

Road Tunnel Technology in Japan

October, 1991

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Synopsis:

This report consists of the four chapters showing the present road tunnel technology in Japan. The contents are mainly based on the technological standards applied to Japanese road tunnels, which are almost all cases mountain tunnels. Chapters 1-3 mainly discuss investigation method, designing and execution method of work of tunnel structures. Chapter 4 discusses facilities attached to road tunnels.

Key Words: Tunnel, Design, ventilation, lighting, emergency

Preface

This report consists of the four chapters showing the present road tunnel technology in Japan. The contents are mainly based on the authorized technological standards applied to Japanese road tunnels, which mainly belong to mountain tunnels. Chapters 1-3 mainly discuss investigation method, designing and execution method of work of tunnel structures. Chapter 4 discusses facilities attached to road tunnels.

We hope that this paper will be helpful in understanding the present road tunnel technology in Japan.

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1 PLANNING AND INVESTIGATION OF ROAD TUNNELS

1.1 Preface

In Japan, 75% of the land consists of mountainous areas. A majority of the total population (75%) lives on the flat land accounting for merely 25% of the total land area. Therefore, for the sake of well-balanced industrial and cultural development throughout the country, it is essential to overcome the geological conditions in mountainous districts which constitute a barrier to the transportation of people, goods and information. Furthermore, in city areas with a high population density, it is important to consider highly efficient land use, including the use of underground space in order to use limited land effectively.

Japanese road networks have been rapidly and steadily improved under a series of laws enacted in the 1950's, such as the "Law of provisional measure regarding financial resources for road improvement, etc." and have played an important role as the base for the economic and social development of Japan. In accordance with the construction of new roads and road improvements, due to topographical conditions unique to Japan, the number of tunnels and the length have been steadily increasing. Especially in the construction of expressways, such as the Tōmei and Meishin expressways, the number of areas where topographical problems must be solved has increased due to high alignment standard. The demand for tunnel construction has increased accordingly. At present, there are about 6,000 road tunnels whose total length reaches about 1,500 km.

In road network improvement, the emphasis has so far been placed rather on those roads which traverse Japan from end to end. However, under the high standard main road network improvement shown in "The 10th five year planning for road improvement" which commenced in 1988, the

emphasis has also been placed on roads which cross the land. Considering such roads pass through mountainous areas, it is very likely that the ratio of total tunnel length to total road length will steadily rise in the future and also that the length of tunnels themselves will be increased even more. Therefore, for the sake of smooth execution of future road network, it is desirable to increase more rational planning, design and execution technology of road tunnels.

In road tunnels, in order to ensure the safety of drivers and to provide a pleasant environment, facilities such as ventilation, lighting and emergency devices are installed. In accordance with the increase of tunnel length, the scale of facilities and the construction costs and control and management costs are rapidly increasing. The facilities play a very important role to the extent that the success of a very long road tunnel depends on the success of its facilities.

Tunnel construction methods consist of mountain tunnel methods, the shield tunnel method, cut-and-cover tunnel method, submerged tunnel method, etc. Since road tunnels in Japan are located mainly in mountainous districts, mountain tunnel methods have been most commonly employed. Now, methods where supports such as spray concrete and rock bolts are combined (known as NATM) have also become standard. In response to this, notification of revision regarding "Road tunnel technique standards" was issued by Director General of the City Bureau and Director General of the Road Bureau of the Ministry of Construction. For this reason, based on the revised standards, discussions refer to mountainous tunnel methods unless otherwise stated.

In the fourth Chapter, facilities attached to road tunnels will be discussed. However, since such facilities are irrelevant to tunnel construction methods by nature, the concept can be applied, not only to moun-

tainous tunnels, but to road tunnels in general.

1.2 Road tunnel planning

1.2.1 Basic concepts for the planning

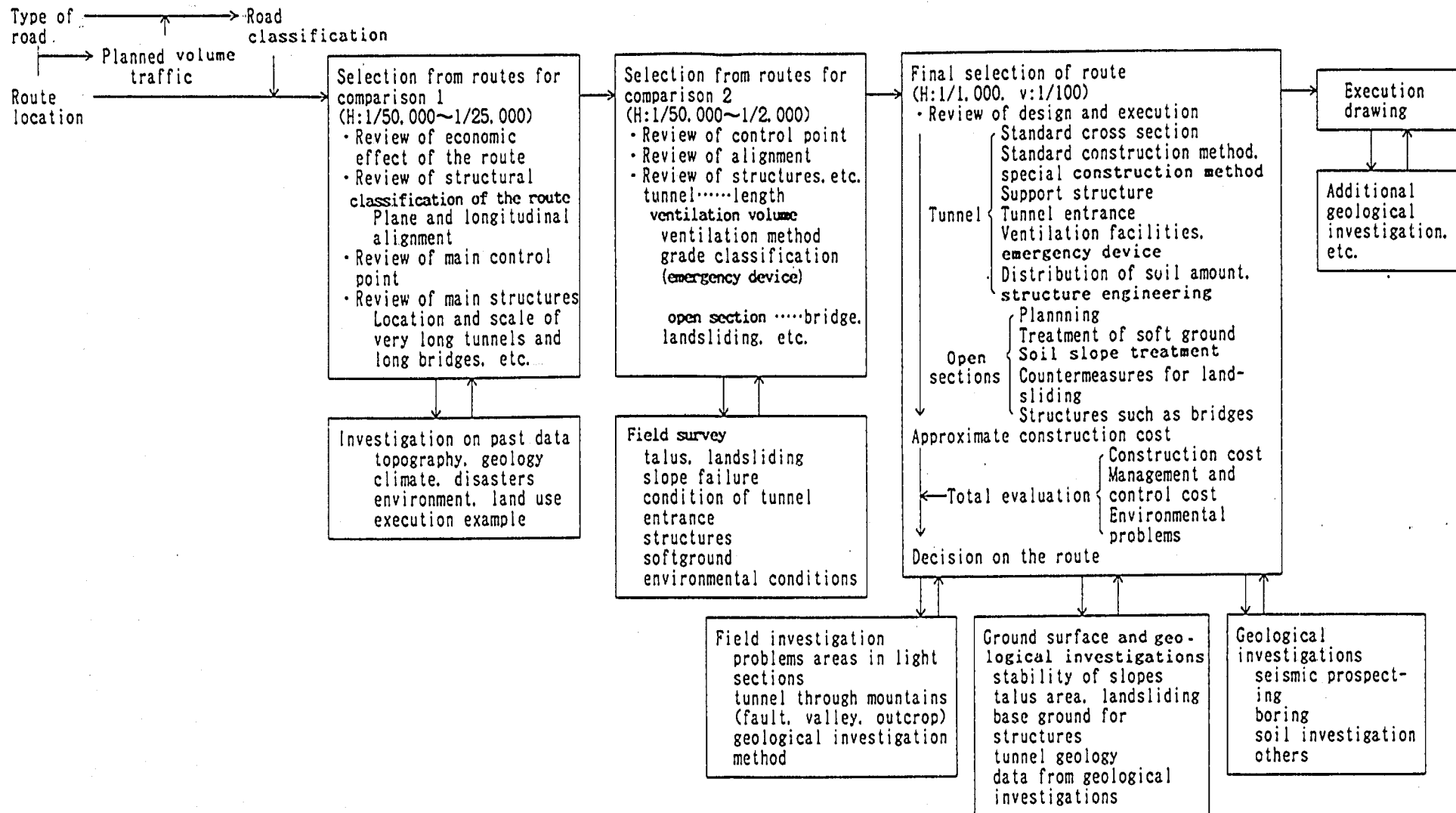
Since a road tunnel constitutes a part of a route, when planning a road tunnel, a comprehensive review must be made with sufficient consideration of the characteristics and roles of the route, bedrock conditions such as topography and geological features around tunnels (including the tunnel itself) and location conditions.

Difficult cases arise at the stages of tunnel design, execution, management and control, where there is a lack of consideration on tunnel techniques as a result of paying too much attention to the alignment of a route. However, at the same time too much emphasis on the design and planning of a tunnel itself will also cause problems in the alignment and structure of the road connected to the tunnel. Therefore, it is important to proceed with the planning on the basis that a tunnel is part of a route.

As shown in Fig.-1.1, the flow of investigation and design of a tunnel indicates that the investigation and design become more minute as the work proceeds, thus the planning must likewise become more concrete. However, due to the fact that tunnels are usually constructed in the deep underground of mountainous districts, there is a limitation on the pursuit of precise investigations at the early stage. Therefore, it is important to continually confirm the rationality of the plan based on new investigation results and if necessary, to go back to the preceding stage and modify planning there.

Since road tunnel construction cost, consisting of tunnel construction cost and operation cost for facilities, total cost of tunnels usually becomes higher in comparison with that of the open road. So, it is impor-

Fig.-1.1 Flow of Investigation and Design of Road Tunnel¹⁾



tant that overall review is carried out to determine whether the whole plan is a rational combination of a tunnel and the facilities. It is necessary to install facilities such as ventilation, lighting and emergency devices to secure traffic safety in a road tunnel. This increases not only the construction cost but also the management cost especially in the long tunnels. In some cases the cost of facilities reaches half of the total construction cost. As ventilation ducts and ventilation outlets, and emergency communication bays, can affect the cross section size or alignment of a tunnel, a comprehensive plan including facilities must be carried out at the planning stage not paying too much attention to tunnel structures alone; the relationship between the two must be grasped. Especially in the case of very long tunnels, careful review, including that of management and control systems is necessary.

1.2.2 Selection of tunnel location

1) Review of routes for comparison

In order to make the final selection of the planned route and tunnel, some alternative routes are usually compared and the best one chosen after technical and economic reviews based on the investigation results. As shown in Fig.1.1, investigation standards differ depending on the level of the investigation. The investigation usually begins with a topographical map drawn on a scale of $1/50,000 \sim 1/25,000$, then proceeds step by step to the maps drawn on a scale of $1/5,000$ and $1/1,000$ in accordance with the narrowing down of the number of candidate routes; and finally the most appropriate route is selected.

The followings are the main control points to which special attention must be paid at the time of route selection.

- ① actual conditions and future plans for land use
- ② connection to the neighboring roads
- ③ existing structures (railways, dams, housing, industrial parks, etc.)
- ④ method of cutting through mountainous areas, rivers, etc.
- ⑤ natural conditions of geology, etc. (landslides, soft ground, faults, climatic conditions, etc.)
- ⑥ natural environment or cultural assets, etc.

Existing geological maps, aerial photographs, etc., are generally used as investigation materials for the preliminary stage. However, in the case of important places, problems are identified and evaluated by a field survey.

Reviews of candidate routes are done on the following items: approximate design and execution planning of the structure and attached facilities of the tunnel, earthworks in open sections, the structures of bridges, etc. Following this, approximate construction cost and maintenance cost are calculated; overall evaluation is made from economic, safety and environmental aspects to make a final decision on the route.

2) Selection of location of tunnel entrance

Careful consideration must be paid to the location of tunnel entrance from the early planning stage. Since there are often weak geological conditions at a tunnel entrance, the location of the tunnel entrance may cause difficulties in the execution of work and, as a result, can increase the construction cost. Therefore, from the planning stage, consideration, including judgment from the aspect of tunneling technology, is essential. Also, since the entrance of a tunnel defines the boundary between a tunnel and a open section, sufficient consideration must be paid on the traffic safety.

Items which must be considered when selecting tunnel entrance location are as follows:

① In the tunnel entrance, it is desirable that the tunnel axial line intersects with a slope with an angle of 90° wherever possible. If it becomes parallel to a slope, it will result either in small overburden depth on the valley side or in continuation of short tunnels. Undesirable elements in the bedrock combined with asymmetrical pressure cause difficulties in construction work and cost increase.

② It is desirable to avoid placing a tunnel entrance deep in the valley. In the valley there are thick uncemented deposits of talus, etc., and much ground water. So there tend to happen construction problems concerning the stability of a tunnel face or a slope. Even after the completion of a tunnel, the area is exposed to natural calamities such as floods from the valley or landslides or, in the case of a cold snowy area, snowslides.

③ Landslide areas must be avoided. If tunnel construction is planned in such an area, problems of tunnel deformation can arise in the construction work or after the tunnel is operated to the public. At the slope of Nagareban, care must be taken since stability of a tunnel entrance can be endangered by the cutting of the entrance.

④ It is desirable to avoid installing an intersection near the entrance or exit of a tunnel. With heavy traffic they can cause problems in traffic safety. Congestion may also cause problems in tunnel ventilation.

3) Alignment of a tunnel

To ensure greater safety, it is necessary that plane alignments of tunnels are made straight or curved with as large a radius as possible in comparison with those in open sections.

As for longitudinal grade, it is traditionally advised to secure a grade of 0.1 ~ 0.2% and over in consideration of waste water drainage at the time of construction work. So, in cases where construction work is executed from both tunnel entrances, the up-grade method has been commonly employed. However, the number of the cases are increasing where a tunnel is graded one-way and execution of work for the down-graded sections is carried out with compulsory draining using a pump because of the alignment of the road. In the case of tunnels where ventilation facilities are necessary, a gradient of less than 3% is desirable because steep slopes cause an increase in the amount of exhaust gas. However, it is necessary to make an overall decision considering all the factors including the alignment of the roads.

1.3 Investigation of road tunnels

1.3.1 Basic concept of investigation

Investigation is carried out for the purpose of obtaining basic data for planning, design, execution and maintenance and control for a safe and rational tunnel design, and is necessary in order to grasp both ground surface and under ground conditions at the tunnel location.

Tunnel investigation can be classified as follows according to the investigation objectives:

- ① Investigation on bedrock condition.....topography,
geology, hydrogeology
- ② Investigation on climatic conditions.....climate
- ③ Investigation on conditions of location.....environment,
execution condition, related laws

These investigations are conducted when necessary at each stage of planning, design and execution of a tunnel. Table - 1.1 explains the contents of the investigations divided into three stages: investigation for

Table-1.1 Stages for Tunnel Construction and Investigation Required¹⁾

Construction Work			Necessary investigations				
Stages	Time	Contents	Stages	Purposes	Contents	Areas	Points of observation
Idea and planning stage	From the review of routes for comparison to the decision of a tunnel location	Reviews and comparisons of the following items: alignment of the route, location of the tunnel, length, approximate structure, execution method, scheme of execution and construction cost	Investigation for route selection	To get data required to choose the route appropriate to the topography, geology and other environmental conditions to review approximate structure, execution method and scheme of execution. To get basic data to make an investigation plan for the following stage	Collection and review of past materials, drawing of maps of scale 1/50,000~1/2,000, approximate investigations of topography, geology, environment, etc.	Large extent, including routes for comparison	Topography, geology, environment, execution requirements and other obstacles which can cause major problems for tunnel construction [grasping of approximate conditions such as topography, geology, environment, etc., and locating problems]
Design stage	After the decision on a tunnel location to the commencement of construction	Decision on detailed structure, execution method, facility design, execution planning, environmental protection measures and construction cost	Investigation for design and a scheme of execution	To get basic materials necessary for composition of execution drawing and scheme of planning suitable for topography, geology and other environmental conditions and basic materials for integration, etc.	Drawing of maps of scale 1/1,000 ~1/500, detailed investigations of topography, geology, environment, etc., investigation on concrete countermeasures for tunnel periphery. Investigations for construction-related facilities	Places related to tunnel construction and their peripheries	Overall conditions such as topography, geology environment, etc., especially stability of slopes of tunnel entrance, rock mass conditions with weak stratification such as fracture zones and shallow depth, condition of ground water, condition of places for shaft
Execution stage	Execution of work	Execution of work and review of design a execution method of support structure, etc. and also of necessity for design change	Investigations during execution of work	To get materials for preevaluation and confirmation of problems during execution and also for execution control and compensation	Geological investigation, environmental investigation and measurement, etc. [Geological investigation is mainly done inside the tunnel. Environmental investigation around the tunnel periphery is done mainly on whether there is any influence from construction work and whether the countermeasures are effective.]	Inside the tunnel and areas which execution can affect	Stability of tunnel face, condition of spring water, geological condition, etc., differ from the conditions evaluated in the early stage of design, condition of convergence of tunnel and ground surface displacement, protection of environment during construction work

route selection, for designing of work and during execution of work, based on the time allowed for investigation and its purpose. Since the contents and precision of the necessary data vary depending on the construction stage, investigations must be carried out repeatedly. Investigation of the same item must be systematically carried out, where investigation range narrows and accuracy increases as the investigation stage level advances, so that the investigation as a whole becomes well-balanced.

Above all, bedrock condition investigation provides data for judgment directly related to the principal of the tunnel structure, such as determination of execution method, design of supporting structure. Therefore, it is important to collect correct information regarding it. Especially in the case of tunnel construction, bedrock materials are made use of, as they are, like structure members, therefore, various characteristics of bedrock including not only the cross section of a tunnel but also a large extent of the tunnel periphery must be studied during the design stage. However, since a tunnel is a linear structure deep in the ground, there are economic and technical limitations to grasping accurately for the whole tunnel, the natures of various bedrocks such as those in Japan. In addition, the facts that bedrock movement varies depending on the presence of water inflow into tunnel and on the way of execution, make the problem above more difficult. Therefore at the stage of design, it is desirable to emphasize the investigations of fracture zones and tunnel entrance sections which are very likely to seriously influence tunnel construction. As for other general sections, it is appropriate to make effective use of information gained by investigations, such as observations and measurements taken during execution.

1.3.2 Rock mass condition investigation

Investigation of topography and geology (bedrock condition investigation) must be systematically carried out by the collection of existing materials such as topographical maps and aerial photos, field investigations, physical probing, boring, etc. Accuracy must increase step by step. (Fig. -1.2)

① Preliminary investigation

This investigation is conducted to obtain basic data for the selection of routes appropriate to the topography, geology, etc. Investigation of existing data and field surveys are carried out.

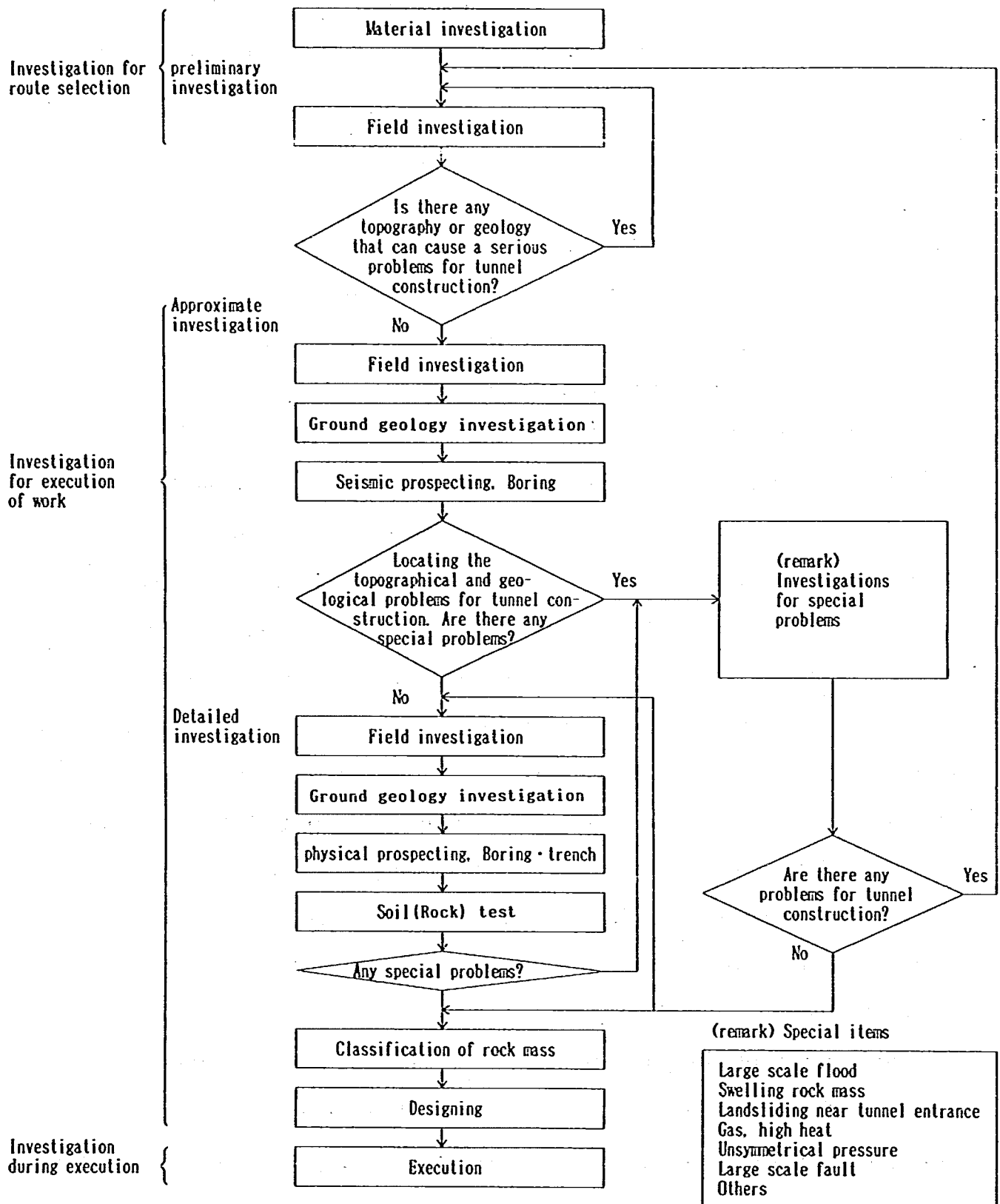
② Outline investigation

This investigation is conducted for selection of planned routes and determination of basic items for construction such as tunnel length, cross section, tunnel entrance, etc. Through clarification of detailed topographical conditions, unstable topography such as landsliding around a tunnel entrance, rock quality and geological structure, the investigation shows the topographical and geological problems of tunneling. Also through field surveys, ground geological surveys, seismic prospecting, boring, etc., the following are clarified: distribution, thickness and properties of landsliding, talus sedimentation, weathering zones, location and properties of fracture zone and alteration zone, condition of underground water, etc.

③ Detailed investigation

This investigation obtains data necessary for an execution drawing, a scheme of execution of work, such as bedrock classification, execution method, supporting structure, etc. When necessary, pilot borings, stratification inspections and soil (rock) tests are conducted in addition to the standard investigations such as field surveys, ground geological surveys,

Fig.-1.2 Flow of Investigation of Topography and Geology¹⁾



physical probing such as seismic prospecting and boring. This inspection clarifies rock strength, fissures, fracture zones, location and properties of swelling rock, ground water level, amount of water inflow, etc.

④ Investigation on special items

This investigation obtains data for special items such as large amounts of water inflow, swelling bedrock and gas which can cause problems for design and execution.

⑤ Investigation during execution

The purpose of this study is to confirm the appropriateness and compatibility of the initial design through observation of headings and various kinds of measurements such as convergence and ground displacement and to rationalize design and execution by altering the design where necessary.

It is necessary to select the investigation method appropriate for each investigation stage and purpose. Table - 1.2 shows general standards. The following are the characteristics of the main investigation methods and the points to be noted.

1) Field investigation

A field investigation is the base for all the investigations, and precedes other investigations and is to be repeated. In a field investigation, characteristic items observed must be recorded as much as possible in addition to the problems which seriously influence tunnel planning, design and execution, such as landsliding, degraded land, talus, fracture zones, weathering and alteration of rock and ground water so that they will be reflected in subsequent investigations and designs.

Table-1.2 Topographical and Geological Investigation Stages and the Investigation Methods thereof''

Stages of investigations \ Investigation method		Investigation on documents	Decipher aerial photographs	Field investigation	Ground geological investigation	Elastic wave probing	Electric probing	Boring	Borehole tests				Soil (Rock) laboratory test
									Standard penetration test	Physical stratification inspections	Loading test in borehole	Water inflow pressure test in borehole	
Preliminary investigations	Hard rock	◎	◎	◎									
	Soft rock, soil	◎	◎	◎									
Approximate investigations	Hard rock	○	○	◎	◎	◎		○					△
	Soft rock, soil	○	○	◎	◎	◎		○	○	△	○		○
Detailed investigations	Hard rock,			◎	◎	◎	△	◎		△		△	△
	Soft rock, soil			◎	◎	○	△	◎	◎	△	○	△	◎

(remark)

◎:investigations generally conducted ○:investigations frequently conducted △:investigations conducted when necessary

2) Ground geology investigation

This investigation enables the drawing of a geological plane map and geological longitudinal map. Types and properties of rocks and faults are investigated through an outcrop investigation. It is also important to try to grasp rock hardness, fissure frequency and conditions, degree of weathering and alteration, degree of fracture, ground water, etc.

3) Seismic prospecting

This method estimates bedrock hardness, fissure degree, weathering degree, location of fault fracture zones, fracture degree, etc. according to the difference in elastic wave velocity. Elastic wave velocity value is a main parameter for classification of bedrock which is a base for tunnel design and is the most commonly employed. However, since the method has some defects which cannot be avoided, it is important to analyze the data taking this into account.

4) Boring investigation and stratification inspection in a borehole

In a boring investigation, since the core is taken when a borehole is made, it is possible to obtain directly the bedrock materials located at the planned height of a tunnel, which provides much engineering information. Therefore, it is necessary to try to increase core recovery, and at the same time sufficient attention must be given to maintenance of the borehole wall for the sake of bore hole stratification inspection, conducted using a bore hole.

Generally, perpendicular boring is used. However, at an area near a tunnel entrance or in a short tunnel, horizontal boring is effective to grasp the condition of bedrock along the tunnel.

5) Soil (Rock) laboratory test

Various physical and mechanical properties are often used as evaluation indicators for soft rock tunnels, soil tunnels and swelling characteristics. Table - 1.3 shows testing methods for this purpose.

6) Investigation of water inflow and shortage of water

Water inflow accompanied by tunnel excavation remarkably degrades the properties of the bedrock and causes degradation of heading and decrease bearing power of soil which greatly affect design and execution of a tunnel. It also causes drying up of wells on the surface due to lack of water.

Though some investigation methods for movement of ground water are proposed, it is difficult to quantitatively obtain this in advance at present.

1.3.3 Other investigations

① Meteorological investigation

In order to plan the countermeasures for safety at the construction stage and for safety and environmental protection after a tunnel is opened to the public, it is necessary to conduct investigations on precipitation (rain, snow), temperature, water temperature, underground temperature, wind direction, wind velocity, fog, snowslides, etc.

② Environmental survey

In order to investigate the effect on the environment around a tunnel, the following investigations are carried out:

Natural environment.....ground water, water inflow,
marshy ground, ecosystem, etc.

Social environment.....land use condition, existing
structures, cultural assets,
etc.

Table-1.3 Main Items for Laboratory Tests of Soil and Rocks and Testing Methods thereof¹⁾

Test item	Physical property value gained through tests	Classification of rock mass				Standard for test			
		Hard-rock	Soft-rock	Earth & sand	Swelling rock mass	JIS	(remark 1) KDK	(remark 2) KODAN	Society of Civil Engineering
Unit volume weight test	Unit volume weight	△	○	○	○	A1202	S0501	A1202	
Natural water content	Water content		○	○	○	A1203	S0501	A1203	
Gradation analysis test	Gradation distribution			○	○	A1204		A1204	
Specific gravity test of soil particles	True specific gravity of soil particles			○	○	A1202		A1202	
Consistency test	Liquid limit, plastic limit, plasticity index			△ △	○ ○	A1205 A1206		A1205 A1206	
Uniaxial compression test	Uniaxial compression strength, modulus of static elasticity, static Poisson's ratio	△	○	○	○	A1216	S0502 S0503		
Triaxial compression test	Cohesion, internal friction angle		○	○	○		Method of triaxial compression test on a rock S0913		Triaxial compression test for softrock
Uniaxial tensile breaking test	Tensile strength	△	△		△		Tensile test method		
Measurement of modulus of dynamic elasticity	P wave velocity, S wave velocity, modulus of dynamic elasticity, dynamic hardness ratio, dynamic Poisson's ratio	△	○		○	A1127	S0503		
Slaking test(flood collapse test)	Flood collapse		○		○			110 111	Simplified slaking test
Positive ion exchange capacity test	Estimation of content such as montmorillonite				△				Measurement of positive ion exchange capacity (CEC)
X ray analysis	Kinds of clay minerals		△	△	○				Method of estimating mineral kinds by X ray particle analysis

(remark 1) KDK : Standards of Tests. P.W.R.I. Ministry of Construction (Proposal)

(remark 2) KODAN : Engineering test method for Japan Highway Public Cooperation

(remark 3) ○ : item frequently tested △ : item tested case by case

Living environment.....shortage of water, noise,
vibration, ground subsidence,
air pollution, traffic safety,
etc.

③ Survey on conditions for execution

Surveys necessary for the planning of roads for construction use, facilities for construction and places for dumping excavated earth are conducted.

④ Investigation on related laws

Investigation on the laws regulating tunnel construction and whether construction causes invasion of judicial rights.

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- 2) Society of Civil Engineering, "Specification for tunnel standards (on mountains) and their commentaries" Nov. 1986

2 DESIGN OF ROAD TUNNELS

2.1 Preface

When designing a road tunnel, not only the structural standard, safety and economic efficiency must be ensured, but also the user's pleasantness must be taken into account at the same time. In the case of tunnel design in particular, the factors of such facilities as ventilation, lighting and emergency facilities needs to be taken into account as well as the structure of the tunnel. Furthermore, since once a tunnel is completed rebuilding is extremely difficult, sufficient consideration must be paid to durability.

Tunnel design can be divided roughly into two: determination of basic elements and structural design based on the basic elements. The basic elements include alignment, the inner section, etc., which are closely related to planning. Once the elements are determined, generally no change is made. However, supporting structures are greatly influenced by bedrock condition, execution method and their design must be changed correspondingly. Bedrock condition, in particular, is rarely uniform and varies in many ways, therefore various kinds of investigations, such as those on topography, geology, etc., need to be carried out. However, various investigations for the whole length of a tunnel are extremely difficult to carry out with today's technology and entail financial problems. Therefore, in general, the design is modified and altered when necessary during the execution of work.

From these reasons, as shown in Fig.-2.1, when designing a tunnel, an preliminary design is made as a standard design after classification of bedrock by technological judgment based on the result of preliminary investigations. This design is not necessarily appropriate for the

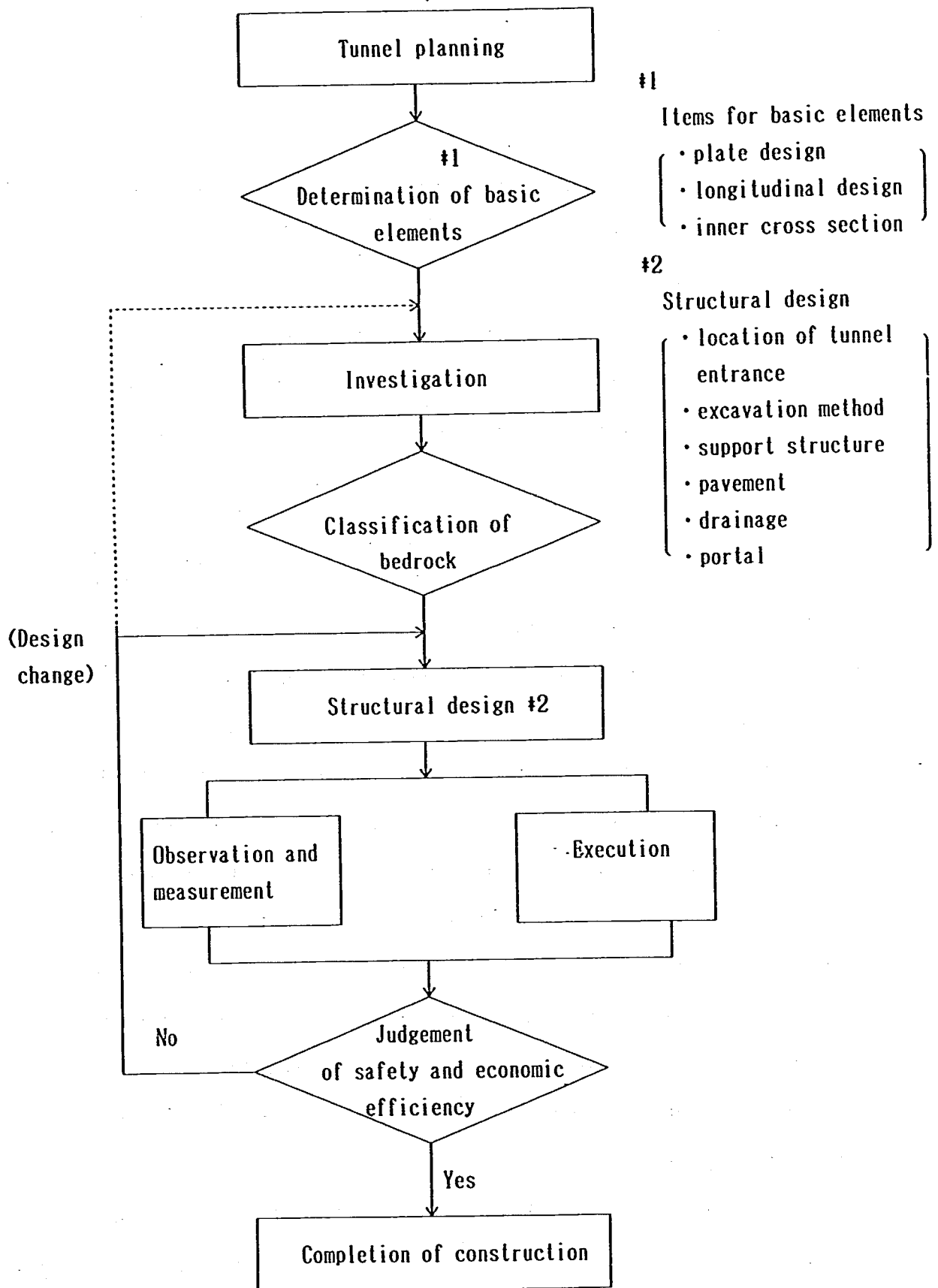


Fig.-2.1 Design of Tunnel Structures and Flow of Execution¹⁾

bedrock conditions. Thus the design is modified or altered when necessary to meet the actual bedrock condition discovered through the observation of heading and measurements during execution. Tunnel design is very different from that of other structures in that design modification and alteration are positively carried out. Here, basic design items and the concept of design will be discussed in relation to design techniques.

2.2 Determination of basic elements

2.2.1 Design of alignment

1) Plane alignment

Plane alignment must be designed using either straight lines or curved lines with large radii so that widening of the cross section to ensure visual distance, which could cause an increase in construction cost, can be avoided. Also, in order that a driver can drive in a tunnel safely, it is desirable to adopt alignment where confirmation of tunnel entrance can be made from a sufficient distance. The location of the tunnel entrance must be determined with sufficient investigation, taking topography, geology, into consideration. This is to prevent the problems unique to tunnel entrances such as slope failure, landsliding, etc.

2) Longitudinal alignment

When determining longitudinal alignment, water inflow treatment during execution, running performance after completion, ventilation, etc., must be considered. The minimum longitudinal grade during execution must generally be at least 0.3-0.5% for natural drainage, and it is desirable that a slope gradient be set at less than 2% so that execution work efficiency is not reduced. Drainage after completion of a tunnel normally requires a

longitudinal grade of more than 0.1-0.2%. If the longitudinal slope is steep, the density of exhaust fumes emitted from vehicles increases, thus, the slope gradient should be kept less than 3% wherever possible.

3) Distance between adjacent tunnels, distance between a tunnel and other structures

In the case where more than two tunnels are built side by side or a tunnel is built near other structures, the distance between the tunnels or between the tunnel and the structures must be far enough that they will not influence each other. Since the extent of influence varies depending on the bedrock condition, it is necessary to examine the distance according to individual conditions. In the case of tunnels built side by side, based on calculation results when the bedrock is assumed to be a completely elastic body, their influences on each other can be ignored if the distance between the two tunnels is twice as far as the width of excavation. However, there are many unsolved problems regarding the influences that occur in the actual bedrock. In the case of tunnels with two lanes or more, the distance between the central points of the two tunnels has often been approximately 30 m. When a tunnel is excavated under an existing architecture, it is necessary to investigate submergence of foundations.

2.2.2 Design of cross sections

There are two kinds of cross section designs: inner cross section and excavated cross section. Inner cross section must be designed to include required clearance and necessary cross section area and allowance. In designing, it is important to note that in the case of a road tunnel which requires ventilation, investigation of factors including ventilation method is necessary since the required cross section area varies great-

ly depending on the ventilation method. In addition, more than 20cm allowance for overlay paving and allowance for execution error should be included. In the case of long tunnels, it is desirable that investigations are carried out taking passage clearance into consideration since it may be necessary to install a passage for maintenance inspection, etc.

Based on the above consideration, inner cross sections generally become in shape a concentric circle with three centers like a horse-shoe shape. When bedrock condition is good, flat cross section from a circle with five centers are adopted.

The area of the excavated section should be the total amount of an area large enough to hold the supporting structure required to ensure the inner section and an area allowance of about 10-20cm for over excavation. However, the cross section can be considerably deformed in the case of bad bedrock condition. In such a case, it is necessary to determine the amount of allowance corresponding to the amount of deformation set on the preliminary design stage.

2.3 Structural design

2.3.1 Supporting structure

A supporting structure ensures the stability of an excavated tunnel. It must ensure safety and efficiency during execution and have lasting durability. Therefore, among tunnel design items, they are particularly important elements.

The present standard mountain tunneling method is known as NATM (New Austrian Tunneling Method) and is the method whereby the spray concrete, rock bolts, steel arch supports and the lining are combined. This concept of support is based on a concept in which the original strength of the bedrock is fully utilized. It is necessary to design taking this concept

into consideration.

1) Concept of supporting structure design

Movement of bedrock accompanied by tunnel excavation varies greatly depending on tunnel configuration and execution method, as well as strength and condition of discontinuous surfaces of bedrock such as joints. Whereas, the supporting structure's effect on bedrock stability varies depending on bedrock movement accompanying tunnel excavation. Therefore, it is important to understand the movement accompanied by tunnel excavation. Basic items such as tunnel face stability, true earth pressure and loosening pressure are discussed below.

(1) Tunnel face stability

It is necessary that the excavated surface stand by itself while supporting structure members are being installed. Bedrock stability is related to bedrock nature and the size of the area of the excavated section. Generally, the larger the excavated face without support is, the shorter its stability time is. Therefore, in bedrock without sufficient stability, a tunnel is divided into several parts for excavation. In this case, care must be taken as supporting structure members constructed in the prior stage can have a disadvantageous influence from the excavation of the next stage. As a measure for ensuring stability of a heading, bedrock may be sometimes strengthened by rock bolts at the front of a heading.

(2) True earth pressure

When bedrock stress due to stress redistribution accompanying tunnel excavation becomes greater than bedrock strength, either of the following phenomena occurs; rock is broken or a plastic zone appears. In order to clarify this concept, an example of the stress condition of the periphery of a tunnel with a circular configuration, the most simple configuration is shown

in Fig.-2.2 assuming that the bedrock has a totally elasto-plastic nature. In this analysis, it is assumed that bedrock internal friction angle $\phi = 10^\circ$ and coefficient of lateral earth pressure λ (ratio of horizontal pressure to vertical pressure) is 1. A solid line shows stress σ_t in the direction of the tangent line, and a dotted line shows stress σ_r in the direction of a radius; q_u/p_o in the figure is the bedrock strength ratio which is the ratio of uniaxial compression strength q_u to stress p_o at the site of tunnel excavation and is a significant index in the classification of bedrock. According to Fig.-2.2, when the bedrock strength ratio is 2, stress on the tunnel excavation surface reaches bedrock strength. Therefore, when bedrock strength ratio exceeds 2, a plastic zone is not formed and stress in the direction of the tangent line shows the maximum value at the excavated surface of the tunnel. The value decreases greatly as the point becomes far from the tunnel and becomes close to that of the initial bedrock stress. When bedrock strength ratio is less than 2, stress σ_t in the direction of the tangent line reaches a maximum at the point somewhat apart from the excavated surface. As a result, a plastic zone is formed from the point to the excavated surface. In other words, the plastic zone becomes the larger as the bedrock strength ratio becomes the smaller.

A tunnel does not immediately become unstable when a plastic zone is formed. Unless deformation becomes excessive, stability of tunnel face is expected. Fig.-2.3 shows the relation between displacement of the excavated surface of a tunnel and inner pressure p_i given by the supporting structure, under the condition of Fig.-2.2. $p_i=0$ refers to the condition without any support. When bedrock strength is high, even if $p_i=0$, deformation decreases to a certain value within a few percent of the tunnel radius. Whereas, when the bedrock strength ratio is low, displacement tends to become infinitely large and unless an appropriate p_i is given, a tunnel

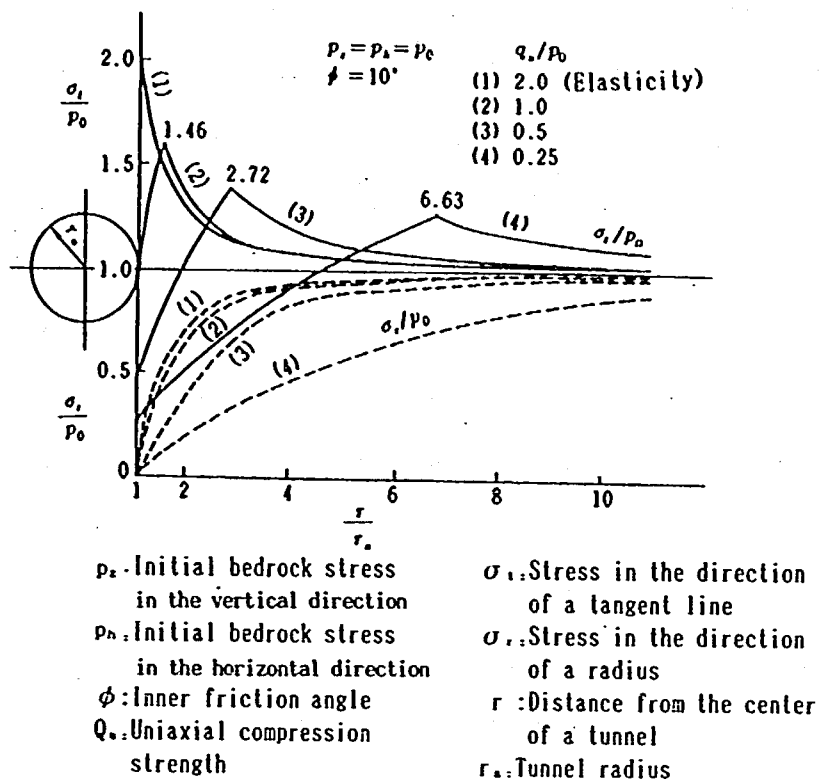


Fig.-2.2 Example of Stress Distribution on the Periphery of a Circular Tunnel"

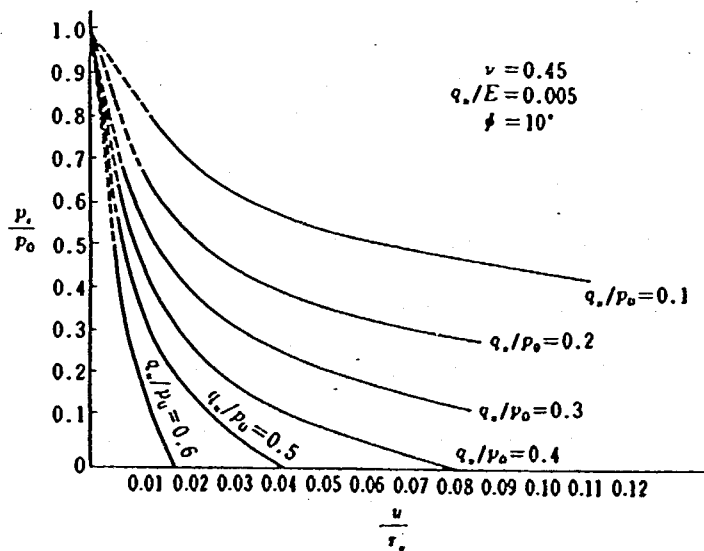


Fig.-2.3 Calculation Example of Displacement of Excavated Surface of a Circular Tunnel"

execution stage starts from a certain displacement on the horizontal axis of Fig.-2.4, since redistribution of stress begins at the same time as tunnel is excavated and displacement has already arisen when supporting structures are installed. When there forms true earth pressure, the points where a tunnel is finally stabilized are the intersecting points of the load displacement curve of the supporting structure and the characteristic curve indicating the relationship between bedrock displacement and P_i . Therefore, the point where a tunnel is stabilized can be found by selecting support hardness and execution stage. The most economical way is to make the P_i value lowest within the range where deformation does not become excessive. For that purpose, it is desirable to construct a supporting structure with characteristics such as those of L_1 . Therefore, it is necessary to adopt a supporting structure appropriate for the bedrock condition considering bedrock classification, which will be mentioned later, and characteristics of each supporting structure.

(3) Loosening pressure

When the stress redistributed by tunnel excavation is less than the rock strength, the bedrock is not broken and a tunnel is stable. However, when there is a discontinuity such as a joint or bedding, the phenomena of bedrock loosening due to bedrock separation and motion occurs in these areas. The load which is generated when the bedrock is supported by a supporting structure from the inside of a tunnel in order to control the loosening mentioned above is called the load of loosened bedrock. In order to stabilize a tunnel when such loosening occurs, other than the method of supporting an excavated surface from the inside by steel arch supports, there is also a method for preventing loosening by unifying rock mass of an excavated surface by spray concrete immediately after excavation. Latter method where a tunnel is stabilized with bedrock strengthened by rock mass unification, positively utilizes the strength of the bedrock

and is advantageous since it can decrease looseness.

2) Bedrock classification (Appendix 1)

Bedrock classification has been studied at various institutions in the past and several classification methods have been proposed. However, a universal classification method has not been established yet as it varies depending on the kind of tunnel to be studied.

Bedrock conditions influencing the degree of difficulty in tunnel excavation and bedrock movement such as earth pressure, are as follows:

- ① hardness and strength of the rock itself
- ② effect of geological structures such as folds, faults, fracturation zones
- ③ condition of cracks such as joints, bedding and schistosity
- ④ degree of weathering and alteration
- ⑤ amount of ground water
- ⑥ depth

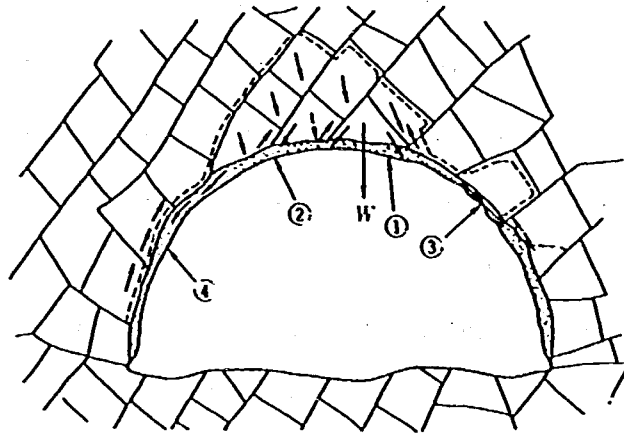
It is necessary to make a decision based on the results of topographical and geological investigations on these conditions. The indexes of bedrock judgment for bedrock classification applied for determination of tunnel execution method and design of supporting structure, are as follows: kind of rock, elastic wave velocity (longitudinal wave velocity) bedrock strength ratio, condition of boring core, RQD (the total length of a core exceeding 10 cm divided by excavation length, expressed in %), bedrock condition, the way cracks occur when the rock is hit with a hammer, distance between cracks, estimated heading stability and amount of deformation after excavation. By adding comprehensive and technical judgments to these indices, bedrock is classified into classes ranging from class A, which is appropriate for a tunnel to class E and is further classified in

detail by rock kind. Appendix shows the present bedrock classification used for road tunnels.

3) Spray concrete

Generally spray concrete is applied immediately after tunnel excavation. There remains much to be clarified regarding the mechanism of spray concrete. However, it is generally considered that as shown in Fig.-2.5, the main effect of spray concrete is to help bedrock obtain strength by itself by preventing a falling off of a partial rock mass and thus preventing further development of loosening. Force transmission between spray concrete and rock mass is done by cohesive force and shear force, whose strength plays an important role. When cohesive force cannot be expected due to poor condition of bedrock, spray concrete supports load as axial members as well as linings and steel arch supports. Therefore, it is necessary to pay attention to whether the condition of the legs supporting axial force is sufficient.

Thickness of spray concrete varies depending on the concept of the spray concrete mechanism mentioned above. When the bedrock is in a good condition and spray concrete is simply to prevent rock masses falling off, thickness is approximately 5 cm. Even when bedrock is in poor condition, the thickness is approximately 25 cm at most. In this case, it is necessary to take the relation with the lining thickness into consideration. Basically, the mix design of spray concrete, must be designed so that standard cohesiveness and the strength characteristics can be required. Since to prevent loosening, initial strength rather than long period strength is extremely important, the mix design must ensure initial strength. Generally four weeks of design standard strength can be attained with 180 kgf/cm².



- | | |
|---|---|
| ①Prevention of direct falling off of rock mass(preservation of key stones) | ④Conveyance of load of loosened bedrock toward side walls |
| ②Prevention of rock mass shearing by filling concaves | ⑤Prevention of rock weathering |
| ③Conveyance of excavated surface stress accompanied by minute movement of rock mass | |

Fig.-2.5 Effects of Spray Concrete''

4) Rock bolts

Rock bolts are generally driven radially from the excavated surface of a tunnel after the application of spray concrete. The effect of a rock bolt varies depending on bedrock conditions and methods for setting the rock bolt. In the case of hardrocks where the discontinuity of a rock mass controls bedrock movement, bedrock can be unified by jointing rock mass. In the case of softrocks where bedrock is plastically deformed, it is considered that rock bolts restrain convergence, keep bedrock in a tri-axial stress state and increase load bearing capability of bedrock near an excavated surface. Rock bolt effects for earth tunnel in cities are still not clear and are expected to be studied in the future.

There are two basic types of rock bolt setting methods; they are the point-bonded type where the end point alone is fixed mechanically or with resin, etc., and the fully-bonded type where the total surface of the rock bolt is bonded by mortar, etc. At present, the fully-bonded type is most

commonly used due to the higher reliability of stabilization and appropriateness for larger varieties bedrock. A rock bolt is generally a differently-shaped reinforcing rod or a steel bar with a special configuration like a spiral, about 25 mm in diameter made of SD 35. When rock bolts are driven into the tunnel face for the purpose of strengthening of the bedrock around the tunnel head, glass fiber bolts are sometimes used since it is necessary to cut off the bolts when excavating.

Rock bolts are used together with bearing plate as large as about 150 mm x 150 mm and as thick as about 9 mm, made of SS41 for the purpose of dispersing the bolt's axial force to the rock mass of an excavated surface.

With regard to a rock bolt's length and placing distance, the following relationships form one of the basis for calculation according to experimental results and experience in the case of hardrocks.

$$L \geq 2P, L \geq 3S, L \geq (1/3 \sim 1/5)B$$

L: length of rock bolt, P: placing distance of rock bolt, S: average distance between joints, B: width of tunnel excavation

There are many problems to be studied concerning bolt length and designs for setting arrangement, in cases where a plastic zone is formed as in hardrocks, earth and sand bedrock. At present, design is carried out based on execution examples and experience.

5) Steel arch supports

Since a steel arch support has the effect of restraining the loosening of bedrock, it is used for deep but weak bedrock, together with spray concrete as a supporting structure to stabilize the bedrock until the spray concrete shows sufficient strength. When an arch effect cannot be expected due to a shallow depth at the tunnel entrance, a steel arch support is used as a hard supporting structure. When it is used to control loosening

ing of bedrock, light-weight steel arch supports, such as H-100~150, U-21 and U29, are generally used.

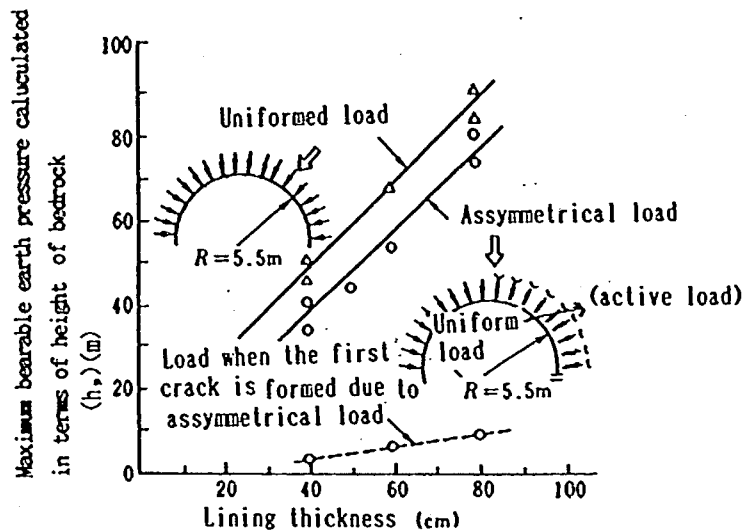
6) Lining

The lining composes part of the supporting structure ensuring tunnel stability together with other supporting structure members, and at the same time plays a role as interior finishing. There are some cases where lining itself bears no load mechanically. Normally, lining is applied for the purpose of interior finishing, durability and the improvements of the safety factor for the problems which are difficult to predict.

It is desirable to shape the lining as an arch or ring so that it can effectively support pressure from outside. When load is very large, a circular lining is most effective. Therefore, in order to make the best use of load bearing capability of lining, a cross section should be closed. When side pressure is large an invert should be installed.

Experimental results with regard to the relationship between load bearing capability of lining and lining thickness are shown in Fig.-2.6. Lining thickness can be determined by referring to these results. In the case of a road tunnel with two lanes, lining thickness is usually 30 cm which is the least thickness necessary for execution. Though lining generally composed by non-reinforced concrete, in the case where depth is shallow or at a tunnel entrance, it is often strengthened by reinforced bars in order to deal with changes in load or unsymmetrical pressure after completion.

There are some cases where cracks occur on the concrete surface of lining. It is considered that this is due to temperature stress resulting from restraint caused by unevenness of spray surface because the concrete lining adheres directly to the spray concrete. Therefore, appropriate crack preventive measures are necessary. There are different types of



Remark 1) This experiment was conducted in an ideal condition equivalent to the case where there is sufficient back-fill grouting and no subsidence of the foundation.
 Remark 2) Assymetrical load refers to the load occurring where uniformed load is placed on half the lining and the other half of the jack prevents deformation towards the outside so that passive load can arise.

Fig.-2.6 Lining Load Bearing Capacity"

methods; 1) a sheet is inserted between the spray concrete and the lining to prevent contact; 2) a sliding joint is installed; 3) concrete quality of lining is improved. It is said that the most effective method is that which uses the sheet, etc., which also prevents water leakage.

7) Combination of supporting structures (Appendix 2)

Design of supporting structures must be appropriate for tunnel conditions, utilizing the characteristics of various types of supporting structures based on the concepts of supporting structures mentioned above. Table-2.1 shows the concept of application of supporting structures. In addition to this structural condition, however, there are some other important elements for determining structure type such as condition of water inflow, durability against freezing and relationship to water-proofing. It is necessary to take all these conditions into consideration when applying

support structures.

With regard to actual supporting structure combination, the standard combination of supporting members corresponding to the bedrock classification grades is determined in an preliminary design of supporting structure since the effect of each supporting structure is not clarified and also it is difficult to accurately grasp bedrock conditions based on the results of the preliminary investigation. Thus, actual supporting structure combination is altered to suit each tunnel with modifications and alterations based on observation and measurement of the heading conducted at the execution stage. For reference, examples of standard combinations of supporting structures are shown in Fig.-2.7 and Appendix 2.

Table-2.1 Concept of Supporting Structure Application¹⁾

Relation between redistributed stress and bedrock strength and bedrock nature			Items to be considered when designing supporting structures	Steel arch support	Rock bolt	Spray concrete	Lining
(Bedrock strength) > (redistributed stress)	With less-developed joints and massive bedrock		Partial rock mass loosening accompanied by execution (loose rock)	—	Random bolting	Simple spray concrete for rock fall prevention	Mechanically not necessary
	With developed joints		Loosening load	Compatible	Pattern bolting (point-banded type, fully-banded type)	When cross section area is large, combination with rock bolts is necessary.	Compatible
(Bedrock strength) < (redistributed stress)	When initial bedrock stress is low (when depth is small)	When friction angle is relatively large	Loosening load (earth pressure)	Compatible	If the face is stable, pattern bolting (fully-banded type)	Compatible, if the face is stable. When a cross section is large, combination with rock bolts is necessary.	Design as an earth pressure resistant structure
		When friction angle is small	Loosening load + displacement condition	Compatible, when displacement is less than about 1% (Hard structure is appropriate).	Pattern bolting (fully-banded type)	Combination with rock bolt	Same as above
	When initial bedrock stress is large	When friction angle is relatively large	Loosening load + displacement condition	Same as above	Same as above	When displacement amount is large, same as above or a hard structure with large durability are necessary in some cases.	It is necessary to execute at the stage where deformation converges.
		When friction angle is small	Loosening load + displacement condition	Not Compatible since displacement amount is generally too large for steel support to follow. In some cases, a large support is employed so that durability of the support system increase	Same as above	Same as above	It is necessary to apply lining at the stage with a certain amount of displacement and to restrain the displacement amount.

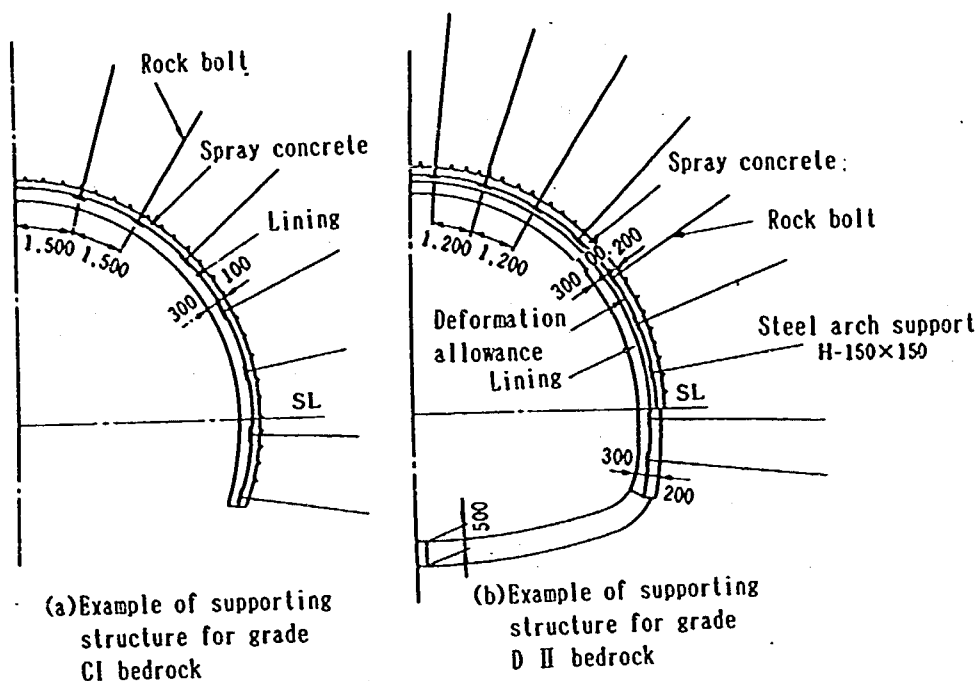


Fig. -2.7 Example of Standard Supporting Structure¹¹

8) (Former) Steel arch and lagging method

The steel arch and lagging method is a traditional method where steel arch supports accompanying steel arch and lagging on sheet piles are the main members of the supporting structure. In this method a considerable amount of vacant space remains between the bedrock and supporting structure members. Therefore, it is considered that load transmission to the steel arch is done by the point support structure through a sheet pile or a wedge. Due to this, bedrock is loosened and the load increased, and at the same time, stress concentrates in the supporting structure. It also results in a decrease in the load bearing capability of the arch structure. Even if back-fill grouting is applied it is still difficult to completely fill the vacant space between the bedrock and the supporting structure members. Thus, problems remain in ensuring long period stability and in how to stop water completely. However, there are some advantageous properties in this method: execution is relatively easy even when a large amount of water inflow under high pressure makes the setting of spray concrete or rock bolts difficult; it

is also effective for extremely unstable bedrock, such as, a bedrock, part of which are likely to fall off. Therefore, the method should be applied in these special cases.

2.3.2 Design of a tunnel entrance

The ground near a tunnel entrance has poor topographical conditions such as shallow depth or slope and is in a poor geological condition since it is softened by talus and extremely weathered stratification. Therefore, disadvantageous phenomena for tunnel construction, such as subsidence of ground surface, slope failure, unsymmetrical pressure are likely to occur. There are some necessary measures taken regarding these problems. One of the methods more frequently employed recently is the vertical forepoling method. The vertical forepoling method stabilizes the bedrock by driving rock bolts from the ground surface. It is said that the method is effective for the prevention of landsliding, slope failure, subsidence of ground surface and unsymmetrical pressure, etc. There are some design concepts of vertical forepoling bolts based on shear resistance and tensile resistance of bolts. When a tunnel is excessively deformed, it is considered that bolts resist bedrock shear force at a sliding bedrock surface. Some experimental results show that resistance can be more effective when bolts are driven horizontally rather than vertically.³⁾ In these experiments, dry sand was used. Thus, investigation for various kinds of bedrock is necessary. As shown in Table-2.2, there are many countermeasures for tunnel entrance problems other than the vertical forepoling method. It is necessary to employ an appropriate method at each tunnel entrance so that proper design can be carried out for expected phenomena.

As the structure of a tunnel entrance must prevent loosening of

Table-2.2 Phenomena Expected at a Tunnel Entrance and Countermeasures Thereof¹⁾

Expected phenomena Countermeasures	Land- sliding	Slope failure	Subsidence of ground	Unsymmetrical earth pressure	Heading edge failure	Lack of earth durability	Spring water	Remarks
Vertical fore method	◎	◎	◎	◎	○			Before excavation
Slope face spray concrete method		◎						"
Slope face strengthen- ing bolt		◎						"
Counter-weight fill	◎	○		◎				"
Enlarged side wall	◎	○		◎				"
Piling work	◎			○				"
Anchor method	◎	○		○				"
Pipe-roof protection		○	◎	○	○			"
Drainage (from the outside of a bore)	◎	○			○		○	"
Grouting method (from the ground surface)		○	○	○	○		○	Before excavation, during excavation
Grouting method (from the inside of a bore)			○		○	○		During excavation
Temporary support		◎	◎		◎			"
Breast board (bolt, spray)			○		○			"
Temporary closure (temporary invert)			◎	◎		◎		"

(Remark) ◎: effective method ○: effective depending on the case

bedrock as much as possible, it is generally designed to be stronger in comparison with other part of the structures. Also in lining design, since it is considered that the lining carries the total amount of overburden depth load and also tends to be influenced by temperature change, dryness and shrinkage, the lining is generally enforced by steel bars and an invert is installed.

2.3.3 Water-proofing and drainage works

Tunnel excavation is often accompanied by water inflow. A great amount of

water inflow from bedrock can degrade execution performance and the quality of spray concrete and also creates pressure on the lining, resulting in the occurrence of cracks. However, if water inflow is completely stopped, underground water pressure level increases. Therefore, water inflow must be discharged as soon as possible. To deal with these problems, it is necessary to execute appropriate water-proofing and drainage. Also, when designing, it is necessary to consider leakage and drainage of tunnel washing water required for tunnel maintenance and the water brought in by vehicles after the tunnel is opened to the public.

Water-proofing and drainage works are classified in detail corresponding to purpose as follows:

(1) Water-proofing

Water-proof sheets set between spray concrete and lining is installed to prevent water leaking into the inside of the tunnel.

(2) Drainage work behind the lining.

Water inflow behind the lining is channeled off to road deck drain or roadside drain.

(3) Base course drainage work

Drainage is installed under the road surface to channel water inflow from the base course and from behind the lining to the outside of the tunnel

(4) Roadside drainage work

Drainage is installed at the shoulders of the road to drain water inflow into the tunnel or water brought into by the tunnel.

Reference

- 1) Japan Road Association, "Technical Standards for Road Tunnels (on structure) and their Commentaries" June 1989
- 2) Society of Civil Engineering, "Specification for Tunnel Standards (on

mountains) and their Commentaries" November 1986

3) Toshinori MIZUTANI, Hideto MASHIMO, Materials of P.W.R.I. "Study Report on Forepoling Bolt Effect in a Sloping Tunnel", December 1988

3 EXECUTION OF WORK OF ROAD TUNNELS

3.1 Preface

Tunnel execution technology is divided into the technology to construct a space in the ground by crushing bedrock and transporting the crushed pieces and the technology to maintain the excavated space. The former is related to excavation and mucking. Productivity to make underground open space has been remarkably increased by recent improvements in equipment like rock drills and transportation machines. Explosives design and use have also improved.

The technology to maintain the stability of the excavated space is related to supports and lining. It is also related to the means and method of excavation, and is a basis for the tunnel design and construction. Technologies for maintaining the tunnel space include the research for redistribution of the stress in the peripheral bedrock caused by tunnel excavation and technology concerning supporting materials used for tunnel stability. Particularly important are the improvements of the support members which stick fast to the bedrock, such as spray concrete or rock bolts. Design options and feasibility of tunnels have greatly increased because of improvements in above support technologies. The traditional concept that supports are for supporting the load of loosened bedrock, changed into a new concept that supports together with bedrock strengthen the rock formation to secure the stability of a tunnel. Realization of this concept allowed reduction in support members and construction under more difficult conditions.

First, we will discuss the technology of excavation, support, lining, auxiliary methods, and changes of design and execution based on measurements made during construction.

3.2 Excavation

From the aspects of stability, durability and economic efficiency of the construction of tunnels, it is ideal to prevent the bedrock from loosening as much as possible. The amount of overbreak (extra excavation) should be as small as possible. However, when bedrock conditions and working efficiency are taken into account, bedrock loosening and overbreak can not be avoided. For this reason, when excavating, the means and methods must be carefully chosen so that the excavation is completely safe and economical.

3.2.1 Excavation method

Among excavation methods, there are blasting excavation, mechanical excavation and manual excavation. Blasting and mechanical excavation are mainly used because they are the most efficient. The features of each excavation method is as follows:

1) Blasting excavation

In blasting excavation, bedrock is broken into pieces by explosion. It is applicable to different kinds of bedrock, ranging from hardrock bedrock to soil bedrock. The method is frequently used due to its high flexibility. However, there are some disadvantages in that the amount of overbreak tends to be large and bedrock is likely to be damaged. In some cases, it is necessary to employ countermeasures for environmental protection from associated noises and vibrations caused by the explosions.

2) Mechanical excavation

In mechanical excavation, bedrock is pressed into pieces or cut into pieces by the machines like a Tunnel Boring Machine. It has the following advantages: bedrock is not loosened as much; the amount of overbreak is small; there is less noise and vibration. Machines are roughly divided into two types: machines of the boom type and tunnel boring machines (TBM). The former

is frequently used for bedrock ranging from soil to soft rocks. TBM are usually used only for circle-shaped cross sections, and the bedrock must be in a stable condition so there are only a few execution examples in Japan.

3) Manual excavation

Manual excavation is conducted mainly by manual work using simple and lightweighted tools such as a pick hammer and a pickax. Manual excavation sometimes can be the only option for certain bedrock conditions. For example, where an excavation must be done by breast board or forepoling sheet pile method due to insufficient stability of a heading of a tunnel entrance, or where a drift with an extremely small cross section is excavated.

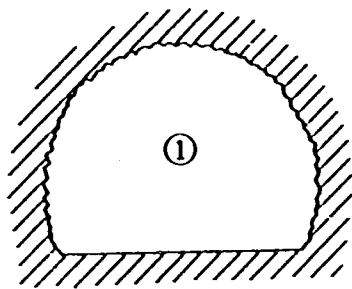
3.2.2 Division of the heading section

Excavation method depends on how the excavated section is divided. Fig.-3.1 shows a typical executing method.

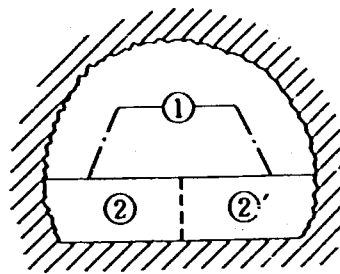
The major factors which affect the choice of the excavating method is the relationship between the largeness of an excavation section and the degree of bedrock stability. Normally, dividing the execution is investigated for stabilization of the heading and its periphery. Based on this, the excavation method is chosen, including a combination of executing machines or a mucking method. The features of each excavation method is as follows:

1) Full face method

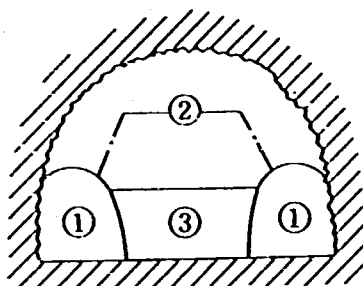
This is the simplest excavation method whereby a full face is excavated at one time. Using this method, a large sized machine can be applied for the execution, and heading control is rather easy. For the application of this method, the conditions are as follows: the rock mass is hard and solid; the heading of a full face is stable; the geological conditions are rather constant for the whole length of the tunnel. This method was adopted in the Kanetsu tunnel which is the longest road tunnel in Japan.



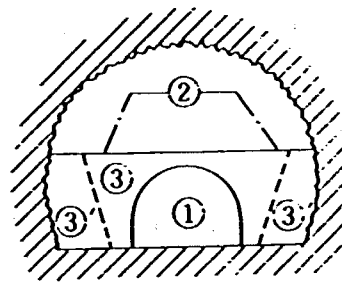
(a) Full face method



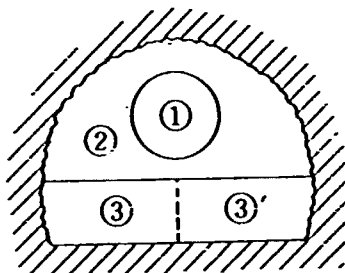
(b) Top heading method



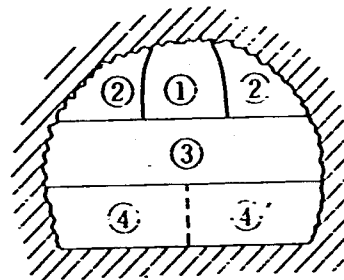
(i) Side wall drift



(ii) Bottom drift

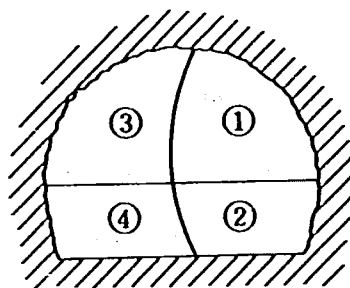


(iii) Center drift



(iv) Top drift

(c) Advancing drift method



(d) Center diaphragm method

Remark1) ①, ②——— shows the excavation orders

Remark2) When a heading does not have sufficient stability the excavation section is sometimes divided into small parts as shown by dashed lines, — — —, in the figure. In the top heading method, it is called a ring cut method.

Fig.-3.1 Typical Excavation Method

When constructing a work tunnel with a cross section of medium or small size (up to about 30 m²), full face excavation is usually used.

2) Top heading method

The top heading method divides the tunnel cross section into the upper half and the lower half for excavation. It can be applied to various kinds of bedrock conditions. With regard to executing machines, usually dump trucks can be used for the transportation of muck. In addition to dump trucks, there are many machines developed for this method. Except for a few particular bedrock types, this method is being widely applied.

3) Advancing drift method

After making a drift in advance in a tunnel cross section, the upper and the lower part of the drift are enlarged by cutting. Sometimes the method is applied to test the bedrock conditions at a spot with complicated geology, or to drain water inflow. Also it is used to divide a tunnel section to improve the stability of the heading and construct the foundation for the upper half arch when the soil bearing capability is not sufficient.

4) Center diaphragm

Center diaphragm method roughly divides the tunnel into the left side and the right side, and an excavation is enlarged by cutting. It is applied where the section is rather flat in a bedrock like a soil to softrock bedrock with poor heading stability and where it is necessary to restrain ground subsidence at a point of shallow depth. In this method, it is necessary to remove the center wall after confirming that there is no load on the center wall to the support of the excavation surface.

This method was applied at a part of the three lane cross section road tunnel between Oimatsuda and Gotenba of Tokyo-Nagoya Express Way.

3.2.3 Mucking

Since mucking occupies a large part of working hours in the excavation work cycle, an improvement in mucking efficiency speeds up tunnel construction and lowers cost. To realize these benefits, the muck loader, muck car and mud dumping equipment, must have well-balanced capabilities as a whole, and correspond to the scale and the amount of the muck.

3.3 Support

Of the tunnel structural members, spray concrete, rockbolt and steel arch supports, are generally called supports.

If a bedrock is left without any supports after excavation, the extent of loosened section increases with time and advancement of a heading. In order to prevent it, supports are required to have high strength. Therefore, it is important that supports are constructed soon after excavation and near a heading where loosened section does not expand. Also, it is desirable to place supports to be unified with bedrock as soon as possible so that loosening of bedrock is prevented.

3.3.1 Spray concrete

1) Spray method

There are two types of spray methods, the dry and the wet method. In the dry method, dry mixed spray materials are sent by pressure to the nozzle, and pressured water is added to spray materials just before the nozzles, then it is sprayed. The dry method has the disadvantages that the amount of dust or the amount of rebound is larger than for the wet method, and an experienced operator is needed for adding water. However, because there are improvements for dust proof mixing, and because water is added near the spray machine, and the length of a tube in which materials are sent can

be long, and because interruption can be made at any time since no cementation is formed in the tube, the number of examples where the dry method is applied is increasing especially in tunnels where the amount of spray per application is small.

In the wet method, wet mixed materials are sent by pressure, and an accelerator is added to the materials in the nozzle, and then it is sprayed. In the wet method, the amount of dust is relatively small. However, when spraying is interrupted, materials in the tube can become cemented and form a blockage in the tube. When it happens, it becomes necessary to carry out time consuming recovery work. Therefore, this method is generally used where the length of the conveying tube is not very long and the amount of spray per application is large. In road tunnel construction, the wet method is generally used.

2) Countermeasures for water inflow

When the amount of water inflow from a bedrock is small, it is possible to execute spraying by increasing the amount of cement and accelerator in the spray materials or by mixing instant accelerator. Sometimes, when there is too much water inflow, spray can not be executed. In such cases, various measures are taken, such as wire netting to prevent cement from falling off, pipe for dewatering, or a permeable mat for full surface water inflow. When there is much water inflow, it is necessary to make a drainage hole or boring in advance or other means before hand. Regardless of the method, water inflow should not be blocked, but be appropriately drained and discharged.

3) Execution of spray concrete.

Spraying must be conducted so that it adheres closely to the bedrock with a designated thickness. The finished surface must be as smooth as possible. In the case of hard rocks, major unevenness on the exca-

vation surface must be finished as smooth as possible so that the lining can be appropriately executed.

4) Dust proof

When spraying is conducted, the quality of the working environment in a tunnel is lowered by dust. Countermeasures for this problem are ventilation in the tunnel, installation and operation of dust collectors, mixing dust control agent into the spray materials and auto spraying by remote operation. When employing any spray method, workers must wear a dust proof mask to prevent their inhaling dust.

3.3.2 Rockbolt

1) Placement of rockbolts

There are two ways to place rockbolts. One is pattern bolting which is usually applied in road tunnels, where bolts are spaced uniformly. The other is non-pattern bolting where bolts are driven partially into bedrock of hard rock, or other hard formations. The direction of the driving in pattern bolting should be the same as the direction of the tunnel radius and should be driven perpendicular to the tunnel wall surface. When it is not possible to drive perpendicular to the wall surface due to the ring cut method, bolts are driven aslant.

In the case of random bolting, bolts are driven in the direction which seems the most appropriate considering the cracks in the bedrock, the direction of joints, and so on.

2) Driving of rockbolts

When driving a rockbolt, if there is a considerable amount of water inflow from the hole, the bolt can not be fastened, and it is necessary to install drainage for the water inflow. If it is still difficult to fasten a rockbolt, reviews should be conducted on whether to change the fixative or kind

of bolt, or try some other cure.

3) Prevention of rock fall

Rock fall can be prevented by spray concrete, wire net, a large sized bearing plate and belt steel, or other means. An appropriate method is selected according to what kind of rock fall is occurring. It is important that a rock fall preventive measure fits well with the condition of an excavated bedrock surface.

3.3.3 Steel arch supports

1) Erecting of steel arch supports

When erected, steel arch supports must be placed at exact intervals in the designated interval. It is also important that supports are placed as closely as possible to the surface of bedrock or sprayed concrete and are driven perpendicularly so that torsion will not occur. Steel arch supports are connected to each other with collar braces. After erecting, concrete is sprayed for fixation between the bedrock or concrete surface and the steel supports.

2) Prevention of steel arch support subsidence

When the foundation of the leg of a steel arch support does not have sufficient bearing capability, it is usually followed that the bedrock is loosened by subsidence or clearance is not kept. To prevent such phenomena, excess clearance should be estimated based on the bedrock condition. Where subsidence is expected to take place frequently, it is necessary to enlarge the foundation area of steel support using a sheet pile or wing rib type steel support or tentatively to cover the upper half, or other measures.

3.4 Lining

The lining includes the arch, side wall, and invert sections. Generally nonreinforced concrete is used for a lining. Its configuration is determined mainly by the inner section and excavation method. Except for where an advancing side drift method is used, the full placing system of the lining is usually applied, where a lining concrete is placed at the same time on an arch and side wall. A form is used for putting concrete on an arch and side wall. There are two types of forms, movable and prefabricated. Generally, when a tunnel is large, movable forms are used, and when the execution length is short prefabricated forms are used.

In principle, the lining is started after the convergence of wall displacement comes to an end. However, when convergence takes a long time, an exception may be made depending on measurement results. Generally, as long as inner displacement speed is about 1 to 3mm per month or less, no problem arises for a lining. Quality control in lining installation must be maintained to accomplish the finish and strength specified, and prevent joint offset, pitting or squeezing. Keeping the specified concrete thickness without vacant spaces is critical, particularly at the crown.

3.5 Auxiliary method

When excavating a tunnel, a heading and a crown need to be stable until the supports become effective after installation. If they are unstable due to a bedrock condition, several measures can be adopted. For instance, the excavation section can be divided, or the excavation length per unit time can be shortened. However, in many cases it is more rational to execute works in a large section rather than several small ones. Various kinds of auxiliary supports are added to increase the stability of a heading or a crown.

Auxiliary supports are those which can be applied without changing regular equipment or the composition of workers. Those which require a change in the equipment or in the composition of the workers are called special support. Table-3.1 and 3.2 show typical auxiliary and special supports.

Table-3.1 Typical Auxiliary Method

Measures	Method	Bedrock condition			Note
		Hardrock	Softrock	Earth & sand	
Measure for crown stability	Forepoling	○	◎	◎	Bolt, reinforced steel, single unit pipe, iron spile
	Injection type forepoling	○	◎	◎	Including injection type rock bolt and rock mass consolidator
Measure for heading stability	Spray concrete, to cutting face method		○	◎	
	Bolting to cutting face method		○	○	Rockbolt, etc.
Measure for insufficient bearing capability of the top heading ground	Enlargement of the bottom of the support		○	◎	
	Temporary invert of top heading		○	○	
Countermeasures for water inflow	Drainage hole	◎	○	○	Drifter

Remark) ◎ : Method frequency applied

○ : Method applied depending on circumstances

Table-3.2 Typical Special Method

Measures	Method	Bedrock condition			Note
		Hardrock	Softrock	Earth & sand	
Measures mainly for heading stability	Drainage boring	◎	◎	◎	
	Drainage drift	○	○	○	
	Chemical grouting method		○	○	Including cement milk, etc.
	Deep well			○	
	Well point			○	
	Pneumatic method			○	
	Artificial soil freezing method			○	
	Perpendicular forepoling method	○	○	○	Reinforced steel, mortar
Measures mainly for ground surface subsidence	Chemical grouting method		○	◎	Including cement milk, etc.
	Pipe-roof protection method		○	○	
	Special steel sheet pile jacking method			○	
	Perpendicular forepoling method		○	○	Reinforced steel, mortar

Remark) ◎ : Method frequency applied

○ : Method applied depending on the case

3.5.1 Auxiliary support

1) Remedies for crown instability

The following are the suggested solutions for an unstable bedrock which falls off before the completion of the supports due to instability in the face of the crown.

① Forepoling support

Forepoling support is a method for restraining bedrock with reinforced steel, single unit pipes, iron spiles placed in the forward direction of a cutting face of a crown. This is the most frequently used among auxiliary support methods. Fig.-3.2 shows an example of a forepoling support execution.

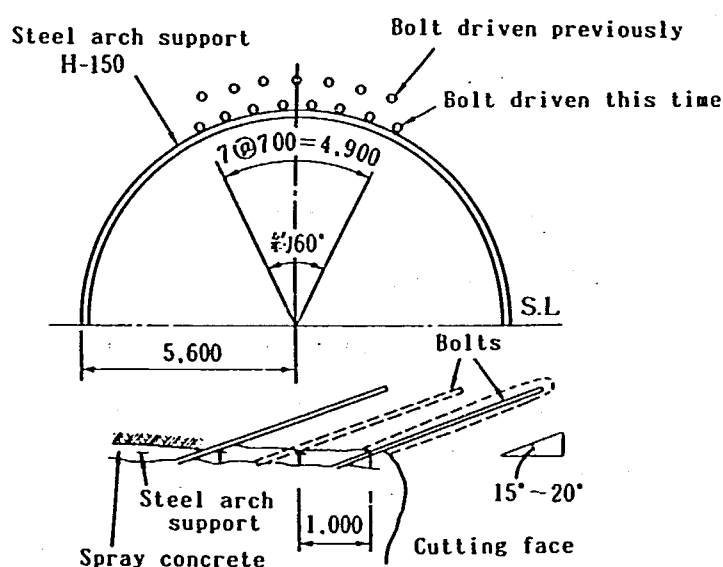


Fig.-3.2 Example of Forepoling Execution

② Injection

This method is used when sufficient stability of a crown can not be obtained by forepoling support. In injection forepoling support, an ultra accelerating cement milk or chemical grouting is injected with rockbolts or pipes.

2) Techniques for stabilizing the heading

① Spray concrete to cutting face

In this method concrete is sprayed on the cutting face immediately after excavation. It can increase stability by preventing an initial failure and easing a stress concentration.

② Bolting to cutting face

In this method, rockbolts are driven in the forward direction on the cutting face. The number of rockbolts and their length are determined by the cutting face condition. Glassfiber reinforced plastic (FRP) bolts are sometimes employed because they are easily cut off.

3) Techniques for improving inadequate bearing capacity of the top heading

Stability of a tunnel is sometimes lost due to deformation caused by insufficient bearing capacity of the ground for a top steel arch support and for spray concrete. Two typical remedies are below.

① Enlargement of the bottom of the support

In order to enlarge the bottom area of the support, the thickness of the bottom part of spray concrete is increased, or wing rib type steel supports are installed. These methods have the advantage that the lower half work can be carried out as usual and work efficiency does not decrease.

② Temporary invert of the top heading

This strengthens the ground around the top heading by covering it with a temporary invert. Although it is very effective, work efficiency sometimes decreases since breaking down of invert is time consuming when working at the lower half. However, this method has the advantage that it can be done immediately in response to the measurement results and the heading condition.

4) Water inflow problems and solutions

Drainage is the countermeasure for heading instability and difficulty in setting support structure members caused by water inflow.

① Drainage by drifter

This is the method where a drainage hole is made at the forward of a heading by a borehole drifter.

② Drainage method

When a considerable amount of water inflow or pressured water comes out throughout a tunnel, special drainage methods as explained in the following section 5.2 must be considered.

3.5.2 Special methods

The special method is defined as the method adopted where excavation is very difficult in a particular bedrock or where the influence of tunneling on peripheral structures must be decreased.

1) Drainage

Drainage is generally adopted when there is much water inflow. Typical drainage methods are drainage boring, drainage drift, well point, and deep well. Well point and deep well are frequently used in uncemented stratification containing water where it is necessary to lower the level of underground water.

2) Water stop method

The water stop method is applied when ground can not be drained due to the existence of a river near the tunnel or when ground would be subsided if drained or when there is a limit on lowering the ground water level. Water stop methods include the injection method, pneumatic method and the artificial soil freezing method.

3) Injection method

There are two cases where the injection method is applied. One is where the

method is used as water stop method mentioned above, for the purpose of decreasing the amount of water inflow by lowering the coefficient of permeability. The other is for the purpose of increasing the stability of a bedrock by consolidating cracks or voids.

4) Pipe-roof protection

This is the method where a pipe is installed in advance at the outside of a tunnel excavation after boring and injection is conducted inside and outside of the pipe. It is effective for preventing the peripheral ground from loosening and is used as a preventive measure for subsidence of structures. Since the method requires large equipments, a long time to complete, and is costly, it should be used only after a through review of the options.

5) Special steel sheet pile jacking method

This method prevents a crown from falling off by advancing a specially processed steel sheet piles (knife sheet) with jacks.

6) Perpendicular forepoling method

Boring is executed from the ground surface and a reinforced bar is inserted into the hole and fastened by mortar. In many cases this method is applied for restraining ground subsidence and for securing heading stability at a tunnel entrance. The method is also used when landsliding or land failure is likely to be induced by tunnel excavation.

3.6 Measurement control

3.6.1 The purpose of measurement controls

A tunnel is an underground structure which is long in the longitudinal direction, which is different from other civil engineering works. It is extremely difficult to know bedrock conditions, such as geology and water inflow exactly throughout the whole tunnel. Therefore, at the planning or designing stage, tunnel construction generally starts with many uncon-

firmed or unknown elements left. Therefore, as construction progresses, it is very important that the bedrock conditions be tested and changes in design or in execution be made when necessary.

The movement of a tunnel must be checked and reflected in changes in the tunnel design and execution for safe, rational and economical tunnel construction.

Fig.-3.3 shows the flow of measurement in a design and execution.

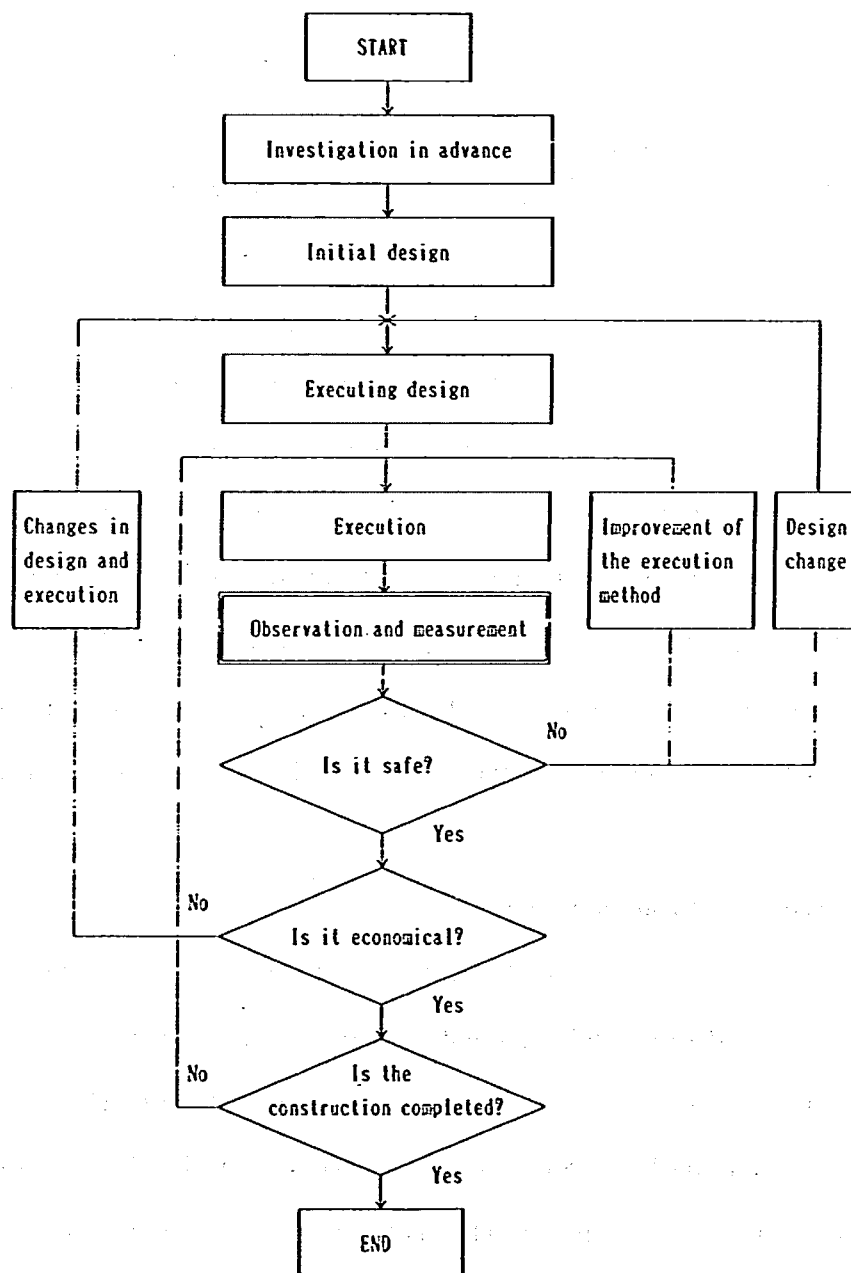


Fig.-3.3 Producer of Design and Execution Placement of Measurement at Work Site

3.6.2 Investigation and measurement

Table-3.3 shows items for investigation and measurement during tunnel construction.

These items are divided roughly into those routinely performed for execution control, and those performed particularly because of bad bedrock conditions. Routine tests for execution control are made at regular intervals in the longitudinal direction of a tunnel. By these tests it can be determined whether bedrock and supports are stabilized or not. Areas between the measured sections should be also routinely observed for unusual effects.

The tests particularly made because of bad bedrock conditions are to clarify whether the planned support members or execution method has been appropriate, and thus they make a tunnel design and execution rational and economical in the end. In good bedrock condition, a representative point is chosen to be tested to see whether the number of supports can be decreased. Bedrock in poor condition such as swelling bedrock, uncemented bedrock containing water, bedrock that has a shallow depth and bedrock with a possibility of failure near a tunnel entrance is likely to move enough to cause problems in a tunnel execution. Detailed inspections together with a review of the countermeasures for problems are necessary.

3.6.3 Use of investigation results

The purposes of investigation during execution are firstly to evaluate safety of the execution and secondly to ensure economical and rational design and execution. To realize these, the results obtained from measurements must be immediately and appropriately applied. Therefore, it is necessary to take advantage of the results of the tests on routine items (investigation by observation inside of a tunnel, crown subsidence meas-

Table-3.3 Items and Contents of Investigation

	Measurement items	Main items obtained through measurements	The kind of measurement
Investigations and experiments at the construction site	Investigation by observation of the inside of a tunnel	1. Heading stability without support 2. Grasping of rock quality, fault fracture zone, folding structure and alteration zone, etc. 3. Grasping the altered condition of supports such as spray concrete, etc. 4. Reevaluation of initial bedrock classification	A Remark 1)
	Measurement of elastic wave velocity in a tunnel	1. Re-evaluation of initial bedrock classification 2. Loosened area 3. Degree of cracking and alteration of stratification 4. Understanding rock mass strength	B Remark 1)
	Boring investigation	1. The nature of rock quality, fault fracture zone, folding structure, alteration zone and gas 2. Sampling of bedrock experiment samples	
	Various investigations and stratification inspections utilizing a boring hole	Soil bearing capacity (standard penetration test), Coefficient of water pressure and permeability (spring water pressure test), Deformation coefficient (lateral loading test in a hole)	
	Rock mass shearing test	Initial shearing strength of bedrock (c, ϕ), Remaining strength (c, ϕ), Deformation coefficient (D)	
	Jack test	Deformation coefficient (D), Bearing capacity coefficient (K)	
2 Bedrock sample test	Uniaxial compression test	Uniaxial compression strength (σ_c), Modulus of static deformation (E), Static Poisson's ratio (ν)	B Remark 2)
	Ultrasonic velocity measurement	Velocity of P wave (V_p), Velocity of S wave (V_s), Dynamic deformation ratio (E), Dynamic Poisson's ratio (ν_d)	
	Unit volume weight test	Unit volume weight (γ), Water content ratio (ω)	
	Water absorption ratio test	Water absorption ratio	
	Tensile test	Tensile strength (σ_t)	
	Creep test	Creep constant (η)	
	Gradation analysis test	In the case of soil bedrock, the test results are used for decisions about heading stability. In the case of mudstone and soft silty clay, they are used for determinations of swelling.	
	Submergence collapse test	In the case of soft rock, the test results are relevant to stability against water	
	Triaxial pressure test	Cohesiveness (c), Inner friction angle (ϕ), Remaining strength (c, ϕ)	
	X-ray analysis test	Kind of clay mineral (whether there is swelling clay or not)	
	Positive ion exchange capacity test (CEC)	Estimation of the amount of clay mineral content	
3 Measurement	Crown subsidence measurement	The stability of a tunnel crown is determined by observing the absolute amount of tunnel crown subsidence and by confirming the condition in section deformation.	A
	Convergence measurement	Judgments are made on the following based on the amount of displacement, displacement velocity, condition of displacement convergence, & the deformation of a cross section: 1. stability of peripheral bedrock, 2. appropriateness of design and execution of supports, 3. a timing for lining execution, etc..	A
	Underground displacement measurement	Appropriateness of the length of a rock bolt and appropriateness of design and execution are judged based on the information obtained from the measurement of loosened areas near a tunnel and the amount of displacement.	B
	Rock bolt axial capability measurement	Rock bolt axial capability and its effect are tested and the appropriate length and radius of the rock bolt are determined based on the amount of the strain created in the rock bolt.	B
	Rock bolt pull out test	An appropriate fastening method and an appropriate rock bolt length are determined based on the rock bolt pull out bearing capability.	Remark 3)
	Spray concrete stress measurement	Soil pressure at the back of spray concrete, Inner stress of spray concrete	B Remark 4)
	Ground surface and underground subsidence measurement	Judgments are made on the influence of tunnel excavation on a ground surface and the effectiveness of subsidence prevention measures. The estimation is made based on an extent of load on a tunnel.	B
	Steel arch support stress measurement	Judgments are made on the appropriate size and pitch of support and necessity of support according to the steel arch support stress. The value and direction of soil pressure on steel arch support and lateral earth pressure coefficient (K_0) are estimated.	B
	Measurement of the heaving	Judgments are made on the necessity and effect of invert.	

Remark 1) Measurement classification A refers to the measurement which must be executed for routine execution control. Measurement classification B refers to measurement chosen in addition to A, depending on the bedrock conditions. Even if the column is left blank or tests and measurement items are not shown in this table, necessary tests should be carried out.

Remark 2) Test items for bedrock sample tests are to be chosen based on the bedrock conditions.

Remark 3) The rock bolt pull out test are not treated as measurement but as an execution control (quality control) are not treated as measurement.

Remark 4) Of spray concrete stress measurements, the measurement in the tunnel radius direction is called soil pressure of the back side and measurement in a tangential direction is called inner stress of the spray concrete.

urement, convergence measurement) for the whole length of a tunnel. For a tunnel at a shallow depth, it is also important to measure ground surface subsidence. To apply the results from observations and measurements appropriately to the design and execution, bedrock conditions, support structures, and execution methods must be evaluated together with the test results. Control standards on the results of routine tests should be used for execution control so that the results can be utilized. The standards should be at the planning stage based on previous experience with similar tunnels.

References

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- 2) Taro Konda, Toshinori MIZUTANI: Materials of P.W.R. I. No. 1702 "Study Report on Tunnel Support Structure", June 1981
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4 FACILITIES ATTACHED TO ROAD TUNNELS

4.1 Preface

Attached facilities are installed in road tunnels according to the tunnel length, traffic flow volume, and design speed to ensure safe and smooth traffic and offer a comfortable environment.

Since the cost of construction and maintenance of attached facilities increase with tunnel length, the planning of the facilities, which influences total tunnel planning, is very important.

The facilities consist of ventilation lighting and emergency facilities. The ventilation and lighting facilities offer a safe and comfortable environment and prevent accidents. On the other hand, the emergency facilities are to prevent an accident or fire inside the tunnel from spreading and becoming a major disaster.

In Japan, the first road tunnel with major facilities was the Kanmon Tunnel constructed in 1958. After that, following the construction of a trunk line network, road tunnels with many kinds of attached facilities were constructed on expressways such as the Nagoya-Kobe Expressway and Tokyo-Nagoya Expressway, and other ordinary roads. Attached facilities have been improved in many ways as exemplified by those installed in the Kan-etu Tunnel, the longest road tunnel in Japan.

The following information discusses ventilation, lighting and emergency for road tunnels.

4.2 Ventilation facilities

The ventilation facilities are set in order to ensure a safe and comfortable environment for motorists and a suitable working environment for maintenance workers by diluting harmful exhaust fumes.

4.2.1 Planning and survey of ventilation facilities

1) Planning

The planning of ventilation facilities is a principal part of the total tunnel planing. As it not only determines the tunnel structure such as a shape of tunnel cross section but also influences vertical or inclined shafts, resulting route selection, it must be carefully planned as a part of the fundamental planning.

2) Investigation

In the planning of the ventilation facilities, investigation on traffic, meteorology, environment, topography, and geology must be carried out.

The traffic investigation needs studies of traffic flow volume, which is the basis for determining fresh air requirement, composition of vehicle types, traffic conditions, and related factors.

The meteorological investigation is composed of pressure differences between shafts, wind direction, wind velocity, temperature, and humidity. Usually only some of these measurements are chosen to be done depending on what is designed.

The investigation of topography and geology is made to supply data for the design of ventilation shaft, the incline, the ventilating station, and the main tunnel. The environmental survey examines exhaust gas around tunnel entrances or exhaust towers, and noise from a ventilator after completion.

3) Traffic flow volume used for ventilation design

Traffic capacity which is a maximum traffic flow volume under a general condition of the tunnel is used in principle as the traffic volume used for the ventilation design. Because fresh air requirement is determined by the composition of vehicle types and the running speed, as well as the traffic

volume, it is necessary to examine ventilation conditions corresponding to the traffic where traffic volume is lower than the design capacity.

When design hourly volume derived from designed daily volume is greatly lower than the design capacity, however, the design hourly volume can be used as the traffic volume for ventilation design.

4) Objective materials of ventilation and their concentration

(1) Objective materials

Carbon monoxide, nitrogen compounds, hydrocarbons and other various components can be thought as the objective harmful materials influencing the design of ventilation facilities. Carbon monoxide is most typically used for ventilation design. When ventilation is designed from the fresh air requirement needed for carbon monoxide dilution, the concentration of other harmful gas materials comes within safe limits. Then the harmful material is represented in the ventilation design by the amount of carbon monoxide exhaust gas.

On the other hand, visibility inside the tunnel is hindered mainly by black smoke contained in diesel motorcar exhaust gas. So called soot, including black smoke and flinging dust, is the objective material in the ventilation design in this aspect.

Then, carbon monoxide and soot is used as the objective material for the ventilation design.

(2) Exhaust volume of harmful component

The exhaust volume of harmful component is greatly different depending on the vehicle types or the running condition. To estimate precisely the exhaust volume, it is desirable to establish exhaust gas units corresponding to the traffic flow volume, the composition of vehicle types and the running condition.

(3) Design concentration

Standard values of design concentrations of soot and carbon monoxide which are necessary to ensure the safety and comfort of traffic and the safety of maintenance working, are shown on Table-4.1.

Table-4.1 Design Concentration¹⁾

design speed	Design concentration of soot (100m transmittance)	Design concentration of carbon monoxide
over 80km/h	50 %	100 ppm
below 60km/h	40 %	

5) Examination of mechanical ventilation necessity

The need for mechanical ventilation should be examined considering the length, grade, traffic conditions, and meteorological conditions of tunnels.

The limit of natural ventilation varies with conditions of geometry, traffic (traffic direction, traffic flow volume, composition of vehicle types and running speed) and meteorology. It is determined from the conditions when fresh air volume derived from ventilation by traffic and natural wind exceed the fresh air requirement. The relationship, between the tunnel length and traffic flow volume of the main tunnels to indicate the necessity of mechanical ventilation are such as $LN=600$ in the case of bi-directional traffic and $LN=2,000$ in the case of one-way traffic (L:length of tunnel km, N:traffic flow volume vehicles/h). If the values calculated from L and N are greater than these values, the mechanical ventilation usually is necessary.

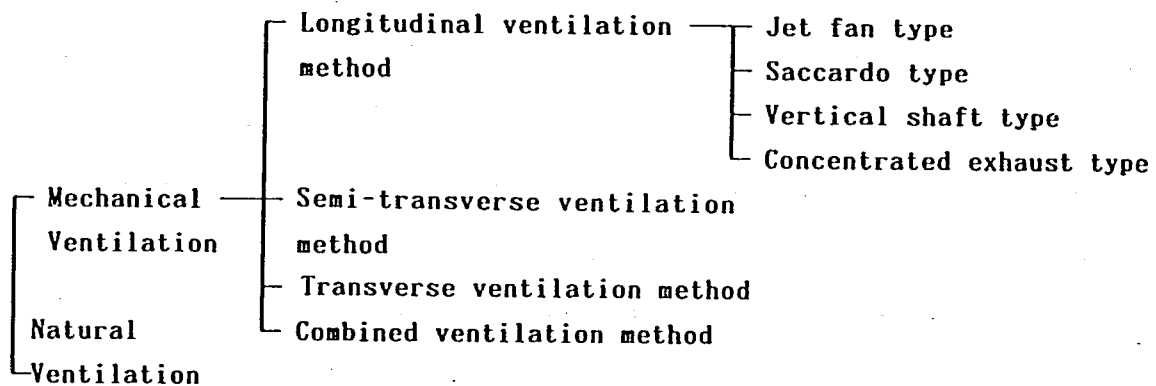
6) Ventilation methods

The most appropriate ventilation method, making the best use of its inherent characteristics, must be selected after each ventilation method is syntheti-

cally examined on the conditions such as tunnel length, fresh air requirement. Attention must also be paid to various conditions such as topography, feature, geology, traffic conditions, meteorological conditions, environmental conditions, ventilation work in the case of fire, maintenance, economy, stage construction and other factors.

Types of ventilation methods are classified as shown in Table-4.2, depending on the direction of air flow. An electric dust collector invented recently is used together with the longitudinal ventilation method. It cleans polluted air concerning soot and re-uses it.

Table-4.2 Kinds of Ventilation Methods''



4.2.2 Design of ventilation facilities

In designing ventilation facilities, various conditions such as the fresh air requirement, the natural ventilation, the mechanical ventilation, the ventilator and the ventilation operation should be examined with sufficient precision at each stage of the planning, such as the stage of determination of cross-section of tunnel and duct, or the stage of a preliminary design of the ventilation facilities.

1) Fresh air requirement

(1) Estimate of fresh air requirement

The fresh air requirement is determined from the exhaust volume of soot and carbon monoxide as mentioned above.

① Fresh air requirement against soot

Exhausted soot volume from vehicles is different depending on the kind, model, or maintenance condition of their engines. Then soot exhausted should not be dealt with as a mean value, but it is calculated from formula (1) with a method considering standard deviation of exhausted volume.

$$Q = \left\{ \frac{3\sigma + \sqrt{9\sigma^2 + 8\mu \cdot K_{v1} \cdot A_r \times 1000}}{\sqrt{8 \cdot T_t \cdot A_r \times 1000 \times K_{v1}}} \right\}^2 \quad \text{----- (1)}$$

Here,

Q : necessary fresh air requirement per 1km of tunnel's length (m³/s/km)

μ : mean value of exhaust soot volume from vehicles (m²/km)

σ : standard deviation of exhaust soot volume from vehicles (m²/km)

A_r : cross-section area of tunnel roadway (m²)

T_t : mean headway of vehicles (sec)=3600/N

K_{v1} : design concentration of soot (1/m, cf. Table-4.1)

② Fresh air requirement against CO

The fresh air requirement against CO is calculated from formula (2), considering the relation between CO concentration and exposure time.

$$Q = \frac{\mu}{T_t \cdot K_{co} \times 10^{-6}} \quad \text{----- (2)}$$

Here,

μ : mean value of exhaust CO volume from vehicles (m³/km)

K_{co} : design concentration of CO (ppm, cf. Table-4.1)

(2) Estimate of standard fresh air requirement

The standard fresh air requirement Q_0 is the quantity for the averaged running condition of vehicles without a vertical grade and below 400m above sea level. The standard fresh air requirement is estimated by formula (3).

$$Q_0 = q_0 \cdot N \cdot L \times 1/1000 \text{ -----(3)}$$

The standard fresh air requirement unit q_0 is the fresh air requirement per 1000m of tunnel and one vehicle/h of traffic flow volume. Q calculated from formulas (1), (2) and traffic volume leads to q_0 .

3) Estimate of required fresh air requirement

The required fresh air requirement Q_{res} is calculated by using formula (4), from the standard fresh air requirement Q_0 multiplied by the grade and speed coefficient (K_i) and altitude coefficient (K_h). For the design concentration of carbon monoxide, however, the grade and speed corrections are not necessary.

$$Q_{res} = Q_0 \cdot K_i \cdot K_h \text{ -----(4)}$$

2) Ventilation wind pressure

Wind pressure requirements of the ventilator is determined by the fresh air requirement necessary in a ventilation section of ducts inside tunnels and connecting ducts. The specifications and number of ventilators will be determined by the wind pressure requirement.

3) Ventilator

There are several kinds of ventilators: such as blowers, jet fans, electric dust collectors.

A blower for tunnel ventilation is generally used under the conditions of

high wind volume and low wind pressure. If only one blower is installed in a ventilation system, the fresh air requirement will be insufficient for many hours in case of breakdown. For this reason, in principle two or more blowers are installed side by side on one ventilation section to disperse dangers.

Jet fans, currently in use have 1000 mm, 1250 mm and 1500 mm calibers.

The principle of electric dust collectors is that polluted micro particles are passed through a space of ion flux and given an electric charge. The charged micro particles are caught on the surface of a charged dust collection board.

4) Ventilation duct

The ventilation ducts are composed of ducts inside the tunnel, and connection ducts between tunnel and shaft. It should be designed based on not only aerodynamics but also economics, taking into consideration costs of both construction and maintenance.

The ducts inside the tunnel are constructed along the roadway in transverse or semi-transverse ventilation methods.

The connection duct is for connection of ducts inside the tunnel with the ventilating station.

5) Ventilating station

The ventilating station is a structure which functionally arranges the ventilator, electric equipment, control equipment and other auxiliary equipment, it possesses absorption and exhaust openings to ventilate the main tunnel. There are two kinds of ventilating stations, portal and underground ventilating stations.

Construction of the building must be functional, easily maintained and inspected for performance evaluation.

4.2.3 Manufacture and installation

Manufacture and installation of the ventilator should be done in safe, as well as be sufficient for specifications.

The stage of work of the main tunnel construction, vertical shaft construction for ventilation, pit work, and how equipment will be installed in the ventilating station in the construction of the ventilating station should be taken into account.

4.2.4 Ventilation control

The purpose of the ventilation control is that required fresh air corresponding to the traffic conditions be supplied with minimum consumption of power.

1) Control sensor

Instruments for measuring ventilation and traffic consist of a light transmittance (VI meter), apparatus for traffic flow volume, a wind vane and anemometer.

The VI meter is an apparatus to measure soot concentration inside the tunnel. The principle is that the decreased intensity of light transmitted through soot layers form a sending unit to a receiving unit at an interval of 100m is measured and the soot condition inside the tunnel is determined from the amount of light decreased.

In measuring CO concentration, there are several methods such as the nondispersive infrared analytical method, or the electrical potential analytical method.

2) Control apparatus

Three kinds of automatic control method of ventilation are used. They are

feedback, feedforward and program method.

In the feedback control they measure the concentration of pollutants inside the tunnel and feed the result back to the control. This method is conducted in many tunnels.

The feedforward control is a method to make the necessary correction before traffic conditions effect the tunnel control system by using information about traffic conditions on the way to the tunnel.

The program control is a method whereby the ventilator is operated on the basis of a preset program.

4.3 Lighting facilities

As the purpose of tunnel lighting is to insure safety and smoothness of traffic inside the tunnel, lighting facilities are designed to give a certain road luminance according to design speed, traffic flow volume, and alignment of roads.

The lighting is composed, as shown in Fig.-4.1 (the case of bi-directional traffic), of fundamental, entrance, exit and connecting roads lighting and emergency lighting.

The luminous source should be selected with consideration for tunnel characteristics such as how an object appears in exhaust gas.

Luminaries should be selected in consideration of tunnel configuration compatibility for maintenance works and light distribution characteristics.

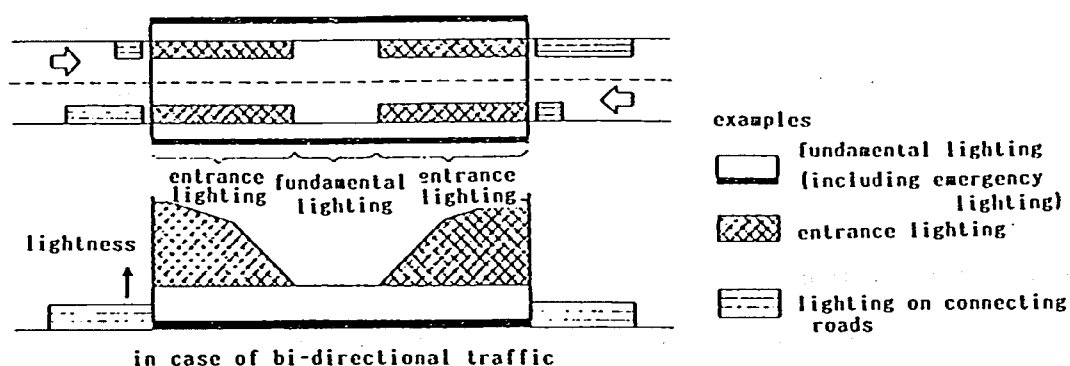


Fig.-4.1 Composition of Tunnel Lighting²¹

4.3.1 Fundamental lighting

The fundamental lighting is necessary for drivers inside the tunnel to see obstacles in front, which is determined according to the design speed of the roads. For fundamental lighting luminaries are arranged at a regular intervals throughout the tunnel.

Standard values of averaged road luminance are shown in Table-4.3. However, lower values than those can be used in response to the traffic flow volume and the tunnel length or during night.

Luminaries are installed, in principle, at a point 4m above the road surface, that is, outside clearances. There are three kinds of lighting arrangements shown in Fig.-4.2, opposite, staggered, and central arrangements.

When the interval between luminaries is determined in designing, glittering must be prevented. So, intervals between luminaries versus installation height should be $S \leq 2.5H$ in the opposite arrangement, $S \leq 1.5H$ in the staggered and the central arrangements (H:the installation height of luminaries, S:the interval between luminaries).

Table-4.3 Averaged Road Luminance of Fundamental Lighting²⁾

Design speed (km/h)	Averaged road luminance (cd/m ²)
100	9.0
80	4.5
60	2.3
below 40	1.5

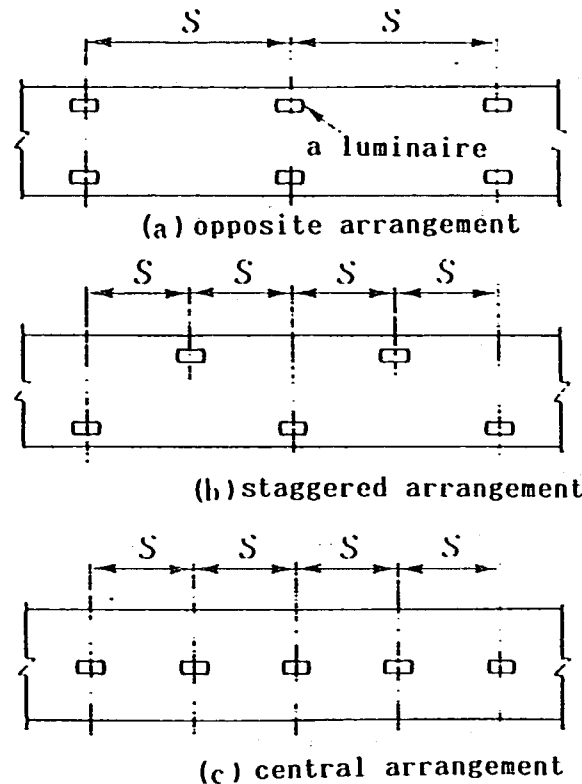


Fig.-4.2 Spacing of Lighting Arrangements²⁾

4.3.2 Entrance lighting

Drivers adapting themselves to high outside luminance during the daytime are usually slow in adapting to the dark circumstances inside the tunnel when they come into the tunnel. To reduce this problem, entrance lighting at a higher level than that of the fundamental lighting is necessary at the entrances of the tunnels longer than 50m.

The entrance lighting is composed of threshold, transition, and adaptation zone, as shown in Fig.-4.3, and installed on tunnels longer than 50m. Standard values of the road luminance and the length of the entrance lighting are determined by the field luminance ($4,000 \text{ cd/m}^2$ on most of tunnels), the design speed and the tunnel length. The road luminance is increased by 1.5 times and decreased 0.75 times of standard values, in cases of field luminance $6,000 \text{ cd/m}^2$ and $3,000 \text{ cd/m}^2$, respectively.

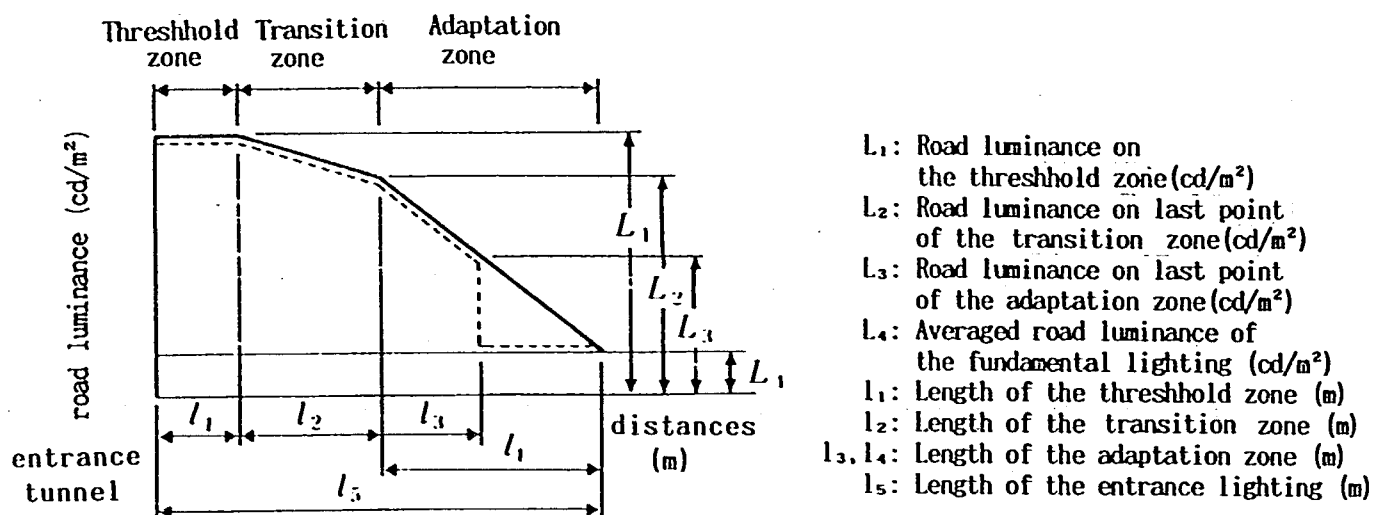


Fig. -4.3 Composition of Entrance Lighting²⁾

4.3.3 Exit lighting

When the traffic flow volume is great and the car spacing is small, it becomes difficult for drivers to see clearly at the exit. Exit lighting shall be installed on the tunnel with a field luminance over 6,000 cd/m², a design speed over 80km/h and for a length of over 400m.

4.3.4 Lighting of connecting road

On roads just outside the tunnel, lighting facilities are set if necessary to show a change of road width, or other changes near the exit or entrance of tunnels at night.

4.3.5 Emergency lighting

In case tunnel users encounter a sudden power outage, emergency lighting shall be set for safety.

There are two methods for providing emergency lighting. These are an alternating current generator method using a diesel engine as a motor, and a method using a battery and inverter.

Lighting at about 1/8 the level of the fundamental lighting should be supplied.

4.4 Emergency facilities

As the tunnel is a closed space, it is necessary to sufficiently consider disaster prevention countermeasures against fire and other accidents. Although a vehicle fire rarely occurs, a disastrous accident such as the Nihonzaka Tunnel fire may happen and careful countermeasures are needed.

Disaster countermeasures help to prevent accidents and minimize damage, should an accident occur. The emergency facilities designed to minimize damage must be planned with the understanding that they are part of the entire disaster prevention system, but not the whole system.

The emergency facilities should be planned after recognizing its purposes and usage definitely and reassuring the maintenance or control system. In cases of urban tunnels which greatly influence their environs and special tunnels such as undersea tunnels, it is desirable to consider their special characteristics.

4.4.1 Kinds of facilities

If a fire or other accident occurs inside the tunnel, it is important to inform tunnel users of it and to prevent the occurrence of a secondary disaster. For these purposes, typical facilities are listed in the left column of Table-4.4, which are information and alarm, fire fighting, and refuge and other facilities.

Table-4.4 Standards of Emergency Facilities of Road Tunnels³⁾

Tunnel Classification		AA	A	B	C	D
Emergency facilities						
Information, alarm equipment	Emergency telephone	O	O	O	O	
	Pushbutton type information equipment	O	O	O	O	
	Fire detector	O	Δ			
	Emergency alarm equipment	O	O	O	O	
Fire Extinguishing Equipment	Fire extinguisher	O	O	O		
	Fire plug	O	O			
Escape and Guidance Equipment	Guide board	O	O	O		
	Smoke discharge equipment, escape passage	O	Δ			
Other equipment	Hydrant	O	Δ			
	Radio communication auxiliary equipment	O	Δ			
	Radio re-broadcasting equipment, loudspeaker equipment	O	Δ			
	Water sprinkler system	O	Δ			
	Observation equipment	O	Δ			

Note: In the table, O indicates that the facility should be installed as a rule, and Δ indicates that the facility should be installed as required.

1) Information and alarm equipments

Information and alarm equipment alert a road administrator, fire station or police station and inform drivers inside and outside the tunnel of a fire or accident.

There are some information facilities such as emergency telephones, push-button alarms and fire detectors. Emergency alarm equipment is to inform drivers inside and outside the tunnel of accidents reported from information equipment.

2) Fire extinguishing equipment

There are an initial extinguishing by tunnel users and a fullscale fire-fighting by professional firemen, the emergency facilities attached to the road tunnel are for the use of an initial tunnel fire. there are fire extinguishers and fireplugs as the extinguishing equipment. They must be easy to use by an unskilled person so he can fight the fire until the professional firemen arrive.

A fire hose is attached to the fireplug and its valve is possible to use on the spot. Water fireplugs are installed in most tunnels, but foam fireplugs are installed in some of them.

3) Escape and Guidance equipments

The escape and guidance equipment are facilities to help refuge activities. Those contributing to secure the refuge environment are smoke exhaust equipment and escape passage. Contributing to refuge information is a refuge plate.

4) Other equipment

Other equipment than that described above from 1) to 3), is emergency equipment designed especially for very long tunnels or large traffic flow volume, or equipment for other purpose then emergency but contributing to firefighting.

Examples of other equipment are, assistant wireless communication equipment, sprinkling equipment, hydrant, a radio re-broadcasting apparatus, a public-address system and ITV equipment.

4.4.2 Planning of the facilities

1) Tunnel classification

The way to set emergency facilities are grouped into the five classes shown in Fig.-4.4 in relation to the tunnel length and the traffic flow volume. Long tunnels on roads with a high design speed such as a national expressway, or tunnels with bad perspective owing to especially winding horizontal or vertical alignment should be in the class higher by one class than the standard.

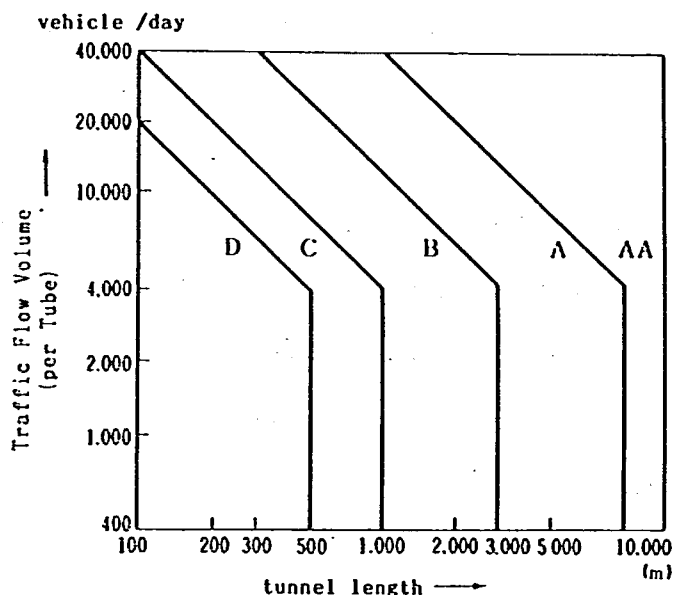


Fig.-4.4 Tunnel Classification"

2) Planning of the facilities

Facilities shown on Table-4.4 should be set in tunnels for use in case of fire or other emergencies and disaster prevention, depending on the tunnel classification. Circles in Table-4.4 indicate facilities that should always be installed as a rule. Triangles indicate optional facilities which maybe needed depending on the tunnel structure, the traffic conditions or other conditions.

4.4.3 Design of the facilities

1) Information and alarm equipment

(1) Emergency telephone

The emergency telephone should be easy to use and capable of the calls to and from the user and administration at the same time. The phones should be set in interval less than 200m on side walls of the tunnel.

There are two setup ways for telephones. Either the way that every telephone connects to an administrator when one picks up a receiver or the way that a user may choose to call the police station, fire department or someone else. Emergency telephones are one of the most frequently used of all information equipment.

(2) Push button

This alarm is similar to the fire alarm type used generally and is manually operated by anyone. The height of installation should be 1.2-1.5m on the side walls of the tunnel for easy operation. Standard spacing is about 50m apart staggered or on one-side. They are sometimes installed adjacent to fire extinguishers or fireplugs.

(3) Fire detector

Fire detectors, because of the peculiar environment inside the tunnel, should be the beam type to detect the amount of glittering or the amount of radiation in the initial stage of a fire and should not be influenced by exhaust gas from vehicles or ventilation flow. Among the beam methods, there are fixed radiation and glittering, two-wave-length and CO₂ sympathetic vibrations methods. Recently, the two-wave-length method and CO₂ sympathetic vibrations method have been used with confidence in many cases. They are mounted on side walls at a height suitable for fire detection but still easy to maintain and inspect. Spacing should be arranged considering the fire detection ability and the discharge sections of sprinkling equipments.

2) Fire extinguishing equipment

(1) Fire extinguisher

The fire extinguisher is a firefighting tool used in the initial stages of a fire and its ease of operation is important for general use. They should be selected for use on both oil and electric fires, and should not generate gases harmful to humans. Standard spacing should be 50m. Fire extinguisher boxes (a pair of fire extinguishers are set usually with fireplugs) are placed on side walls at a height for easy use.

(2) Fireplug

Fireplugs should be available to fight initial stages of a fire along with fire extinguishers. They must be easy to operate for the general public even when they have no experience. It is desirable to install the type that discharges water as soon as a valve opens. Standard spacing should be 50m apart. They are installed on side walls at a height for easy hose removal in a fireplug box.

3) Escape and Guidance equipment

(1) Guide board

The guide board shows information such as the distance and direction to the emergency pass and its position. It is to induce drivers and others inside the tunnel to go out. The refuge plate is lighted, if necessary, by internal illumination.

(2) Smoke exhaust equipment

The alternative of the smoke exhaust equipment is determined in relation to the general ventilation design. It is designed within the limits of the planned ventilation method, considering traffic conditions, and other factors.

In the cases of the semi-transverse or the jet fan longitudinal ventilation

methods, it should be designed to work inversely to ventilation, and electronic wiring should be fireproof in the latter case. In the cases of the transverse and the semi-transverse ventilation methods which are designed to exhaust smoke, duct cooling equipment should be installed to prevent thermal damage to the ventilator.

(3) Escape passage

Typical escape passages are I) emergency tunnel built beside and along the main tunnel, II) emergency connection tunnel which join the main tunnel and a parallel emergency tunnel, or two adjacent main tunnels and III) emergency exits of an urban tunnel to escape from the tunnel to above ground. Factors to be considered in passage design are tunnel length, traffic system, traffic flow volume, smoke exhaust equipment and topography.

Spacing of emergency connection tunnel is about 750m apart for two adjacent uni-directional traffic tunnels. Spacing is about 350m for most bi-directional traffic tunnels using a longitudinal ventilation design. Auxiliary equipment for emergency passes should provide the necessary illumination to ensure a safe escape from the tunnel.

Doors should be able to shut off smoke and be fireproof. They are duplicated in some cases. They should be easily opened and automatically closed.

4) Other equipment

(1) Hydrant

Hydrants are for firefighting inside the tunnel by firemen not by drivers. Although it is standard to put hydrants at both an entrance and an exit of the tunnel, they should also be at emergency parking lanes inside the tunnel and near the entrance to emergency connection tunnel, if necessary. When hydrants are installed inside the tunnel, they should be installed at both the entrance and the exit of the tunnel. The mouth should be 65mm in caliber operated bi-

directionally.

(2) Radio communication auxiliary equipment

This equipment is to communicate with the outside of the tunnel in a rescue action or similar emergency.

(3) Radio re-broadcasting equipment

This includes an induction antenna inside the tunnel and to receive and retransmit radio re-broadcasts that are received outside the tunnel. It can interrupt radio broadcasting in an emergency and transmit information to drivers through their car radio.

(4) Loudspeaker equipment

A road administrator can notify users inside the tunnel in case of a fire or other accident with this system.

(5) Water sprinkler

Equipment discharges minute droplets of water from sprinkling heads and helps suppress fires by cooling. The water discharge section should be over 50m long considering that the area of fire coverage would be 20-30m.

The standard discharge volume should be 6 liter/min/m². A suitable reservoir should be able to support a discharge for over 40 minutes.

(6) Observation equipment

(I.T.V.) is used to confirm information from other sensors and to monitor the progress fire extinguishing or escape behavior in an emergency. Under normal circumstance, traffic conditions are monitored for traffic control. Standard spacing of cameras is about 200m apart on two-lane roads.

If possible, ITV should be linked with other information equipment such as the emergency telephone, the push button alarm, and the fire detector in order to turn the camera toward an accident or fire.

Reference

- 1) Japan Road Association: Technical Standard of Road tunnels (Ventilation), December, 1985.
- 2) Japan Road Association: standard of Road Lighting Facilities, April 1981.
- 3) Gyousei: Notifications of Technical Standards of Roads (Third Revision), April, 1987.

Appendix 1

Table Ground

Ground classes	Rock kinds	Deciding standards of ground										
		(1) seismic velocity (V_p , km/s)	(2) ground strength ratio	(3) boring core								
				condition of core	RQD(%)							
		1.0	2.0	3.0	4.0	5.0	6.0					
A	a								Core recovery is over 90% and cores show perfect form with length over 20cm with almost no small pieces.	over 80		
	b											
	c											
	d ₁											
B	a								Core recovery is over 70% and cores show large rock pieces -short column-stick from with length of about 10-20cm, sometimes about 5 cm.	90~60		
	b											
	c											
	d ₁											
C	I	a							over 4	Core recovery is 40-70%, cores show condition with many cracks and easily crushed, then a large quantity of small pieces below 5cm are obtained. Difficult or impossible to restore to the original form	70~20	
		b										
		c										
		d ₁										
		d ₂										
	II	a							over 4			
		b										
		c										
		d ₁										
		d ₂										
D	I	a							4~2	Core recovery is low, below 40% in many cases, and cores show small pieces or sometimes sand mixed with square stones or clay.	below 20	
		b										
		c										
		d ₁										
		d ₂										
	II	e							over 2			
		a										2~1
		b										
		c										
		d ₁										
E	a							below 1	—	—		
	b											
	c											
	d ₁											
	d ₂											
	e											

Notes) 1. Rock kinds a: Metamorphic rock (phylite, graphite schist, silicate graphite schist, quartz schist, green schist, gneiss, serpentinite, hornfels, etc.)

b: Paleozoic and Mesozoic strata (slate, sandstone and conglomerate, graywacke, limestone, quartzite, schalstein, etc.)

c: Volcanic rock (liparite, andesite, basalt, etc.)
dyke rock (granitic quartz porphyry, quartz porphyry, diabase, etc.)
plutonic rock (granite, diorite, etc.)

2. Condition of boring core. RQD and crack spacing are adapted to a rock kinds of a, b, c, d₁.

Classification

(4) Ground condition (result of ground investigation or condition of excavation surface)	(5) Observation		(6) Condition after excavation	
	fracture of hammer hit	crack spacing (cm)	Stability of cutting surface	convergence (mm)
- Nature of ground is very hard and fresh, showing large massive structure, almost without cracks, and continuously stable. - No deterioration by water	A hammer is sprung back. Cracked by strong hit on a fresh surface.	over 100~50	Stability is very good and does not become loose for a long time.	very little
- Nature of ground is fresh and hard with relatively few cracks. The nature of ground is fairly hard but there is deterioration by weathering. The nature of ground is hard, but laminated with bedding or sistosity and easy to crack on those surfaces. - No deterioration by water is found.	Cracked in relatively large pieces by strong hit of hammer along cracks or joint in most cases.	70~30	Cutting surface is stable and local spalling is found on unsupported surface, which is mostly stable. Ground needs to be partially supported on locally loose portion.	very little
- Rocks are deteriorated by weathering and the nature of ground is fairly soft. The nature of the ground is relatively hard with many fine cracks in which there is thin clay. - Rocks have considerable bedding, very thin and easy to crack. - It is permeated with small narrow faults. - Little deterioration by water is found.	Cracked easily by hammer. Cracked in relatively small pieces along crack surfaces but difficult to crack along other surfaces.	below 50	Cutting surface is stable. Ground needs to be sprayed on crown part of unsupported surface just after blast.	below 50
			Cutting surface is stable. Ground is spalling near top of unsupported surface and in need of pre-defence support.	
- It is considerably deteriorated by weathering, part is already soil, and soft fragile, remaining is a relatively hard portion inside it. It is composed of very many cracks and easy to scrape from every part other than cracks. It is a fracture zone not progressed to clay, mixed with clay soil and small pieces of rocks, containing relatively hard portion. - Soil, talus, etc. - It is DII when cutting surface is softened by water.	Crushed easily by hammer. Rock is very fragile and cracked easily by the tip of a finger.	—	Considerable spalling is found on both cutting and unsupported surfaces in some cases, a little squeezing is found on sides in other cases. Ground is in need of pre-defence support and face protection in an early stage.	below 60
	Crushed by a little tap of the hammer. A tip of hammer sticks in.	—	Considerable spalling is found on cutting face. Size squeezing is found on unsupported surface.	below 200
Relatively wide and remarkably clayish fault, fracture zone, large talus zone, etc. with remarkably side pressure and surrounding pressure. Considerable deterioration by water is produced as it is softened.		—	Squeezing is found on the cutting surface and collapsed in notable cases. Squeezing is found on the unsupported surface by surrounding pressure.	below 400

d: Tertiary and lower diluvium (limestone, shale, silicate shale, sandstone and conglomerate, tuff, tuff breccia, etc.)

Provided that subdivided into d₁ and d₂ based on unconfined compression strength, (q_u) 200kgf/cm², of fresh rock sample.

e: Upper diluvium (loam and clay, pyroclastic rock), alluvium (talus, surface soil, etc.)

Appendix 2

Table Standard Patterns of Supportig Structure
(in case of about 10m inside diameter and top heading method)

Ground classes	Rock bolts			Steel arched supports			Depth of shotcrete (cm)	Thickness of lining (cm)	Thickness of invert (cm)
	length (m)	Construction spacing		Top heading	Bench	Longitudinal pitch of steel support (m)			
		Surrounding direction (m)	Longitudinal direction (m)						
A	Determined in each case to be very different owing to ground condition.								
B	3.0	1.5 (only top heading)	2.0	None	None	—	5	30	—
C I	3.0	1.5	1.5	None	None	—	10	30	(40)
C II	3.0	1.5	1.2	U-125 U-21	None	1.2	10	30	(40)
D I	4.0	1.2	1.0	U-125 U-21	U-125 U-21	1.0	15	30	45
D II	4.0	1.2	below 1.0	U-150 U-29	U-150 U-29	below 1.0	20	30	50
E	Determined in each case to be very different owing to ground condition.								

Note 1) Rock bolts

① Standard diameter of rock bolt should be about 25mm taking into account construction adaptability, etc.

② When grouting forepoling rock bolts are set on face crown, rock bolt in that part can be omitted.

Note 2) Invert

① Invert can be constructed even in cases of ground classes CI and CII when long term stability is doubtful owing to geological conditions such as mudstone, tuff, etc.

② Invert can be omitted even in the case of ground class DI when rock strength is enough in the long term and no squeezing is expected.

Note 3) Wire netting

① It should be installed near the crown in ground classes of A, B, CI, CII, if necessary.

② It is generally installed on the top heading in ground class DI and on both the top heading and bench in ground class DII.

③ The wire netting can be omitted in cast that steel fiber reinforced concrete (SFRC) is used.

Note 4) Expected convergence

For ground type DII, 10cm of convergence is generally expected and designed on the top heading.

The expected convergence should be properly modified by measurements during actual construction.

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Synopsis:

This report consists of the four chapters showing the present road tunnel technology in Japan. The contents are mainly based on the technological standards applied to Japanese road tunnels, which are almost all cases mountain tunnels. Chapters 1-3 mainly discuss investigation method, designing and execution method of work of tunnel structures. Chapter 4 discusses facilities attached to road tunnels.

Key Words: Tunnel, Design, ventilation, lighting, emergency

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