4. ATTACHED FACILITIES DESIGN AND OPERATION

Kind of tunnel facilities

1) Ventilation
2) Lighting
3) Emergency facilities

Full-scale test tunnel in NILIM and PWRI

Length : 700m
Area : 57m^2 (equal to 2 lanes road tunnel)
Ventilation : axial fan (300m^3/sec)
Lighting : sodium lamp

What is a Ventilation System?

- Road tunnel is enclosed space with passing vehicles, thus ventilation is often required to maintain a safe environment within the tunnel.

Source: http://www.pref.akita.jp/chuodo/new/newimg/h19.06.29pic/J-fan-large.jpg
http://www.g-mark.org/award/describe/34581

Ventilation Towers of YAMATE Tunnel, Metropolitan Expressway

Design concentration for ventilation

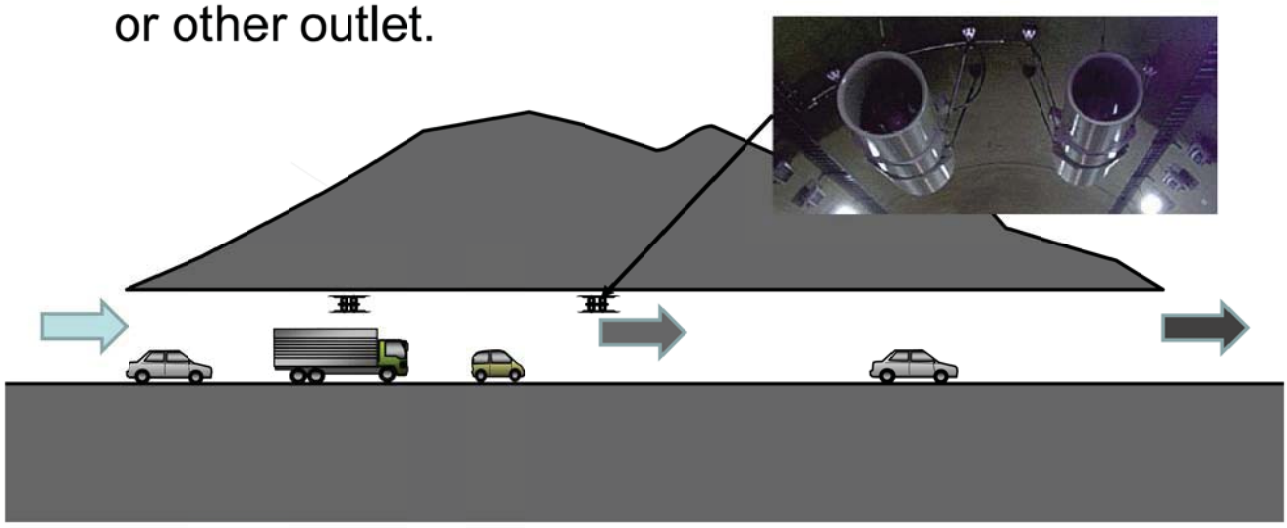
design speed	Design concentration of soot (100m transmittance)	Design concentration of carbon monoxide
over 80km/h	50 %	100 ppm
below 60km/h	40 %	

Ventilation method

- Mechanical Ventilation
  - Longitudinal ventilation method
    - Jet fan type
    - Saccardo type
    - Vertical shaft type
    - Concentrated exhaust type
  - Semi-transverse ventilation method
  - Transverse ventilation method
  - Combined ventilation method
- Natural Ventilation

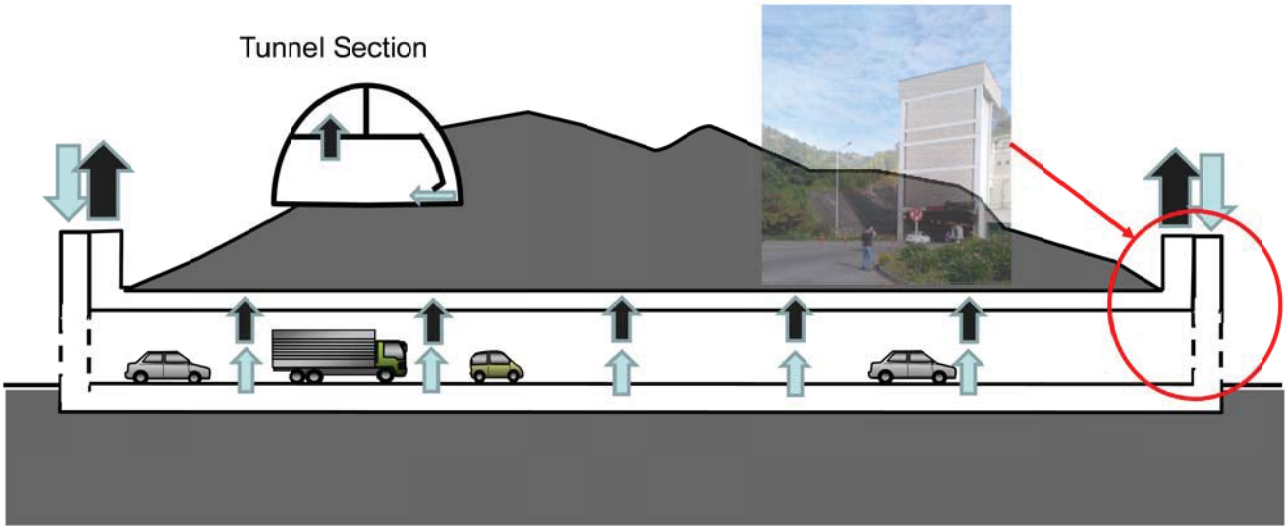
Longitudinal ventilation system

- Longitudinal ventilation system has the simple ventilating system. It sends the fresh air from the entrance of tunnel, and emit from the other side or other outlet.

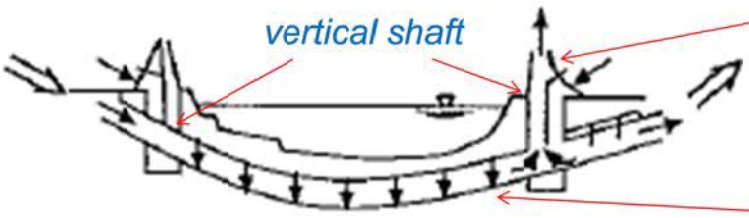


Transverse ventilation system

- Transverse ventilation system supply the fresh air and remove the exhaust air across the tunnel.



Example of Ventilation System

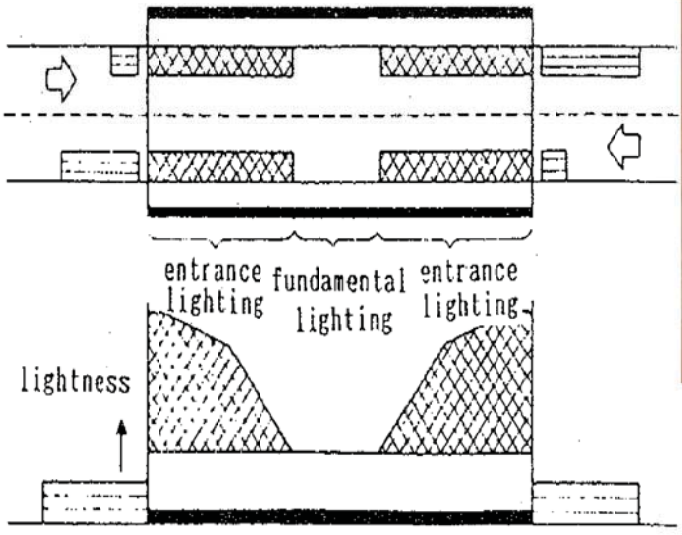


exhaust tower (concentrated exhaust)

exhaust ducts (semi-transverse ventilation)

exhaust tower (concentrated exhaust)

Composition of tunnel lighting



in case of bi-directional traffic

examples

fundamental lighting (including emergency lighting)

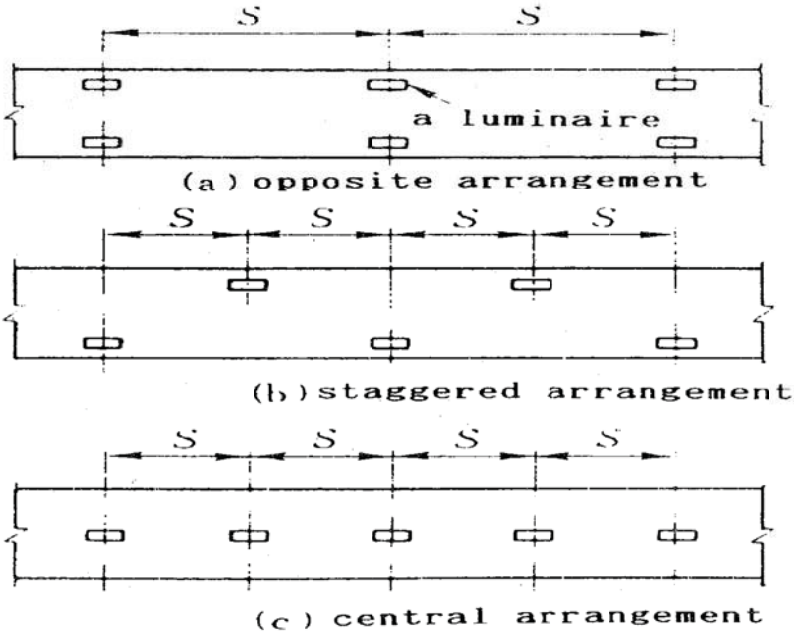
entrance lighting

lighting on connecting roads

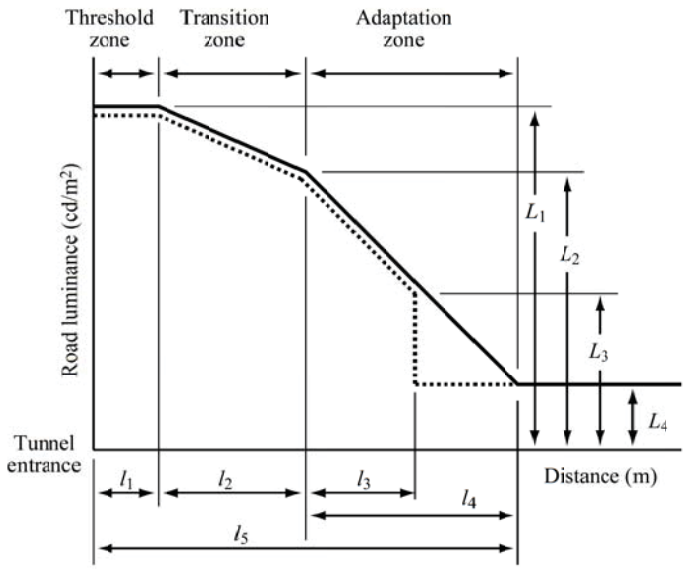
Average road luminance in fundamental lighting

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

Spacing of lighting arrangements

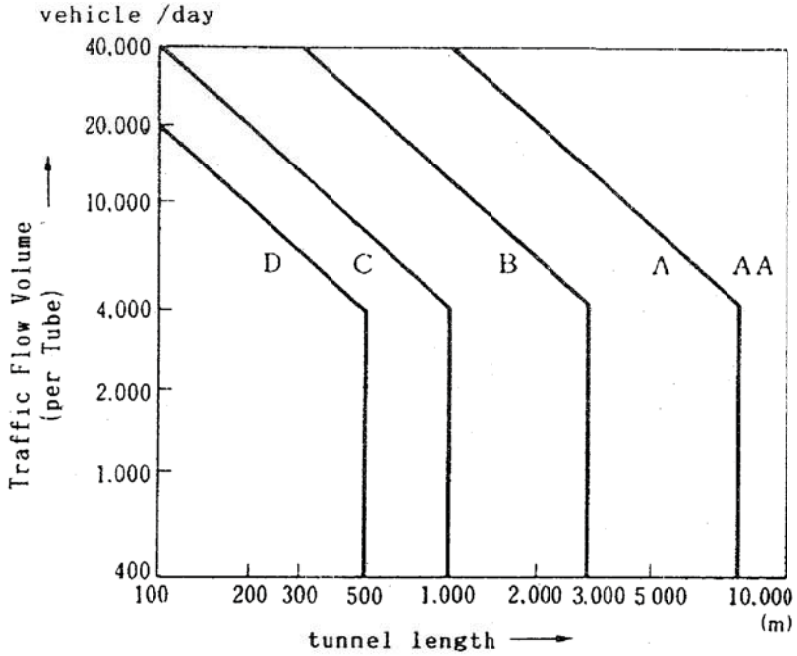


Composition of entrance lighting



L_1 : Road luminance on the threshold zone (cd/m^2)
L_2 : Road luminance on last point of the transition zone (cd/m^2)
L_3 : Road luminance on last point of the adaptation zone (cd/m^2)
L_4 : Averaged road luminance of the fundamental lighting (cd/m^2)
l_1 : Length of the threshold zone (m)
l_2 : Length of the transition zone (m)
l_3, l_4 : Length of the adaptation zone (m)
l_5 : Length of the entrance lighting (m)

Tunnel classification



Emergency facilities in road tunnel

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

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

Emergency telephone

Fire extinguisher and Plug

5. MAINTENANCE CONCEPT

Defects and deformation

Defects in terms of the position of tunnel

Crack on lining

Crack on portal

Heaving of road surface

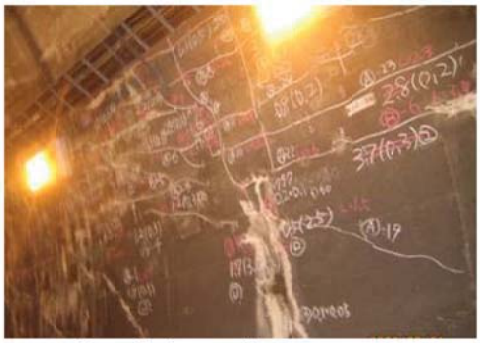
Deformed ditch in roadside

Bump on sidewall

Leakage in joint

Defects by external load

Earth pressure by swelling rock



Partial earth pressure

Landslide

Earthquake

Defects by material and construction condition

Shrinkage by temperature or moisture

Cold joint

Honeycomb

Crack by poor workmanship in setting form

Shortage of concrete casting

Very difficult to detect the cause of defects

Summarizing the cause of defects

- Tunnel inspection is performed as part of road maintenance for the purpose of understanding tunnel's current status for early detection of any abnormity or deformation, determining emergent countermeasures and need for survey, as well as collecting and accumulating information to be utilized for tunnel's rational maintenance.

Summarizing the cause of defects

- By external force
  - Loosened earth pressure
  - Swelling and squeezing
  - Partial earth pressure
  - Landslide
  - Shortage of bearing capacity
  - Water pressure
  - Frost heaving
  - Earthquake
- By material, construction condition
  - Aged deterioration
  - Shrinkage by temperature or moisture
  - Cold joint
  - Honeycomb
  - Poor workmanship with bad formwork, shortage of concrete curing
  - Rebar corrosion

Overall collapse of structure may be induced by the deformation through external force

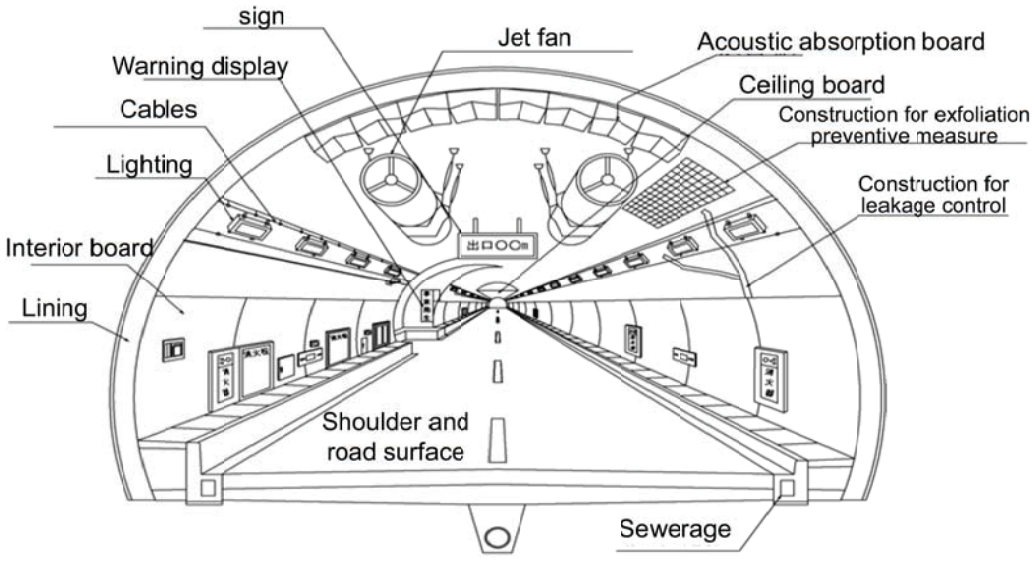
Inspection

Purpose of inspection

- Tunnel inspection is performed as part of road maintenance for the purpose of understanding tunnel's current status for early detection of any abnormity or deformation, determining emergent countermeasures and need for survey, as well as collecting and accumulating information to be utilized for tunnel's rational maintenance.

Inspection points of tunnel

- Main body of tunnel
- Attachments（check their installation status)



Method of periodical inspection

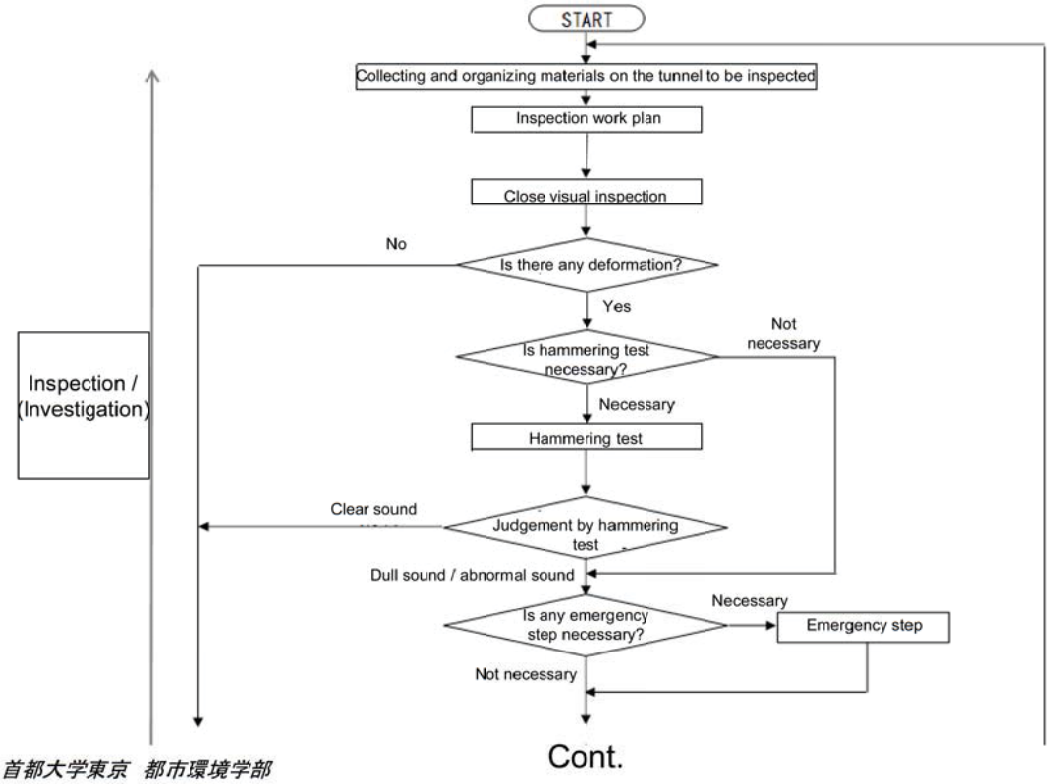
Periodic inspection is performed by close visual inspection in principle.
Non-destructive inspection including test by touching and hammering is also used in combination, if necessary.

Method of periodical inspection

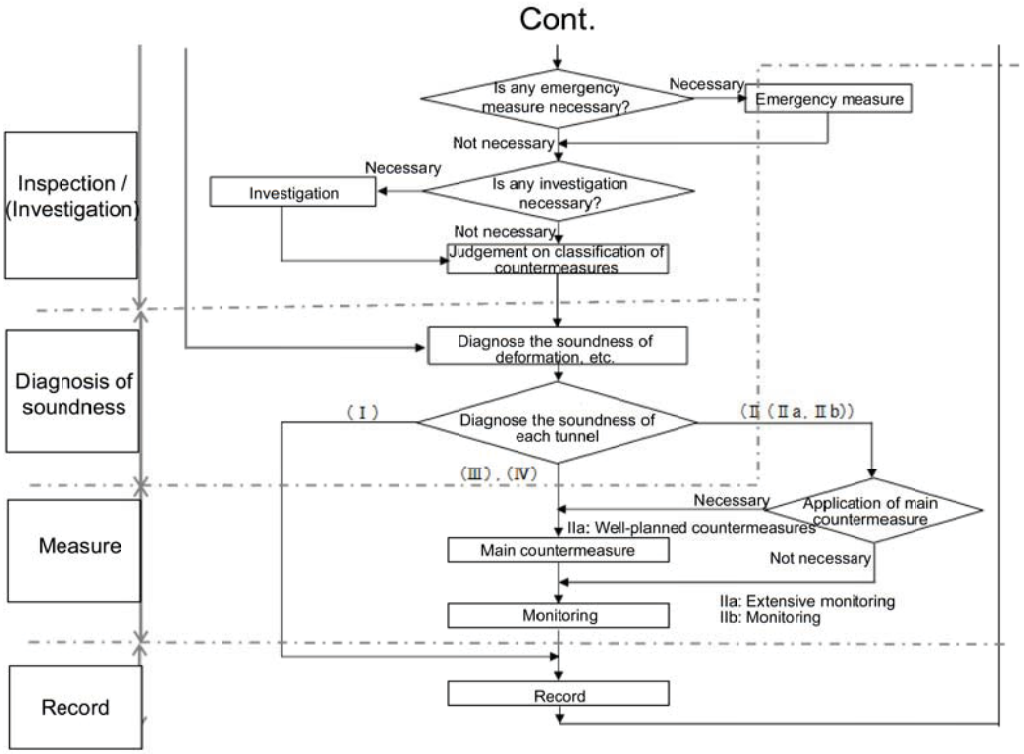
1) Main structure

- Basically, main body of tunnel is observed for deformation by close visual inspection.
- For points with possibility of flaking and spalling of lining surfaces, hammering test is performed to find presence or absence of such flaking or spalling and its range if any.
- Any concrete flaking and spalling which may cause damage to users is removed or treated otherwise as an emergency countermeasure.
- If a new technology is developed in the future which is considered to provide the same level of evaluation as that of close visual inspection by inspection engineer, combined use of such new technology will not be precluded.

Periodical inspection flow (1)



Periodical inspection flow (2)



Aim of tunnel periodical inspection

Visual check by using a boom lift

- Surface of concrete lining

Sketch of concrete surface

Crack detection

Detection of lossening and spalling section

Hammer strike

- Inside of concrete lining

Detection of internal defect

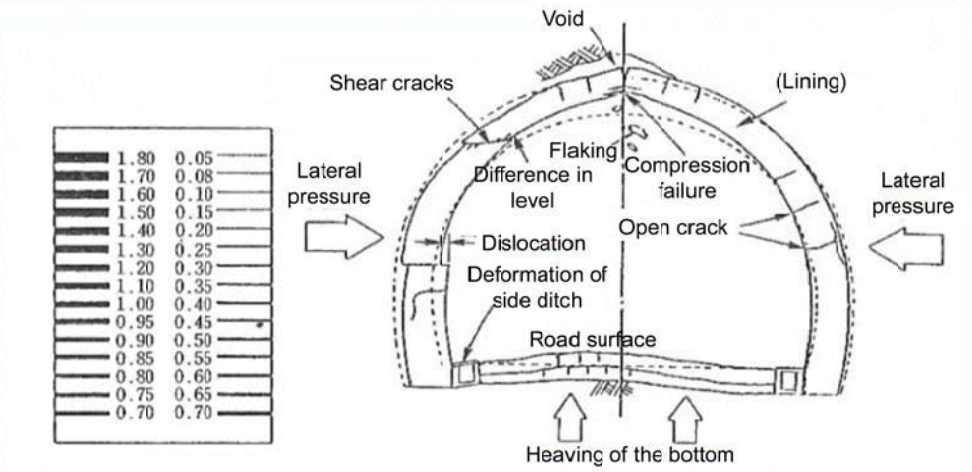
Some problems are
A lane to be closed, Time-consuming,
Difficulty to easily detect cracks high up such as on arches,
Suffering from subjectivity in recording the crack….

Close visual inspection (1)

- For upper part of lining arch, foreside of portal or other parts which may have deformation or abnormity that are difficult to find during facility's daily status check, visual inspection is performed by using a tunnel inspection car to get close enough to make evaluation of any deformation or other status of members, and observation is made on conditions of crack, flaking, spalling, water leak, and installation of attachments inside tunnel.

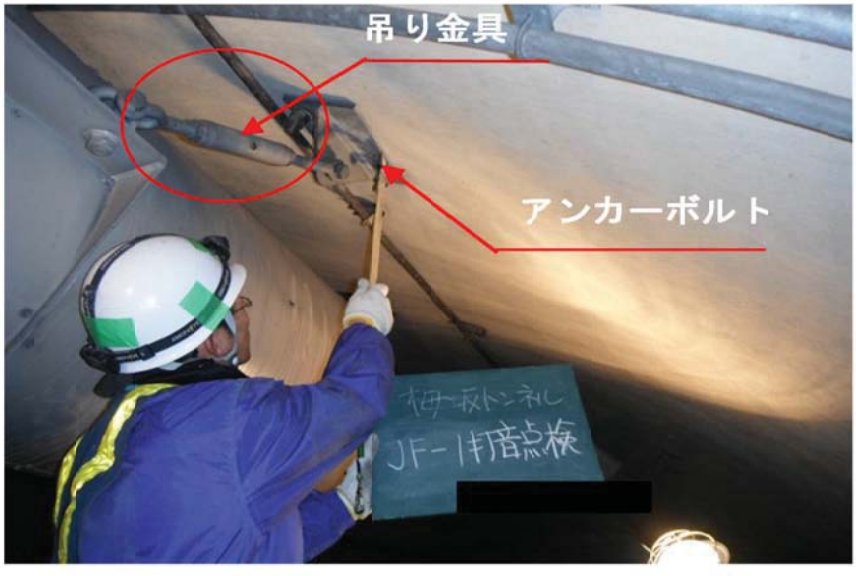
Close visual inspection (2)

- If necessary, cracks' position, length, width and difference in level are measured by using a scaled magnifier or crack scale.



Hammer strike test

- By using a inspection hammer with a head of about 100～300g, flaking and spalling are detected based on the sound (clear sound or dull sound) when hit.



Execution of inspection and survey

Method	Item checked	Problems
Visual check by walking or using a boom lift	Cracks	A lane to be closed Time-consuming Difficulty to easily detect cracks high up such as on arches Suffering from subjectivity in recording the crack
Hammer strike by workmen on boom lift	Spalling of concrete lining	(Same as above)
Vehicles equipped with electromagnetic -wave probes	Voids behind the lining and the thickness of the concrete	Requiring sophisticated and specialized knowledge to interpret the results Not applicable when there are rebars and sections of high water content in the lining

Classification of Tunnel's Soundness Diagnosis

Classification I ~ IV and respective countermeasures

Classification		Definition
I		Because of no possibility of influence on users, countermeasures are not necessary.
II		(Description of national version) Because users are likely to be influenced in the future, monitoring, or from the preventive point of view, countermeasures are necessary.
	IIb	(Description of jurisdictional version) Because users are likely to be influenced in the future, monitoring is necessary.
	IIa	(Description of jurisdictional version) Because users are likely to be influenced in the future, intensive monitoring, and from the preventive point of view, well-planned countermeasures are necessary.
III		Because users are more likely to be influenced sooner or later, it is necessary to take countermeasures early.
IV		Because users are more likely to be influenced, it is necessary to take countermeasures urgently.

Useful tips to judge defects

- Cracks
  - Characteristics from such as compressive, shear or tensile
  - Location
  - Direction such as transverse, longitudinal, horizontal, vertical, diagonal
  - Development speed and degree of penetration

- Condition of tunnel
  - Construction method (eg. NATM or other method)
  - Geological and geographical condition
  - Shape, dimension and structure (eg. with/without invert)
  - Behavior during construction (eg. Large deformation)
  - With/without structure near tunnel
  - Underground water

Survey

Problem for proper inspection and survey

- At the stage of inspection execution,
  - To collect the data of tunnel defects, rapidly and quantitatively
- At the stage of results evaluation from inspection,
  - To predict the cause of defects, whether by external load or by material.
  - To judge the current state and need of countermeasure
- At the stage of countermeasure decision,
  - To select proper countermeasure method in accordance with the cause
  - To ensure the safety of construction under traffic

Countermeasure

Countermeasure

- Based on the result of inspection and survey, the road tunnel administrator comprehensively considers optimal countermeasures for restoration of the tunnel's function and durability.
- Countermeasures are classified as below, depending on effect, durability and readiness of countermeasures to be applied, as well as on easiness of survey to be performed after inspection.
  - ✓ Countermeasures
    - Temporary countermeasures
    - Main countermeasures
  - ✓ Monitoring

Basic concept of selection of countermeasure

By material and construction condition

・countermeasure against flaking

= Repairing the lining to prevent the flaking from affecting users and vehicles

By external force

・countermeasure against flaking

・countermeasure against external force

= Reinforcing the lining to improve the bearing capacity and stability of the tunnel structure

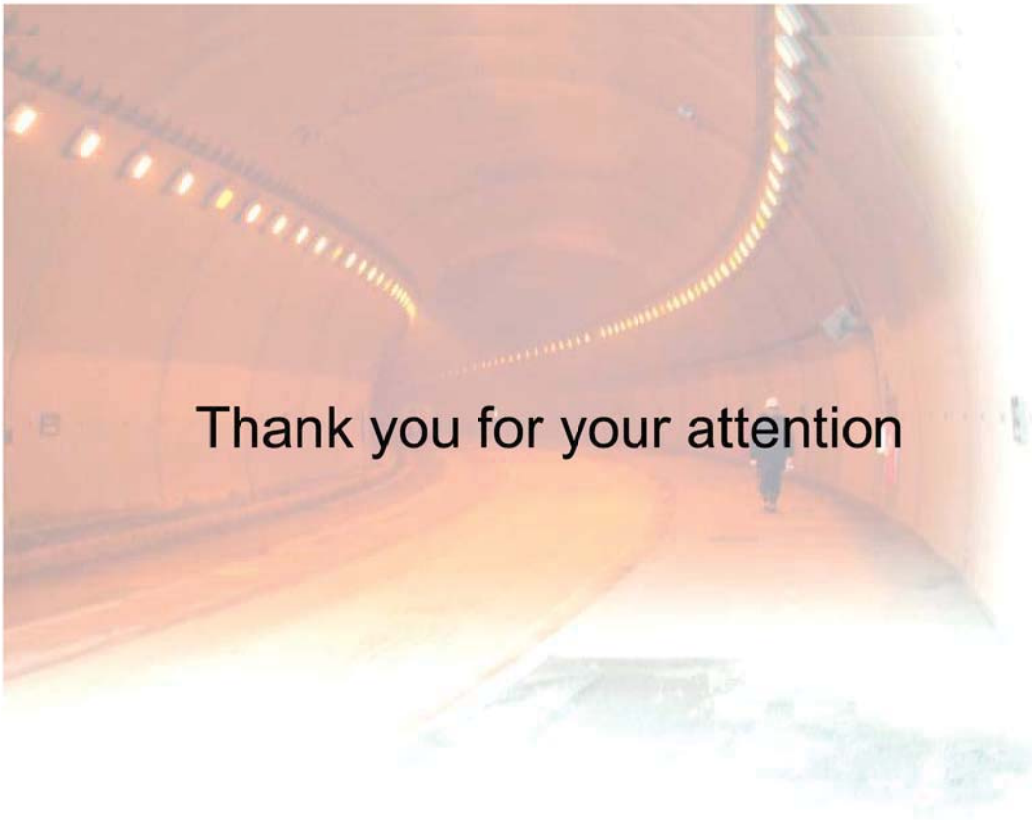
Future prospects

- Tunnels should be designed so as to reduce the life cycle cost.
- Tunnels should be constructed by strictly controlling the quality in order to prevent defects in future.
- Tunnels should be inspected, surveyed and evaluated, taking objective records of quantitative data and using consistent evaluation criteria.

⇩

In advance, attention should be paid that…..

- Technologies need to be developed
- Experts should be trained
- Various maintenance is needed not only for structure but also for facilities in tunnel



Seminario de túneles en Colombia

Nuevas Tecnologías de Construcción de Túneles en Japón

Nobuyuki Kawabe

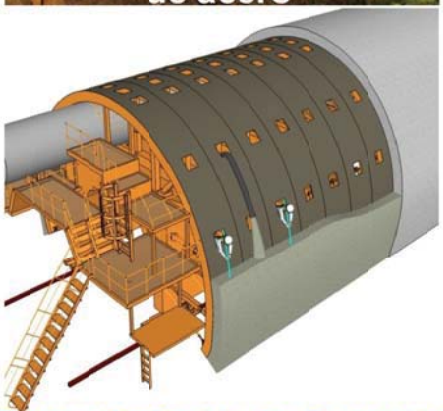
División de Ingeniería Civil
HAZAMA ANDO CORPORATION
Japón

Mayo 25, 2018

Seminario de túneles en Colombia

Construcción estándar con NATM

Ciclo de construcción del túnel mediante voladura

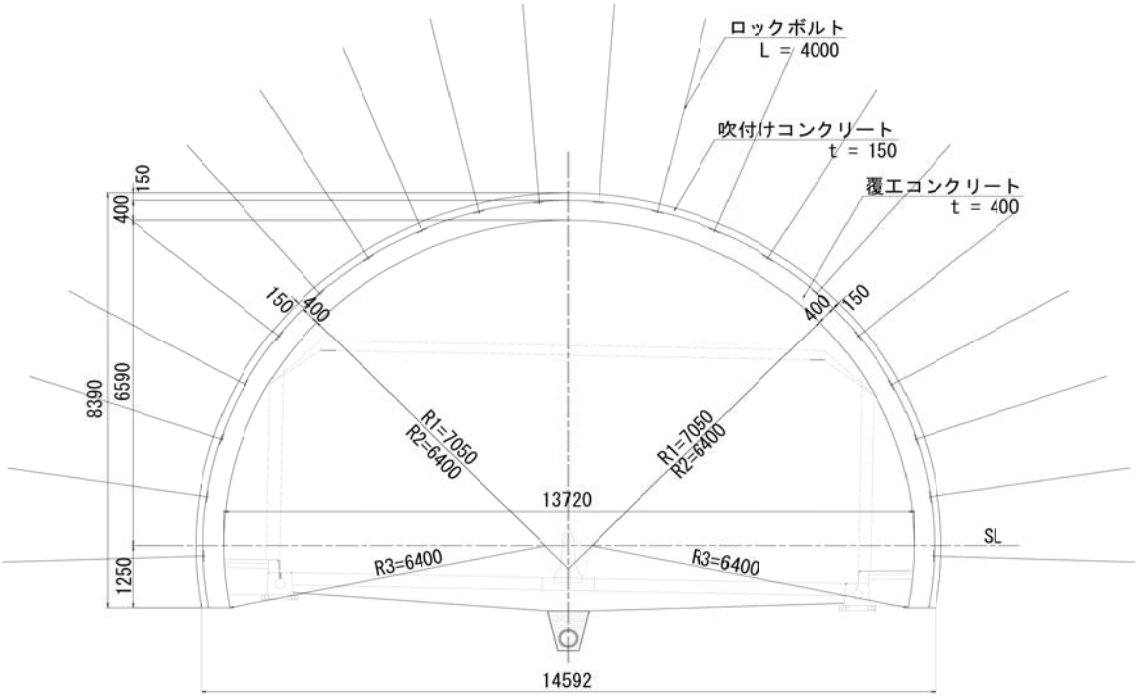


Revestimiento de Concreto

Sección Transversal de un túnel en Japón

Sección Transversal de Excavación : 101.52㎡

Sección Transversal del Espacio Interior : 88㎡



Perforadora Jumbo (Voladura, Perno de Roca)

Perforadora Jumbo Furukawa con 3 booms y 2 plataformas de carga
＜JTH3200R-ⅢPULS＞

Máquina de concreto proyectado con elector de soporte de acero

Cargador de Ruedas

Cargador de Ruedas
Capacidad del Cucharón 5.8 m3

Situación de Limpieza (Cargadora de ruedas y Camión volquete)

Problema de Construcción de Túneles en Japón: Parte1

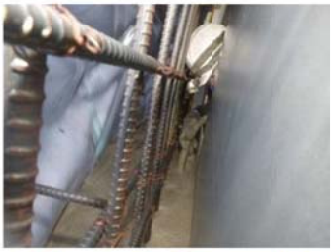
Situación actual del trabajo de excavación de túneles

Duro trabajo en el túnel ⇒ Falta de trabajadores calificados en túneles

Cargando explosivos

Eligiendo soportes de acero

Colocando el perno de roca



Colocando Concreto

- Mejorar la productividad de la construcción de túneles
- Excavación de túneles sin la necesidad de trabajadores especializados

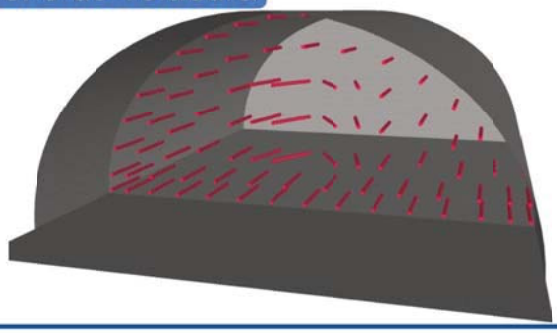
Adopción de un nuevo taladro jumbo sobre ruedas

Voladura por método convencional

Trabajos de voladura por método convencional

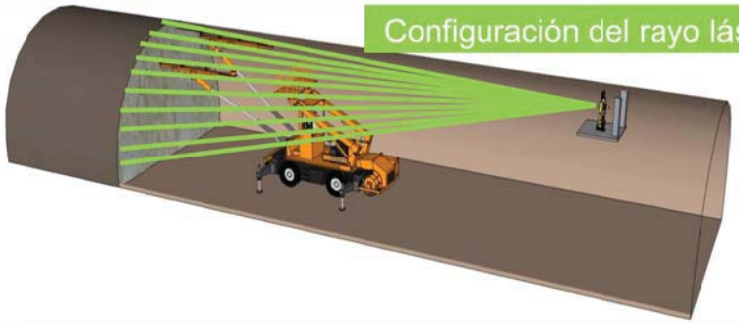
Marcado de puntos de perforación ①

Diseño de voladura



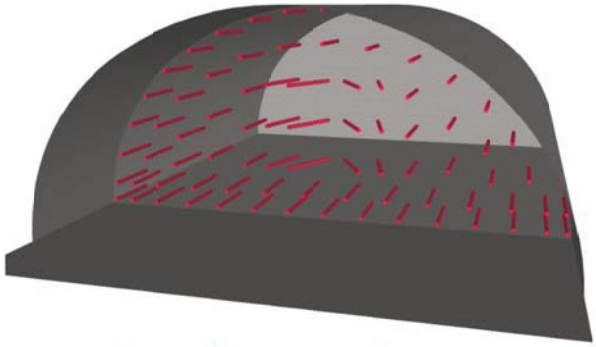
Medición de puntos de perforación ②

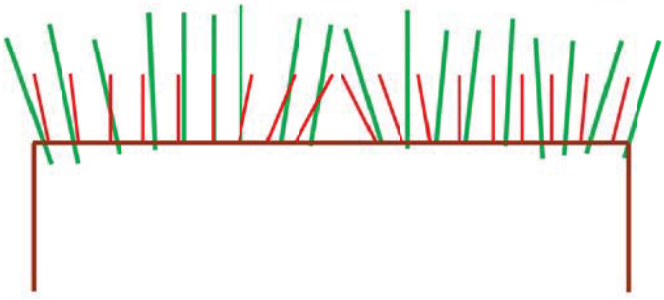
Configuración del rayo láser



Voladura por método convencional

Método Convencional





- Línea roja :

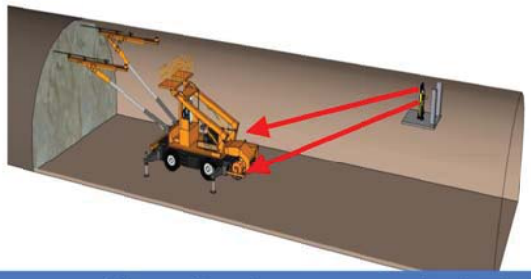
Línea de diseño de agujero de perforación

- Línea verde :

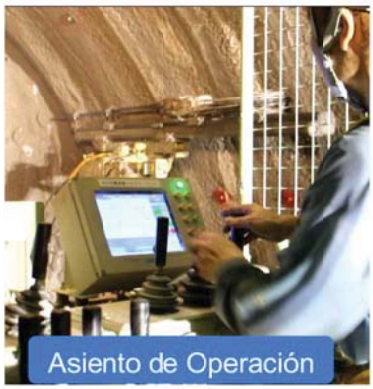
Línea real del agujero de perforación

Voladura por método avanzado

Perforadora jumbo con la función de guiado del taladro hacia el agujero de perforación



Máquina topográfica utilizada para controla el taladro jumbo



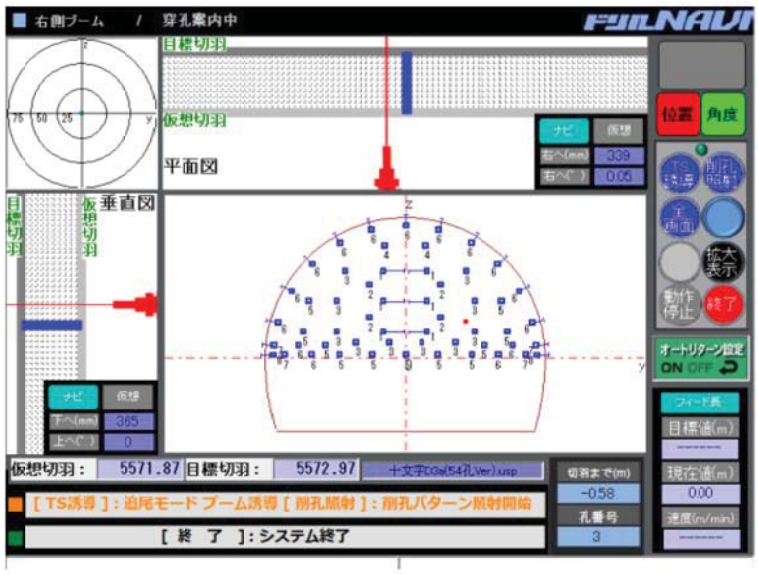
Asiento de Operación

Pantalla de Guía

Voladura por método avanzado

Perforadora jumbo con la función de guiado del taladro hacia el agujero de perforación

Operación



Pantalla de Guía

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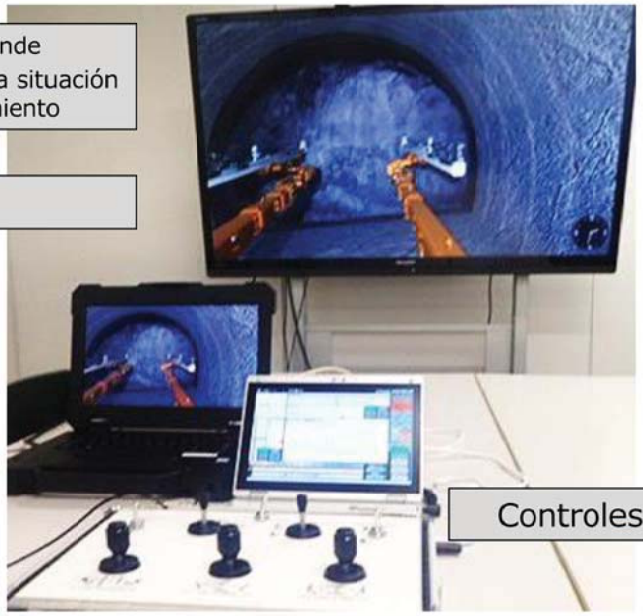
Voladura por método avanzado

Introducción del simulador para la operación de perforación

Monitor grande
※ Simulación de la situación de enfrentamiento

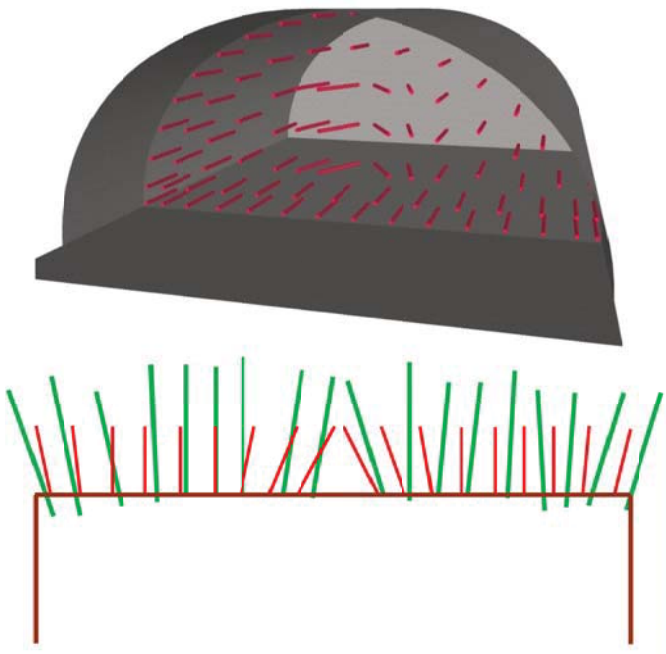
P.C.



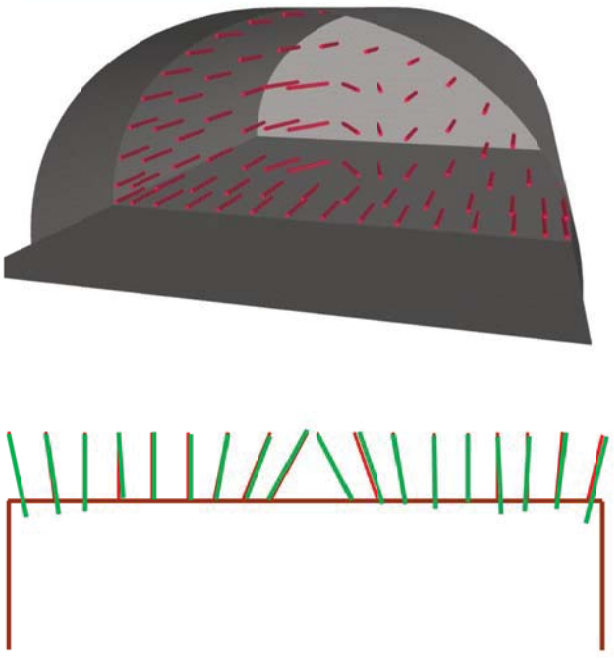
Controles

Voladura por método avanzado

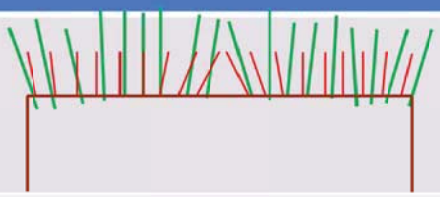
Método Convencional



Método Avanzado



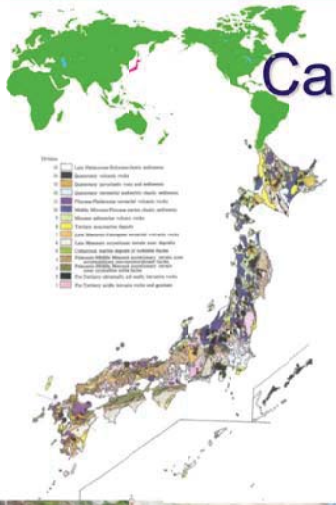
Voladura por método avanzado

	Método Convencional	Método Avanzado	
Patrón de perforación			
Longitud del ciclo	1.5 m	1.5 m	
Longitud promedio de perforación	2.4 m	1.9 m	▲19%
Tiempo de perforación	145 min	75 min	▲48%
Explosivos	191 kg	139 kg	▲27%
Longitud del túnel / día	3.7 m	5.6 m	△50%

Adopción de TFS-learning

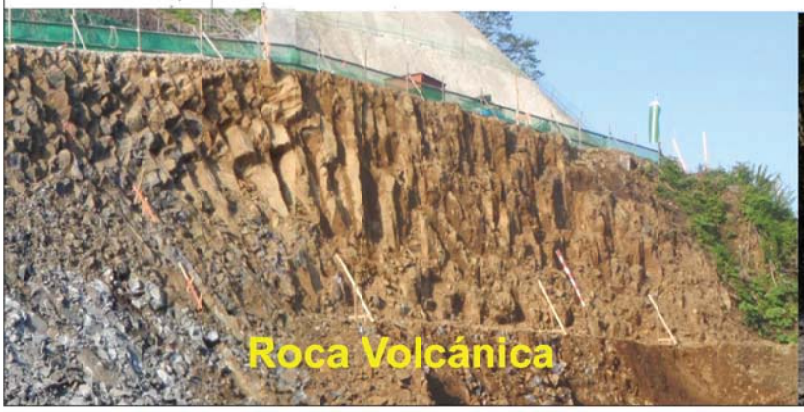
※ Sistema de cálculo de estabilidad del frente del túnel mediante aprendizaje automático

Problema de Construcción de Túneles en Japón: Parte 2



Características geológicas de Japón

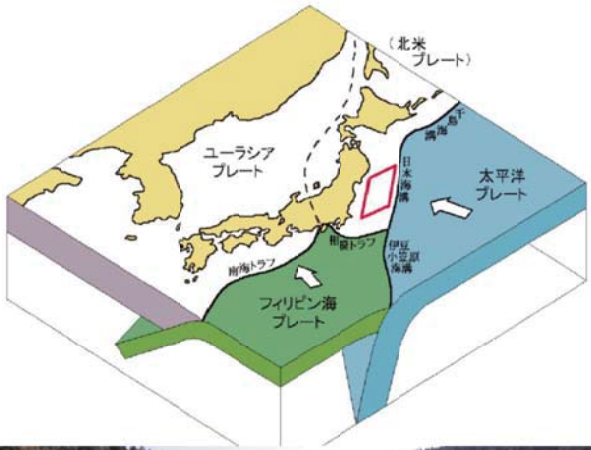
- Las características geológicas del archipiélago japonés son complejas, con regiones montañosas que cubren el 75% del país.



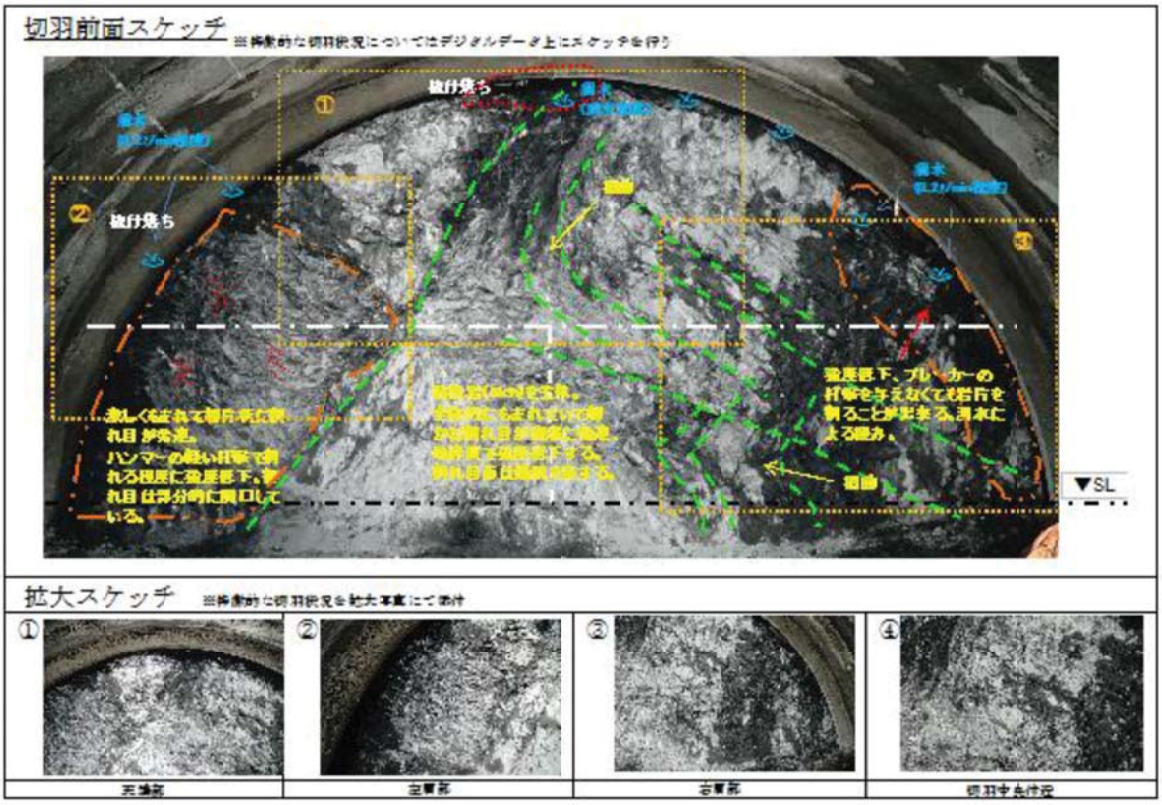
Problema de Construcción de Túneles en Japón: Parte 2

Terremotos de Japón

- Además, el 10% de los terremotos del mundo de magnitud 7,0 o superior se producen en Japón, donde los límites de múltiples placas se distribuyen en toda la región.



Situación Geológica Compleja en Japón



Situación Geológica Compleja en Japón

【 Colapso del frente de ataque】

Situación Geológica Compleja en Japón

Este es un trabajo peligroso debido la caída de rocas en el frente del túnel

【Cargando explosivos】

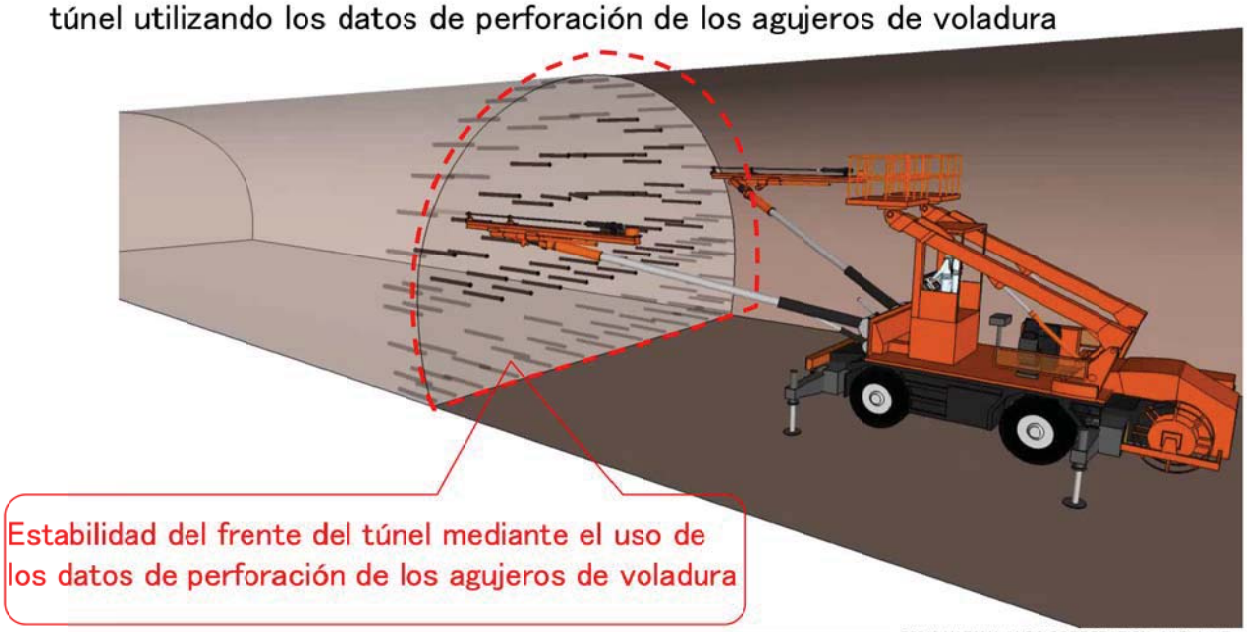
【Eligiendo soportes de acero】

Desarrollo de TFS-learning

TFS-learning:

Sistema de cálculo de estabilidad del frente del túnel (Tunnel Face Stability) mediante aprendizaje automático

※ Este es un sistema que puede predecir automáticamente la estabilidad del frente del túnel utilizando los datos de perforación de los agujeros de voladura

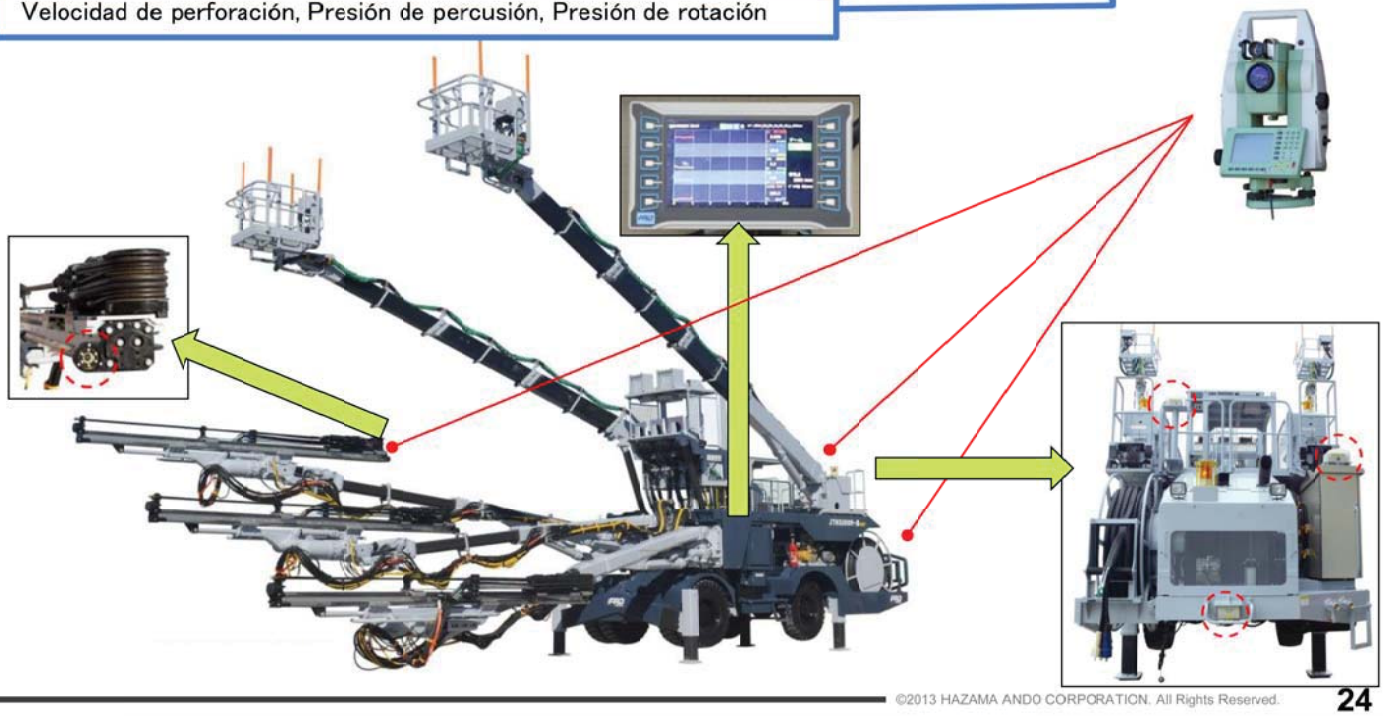


Desarrollo de TFS-learning

Perforadora jumbo con la función de guiar el taladro al agujero de perforación

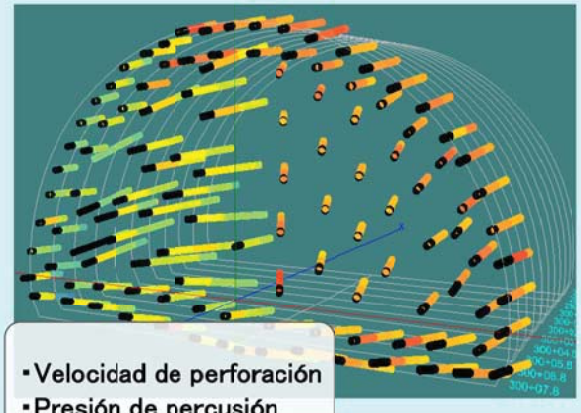
Posición de perforación, Dirección de perforación, Longitud de perforación, datos de la máquina en el momento de la perforación

Velocidad de perforación, Presión de percusión, Presión de rotación

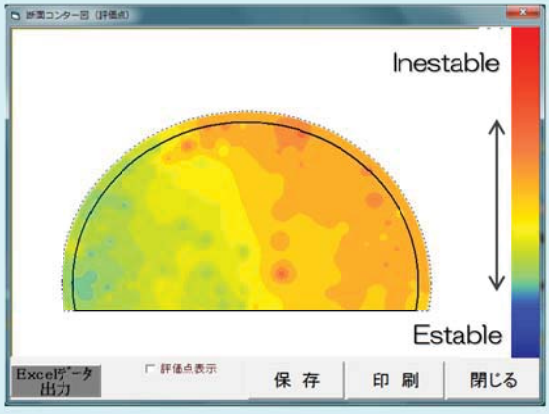


Desarrollo de TFS-learning

Datos de perforación de todos los agujeros de explosión → Estabilidad del Frente del Túnel



- Velocidad de perforación
- Presión de percusión
- Presión de rotación

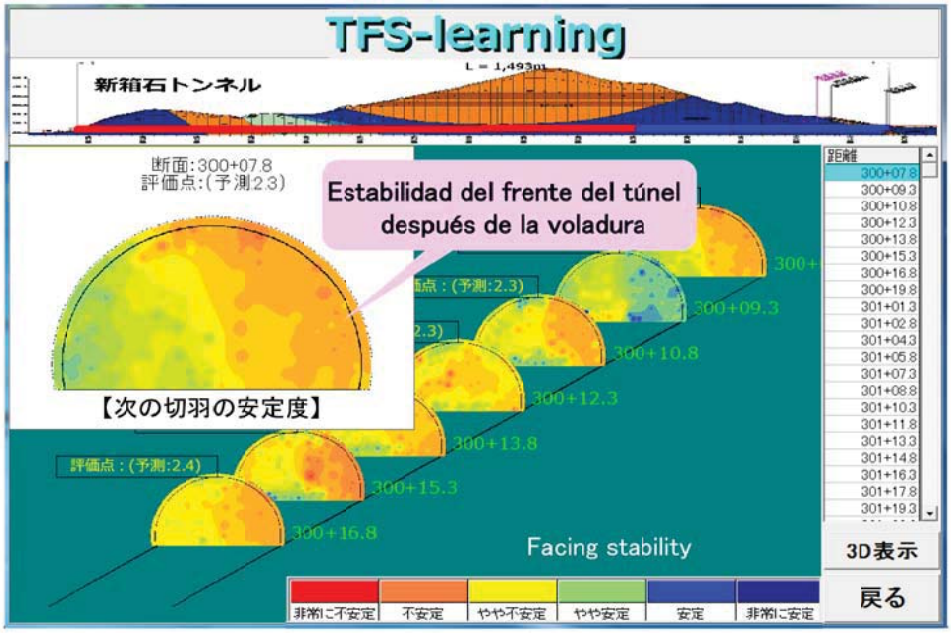


Relación entre la estabilidad del frente y las condiciones geológicas

【Estabilidad del Frente】 Azul ⟷ Rojo

【Condiciones Geológicas】 Estable ⟷ Inestable

Desarrollo de TFS-learning



Aplicar métodos auxiliares según sea necesario

La seguridad de los trabajo en el frente del túnel ha mejorado drásticamente

Desarrollo de TFS-learning

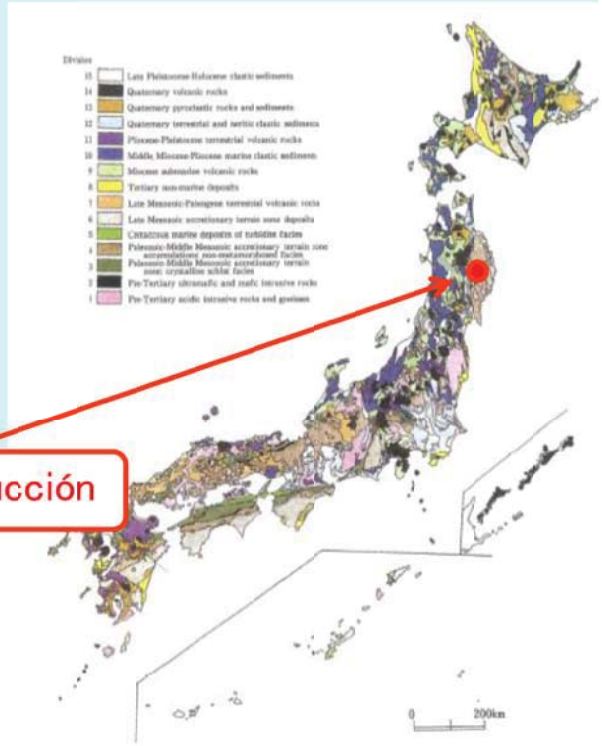
【Sitio en construcción】

Nombre del túnel : Túnel Shin- Hakoishi

Ubicación del túnel : Prefectura de Iwate

Geología : Pizarra

Longitud del túnel : 1,493 m



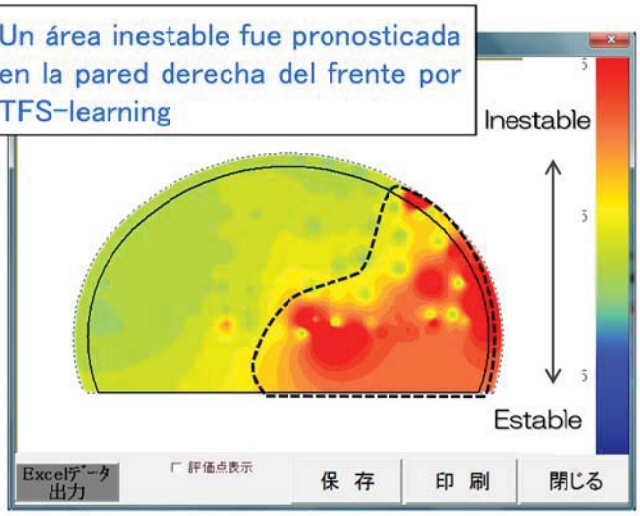
Desarrollo de TFS-learning

【 Aplicación de TFS-learning en el túnel Shin – Hakoishi 】

Un ejemplo del efecto de TFS- Learning en el túnel Shin – Hakoishi se muestra a continuación.

Captamos la parte inestable del frente y lo retroalimentamos a la construcción.

Un área inestable fue pronosticada en la pared derecha del frente por TFS-learning



【 El resultado predicho antes de la voladura 】

Roca erosionada de color marrón apareció en la pared derecha del frente

【 Condición geológica después de la voladura 】

Gracias por su atención.