(3)第４回現地調査時 ACTOS セミナー

Tunnel Technology in Japan

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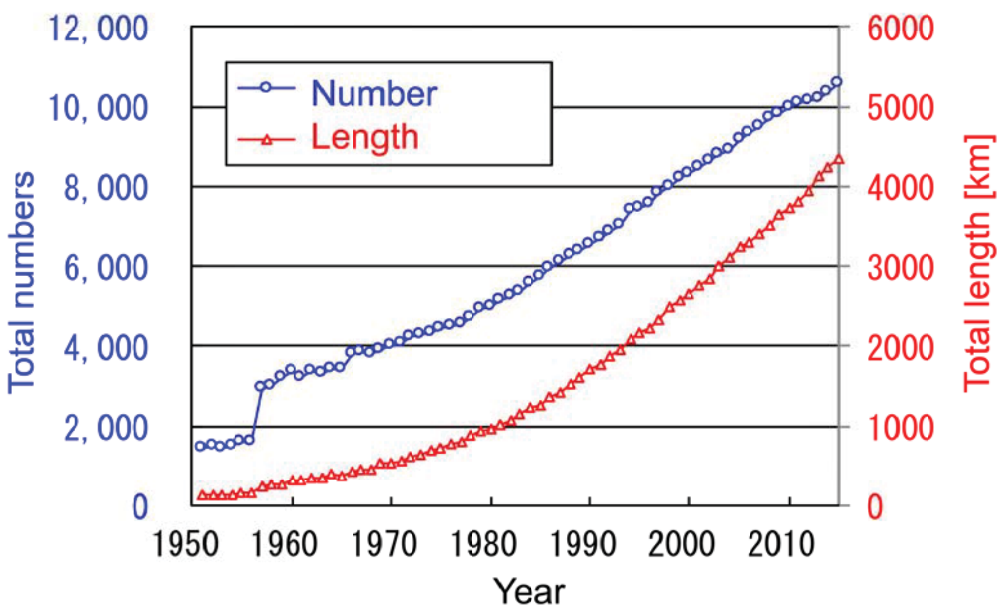
Today's agenda

1. Overall information of mountain tunnel in Japan
2. Planning and design methodology
3. Construction concept and methodology
4. Attached facilities design and operation
5. Tunnel maintenance concept

1. OVERALL INFORMATION OF MOUNTAIN TUNNEL IN JAPAN

Current status of road tunnels in Japan

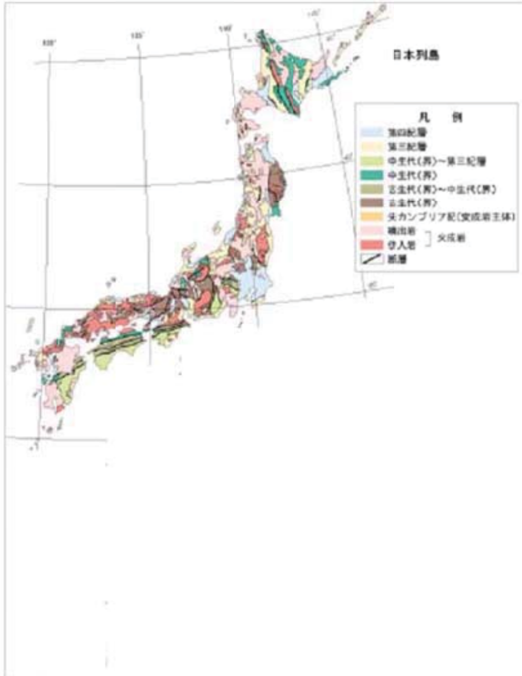


As of April 2015 Total number of road tunnels: 10,552
Total length of road tunnels : 4,349 km

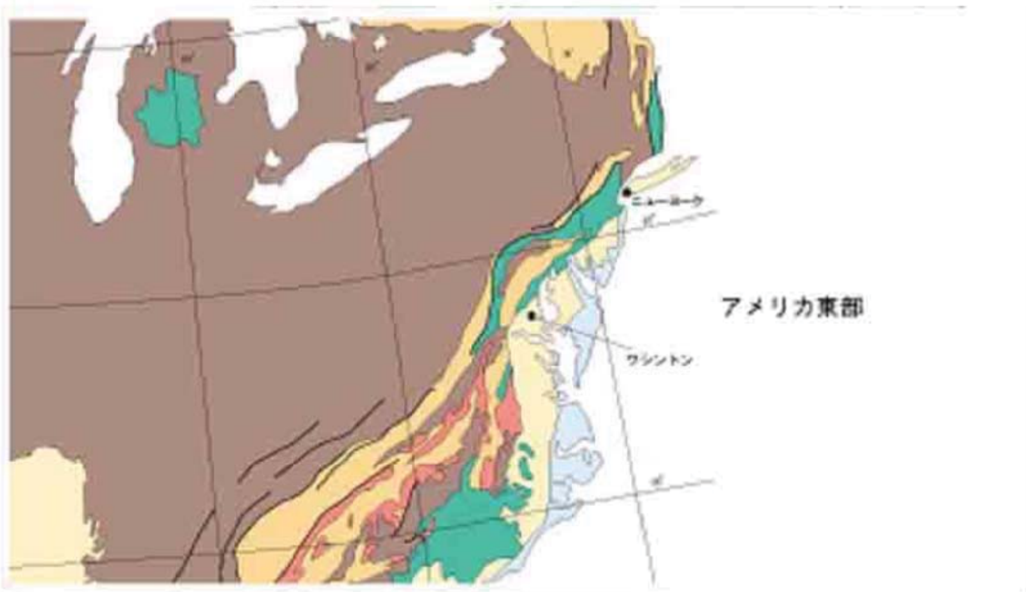
Geological condition in Japan

Japan has complex geological condition

Same legend in Europe



Geological condition in Japan



US is also simple except limited area

Difference of general structure and tunnel

General structure

Design condition
Load: Confirmed
Material: Artificial, Uniform
Material characteristics: Known

↓

Design
Structural design
(Confirmation of safety and economy)

↓

Construction
Construction based on design

Earth pressure on tunnel is complicated and it is explained only in concept not in quantitative one

Mountain tunnel

Design condition
Load: Unconfirmed
Material: Natural, non-uniform
Material characteristics: Unknown

↓

Design
Setting of load is difficult, and evaluation of analysis is also difficult

Design
Support pattern based on ground classification

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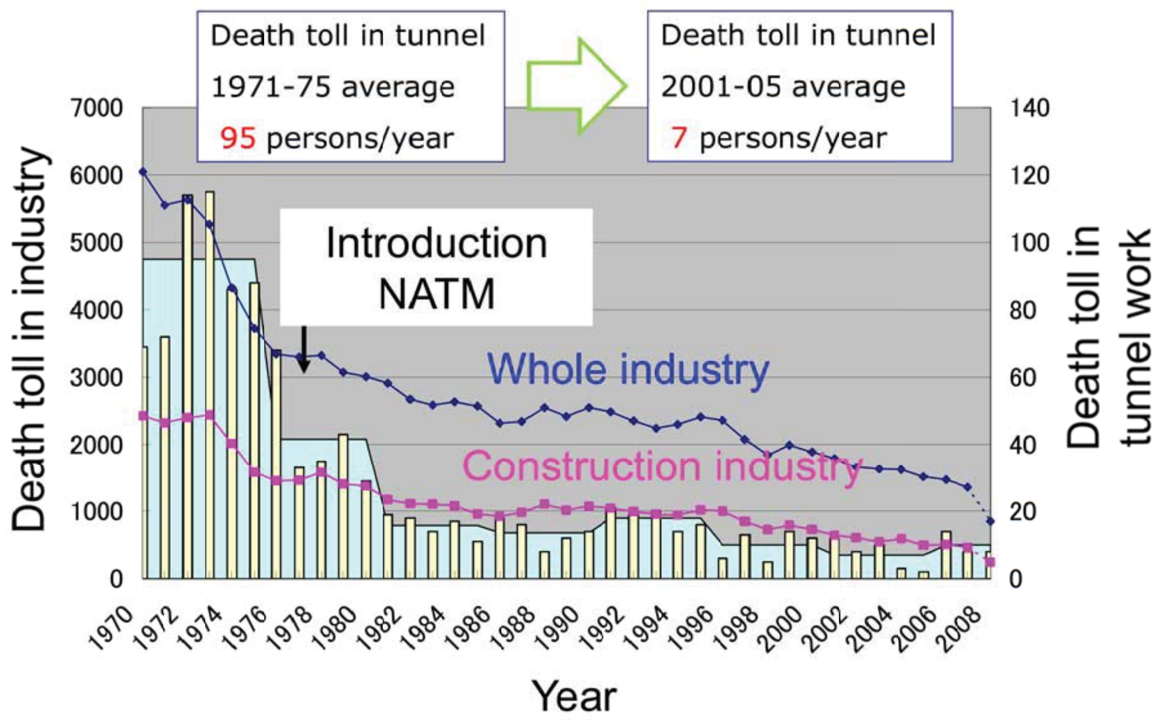
Construction
Validity of support is evaluated during construction stage

↓

Measurement
Confirmation of safety and economy

Construction safety transition of tunnel in Japan



Enactment or law relating to tunnel

By government

Road law

- Standard for road structure
  - Technical standard for road tunnel
  - Technical standard for emergency facilities in tunnel

>> It's only written in concept and minimum requirements.

Enactment or law relating to tunnel

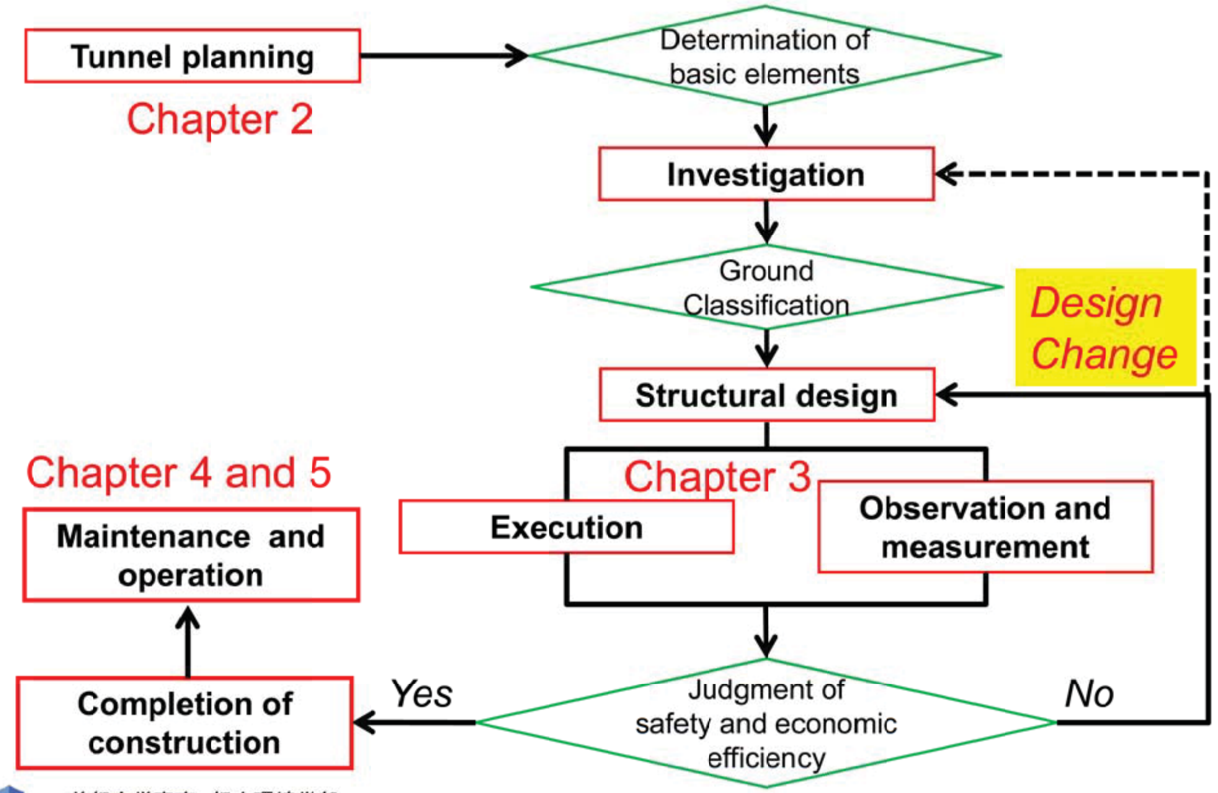
By Japan Road Association

- Technical standard for road tunnel and its explanation (for structure)
- Technical standard for road tunnel and its explanation (for ventilation)
- Technical standard for emergency facilities in tunnel and its explanation
  - Technical guideline for observation and measurement for road tunnel
  - Technical memorandum for maintenance for road tunnel

By PWRI

- Technical Manual for deformed road tunnel
- Technical memorandum for diagnosis of tunnel

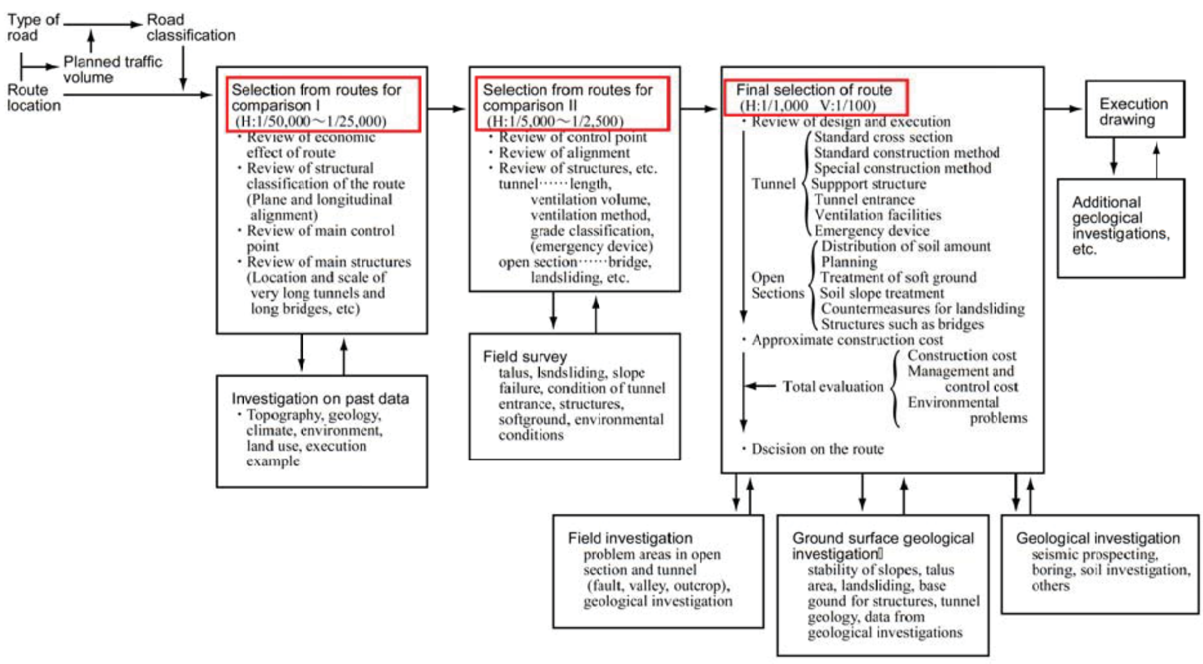
Rough flow of road tunnel construction



2. PLANNING AND DESIGN METHODOLOGY IN JAPAN

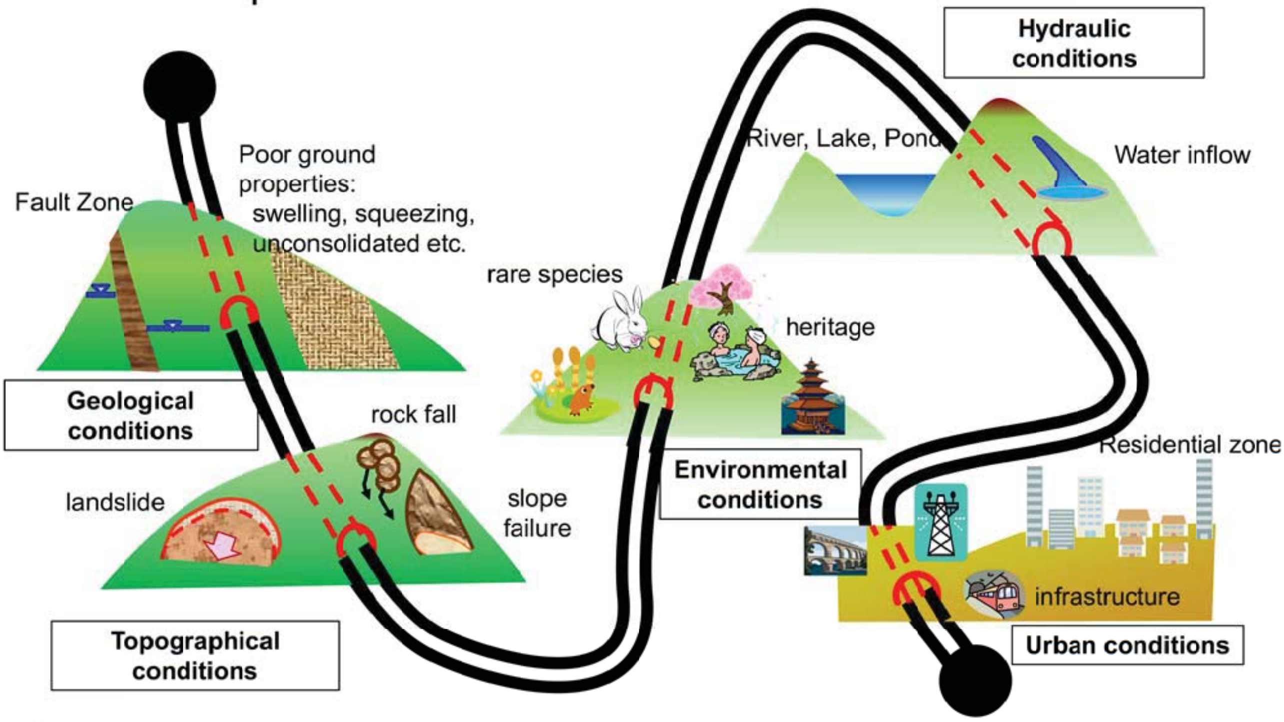
(1) Plan

Basic concepts for road tunnel planning

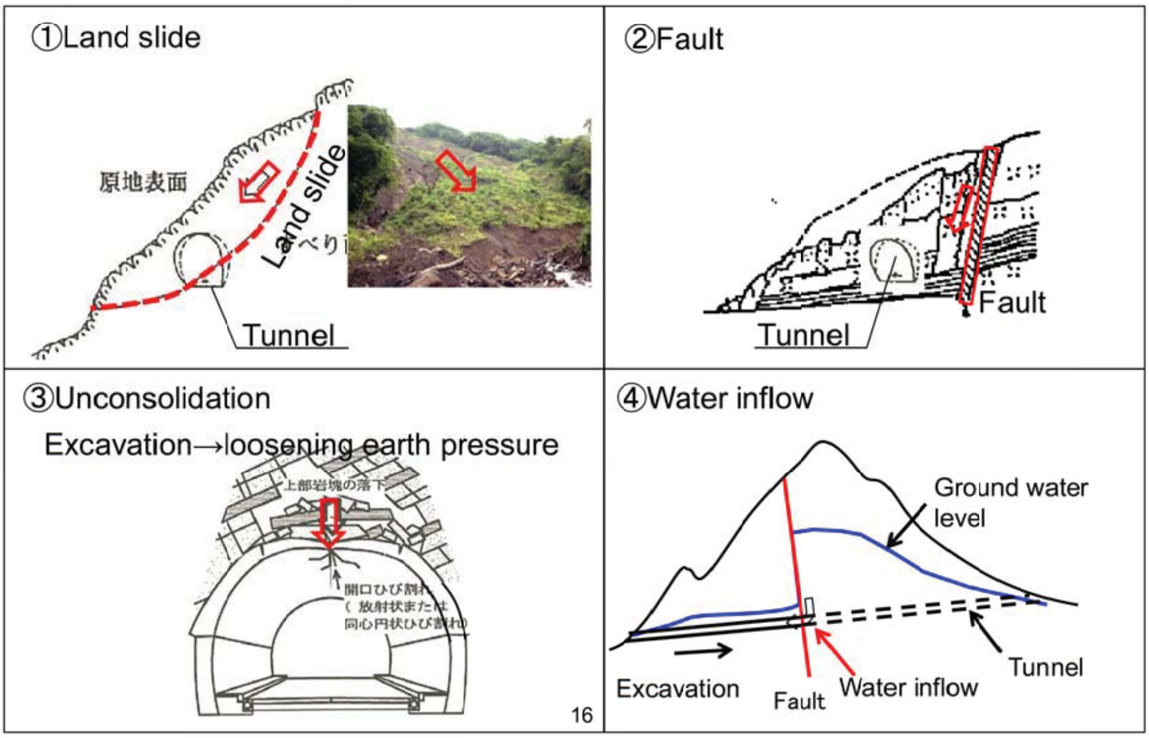


Basic concepts for road tunnel planning

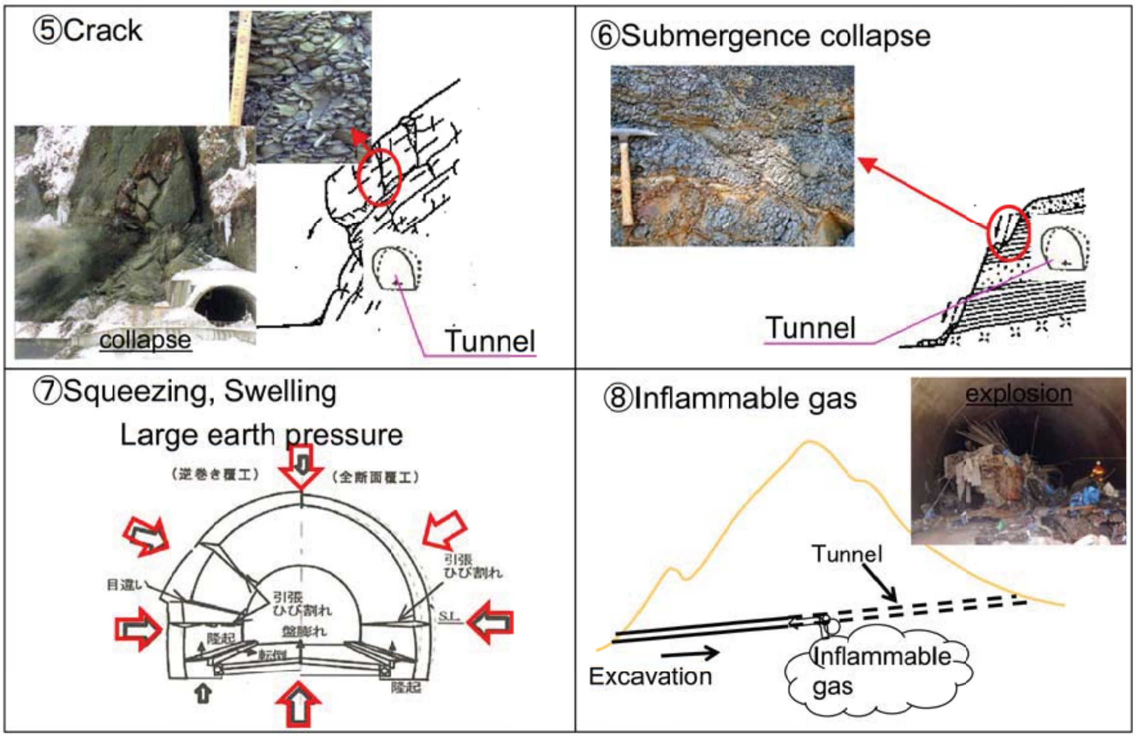
➢ Control points of route selection



Risk factor

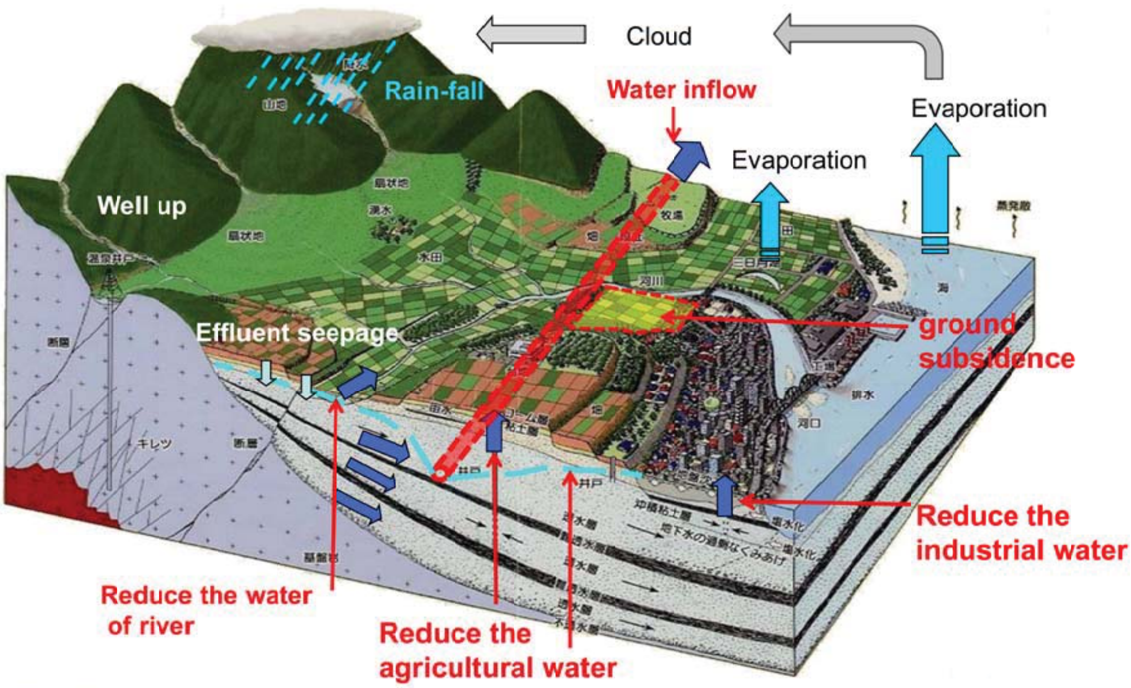


Risk factor



Influence on surrounding environment

If lowering of groundwater level,

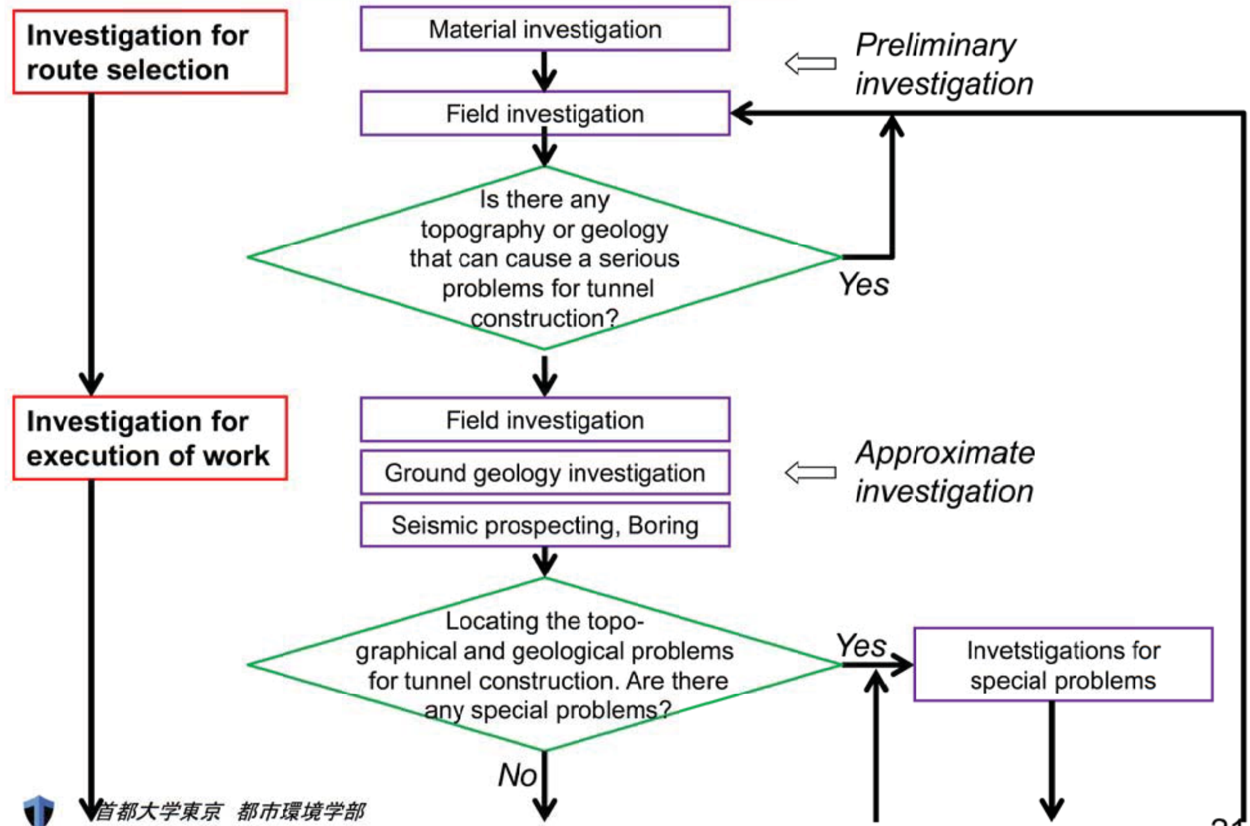


Longitudinal design

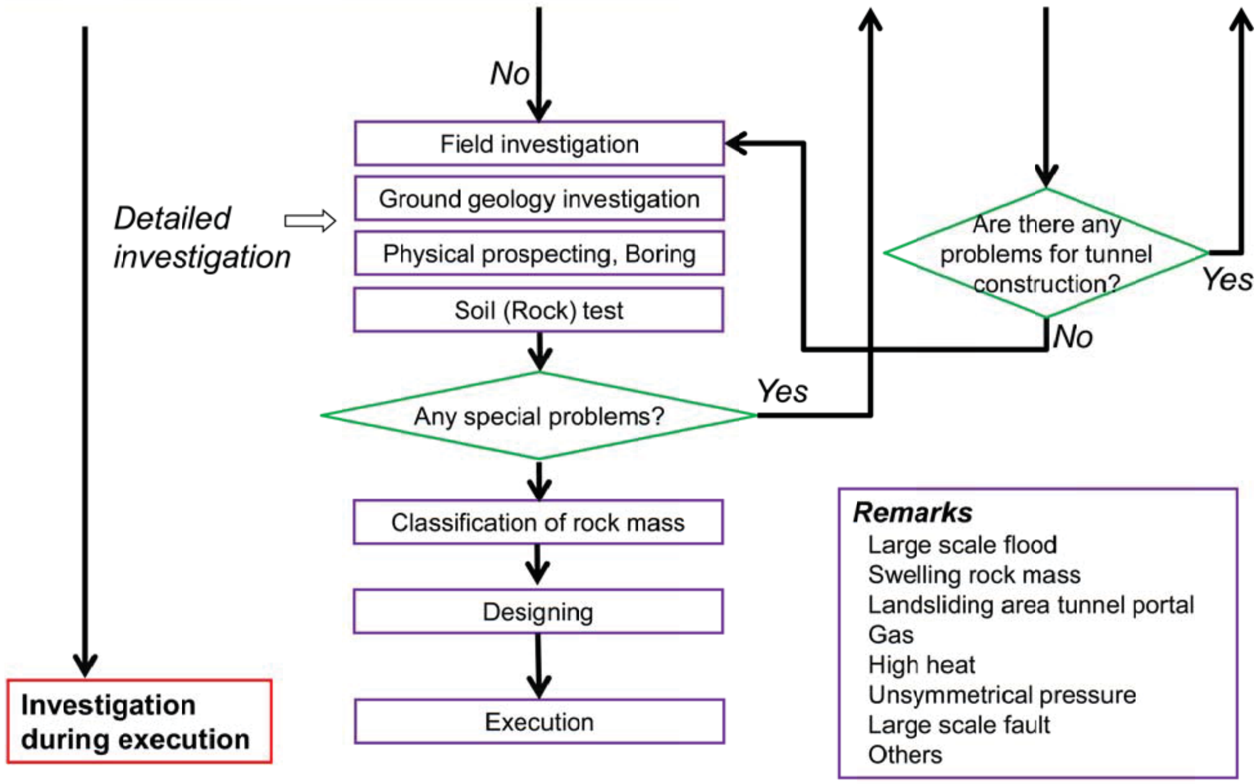
		One-side Decline	Outward Both-side Decline	Inward Both-side Decline
Sketch → : Water flow				
Drainage	Method	Gravity flow	Gravity flow	Forced drainage by pumping
	Direction	Pit mouth at lower altitude	Both pit mouths	Either pit mouth
Advantage		・Desirable to construct from the pit mouth at lower altitude	・Possible to construct from both pit mouths	None
Disadvantage		・Spring water travels down only to one pit mouth	・If construction goes in one direction, part of the construction is performed on downward pitch	・Due to drainage by pumping, it requires more construction and maintenance costs (during and after construction) ・Construction is performed on downward pitch.
Evaluation		○		×

(2) Investigation

Basic flow of investigation



Basic flow of investigation



Investigation required for each stage

- Idea and planning stage
- ✓ Purpose: Investigation for route selection
- ✓ Investigation: Review of past materials, approximate investigation of geology

- Design stage
- ✓ Purpose: Drawing a detail map (1/1000~1/500),
- ✓ Investigation: Overall conditions (main structure + portal area), ground water, stratification, fracture zone

- Execution stage
- ✓ Purpose: For safety of tunnel construction
- ✓ Investigation: Stability of face and roof, Validity of support structure, protection for environmental condition

Basic items of investigation

- Investigation for route selection
  Material investigation, Field investigation
- Survey for construction work
  Geological survey, boring, seismic prospecting, soil test
- Classification of rock mass
- Design of structure
- Measurement and investigation during construction execution -- Checking validity of structure while construction

Topographical and geological investigation stages and the investigation method

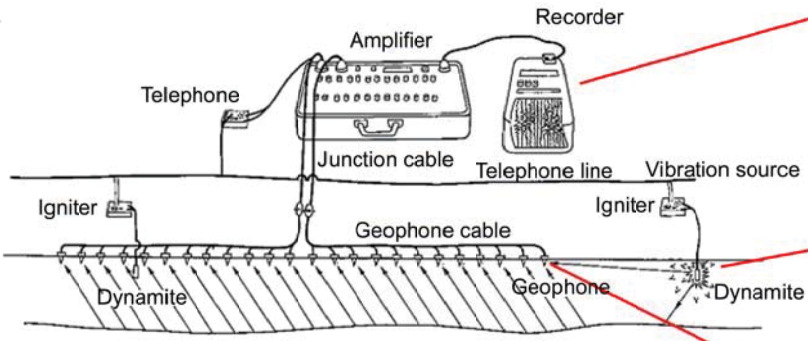
1. Field investigation
2. Elastic wave probing
   Typical: Classification of ground
3. Boring
   Typical: Characteristic of core
   Detailed kind of geology
   RQD
4. Soil (Rock) laboratory test
   Typical: Unit weight volume
   Uniaxial compressive strength
   Modulus of elasticity or deformation etc.

= Depending on kinds of rock and environmental conditions

Field investigation

Elastic wave probing

We measure elastic wave occurred by the artificial explosion.
This method estimates ground hardness, fissure degree, weathering degree, location of fault fracture zone etc, according to the difference in elastic wave velocity(seismic velocity).



Data logger

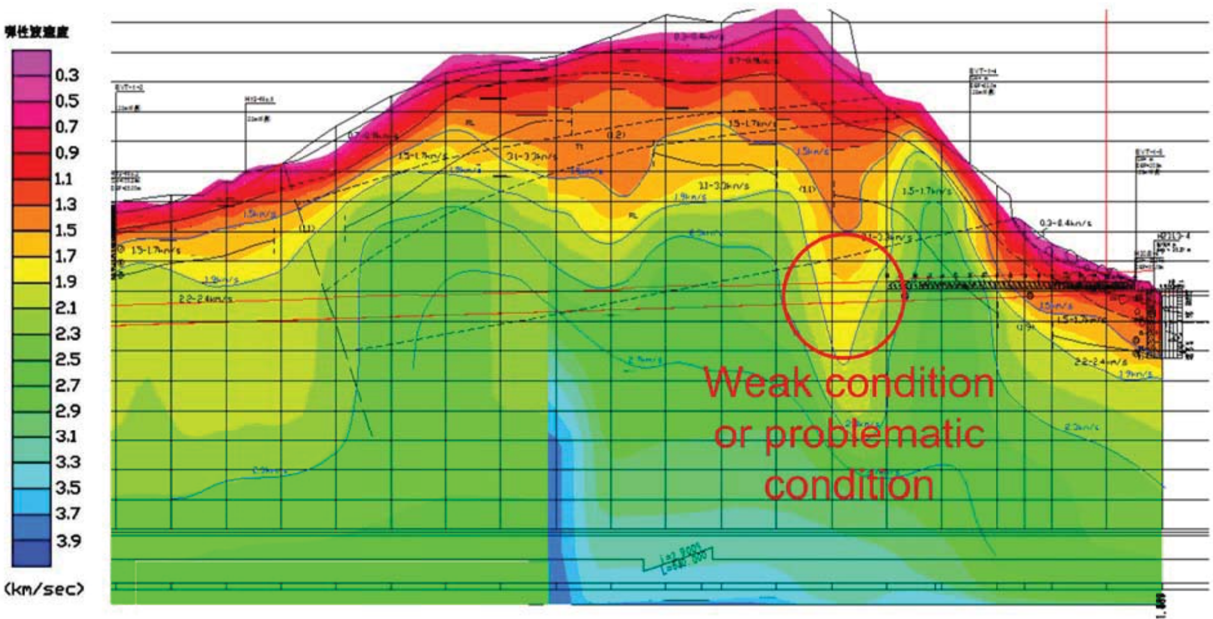
Slurry explosive

Sensor

The Japanese Geotechnical Society, Method and description of ground survey, 2004

Elastic wave (seismic wave) probing

Result



⇒These data are the basis of ground classification

Drilling survey

Drilled the ground directly, and confirm geology and ground property.

Information	Purpose and result
①Boring core ②Ground water level	①Grasp geology and ground property ②Grasp fault, fracture zone, crack ③Sampling of laboratory test　etc.

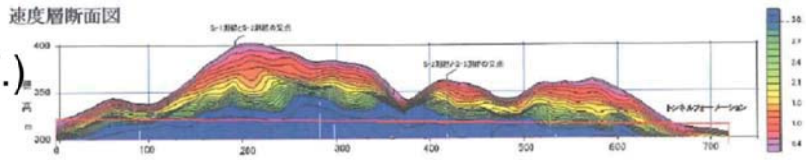
Drilling situation

sample

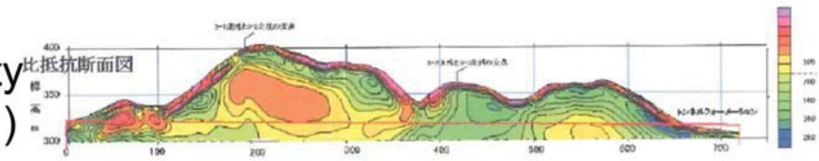
Combination of survey methods

- Geophysical Explorations

➢ Seismic Tomography (S.T.)



➢ Electric Resistivity Exploration (E.R.)

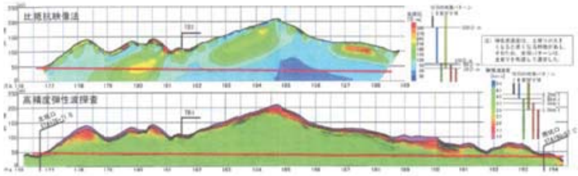


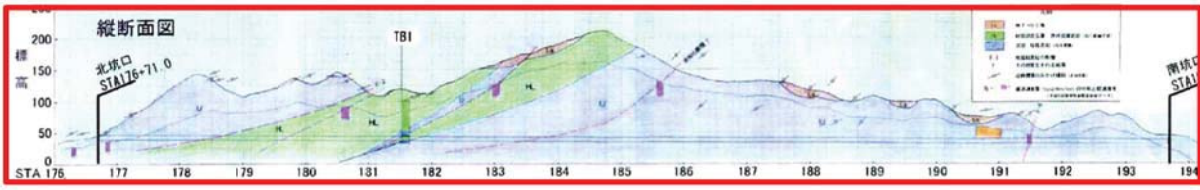
➢ Developing Technology

- Combining Evaluation
- using several methods

Fault predicted by only S.T.
Fault predicted additionally by S.T. & E.R

Geological evaluation





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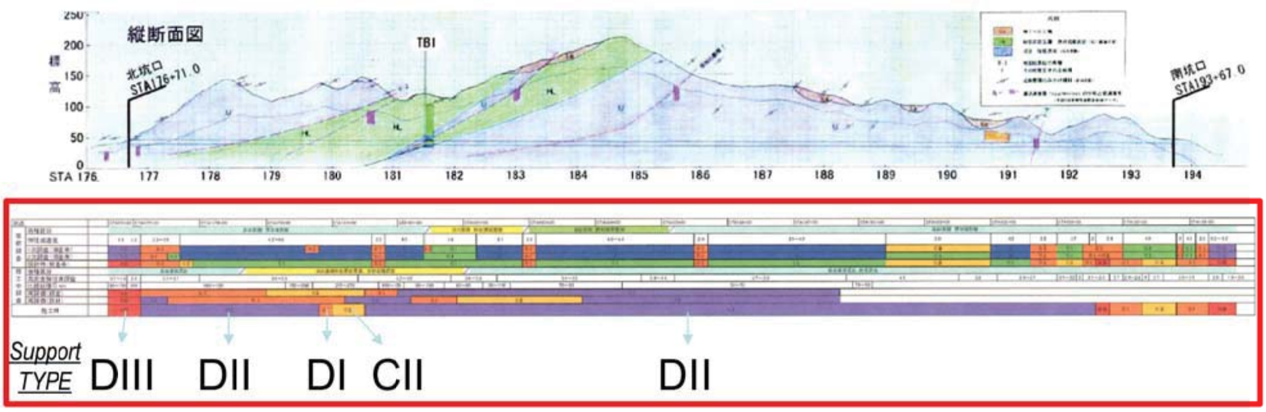
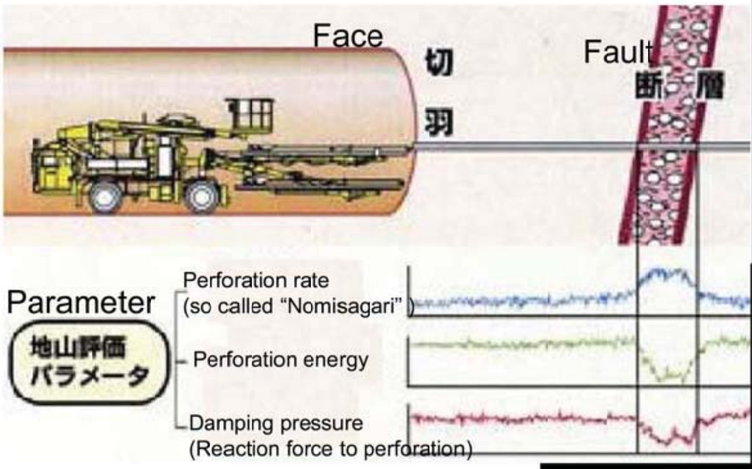
Geological evaluation

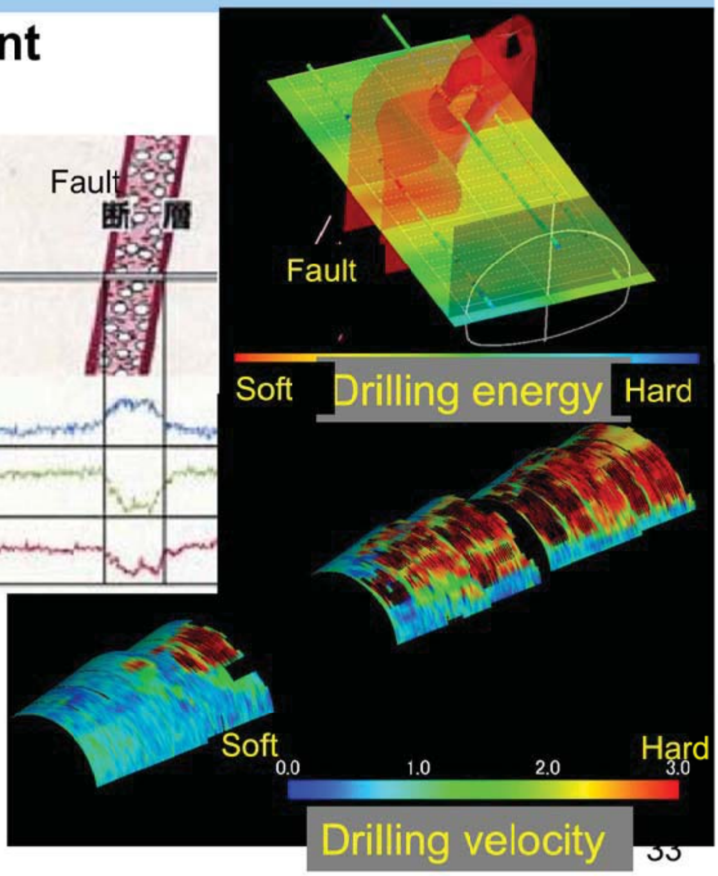
- Characterize the layers based on design standards
- Estimate & select support type of construction in case of applying NATM



Investigation during construction

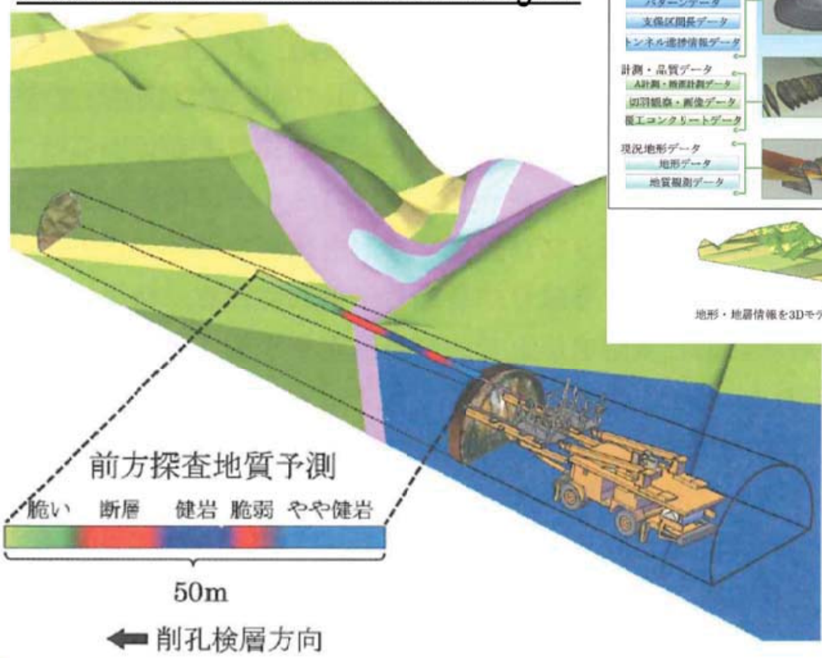
Probing method in front of tunnel face

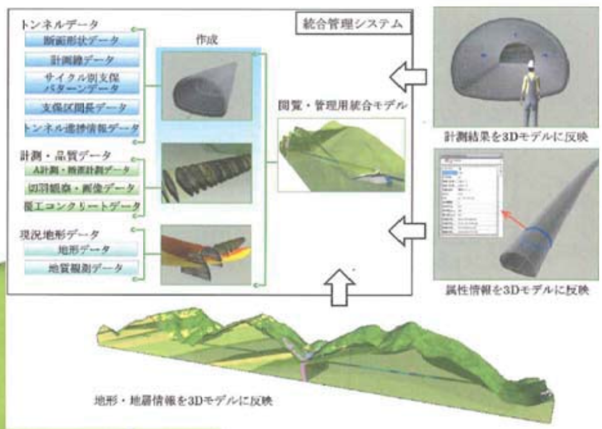




Survey during construction

Pre-boring during construction & advanced evaluation technologies

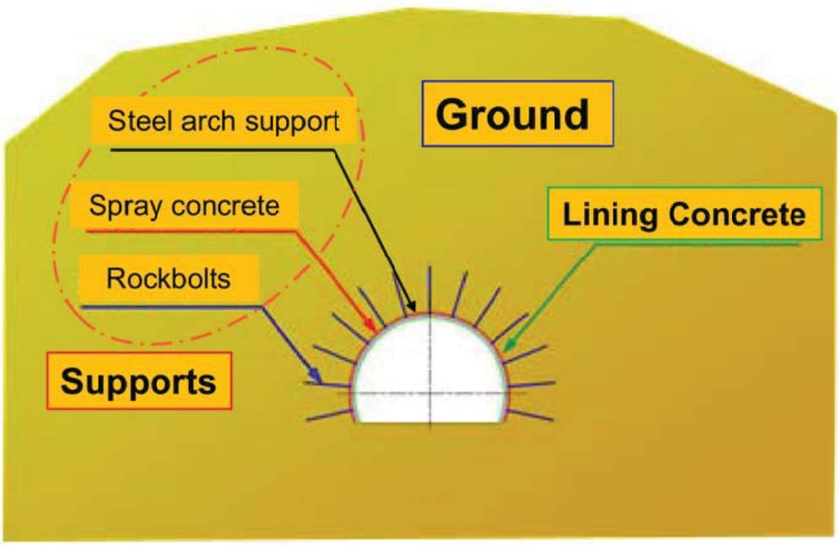




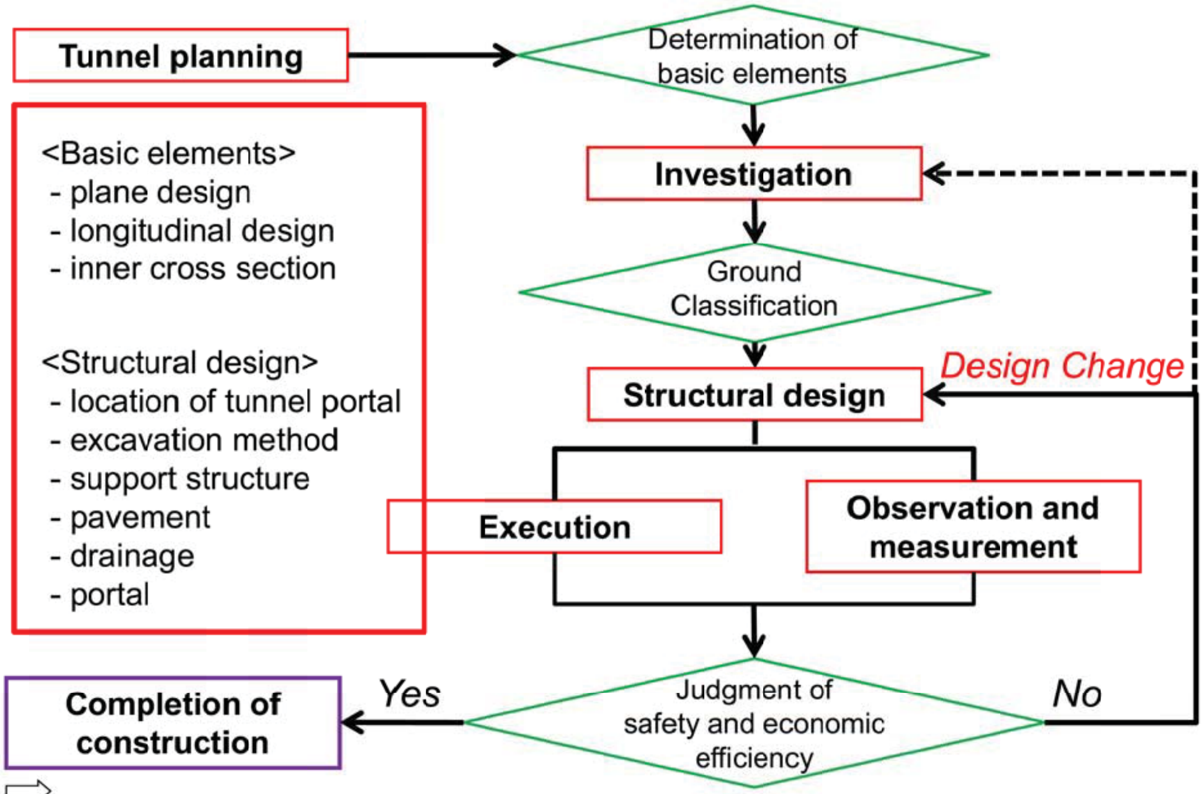
(3) Design

Basic structure of mountain tunnel (NATM)

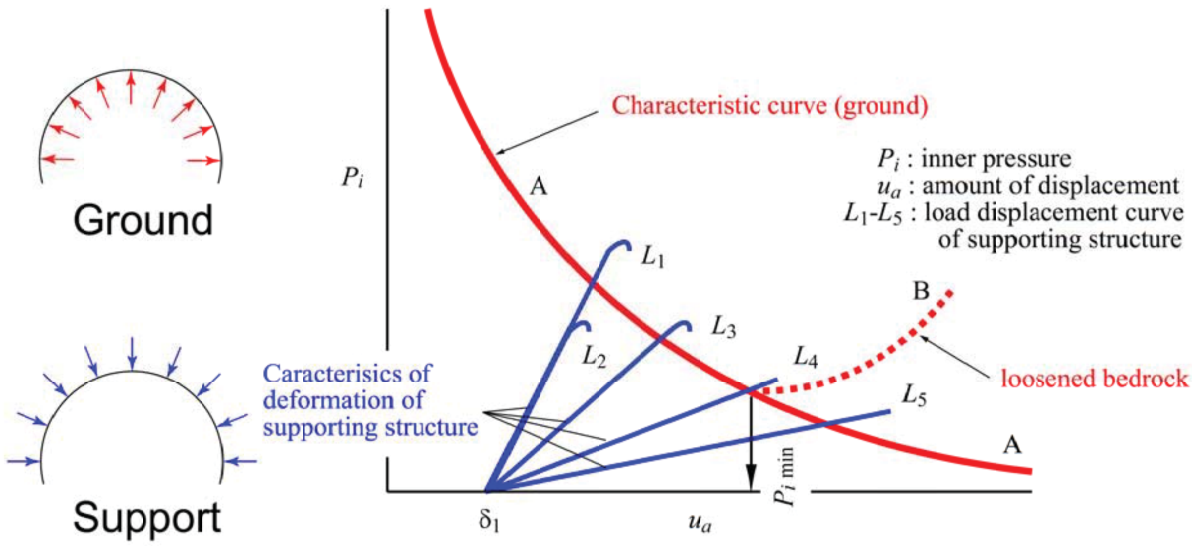
- **Ground** is fundamental factor to determine the spec. of tunnel
- **Supports** counter the load from ground by excavation
- **Lining concrete** finally ensures the stability of tunnel structure



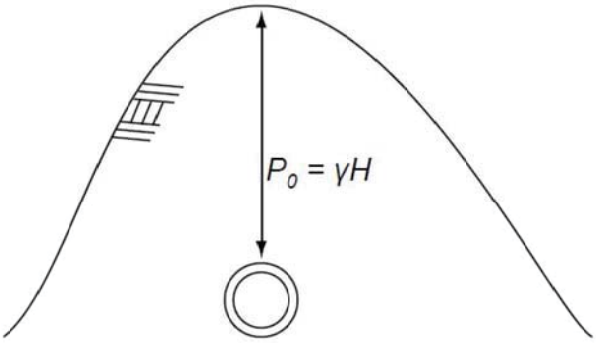
Design of tunnel structure and flow of execution

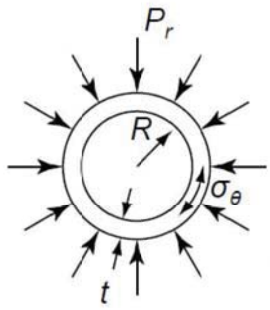


Load-displacement curve - Characteristic curve



Earth pressure in ground and load-bearing capacity of lining





$$\sigma_\theta = \frac{P_r \cdot R}{t}$$

γ : unit weight
H : overburden depth

P_r : earth pressure acting on lining
R : tunnel radius
t : thickness of lining

γ = 23 kN/m^3
H = 100 m

⬇

P_0 = 2.3 N/mm^2

σ_θ = 18 N/mm^2
t = 30 cm
R = 5 m

⬇

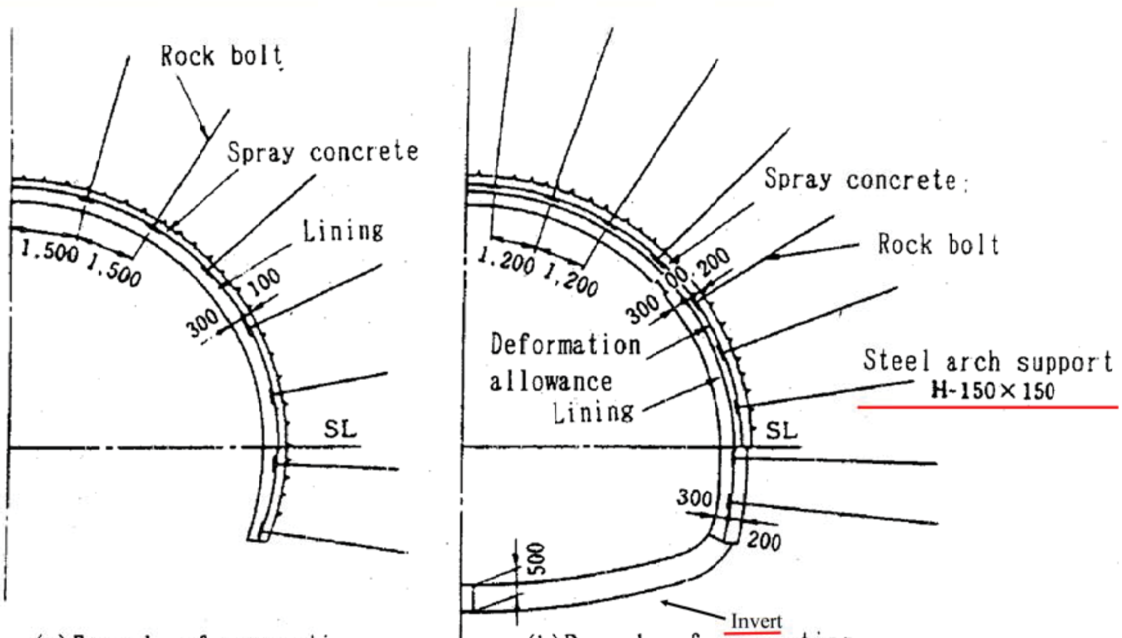
P_r = 1.08 N/mm^2

(4) Ground classification and support pattern

Example of ground classification

Ground class	Rock group	Rock kind	Seismic velocity Vp (km/s) 1.0 2.0 3.0 4.0 5.0	Ground condition: Rock quality and influence of water	Ground condition: Interval of discontinuity	Ground condition: Condition of discontinuity	Condition of core, RQD (%)	Competence factor
B	H-Massive	granite, granodiorite, quartz porphyry, hornfels		･Very hard and fresh, or weakly weathered. ･No deterioration by water.	･Joint interval is averagely 50 cm. ･Rock has bedding and schistosity, scarecely affecting excavation.	･Slickenside and thin clay are seldom observed. ･Discontinuity is mostly adhered.	･Cores show rock fragment or short column or stick. ･Core length is mostly 10 - 20 cm and occasionally around 5 cm. ･RQD is over 70.	----
		Mesozoic-Paleozoic sandstone, chert						
	M-Massive	andesite, basalt, rhyolite, crystal andesite						
		tertiary sandstone, conglomerate						
	L-Massive	serpentinite, tuff, tuff breccia						
	M-Layered	slate, Mesozoic-Paleozoic shale						
	L-Layered	black schist, green schist						
		tertiary mudstone						
CI	H-Massive	granite, granodiorite, quartz porphyry, hornfels		･Relatively hard and fresh, or weakly weathered. ･Soft rock comparatively cemented. ･No deterioration by water.	･Joint interval is averagely 30 cm. ･Rock has considerable bedding and schistosity, affecting excavation.	･Slickenside and thin clay are occasionally observed. ･Discontinuity is partly open but small.	･Core length is mostly 5 - 20 cm and occasionally below 5 cm. ･RQD is 40 - 70.	----
		Mesozoic-Paleozoic sandstone, chert						
	M-Massive	andesite, basalt, rhyolite, crystal andesite						over 4
		tertiary sandstone, conglomerate						
	L-Massive	serpentinite, tuff, tuff breccia						
	M-Layered	slate, Mesozoic-Paleozoic shale						
	L-Layered	black schist, green schist						
		tertiary mudstone						

Example of standard support structure



(a) Example of supporting structure for grade CI bedrock

(b) Example of supporting structure for grade DⅡ bedrock

Ground classification and support pattern

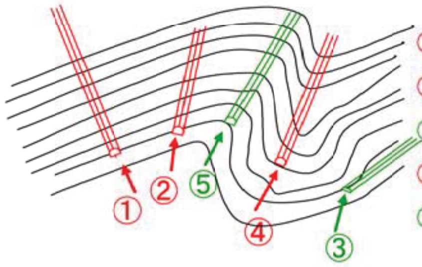
Ground class	Support pattern	Cycle length (m)	Rock bolts			
			Length (m)	Construction spacing		Construction sphere
				Circumferential direction (m)	Longitudinal direction (m)	
B	B	2.0	3.0	1.5	2.0	120 deg on top heading
CI	CI	1.5	3.0	1.5	1.5	Top heading
CII	CII-a	1.2	3.0	1.5	1.2	Top and bottom heading
	CII-b					
DI	DI-a	1.0	3.0	1.2	1.0	Top and bottom heading
	DI-b		4.0			
DII	DII	below 1.0	4.0	1.2	below 1.0	Top and bottom heading

Ground class	Support pattern	Steel arched support			Thickness of shotcrete (cm)	Thickness of lining		Allowed deformation (cm)	Excavation method
		Top heading	Bottom heading	Longitudinal pitch (m)		Arch (cm)	Invert (cm)		
B	B	-	-	-	5	30	0	0	Full face method with auxiliary bench or top heading method
CI	CI	-	-	-	10	30	(40)	0	
CII	CII-a	-	-	-	10	30	(40)	0	
	CII-b	H-125	-	-					
DI	DI-a	H-125	H-125	1.2	15	30	45	0	
	DI-b			1.0					
DII	DII	H-150	H-150	below 1.0	20	30	50	10	

(5) Portal design

Position of portal for slope gradient

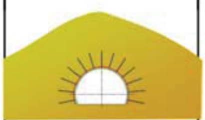
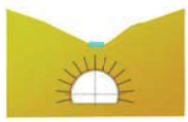
- Difficulty level of construction at portal varies greatly depending on positional relation between geography and tunnel axial direction.



① Perpendicular to contours-type ->Large
② Diagonal to contours-type ->Large
③ Parallel to contours-type ->Small
④ Penetrating the ridge-type ->Large
⑤ Penetrating the valley-type ->Small

Position of portal for slope gradient

- Difficulty level of construction at portal varies greatly depending on positional relation between geography and tunnel axial direction.

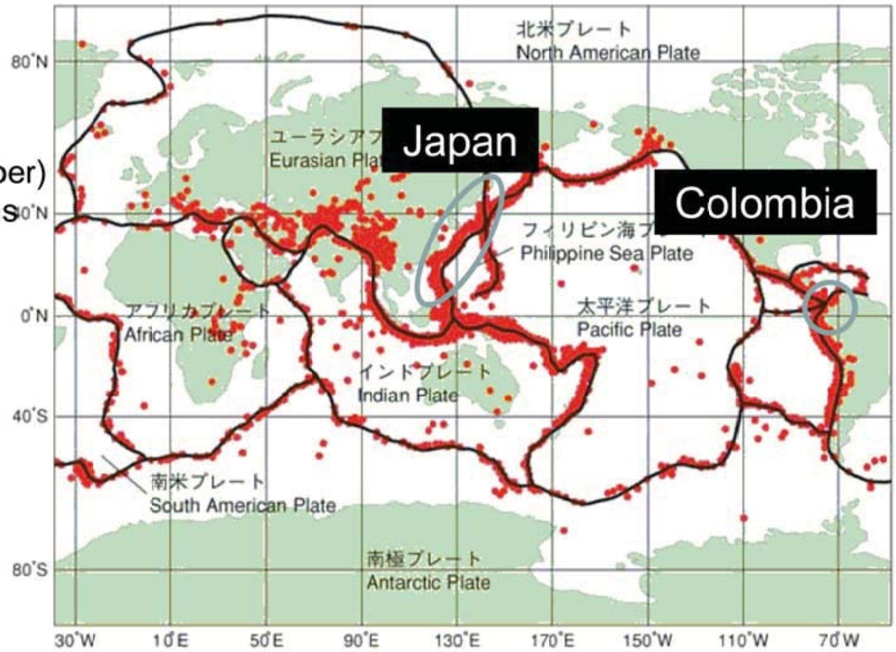
	① Perpendicular to contours-type	② Diagonal to contours-type	③ Parallel to contours-type	④ Penetrating the ridge-type	⑤ Penetrating the valley-type
Cross-section					
Earth covering	Large	Large	Small	Large	Small
Problem	None in particular	Unsymmetrical earth pressure	Unsymmetrical earth pressure	None in particular	Small earth covering, thick unconsolidated layer
Evaluation order	Most ideal	Avoid if possible	Avoid as much as possible	Generally stable	Consider carefully

(6) Against earthquake

Natural disaster in Japan

- Japan has wide variety of natural disasters

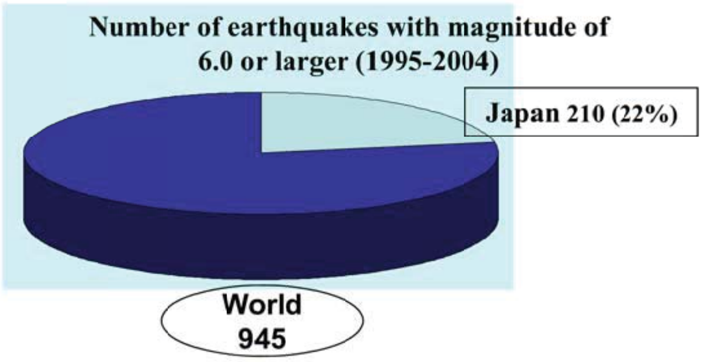
- Earthquakes
- Tsunamis
- Volcanic Eruptions
- Typhoons
  (Season; July – October)
- Heavy Monsoon Rains
  (Season; May – July)
- Floods
- Landslides
- Snow Avalanches



Earthquake in Japan

- Japan is prone to earthquakes

10% of whole earthquake energy in the world is released around Japan



- Most dreadful things historically in Japan (tradition)

1. earthquakes, 2. lightning/thunder, 3. fire, 4. father

Jishin Kaminari Kaji Oyaji

Earthquake in Japan

- Traditional "UKIYOE" drawing after 1855 October Ansei-Edo Earthquake

- Edo (Old name of Tokyo) citizens beating the legendary Catfish Monster, believed to cause earthquake

Example of damage by earthquake (Niigataken Chuuetsu earthquake in Oct.23 2005)

Collapse of sidewall – Regional road

Distance from epicenter : Within 10km
Magnitude : 6.8

Example of damage by earthquake (Niigataken Chuuetsu earthquake in Oct.23 2005)

- This tunnel reopened after 1 week with protection
- Sidewall was repaired after that

Example of damage by earthquake (Niigataken Chuuetsu earthquake in Oct.23 2005)

- Fall out of lining concrete – NH 8

= Road reopened within one week
by emergency countermeasures

Example of damage by earthquake (East Japan earthquake in Mar 11 2011)

- Only small horizontal cracks at sidewall

Distance from epicenter : About 100km
Magnitude : 9.0

Example of damage by earthquake (East Japan earthquake in Mar 11 2011)

Very small damage
No tunnel disrupted by this earthquake

Tunnel is high mitigation against disaster from past experiences in Japan

Example of damage by earthquake (Kumamoto earthquake in Apr 16 2016)

- Permanent lining fell down due to earthquake
- Fault and poor ground condition
- But the area is limited

(7) Design by numerical analysis

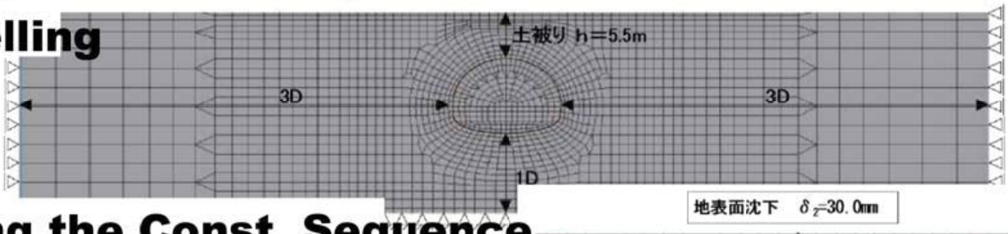
Analysis Methods

Methods	Type	Applicability
Frame model	Separated type model	Easy calculated and the concrete outer force grasped
Finite Element Method (FEM)	Continuum analysis	Popular and many experiences, not suitable for phenomenon with large deformation
Finite Difference Method (FDM)	Continuum analysis	More suitable for phenomenon with large deformation Frequently used recently
Discrete Element Method (DEM)	Non-Continuum analysis	Not many experiences, Suitable as large deformation analysis
Discontinuous Deformation Analysis (DDA)	Non-Continuum analysis	Not many experiences, Suitable as large deformation and non-continuum analysis

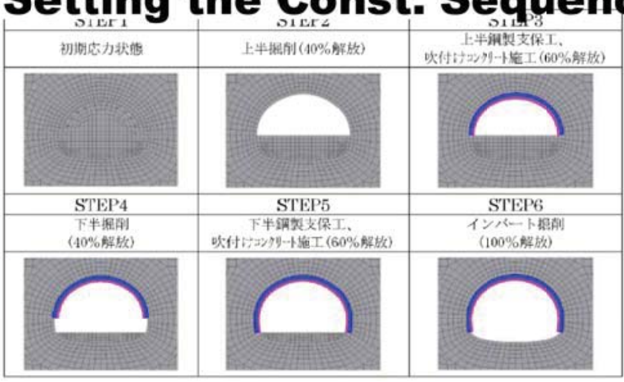
Finite Element Method (FEM)

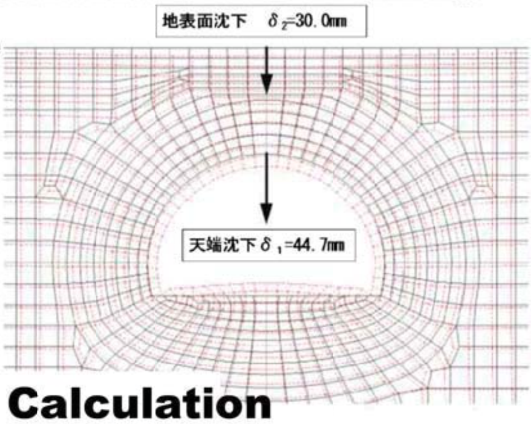
- Most common, Easy to conduct, Not suitable for large deformation phenomenon

Modelling



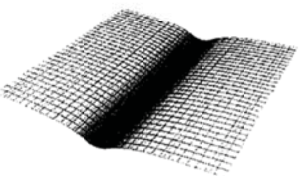
Setting the Const. Sequence



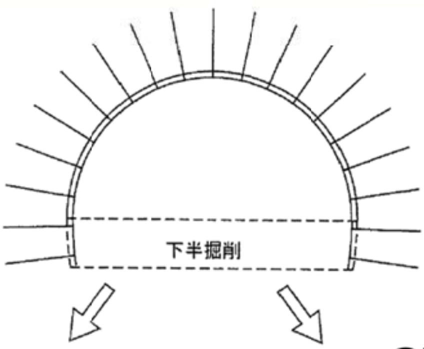


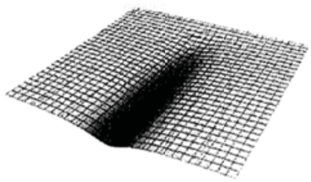
Calculation

Finite Element Method (FEM)



地表面沈下分布
解析断面の横断面での分布がわかる

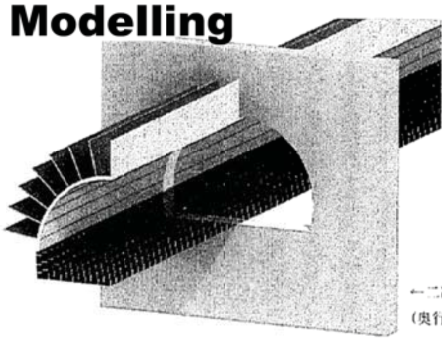




地表面沈下分布
切羽到達前・到達後での分布の広がりかたがわかる

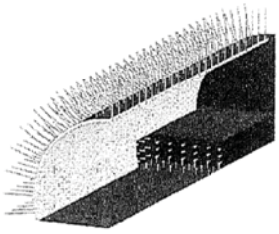
2D Modelling

3D Modelling



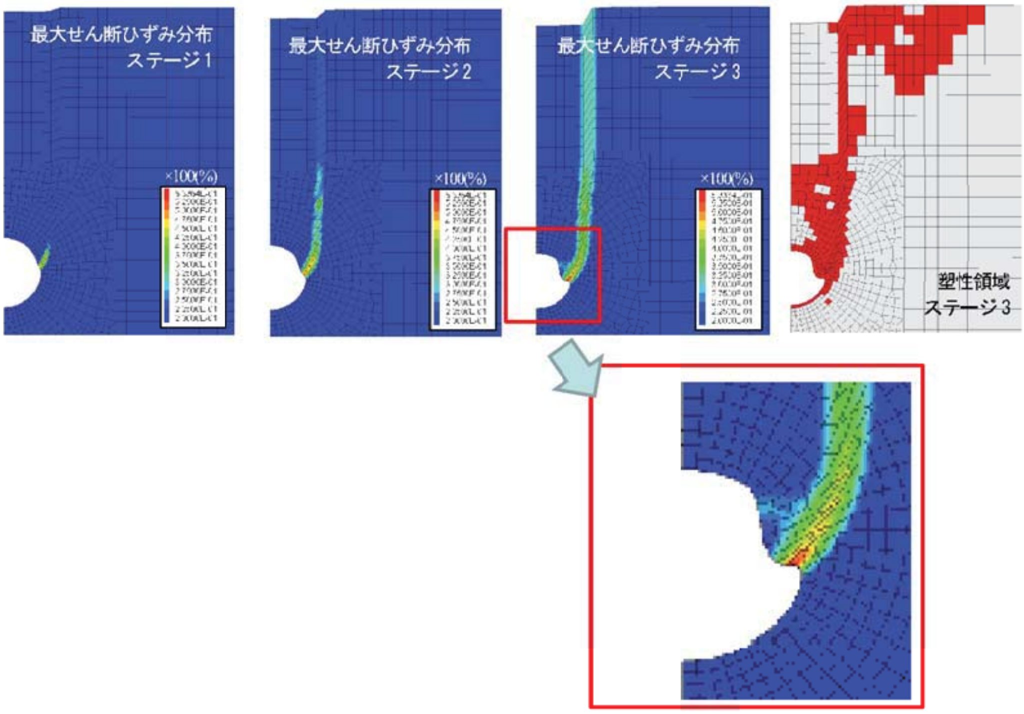
←二次元平面ひずみの解析領域
（奥行き 1m としてモデル化する）

二次元平面ひずみ解析モデルの例



三次元解析モデルの例

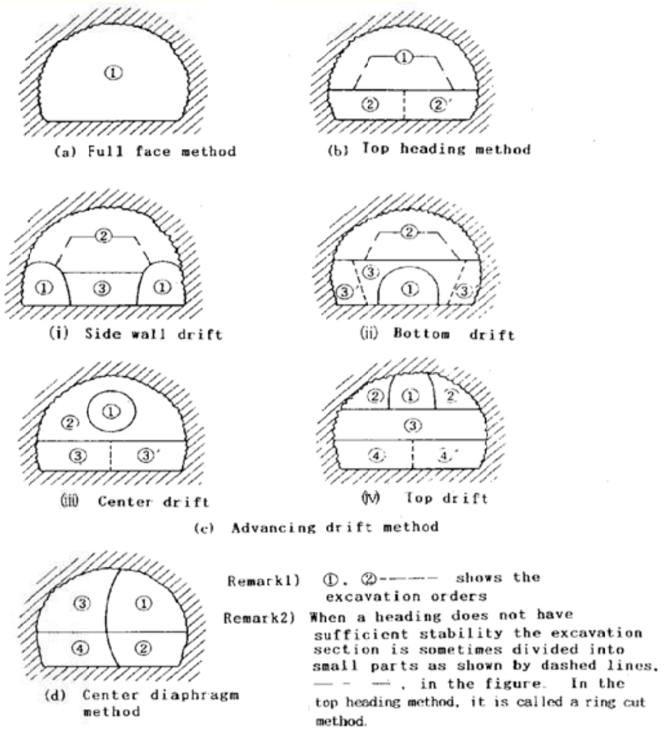
Finite Difference Method (FDM)



3. CONSTRUCTION CONCEPT IN JAPAN

Construction of mountain tunnel

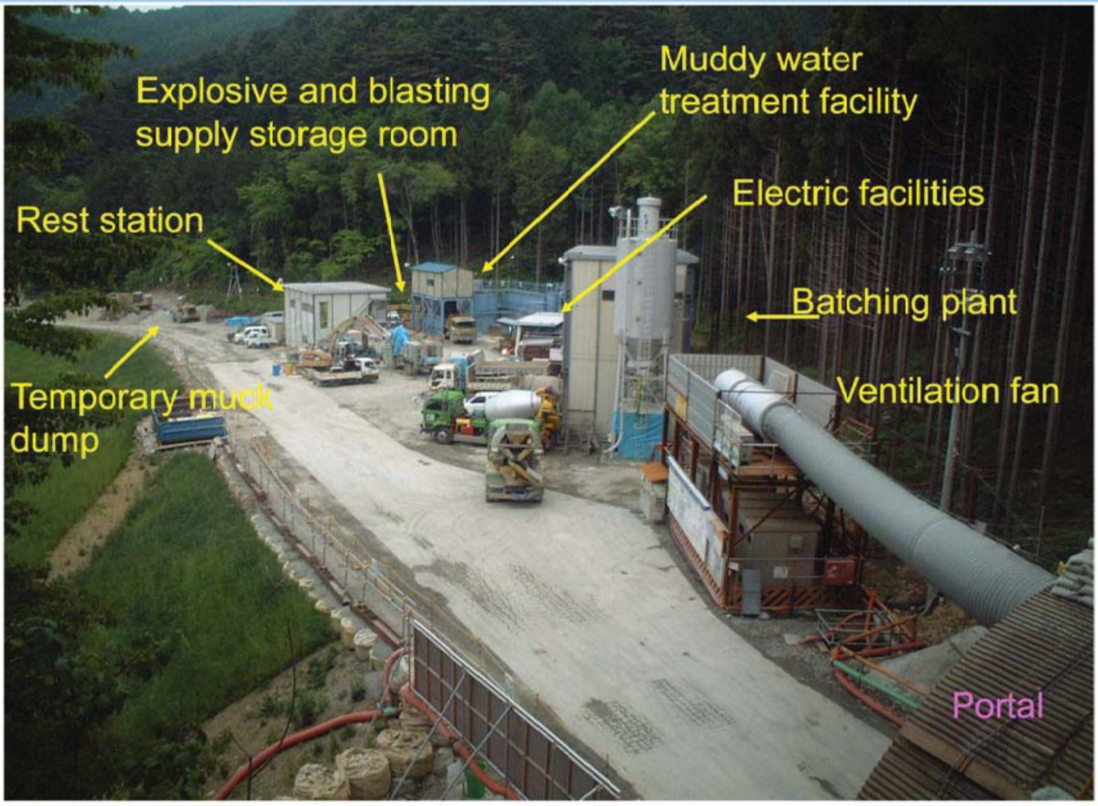
Division of heading section



Kind of support and structure

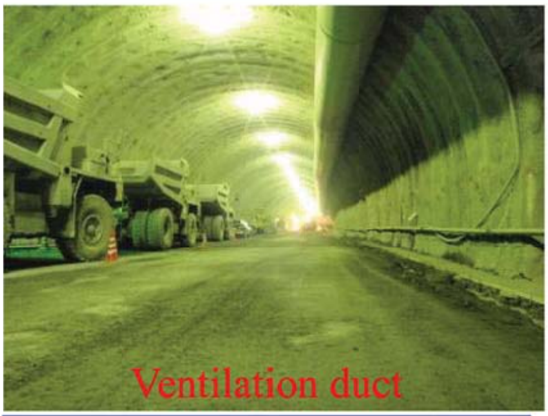
1) Shotcrete
   - Dry, Wet ; Dust problem
   - Auxiliary method ; water inflow
2) Rock bolt
3) Steel rib
4) Lining and invert
5) Auxiliary method

Facilities for construction



Facilities for construction

Ventilation facility



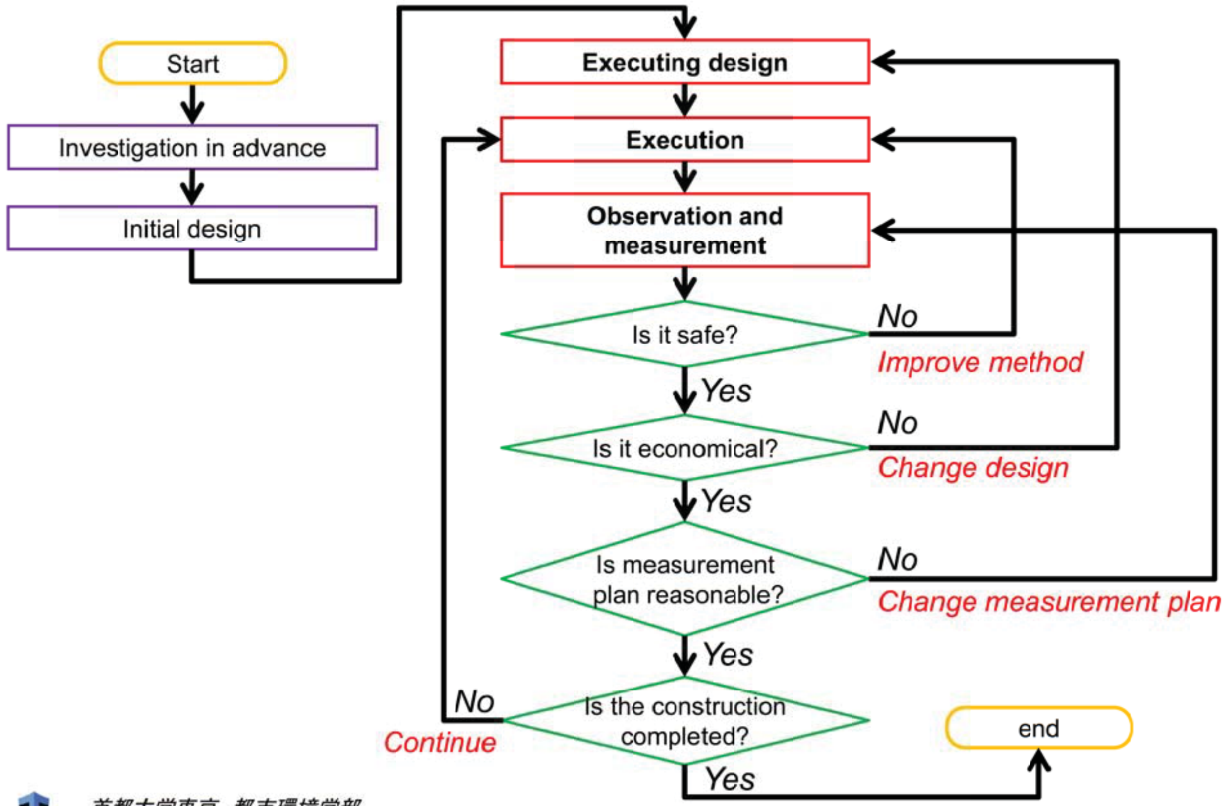
Ventilation duct

Muddy water treatment facility

Batching plant

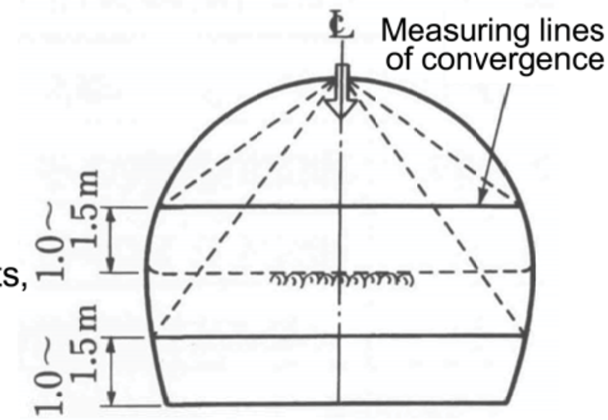
Measurement

Measurement at work site



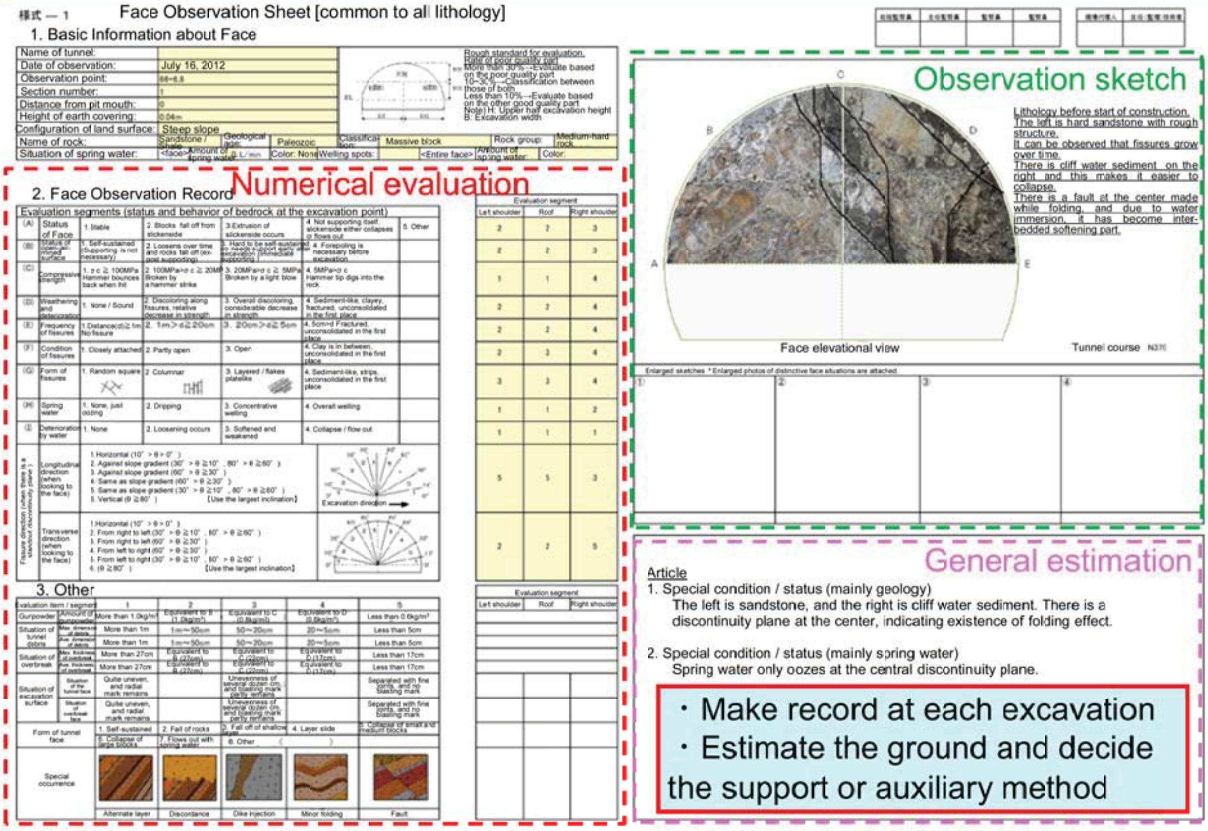
Typical measurement items in Japan

- Observation
  - Cracks and fissures, ground stability, water flow
- Measurement A
  - Convergence and Crown Settlement measurement
- Measurement B
  - Measurement of stress in supports, measurement of ground displacement
- Others
  - Measurement of surface displacement, groundwater level, etc.

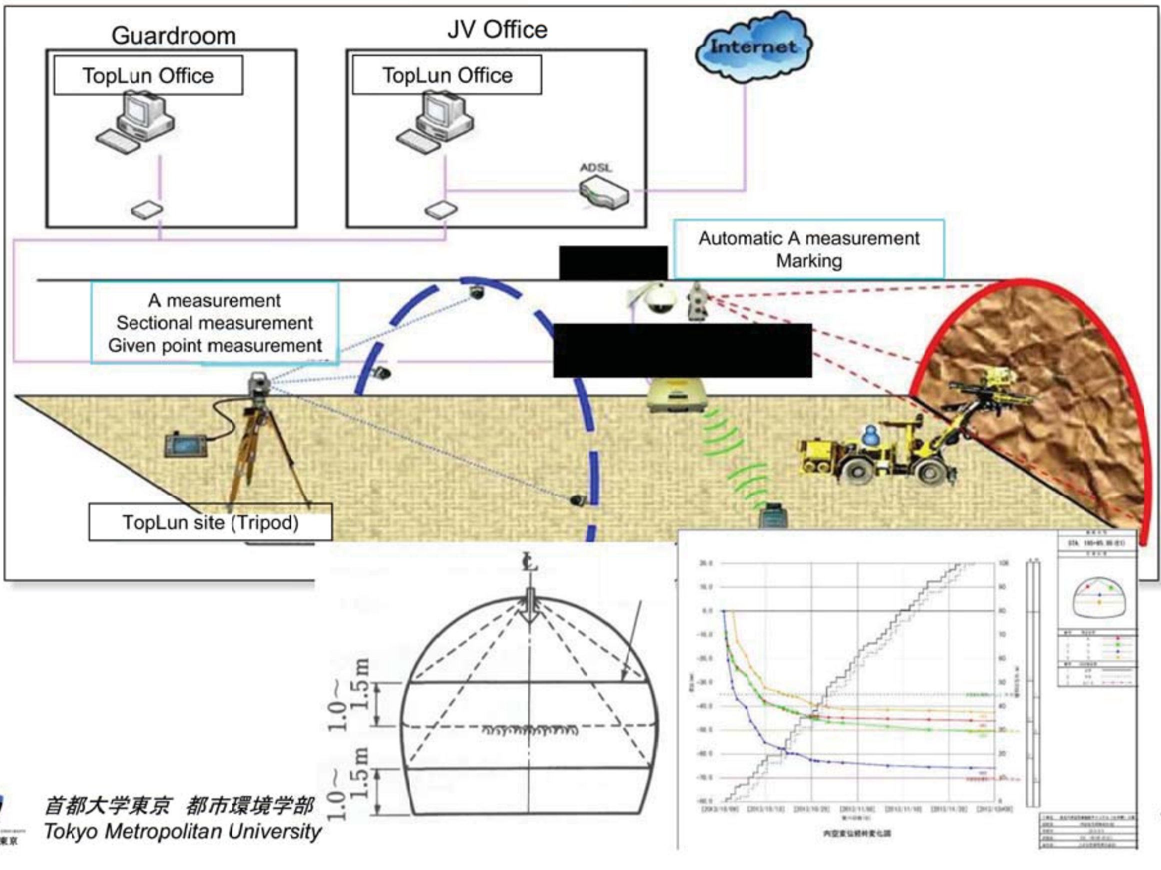


⇒confirmation and estimation of support design
=Economical and rational method

Observation and evaluation

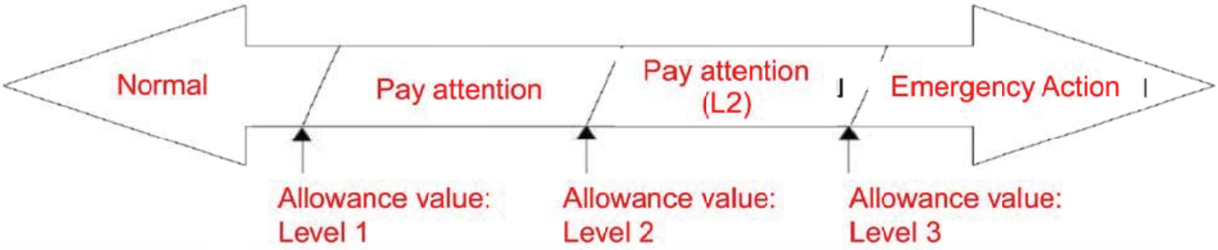


Measurement A



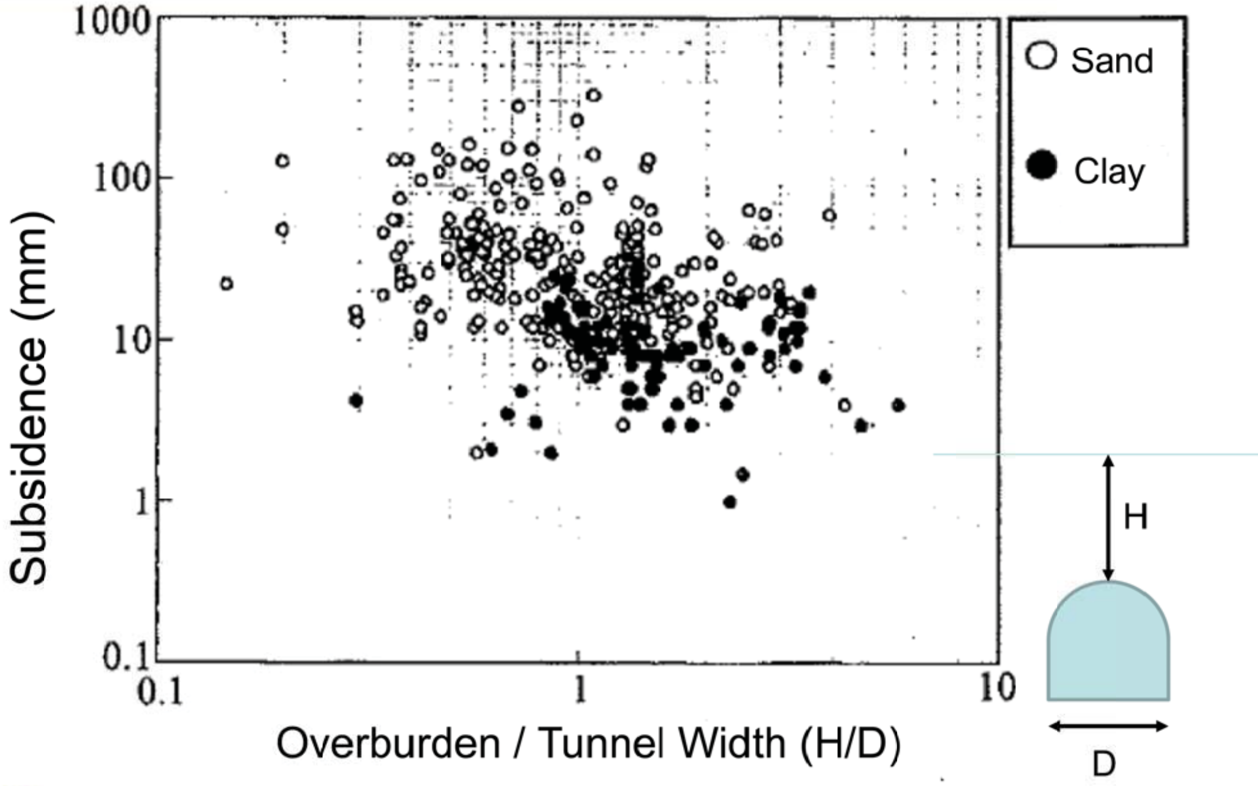
Concept of measurement control

- Basic concept of Safety Management Plan



Level 0: Normal	➢ Normal construction management
Level 1: Pay Attention	➢ Increasing frequency of monitoring ➢ Safety Instruction to workers
Level 2: Pay Attention(L2)	➢ Increasing frequency of monitoring ➢ Study on cause of deformation, prediction of future behavior ➢ Study on measures and application
Level 3: Emergency Action	➢ Terminate the work, discussion between stakeholders ➢ Study on cause of deformation, prediction of future behavior ➢ Study on measures and application

Statistical chart of Japanese experiences



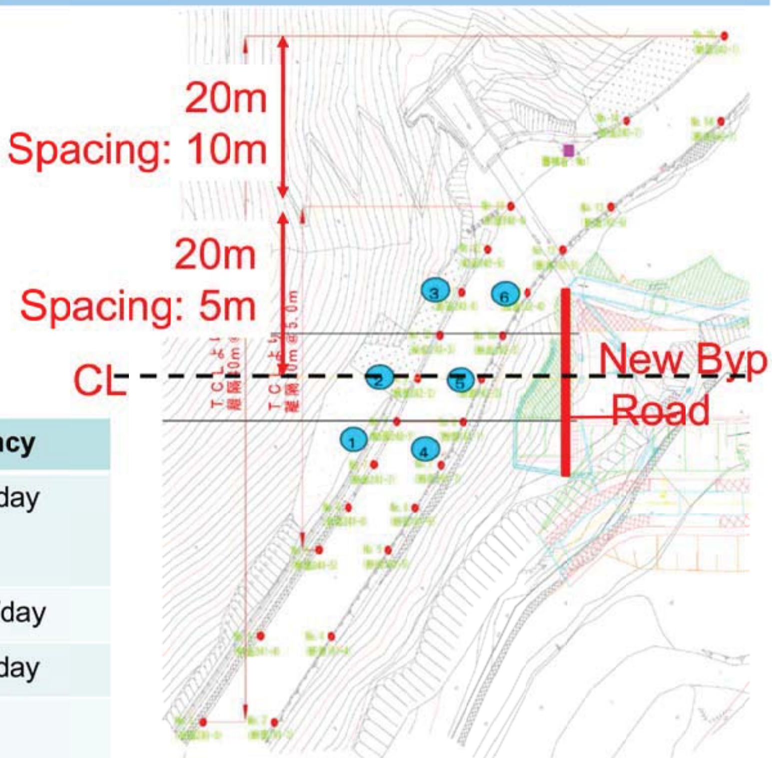
Example of setting control value

- Monitoring Item : Deformation of Tunnel
- Method (equipment) : Total Station with automatic target recognition, CCTV
- Allowance values

Management Level	Allowance value (mm)	Remarks
I	15	50% of Level III
II	22	75% of Level II
III	30	From Japanese Road Maintenance Standard

Example of setting control value

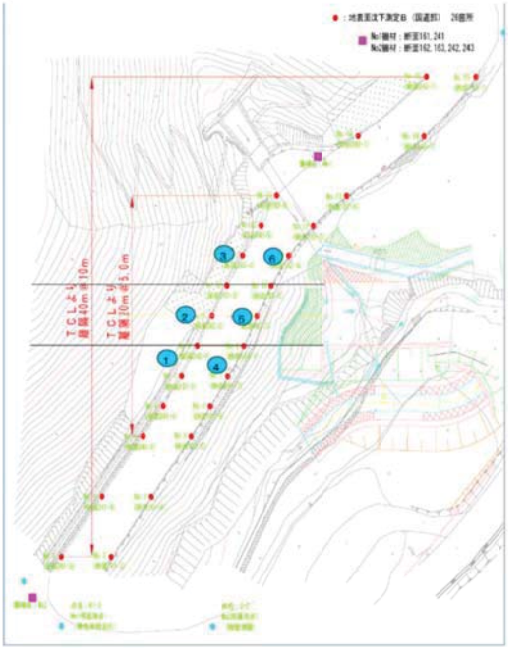
- Location and Plan
- Target: 26 nos.

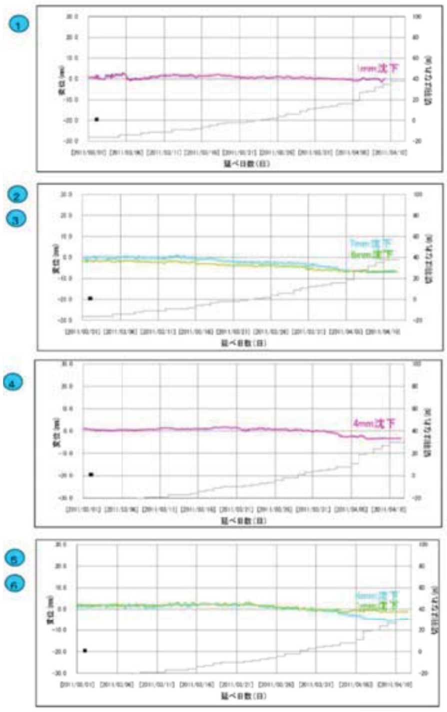


Period	Frequency
Before construction ~ beginning of the construction	1 time / day
During construction	2 times /day
After construction*	1 time / day
* Monitoring can be terminated after confirming the stable results	

Example of setting control value

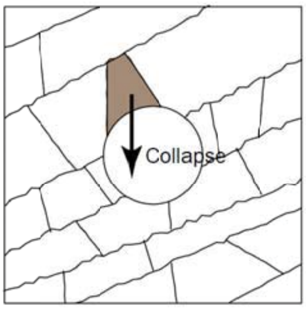
- Monitoring Plan and Results

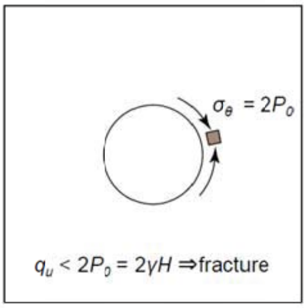


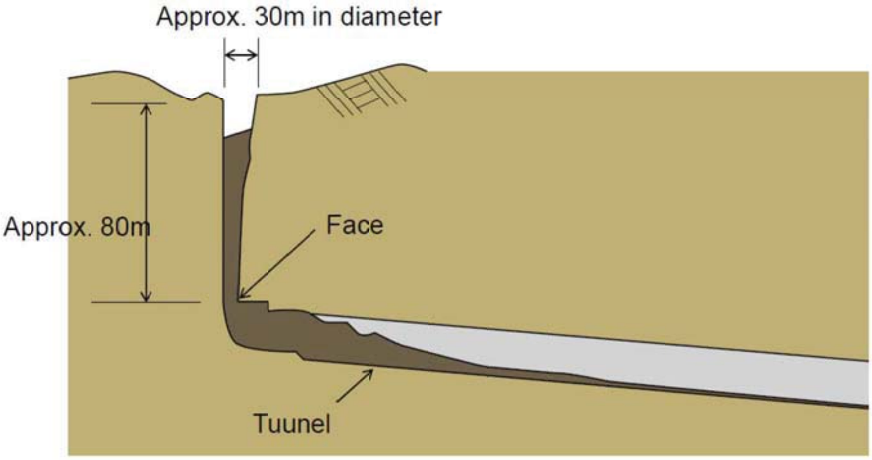


Auxiliary method

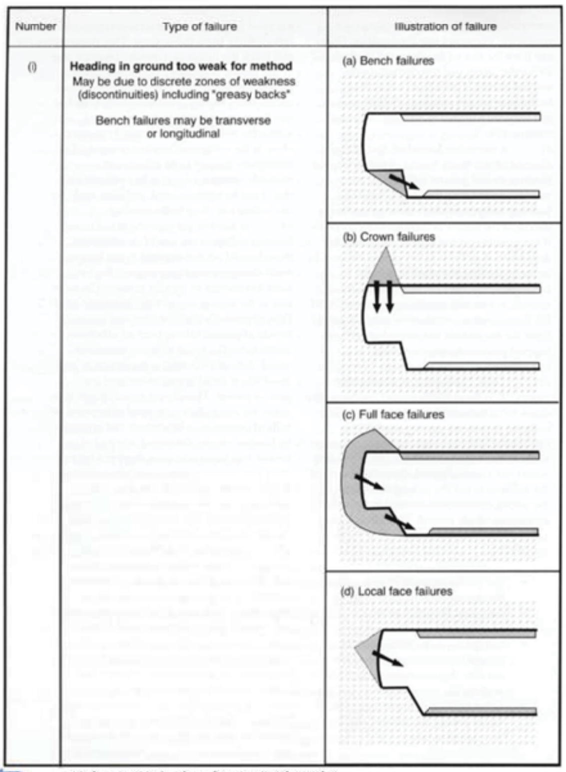
Example of collapse of tunnel



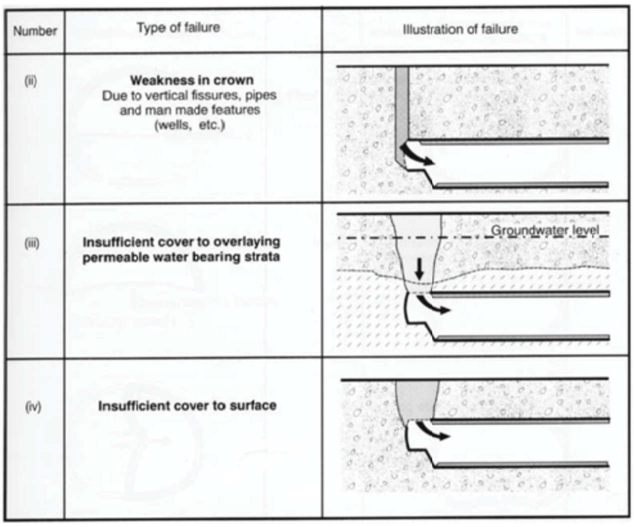




Type of failures



Number	Type of failure	Illustration of failure
(i)	**Heading in ground too weak for method** May be due to discrete zones of weakness (discontinuities) including "greasy backs" Bench failures may be transverse or longitudinal	(a) Bench failures (b) Crown failures (c) Full face failures (d) Local face failures



Number	Type of failure	Illustration of failure
(ii)	**Weakness in crown** Due to vertical fissures, pipes and man made features (wells, etc.)	
(iii)	**Insufficient cover to overlaying permeable water bearing strata**	Groundwater level
(iv)	**Insufficient cover to surface**	

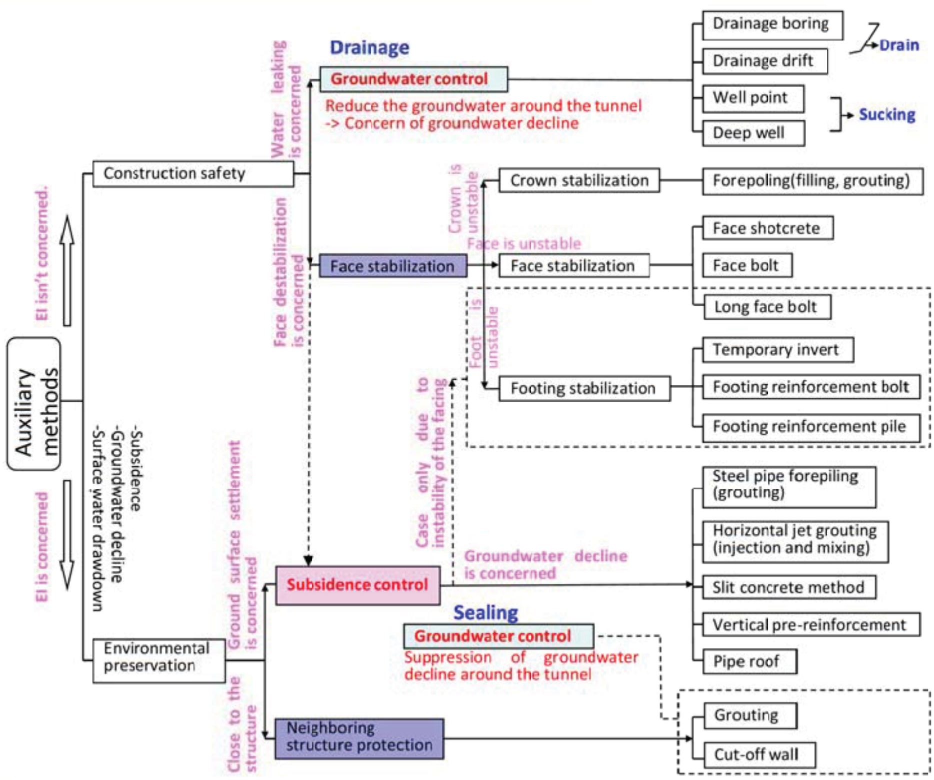
Source: Safety of NATM tunnels, Health and Safety Executives UK 1996

http://www.hse.gov.uk/pubns/natm.htm

Kind of Auxiliary method

Method	Purpose	Measures for roof stability	Measures for face stability	Measures for bottom stability	Measures for water inflow	Measures for ground surface subsidence	Measures for neighbor structure protection
Presupport	Filling type forepoling	◎	○				○
	Injection type forepcling	◎	○			○	○
	Steel pipe forepiling	○	○			○	○
	Piperoof	○	○			◎	○
	Horizontal jet grouting	○	○	○		○	○
	Prelining	○	○			○	○
Reinforcement of face	Spray concrete to face		◎				
	Bolting to face		◎				
Reinforcement of footing	Footing enlargement of support			◎		◎	
	Temporary invert of top heading			○		○	
	Footing reinforcement bolt/pile			○		○	
	Improvement of footing			○		○	
Reinforcement of ground	Drainage boring	○	○		◎		
	Well point	○	○		○		
	Perpendicular forepoling	○	○			○	

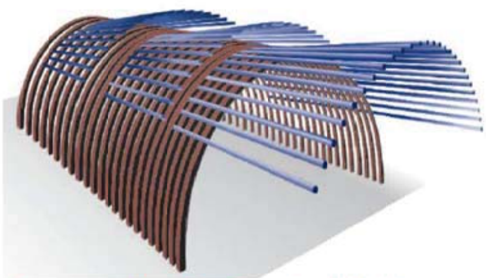
Selection of Auxiliary method



Frequent example of Auxiliary method

a) AGF (All Ground Fasten), Against subsidence

- This method that forms composite reinforcements consisting of steel pipes and grout material, where the ground is reinforced by injecting cement paste or chemical paste or chemical grout into the ground around the steel pipes.



Long steel pipe L=12.5m

Wide coverage, cohesive soil - Hard rock

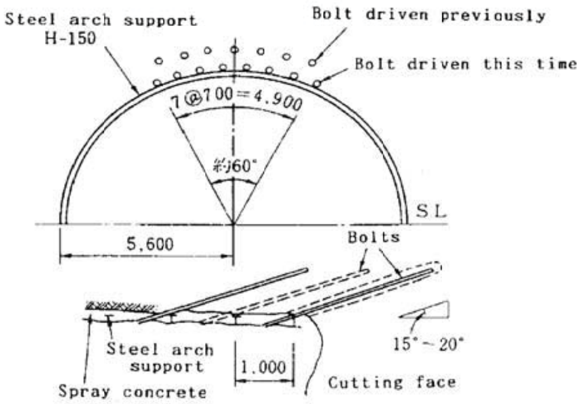
Crown stabilization type

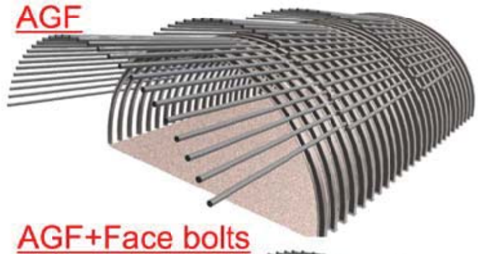
Prevention of deformation by fore-roof

Lowering water pressure type

Prevention of ground breakup with water flow

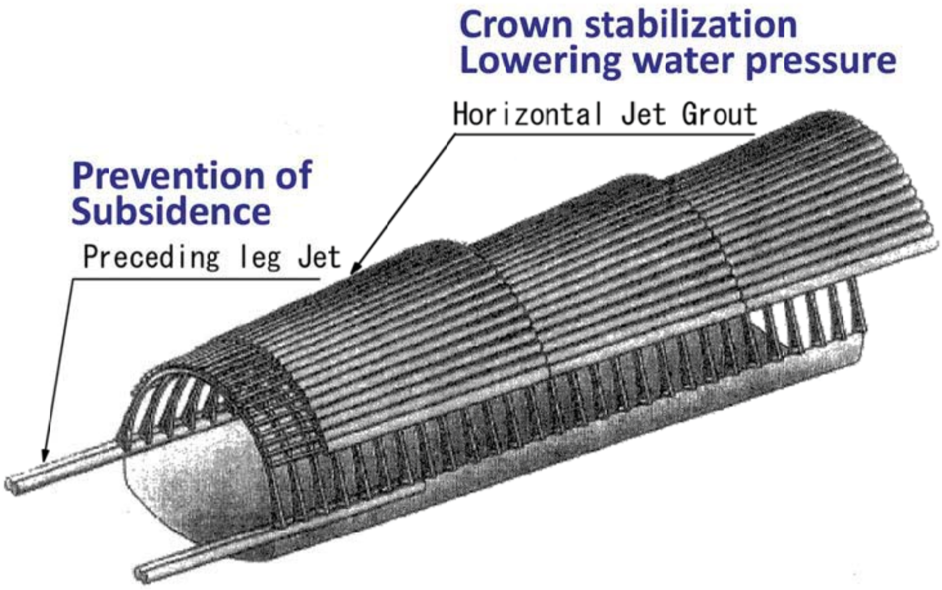
Frequent example of Auxiliary method





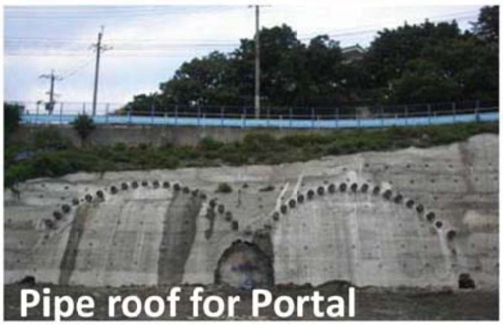
Frequent example of Auxiliary method

b) Horizontal jet grouting method, Against subsidence



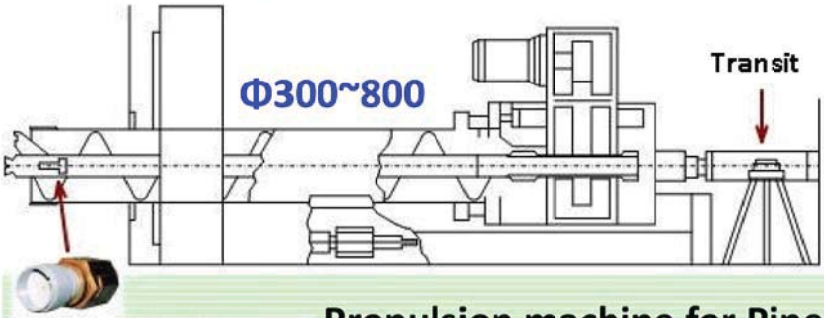
Frequent example of Auxiliary method

c) Pipe roof protection, Against subsidence



Target by LED type

Directional correction equipment

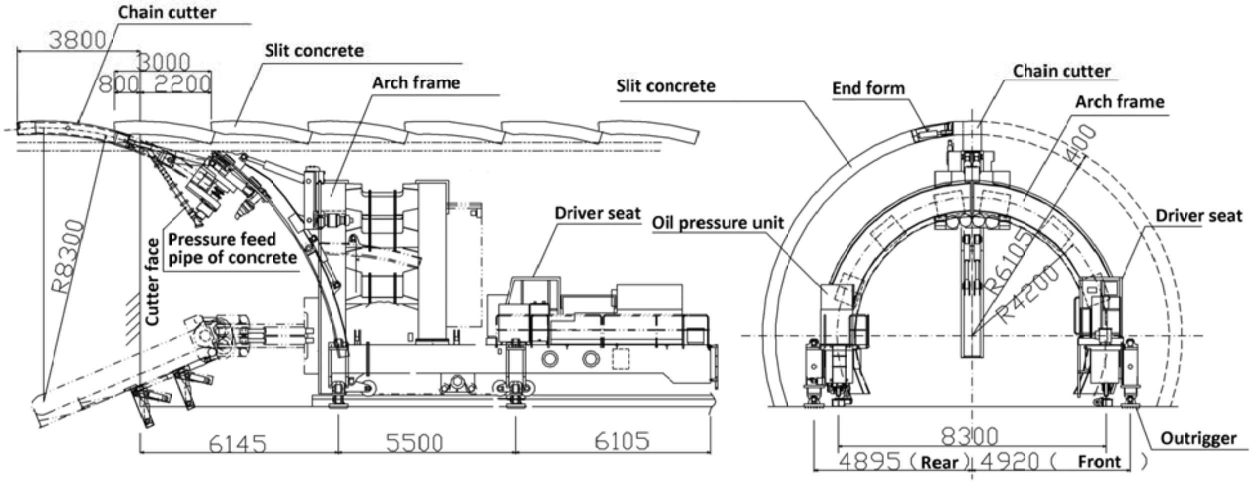


Luminous diode type target

Propulsion machine for Pipe roof

Frequent example of Auxiliary method

d) Pre-Lining, Slit concrete method, Against subsidence



Consideration

- High Risk Geological Condition?
  - Unconsolidated Soil, Rock Stratum
  - Thin Overburden
  - High Groundwater Pressure

- Cause of the accidents ?
  - Wrong assumption of geological condition before construction
  - Over-reliance on technology
  - Shortage of construction and evaluation skill

Example of large deformation

Collapse in the urban tunnel – Hakata station

W27m x L30m x D15m

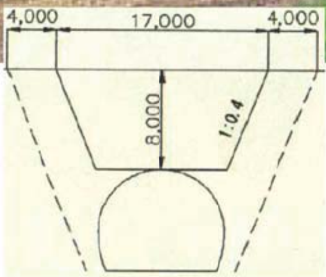
Source: MLIT Report

- Source: Asahi.com

Collapse in the shallow tunnel – Ushikagi tunnel

➢ Large sized Collapse had happened during

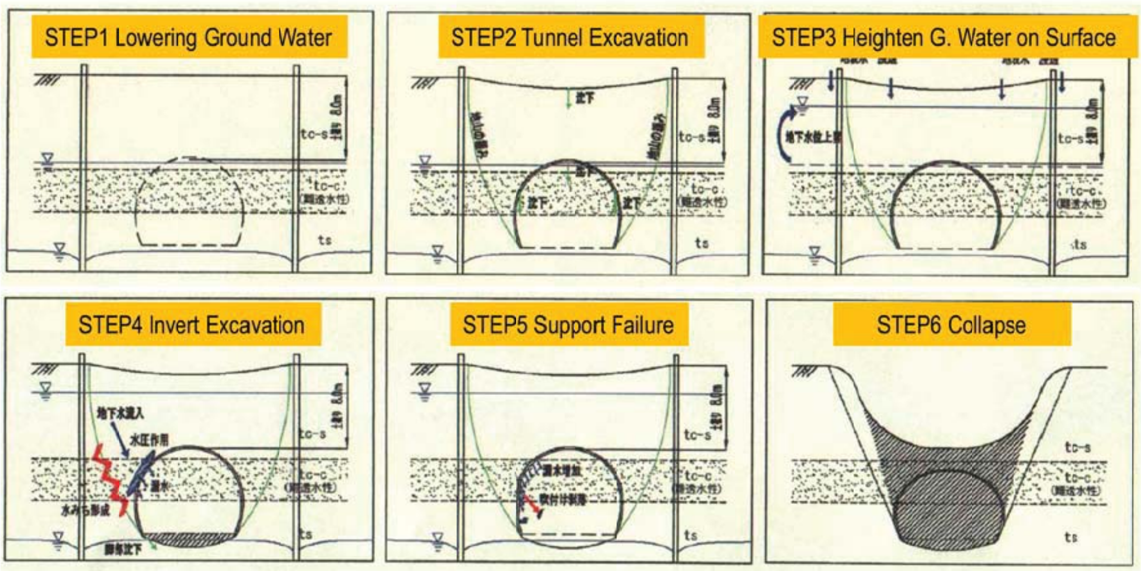
W20m x L60m x D10m



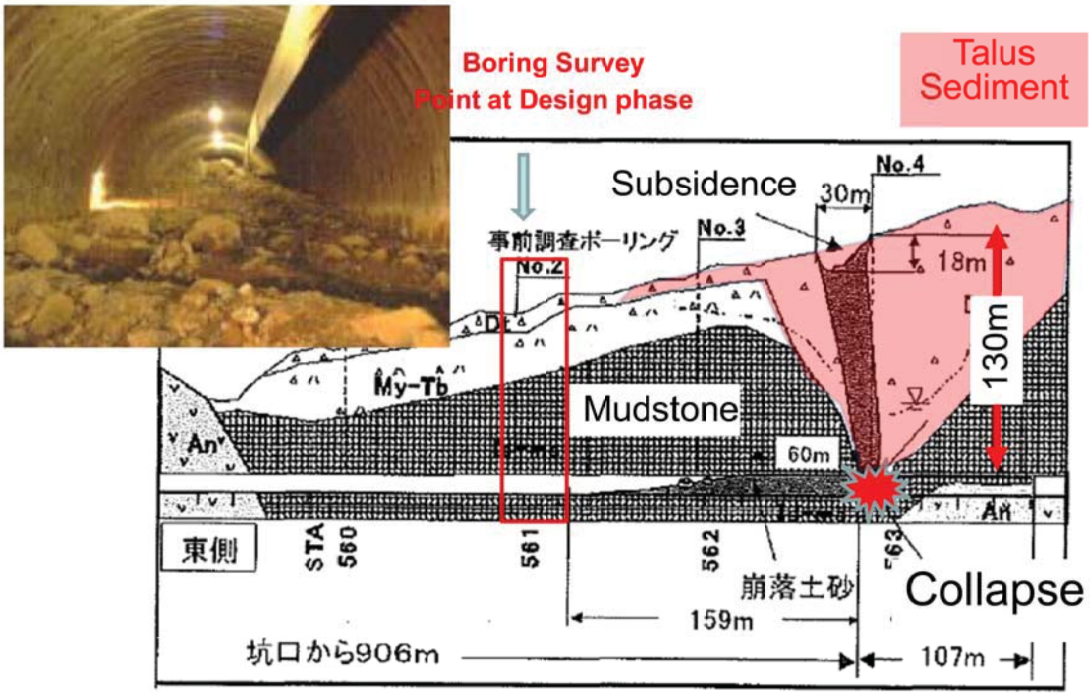
Collapse in the shallow tunnel – Ushikagi tunnel

➢ Heighten G.W.L because of Paddy field was the main cause

➢ Open cut method was applied for the section collapsed for the recovery works



Collapse at Talus sediment



Construction example

List of example

- Kan-etsu tunnel ; Longest mountain tunnel
- Hida tunnel; Hard rock TBM adopted in Japan
- Akaiwa tunnel; Construction in very big landslide area
- Nikkureyama tunnel; Large heaving occurred
- Kishitani Namamugi tunnel; Twin tunnel with shallow overburden

Kan-etsu tunnel

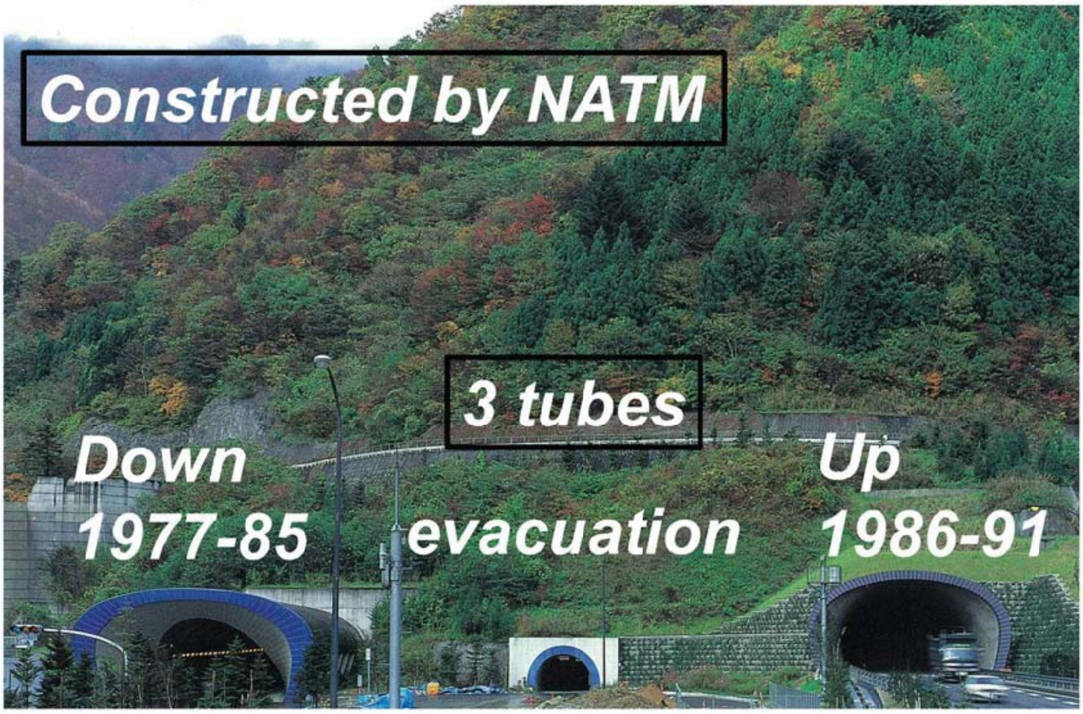
- The longest road tunnel in Japan

Kan-etsu tunnel

- The longest road tunnel in Japan

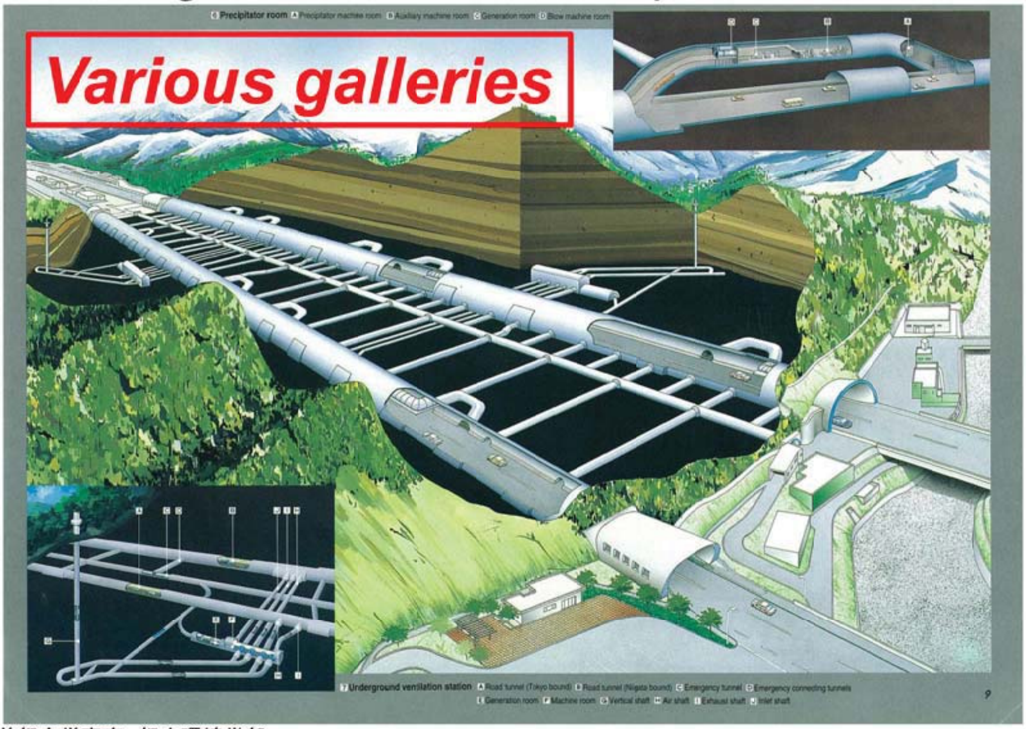
Kan-etsu tunnel

- The longest road tunnel in Japan



Kan-etsu tunnel

- The longest road tunnel in Japan



Hida tunnel

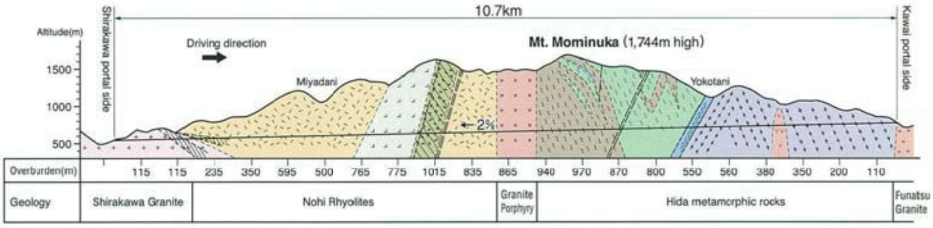
- Adoption of hardrock TBM in Japan

Type	Improved open-type
Excavation diameter	12.84m
Machine length	19.5m
Overall length	Approx. 160m
Weight: Boring machine	1,950t ＋Backup system:1,000t
Total output	7,200kw
Disc cutter diameter	19inches (483mm)
Number of disc cutters	91pcs (incl. three over-cutters)

Type	Full-shield
Excavation diameter	4.5m
Machine length	8.85m
Overall length	Approx. 130m
Weight	310t (machine) 147t (backup)
Total output	1,618kw
Disc cutter diameter	17inches (432mm)
Number of disc cutters	32pieces

Hida tunnel

- Adoption of hardrock TBM in Japan



Hida tunnel

- Adoption of hardrock TBM in Japan

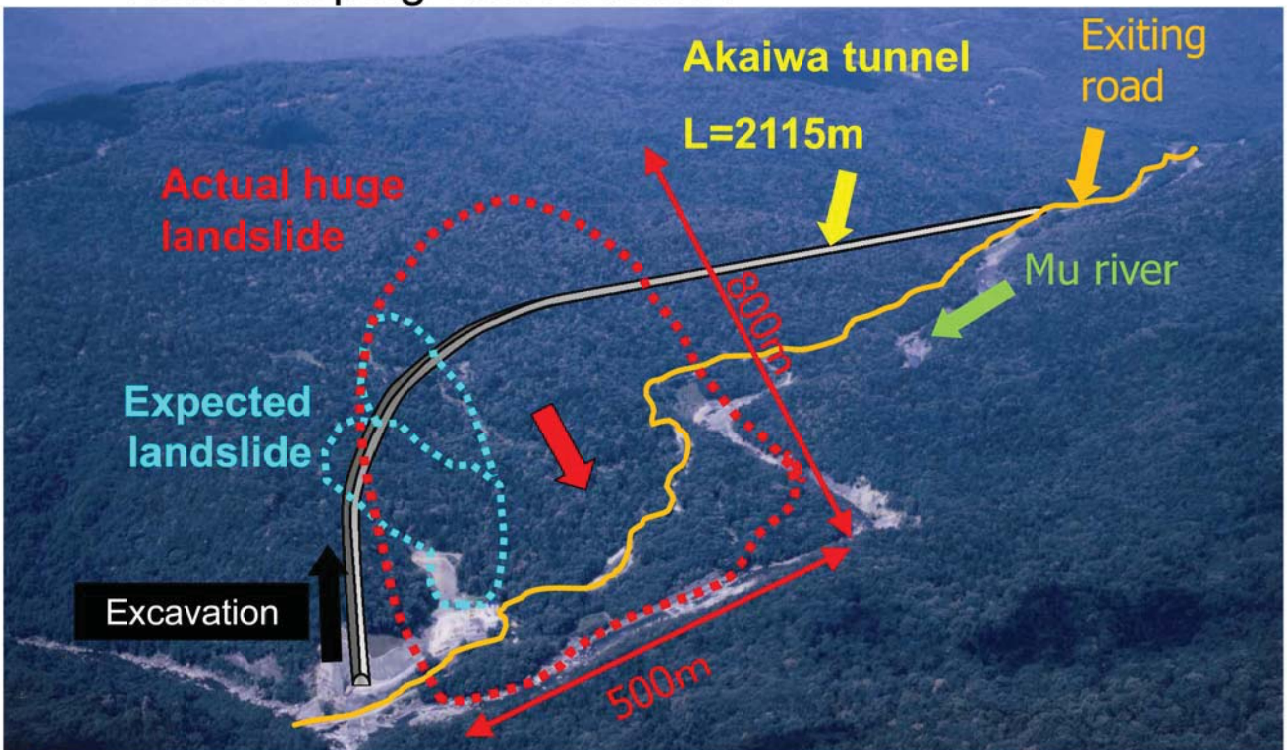
Aimed at rapid excavation, but battle against big earth pressure and huge water

Akaiwa tunnel

- Tunnel coping with landslide

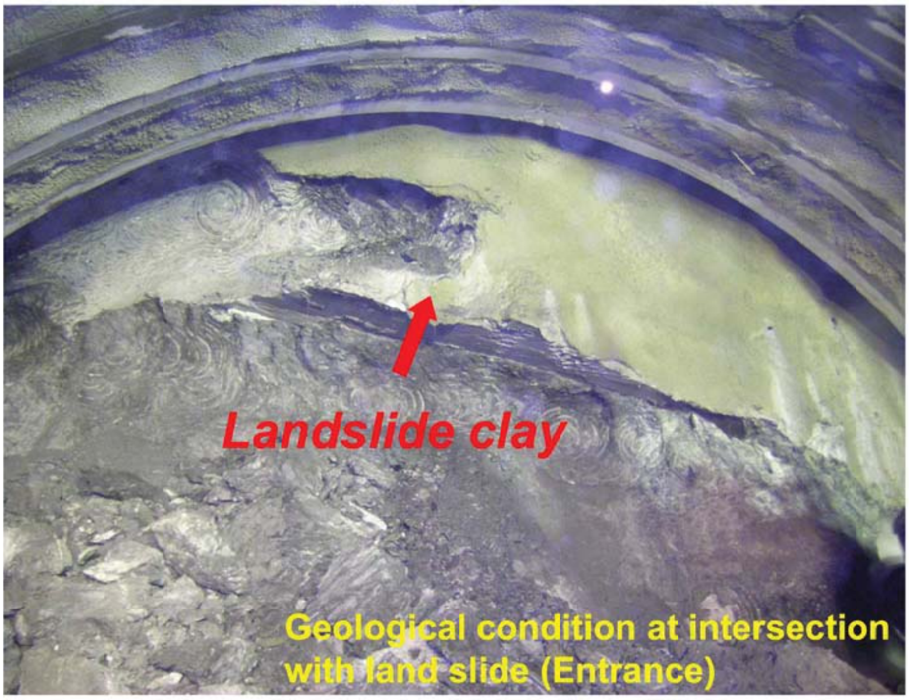
Akaiwa tunnel

- Tunnel coping with landslide



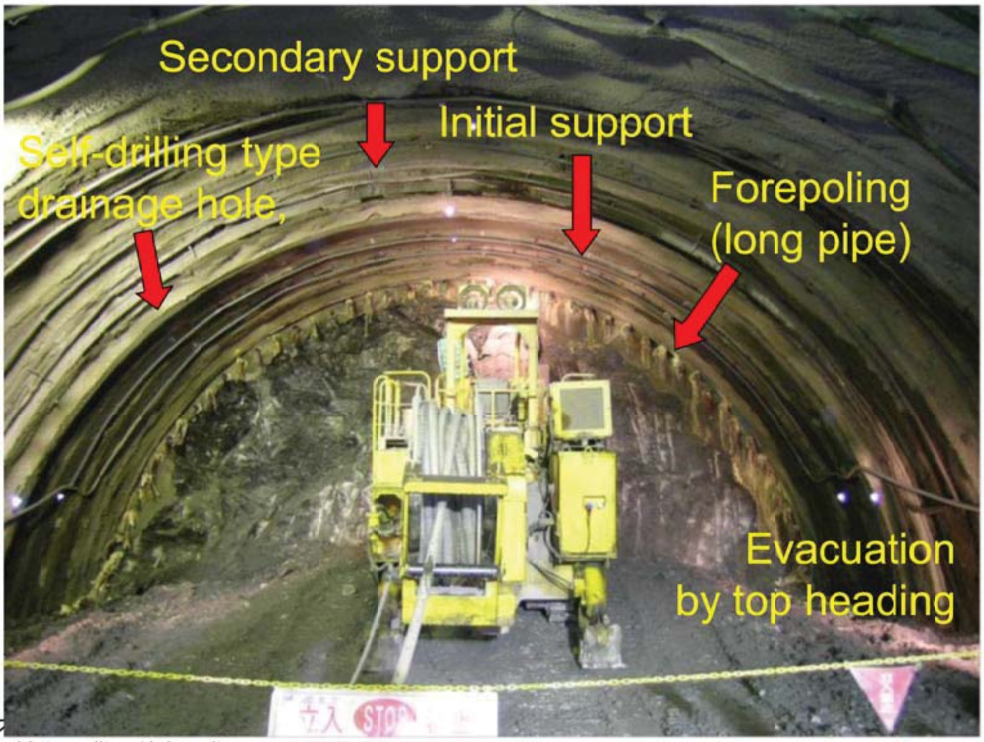
Akaiwa tunnel

- Tunnel coping with landslide



Akaiwa tunnel

- Tunnel coping with landslide



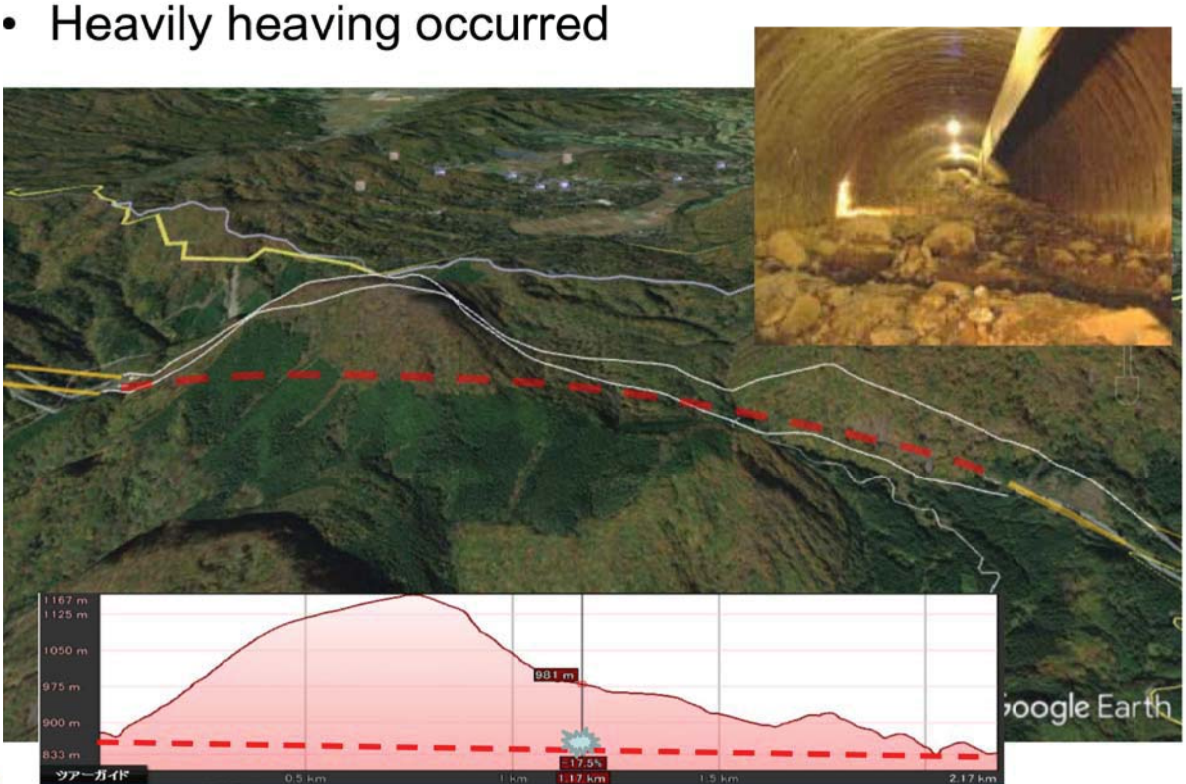
Nikkureyama Tunnel

- Heavily heaving occurred

- Const. Period 2007 – 2011
- 2.1km in total, Width 10m
- Const. Method: NATM
- Geo: Mudstone, Talus sediment
- Overburden 130m

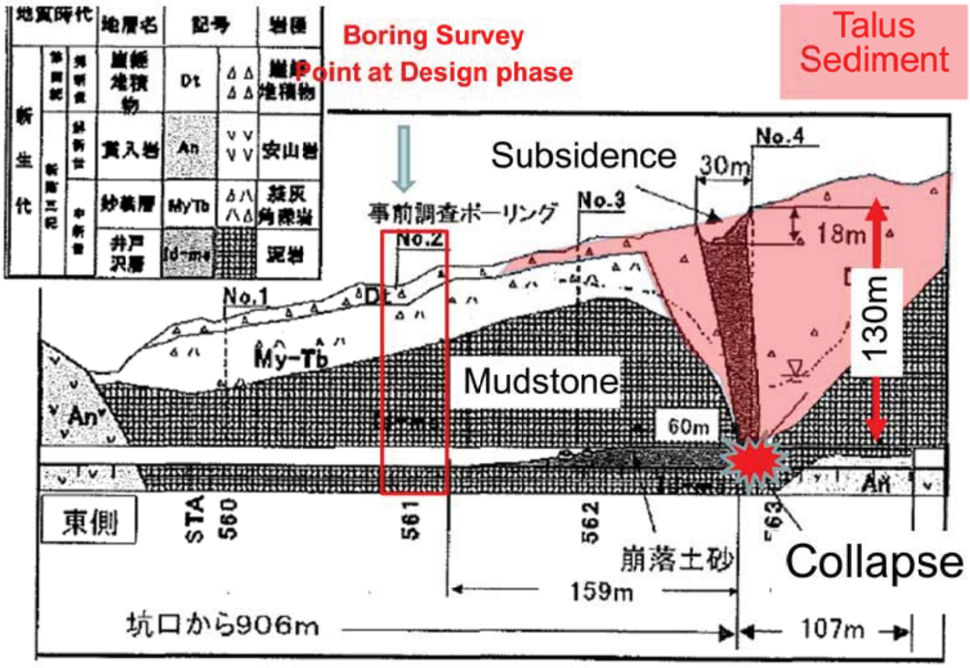
Nikkureyama Tunnel

- Heavily heaving occurred



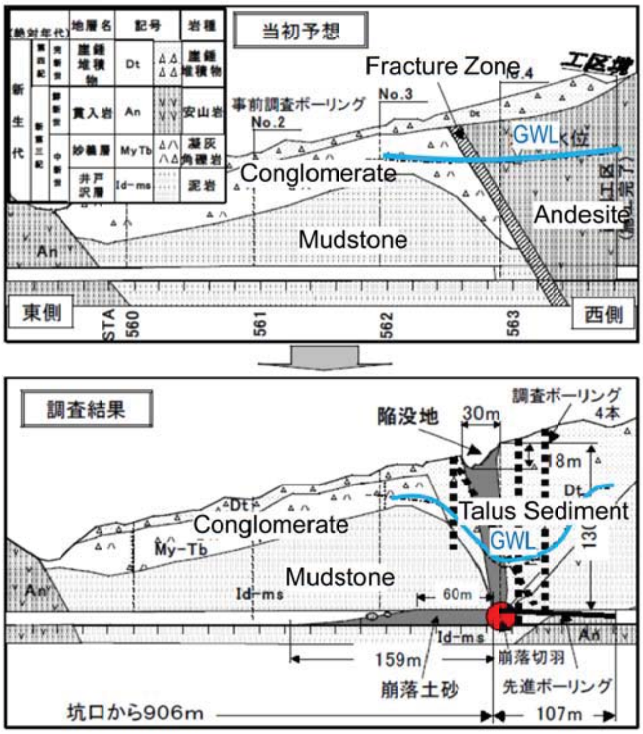
Nikkureyama Tunnel

- Heavily heaving occurred

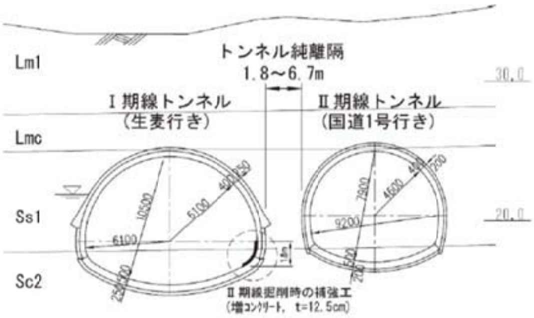


Nikkureyama Tunnel

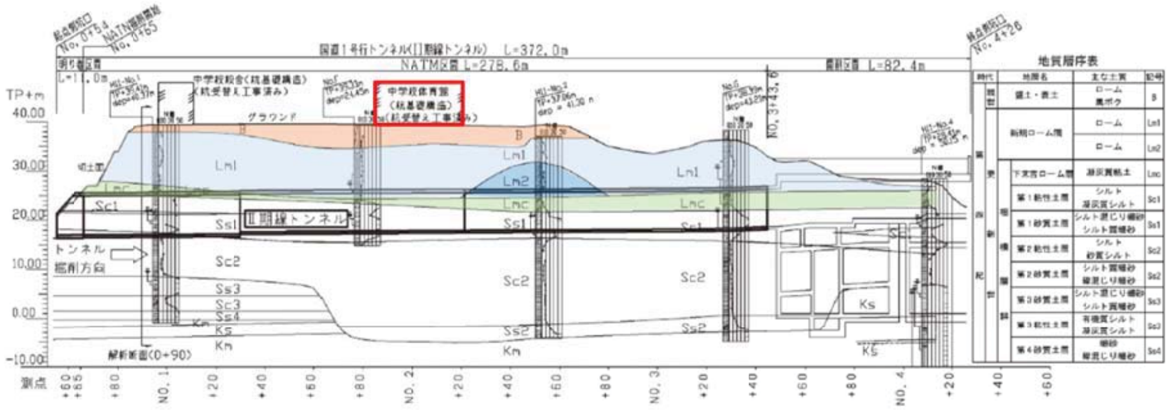
- The Cause: Existing of Talus sediment and High G.W.L.
- The large Talus sediment was not identified before construction



Kishitani Namamugi Tunnel



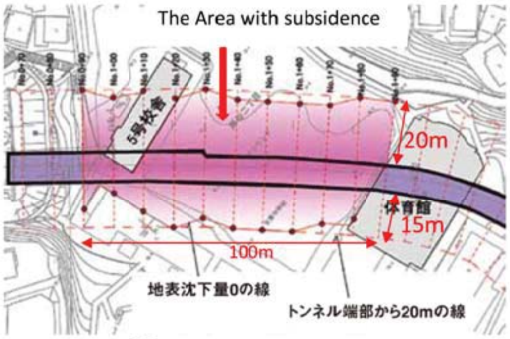
- Road Tunnel near Tokyo, Japan
- Const. Period 2011 – 2017
- 1,250m in total, Width 12m & 9m
- Const. Method NATM
- Volcanic Ash Loam, Low N values
- Important building above the tunnel

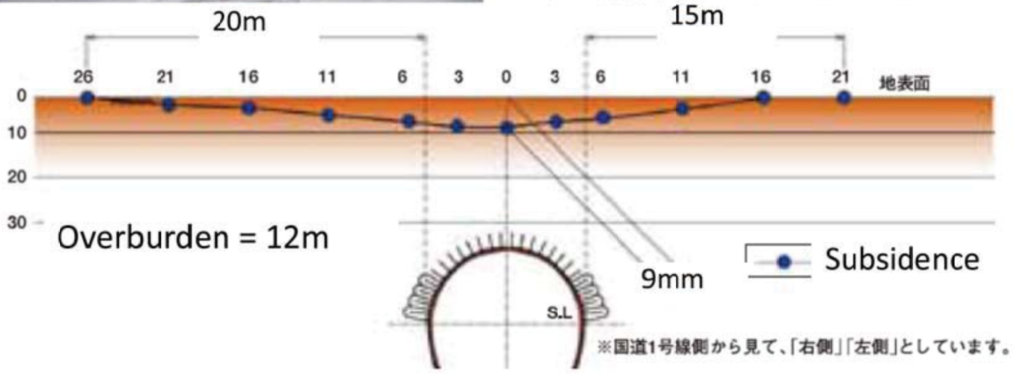


Kishitani Namamugi Tunnel

- Before the construction,
  - Identify one of the risks, surface settlement
  - Detailed survey, evaluation of the expected deformation by FDM.
  - Plan the construction method
  - Determine Support type (H200@1m)
  - Early closure of lining concrete (t=25cm)
  - Preparing monitoring plan during construction

Kishitani Namamugi Tunnel





Consideration

- For Decreasing the risks
  - Careful consideration before planning of Geo Investigation
  - Careful observation and consideration based on obtaining results
  - Careful study, estimation of the behavior of the ground
  - Appropriate auxiliary method

Geological Uncertainty remains definitely

- Monitoring and safety management
- Emergency action plan