Steel Support			Thickness of shotcrete (cm)	Thickness of lining		The amount of allowable deformation (cm)	Excavation method
			Length(m)	Spacing		Area of installation	Top heading	Bench	Spacing (m)		Arch,side wall(cm)	Invert(cm)		
				Circumferetilal direction	Longitudial direction									
B	B-a	2.0	3.0	1.5	2.0	Top heading 120°	–	–	–	5	30	0	0	Full face metod with auxiliary bench cut , or bench cut method
C Ⅰ	C Ⅰ -a	1.5	3.0	1.5	1.5	Top heading	–	–	–	10	30	(40)	0	
C Ⅱ	C Ⅱ -a	1.2	3.0	1.5	1.2	Top heading, bench	–	–	–	10	30	(40)	0	
	C Ⅱ -b						H-125	–	1.2					
D Ⅰ	D Ⅰ -a	1.0	3.0	1.2	1.0	Top heading, bench	H-125	H-125	1.0	15	30	45	0	
	D Ⅰ -b		4.0											
D Ⅱ	D Ⅱ -a	1.0 or less	4.0	1.2	1.0 or less	Top heading,bench	H-150	H-150	1.0 or less	20	30	50	10	

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(Source: Design Procedure 3rd Collection for Tunnel Conservation-Tunnel Construction, 2017, NEXCO RI (in Japanese))

3.2.3 Application of the Design Based on Similar Conditions

If there is an existing tunnel in the proximity of the target tunnel and the construction result can be obtained, more reasonable initial design becomes possible by considering the actual results of the constructed tunnel. When designing the two close tunnels, measurement data of tunnels drilled at the beginning will be effective in designing the support pattern and construction method of the tunnel to be excavated later.

In cases that the ground conditions and design conditions, such as tunnel cross-section, are judged to be almost same, it is possible to apply the existing tunnel design to others after considering the similarity even if the existing tunnel is located far from the target tunnel. The point of view of similarity is shown in Table 3-4.

Table 3-4 Focus Points regarding Similarity of Tunnels

Item		Focus Points
Function of tunnel		Are the functions of the tunnel the same?
Ground condition	class of ground	Is the Class of ground the same?
	toptgraphy overburden	Are the topography and overburden similar?
	property of ground	Whether rock species and geology ages, groundwater conditions, etc. are similar
Cross section shape and dimension		Cross section shape and dimension are similar?
Impact on surroundings		Whether the regulation values are similar
Proximity construction after completion		Type, positional relationship, scale, etc. are similar

(Source: JICA project)

3.2.4 Application of Analytical Methods

Tunnel design using analysis method is adopted for special tunnels (e.g. large cross-section tunnels and parallel tunnels), special mountains (e.g. unconsolidated land and expansive grounds) and special conditions (e.g. proximity to urban areas and existing structures).

Typical analysis methods are theoretical analysis method, FEM (Finite Element Method) analysis method, framework structure analysis, etc.

Design objects and their objectives for each analysis method are shown in Table 3-5.

Table 3-5 List of Analytical Design Method

Analysis method	Object of design	Aim of analysis
Theoretical analysis method	Suport	Preliminary study of numerical analysis Evaluate the stability of the support
FEM analysis method	Auxiliary Mehod supprt Lining	Grasp the behavior of the ground during excavation Evaluation of the stability of the support Confirm the effect of auxiliary method estimation of environmental impact Grasp the behavior of the lining of the expansive mountain Consider the influence of proximity construction
Framework structure analysis	Lining	Evaluate the structural stability of the lining

(Source: JICA project)

(1) Theoretical Analysis Method

This method is based on elastic theory by continuum mechanics. Generally, detailed conditions can't be reflected in this method because there are limitations on analysis conditions such as handling the tunnel as a circle and supporting structures being constructed simultaneously with the excavation. It is common practice to conduct a preliminary study of design by numerical analysis.

(2) FEM Analysis Method

This method is carried out for the purpose of examining the behavior of the mountain by grand designing the supporting structures. In this method, a complex stratum structure can be reproduced and handling of the construction process can be handled by expressing the ground within element model. In this analysis, two-dimensional analysis is often applied, but application examples of three-dimensional analysis are also increasing in recent years.

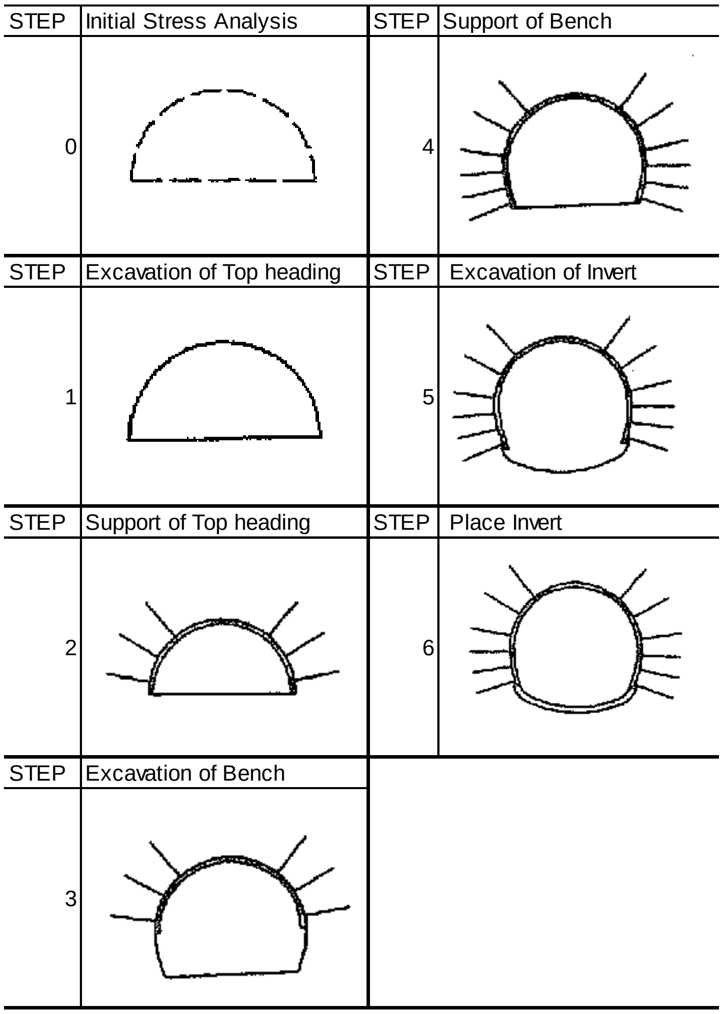


Figure 3-1 Example of Two-dimensional FEM Analysis

(Source: Mountain tunnel construction method, from survey, design to construction, 2007, Japanese Geotechnical Society (in Japanese))

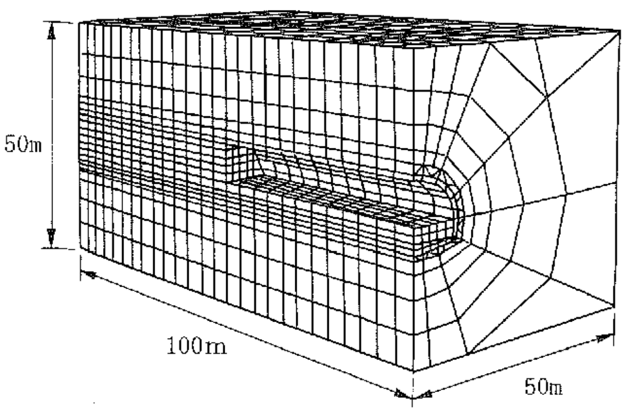


Figure 3-2 Example of Mesh Diagram for 3D FEM Analysis

(Source: Mountain tunnel construction method, from survey, design to construction, 2007, Japanese Geotechnical Society (in Japanese))

(3) Framework Structure Method

In this method, a horseshoe-shaped tunnel cross section is modeled by a beam member pseudo-divided by a linear member; and the deformation of the tunnel due to the load is supported by the ground spring. Since it is relatively easy to handle, it is widely adopted in lining design.

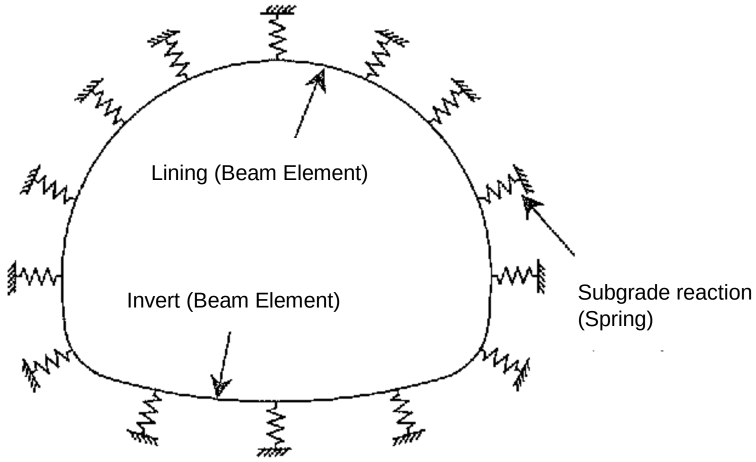


Figure 3-3 Example of Framework Analysis

(Source: Mountain tunnel construction method, from survey, design to construction, 2007, Japanese Geotechnical Society (in Japanese))

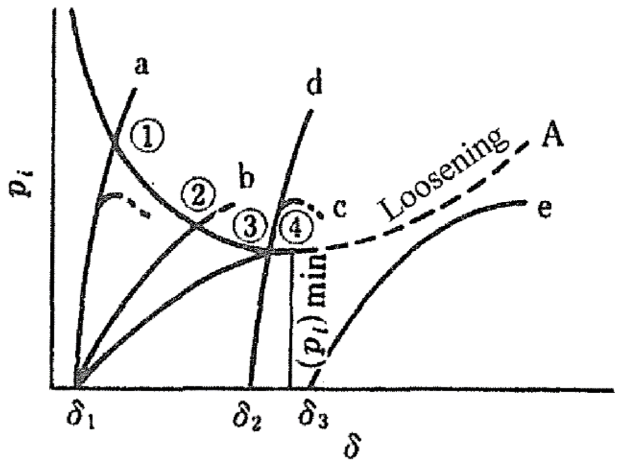
3.3 Concept of Modified Design

3.3.1 Concept of Modified Design

Since the tunnel is a linear structure, it will encounter various geological structures. However, it is difficult to grasp in advance the characteristics of the ground in detail. Therefore, the initial design is only based on limited information. Then, the actual construction will modify the design as necessary while evaluating on-site measurement results etc. Hence, it is important to identify displacement and stress of ground, displacement and stress of the support with high accuracy during construction.

3.3.2 Concept of Modified Design in Construction

In the rock tunnel construction method, it is important to "make maximum use of the strength of the mountain without deteriorating it". Moreover, in order to stabilize by the interaction between the ground and the support, looseness occurs as shown in the figure, causing a change. The looseness occurs depending on the strength of the ground, the rigidity of the support and the installation time. For this reason, various surveys and measurements at the time of construction are conducted. Moreover, the validity of the ground design and corresponding initial design are evaluated while confirming the behavior of the ground and the effect of the support accompanying the excavation by measuring etc. It is important to make corrections and promptly reflect on design and construction.



p_i: Supporting pressure
δ: Displacement of excavation surface
Note: Curve A is settled by ground properties.
Curve a-e is the relation between load and displacement of support.

Figure 3-4 Conceptual Diagram of Ground and Support Characteristic Curve (Fenner-Pacher Curve)

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-58)

However, as shown in Figure 3-5, in general, the displacement amount obtained at the time of construction is about 60% of the total displacement amount; the influence of the excavation is about ± 1 D (D is excavation width), so it needs careful measurement management in this section.

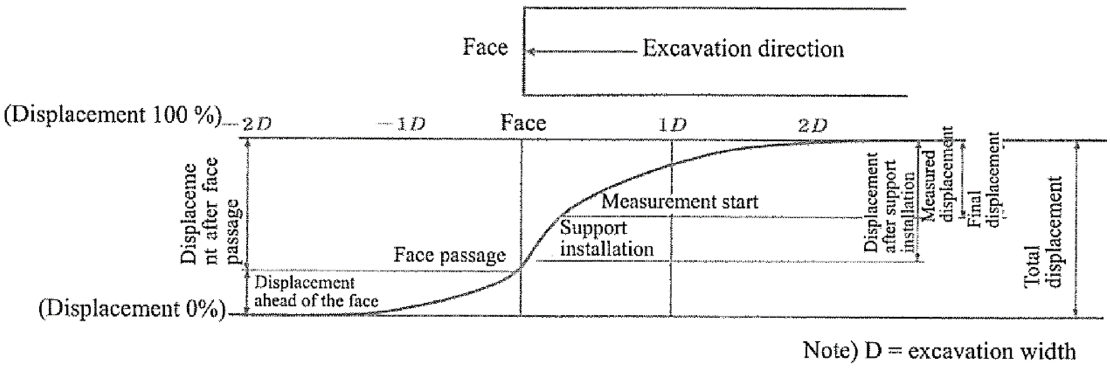


Figure 3-5 Typical Relationship between Face Position and Behavior Surrounding Ground

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-238)

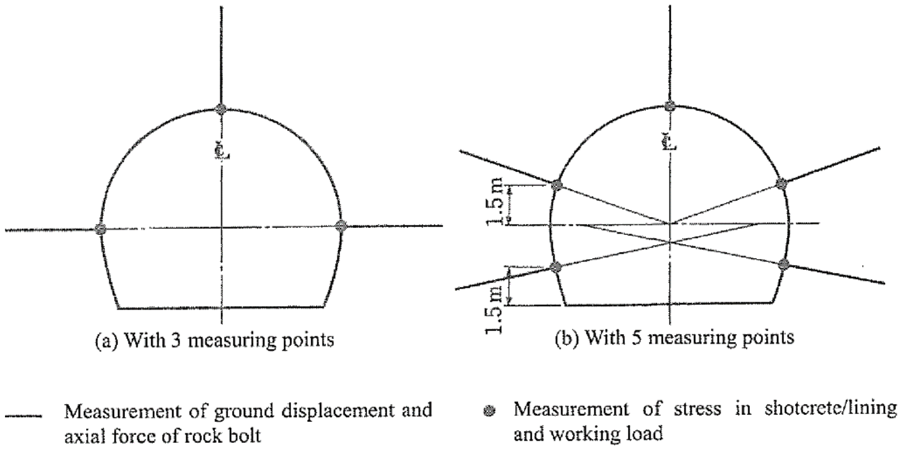


Figure 3-6 Examples of Arrangement of Different Measuring Instruments

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-237)

It is very important to modify the original design / construction method to be suitable for the mountains in order to ensure the safety and economy of construction and to maintain long-term functions and quality of tunnel structures. The Table 3-6 shows the items of survey and measurement under construction and the evaluation of the results.

Table 3-6 Items of Survey and Measurement under Construction and Evaluation of Results.

Investigation ansd Measurement	Deatail item	evalution of result
Ground Strength	Driling Speed Using Exposive amounts Exacavatiuon Speed (/day)	Confirm ground condition
Face Conditons	Rock Type, Rock Quality,Cracking condition Reaon density ,Strike , Tipping	Confirm ground condition prediction condition front of face
Water Inflow	water inflow in face,water pressure in face Drainge Condition	Confirm water inflow
Measurement A	Crown Settlement, Convergence Convergence situation of displacement	Grasp ground action and support stability
Measurement B	Geographical situation around tunnel excavation	Grasp ground action and support stability
Influence of proximity Construction	Behavior of ground surface, ground and surrounding structures Behavior of portal	Grasp influence of proximity structure and ground surface
Weather Condition	weather, Temperatura, amount of rainfall,earrhquake	Estimate damage condition
Ground water at Surronding Area	River flow ,Ground water Level	Grasp influence of excavation
Work environment in a Tunnel	Temperatura,humidity,oxygen concentration Ventilation mounts ,Dust concentaration Inflammable gas and Methane,poisonous gas concentration	Grasp site environment
Enviroment at Srrounding Area	noise,vibration,low frequency sound, drainge cocentration	Grasp environment srrounding area

(Source: JICA project)

In some case, the large deformation of the ground and a change in support structures occurs even if the construction is carried out as designed. In that case, consideration of countermeasure work is required. The main countermeasures are listed below.

a. Size of support
b. Reinforcing of face and face forward ground
c. Changing of the buckwheat breakage, construction law (change of bench length, installation of invert, etc.)
d. Early launch of concrete
e. Securing or expanding deformation allowance

3.3.3 Concept of Modifying Design of Future Section

In the design of future sections, the following four cases are assumed from the situation at the time of construction.

a. The tunnel is stabilized by the supporting members and construction method as designed, and the amount of displacement is also within the assumption.

b. The tunnel is stable at a position less than the assumed amount of displacement

c. Supplementing the support and changing the construction method are required to suppress to the assumed amount of displacement.

d. A displacement which is greatly larger than the assumed amount of displacement occurs, and as a result, it is impossible to secure the cross section, which leads a substantial increase in the supporting structure and a significant change in the construction method.

The countermeasures of the four cases mentioned above are described below.

(1) “Tunnel stabilized by supporting members and construction method as designed”

Since it is judged that design and construction are mostly conforming to the target ground, it can be judged that there will be no problem in future sections by construction as designed.

However, from the economic point of view, if there is a possibility of mitigating support structures, it is desirable to consider reducing the size of the support by analyzing the results of the measurement work.

(2) “The tunnel is stable but displacement is small”

The ground is better than what was assumed at initial design. There was a possibility that the designed supporting members and construction methods were excessive.

Therefore, it is necessary to consider reduction of supporting members and change of support patterns. However, there are also cases where the ground changes suddenly, so it is important to formulate a detailed measurement tool as well as possible.

(3) “Changing support pattern and construction method to reduce displacement amount required”

Study of the auxiliary construction method is necessary when it is confirmed that the construction method as designed is implemented and that the support is installed at the appropriate time and there is no problem in construction.

However, it is necessary to carefully examine the workability and economic efficiency as to whether the change of the support pattern is good or the addition of the auxiliary construction method is good. After the examination, it is necessary to make a modified design.

(4) "Changing major support and construction method to reduce displacement amount required"

Drastic review and modification of design and construction method are required. Based on the measurement results, it is necessary to investigate optimum support and construction method using analytical methods and the like.

It is also necessary to study examples of similar ground conditions.

3.4 Detail of Design Method

3.4.1 Flow of Design

A flow of tunnel design is shown Figure 3-7.

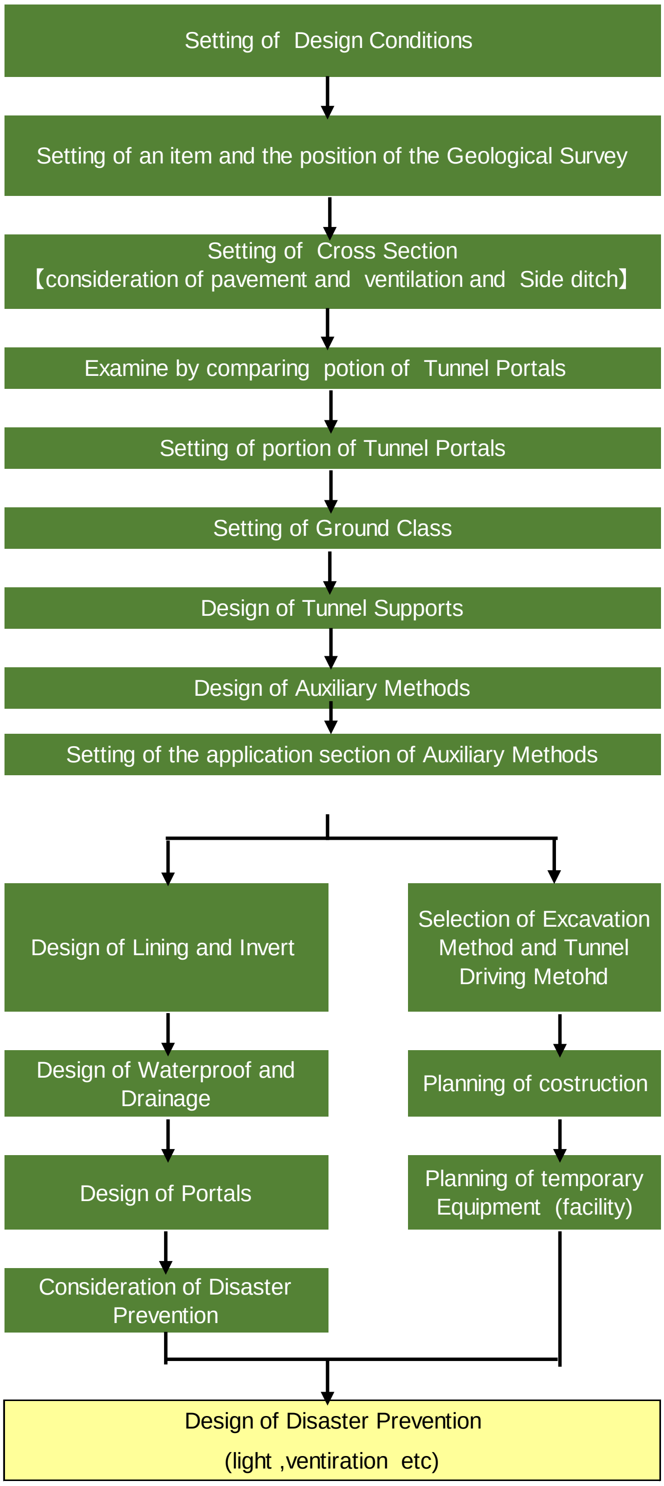


Figure 3-7 Flow of Tunnel Design

(Source: JICA project)

3.4.2 Design Condition

(1) Ground Conditions

Since the rock tunnel is a structure that utilizes the support function of the ground, it must be designed considering the geographical conditions consisting of topography, geology and hydrology. Also, when considering geotechnical conditions, the strength and deformation characteristics of the ground, the stability of the face and the geological characteristics such as spring water must be considered.

(2) Location Requirement

In designing the tunnel, the impacts of tunnel construction on surrounding environment should be considered. Furthermore, the impacts of nearby constructions and special tunnel position should be also considered. Regarding the surrounding environment at tunnel construction, it is necessary to pay attention to the following points.

a. Noise and vibration of blasting, noise caused by construction vehicles, vibration and traffic problems
b. Water pollution such as groundwater and river water by excavated shear and construction wastewater
c. Drought and ground subsidence around the tunnel
d. Contamination and uplift of groundwater by injection of chemical liquid etc.
e. Impact of excavation on ground surface and nearby underground structures

On the other hand, the influence on the surrounding environment after construction can be considered as follows.

a. Drought phenomenon of rivers and wells due to change of groundwater environment
b. Ground surface subsidence due to loosened ground and lower groundwater
c. Changes in water quality of long-term groundwater by injection of chemical liquid etc.
d. Traffic vibration and noise
e. Effects of the portal area on the surrounding environment

(3) Shape and Dimensions

When designing the cross section, it is necessary to consider the shape and dimensions of the tunnel determined from the purpose and form of use.

NATM has a high degree of freedom with respect to shape and size, and it is possible to

construct tunnels of various shapes and dimensions as long as the ground, support, and lining have the ability to hold space. That is one of the strong point of NATM.
The cross section includes a predetermined construction gauge, required facilities, allowance etc., and taking safety and economics into consideration.

In addition to the construction gauge, the road tunnel is determined taking into consideration construction limitations, ventilation, lighting, emergency facilities, interior wall, passage for management, installation space for pavement (overlay), drainage, and allowance for construction error of lining.

(4) Conditions for Taking Action of External Force into Consideration

When designing a tunnel, the influences of earth pressure, water pressure, earthquake, etc., which act after tunnel completion, should be considered as necessary.

Earth pressure is categorized as plastic pressure, loose earth pressure and unbalanced earth pressure. When these earth pressure effects are assumed, it is necessary to consider them in the design.

Water pressure has external water pressure and internal water pressure, and it is necessary to consider in the design when it is assumed that they act. As for earthquakes, since the tunnel behaves together with the surrounding land, the influence of earthquake is small compared with other structures. However, from the damage case of the major earthquake in Japan, attention should be paid in the following cases at the time of design considering the influence of the earthquake.

a. Earth covering of Tunnel is small and the tunnel exists in unconsolidated mountains
b. The tunnel exists in the geological failure section
c. Tunnel intersects an active fault

3.4.3 Cross Section

The method of determining the cross section in Japan is introduced the following section.
The cross section of the tunnel includes the construction gauge prescribed by the Road Structure Order and the necessary allowance, and it is decided in consideration of the safety and economy of the tunnel and the running performance of the vehicle. In addition, it is necessary to secure a space for installing ventilation facilities, lighting facilities, emergency facilities, interior management passage, pavement and drainage. In addition, a cross section

should include allowance for construction error of lining. Thus, the elements determining the inner space section are as follows.

a. Road specifications and cross road construction
b. Allowance of construction gauge and tunnel cross section
c. Presence or absence of ventilation equipment
d. Presence of interior board
e. Pavement composition

In consideration of safety and economic efficiency, the cross section of the tunnel is usually a horseshoe shape consisting of a top heading triangle (top heading semicircle) or a flat cross section such as a fifth centered circle.

Figure 3-8 Example of shape of tunnel cross section

(Source: JICA project)

In the case of using Tunnel Boring Machine (TBM), there are many cases of circular cross sections in general.

(1) Representative Japanese Road Tunnel Cross Section

Representative Japanese road tunnel cross section is shown in Figure 3-9.

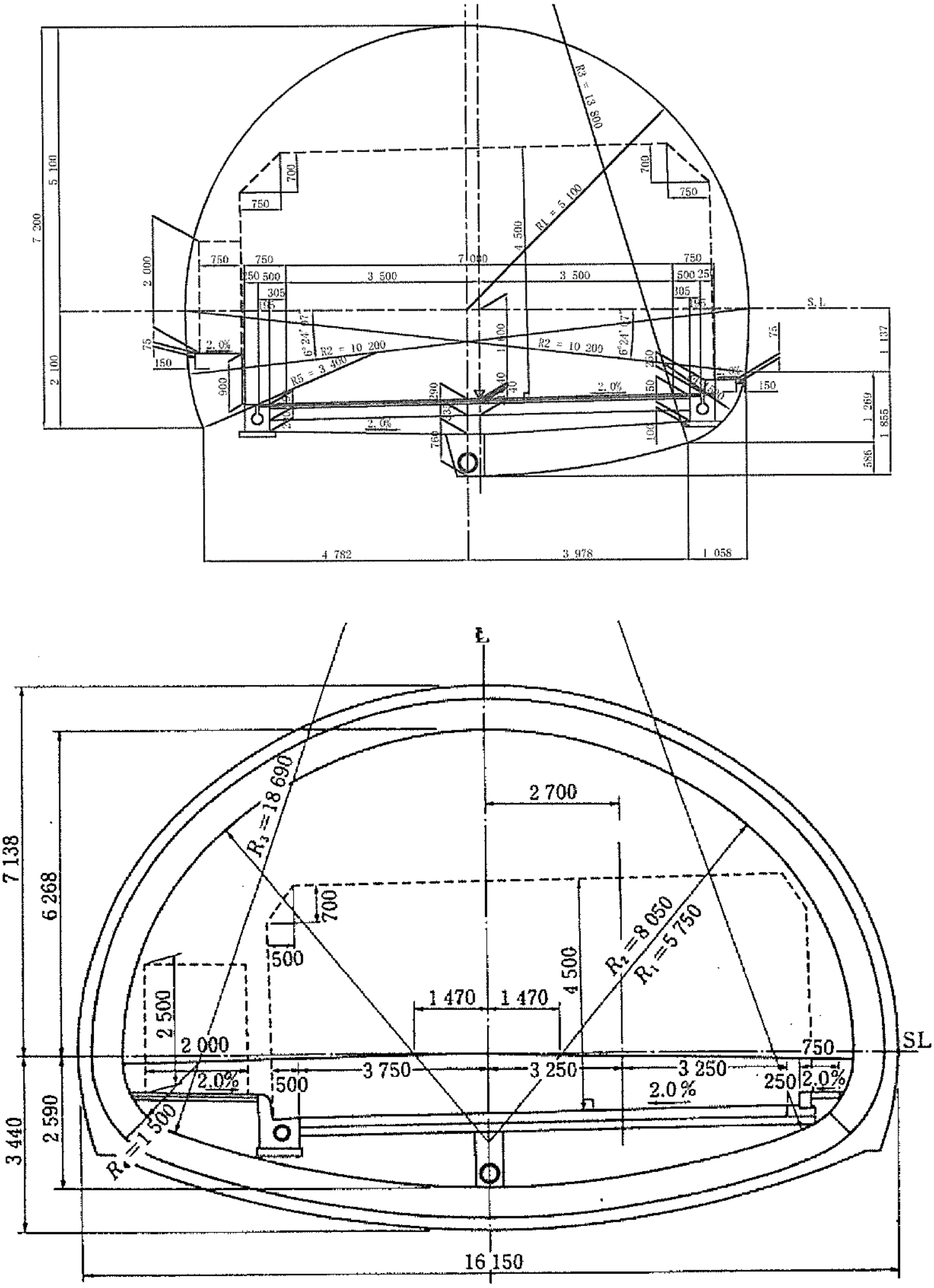


Figure 3-9 Example of Standard Japanese Tunnel Section

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-11)

(2) Flow of Determination of Road Tunnel Cross Section

Flow of determination of road tunnel cross section is shown in Figure 3-10. In Sri Lanka, some tunnel design condition is not decided at present. Therefore, it is necessary to examine the gradient (slope) of the pavement, the structure of the pavement, the shape of the drainage, the decision on the need for parking zone and others, to determine the final cross section. Moreover, it is necessary to examine the cross-section from view point of economic efficiency and consistency among the tunnels located near the target tunnel.

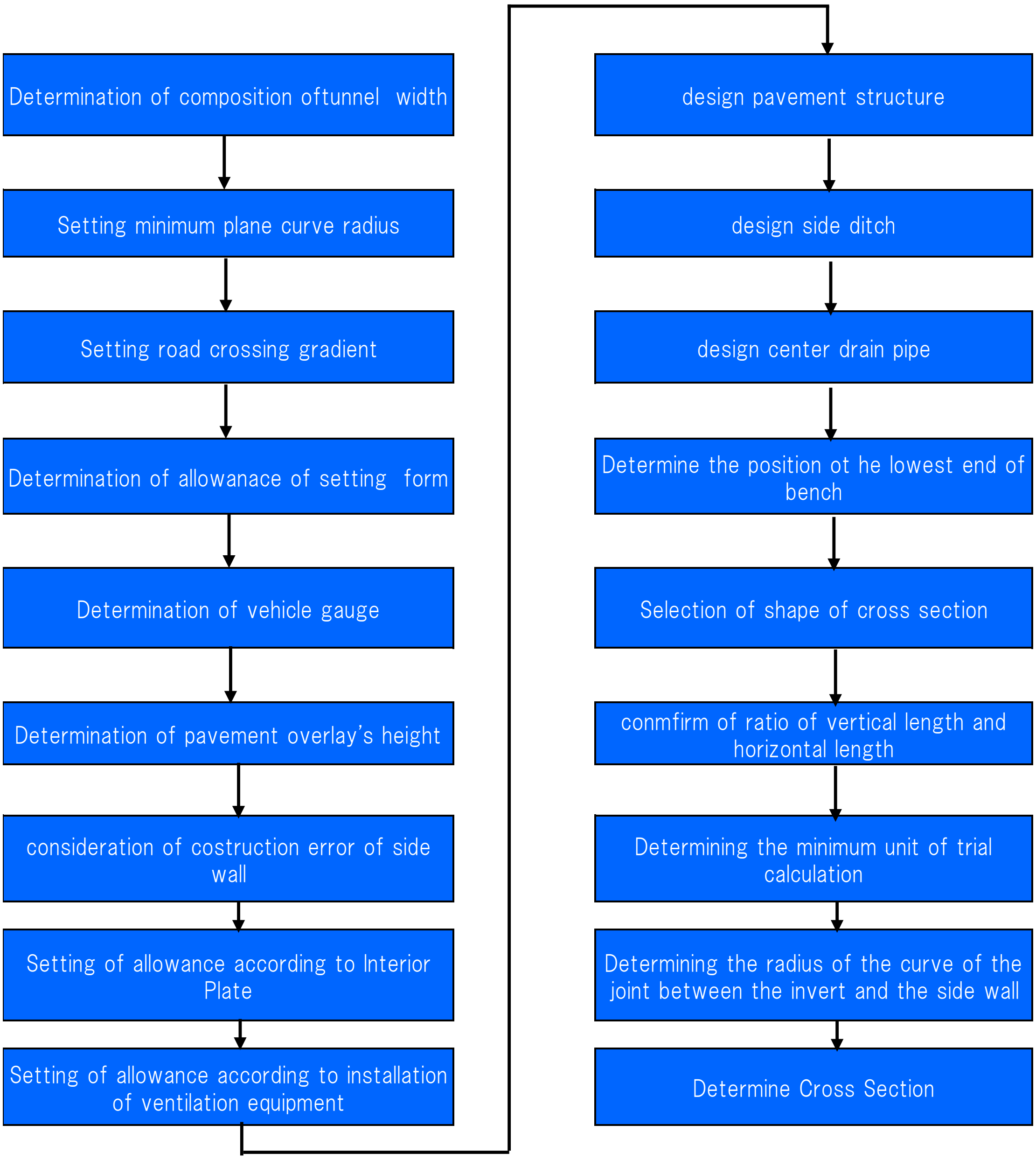


Figure 3-10 Flow of determination of Road Tunnel Cross Section

(Source: JICA project)

3.4.4 Design of Portal Zones and Portals

(1) Points to Note when Designing the Portal Zone

Portal zones are the areas near the tunnel entrance and exit where the overburden is generally small and a ground arch is not formed easily. Portals are frequently located in a generally weak geologic zone where erosion develops and complicated topography is created. While the tunnel is in service, portals are susceptible to natural and meteorological disasters such as rock falls, avalanches, debris flows and earthquake. Portals sometimes may be subjected to overburdened loads or earth pressure after being placed into service. Therefore during the design of the portal zone and portals, the engineer must decide on an appropriate portal structure construction method, portal forms, portal shapes, and the portal structures by giving sufficient consideration to natural conditions such as the topographic features, geology, groundwater and weather in the vicinity of the portals and socially restrictive conditions including the presence or absence of homes and structures.

Table 3-7 and Table 3-8list problems expected mainly during the construction of a tunnel portal zone and design conditions. The portal zone is generally defined as an area where the depth of overburden is one to two times the excavation diameter where development of the ground arch is difficult, as shown in Figure 3-11.

Table 3-7 Problems Expected in Tunnel Portal Zone and Design Considerations (1)

Problem	Consideration
Slope failure or landslide	Construction in the portal zone sometimes induces a slope failure or landslide. This can be attributed to loosening because of tunnel excavation or slope cut for the construction of the portal. When there is a possibility of a slope failure or landslide because of tunnel excavation, measures should be taken to protect the slope in advance of the excavation.
Unsymmetrical pressure	Unsymmetrical pressure may act on the tunnel section and a large stress may occur in the tunnel depending on the positions and relationship of the slope and tunnel. Unless the tunnel is stable, measures are required to balance the earth pressure by using a counter-weight fill or cut for slope stabilization.

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-112)

Table 3-8 Problems Expected in Tunnel Portal Zone and Design Considerations (2)

Insufficient bearing capacity of ground	In the portal zone, where the depth of overburden is small, the total load over the tunnel sometimes may act on the tunnel. Because the ground in the portal zone consists of unconsolidated deposits or is in a weathered zone, the base often suffers from settlement or deformation because of the insufficient bearing capacity of the ground. Design of the portal zone including the construction method must be decided so the required bearing capacity of the ground can be obtained.
Face collapse	In the portal zone, the ground is often weak and poorly consolidated. Even when the ground consists of hard rocks, faults or fracture zones may induce the development of fractures and the stability of the face frequently will be poor. When the face cannot be expected to stand for an adequate length of time, an excavation method or auxiliary method to prevent face collapse must be studied.
Ground surface settlement	In the portal zone, small overburden, insufficient bearing capacity of the ground and insufficient stand-up time at the face might cause the impact of settlement to be conveyed to the ground surface. When there are ground level structures for which settlement must be restricted, adequate measures must be taken to prevent problems and an auxiliary method must be adopted whenever required.
Rock falls, debris flow or avalanches	The portal zone must be designed for a location free from rock falls, debris flows or avalanches. When such positioning of the portal is impossible, adequate measures should be taken against possible disasters.
Neighboring structures	The impact of tunneling construction on existing structures in the neighborhood such as houses, steel towers, roads and railways, and the effect of noise and exhaust gas after the tunnel is placed into service, also should be studied.

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-113)

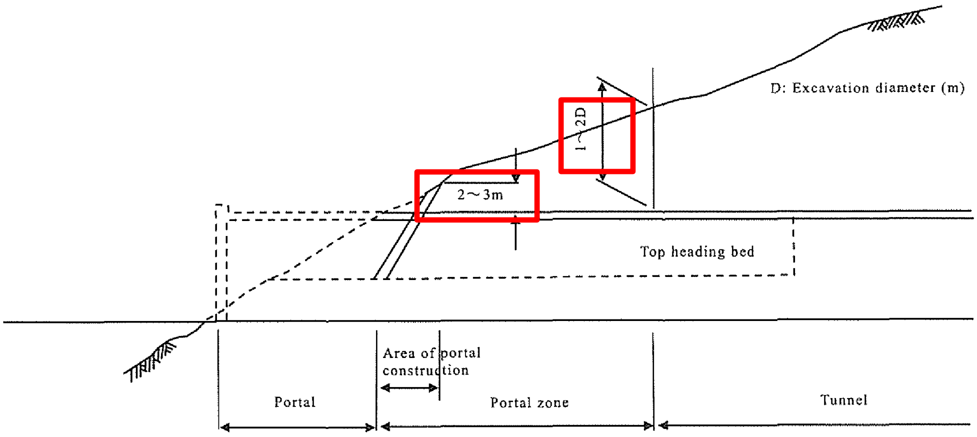


Figure 3-11 Area of Standard Portal Zone

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-113)

(2) Support of Portal zones

Since the soil covering is small in the portal zones, the arch action does not work. Hence, uneven ground pressure acts as a load on the support structure. From this, it is necessary to stabilize it with a rigid support.

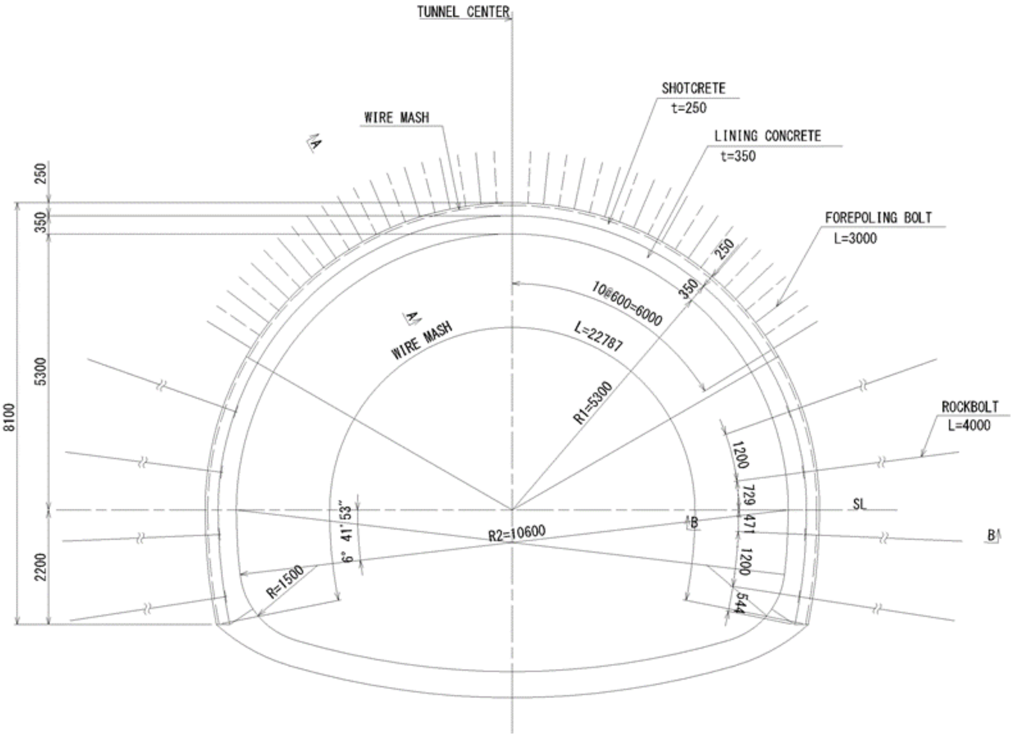


Figure 3-12 Example of Support Pattern Type DIII

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-113)

(3) Lining of Portal Zones

Considering the drying shrinkage of concrete, the influence of earth pressure, and the influence of earthquake, the lining generally has a reinforcing bar structure. Normally, the main reinforcement is set to D19 mm or more, and the force distributing bar is set to D16 mm or more, and it is set as a single rebar.

(4) Design of Portals

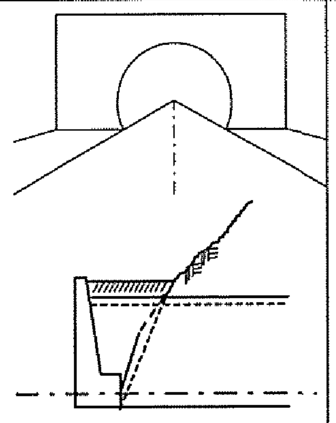
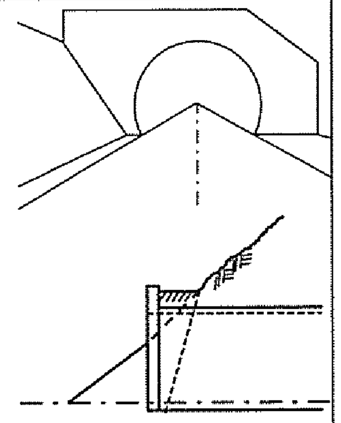
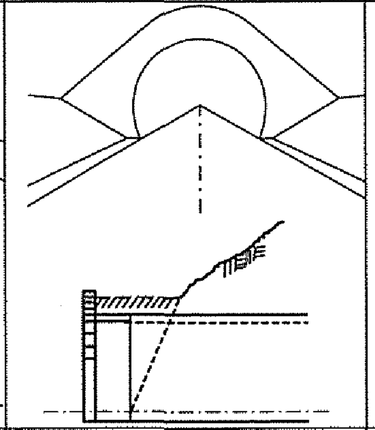
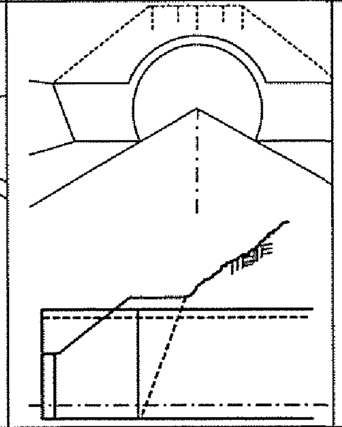
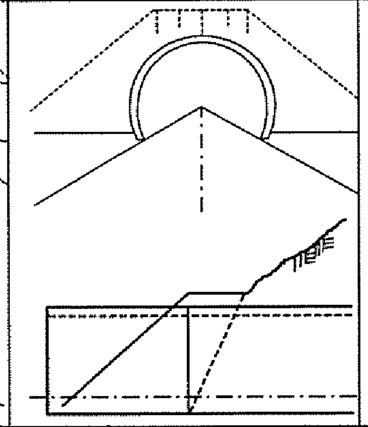
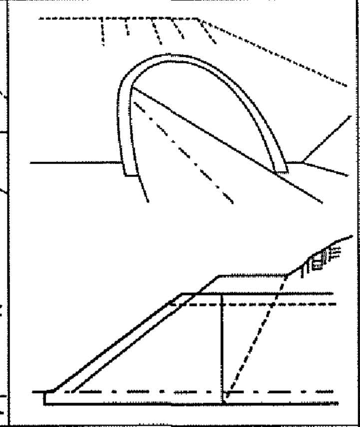
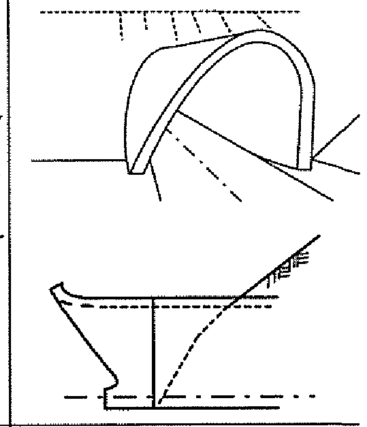
The structures at tunnel portal protect the portal zone from landslide, rock falls and avalanches down the slope's surface, and require a mechanically stable design. The external appearance and shape of the portal should be determined according to the use of the tunnel and in order to preserve compatibility with surrounding natural environment and landscape. When determining the location and the type of the portal, the following conditions shall be studied comprehensively.

- Topographic and geologic conditions
  (bearing capacity of lower portion of the portal, stability of the surface behind the slope, presence of unbalanced earth pressure, possibility of landsides or rock falls, positional relative to swamps and valleys)
- Meteorological conditions
  (snow, snowfall, snow cornices, drifting snow, avalanches)

- Portal location during construction
- Environmental conditions
  (land use conditions, extent of changes in surrounding environment and landscape in the surrounding area)
- Coordination with plans for the vicinity
  (tie-in with open sections such as bridges, relationship with relocated roads, shifting channels, location of planned future maintenance management facilities near the portal)
- Economic efficiency
- Others (direction of incident sun light etc.)

Portal forms are classified as either wall type or protruding type. Characteristics of the general types of portals are shown in Table 3-9.

Table 3-9 Types and Characteristics of Tunnel Portals

Type / Item	Wall type			Protruding type			
	Gravity/ Semi-gravity type	Wing type	Arch wing type	Half protruding type Parapet type	Protruding type	Split bamboo type Bell mouth type	Inverted split bamboo type Inverted bell mouth type
Shape							
Overview	Gravity type retaining wall placed about 10m forward of the portal position. Recently replaced by wing type and now is seldom adopted.	Planned as an earth retaining wall by cutting the ground. Economical because tunnel length can be shortened. Adopted for most railway tunnels.	In contrast to wing type, the shape mitigates the exertion of pressure by enabling extension of the tunnel length and round form.	Arch section created as a protruding type and an earth retaining wall added to prevent fill collapse. A reasonable structure as a portal.	A form used mainly to improve the landscape using open tunneling and constructing the portal so the inside section united with the tunnel is protruding.	This form eliminates the concrete exposed section of a protruding type portal, creating a bell mouth type portal with a trumpet-like opening.	Portal can be made to appear larger because in contrast to split bamboo type or bell mouth type, the form increases the concrete exposure of the upper section
Ground conditions appropriate for application	- Comparatively steep topographic features or where a structure like an earth retaining wall is required - Where rock falls are expected	- Comparatively steep topographic features where ground will be cut and portal constructed - Where an earth retaining wall or enlarged retaining wall will be constructed for an oblique type slope	- Where topographic features are comparatively moderate - Where cut on both sides is comparatively small	- Where there are ridge-like topographic features or where few structures on either side will be connected to the portal	- Where the surrounding topographic features are comparatively moderate - Where an oblique type slope is difficult to correct - Where counterweight fill works are used as slope measures - Where rock falls are expected	- Where the surrounding topographic features are moderate and the area surrounding the portal is open - Where the slope is perpendicular - Where site will include landscaping around the portal	- Where the ground cannot be cut in a steep slope - Where rock falls are frequent
Meteorological conditions appropriate for application	- Few problems even when used in snowy areas	- Few problems even when used in snowy areas	- Few problems even when used in snowy areas	- Few problems even when used in snowy areas	- Few problems even when used in snowy areas	- Snow drifting and snow cornices occur easily when used in snowy areas	- Can be expected to prevent snow drifting and formation of snow cornices in snowy areas
Points to note for design and construction	- Might require piles or a large-scale replacement foundation depending on geological conditions	- Integration of the portal into the tunnel is required	- Opening tunneling may be required depending on the topography (especially in arch sections) - A certain quantity of fill is required for slope protection	- Open tunneling of several meters in the main tunnel is required, and some earth retaining walls will be required to prevent fill collapse	- Tunnel length will be extended - Protective fill normally required	- Form work and arrangement of reinforcing bars require much effort and cost - Protective fill normally required	- Adequate study of bearing capacity of the foundation required because of relationship to the center of gravity point - Form work and arrangement of reinforcing bars require much effort and cost
Landscape	- Because the wall has a large area, brightness must be reduced (for example, by chipping the wall surface) - Because the portal looks massive, it also makes drivers feel oppressed	- Same as the gravity/semi-gravity type	- Exertion of weight and pressure can be mitigated by the arch section curve - Must consider compatibility with the surrounding topographic features	- Exertion of weight and pressure is comparatively small because of a small wall area - Compatible with the topography surrounding the portal	- Same as half protruding type/parapet type	- Bell mouth type with widened entrance is easy to enter. - Portal can be harmonized with surrounding topographic features by landscaping	- Has little impact on traveling vehicles - Highly compatible with the topography surrounding the portal

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-118)

3.4.5 Shotcrete

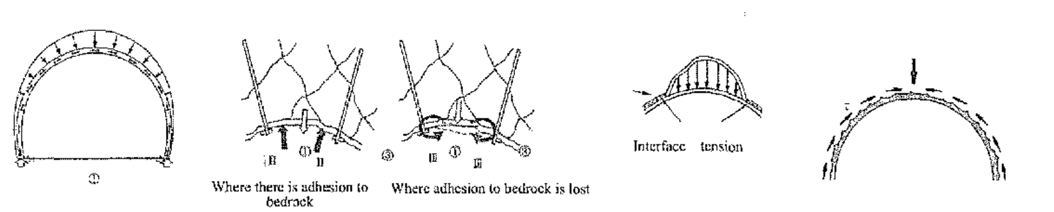
(1) Conception of Function and Effects

Shotcrete concrete is the most important supporting member that does not loosen the ground because it can be installed in any shape immediately after excavation of the tunnel, and it comes into close contact with the ground. The support function of shotcrete is thought to be its resistance to the deformation of bedrock which accompanies boring, and the compaction and shear resulting from external forces. These functions of shotcrete provide effective support in various combinations, and stabilize bedrock.

Various concepts of these functions and effects as tunnel support can be considered together with conceptual diagrams as given in Table 3-10 and Table 3-11. It is necessary to decide specifications for thickness, strength, and other design values of shotcrete taking into consideration bedrock conditions, the purpose of the tunnel and other conditions, in order to ensure the stability of the tunnel after boring.

Table 3-10 Concepts of the Function and Effect of Shotcrete (1)

Category of function, effect			Summary of function and expected effect
Function	I	axial compaction resistance of concrete	Resisting comparatively uniform external forces mainly against the internal space creating the arch, and resisting the axial forces which cause deformation, using the axial compaction resistance and rigidity of concrete.
	II	shear resistance of concrete	Resisting shear force and shear displacement which causes localized ejection, using the shear resistance and rigidity of concrete. Adhesion between the bedrock and shotcrete is necessary. If adhesion is lost, concrete goes into flex resistance mode.
	III	flex resistance of concrete	Resisting flexing moment which causes localized ejection, using the flex resistance and rigidity of concrete.
	IV	shear resistance, adhesion resistance of concrete - bedrock interface	Support of loads taken by I to III above, and distribution of that support function over the bedrock, using the shear resistance (adhesion resistance) at the shotcrete - bedrock interface.



I axial compaction resistance II shear resistance III flex resistance IV shear resistance, adhesion resistance of concrete – bedrock interface

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-72)

Table 3-11 Concepts of the Function and Effect of Shotcrete (2)

Effect	①	rock fall prevention, retaining of small rock masses	Work safety is ensured by protecting small rock masses separated by the surfaces of discontinuity which are about to fall from the tunnel face immediately after boring due to action of gravity; prevents carelessness that can result in repeated rock collapse
	②	application of internal pressure to bedrock	In soft bedrock or sedimentary bedrock tunnels where portal deformation is pronounced, shotcrete, as a reaction force, provides the bedrock with radial outward binding force, and by preserving the triaxial conditions of the bedrock in the vicinity of the tunnel boring face, increases the load bearing capacity of the bedrock.
	③	reinforcement of weak strata and protection of shape	At weaknesses in the bedrock, such as open fissures and small weak strata, plug reinforcement with shotcrete, or fusing or integrating parts of the bedrock which are comparatively strong straddling the weaknesses, reduces the effects of surfaces of discontinuity and weak strata within the bedrock.
	④	leveling out of stress distribution	By plugging crevices, and finishing the spray surface in a smooth arc, circumferential stress distribution in the shotcrete and bedrock is leveled out. Further, the support effect of rock bolts and steel tunnel supports arranged locally is enlarged and transmitted over the surface, and tunnel biased loads, localized loads appearing in the tunnel are supported and distributed over the surface.
	⑤	protective covering, prevention of degradation of bedrock	Provides a protective covering of the boring bedrock surface, and prevents the degradation of bedrock by dehydration or oxidation through contact with air, and softening of bedrock and outward flow of soil particles through contact with water inflow.

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-72)

The mechanical characteristics of shotcrete shall be determined taking into account the expected function, effect and bedrock conditions. In general, comparatively high compaction strength is commonly required in the initial stage after application for shotcrete used in tunnels. Required typical strength settings one day after application are as follows,

- Two lane road tunnel one day strength of 5N/mm^2
- Bullet tunnel (shinkansen) one day strength of 8 N/mm^2
- Large cross section road tunnel one day strength of 10N/mm^2

Design standard strength is generally defined as uniaxial compaction strength 28 days after application, i.e. long-term strength, set at 18N/mm^2 for a two lane road tunnel and a railway tunnel. On the other hand, higher strength of 36N/mm^2 may be set for large cross section road tunnels, to reduce thickness of spraying and to increase resistance with the expansive bedrock.

(3) Mix of Shotcrete

Mix of Shotcrete shall be determined taking into consideration qualities such as required strength and constraints on construction, as well as design standard strength and related strengths together with variation in concrete strength which occurs on the side. In planning the mix of shotcrete, it is important to take into consideration constraints on construction in addition to qualities such as strength. The main items to consider in shotcrete mix are as follows:

a. Strength (initial stage strength, early stage strength, long-term strength)
b. Adhesion
c. Compactness (adsorbed moisture, void volume, permeability and others)
d. Durability (freeze/thaw resistance, chemical resistance, carbonation resistance)
e. Rebound ratio
f. Volume of dust produced

Since strength of shotcrete depends on the spraying method, water inflow conditions of the sprayed face, portal air temperature, humidity, water/cement ratio or water/bonding, material ratio, fine aggregate ratio, maximum dimensions of coarse aggregate and other materials used, it is essential that the characteristics of these materials must be considered and ingredients should be selected appropriately. Examples of specified mixes used in a road tunnel are shown in Table 3-12.

Table 3-12 Examples of Specified Mixes of Shotcrete in Road Tunnel

		Maximum dimensions of coarse aggregate Gmax(mm)	slump (cm)	Cement C (kg)	Accelerating agent C×%
Road	Normal mix Dry method	15	—	360	5.5
	Normal mix Wet method	15	8	360	5.5
Expressway	high strength mix	10	18±2	450	10.0
	standard mix	15	18±2	360	7.0

Source: JICA project)

(4) Reinforced Shotcrete

In case that reinforced is necessary in shotcrete, the strength characteristics of shotcrete materials should be improved, or the sprayed thickness should be increased. Of these two methods, the strength characteristics of shotcrete materials can be improved by reinforcement with wire nets or fibers to improve shear strength, tensile strength and toughness in addition to increasing compaction strength.

1) Wire netting

Wire netting is used to improve the shear reinforcement of shotcrete to prevent peeling at and after time of application and to improve toughness after the appearance of cracks. In bedrock which shows a large degree of deformation such as expansive bedrock, many cracks may form in shotcrete. Furthermore, lumps of concrete may peel. In this case, it is common to use wire netting to improve peeling and toughness. On the other hand, where there are many joints and fissures in hard rock with concern that rock masses might collapse suddenly, wire netting is commonly used to reinforce the shear strength and to improve toughness of shotcrete. Welded wire netting is generally used commonly with a mesh of 100×100mm or 150×150mm and wire diameter of about 3.2 to 6.0mm.

2) Fiber reinforcement

Fiber reinforced shotcrete may be effectively used in places where deformation is large and toughness is necessary, or places where the stress distribution of tunnel support is complex, and toughness and flex resistance is necessary.

The examples of mixes for fiber reinforced shotcrete are shown in Table 3-13.

Table 3-13 Examples of Fiber Reinforcement Mix

σ_{28} N/mm^2	units kg/m^3						
	cement C	water W	fine aggregate S	coarse aggregate G	additive agent	acceleratin g agent	steel fiber
36	450	202.5	1 114	478	1.76	45.0	78.5

(b) Vinylon fiber reinforced shotcrete mix in the Tohoku bullet train Iwate tunnel Mega dept.

fine aggregate ratio S/a %	cement C kg/m^3	silica fume %	accelerating agent %	vinylon fiber kg	wetting agent %
65	360	5	5.5	10	2

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-80)

Figure 3-13 Example of Fiber Material

(Source: manufacturer's catalog)

3.4.6 Rock Bolt

(1) Conception of Function and Effects of Rock Bolt

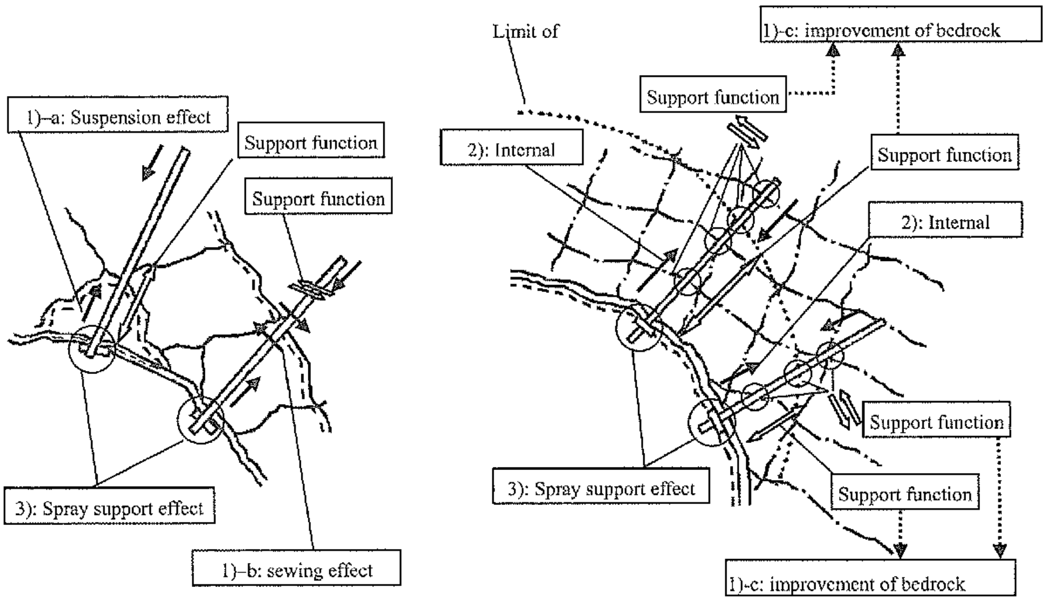
Rock bolt is made up of plates and nuts for fixing to the sprayed concrete, and reinforcing bars inserted in the drilled holes. As opposed to shotcrete and steel tunnel supports, the characteristics of rock bolts is that rock bolts have a support function from inside of the bedrock. It is thought that the support function of rock bolts is mainly to suppress relative displacement parallel to or at right angles to the fissure plane in the case of medium hard and hard bedrock which has developed fissures, and to suppress relative displacement in a direction radial to the tunnel between the tunnel wall surface and the bedrock in the case of soft bedrock and sedimentary bedrock. These functions and effects of rock bolts as tunnel supports are shown in Table 3-14. Further, the relationship between bedrock conditions and function and effect of rock bolts is shown in Table 3-14.

In planning rock bolts, it is necessary to decide the specification of the anchorage system, anchorage material, distribution and dimensions, material and shape, taking into consideration geologic structure and the relationship to the function and effects of rock bolts, bedrock conditions, the aim of the tunnel, and constraints on construction, in order to ensure the stability of the tunnel after excavation.

Table 3-14 Concepts of Function and Effects of Rock Bolts

Category of function, effect			Summary of function and expected effect
Function	I	tensile resistance of rock bolt	Function to suppress displacement relative to bedrock in the axial direction, by the tensile resistance of the rock bolt in that direction
Function	II	shear resistance of rock bolt	Function to suppress displacement relative to bedrock at right angles to axial direction, by the shear resistance of the rock bolt in that direction
Effect	1) Reinforcement effect of bedrock	a: suspension effect b: stitch effect	In medium hard bedrock and hard bedrock, which has developed fissures, binds unstable masses of rock partitioned by fissures to deep bedrock, and inhibits the peeling and ejection of those masses of rock.
Effect	1) Reinforcement effect of bedrock	c: effect of improvement to the nature of the bedrock	In medium hard bedrock and hard bedrock, if rock bolts are placed to intersect with fissures, shear strength of the fissure plane is increased, and the apparent effect of improvement to the nature of the bedrock can be expected. Also, in the case of soft bedrock or sedimentary bedrock with little strength, depending on placement of rock bolts, the improvement of shear resistance of bedrock, and of residual strength after yield, and the apparent effect of improvement to the nature of the bedrock can be expected.
Effect	2)	internal pressure effect	In the case of soft bedrock or sedimentary bedrock, the axial forces developed by the rock bolt act on the shaft wall through the medium of the shotcrete, demonstrating an apparent internal pressure, and the suppression of plasticization of bedrock surrounding the tunnel and its extension can be expected.
Effect	3)	Shotcrete support effect	Rock fragments smaller than the placement interval of rock bolts, which have separated from the bedrock, are supported by shotcrete. Shotcrete supports the load by adhesion to the bedrock. However where adhesion between the shotcrete and the bedrock is lost, by stitching the shotcrete to the bedrock, rock bolts can be expected to support that load.

Summary of function and effect



(a) Medium hard, hard bedrock (b) Soft bedrock, sedimentary bedrock

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-82)

Table 3-15 Relationship between Bedrock Conditions and Function and Effect of Rock Bolts

Bedrock conditions / Support function	Bedrock conditions
	Discontinuous ↔ Continuous
	Hard rock, medium hard rock ↔ Soft rock, sediment
Axial tensile resistance (perpendicular rigidity and strength)	Suspension effect ↔ Internal pressure effect ← Spray support effect →
Shear resistance at right angles to axis (shear rigidity and strength)	stitch effect ← Effect of improvement to the nature of the bedrock

Reference

1) Japan Highway Public Corporation: Design Code No.3 Tunnel, Version "(1) Construction of the Main Tunnel Framework (Tunnels on the Second Tomei and Meishin Expressway)", pp. 55-65, 2002.
2) Japan Society of Civil Engineers Rock Mechanical Committee･rock bolt design WG: No.30 Rock mechanical symposium, pp.393-401, 2000.

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-83)

(2) Rock bolt Anchorage System

The common rock bolt anchorage system is the complete anchorage systems which fixes the whole length of the rock bolt to the ground. There are two types of complete anchorage systems depending on the rock bolt anchorage method: anchorage material type and friction type. They are categorized based on structure and type of anchorage material as explained in Figure 3-14. The characteristics and limits of use for both methods are explained in Table 3-16.

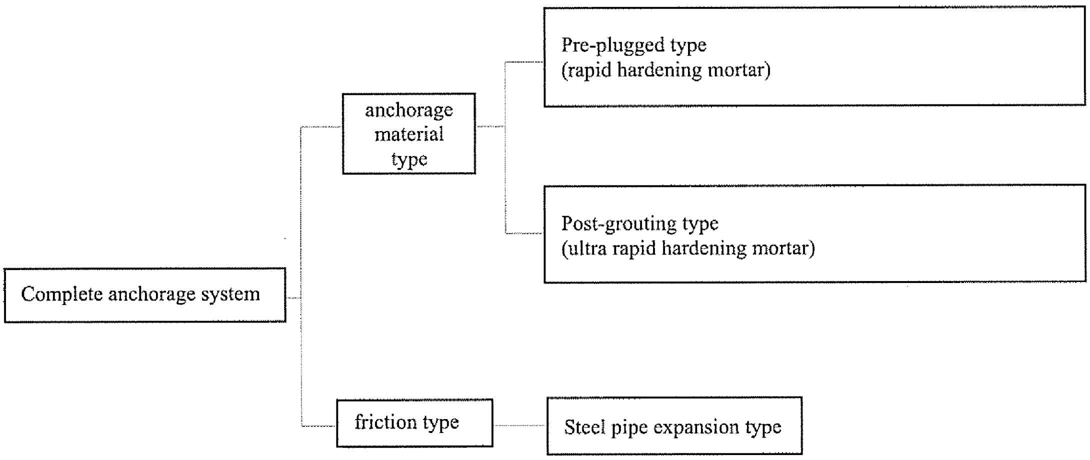
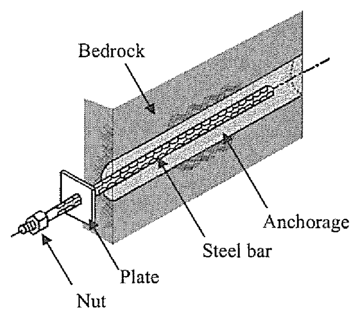
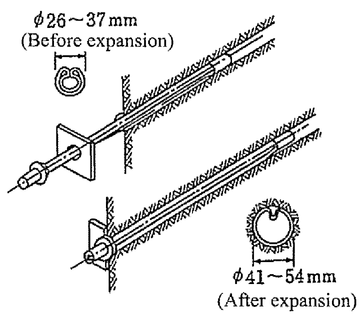


Figure 3-14 Classification of Rock Bolts for Complete Anchorage Systems

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-84)

Table 3-16 Summary of Complete Anchorage Systems

	Anchorage method	Characteristics	Application limits	Schematic drawing
Anchorage material type	In the pre-plugged type, the core is inserted and fixed into a hole plugged with anchorage material. In the post-grouting type, anchorage material is injected after the core is inserted and fixed. Rapid hardening mortar is used as anchorage material for pre-plugged type, and ultra rapid hardening mortar or resin is used as anchorage material for post-grouting type.	Using anchorage material, the whole length of the core is anchored to the bedrock. There are a variety of types, to match bedrock conditions (fissures, water inflow conditions), soundness of hole wall, etc.	Can be applied to various types of bedrock, not only hard rock, medium hard rock, soft rock, sedimentary bedrock, but also expansive bedrock.	pre-plugged type 
Friction type	Anchorage is achieved by friction by attaching the core closely to the surface of the hole wall. Steel pipe expansion type is representative.	In steel pipe expansion type, a steel pipe with its leading tip closed off is inserted into a drilled hole. Instantaneous support is achieved by expanding the steel pipe by injecting high pressure. It is necessary to sufficiently consider reduction of durability such as corrosion of the surface of the steel pipe and degradation of the pushing force added to the surface of the hole wall.	Friction type may be applied to bedrock where water inflow is large. In steel pipe expansion type, since a large degree of plastic deformation in the drilled hole is possible in the radial direction, it can be applied to a wide range of bedrock, so long as the hole wall is sound.	Steel pipe expansion type 

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-85)

(3) Distribution and Dimensions of Rock Bolts

Distribution of rock bolts is decided taking into consideration bedrock conditions, size of tunnel cross section, shape, drilling method, constraints on construction and other conditions. In principle, it is best to distribute rock bolts for support to efficiently reinforce those areas affected by tunnel drilling.

However, distribution is normally decided using a systematic arrangement of bolts which is a tried and tested standard support pattern chosen on the basis of the determined bedrock classification taking into consideration bedrock conditions.

The dimensions of the lock bolt are generally based on about 2 to 4 m.

In addition, those whose diameter is about 22 to 25 mm are used.

Examples of distribution of rock bolts based on differing bedrock conditions are shown in Figure 3-15.

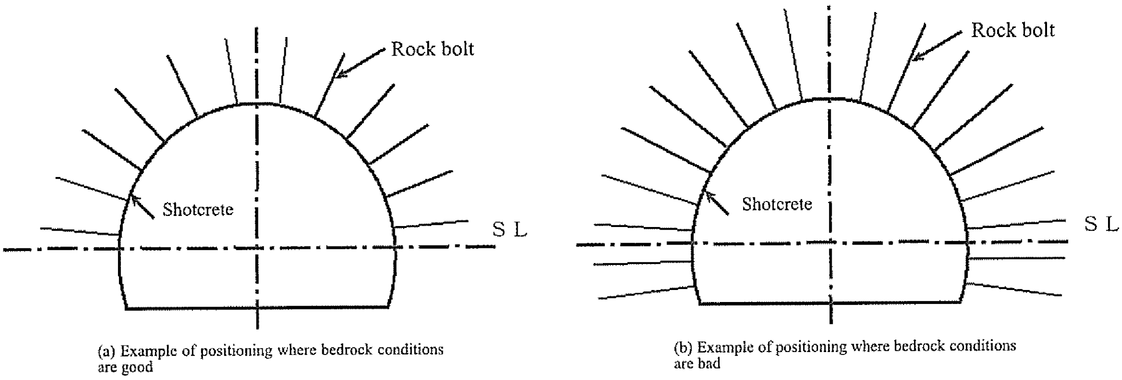


Figure 3-15 Examples of Distribution of Rock Bolts in the Tunnel Transecting Direction

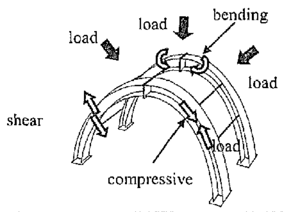
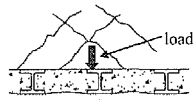
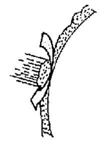
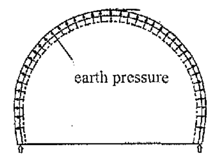
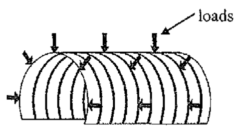
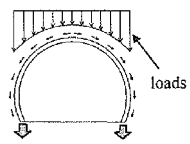
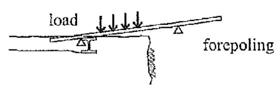
(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-89)

3.4.7 Steel Supports

(1) Conception of Function and Effects of Steel Supports

Since steel supports, which are arch shaped reinforcements fitted against excavated tunnel surfaces, should take effect as soon as they are installed, they contribute to stabilizing the excavated tunnel face until the strength of shotcrete is fully developed. Steel supports also make easier stabilization of the tunnel by combining with shotcrete. The function and effect of steel supports are shown in Table 3-17.

Table 3-17 Concept of Function and Effect of Steel Supports

Function or Effect			Description of function and obtainable effect	
Function	I	Axial compressive resistance Shear resistance Bending resistance	Similar to shotcrete, steel supports can resist external forces with compressive resistance, shear resistance and bending resistance. Those functions are effective immediately after installation. When the shotcrete reaches an effective strength, the resistance supplied by the steel supports unites with the shotcrete.	
Effect	1)	Support of rock mass	Steel supports can be tightly attached to the tunnel to prevent spalling of partial rock blocks due to bending or shear resistance.	
	2)	Reinforcement of weak ground	Steel supports can reduce the effect of discontinuities and weak layers by supporting cracks and openings or small-scale weak layer.	
	3)	Utilization of inner pressure toward the ground	Steel supports can provide inner pressures along the tunnel wall in the radial direction for weak ground that cannot be expected to form a ground arch. This allows confined stress state that increases load carrying capacity of entire ground.	
	4)	Reinforcement of shotcrete	Steel supports fuse with the shotcrete to improve the stiffness and toughness of shotcrete particularly at early age of shotcrete with low elastic modulus and strength. In addition, after appearance of sufficient strength in the shotcrete, steel supports can be integrated into the shotcrete and applied tightly on the tunnel wall to form an arch shell structure and then stabilize the tunnel and the surroundings.	
	5)	Transfer of loads to ground (footing)	Steel supports can transfer the loads from the surroundings to the foundation through the wing ribs.	
	6)	Support for forepoling	Steel supports can function as the reaction point for the forepoling supporting the ground ahead of the tunnel face and restrain the failure or loosening of surrounding ground.	

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-93)

(2) Shape of Steel Supports

Steel supports should be designed properly to support the strength transferred through the shotcrete with a yield bending moment as small as possible in a shape similar to the excavated section. The shape of steel supports includes top heading, upper and lower halves, and all surrounding as shown in Figure 3-16. Also the shape of steel supports is determined based on the nature of surrounding ground, intensity and direction of applied strength, and method of installation.

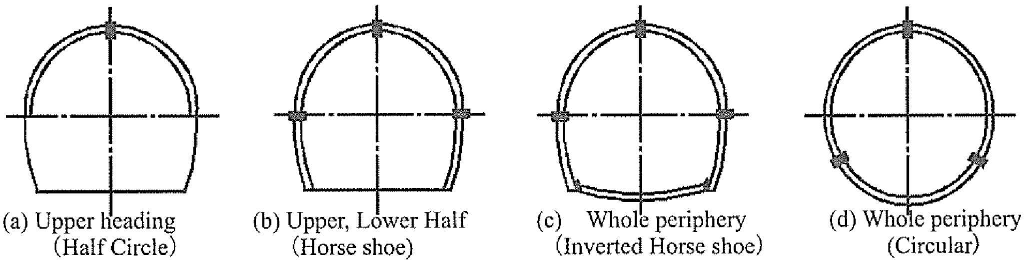


Figure 3-16 Various Shapes of Steel Support

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-93)

(3) Steel Support Material

The steel used for steel supports usually includes H-beams, U-beams, circular pipes, and lattice girders. Currently H-beams are most frequently used. Parameters of steel products for steel supports in Japan are shown in Table 3-18.

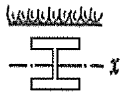
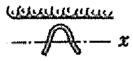
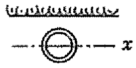
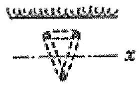
(4) Joints and Base Plates for Steel Supports

Since the joints of the steel supports may become a structural weak point of the support members, it is necessary to design joint positions and connected mechanisms considering the excavation shape as well as the size and distribution of the resulting stress. Figure 3-17 illustrates an example of joints and base plates for steel supports.

(5) Collar Braces for Steel Supports

Steel supports next to each other are fixed by collar braces. Collar braces shall be properly installed on the newly erected steel supports to prevent collapse until the support is fixed in place by shotcrete. There are two types of the collar braces as shown in Figure 3-18.

Table 3-18 Parameters of Steel Products for Steel Support

Type	Material	Dimension (mm)	Sectional Area A (cm^2)	Density W (kg/m)	Moment of Inertia Ix (cm^4)	Section Modulus Zx (cm^3)	Minimum Radius of Curvature R (cm)	Illustration of Use
H-beam	SS400	H-100×100×6×8	21.59	16.9	378	75.6	120	
		H-125×125×6.5×9	30.00	23.6	839	134	150	
		H-150×150×7×10	39.65	31.1	1 620	216	200	
		H-175×175×7.5×11	51.42	40.4	2 900	331	340	
		H-200×200×8×12	63.53	49.9	4 720	472	420	
		H-250×250×9×14	91.43	71.8	10 700	860	550	
	HT590/ SS540	H-154×151×8×12	47.19	37.0	2 000	260	400	
		H-200×201×9×12	65.53	51.4	4 782	478	450	
U-beam	SM490	MU-21	26.80	21.0	296	56.6	135	
		MU-29	37.00	29.0	581	97.4	150	
Steel Pipe	STK400	φ76.3×3.2	7.35	5.8	49.2	12.9	65	
		φ89.1×3.2	8.64	6.8	79.8	17.9	80	
		φ101.6×5.0	15.17	11.9	117	34.9	100	
		φ114.3×4.5	15.52	12.2	234	41.0	120	
		φ139.8×6.0	25.22	19.8	566	80.2	140	
		φ216.3×8.2	53.61	42.1	2 190	269	250	
		φ267.4×9.3	75.41	59.2	6 290	470	450	
Re-bars	SD295	D16×3+D10	6.00	7.4	94.4	26.2	-	

* Values of minimum radius of curvature R are by means of the cold processes

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-93)

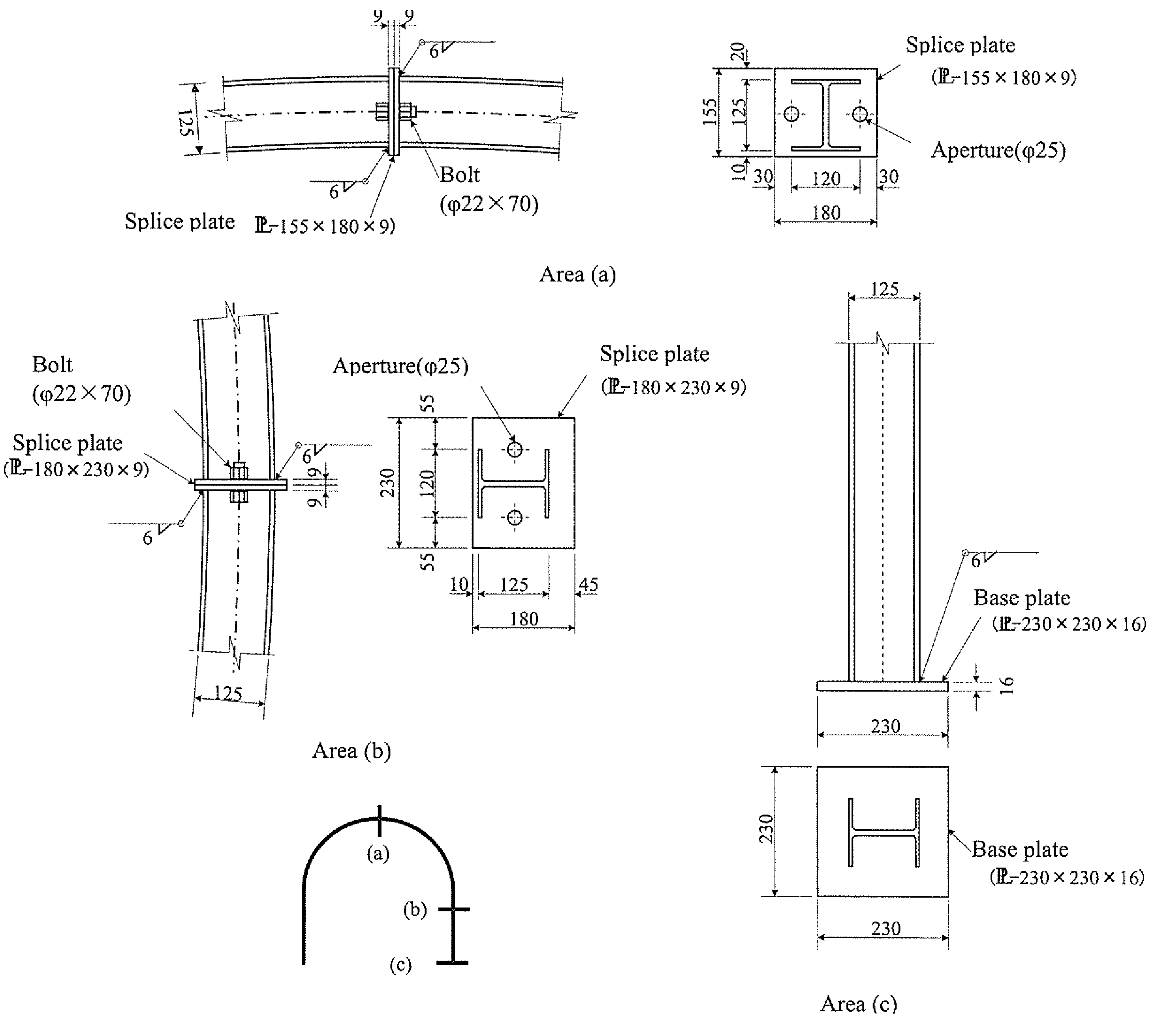


Figure 3-17 Examples of Joint and Base Plate

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-97)

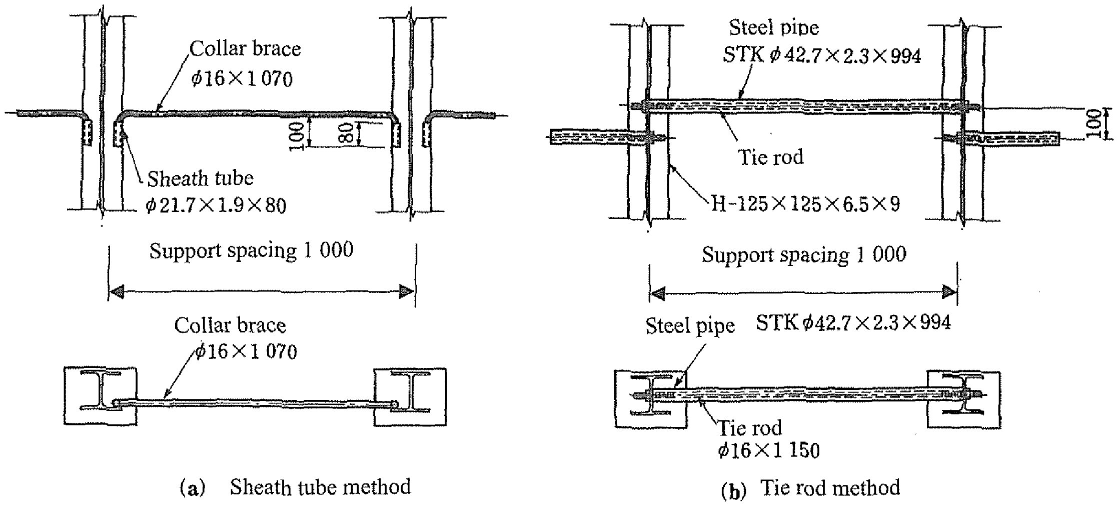


Figure 3-18 Example of Collar Brace

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-98)

3.4.8 Lining and Invert

(1) Roles and Functions Required for Lining

Since the roles and functions required for lining are different depending on the purpose of use and conditions of use of the tunnel, it is necessary to design so as to exert the function suitable for them. It also needs to withstand the load acting for a long time and have durable performance with little leakage. The lining, a part of tunnel support, is required to have a mechanical function depending on necessary functions, the provision function for future uncertain factors, and special ground conditions and mechanical conditions as specified bellow.

1) Functions Related to Service
   - Function to hold section
   - Function to waterproof
   - Function to Refractory
   - Function to Maintenance management
   - Function to interior
   - Function to hold facility
2) Functions for Uncertain Elements
   - Function to retain reserve capacity
   - Function to maintain deformability
   - Function to maintain structural stability

3) Function to Mechanical

- Function to counter the added external force
- Function to complement the support

(2) Basics of Lining Design

In the design of the lining, it is necessary to examine conditions such as mountain conditions, load conditions and importance of the structure, and to satisfy necessary functions and performance from purpose and conditions of use.

In addition, the lining can be roughly divided into a design that does not add a mechanical function and a design that adds a mechanical function.

1) Design without a Mechanical Function

In the case of NATM of the rock tunnel, it is considered that the mechanical load does not act on the lining because the support is responsible for the load.

The thickness of the lining in this case is basically about 30 to 40 cm.

2) Design with a Mechanical Function

This design is a case where an external force is acting. The external forces are, for example, water pressure, earth pressure and plastic pressure of the expansive ground. In addition, when planning a parallel tunnel or proximity construction, there are cases that water pressure should be taken into consideration (e.g. targeting unconsolidated ground in urban areas). In this case, a numerical analysis is used. Generally, framework structure analysis is carried out, and lamination thickness, rebar strength and concrete strength are determined.

(3) Mix and Strength of Lining

The desired strength of lining concrete varies depending upon such conditions as the characteristics of the ground, shape of lining, type of support and load applied to the lining.

The specified concrete strength is often adjusted to about 18 to 30 N/mm^2 expect in special cases.

Table 3-19 lists the specifications of lining concrete for Japanese road tunnels.

Table 3-19 Example of Specification of Lining Concrete for Japanese Tunnel

Type of Road	Types of cement	Design standard strength (28 day strength) (N/mm2)	Maximum size of coarse aggregate (mm)	Slump (cm)	Air (%)	Unit water amount (kg/m3)	Unit Cement amount (kg/m3)	water cement ratio (%)	Mximun of Chloride content (kg/m3)	Remarks
Expressway 2Lane (formor standard)	Ordinary Portland cement Blast furnace cement B type	18	40	15±2.5	4.5±1.5		270 or more		0.3	0.3
	Ordinary Portland cement Blast furnace cement B type	18	20.25	15±2.5	4.5±1.5	175 or less	310 or more		0.3	fiber reinforced
	Ordinary Portland cement	30	20.25	15±2.5	4.5±1.5	175 or less			0.3	fiber reinforced
National road 2 Lane	Ordinary Portland cement Blast furnace cement B type	18	40	12	—	—	270 or more	60or less (Plain concrete) 55 or less (Reinfoced cocrete)		

(Source: JICA project)

(4) Functions of Inverts

Considering that inverts are extremely difficult to repair after the tunnel is put in service, it is necessary to design the inverts to stabilize the surrounding ground by merging into the adjacent tunnel supports, and then to achieve a satisfactory role as a permanent structure carefully considering ground conditions, side conditions, purpose of use and necessary functions and quality.

Inverts are recommended to provide the following functions.

1) For Serviceability

- Function to hold necessary inner section lining together.
- Function to provide smooth flow path lining together.

2) For Mechanical Characteristics

- Function to prevent settlement due to lack of bearing capacity in case of poor ground or displacement of side wall of tunnel induced by plastic earth pressure.
- Function to enhance structural stability by forming a ring-shaped structure in combination with lining to achieve sufficient load-carrying capacity against earth and water pressure exerted on tunnels in urban areas for a long period.
- Function to improve durability of tunnel against deformation due to heaving in the ground that is likely to undergo deterioration or swelling, or deterioration due to application of repeated loads before and after construction.
- Function to improve stability against structural deformation of tunnel by early formation or a ring-like structure which combines with tunnel supports to control convergences of the tunnel during construction similar to temporary invert placed by shotcrete.

3) Shape and Thickness of Invert

Please refer to chapter 3.2.2 for the thickness and shape of invert.

3.4.9 Waterproofing and Drainage

(1) Waterproofing

For the purpose of preventing leakage into the tunnel, waterproofing should be installed between the shotcrete and the lining. Water leakage to the tunnel will impair its durability; it will lead to an increase in maintenance and repair cost of equipment inside the tunnel. Thus, careful design and construction are required. If the groundwater is high and is not allowed to be lowered, there is an example of making it a no drainage type tunnel because it is not possible to allow leakage to the tunnel. In the rock tunnel waterproofing sheet, the seat system is generally adopted for the following reason.

- It can be installed all around the lining.
- It closely adheres to shotcrete and waterproofing of the whole surface is possible.

The waterproofing sheet needs to have strength and elongation so that it does not break when concrete is put in. The main waterproofing sheet material is Ethylene Vinylacetate Copolymer (EVA), Polyvinyl Chloride (PVC) and Ethylene Copolymer Bitumen (ECB). Also the thickness of the waterproofing sheet is basically 8mm. However, in the case of a no drain type tunnel, the thickness is 1.2 to 1.8 mm. The sheet quality standards in Japan is shown in Table 3-20.

Table 3-20 Quality Standards of Waterproofing Sheet in japan

testing requirement		standard value			Test method in Japan
		EVA	PVC	ECB	
specific gravity		0.95±0.05	1.30±0.05	1.00±0.05	JIS K 6773
hardness		98 or less	98 or less	98 or less	JIS K 6773
thickness		The average value of 5 measurement points in the axial direction must be equal to or greater than the specified thickness and minimum thickness is within -5%			JIS K 6008
Tensile strength	20℃	15.7 or more	15.7 or more	9.8 or more	JIS K 6773
	−10℃	29.4 or more	19.6 or more	17.7 or more	
elongation	20℃	600 or more	280 or more	500 or more	JIS K 6773
	−10℃	500 or more	100 or more	350 or more	
tear strength(N/mm^2)		49.0 or more	39.2 or more	38.2 or more	JIS K 6301
flexibility(℃)		-30 or less	-30 or less	-30 or less	JIS K 6773
chemical resistance mass change	alkali(%)	±1 within	±1 within	±1 within	JIS K 6773
Joint strength (suvival ratio%)		30 or more	30 or more	30 or more	JTA

(Source: JICA project)

As a general structure of the waterproofing sheet, a composite laminated sheet having a thickness of 0.8 mm and a backside drainage material having a basis weight of 300 g / m^2 or more is used.

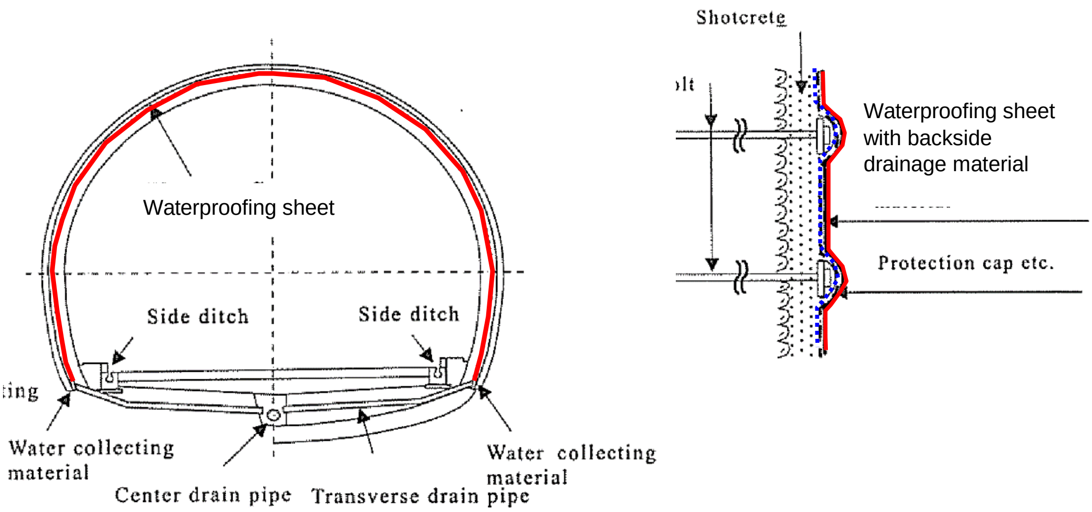


Figure 3-19 Examples of Waterproofing and Drainage

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-109)

Figure 3-20 Example of Waterproofing Sheet (left) and Installation of Waterproofing Sheet (right)

(Source: Material Manufacturer)

(2) Drainage

The tunnel must be designed with appropriate drainage so that water flowing in the tunnel can be discharged without stagnation. For appropriate drainage in the tunnel, it is necessary to install suitable drainage materials in advance with the proper method and interval so that the water flowing surely drains from the lining wall. In order to let the water on the back of the waterproofing sheet flow down to the drainage, a drain pipe and a water collecting material are installed on end of waterproofing sheet. Then, the collected water is guided to the central drain pipe ditch by a transverse pipe ditch.

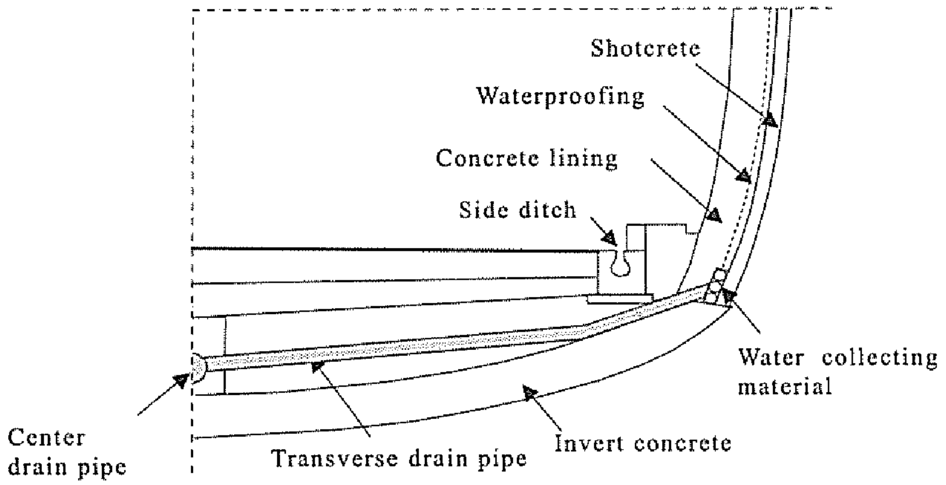


Figure 3-21 Examples of Drainage Systems

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-111)

Figure 3-22 Example of Center Drain Pipe and Water Collecting Material

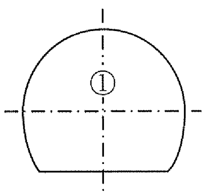
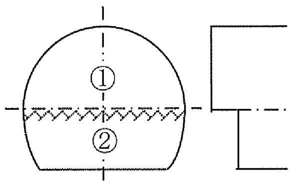
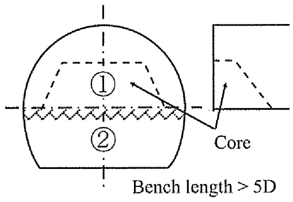
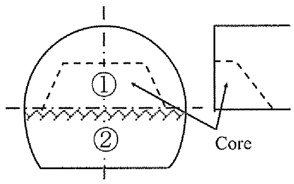
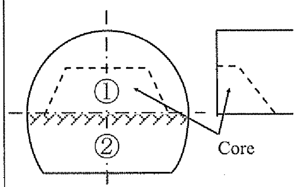
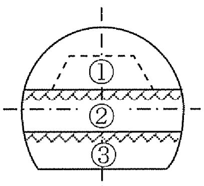
(Source: Material Manufacturer)

3.5 Planning

3.5.1 Excavation Methods

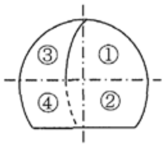
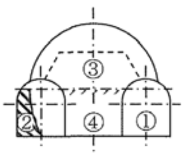
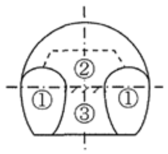
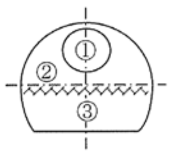
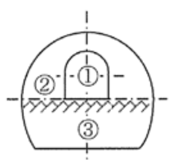
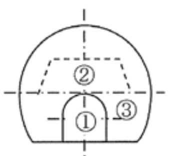
The classification and characteristics of excavation methods are shown in Table 3-21 and Table 3-22. Excavation methods widely used are the full face method, bench cut method and drift advancing method. The counter diaphragm method is also used for projects of large sections and tunneling in urban areas.

Table 3-21 Classifications and Characteristics of Excavation Methods (1)

Excavation Method		Division of Heading	Applicable Ground Conditions	Advantages	Disadvantages
Full Face Method			- Almost all ground for small section tunnels - Very stable ground for large section tunnels ($A>60m^2$) - Fairly stable ground for medium section tunnels ($A>30m^2$) - Unfit for relatively good ground interspersed with bad ground that may require change of the excavation method	- Labor saving by mechanization - Construction management including safety control is easy because of the single-face excavation.	- Full tunnel length cannot necessarily be excavated by full face alone. Auxiliary bench cut will be adopted as required. - Unsteady stone from the crown may fall down with increased energy, and additional safety measures are required.
Full Face Method with Auxiliary Bench Cut		 Bench length ≒2 - 4m	- Fairly stable ground, but difficult to apply full face method - In case that full face method becomes difficult during construction - Relatively good ground interspersed with bad ground	- Labor saving by mechanization and parallel excavation of top heading and bench - Construction management including safety control is easy because of the single-face excavation.	- Difficult to switch to other excavation methods when the face becomes unstable
Bench Cut Method	Long Bench Cut Method	 Core Bench length > 5D	- Fairly stable ground, but difficult to apply full face method - Ring cut method is applied when the face is unstable.	- Alternate excavation of top heading and bench reduces equipment and manpower.	- Alternate excavation lengthens the construction period.
	Short Bench Cut Method	 Core D < Bench length < 5D	- Ring cut method is applied when the face is unstable.	- Adaptable to changes in ground conditions - Alternate excavation of top heading and bench reduces equipment and manpower.	- Parallel excavation makes it difficult to balance the construction cycle of top heading and bench. - Alternate excavation lengthens the construction period.
	Mini Bench Cut Method	 Core Bench length < D	- In case convergence needs less control than short bench cut method - Squeezing ground that requires an early closure of excavation cross section - Ring cut method is applied when the face is unstable.	- Easy to make early closure by invert - Alternate excavation of top heading and bench reduces equipment and manpower.	- Selection of construction equipment tends to be limited when they are planned to work on the top heading bed.
	Multiple Bench Cut Method		- Fairly good ground for high and large section tunnel - Bad ground that requires small section of heading to stabilize the face	- Face is easily stabilized.	- Large deformation may develop if the closure is delayed in bad ground. - Each bench length is limited and working space is restricted. - Careful operation of mucking at each bench is required.

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-54)

Table 3-22 Classifications and Characteristics of Excavation Methods (2)

Excavation Method		Division of Heading	Applicable Ground Conditions	Advantages	Disadvantages
Center Diaphragm Method		 One method is to provide a diaphragm only for the top heading, while the other is to provide both top heading and bench.	- Soil ground with shallow overburden where ground surface settlement is required to be kept at minimum - Relatively bad ground for large section tunnel	- Face is stabilized by dividing into small sections. - Ground surface settlement can be reduced. - Divided sections of heading are larger than those in side drift method, and larger equipment can be used.	- Displacement or settlement by removal of diaphragm should be examined. - Removal of diaphragm is added to the construction process. - The adoption of a special auxiliary method in the tunnel is difficult.
Side Drift Advancing Method	with Side Wall Concrete		- Ground where bearing capacity is insufficient and bearing capacity must be improved before the excavation of top heading - Soft rock ground or soil ground with shallow overburden where unsymmetrical ground pressure or landslide is anticipated	- Relatively massive concrete wall for side drift improves the bearing capacity and strengthens resistance against unsymmetrical ground pressure.	- Small equipment has to be used for drift excavation. - The upper ground may be loosened by drift excavation.
	without Side Wall Concrete		- Ground where bearing capacity is insufficient to apply bench cut method. - Soil ground with shallow overburden where ground surface settlement is required to be kept at a minimum.	- Ground surface settlement can be reduced. - Temporary diaphragm can be more easily removed than those in center diaphragm method.	- Small equipment has to be used for drift excavation.
Other Drift Advancing Methods	Top Drift Advancing Method		- Ground that requires the confirmation of geology, drainage effect and the reduction in preceding displacement and supporting pressure - TBM may be adopted to advance drift.	- The confirmation of geology, drainage effect and the reduction in preceding displacement and supporting pressure can be achieved by advancing drift. - Center cut is unnecessary in drill and blast method. Blasting vibration and noise can be therefore reduced. - Face stability can be improved when enlarged - Ventilation effect can be expected when drift excavation is completed.	- Drift excavation by TBM may take time unless ground is fairly stable. - Small equipment has to be used for drift excavation.
	Center Drift Advancing Method		- Ground that requires the confirmation of geology, drainage effect and the reduction in preceding displacement and supporting pressure	- The confirmation of geology, drainage effect and the reduction in preceding displacement and supporting pressure can be achieved by advancing drift. - Center cut is unnecessary in drill and blast method. Blasting vibration and noise can be therefore reduced. - Face stability can be improved when enlarged.	- Small equipment has to be used for drift excavation.
	Bottom Drift Advancing Method		- Ground that requires dewatering method	- Geology can be confirmed by advancing drift. - Additional face is produced from drift, and construction period can be shortened.	- Difficult to balance the construction cycle of each face - Various types of equipment are required.

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-55-56)

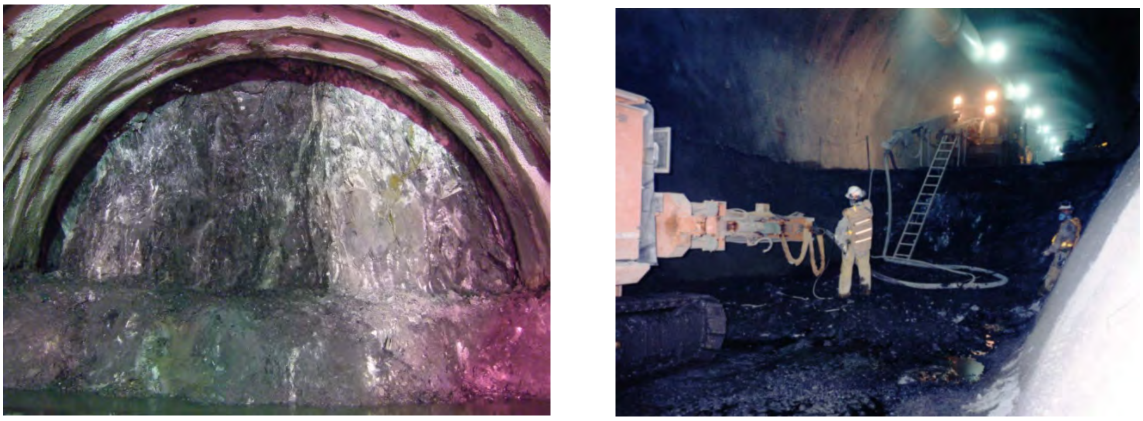


Figure 3-23 Full Face Method with Auxiliary Bench Cut (left) and Short Bench Cut (right)

Figure 3-24 Side Drift Advancing Method (left) and Top Drift Advancing Method (right)

(Source: JICA project)

3.5.2 Excavation Driving Method

Excavation driving methods include drill and blast, mechanical excavation, and combinations of these methods. As a general rule, the main concern in the selection of the excavation driving method is the ground condition. The drill and blast method is mainly applied to hard or medium hard rock ground. The mechanical method is usually applied to medium hard rock or soil ground. Excavation equipment should be properly selected in consideration of tunnel length and ground properties. TBM can be also used for a relatively long tunnel in hard or medium rock ground. When applying the TBM method, excavation efficiency and countermeasures against problems should be studied exhaustively in advance. In Japan, the excavation driving method is decided by the following flow.

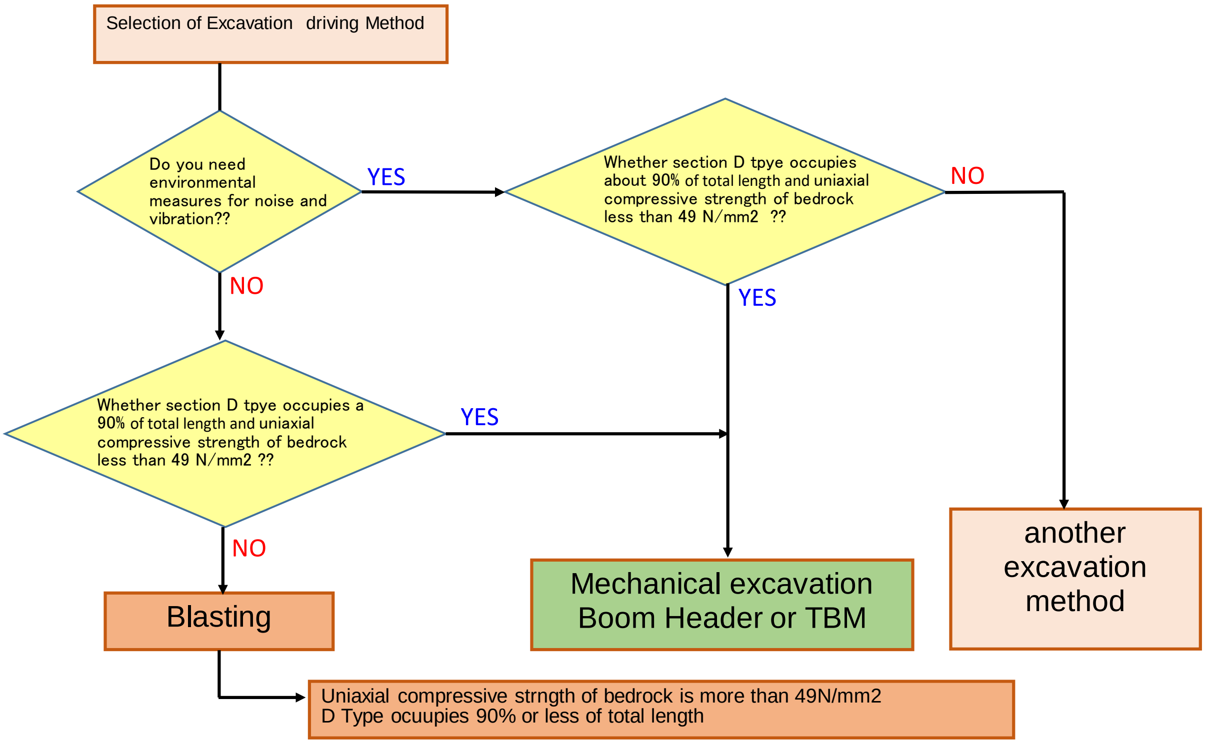


Figure 3-25　Flow of Selection Excavation Driving Method

(Source: JICA project)

Figure 3-26　Drilling and Blasting (top-left), Mechanical Excavation by Boom Header (top-right) and Mechanical Excavation by TBM (bottom-left)

(Source: JICA project)

3.5.3 Mucking

There are three transport methods.

- Road hauling
- Rail hauling
- Belt conveyer

The muck transport methods in the tunnel are shown in Table 3-23. Road hauling uses load haul dump truck and large dump truck (20-40T)

Rail hauling uses shuttle cars. Other types of hauling are container method, conveyer method, and capsule method.

TBM for small cross section uses the fluid hauling method.

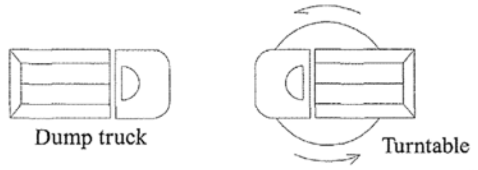
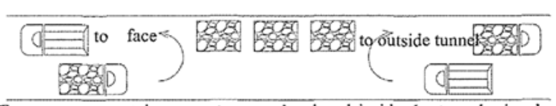
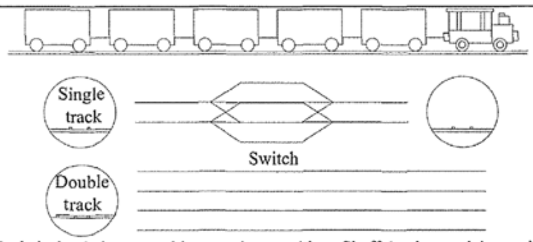
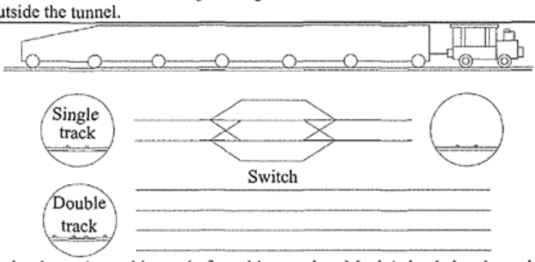
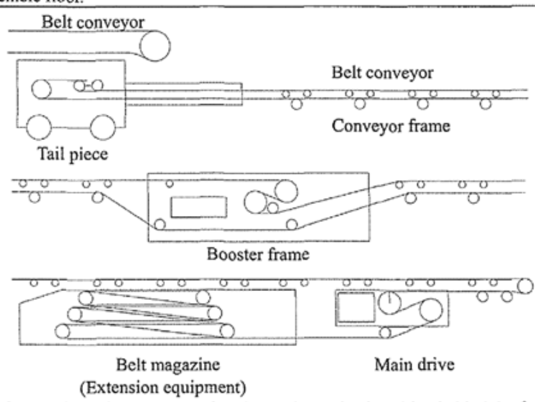
When selecting the mucking method, their size and number shall be determined appropriately for the tunnel sectional area and mucking capacity.

The capacity of the temporary muck yard should be suitably planned considering the quantity of muck during construction, hauling system, road traffic situation and muck receiving structure so that problems may not arise during tunnel drilling.

Figure 3-27 Road Hauling (top-left), Railway Hauling (top-right) and Belt Conveyer (bottom-left)

(Source: JICA project)

Table 3-23 Comparison of the Typical Mucking Methods in Tunnels

System		Overview	Ease of work	Environment in the tunnel	Equipment
Road hauling	Dump truck	 Muck is loaded on a dump truck with a wheel loader, etc., to be carried outside the tunnel.	・Muck loading is interrupted when the truck is made to wait. ・Complicated truck traffic	・Since internal combustion engines are used , sufficient ventilation shall be provided in the tunnel.	・A turntable may be required to change the direction of dump trucks. (dump truck, large- dump truck, and load hole dump truck)
	Container type	 Two or more containers are temporarily placed inside the tunnel, aimed at early opening of the face.	・Muck is temporarily placed behind the face, requiring less time in handling at the face.	・Same as above	・A turntable may be required for changing the direction.
Rail hauling	Muck car	 Muck is loaded on mucking carriages with a Shaff loader, and is carried outside the tunnel.	・Muck loading is interrupted when the truck is made to wait. ・When trains with multiple cars are used, their operation shall be managed properly.	・Use of battery powered engine keeps clean environment inside the tunnel.	・Track equipment ・With a single track, a shunting section is needed.
	Shuttle car	 A shuttle car is used instead of mucking truck. Muck is loaded at the end of the shuttle car, and transported backward by the chain conveyor on the vehicle floor.	・Same as above ・Unlike the muck car, muck loading is rarely interrupted because the shuttle car capacity is larger.	・Same as above	・Same as above
Belt conveyor		 After muck has been conveyed to the predetermined position behind the face, it is transported directly and continuously outside the tunnel, using an extensible conveyor.	・Along with advance of the face, additional conveyor belt, conveyor frame and booster drive are necessary.	・Since no internal combustion engine is used, the environment inside the tunnel can be kept clean.	・Conveyor belt ・Conveyor frame ・Motor drive ・Extension equipment ・For drill and blast, a crusher is necessary.

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-149)

3.5.4 Selection of Spray Shotcrete

There are two types of spray shotcrete: dry-process shotcrete and wet-process shotcrete. Although wet-process shotcrete is generally adopted, the method is chosen depending on scale of construction, volume of shotcrete and other conditions. Systematic diagram of dry-process spray shotcrete and wet-process spray shotcrete are shown in Figure 3-28. Characteristics of spray shotcrete methods are shown in Table 3-24.

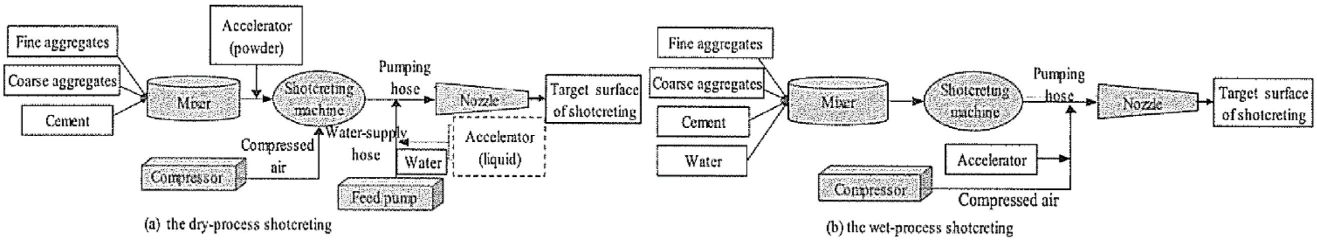


Figure 3-28 Diagram of Shotcreting Method

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-154)

Figure 3-29 Shotcreting Machine (left) and Shotcreting (wet- process, right)

(Source: JICA project)

Table 3-24 Characteristics of Shotcreting Methods

Items	Shotcreting process type	Dry process	Wet process
Properties of concrete	Characteristics related to mix design management	Depending on the condition (dry or wet) of the target surface of shotcreting, the water-cement ratio can be altered at the nozzle section. Since the water-cement ratio is dependent upon the skill of the nozzleman, the variance in the mix formula may vary greatly in some cases. The water flow rate can be controlled to limit fluctuations of the water-cement ratio.	With base concrete produced at a plant, management equivalent to that for conventional concrete is possible.
	Strength characteristics (Initial strength)	Initial strength develops more quickly than in the wet process due to the fact that the water-cement ratio generally tends to be lower than in the wet process.	Initial strength develops more slowly than in the dry process due to the fact that the water-cement ratio generally tends to be greater than in the dry process for the purpose of securing pumpability.
	Workmanship	Because the development of the strength immediately after shotcreting is great, the surface with shotcrete applied relatively easily attains smooth surface.	Probably because the development of the strength immediately after shotcreting is relatively slow, the surface with shotcrete applied tends to be rough, depending on the types of aggregates that stick to the surface later.
Placing performance	Pumping distance	Horizontal：150～300m（max.1 000m） Vertical：100～150m	Horizontal: 100 m Vertical: 30-50m
	Construction capacity	Max.12m^3/h	Max. 20 m^3/h
Others	Dust	It is possible to reduce dust generation to some extent by defining the pumping method, the type of set accelerating agent, gunning method, mix of the dry-mixed concrete, etc. appropriately. Typically, this process involves a higher level of dust generation compared to the wet process application.	It is possible to reduce dust generation to some extent by appropriately defining the pumping method, the type of set accelerating agent, gunning method, mix of the base concrete, etc. Typically, this process involves a lower level of dust generation compared to the dry process application.
	Rebound	It is possible to reduce rebound by defining the pumping method, the type of set accelerating agent, gunning method, mix of the dry-mixed concrete, etc. appropriately.	It is possible to reduce rebound by defining the pumping method, the type of set accelerating agent, gunning method, mix of the base concrete, etc. appropriately.
	Measures against water ingress	Possible to cope with since adjustment of mix design is easy.	Difficult to cope with since adjustment of mix design is not easy
	Time from mixing to gunning	Depending on the surface moisture volume of the aggregates, greater flexibility compared to the wet-process allocation.	Within 1.5 hours (at a temperature exceeding 25℃) Within 2.0 hours (at a temperature of 25℃ or lower)
	Production equipment, Shotcreting equipment	While there is some large-scale shotcreting equipment, simple and highly mobile equipment can be used. The production equipment does not need to incorporate turbid water treatment equipment.	The shotcreting equipment tends to be large in scale, often requiring a plant on the site. The production equipment needs to incorporate turbid water treatment equipment.
	Cleaning	No more than an air-cleaning level is required for the machinery, batcher plant and hose.	Complete water washing is required for the shotcreting machine, production equipment, and hose.

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-154)

3.5.5 Lining Forms

Moving forms are used for lining concrete casting. The moving forms consist of a set panels (metal form) or skin plates and framed structure, gantry and accessories. The following two types are commonly used: moving forms and assembled forms.

The moving forms are produced that can move as a single unit on a moving platform by incorporating a framed structure with steel plates or skin plates. The assembled form is designed so that the framed structure and steel panels are assembled and dismantled each time when the concrete is being poured. The assembled forms are basically used for enlargement areas. However, moving forms are usually used for lining. The length of moving form is a span of one section of concrete. One section of moving form is determined considering the work schedule, concrete supply capacity and curve radius of alignment. A basically length of the form is 9 to 12m.,because longer length of the one section of the form can cause cracks due to thermal drying shrinkage.

Figure 3-30 Example of Moving Form (1)

(Source: JICA project)

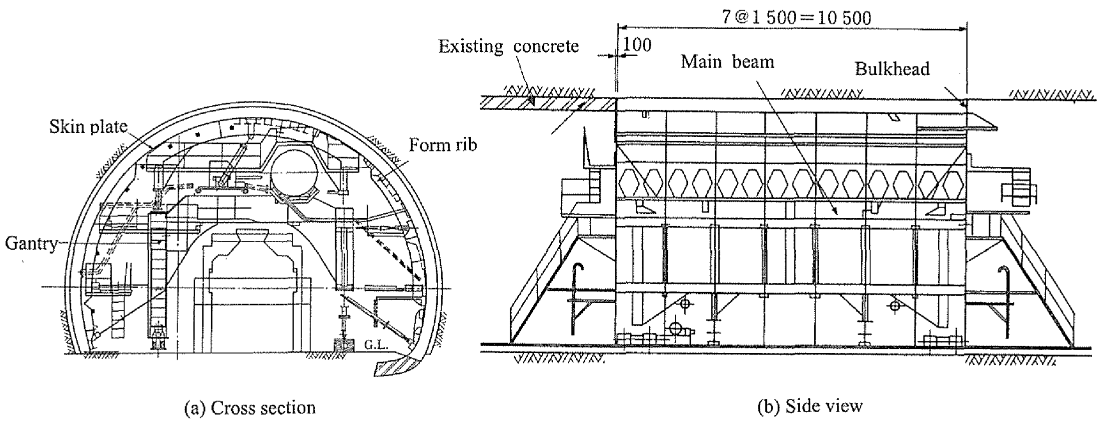


Figure 3-31 Example of Moving Form (2)

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-160)

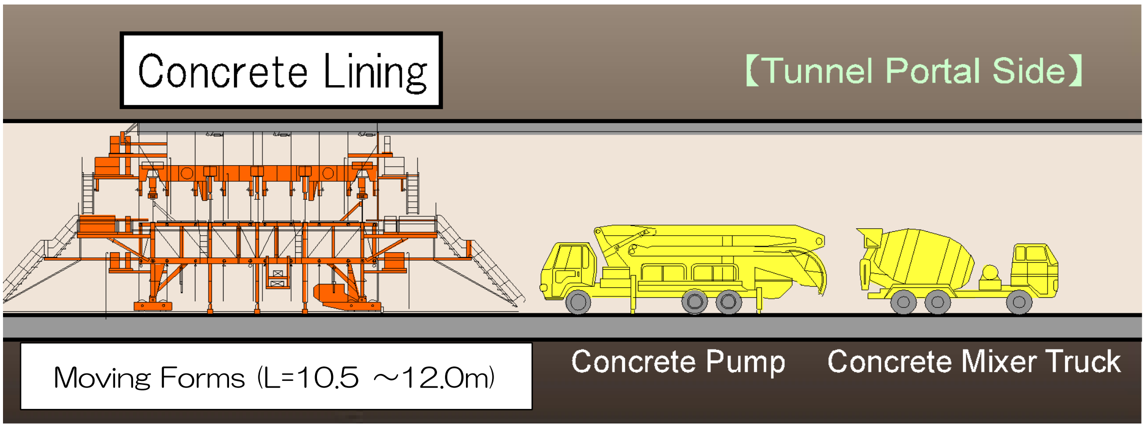


Figure 3-32 Concept Diagram of Concrete Lining

(Source: JICA project)

Forms should not be released until the concrete is strong enough that it can be worthy of holding its own weight. The time when a form may be removed varies depending on the type of concrete, the size of the tunnel, the shape of the tunnel, the lining width and the construction season. Basically the forms are removed 12 to 20 hours after the placement of concrete. For a round arch tunnel, the strength of the concrete at the time of form removal is often controlled with the reference value of concrete compressive strength of about 2 to 3 N/mm^2.

3.5.6 Construction of Portals

During the construction of portals, the post-excavation slope gradient should preferably be minimized to prevent ground failure while excavating in order to stabilize the portal slope and to facilitate construction. To that end, the slope should be reinforced by applying shotcrete on the slope or installing rock bolts to proactively stabilize the ground at the portal.

The typical methods of portals construction are shown in Figure 3-33.

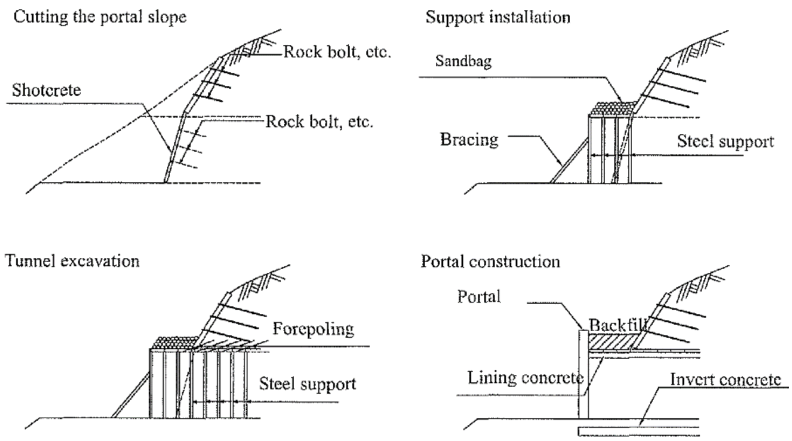


Figure 3-33 Typical Sequence of Portal Construction

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-172)

4 Auxiliary Methods

4.1 Concept of Auxiliary Methods

In the tunnel construction period, an additional construction method is necessary in cases that it is impossible to keep excavation stability, to excavate safely, to minimize the influence on surrounding environment, and to satisfy management standard value. This method is called an auxiliary method. The auxiliary construction method can be roughly divided into a construction method that can be constructed with basic machine equipment and a construction method using a special machine. Mountain tunnels are premised on a stable face. Therefore, the most dangerous area is the face immediately after drilling and the unsupported section of drilling progress. From this, the auxiliary method is carried out to maintain the stability of the face and unsupported section. When considering the auxiliary method, it is necessary to pay attention to the following points.

- Topography and geological conditions should be thoroughly considered.
- Distribution of groundwater should be understood.
- The plastic region occurring ahead of the face can’t be controlled by the support after excavation
- The expansion of the plastic region generated ahead of the face affects looseness (speed, area) after excavation.

Figure 4-1 shows the flow of surveys, design and tunnel construction, which summarized from the viewpoint of the auxiliary method.

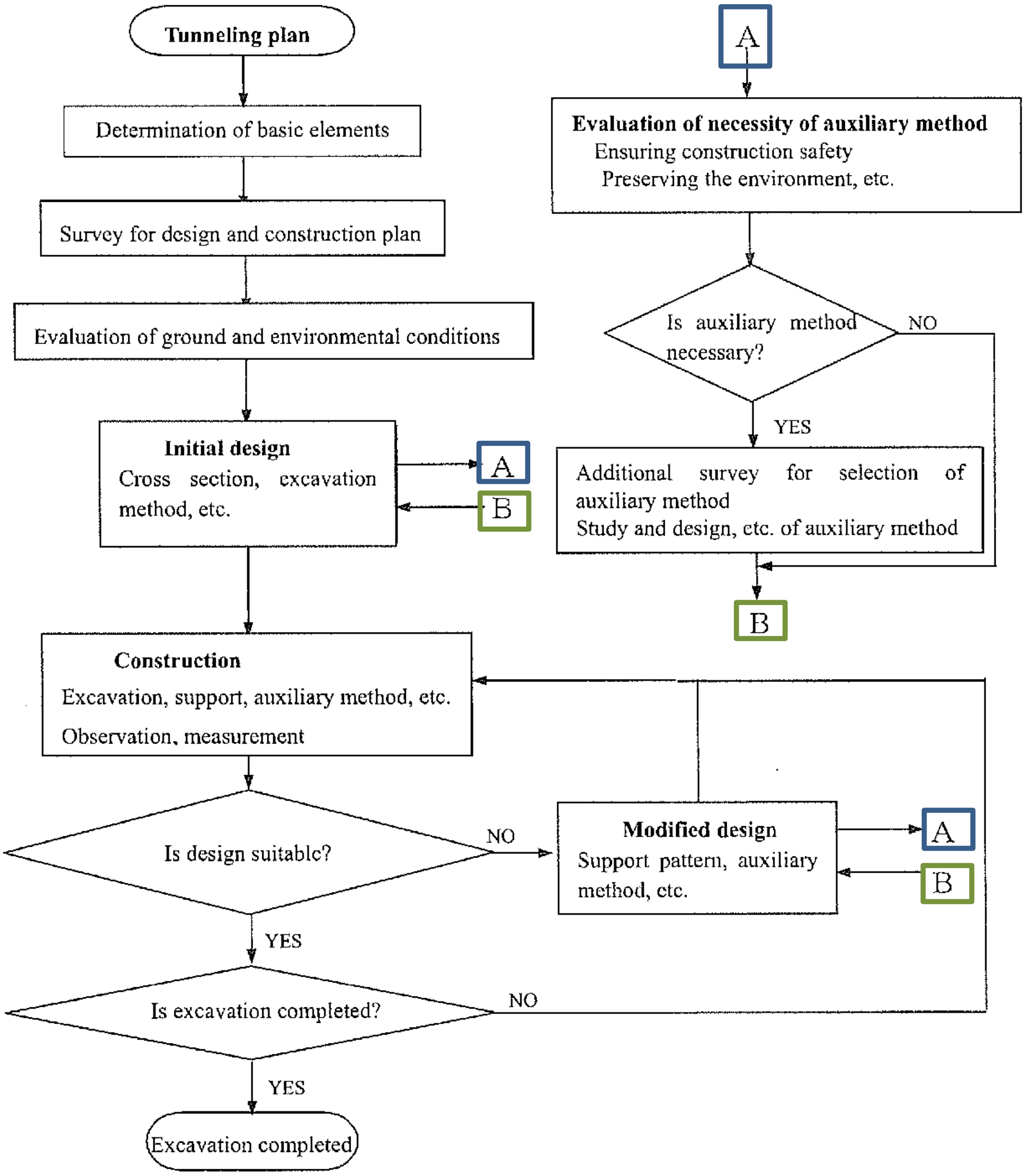


Figure 4-1　Flow of Surveys, Design and Tunnel Construction Focusing on the Auxiliary Method

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-175)

4.2　Application of Auxiliary Methods

Auxiliary methods are classified into categories according to their objectives: face stabilization, groundwater control, reduction of face settlement and reduction of influence on neighboring structures. Auxiliary methods should be selected that are superior in terms of safety, effects and cost performance evaluating the condition ahead of face and face itself. Several kinds of auxiliary methods are used at the same time according to circumstances.

Efficient and cost effective auxiliary methods should be selected by thoroughly evaluating not only tunnel construction methods and ground conditions, but also environmental conditions. Table 4-1 lists typical methods among various auxiliary methods currently used in Japan.

Table 4-1 Classification of Auxiliary Methods

Method			Purpose							Ground to which method can be applied			Re-marks
			Construction safety					Environmental preservation					
			Face stabilization			Ground-water control		Ground surface settlement control	Neigh-boring structure protection	Hard rock	Soft rock	Soil	
			Crown stabilization	Face stabilization	Footing stabilization								
Presupport		Forepoling (filling, grouting)	○							○	○	○	
Presupport		Steel pipe forepiling (grouting)	○					○	○		○	○	*2
Presupport		Pipe roof	○					○	○		○	○	*1
Presupport		Horizontal jet grouting (injection and mixing)	○	○	○			○	○			○	*1
Presupport		Slit concrete method	○					○	○		○	○	*1
Face reinforcement		Face shotcrete		○						○	○	○	
Face reinforcement		Face bolt		○						○	○	○	
Face reinforcement		Long face bolt		○				○		○	○	○	
Footing reinforcement		Footing reinforcement bolt			○			○			○	○	
Footing reinforcement		Footing reinforcement pile			○			○			○	○	*2
Footing reinforcement		Temporary invert			○			○			○	○	
Water inflow control	Drainage	Drainage boring	○	○	○	○				○	○	○	*2
Water inflow control	Drainage	Well point	○	○	○	○						○	*1
Water inflow control	Drainage	Deep well	○	○	○	○						○	*1
Water inflow control	Drainage	Drainage drift	○	○	○	○				○	○	○	*1
Water inflow control	Water sealing	Grouting	○	○	○	○	○	○	○	○	○	○	*1
Water inflow control	Water sealing	Cut-off wall				○	○	○	○			○	*1
Ground reinforcement		Grouting	○	○				○	○			○	*1
Ground reinforcement		Vertical pre-reinforcement	○	○				○				○	*1

Note) ○: relatively common method,

*1: measures that are difficult to implement with conventional tunnel construction machinery and facilities control.

*2: Method that requires modification of tunnel construction machines and materials depending upon the specific technique selected.

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-177)

4.2.1 Stabilization Methods of Crown

A NATM tunnel is premised on the stability of the cutting face and the crown of the tunnel until supports have been set up.

If the ground is weak and the cutting face does not become self-supporting, an auxiliary method to hold the face will be needed.

Ground stabilization for the face can be classified into three categories according to the site at which they are applied.

- Stabilization of the crown
- Stabilization of the face
- Stabilization of the footing

It is important to plan countermeasures against possible instability in advance, to continually evaluate the face stability by observation and other methods, and to execute the plan before it becomes too late.

(1) Filling Type Forepoling

Filling type forepoling use the bolts, steel bars or pipes, which are a length of less than 5m. They are driven into the ground around the top heading arch, as shown in Figure 4-2. The aim of the method is to increase the shear strength of the ground at the crown and to prevent the loosing of ground ahead of the face. This method is generally used for preventing collapse or falling of the crown and is often implemented at an early stage of stabilization.

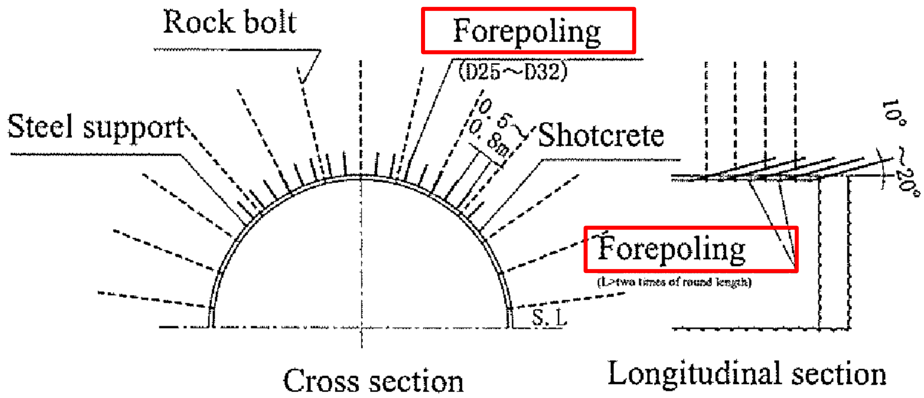


Figure 4-2 Example of filling type forpoling

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-179)

(2) Grouting Type Forepoling

Grouting type forepoling uses the hollow bolts, or pipes, which are length of less than 5m. They are driven diagonally into the ground ahead of the face, with simultaneous injection (under pressure) of quick-setting cement paste or a chemical grout, in order to enhance the stability of the crown ahead of the face, as shown in Figure 4-3.

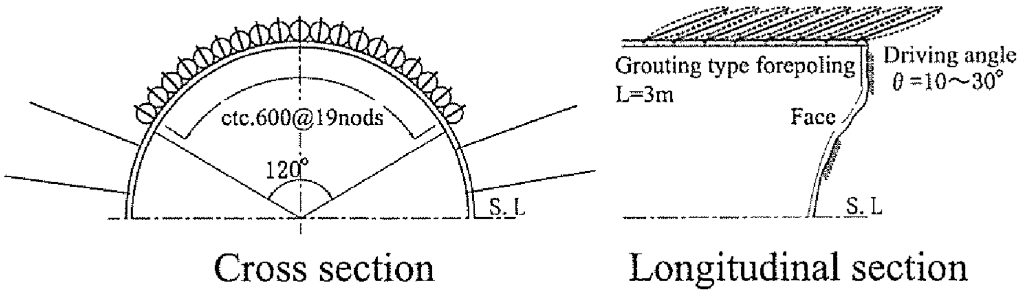


Figure 4-3 Example of Grouting Type Forepoling

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-180)

(3) Pipe Forepiling

Pipe forepiling is an auxiliary method for reinforcing unstable ground, such as talus, fault fracture zone or unconsolidated ground, where the ground arch is not expected. An additional benefit of the method is a reduction in prior displacement. Usually steel pipe longer than 5m in length is used. This method is mainly used for stabilization of the crown. However, it may require a change in the excavation cross section or kind of machinery used in the application. Therefore it is necessary to check the time schedule before adopting this method. Pipes are inserted into the ground along the upper perimeter of the planned excavation cross the section prior to tunnel excavation, but the exact arrangement of pipes varies depending on the ground conditions and the position of nearby structures.

There are two methods; one with specialized machines and the other with a drill jumbo. The method using a drill jumbo is usual. Filling type forepiling, which can also be used for improving ground stabilization, achieves a tight contact between steel pipes and ground by filling the space between the steel pipes and the ground with a grout, such as cement paste.

Another example is the grouting type forepiling method that forms composite reinforcements consisting of steel pipes and grout material, where the ground is reinforced by injecting cement paste or chemical grout into the ground around the steel pipes.

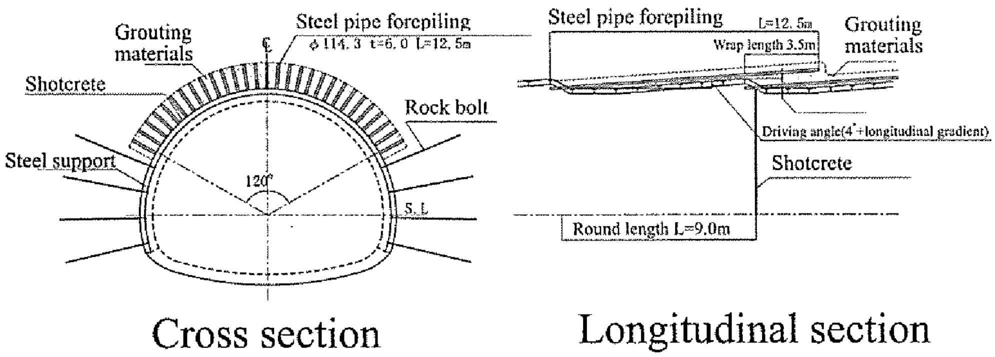


Figure 4-4 Example of Pipe Forepiling

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-180)

4.2.2 Stabilization Methods of the Face

There are ground stabilization methods for the cutting face such as ring cutting, shotcreting, face bolting and grouting. Face stability is affected by both the scale and shape of the cutting face. In order to improve the face stability, it is important to spray concrete as early as possible by excavating the face part by part.

(1) Face Shotcrete

Face shotcrete is sprayed onto the face at the thickness of 3 to 10cm as soon as it is excavated in order to increase the stand-up time of the face as shown in Figure 4-5.

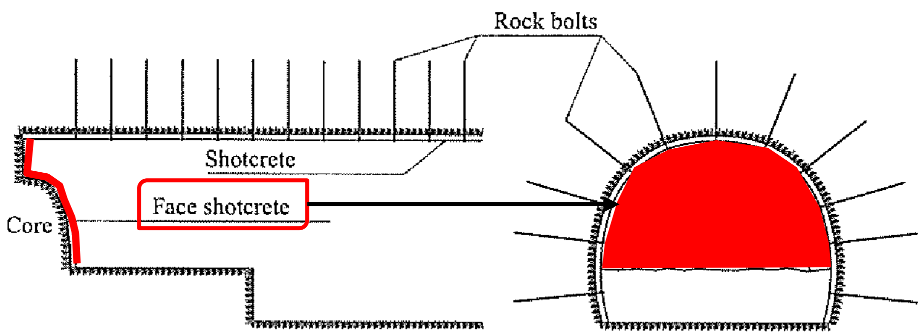


Figure 4-5 Example of face shotcrete

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-181)

(2) Face Bolt and Long Face Bolt

There are two types of face bolts. One is slightly shorter than 5m length; the other is longer than 5m. The purpose of the face bolt is to stabilize the cutting face and reduce the ground surface settlement by supporting a part or the whole of the face with rock bolts. Face bolting is more effective when used in conjunction with face shotcrete. The length of the face bolts should ideally maintain an effective residual length when they are cut by tunnel excavation. Grouting face bolts may be used for an increased reinforcement. Glass fiber reinforced plastic bolts are often used because they are easy to cut.

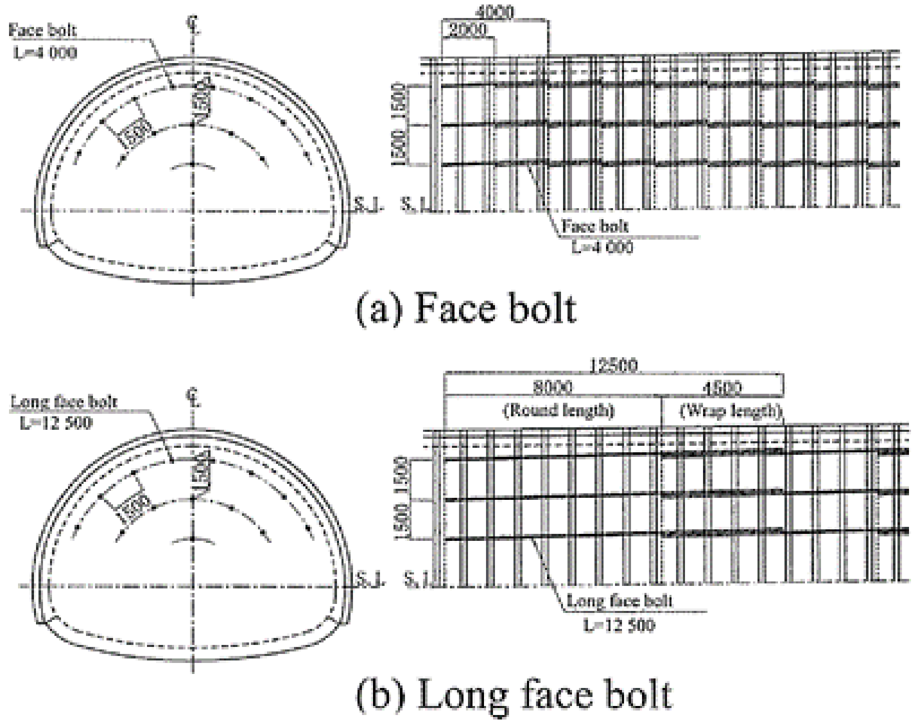


Figure 4-6 Example of Face Bolts

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-181)

(3) Grouting

Grouting is a method for stabilization of the face in which cement materials (such as cement paste) or chemical materials (such as water-glass grout) are injected into the ground for soil improvement. One purpose of grouting is to reduce water inflow into the tunnel lowering the permeability of the soil. Another purpose is to stabilize highly fractured ground that is likely to collapse.

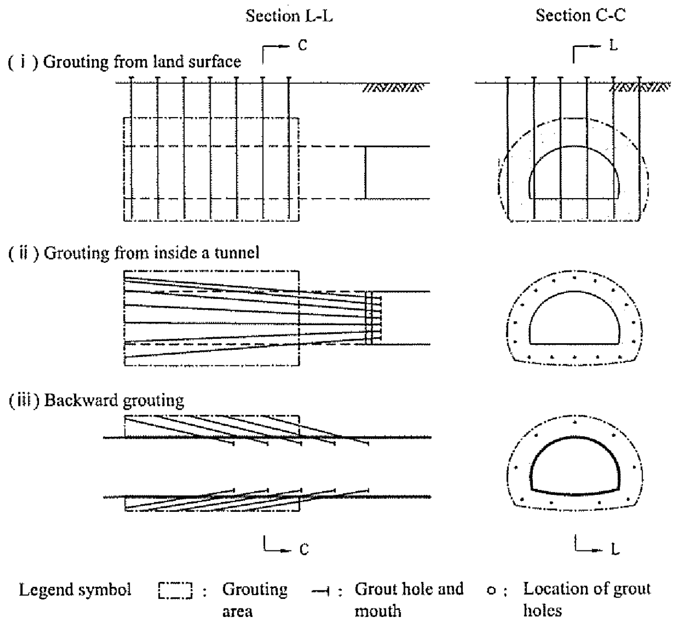


Figure 4-7 Example of Grouting

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-182)

4.2.3 Stabilization Methods of the Footing

Stabilization methods for the footing help protect against damage by foot settlement caused by lack of the bearing capacity of the ground. Methods include shotcreting (for top heading temporary inverted arch), downward bolting (in which rock bolts or steel pipes are used at the footing supports) or jet grouting. These methods increase the bearing capacity of the ground.

(1) Top Heading Temporary Inverted Arch

Generally, a top heading temporary inverted arch temporarily closes the top heading bed by shotcreting. This is a very efficient method. This method has the advantage of being able to base construction on face conditions and results of monitoring. However, since the temporary top heading invert must be removed, the efficiency of bench excavation will be reduced.

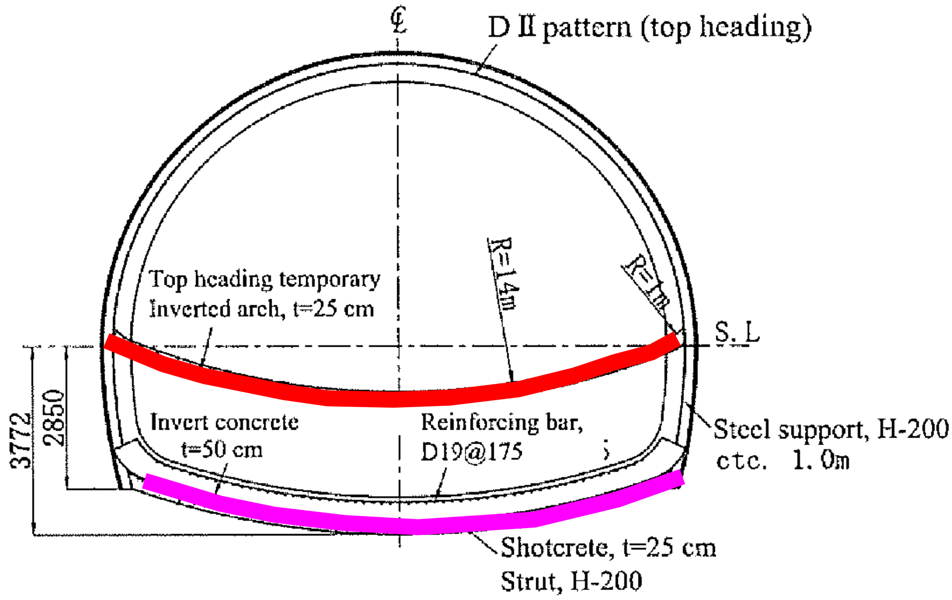


Figure 4-8　Example of Temporary Inverts at Top Heading and Bench

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-182)

(2) Foot Reinforcement Bolt and Pipe

Foot reinforcement bolt and pipe (installation of downward-facing rock bolts at the footing of supports or small-diameter steel pipes, and jet grouting) have the purpose of reducing the stresses in the contact ground of the heading support and preventing the collapse of the ground during bench excavation. If the strength of the ground around the footing is lower, the injecting bolts with cement paste grouting or chemical grouting can increase the strength of the ground.

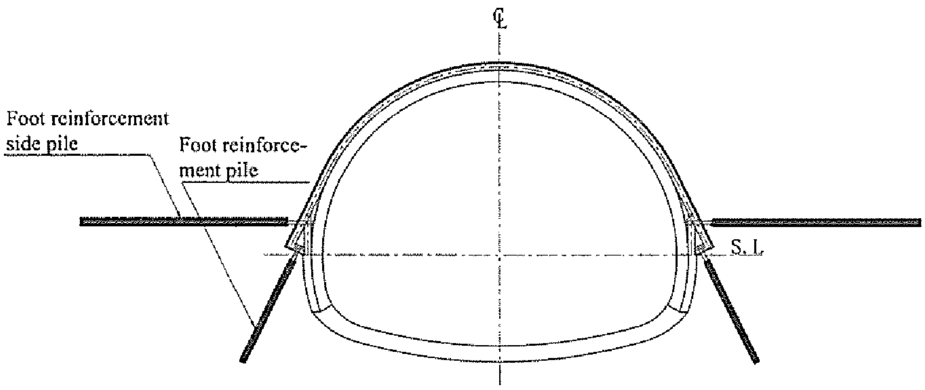


Figure 4-9　Example of Reinforcement Foot Pile and Side Pile

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-183)

4.2.4 Auxiliary Methods of Controlling Water Inflow

If the amount of water inflow is large during tunnel excavation, it will be a big problem. There is possibilities to occur lack of face stability, collapse of the face, insufficient adherence of shotcrete and rock bolts, and decreased tunneling work efficiency.

Countermeasures to control water inflow can be classified into two categories:

- Drainage methods
- Water sealing methods

(1) Drainage Methods

Drainage methods are more widely used than water sealing methods. However, prevention on the groundwater level lowering may be inadequate in some cases (due to ground surface conditions in the surrounding environments, and/or the abundance of groundwater). Therefore, drainage methods should be selected by considering the above subjects.

1) Drainage Boring

Drainage boring is a widely used method. This method removes groundwater through the boreholes drilled by a boring machine or drill jumbo in order to lower water pressure and the groundwater level. However, drainage boring on the unconsolidated ground needs to pay attention for the outflow of the sediment.

2) Drainage Adit

Drainage adit, approach of providing a pilot adit of small diameter, is often used in conjunction with drainage boring for sites with a large amount of groundwater. A lot of adit may be required at an aquifer with high water pressure.

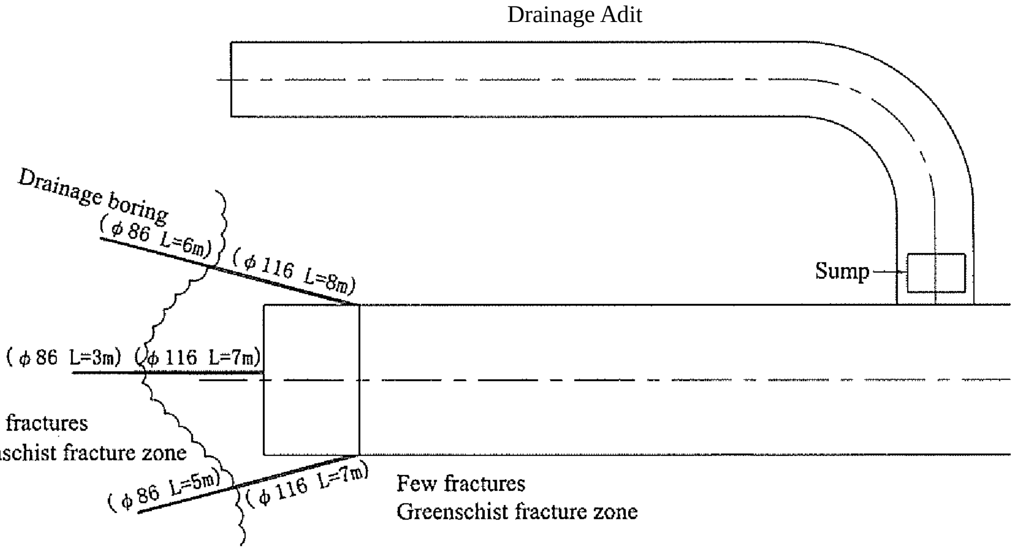


Figure 4-10 Example of Combined Use of Drainage Adit and Drainage Boring

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-184)

3) Well Point Drainage

Well point drainage is a method used for removing groundwater under negative pressure, in which groundwater collecting pipes called “well points “ are inserted into the ground. The well point is a water pipe with a diameter of 2 to 2.5 inches and a length of 0.7 to 1 m and a water collecting device called a well point attached to the tip of a special pipe (about 1.5 inch diameter, about 7 m in length) by a water jet. It is a construction method which lowers the groundwater level by driving into the ground, vacuuming suction and draining it.

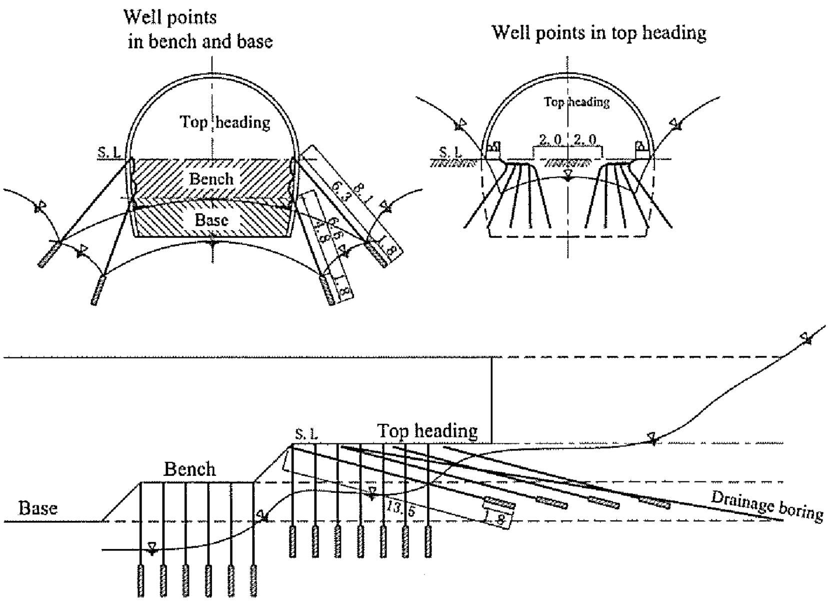


Figure 4-11 Example of the Well Ponit Method

(Source: Standard Specifications For Tunneling-2006: Mountain Tunnels, 2007, Japan Society of Civil Engineers, P-184)

5 Outline of Tunnel Equipment Design

5.1 Outline

Fixtures including ventilation, lighting and emergency devices are installed in road tunnels for safety in traffic by considering tunnel length, traffic volume and other conditions. Ventilation equipment is one of the most basic devices for securing the safety of tunnel users and smooth traffic.

5.2 Ventilation Equipment

5.2.1 General Ventilation Plan

Ventilation is required for preventing air pollution inside a tunnel due to the exhaust gas from automobiles running inside the tunnel. If the tunnel length is short, natural ventilation suffices in some cases, but if the tunnel length is long and traffic volume is large, ventilation equipment is necessary.

5.2.2 Discussion on the Necessity of Ventilation Equipment

Necessity of ventilation equipment for two way tunnels can be judged according to the following empirical equation in Japan:

$$L \cdot N = 600$$

Where, L: tunnel length [km]

N: traffic volume per hour [vehicles/h]

$L \cdot N < 600$ Ventilation is unnecessary

$L \cdot N > 600$ Ventilation is necessary

This equation is based on Japanese emission regulations. However, there is no emission regulation in Sri Lanka. Therefore, it is recommended to revise the equation considering Sri Lankan situation. Furthermore, detailed examination is necessary in the detail design stage because this formula is an outline examination method.

Figure 5-1 Attached Jet Fans (freely suspended type)

(Source: JICA project)

5.3 Lighting Equipment

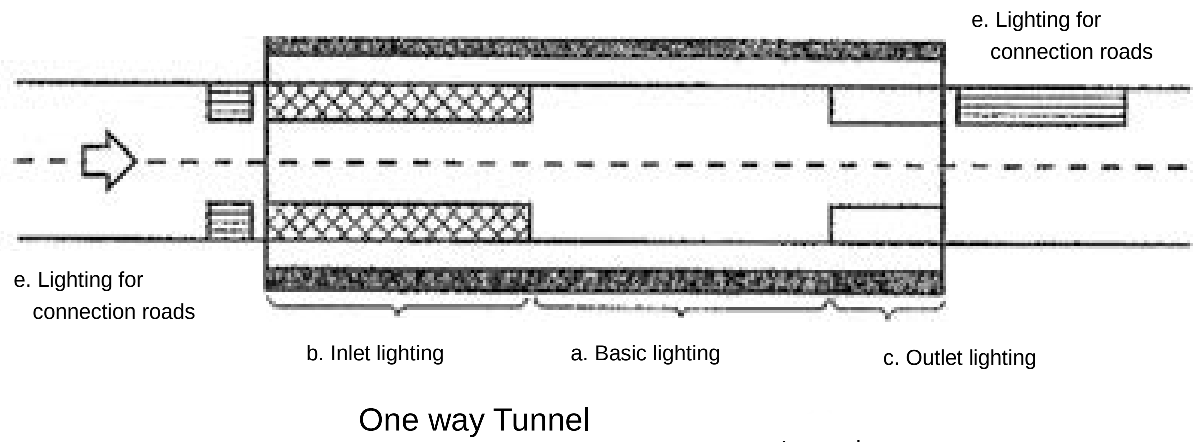
5.3.1 Purpose of Road Lighting

Road lighting is aimed at securing good visibility to see road and traffic conditions accurately in places where brightness changes abruptly, such as tunnels, and achieving safe and smooth road traffic. In the case of tunnels, road lighting equipment is installed according to tunnel length traffic volume and other conditions.

5.3.2 Compositions of Tunnel Lighting

The compositions of tunnel lighting are as follows:

a. Basic lighting (tunnel body lighting)
b. Inlet lighting
c. Outlet lighting
d. Lighting for power outage
e. Lighting for connection roads



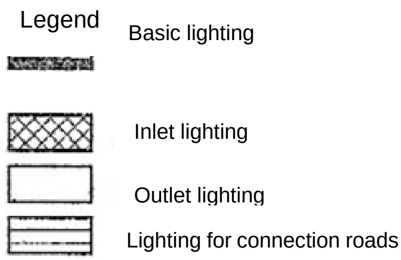
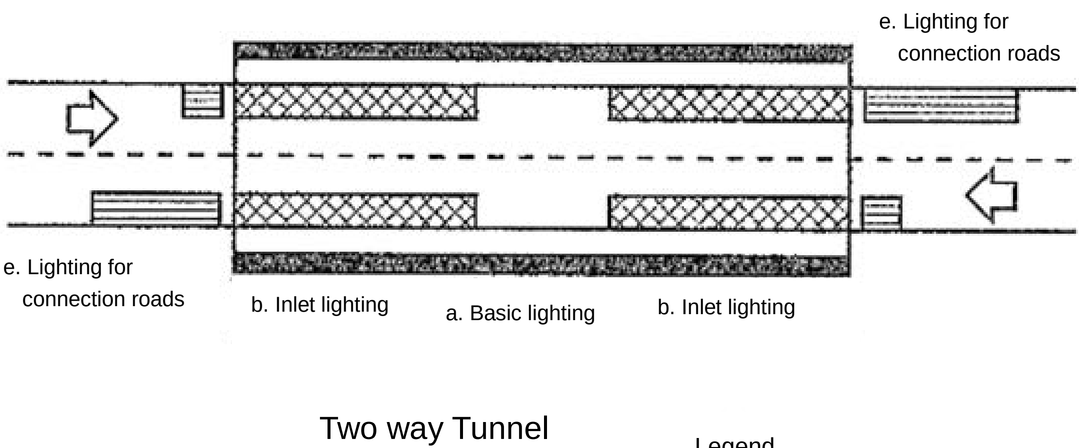


Figure 5-2 Example of Lighting System (one way tunnel)

(Source: JICA project)



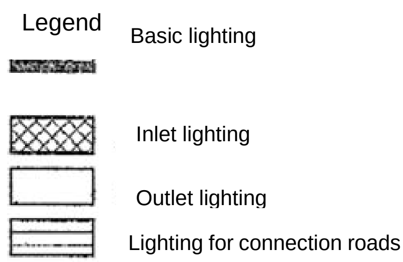


Figure 5-3 Example of Lighting System (two way tunnel)

(Source: JICA project)

5.3.3 LED Lighting

Light emitting diode (LED) lighting is expanding its use in various applications along with improvements in technology and cost reduction of lamps, which aims at the reduction of lighting cost and power consumption.

In Japan, LED road / tunnel lighting design guidelines were created in 2015, and all new tunnels are installed with LED lighting based on this guideline.

From economic efficiency and durability, it is desirable to design tunnel lighting based on LED lighting.

Figure 5-4 Example of LED

(Source: Manufacturer catalog)

5.4 Emergency Equipment

Since a tunnel is a closed space, it is necessary to sufficiently consider anti-disaster measures for fire, tunnel collapse and other disasters Anti-disaster measures for tunnels are composed of safety of tunnel users, the observance of legal regulations, and emergency equipment for minimizing the damage due to accidents. In Japan, the tunnel grade is defined by the traffic volume and tunnel length to determine the necessity of emergency equipment. The criteria and list of emergency equipment are shown in Figure 5-5 and Table 5-1.

Main purposes of the emergency equipment are emergency notification, fire extinguishing and evacuation guidance. However, the criteria shown in Figure 5-5 are for outline design based on Japanese experiences. Therefore, it is necessary to revise the criteria considering the traffic condition in Sri Lanka.

The other issue is operation and maintenance (O/M) of the emergency equipment. It is necessary to fix O/M system in RDA for emergency equipment because the emergency equipment requires O/M organizations (e.g. 24/7 call center and/or maintenance division) and budgets. Hence, the O/M organization structures and the budgets must be ensured to decide the detail specification and quantity of the emergency equipment.

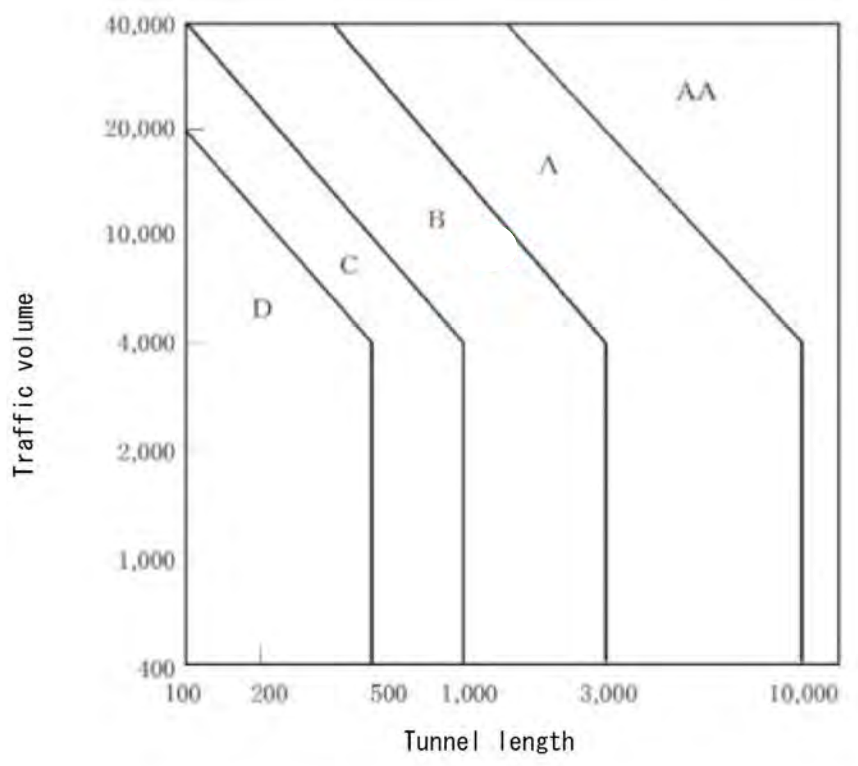


Figure 5-5 Tunnel Classification

(Source: Road Tunnel Emergency Facility Installation Criteria Commentary, 2001, Japan road association P-9)

Table 5-1 Emergency Equipment by Tunnel Clasification

Emergency equipment	Tunnel grade	AA	A	B	C	D
Notifying and alerting devices	Emergency telephones	○	○	○	○	
	Push button call units	○	○	○	○	
	Fire detectors	○	△			
	Emergency alarms	○	○	○	○	
Fire extinguishing equipment	Fire extinguishers	○	○	○		
	Hydrants	○	○			
Evacuation guidance equipment	Guidance display panels	○	○	○		
	Smoke vents or evacuation passages	○	△			
Other devices	Water plugs	○	△			
	Wireless communication supporting equipment	○	△			
	Radio repeating devices or public-address systems	○	△			
	Water spray apparatus	○	△			
	Monitors	○	△			

○ : Installation required

△ : Decide after consultation with other agencies

(Road Tunnel Emergency Facility Installation Criteria · Commentary, 2001, Japan road association P-14)

6 Outline of Alignment Standard in Japan

Road design is defined by a combination of horizontal alignment and vertical alignment, and is closely related to design speed. Regulation of horizontal alignment is composed of curvature radius, superelevation of curvature and transition curve. The definition of vertical alignment consists of longitudinal slope and longitudinal curve.

The alignment standards shown in following sections are based on Japanese traffic condition. Therefore, those standards should be revised considering actual traffic condition in Sri Lanka.

6.1 Horizontal Alignment

6.1.1 Curve of Road

Curve of road consists of a curve section and transition section. It is desirable to use a clothoid curve close to the actual transition curve

6.1.2 Radius of the Curvature

The radius of curvature of the center line shall be not less than the value of the Table 6-1. When it is unavoidable to set less radius of curvature due to the topographic situation and other limitations, it is possible to reduce the number in the right column.

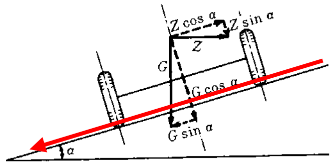
Table 6-1 Curve Radius

Design Speed	Curve radius(m)	
(km/h)	not lesst han the following figure	minimum
120	710	570
100	460	380
80	280	230
60	150	120
50	100	80
40	60	50
30	30	
20	15	

(Source: Japanese road structure order)

6.1.3 Superelevation (slope) of Curvature

The curvilinear portion is provided with a single gradient to alleviate the force that the automobile receives in the lateral direction. The superelevation is determined by the design speed and the curve radius.



Region	Region	Maximum of superelevation (%)
Snowly cold region	Extraordinary	6
	other	8
other		10

Design Speed	Curve radius(m)				
(km/h)	standard	Maximum of superelevation(%)			Level
		6%	8%	10%	
120	710	710	630	570	
100	460	460	410	380	
80	280	280	250	230	
60	150	150	140	120	220
50	100	100	90	80	150
40	60	60	55	50	100
30	30				55
20	15				25

Figure 6-1 Extra Region (left) and Curve Radius (right)

(Source: Japanese road structure order)

6.1.4 Desired Curve Radius

A value that guarantees the comfort of running of vehicle is shown in Table 6-2.

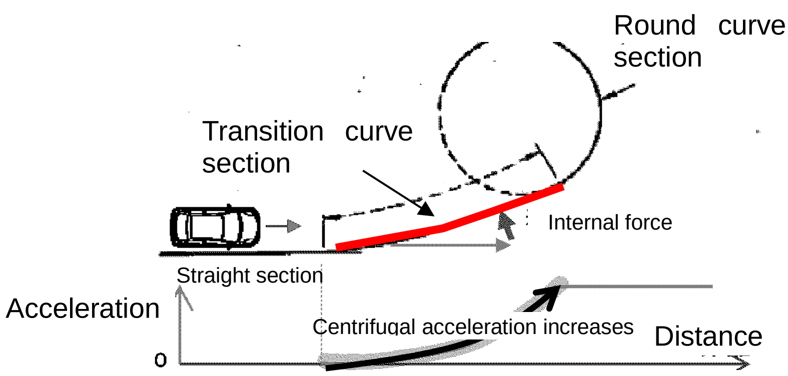
Table 6-2 Desired Curve Radius

Design Speed (km/h)	Curve radius(m)
120	1000
100	700
80	400
60	200
50	150
40	100
30	65
20	30

(Source: Japanese road structure order)

6.1.5 Transition Curve

It is required to consider a transition curve to prevent sudden steering wheel operation caused by sudden change of linearity and shock to occupants. The transition curve length shall be not less than the value listed in Figure 6-2 according to the design speed.



Design Speed (km/h)	Transition curve of length(m)
120	100
100	85
80	70
60	50
50	40
40	35
30	25
20	20

Figure 6-2 Transition Curve (left) and Transition Curve of Length (right)

(Source: Japanese road structure order)

6.2 Vertical Section Alignment

6.2.1 Longitudinal Slope

In order to avoid a decline in the traffic capacity of the road caused by a vehicle with a remarkable drop in speed and a decrease in traffic safety, a longitudinal slope is set according to the design speed. The longitudinal slope shall be less than or equal to the value listed in the Table 6-3 according to the design speed.

Table 6-3 Longitudinal Slope

Design Speed (km/h)	longitudinal slope(%)
120	2
100	3
80	4
60	5
50	6
40	7
30	8
20	9

(Source: Japanese road structure order)

6.2.2 Radius of Longitudinal Curves

A longitudinal curve is set at a position where the longitudinal slope changes. The radius of longitudinal curves shall be not less than the following value (Figure 6-3) according to the design speed.

Design Speed (km/h)	Radius of longitudinal Curves（m）		length of longitudinal Curves（m）
120	vertical curve at crest(凸)	11000	100
	vertical curve at sag(凹)	4000	
100	vertical curve at crest(凸)	6500	85
	vertical curve at sag(凹)	3000	
80	vertical curve at crest(凸)	3000	70
	vertical curve at sag(凹)	2000	
60	vertical curve at crest(凸)	1400	50
	vertical curve at sag(凹)	1000	
50	vertical curve at crest(凸)	800	40
	vertical curve at sag(凹)	700	
40	vertical curve at crest(凸)	450	35
	vertical curve at sag(凹)	450	
30	vertical curve at crest(凸)	250	25
	vertical curve at sag(凹)	250	
20	vertical curve at crest(凸)	100	20
	vertical curve at sag(凹)	100	

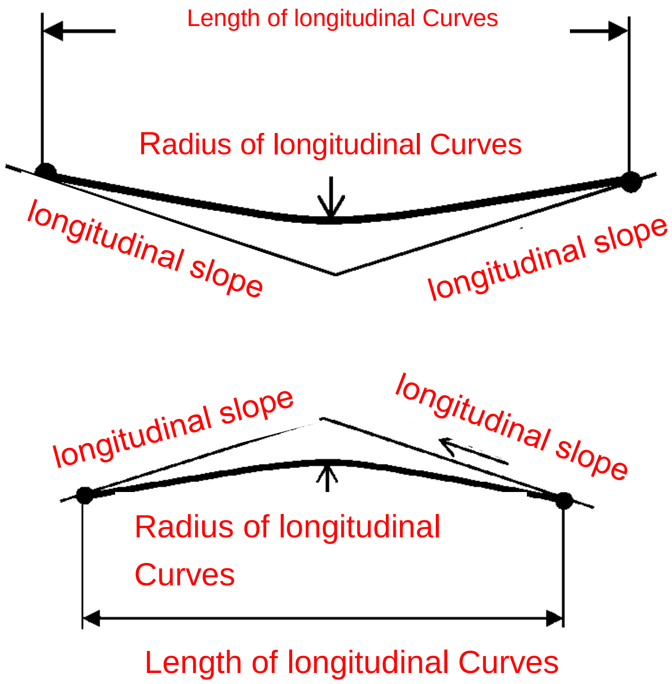


Figure 6-3 Radius of Longitudinal Curves
(Source: Japanese road structure order)

6.3 Visual Range

The visual range is the distance from the observation point with height of 1.2 m on the center of the lane to an object, which can be seen, with height of 10 cm on the center of the same lane.

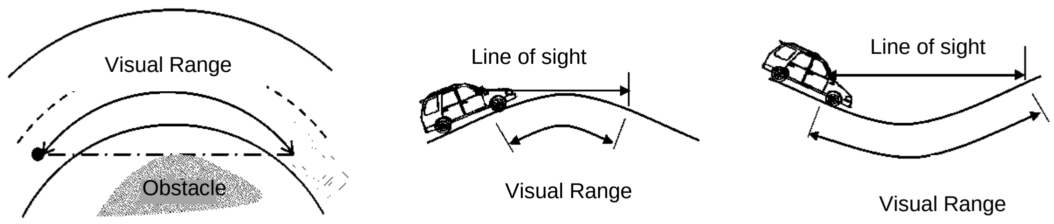


Figure 6-4 Visual Range

(Source: Japanese road structure order)

- Braking stopping distance

Speed and braking distance are expressed by the following equation.

$$D = \frac{V}{3.6}T + \frac{V^2}{2gf(3.6)^2}$$

where,

D: Braking stopping distance

V: Speed (km/h)

F: Friction coefficient of road surface and tire against longitudinal slip

T: Judgement time and reaction time

According to American Association of State Highway and Transportation Officials (AASHTO), the judgment time and the reaction time is estimated as 1 second and 1.5 second, respectively. Thus, 2.5 s for T and 9.8 for g are substituted to the above equation. Then, the following equation is obtained.

$$D = 0.694V + \frac{0.00394V^2}{f}$$

Considering the wet road surface, the braking stopping distance (which is corresponding to the visual range) is calculated as the traveling speed from 85% to 90% of the design speed.

Table 6-4 Braking Stopping Distance

(Source: Japanese road structure order)

Design speed (km/h)	Traveling speed (km/h)	f	$0.694V$	$0.00394\frac{V^2}{f}$	D (m)	Criteria (m)
120	102	0.29	70.7	141.3	212.0	210
100	85	0.30	58.9	94.8	153.7	160
80	68	0.31	47.1	58.7	105.8	110
60	54	0.33	37.4	34.8	72.2	75
50	45	0.35	31.2	22.8	54.0	55
40	36	0.38	24.9	13.4	38.3	40
30	30	0.44	20.8	8.1	28.9	30
20	20	0.44	13.9	3.6	17.5	20

Braking stopping distance