V.セミナー資料

(1)第２回現地調査時ミニセミナー

(2)第３回現地調査時ミニセミナー

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Colombia

NIPPON KOEI

Advisor for Strengthening for ANLA Institutional Capacity on the Tunnel Sector

Environmental Management in Operation Phase

25 October 2017

Environmental Engineer
Shinji TANAKA

NIPPON KOEI CO., LTD
Japan's No.1 International Engineering Consultants
http://www.n-koei.co.jp/english/

Outline

1. General
2. EMP for Road Tunnel
3. What is a Ventilation System?
4. Types of Ventilation System
5. Design of Tunnel Ventilation
6. Impact to Ambient Air Quality
7. Conclusion

1. General

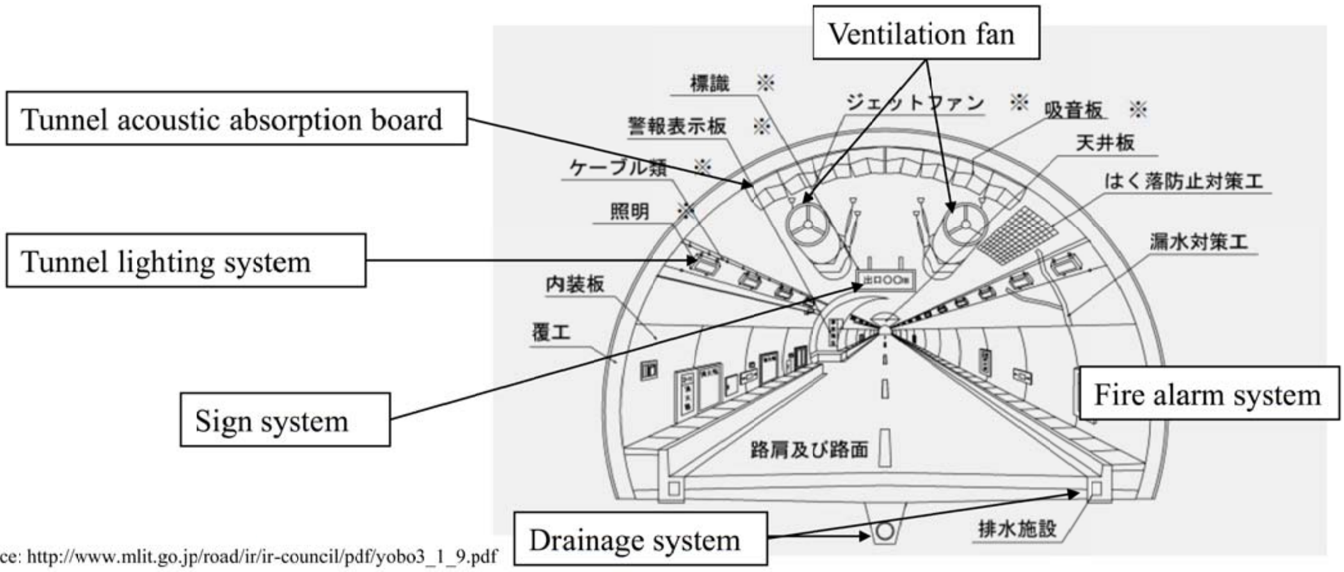
Background

In general, road tunnel is required much kinds of management than other road facilities. On the part of these management method, there are some items for conservation environment in operation phase. On EIA study in Japan, we usually conduct prediction of Environmental impact in operation phase and prepare the environmental management plan for road tunnel project in operation phase.

2. EMP for Road Tunnel

EMP in operation phase

Many kinds of tunnel equipment and facility is used for EMP in operation phase.

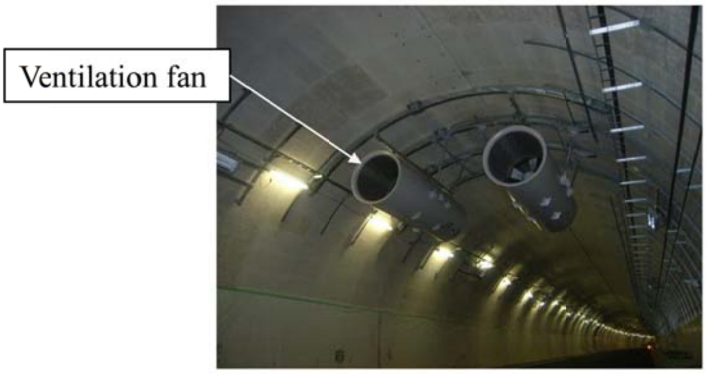


Source: http://www.mlit.go.jp/road/ir/ir-council/pdf/yobo3_1_9.pdf

3. What is a Ventilation System?

Ventilation System

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



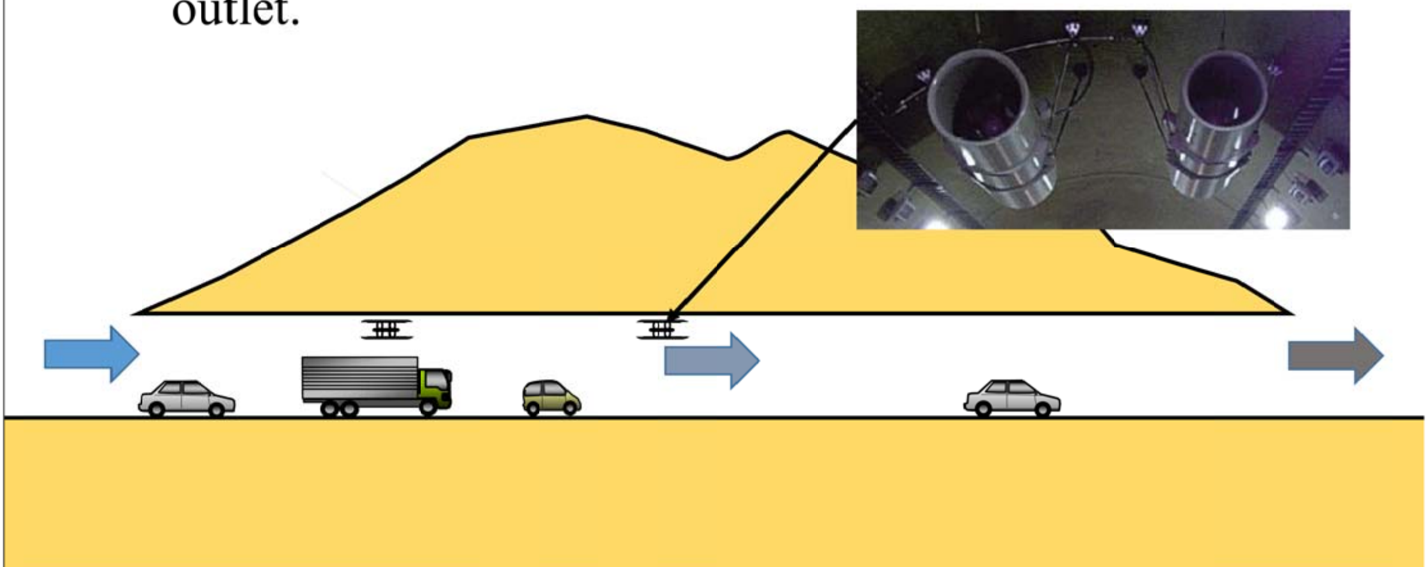
Ventilation Towers of YAMATE Tunnel, Metropolitan Expressway

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

4. Types of Ventilation System

4.1 Longitudinal ventilation system

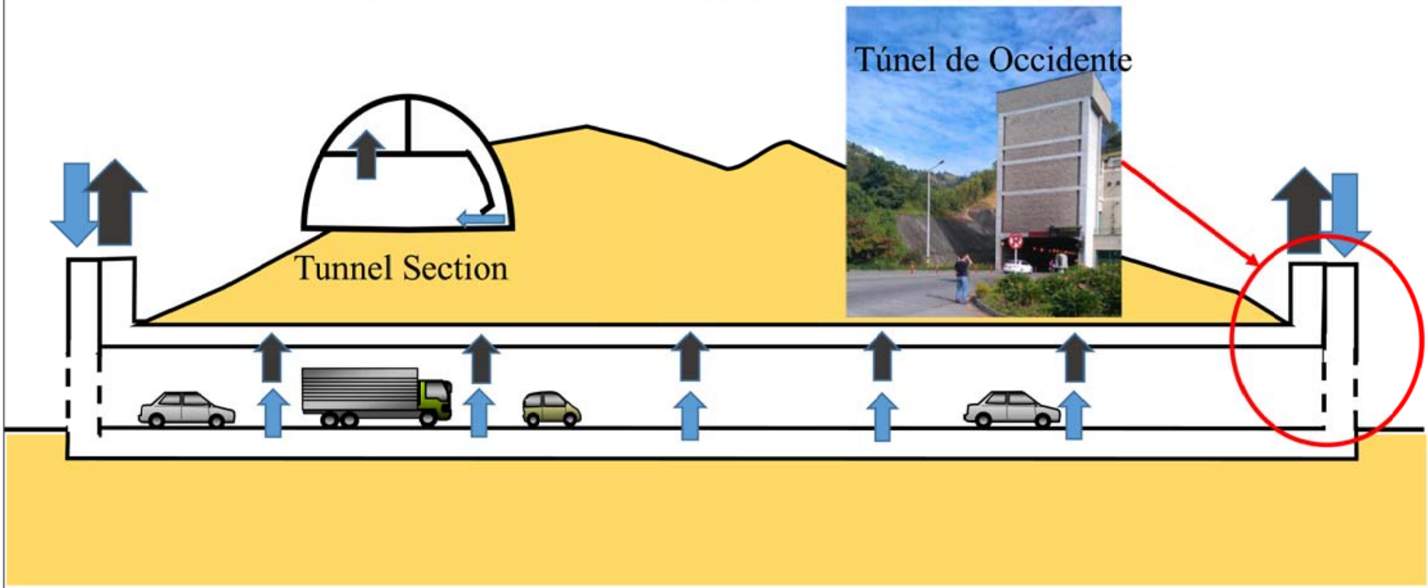
Longitudinal ventilation system has the simple ventilating system. It sends the fresh air from the entrance of tunnel, and emit from the other side or other outlet.



4. Types of Ventilation System

4.2 Transverse ventilation system

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



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5. Design of Tunnel Ventilation

Design

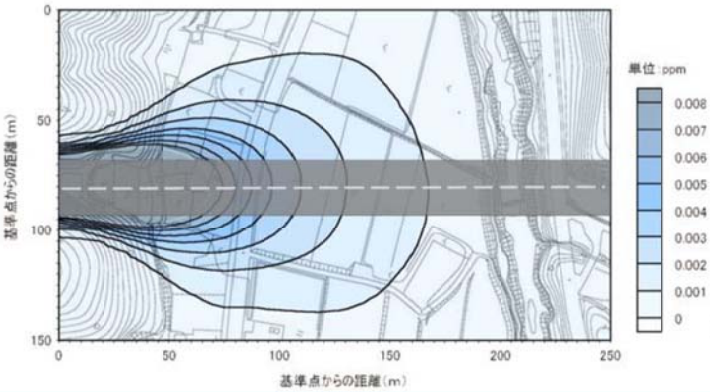
The operation of a tunnel ventilation system is designed to meet a set of air quality and fire safety performance requirements under it's expected operating scenarios (i.e. tunnel length and cross section, traffic volumes and mix). The key air quality performance requirements are:

1. In-tunnel air quality criteria
2. External or ambient air quality criteria

6. Impact to Ambient Air Quality

6.1 Impact to ambient air

In the case of existing residence near the entrance of tunnel, it would be assumed to become deterioration for their ambient air quality. On the EIA study in Japan, we often predict future air quality around entrance of road tunnel. On that study, we usually make EMP for conservation of the ambient air quality.

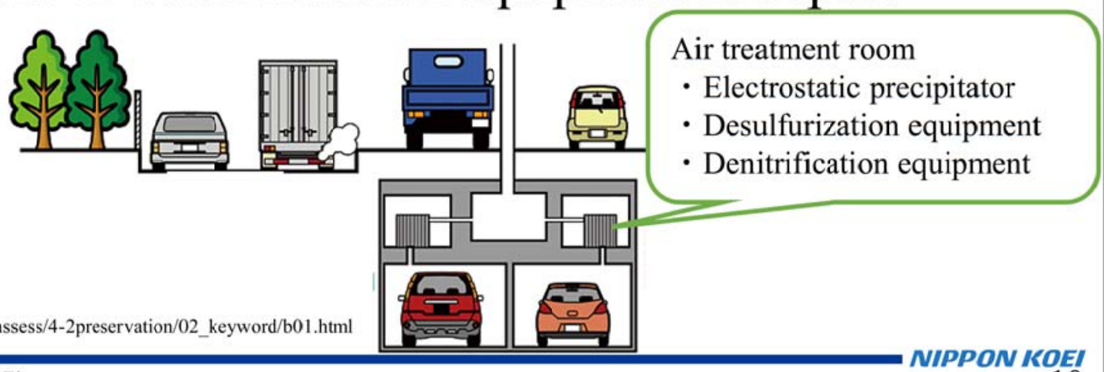


Contour map of air pollutant

6. Impact to Ambient Air Quality

6.2 EMP for ambient air quality

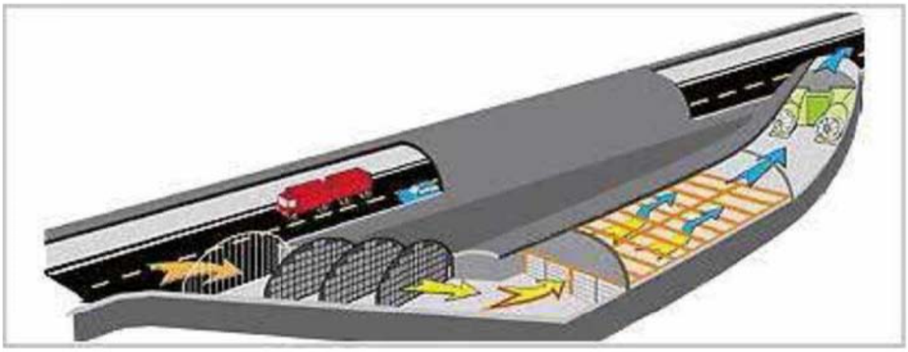
From the result of forecasting ambient air quality of operating phase, mitigation study for air quality would be conducted. If impact of dust or particulate matter is significant, electrostatic precipitator would be installed into the tunnel. In addition in that, there are some tunnel which have desulfurization equipment or denitrification equipment in Japan.



Source: http://www.env.go.jp/policy/assess/4-2preservation/02_keyword/b01.html

7. Conclusion

Air quality has become a major health and environmental issue in developed countries. It is easily assumed that EMP for ambient air quality in operation phase will be getting important more in Colombia too. So I consider it would be necessary for EIA engineer in Colombia to know these technology.



Bypass-type air treatment system

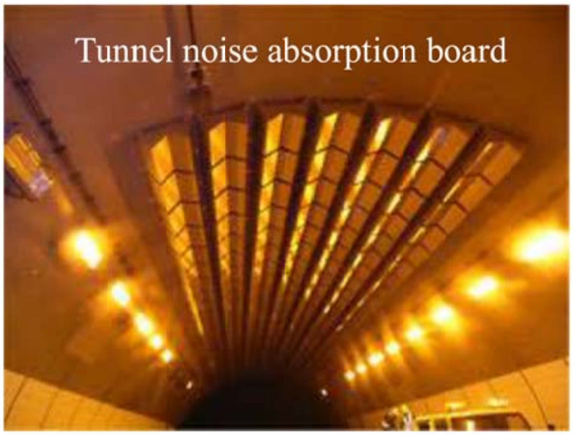
Source: http://www.cetu.developpement-durable.gouv.fr/IMG/pdf/cetu_di_traitement_de_l_air-en-19_07_2017.pdf

Noise absorption

Noise diffusion model

In Japan, we use the noise diffusion model "ASJ RTN-Model" .This Model could calculate the noise from the tunnel and effect of the absorption board.

Rockwool and Grass wool are using for sound absorption material



Tunnel noise absorption board

Ventilation design

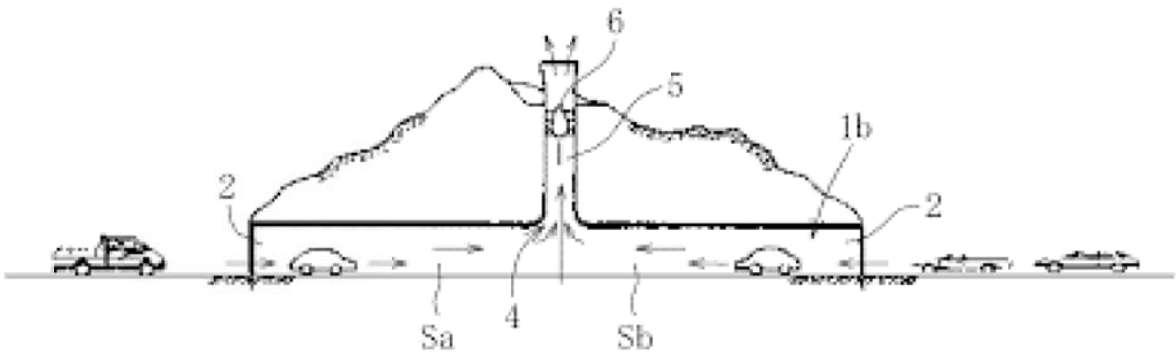
We use the formula of basic flow mechanism based on Bernoulli's principle in tunnel ventilation system.

This formula is very easy to calculate. (I use Excel sheet book for this purpose.)

For predict ambient air quality, we use the formula of analysis solution. (Gaussian dispersion models)

$$c(x,y,z)=\frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left(\exp\left(\frac{-(z-h)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+h)^2}{2\sigma_z^2}\right)\right)$$

Other management measures



Vertical Shaft ventilation system

This is a kind of countermeasure for community located in near the tunnel entrance.

Muchas Gracias!

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Fundamentals of Groundwater

25 October 2017

Hydrogeology Engineer
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Outline

1. What is Groundwater?
2. How is groundwater flowing?
3. Water Inflow into Tunnel
4. Groundwater Survey

1. What is Groundwater?

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What is Groundwater?

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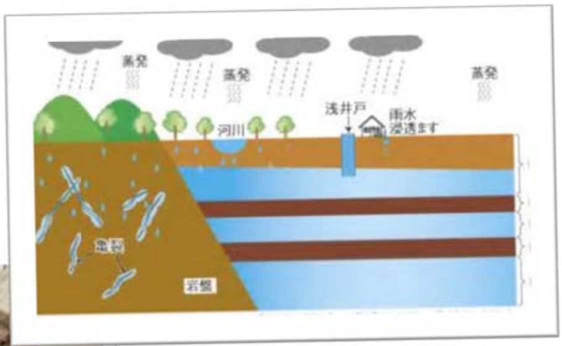
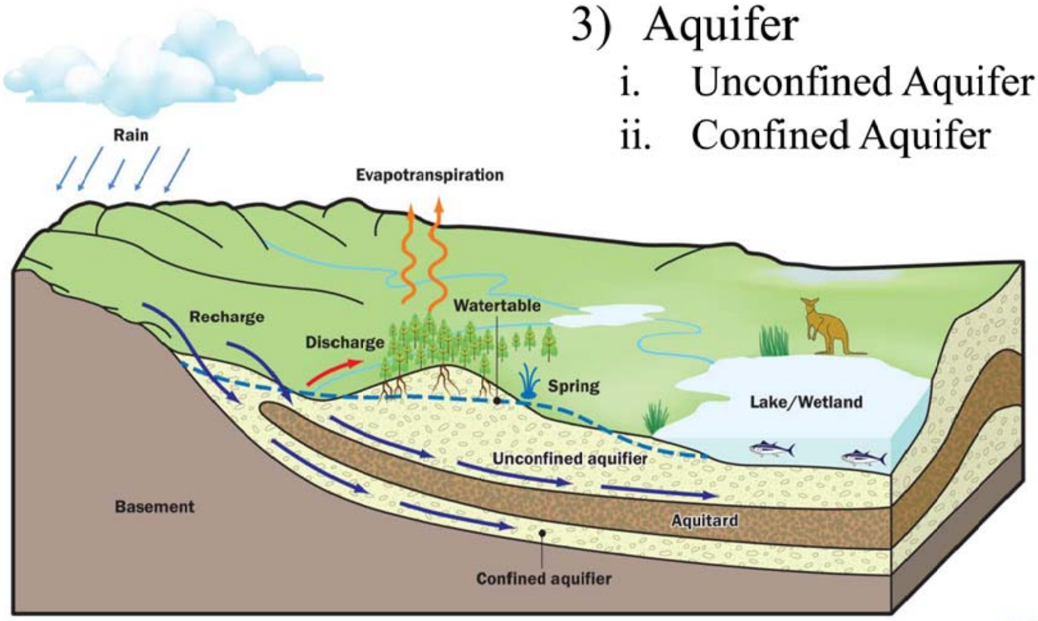
What is Groundwater?

How do you imagine about “Groundwater”?



1. Definition of Words

1) Groundwater
2) Water Table
3) Aquifer
   i. Unconfined Aquifer
   ii. Confined Aquifer



1) Groundwater

The water found **subsurface** that has come from the seepage of **surface water**. It fills the **porous** in soil, sediment and rocks.

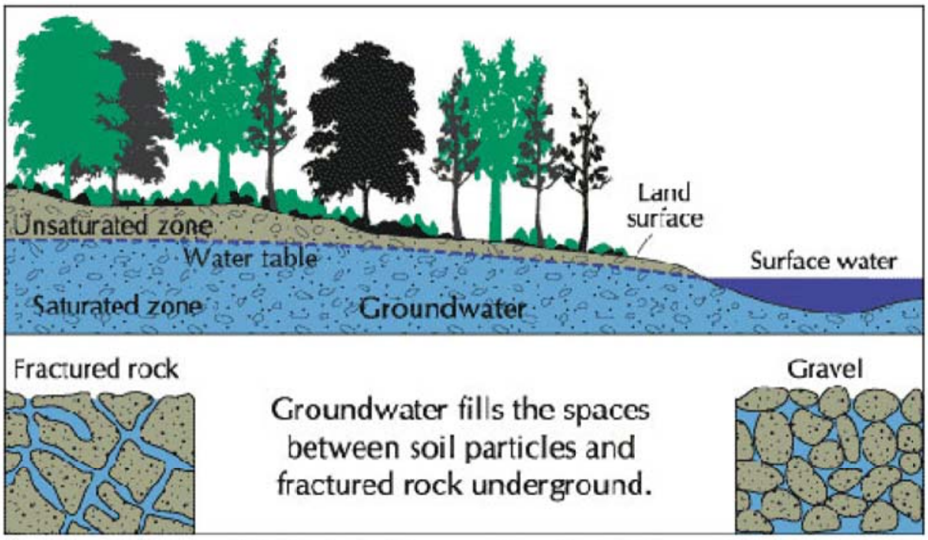
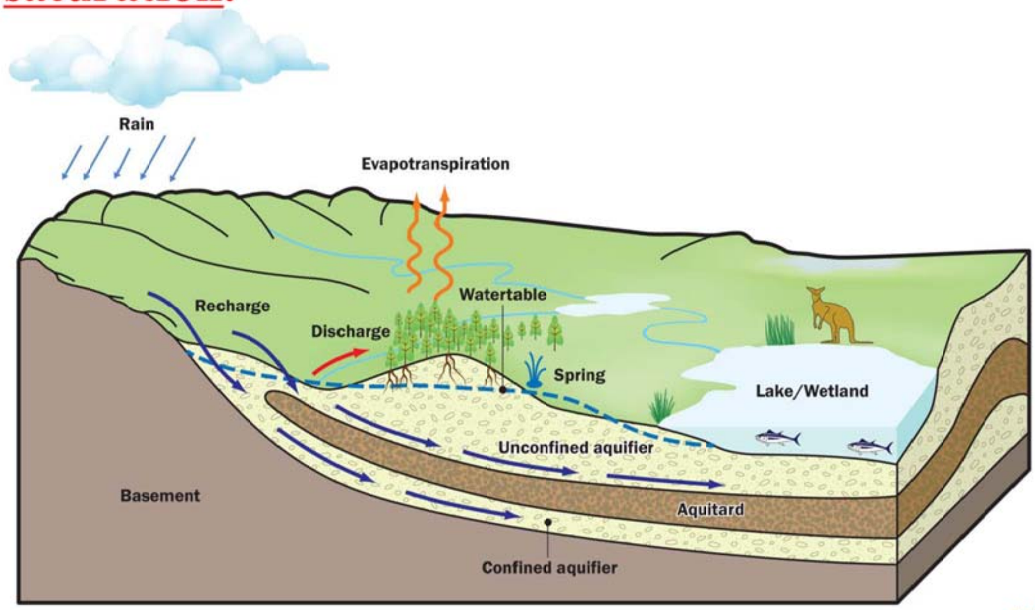


Image compliments of US Geological Survey, adapted by The Groundwater Foundation.

2) Water Table

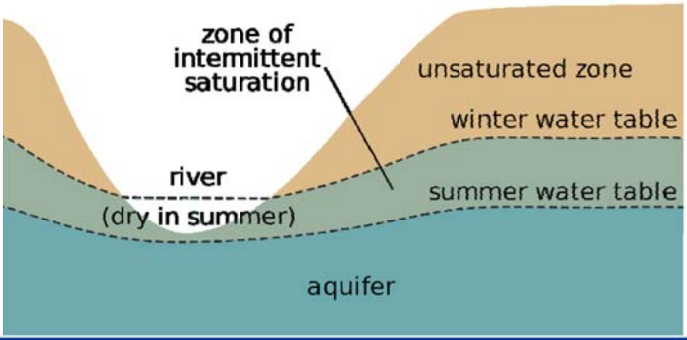
The upper surface of an area filled with **groundwater**, separating the **zone of aeration** from the **zone of saturation.**



2) Water Table

(continued…)

- The water table is not flat but has peaks and valleys that generally conform to the overlying land surface.
- Water tables rise and fall with seasonal rainfall variation, water absorption by vegetation, and the withdrawal of groundwater from wells, among other factors.



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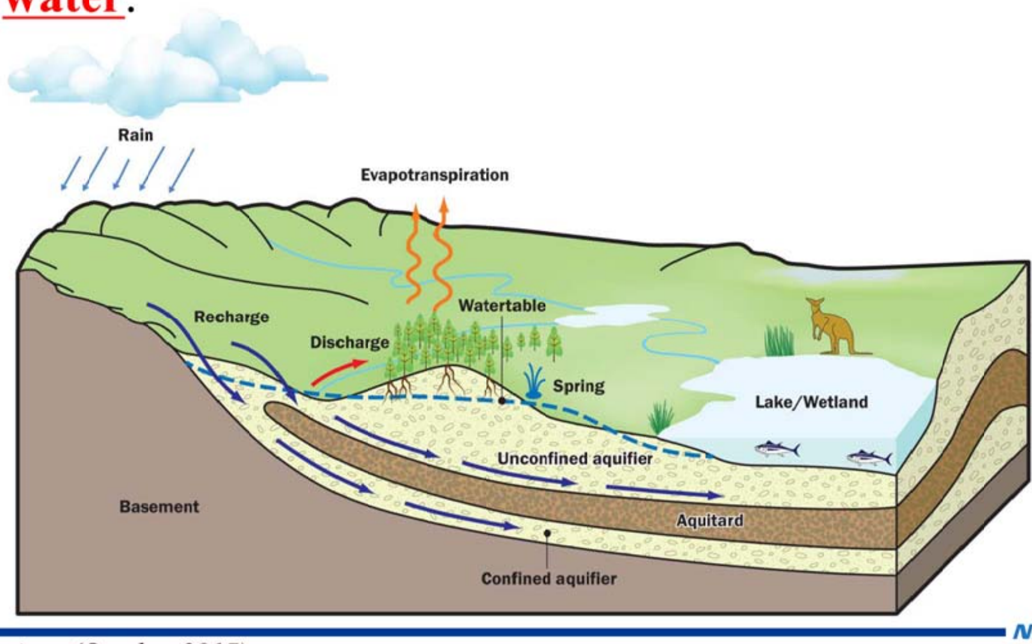
3) Aquifer

An underground layer of **permeable** rock, sediment (usually **sand** or **gravel**), or soil that yields **water**.



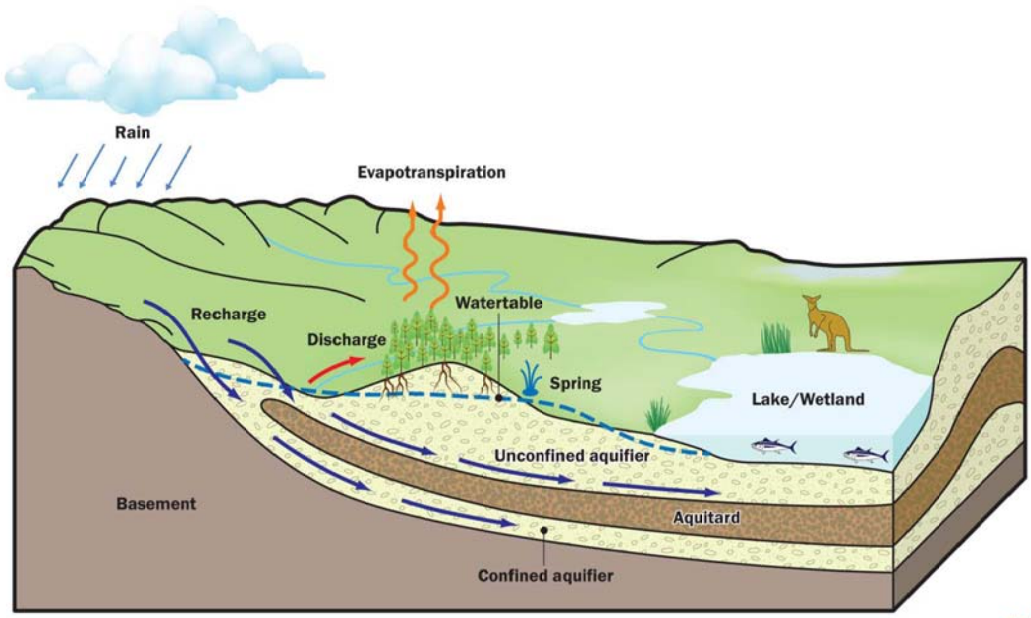
3) Aquifer

(continued…)

- The pore spaces in aquifers are filled with water and are interconnected, so that water flows through them.
- Sandstones, unconsolidated gravels, and porous limestones make the best aquifers.
- Aquifers can range from a few square kilometers to thousands of square kilometers in size.

cf) Aquitard

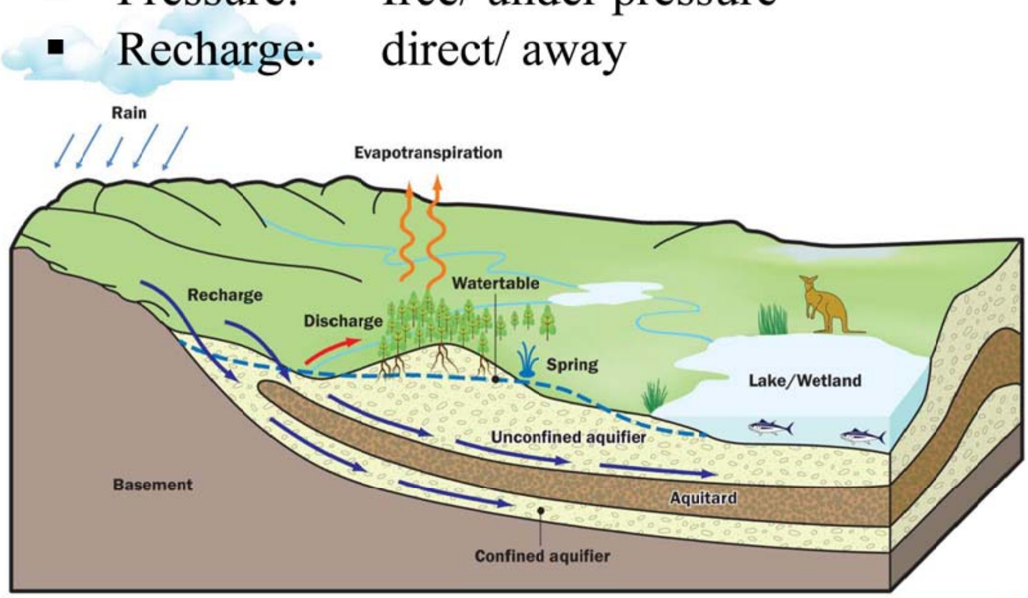
An underground layer of **impermeable** rock, sediment (usually **silt** or **mud**), that can't yield water.



3) Aquifer- two types

a) Unconfined aquifer, b) Confined aquifer

- Depth: shallow/ deep
- Pressure: free/ under pressure
- Recharge: direct/ away



3) Aquifer

a) Unconfined aquifer

- Groundwater is in **direct contact with the atmosphere** through the open pore spaces of the overlying soil or rock.
- The upper groundwater surface in an unconfined aquifer is called the **water table**.
- Unconfined aquifers are usually recharged by rain or streamwater infiltrating directly through the overlying formation.

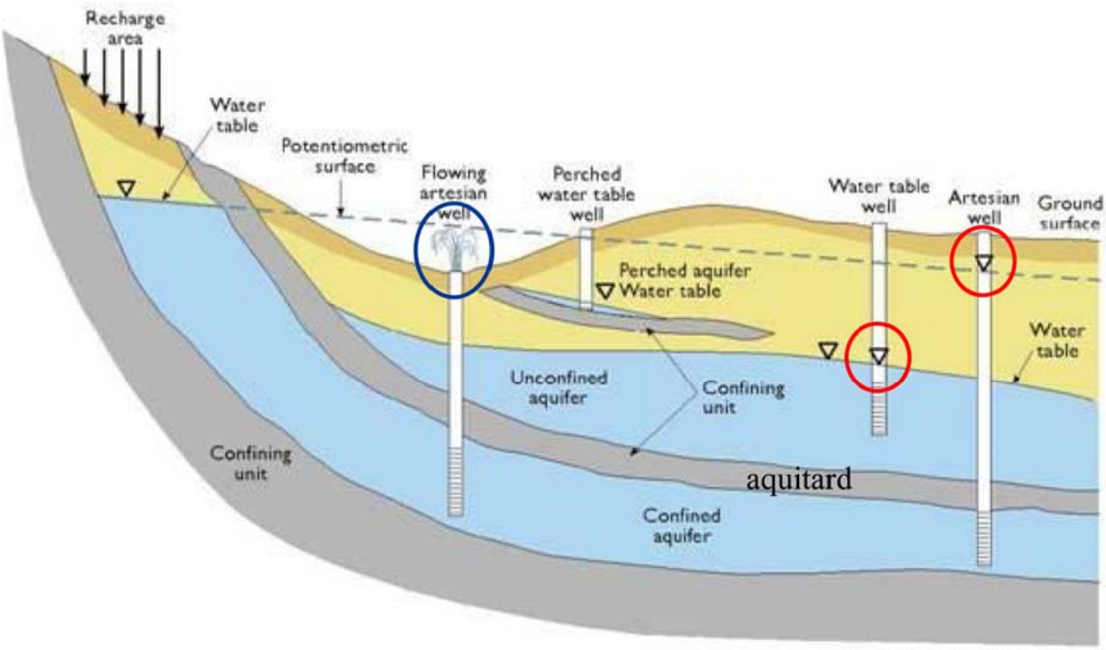
3) Aquifer

b) Confined aquifer

- Confined aquifers are permeable rock units that are usually deeper under the ground than unconfined aquifers. They are **overlain by impermeable rock or clay**.
- Groundwater in a confined aquifer is **under pressure** and will rise up inside a borehole drilled into the aquifer. The level to which the water rises is called the **potentiometric surface**. An artesian flow is where water flows out of the borehole under natural pressure.
- Confined aquifers may be recharged by rain or streamwater infilitrating the rock at some considerable **distance away** from the confined aquifer. Groundwater in these aquifers can sometimes be thousands of years old.

3) Aquifer

a) Unconfined aquifer, b) Confined aquifer



Modified after Harlan and others, 1989

2. How is Groundwater Flowing?

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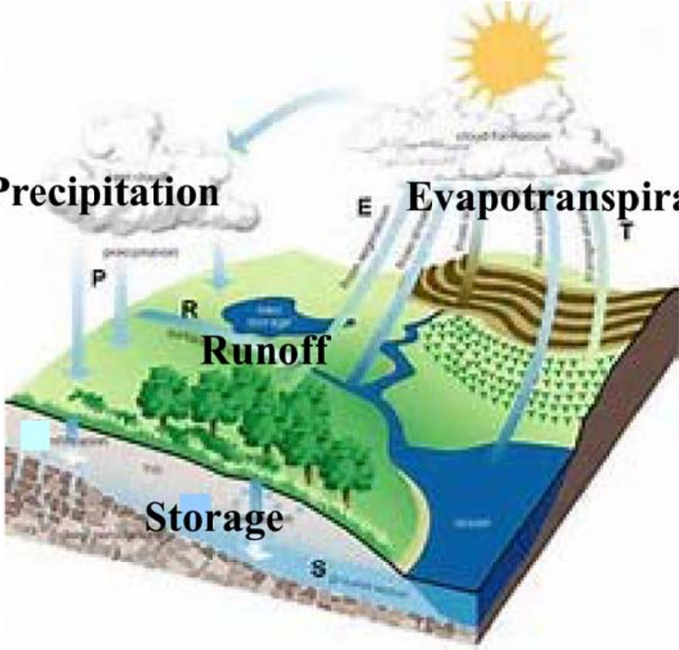
Basis of groundwater flow

[Key Questions] **[Basis of groundwater]**

1. Source of groundwater
   - Where is water coming from?
   - How much water is there? → Conservation of Mass
2. Flow rate
   - How fast does water flow? → Darcy's Law
3. Flow direction
   - Where is water flowing to?
   - What is the driving energy? → Potential Flow

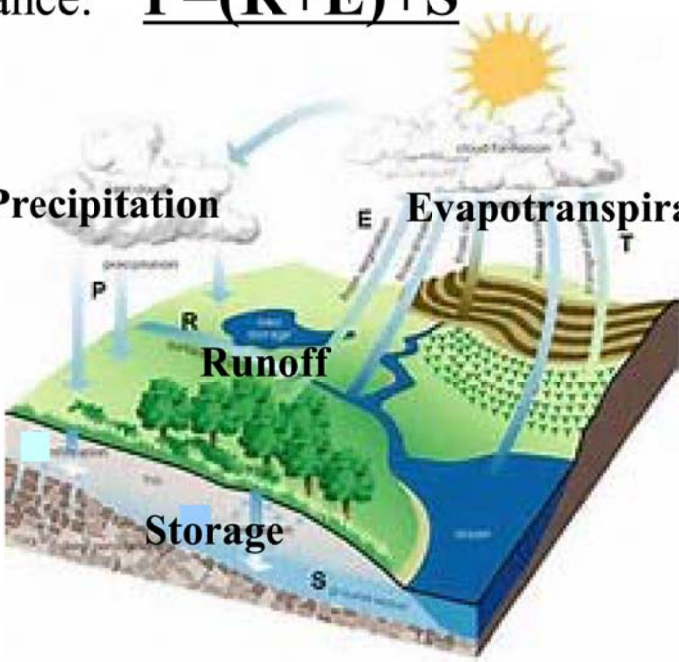
1) Conservation of Mass

Inflows and outflows must balance.



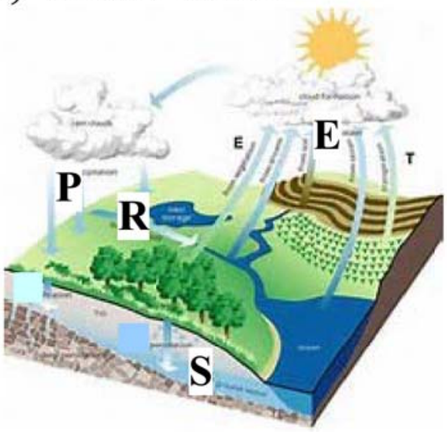
1) Conservation of Mass

Water Balance: **P=(R+E)+S**



1) Conservation of Mass

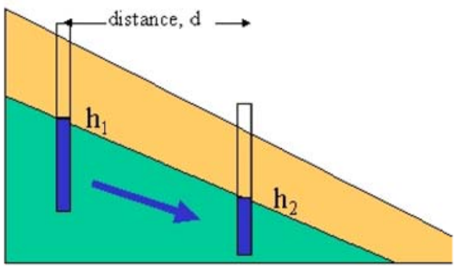
- The change in Storage is the change in volume of groundwater over time ⊿S/t.
- If the storage is decreased, water table declines.



2) Darcy's Law

Flow rate is limited by the permeability of the formation.

$$v = K (h_1 - h_2)/d$$



- v: flow rate (m/day)
- K: average permeability (m/day)
- h: hydraulic head (m)
- $(h_1-h_2)/d$: head difference over the distance "d (m)"

Permeability: the capability of a porous rock or sediment to permit the flow of fluids through its pore spaces.

Reference: coefficients of permeability of common rock types

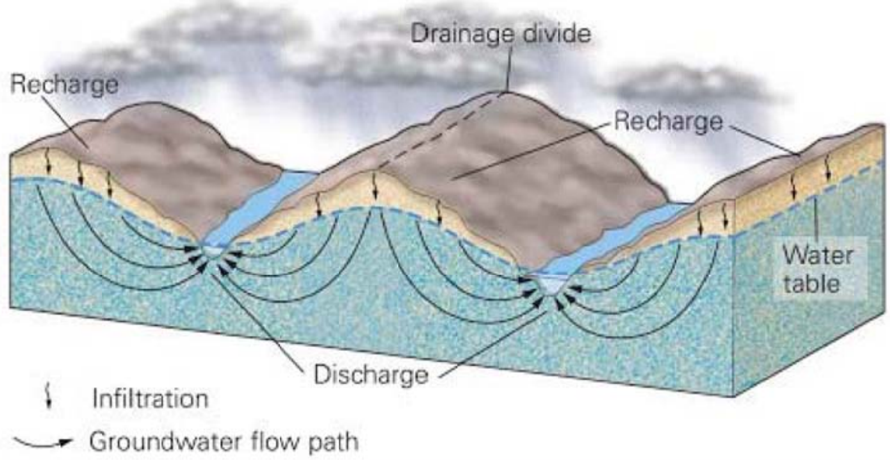
Rock type	Coefficients of permeability (m/day)
Unconsolidated rock	
Gravel	200 – over 1000
Coarse sand[1]	50 – 200
Medium to coarse sand[1]	20 – 70
Fine to medium sand[1]	5 – 30
Fine sand[2]	10^{-1} – 10
Silt	10^{-3} – 10^{-1}
Sandy clay	10^{-3} – 1
"Loose" clay	10^{-7} – 10^{-3}
Compact clay	10^{-10} – 10^{-5}
Consolidated rock	
Vesicular basalt	10^{-3} – 10^{3} [3]
Karstic limestone	10^{-1} – 10^{3} [3]
Fractured sandstone	10^{-3} – 1
Limestone, non-karstic	10^{-6} – 10^{-1}
Shale	10^{-8} – 10^{-4}
Fractured intrusive/metamorphic rock	10^{-3} – 10
Hardly fractured intrusive/metamorphic rock	10^{-9} – 10^{-5}

Have potential to be aquifer (Gravel to Fine sand)

[1] With very low silt content. [2] With varying silt content. [3] Application of Darcy's Law equation (section 3.1) questionable for these very high permeabilities.

3) Potential Flow

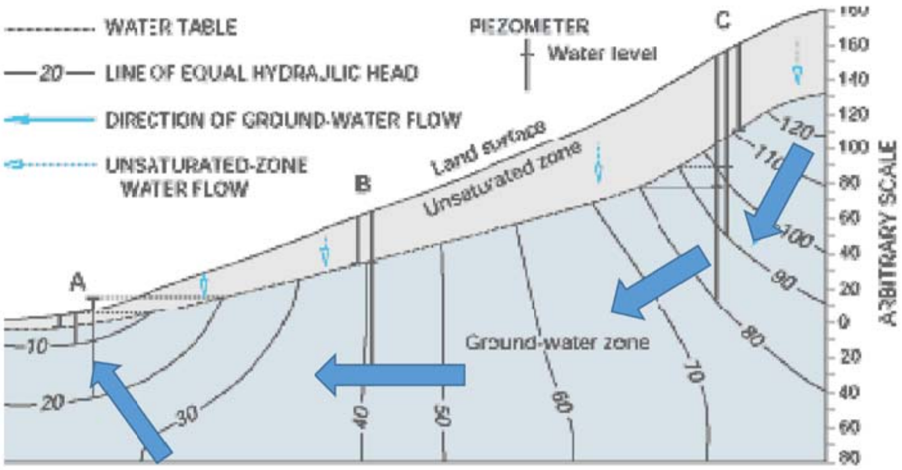
Groundwater flow always moves from **high to low hydraulic head.**



⇒ *GW flows from recharge area to discharge area.*

3) Potential Flow

Relation between "Line of equal hydraulic head" and "direction of groundwater flow"



⇒ *Flow direction is always vertical to line of equal hydraulic head.*

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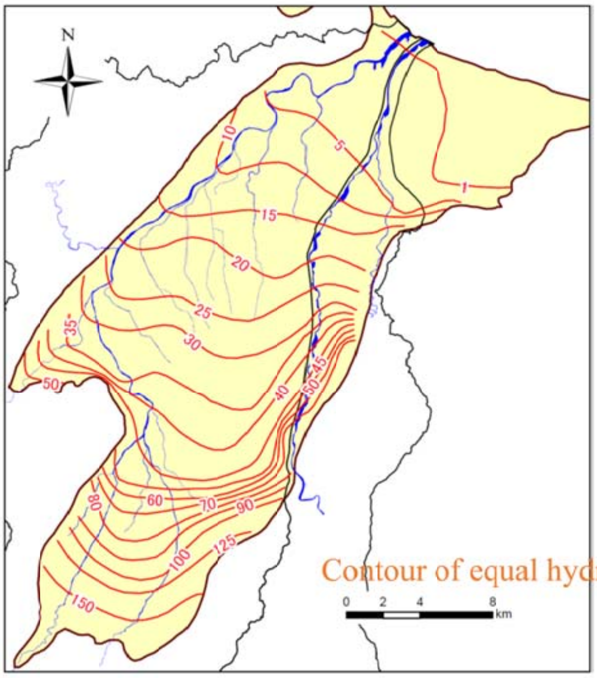
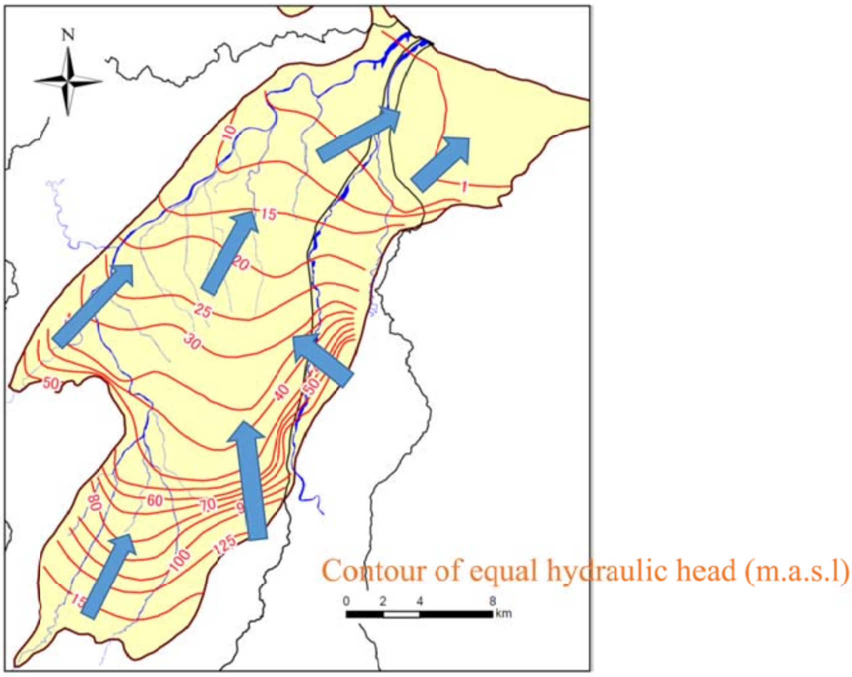
3) Potential Flow

- Example1: GW flow direction in the catchment area.



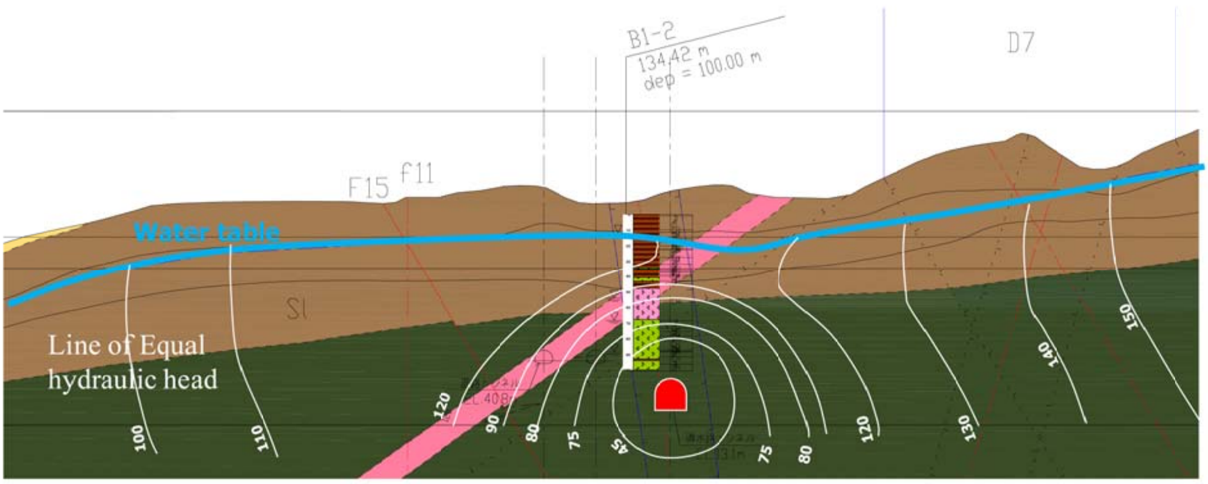
3) Potential Flow

- Answer: GW flow direction in the catchment area.



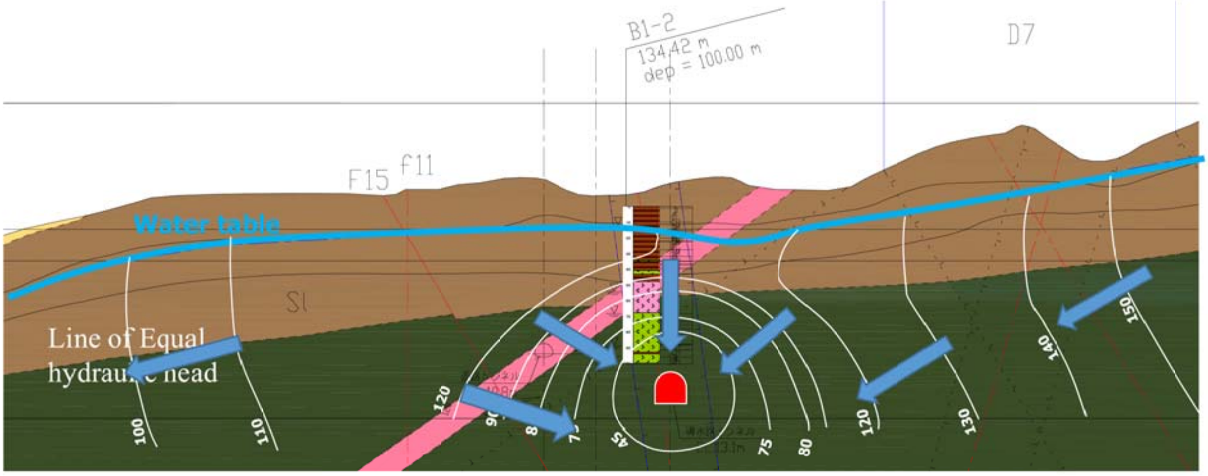
3) Potential Flow

- Example2: Groundwater flow direction around tunnel.



3) Potential Flow

- Answer: Groundwater flow direction



3. Water Inflow into Tunnel

Investigation of Inflow into Tunnel

Investigation of Inflow into Tunnel

[Three requirements]

1. Source
   - What is the source of the inflow water?

   → Conservation of Mass

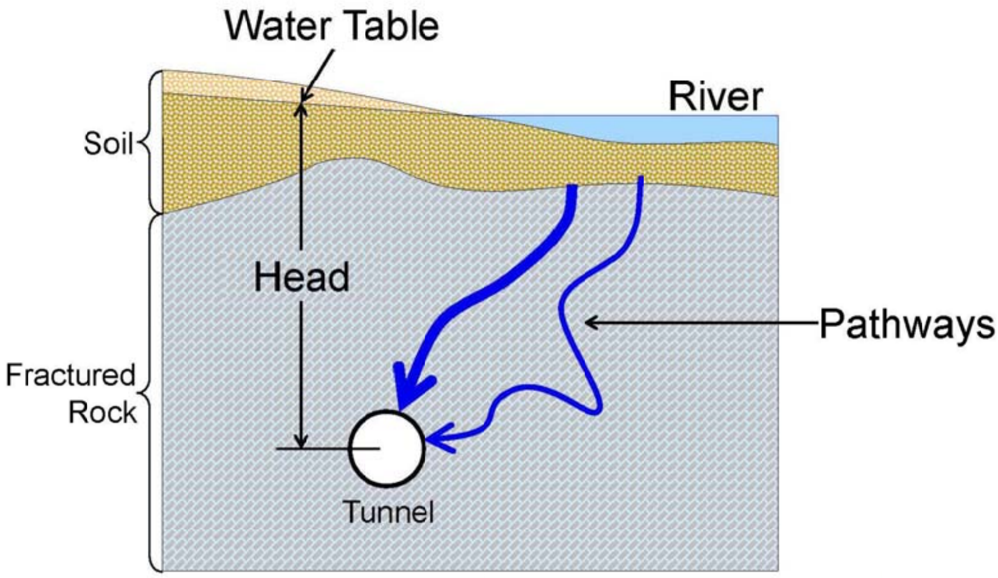
2. Pathway
   - How much resistance will the rock mass create?
   - Where is the pathway of water to tunnel?

   → Darcy's Law

3. Potential Energy (water head)
   - How much energy is available to drive the flow?

   → Potential Flow

Source, Pathway , Energy (head)



(Source:Jacobs, 2016)

Rule of Uneven Inflow

1. **Much** of the tunnel is **dry**
   - ❖ Long reaches have no water-bearing fractures
2. **Some** of the inflow occurs in **many** places
   - ❖ From many smaller interconnected fractures
3. **Most** of the inflow occurs in **a few** places
   - ❖ From a few, well-connected, open fractures

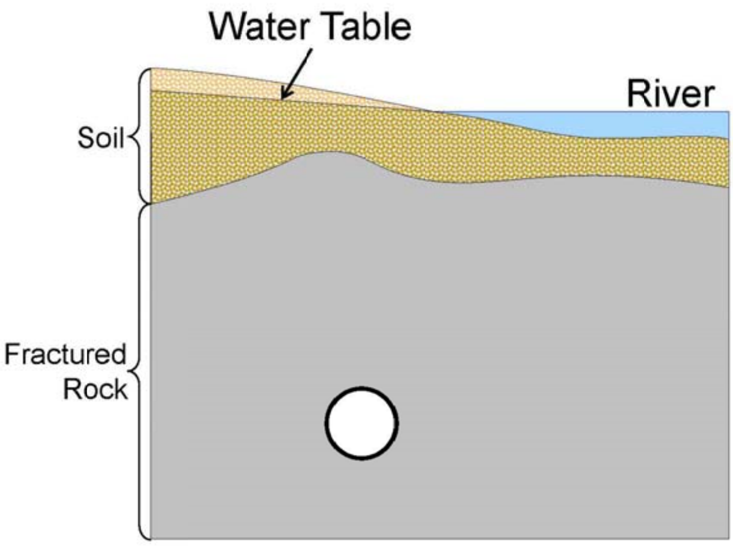
Possible Pathway

[Five hydrogeological conditions]

1. Massive rock
2. Blocky rock
3. Horizontal fractures
4. Dipping fractures
5. Karstic systems

Massive rock

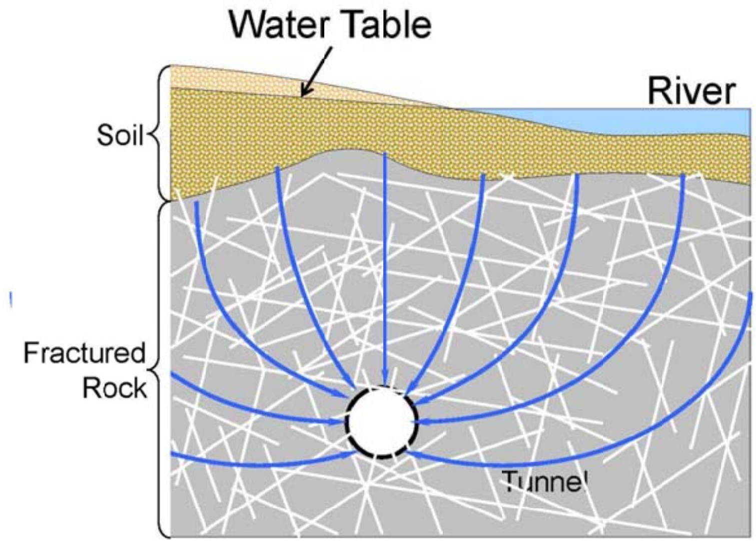
- No Significant Pathways = Dry Tunnel



(Source:Jacobs, 2016)

Blocky rock

- Multiple Open Fractures = flow in any direction



(Source:Jacobs, 2016)

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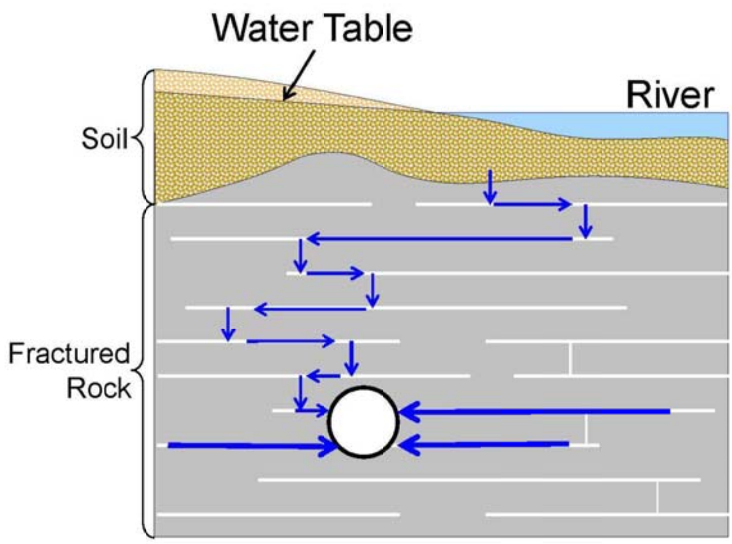
Horizontal fractures

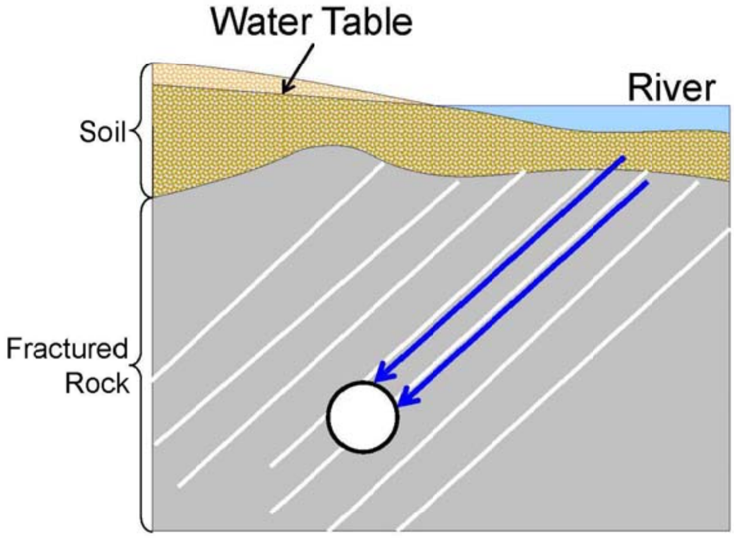
- Poor Vertical Connection to the Source



(Source:Jacobs, 2016)

Dipping fractures

- Direct Connection between Source and Tunnel



(Source:Jacobs, 2016)

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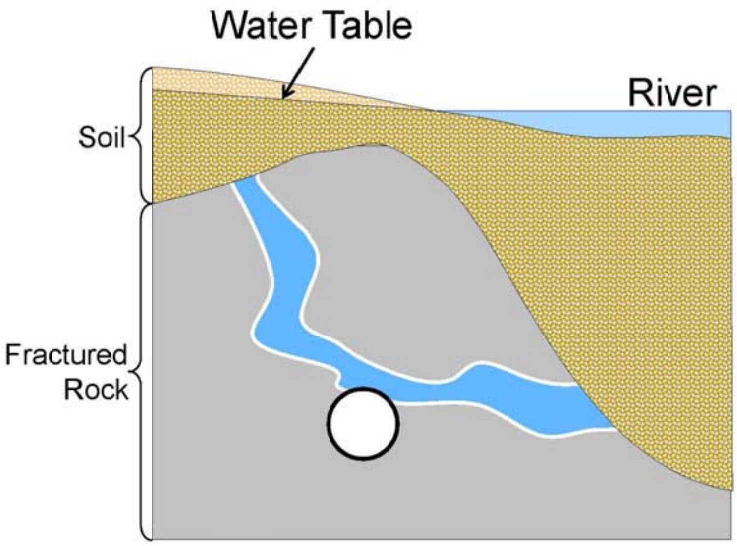
Karstic systems

- Pipelines to the Source



(Source:Jacobs, 2016)

4. Groundwater Survey

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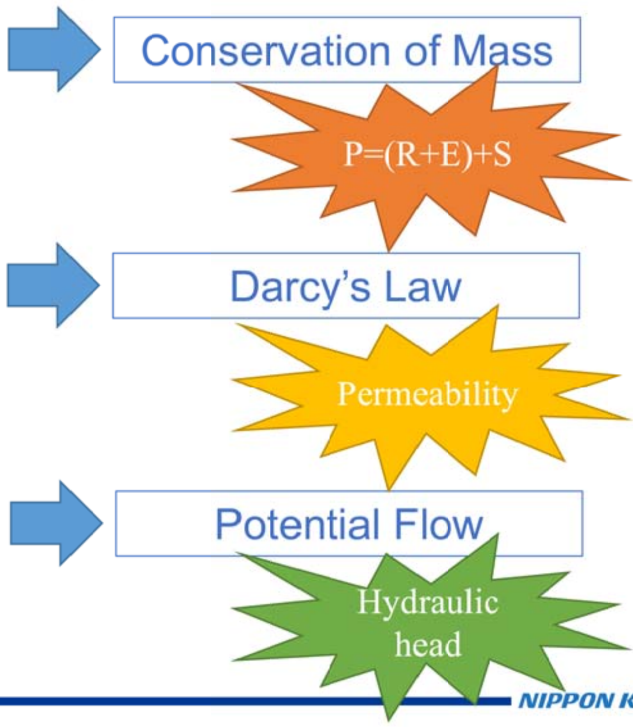
Basis of groundwater flow

1. Source of groundwater
   - Where is water coming from?
   - How much water is there?
2. Flow rate
   - How fast does water flow?
3. Flow direction
   - Where is water flowing to?
   - What is the driving energy?



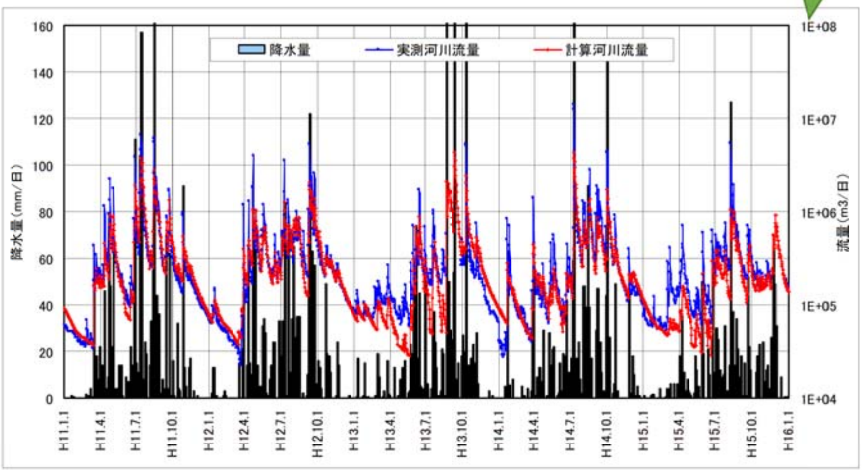
Hydrological data

Water Balance

P=(R+E)+S

Hydraulic head

(Rainfall, Runoff, Temperature, Groundwater table)



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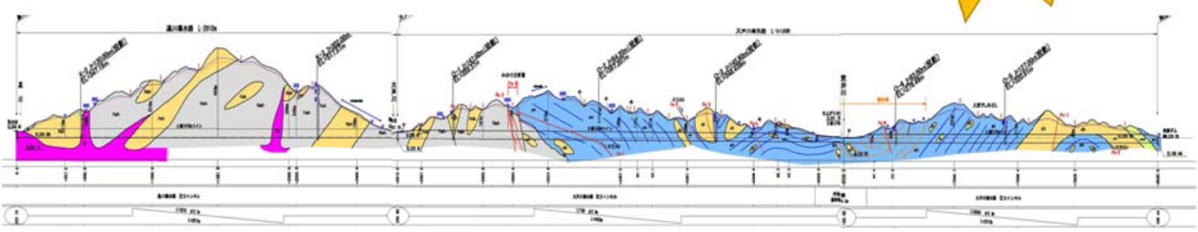
Geological/Hydrogeological data

Groundwater flow direction, pathway and flux

(hydrogeological structure, aquifer structure, permeability)

Permeability



Muchas Gracias!

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Colombia

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Advisor for Strengthening for ANLA Institutional Capacity on the Tunnel Sector

Ground Subsidence
- Prediction, Monitoring and Mitigation Measures -

Geological Engineer
Yasuhiro Nozue

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Japan's No.1 International Engineering Consultants
http://www.n-koei.co.jp

Contents

1. Ground Subsidence

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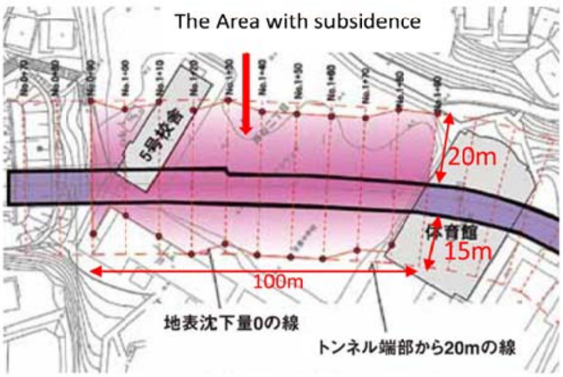
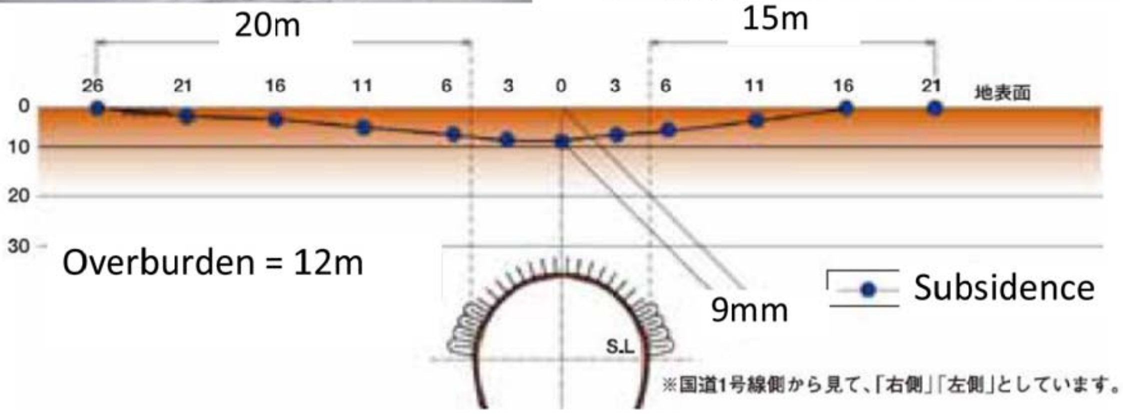
Subsidence of Ground Surface





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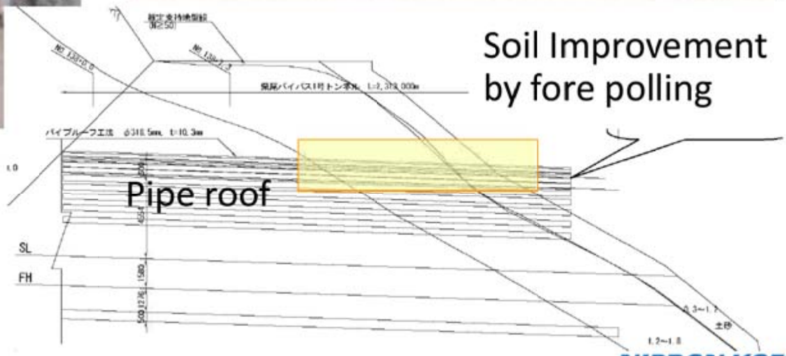
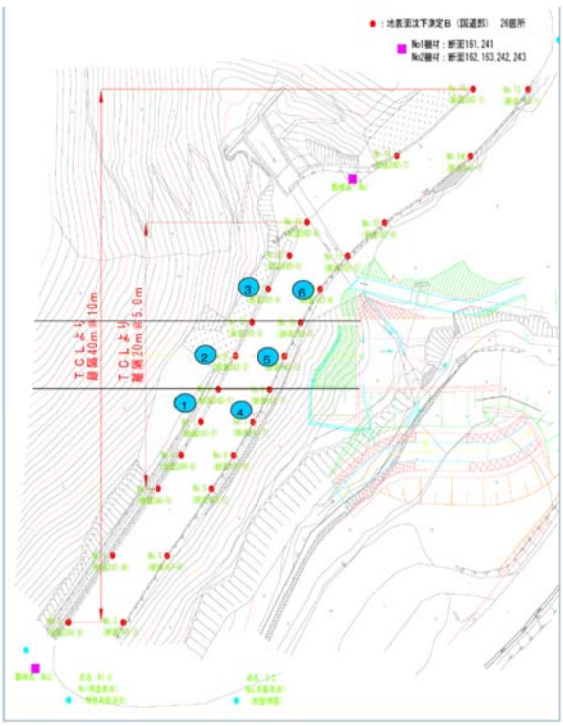
Subsidence of Tunnel Mouth

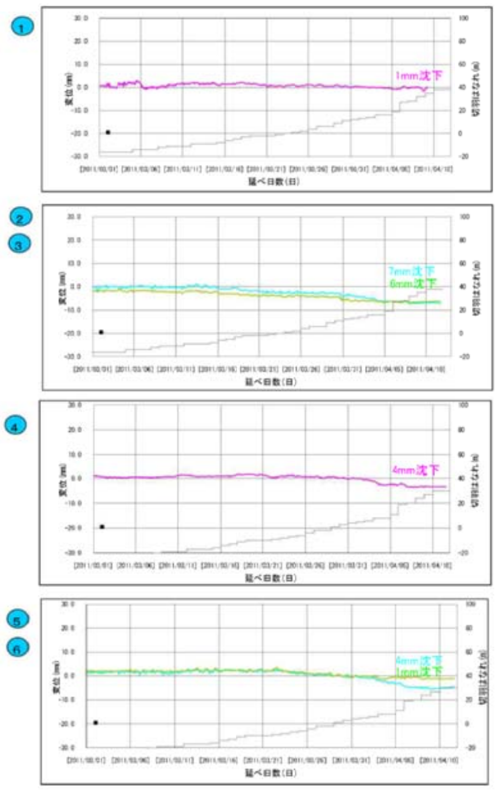
National Road on TN mouth



Subsidence of Ground Surface

Monitoring Plan and Results





Collapse in the shallow section I

W20m x L60m x D10m

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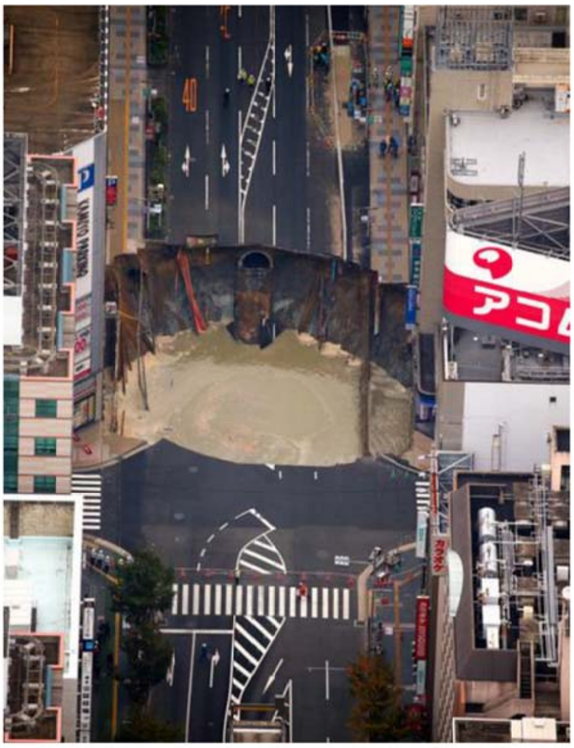
Collapse in the shallow section I

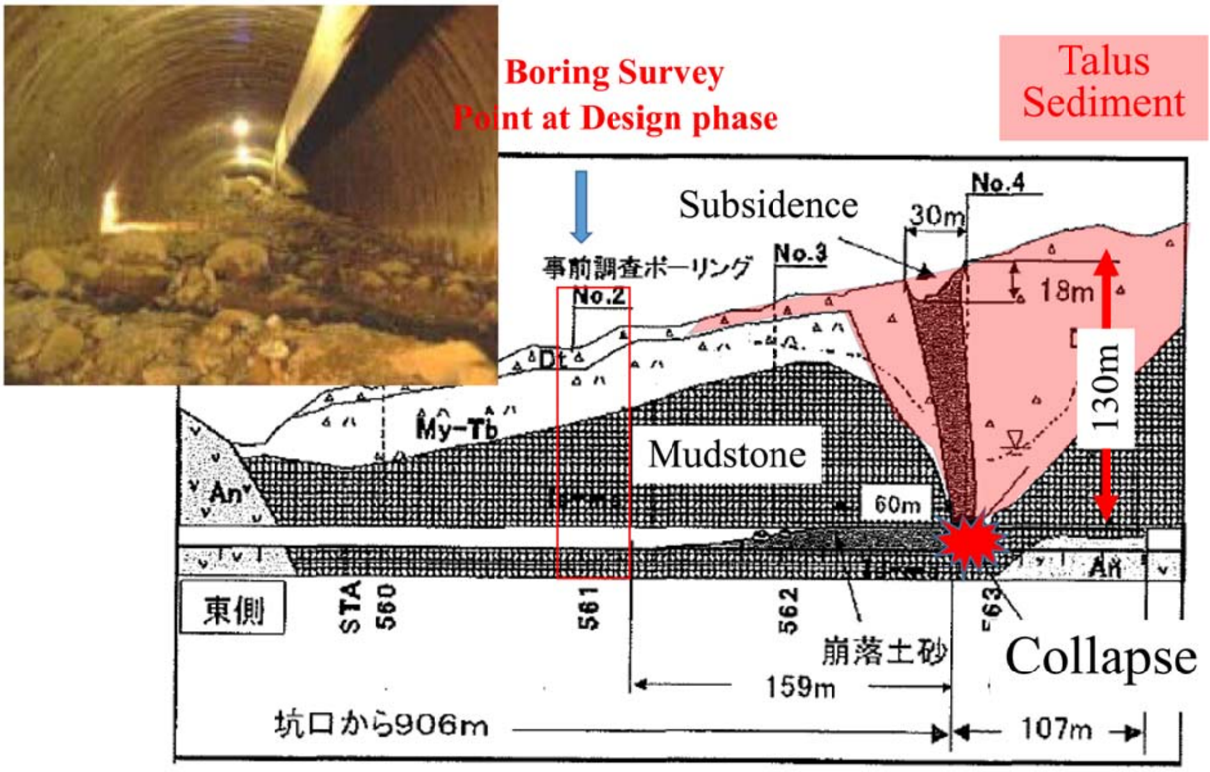


W27m x L30m x D15m

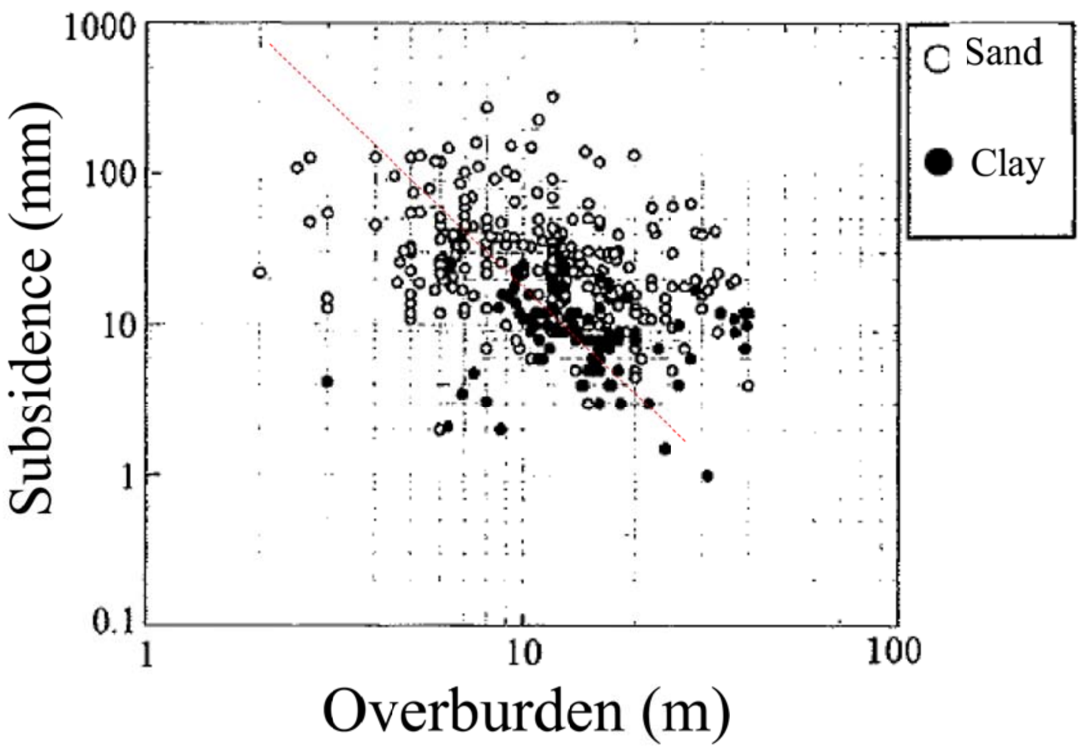
Source: MLIT Report

Source: Asahi.com

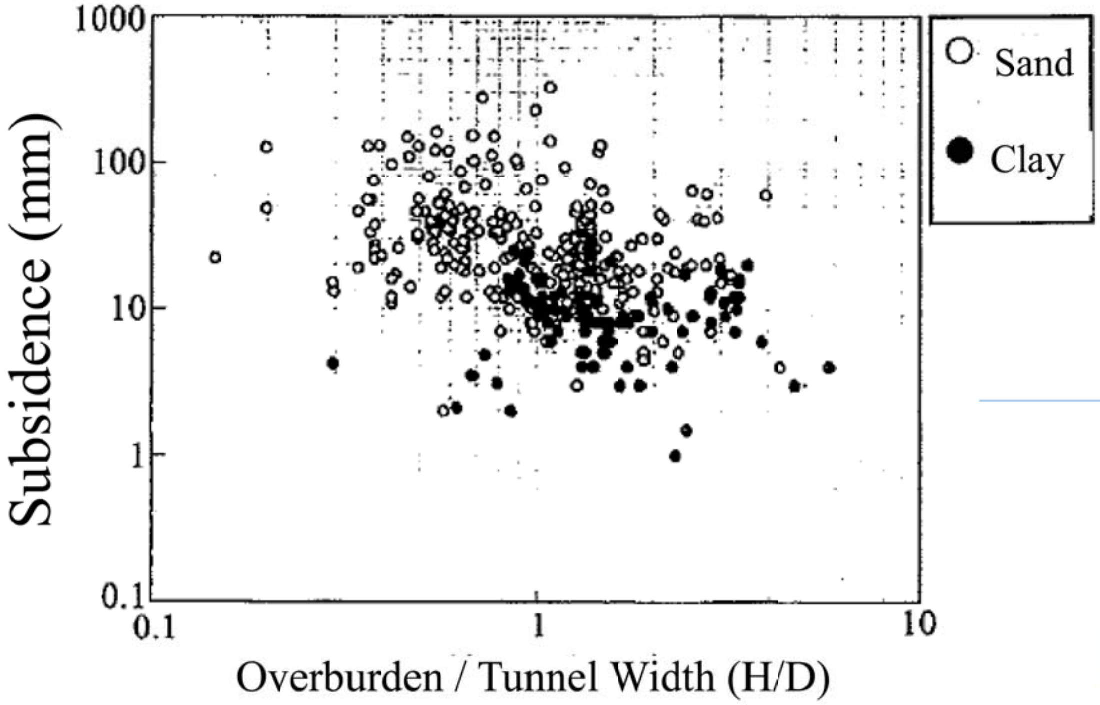
Collapse at Talus sediment

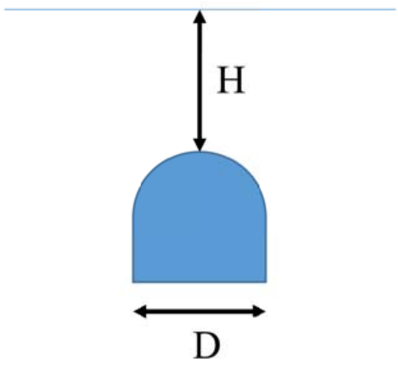


Statistical chart of Japanese experiences

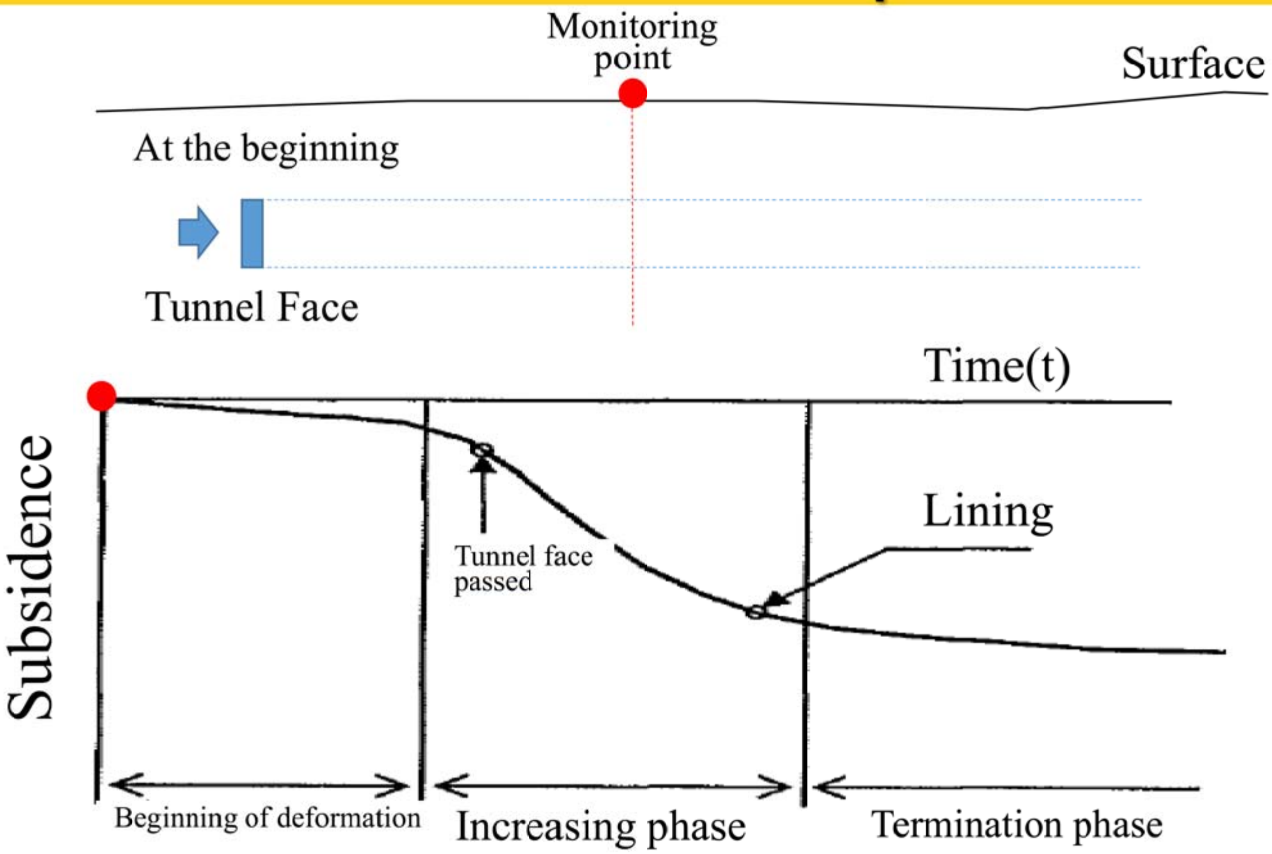


Statistical chart of Japanese experiences

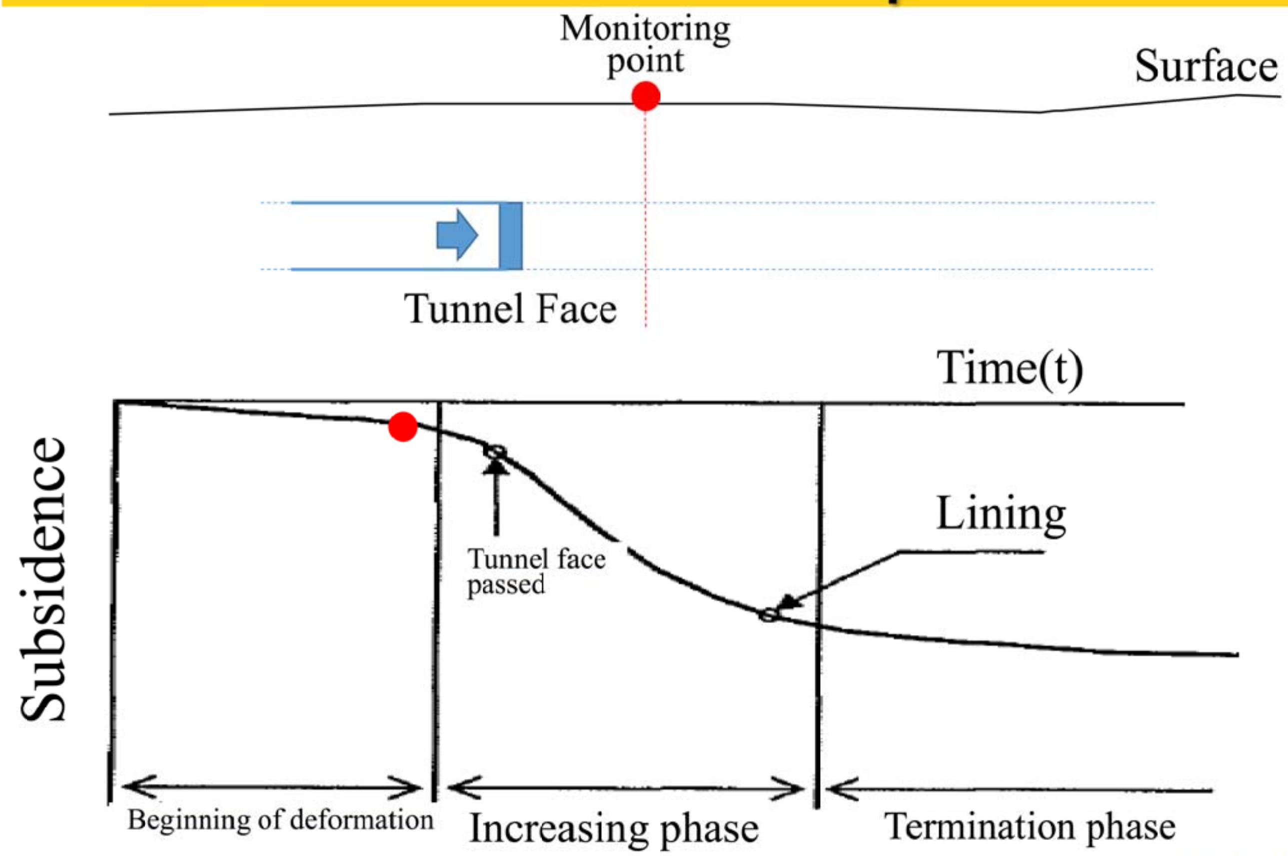




Subsidence of time-dependent



Subsidence of time-dependent



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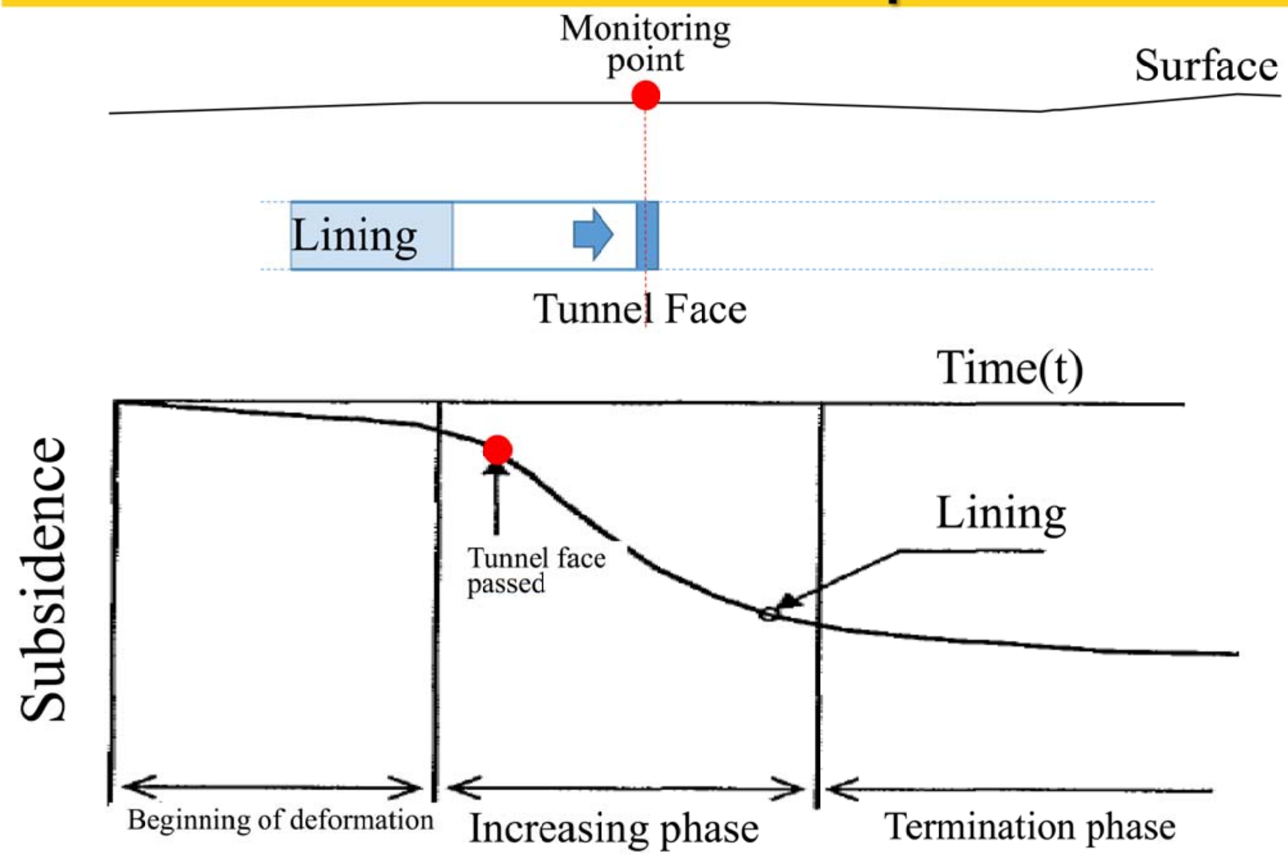
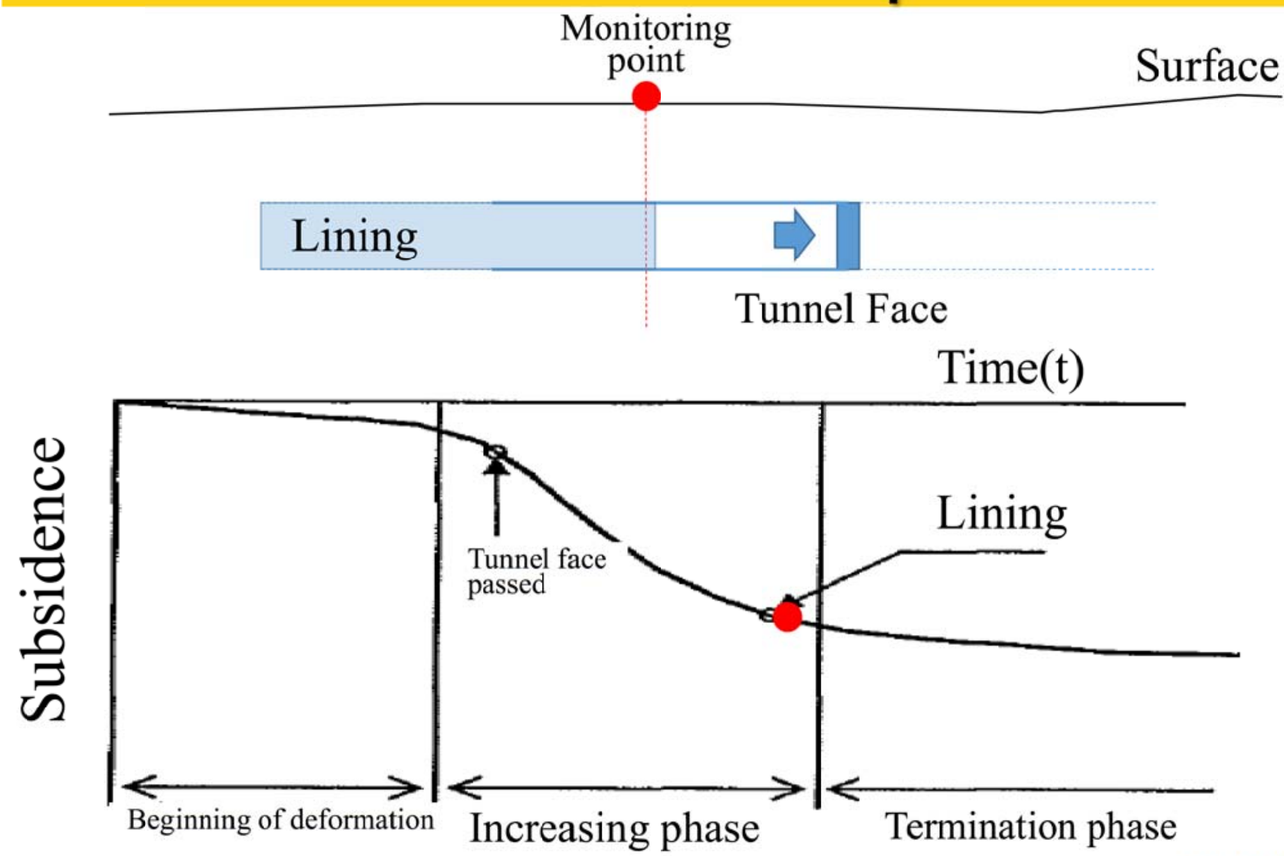
Subsidence of time-dependent



Subsidence of time-dependent

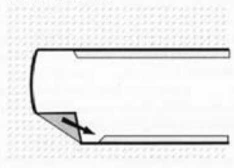
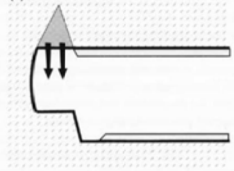
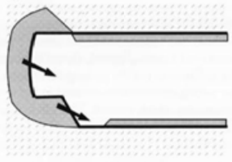
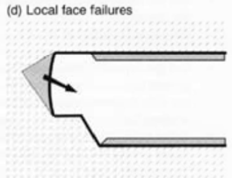


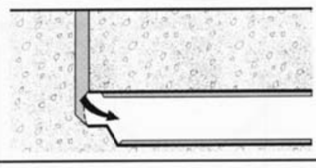
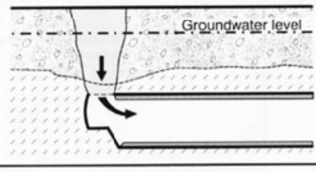
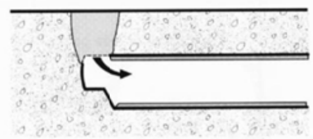
The Condition to be paid attention

- Tunnel Portal
- Thin Overburden
- Fragile geological feature

  Fracture zone, Fault, Unconsolidated sediments (Talus or some)
- High pressure of ground water

Ref. 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**	
(iv)	**Insufficient cover to surface**	

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

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

2. Geological Investigation

Survey Procedures (Ref. J. standard)

Project Phase	Root Selection — Investigation for Root Selection	Root Determination — Investigation for the Design & Const. Plan	Construction Starts — Investigation during Construction	Completion — Monitoring after Construction
Objective	Collect the information of topographical, geological & environmental matters for root comparison and planning of the study on next phase.	Collect the basic information for the design, construction planning & cost estimates.	Predict the occurrence of problems during const. Collect the information for schedule management, QC, design modification and study for compensation after const.	Confirmation of the problem occurred during/after const. Collect the information for the study on compensation or countermeasures.
Contents / Survey Items	Geological, topographical and environmental survey. Comprehensive & general exploration.	Geological, topographical and environmental survey. Detailed exploration for the study on design and construction planning.	Geological, topographical survey. Environmental & deformation monitoring. Environmental monitoring is mainly for clarify the impact of construction.	Geological survey & environmental monitoring. Environmental monitoring is mainly for clarify the impact of construction and effect of countermeasures.
Target	Wide area including alternative alignments	The area including tunnel route and the related for construction.	Inside the tunnel and the area where the construction may give the impact	The area affected by the project.

Survey Procedures (Ref. INVIAS M)

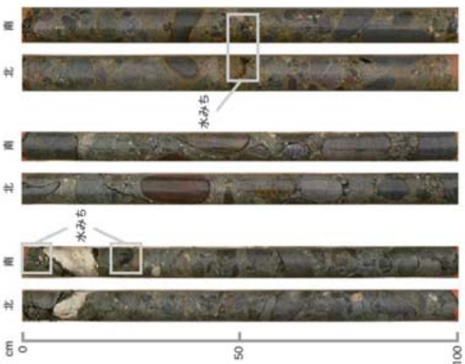
Phase		Main Tasks	Geological Survey Items, etc
Study & Design	Phase I	➢ Conceptual Design ➢ Comparing Alternatives ➢ Feasibility Study	➢ Data collection (Geological Map, Topographic Map, Satellite Images, etc) ➢ Technical Field Reconnaissance
	Phase II	➢ Preliminary Design ➢ Environmental Impact Assessment (EIA)	➢ Preliminary Geological Field Investigation Borehole survey, Seismic or Electric exploration
	Phase III	➢ Detailed Engineering Studies ➢ Detailed design for bidding	➢ Geological Field Investigation in detail
Construction		➢ Control the construction safety	➢ Pre-boring ➢ Monitoring deformation or ground water table
Operation & Maintenance			➢ Monitoring deformation or ground water level

Survey Methods

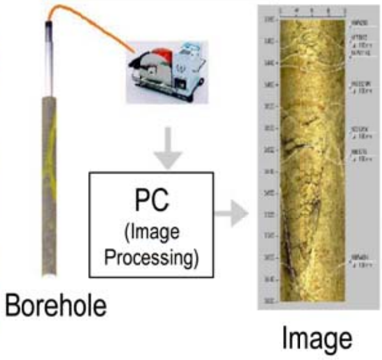
(1) Borehole Survey

- ➢ Appropriate Plan (Location, Qty, Schedule)
- ➢ Quality Control (Apparatus, Procedures)
- ➢ Advanced/Developing Technologies

High Quality Coring



Borehole Scanner



Super Long Horizontal Boring

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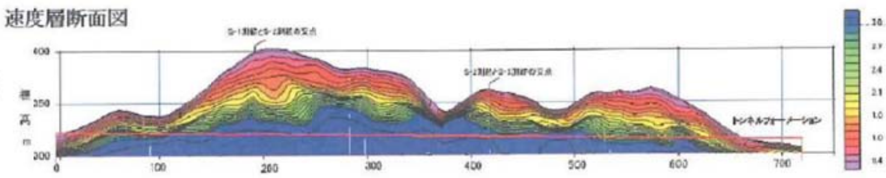
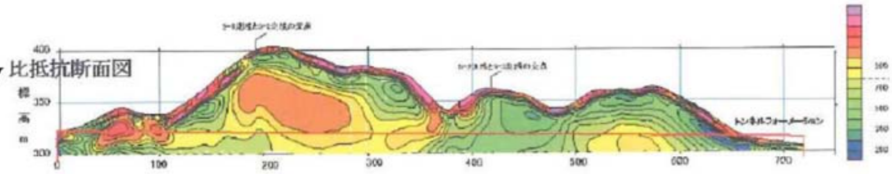
Survey Methods

(2) Geophysical Explorations

- ➢ Seismic Tomography (S.T.)



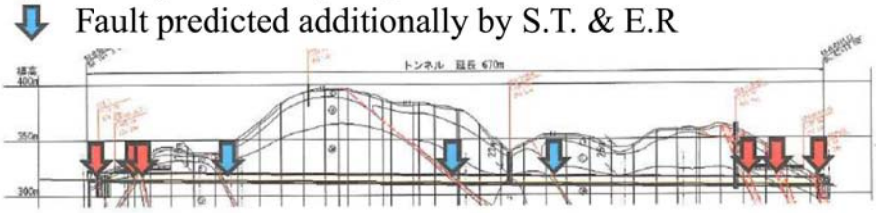
- ➢ Electric Resistivity Exploration (E.R.)



- ➢ Developing Technology

Combining Evaluation using several methods

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



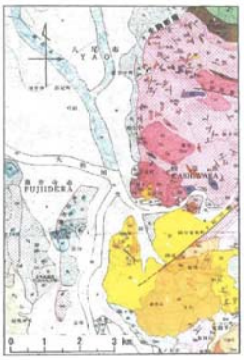
Selection of Survey Methods

Investigation Items \ Investigation Methods		Document Survey	Geological Reconnaissance	Seismic Exploration	Hydrological Survey	Groundwater Investigation	Borehole Survey	Borehole logging: Velocity Wave	Borehole logging: Electric Logging	Borehole logging: Diameter Logging	Borehole logging: Temperature Logging	Standard Penetratoin Test	Borehole Loading Test	Laboratory Tests	Borehole observation
Topo	Land Slide	○	○				○								
	Uneaven earth pressure	○	○												
	Overburden thickness	○		△											
Geo. Structure	Geological Profile	△	○	○			○	△	△						○
	Fault, Fold	△	○				○	△							○
Soil & Rock Characterization	Characterization of rocks	△	○				○		△						○
	Rock facies	△	○				○								○
	Fracture		△	○			○	○							○
	Weathering, Alteration		△	○			○	○	△						○
	Concretion degree		○	△			○	△	△	○		○			○
Under groundwater	Aquifer Stratum		○		○	○	○		○	○	△				○
	Underground water level		△			○	○								
	Permiability					○									
Mechanical Property	Shear Strength											△		○	△
	Cohesive strength, Friction Angle											△		○	△
	Deformation coefficient											△	○	○	○
	N value											○			
Physical Property	Elastic wave velocity			○				○							
	Ultrasonic velocity													○	
	Density													○	
	Grain size													○	
	Liquid and Plastic Limit													○	
	Water content													○	
Mineralogical Characteristics	Clay mineral													○	
	Slaking													○	
	Water absorption													○	

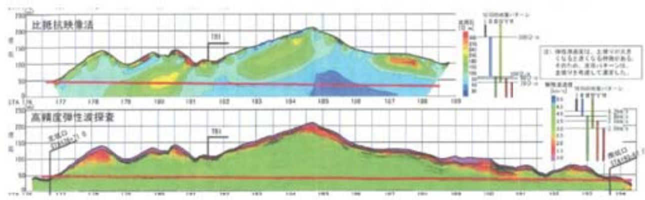
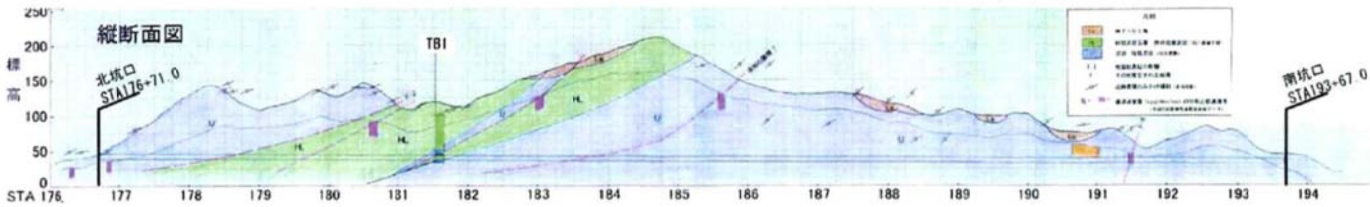
○ Highly Effective

△ Effective

Geological Evaluation

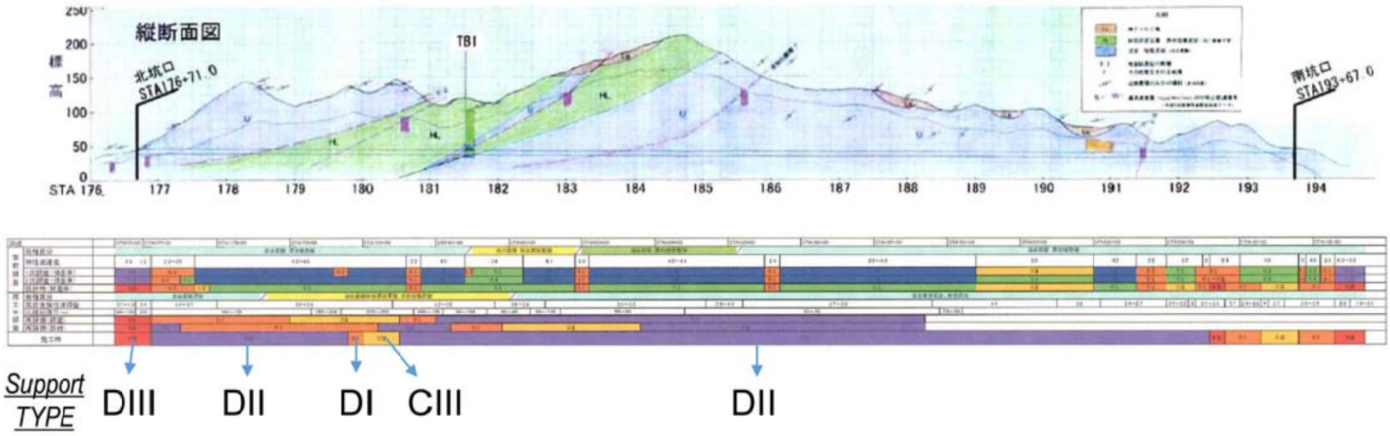




Geological Evaluation

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



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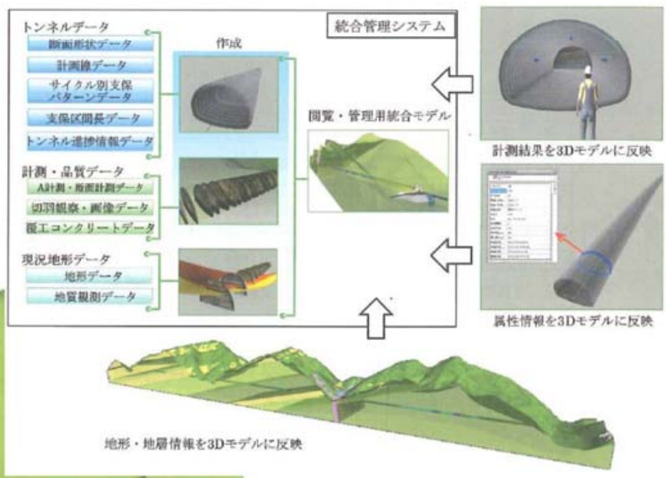
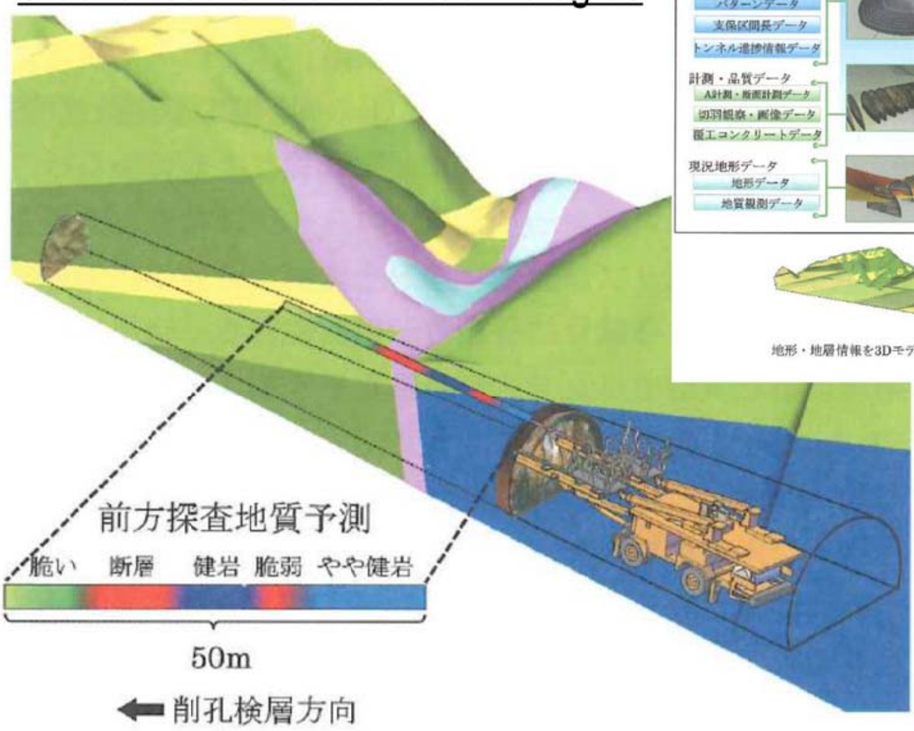
Survey during construction

Pre-boring during construction & advanced evaluation technologies





3. Study on Ground Subsidence due to Tunnel Construction

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Study Procedures

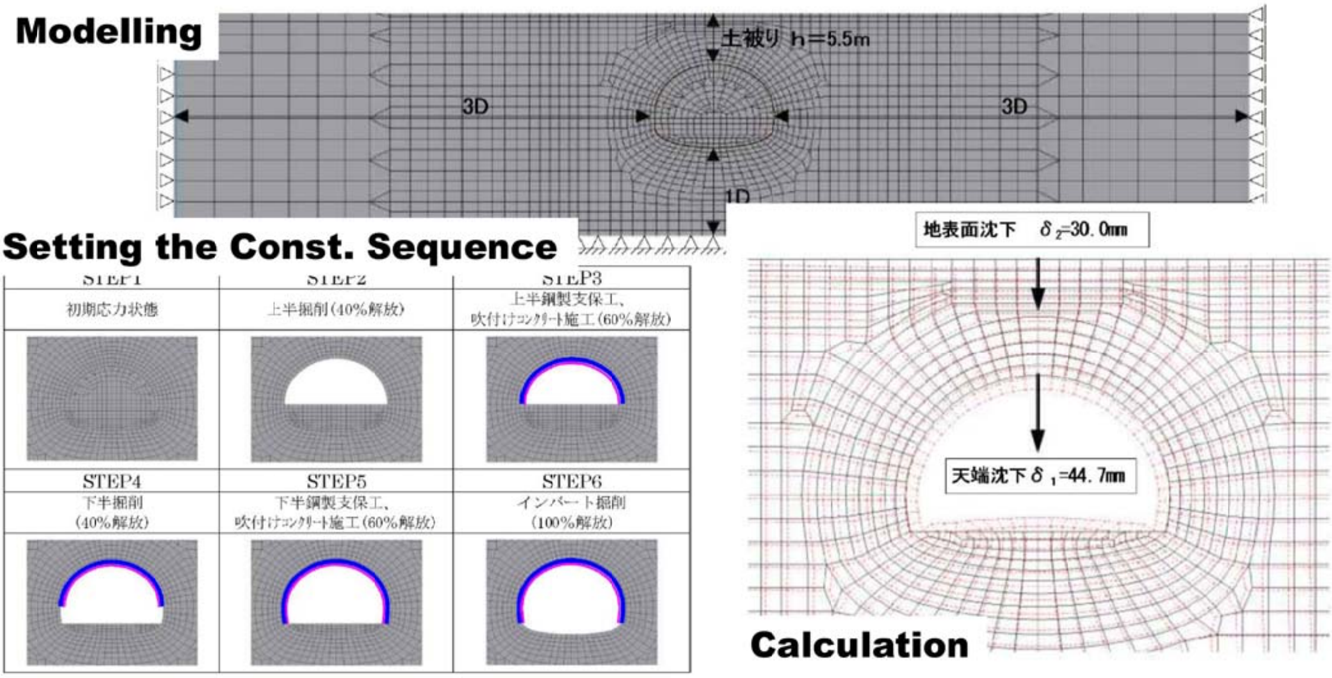
Step 1 Identify the area with potential risks of ground subsidence	Before the study, It's important to make clear the area to be focused on.
Step 2 Conduct geological investigation and analyze the results	Need to obtain the information for conducting the analysis
Step 3 Evaluation of the deformation	Generally using some numerical model, sometimes experimental analysis
Step 4 Study on Mitigation measures if necessary	If the analysis results cannot be accepted, need to study further. Make additional numerical model with countermeasures, and analyze
Step 5 Make a monitoring plan	For safety construction management

Analysis Methods

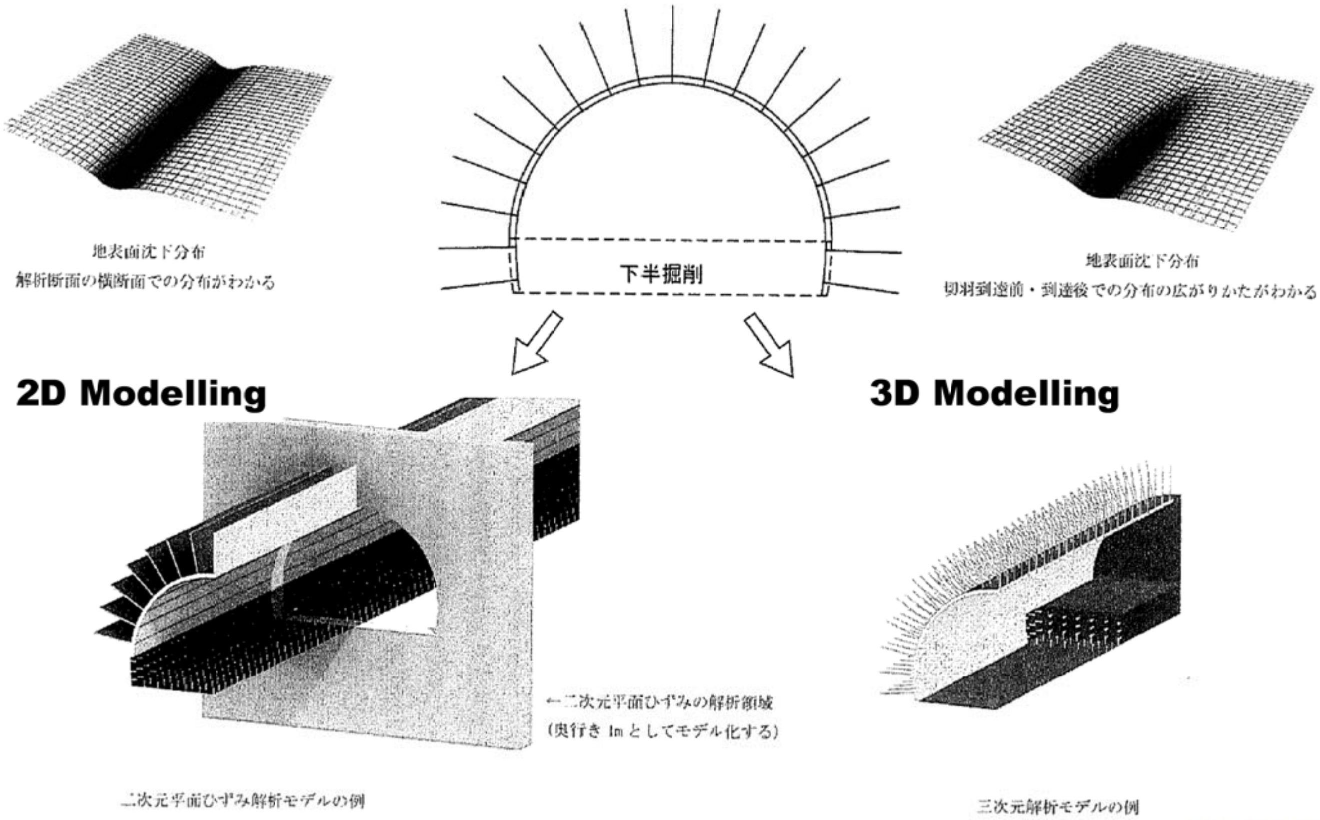
Methods	Type	Applicability
Finite Element Method (FEM)	Continuum analysis	Most popular and many experiences, not suitable for phenomenon with large deformation
Finite Difference Method (FDM)	Continuum analysis	More suitable for phenomenon with large deformation
Discrete Element Method (DEM)	Non-Continuum 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



Finite Element Method (FEM)



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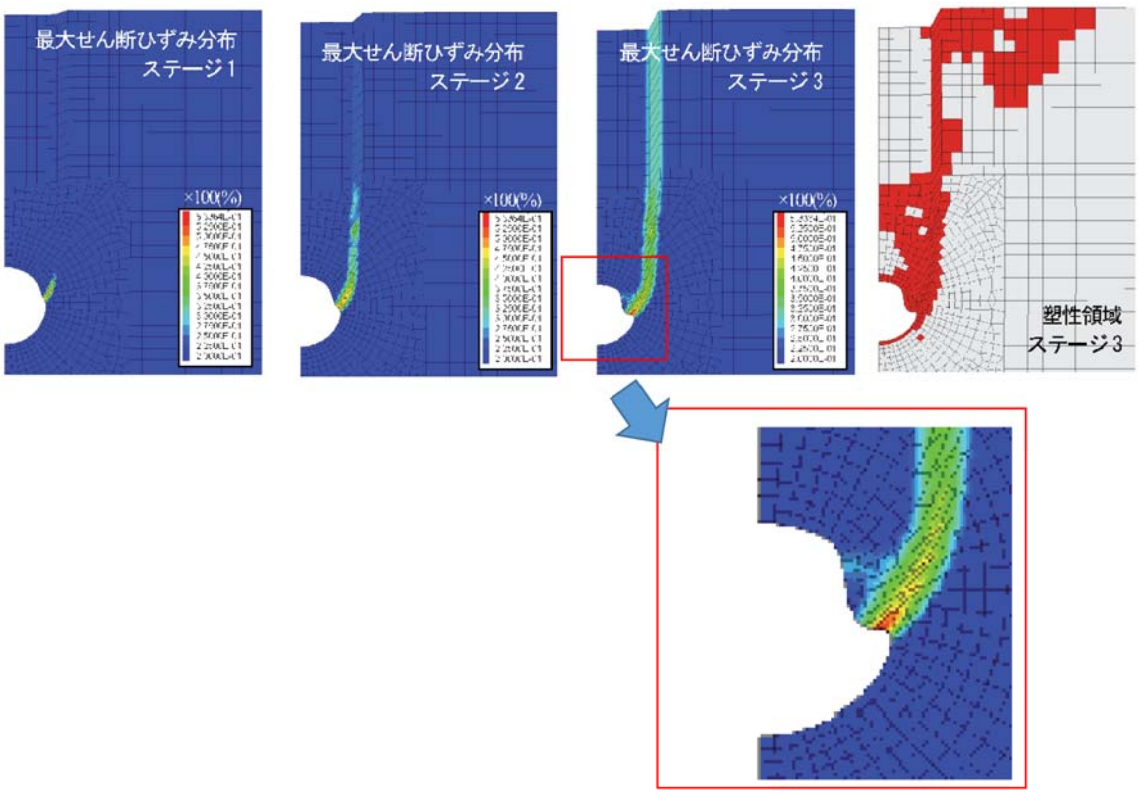
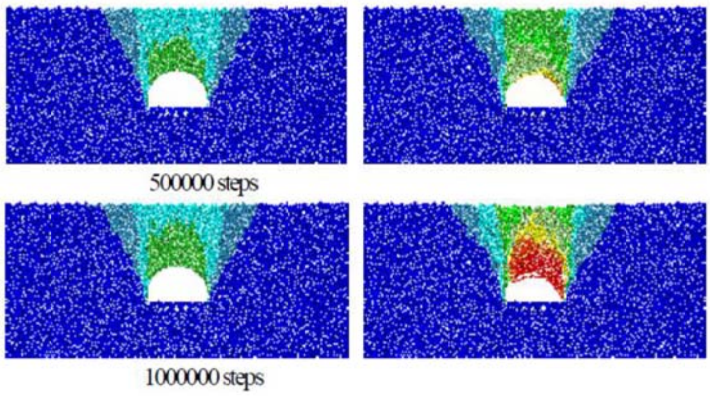
Finite Difference Method (FDM)

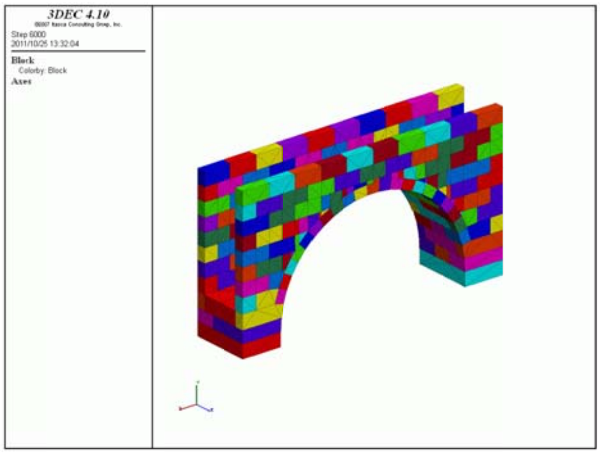


DEM & DDA

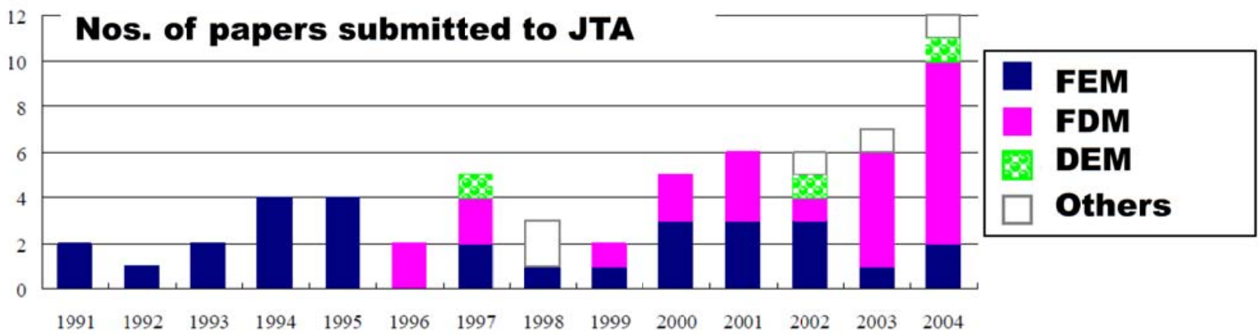
Discrete Element Method

Discontinuous Deformation Analysis





Methods	Applicability
FEM	➢ Most practical and common at the design stage of TN projects
FDM	➢ Practical, For some cases in which larger deformation are predicted
DEM & DDA	➢ Still Academic ➢ Suitable for reverse engineering after occurrence of incidents



4. Monitoring Plan and Example

Monitoring Plan

- Objectives
- Monitoring Item
- Allowance values
- Location & Nos.
- Period & Frequency
- Management Plan for monitoring & Safety control

Points to be considered

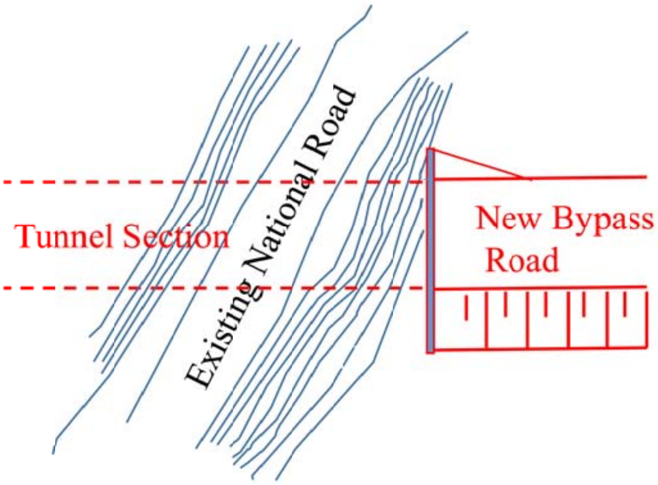
Item	Points to be considered
Measurement items	➢ Clarify purposes of the measurement ➢ Importance of the target facility, level of the predicted impact, allowable limit of the impact
Accuracy	➢ Necessary accuracy of monitoring shall be secured for keeping the safety of target facility, need to compare actual behavior and allowance
Monitoring Location	➢ Estimated deformation area, importance of the target facility ➢ Can be evaluated with reference to Pre-estimation by numerical model
Monitoring points	➢ Importance of the target facility, frequency ➢ Layout of construction facility
Monitoring methods	➢ Accuracy, measurement items, frequency ➢ Secure the construction safety
Monitoring period	➢ From : before having the impact by construction works To: After confirmation of the settling of impacts
Monitoring frequency	➢ Importance of the target facility ➢ Estimated progress rate of deformation
Management structure for monitoring	➢ Determination of the allowance for management ➢ Management and monitoring structure ➢ Assignment of monitoring manager, Establish of emergency network
Data collection and strage	➢ Utilizing for O&M, Feedback for the planning and design in the future, Further study

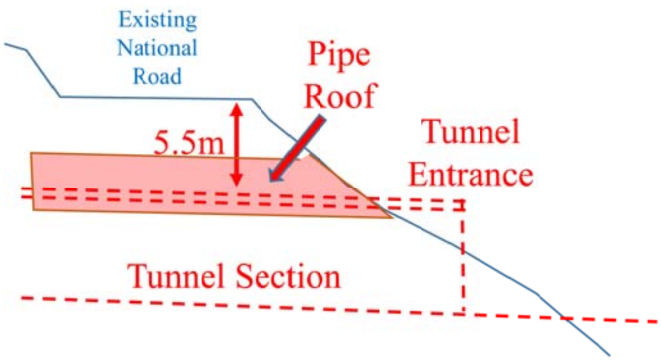
Monitoring Plan

Management Plan for monitoring
& Safety control

- Who is responsible for Monitoring?
- Who is responsible for Safety Management?
- Emergency Network
- Who control the construction?

Case Study - Kurio bypass Tunnel -





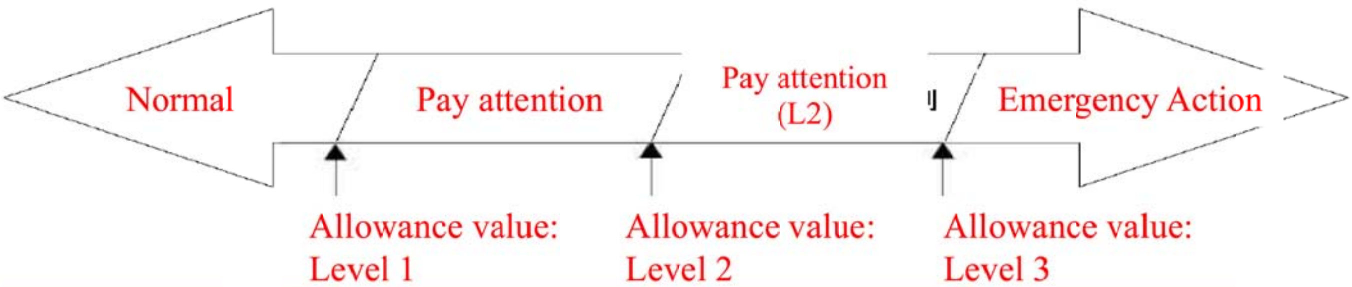
To keep safety of the traffic is Essential

<u>Purpose of the monitoring</u>

To keep safety of the existing traffic on National Road

Case Study - Kurio bypass Tunnel -

- Basic concept of Safety Management



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

Case Study - Kurio bypass Tunnel -

- 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

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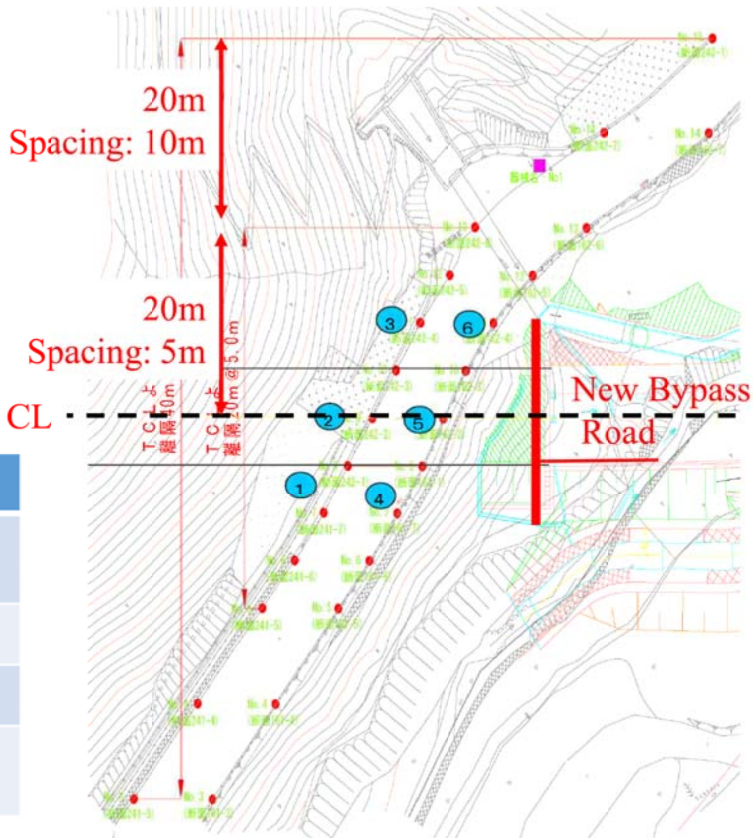
Case Study - Kurio bypass Tunnel -

- Location and Plan

  Target: 26 nos.

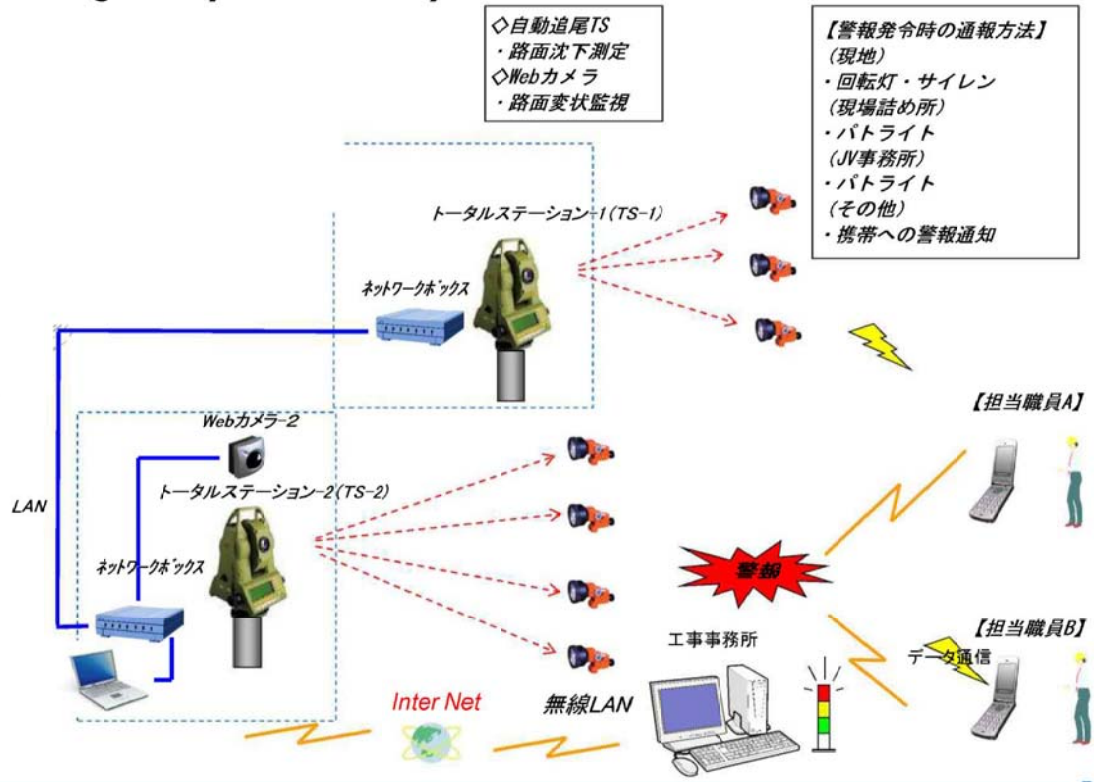


- Period and Frequency

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	

Case Study - Kurio bypass Tunnel -

➤ Emergency Alert System



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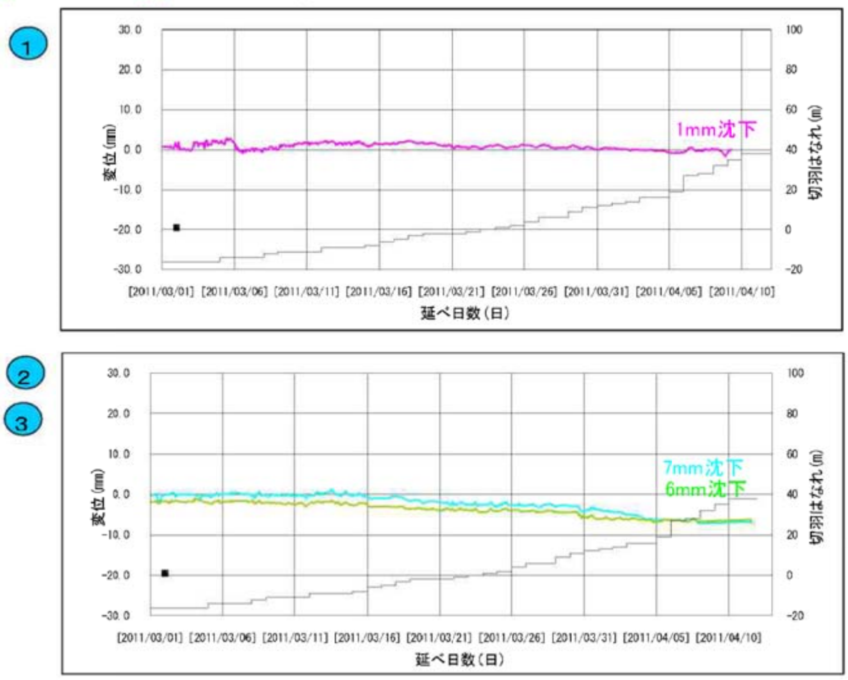
Case Study - Kurio bypass Tunnel -



5. Mitigation Measures

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Auxiliary Method - comparing table -

Method				Purpose							Ground which method can be applied		
				Construction safety					Environmental preservation				
				Face stabilization									
				Crown stabilization	Face stabilization	Footing stabilization	Groundwater control		Subsidence control	Neighboring structure protection	Hard rock	Soft rock	Soil
	Presupport		Forepoling (filling, grouting)	X							X	X	X
Subsidence control	Presupport		Steel pipe forepiling (grouting)	X					X	X		X	X
Subsidence control	Presupport		Pipe roof	X					X	X		X	X
Subsidence control	Presupport		Horizontal jet grouting (injection and mixing)	X	X	X			X	X			X
Subsidence control	Presupport		Slit concrete method	X					X	X		X	X
Face	Face reinforcement		Face shotcrete		X						X	X	X
Face	Face reinforcement		Face bolt		X						X	X	X
Subsidence control	Face reinforcement		Long face bolt		X				X		X	X	X
Subsidence control	Footing reinforcement		Footing reinforcement bolt			X			X			X	X
Subsidence control	Footing reinforcement		Footing reinforcement pile			X			X			X	X
Subsidence control	Footing reinforcement		Temporary invert			X			X			X	X
	Groundwater control	Drainage	Drainage boring	X	X	X	X				X	X	X
	Groundwater control	Drainage	Well point	X	X	X	X						X
	Groundwater control	Drainage	Deep well	X	X	X	X						X
	Groundwater control	Drainage	Drainage drift	X	X	X	X				X	X	X
Subsidence control	Groundwater control	Water searing	Grouting	X	X	X	X	X	X	X	X	X	X
Subsidence control	Groundwater control	Water searing	Cut-off wall				X	X	X	X			X
Subsidence control	Ground reinforcement		Grouting	X	X				X	X			X
Subsidence control	Ground reinforcement		Vertical pre-reinforcement	X	X				X				X

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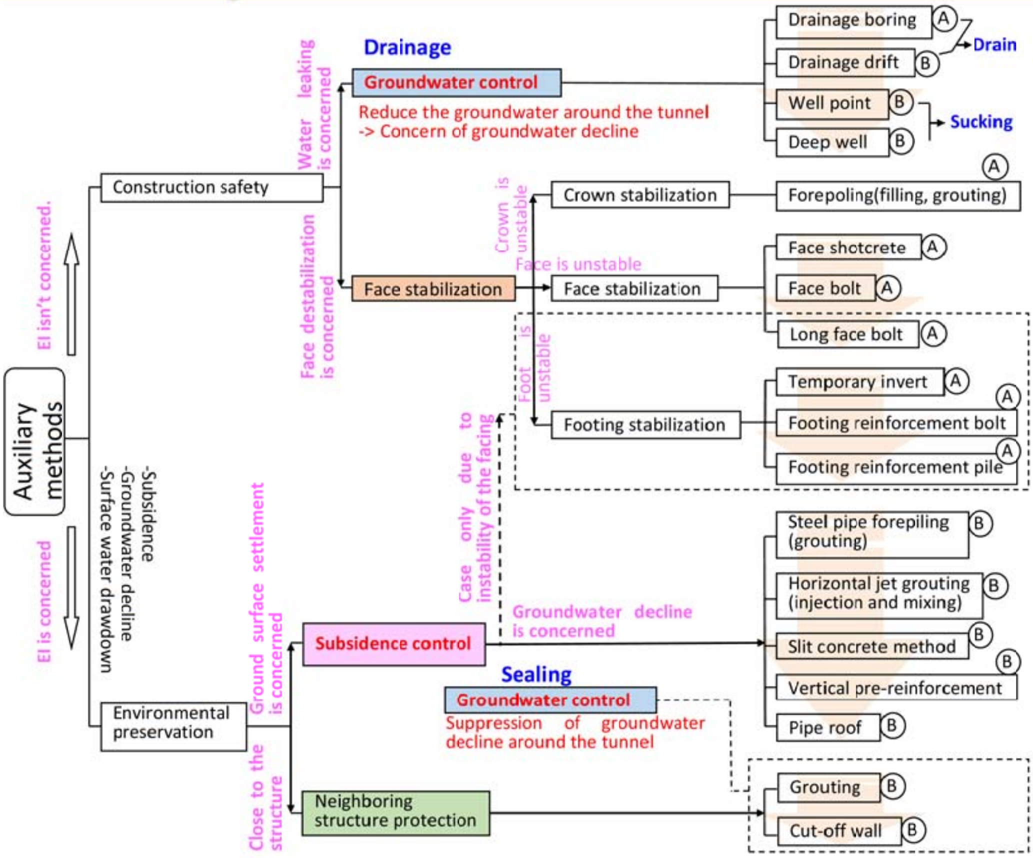
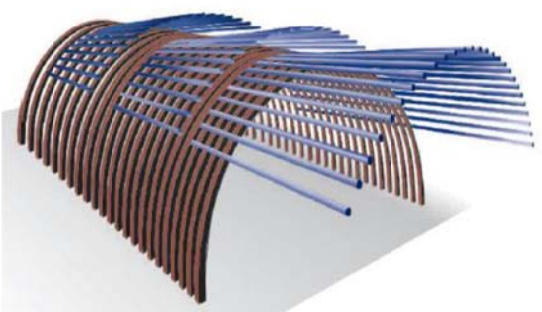
Auxiliary Method - selection chart -



Auxiliary Method - countermeasure for subsidence -

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. **Wide coverage, cohesive soil - Hard rock**



Long steel pipe L=12.5m

Crown stabilization type

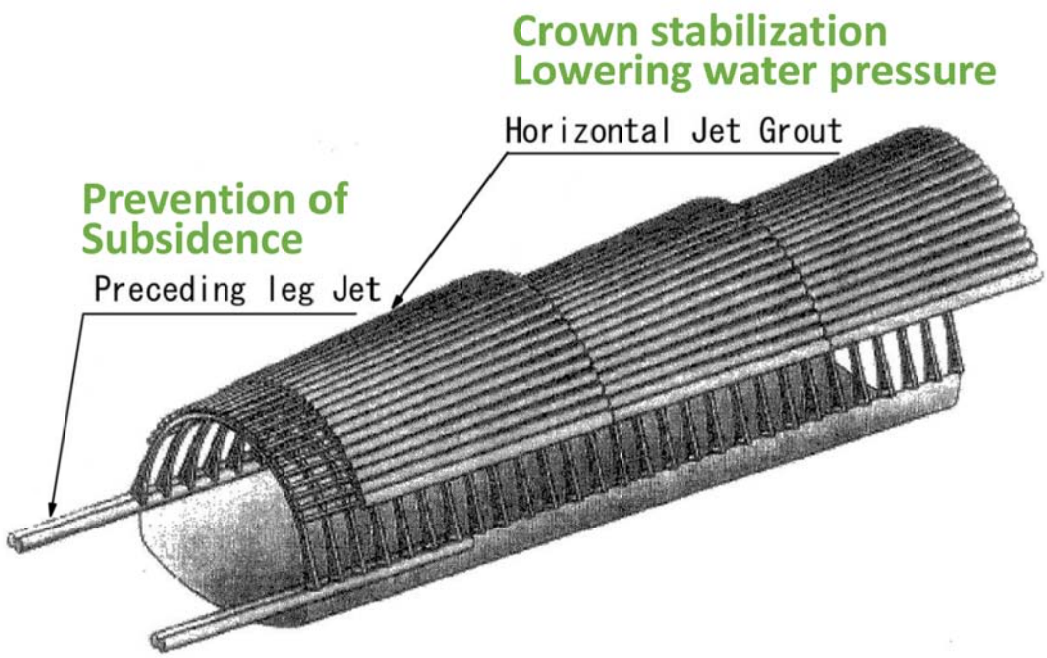
Prevention of deformation by fore-roof

Lowering water pressure type

Prevention of ground breakup with water flow

Auxiliary Method - countermeasure for subsidence -

b) Horizontal jet grouting method, Against subsidence



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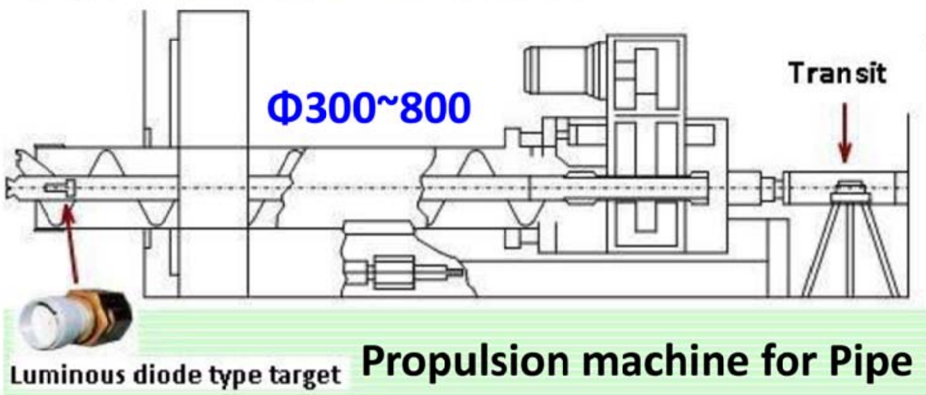
Auxiliary Method - countermeasure for subsidence -

c) Pipe roof protection, Against subsidence

Target by LED type

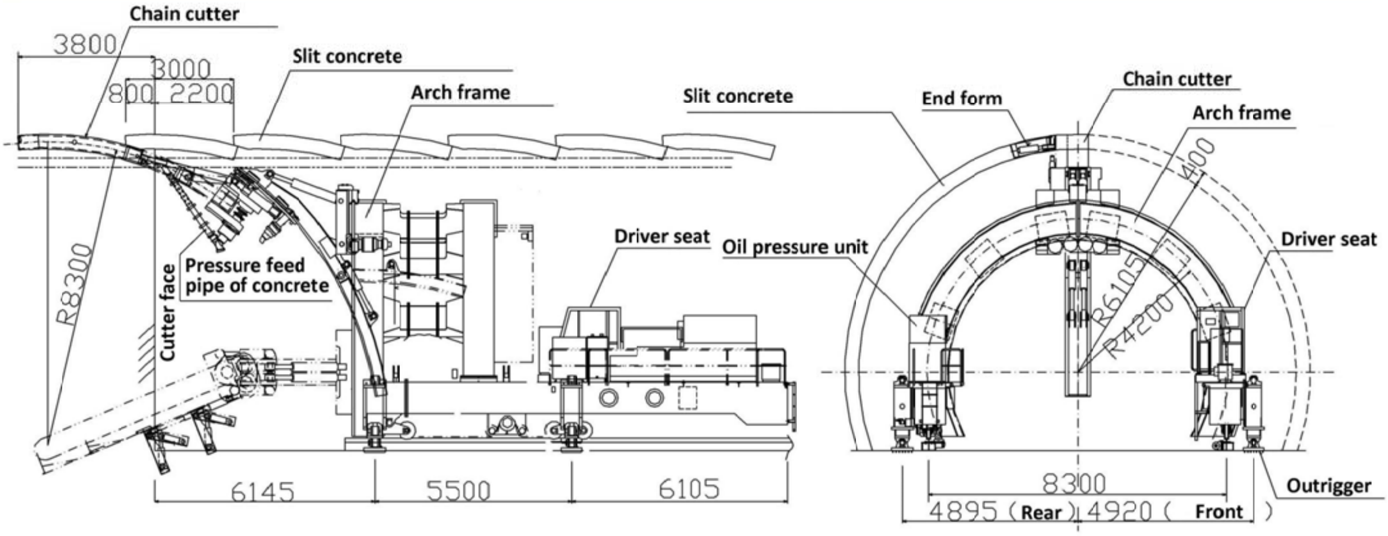
Directional correction equipment



Propulsion machine for Pipe roof

Auxiliary Method - countermeasure for subsidence -

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



ご清聴ありがとうございました

Muchas Gracias

Colombia

NIPPON KOEI

Advisor for Strengthening for ANLA Institutional Capacity on the Tunnel Sector

Water Contamination in Tunnel Construction Works

26 October 2017

Water Quality Engineer
Satoshi MIYAICHI

NIPPON KOEI CO., LTD
Japan's No.1 International Engineering Consultants
http://www.n-koei.co.jp/english/

Outline

1. General
2. Water Pollutant
3. Mechanism of Water Contamination
4. Countermeasures for Water Contamination
5. Japan's Experiences of Water Contamination Caused by Tunnel Projects
6. Conclusion

1. General

Contaminated water caused by tunnel projects are :

1. Muddy water
2. Alkaline / Acid drainage water
3. Drainage water containing high amount of Metals, Metalloids

✓ It is important to note that No.2 and 3 might be from natural sources.

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2. Water Pollutant

Project Phase	Material	Water Pollutant				Activity
		SS	Alkaline	Acid	Metals	
Construction	Soil	x				Earth Works such as muck disposal
	Cement	x	x		x	Cement Works such as Grouting
	Groundwater		x	x	x	Exavation -> Inflow Water
Operation	Groundwater		x	x	x	Continuing Inflow Water
	Rock, soil			x	x	Muck disposal

Shading : natural source

3. Mechanism of Contamination

Material	Pollutant	Mechanism
Soil	SS	Rainwater causes soil erosion from embankment or bare field.
Cement	Alkaline	Wastewater from concrete / cement work are strongly alkaline due to their high lime content.
Cement	Metals	Heavy metals and metalloids have a possibility of elution. It depends on the raw materials of cement.
Groundwater	Acid, Alkaline, Metals	In case that the groundwater is already highly contaminate.
Rock, Soil	Metals	Heavy metals and metalloids have a possibility of elution. It depends on the degree of content.
Rock, Soil	Acid	Acidification Process 1.Sulfide is exposed to air and water by excavation. 2.Acid water is produced from sulfide, H_2O and O_2. 3.Acid water dissolves heavy metals and metalloids.

3.1 Contaminants and associated geology (1)

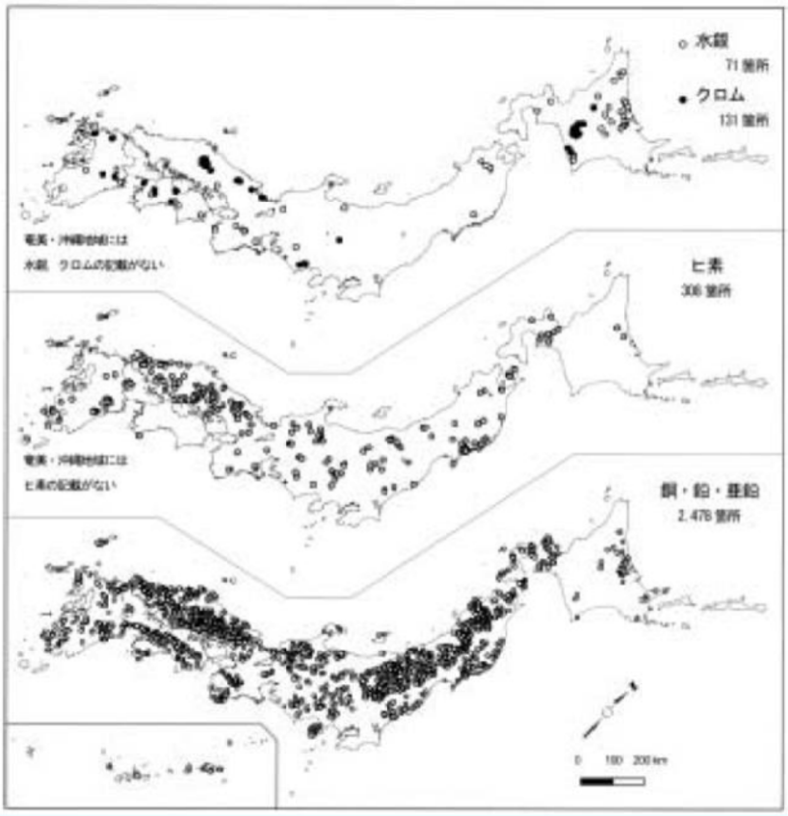
Example of Japanese regulated Pollutants originated from natural source.

pollutants	Clarke's number (mg/kg)	Associated Geology
Zinc (Zn)	70	Usually associated with ores of other common metals such as Pb, Cu, Cd, and Fe.
Cadmium (Cd)	0.2	Usually found associated with zinc ores.
Chromium (Cr)	100	Naturally found in soils. Ultra basic rock and Serpentinite may contain more than 1000mg/kg.
Mercury (Hg)	0.08	Usually lain between volcano or hydrothermal minerals near metallic ore deposit
Selenium (Se)	0.05	Sedimentary rock such as sandstone, limestone and phosphate rock may contain 1 to 100mg/kg.
Copper (Cu)	55	Sedimentary rocks with copper deposit
Lead (Pb)	13	There is a tendency that total content is higher in alkali soil than in acid soil.
Arsenic (As)	1.8	It can be much more concentrated in arsenic-containing ores such as arsenopyrite (FeAsS). especially those found near gold- and other metal-rich areas.
Fluorine (F)	625	Generally occurred as minerals such as fluorspar (CaF_2), cryolite (Na_2AlF_6), fluorapatite $Ca_5(PO_4)_3F$)
Boron (B)	10	Marine mudstone may contain around 100mg/kg.

Clarke's Number : Numbers expressing the average content of the chemical elements in the earth's crust

3.1 Contaminants and associated geology (2)

Locations of mine which produced heavy metals in Japan



○ Hg
● Cr

As

Cu / Pb /Zn

http://www.mlit.go.jp/sogoseisaku/region/recycle/pdf/recyclehou/manual/sizenyuraimanyu_zantei_honbun.pdf

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3.2 Mechanism of Acidification

Series of chemical reaction of iron pyrite.

掘削土に含まれる黄鉄鉱の風化（酸化）

$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4$
黄鉄鉱　酸素　水　硫酸第一鉄　硫酸

Iron pyrite is oxidized by O_2 and H_2O -> iron(II) sulfate and sulfuric acid

生成した硫酸は各種硫化物を溶解する

sulfuric acid dissolves sulfide

硫酸第一鉄の酸化

$2FeSO_4 + H_2SO_4 + 1/2O_2 \rightarrow Fe_2(SO_4)_3 + H_2O$
硫酸第一鉄　硫酸　硫酸第二鉄

iron(II) sulfate is oxidized by sulfuric acid and O_2 -> iron(III) sulfate

硫酸第二鉄が各種硫化物を溶解

Sulfide, iron(III) sulfate and H_2O -> Acid water containing metals is produced.

$CuFeS_2 + 8Fe_2(SO_4)_3 + 8H_2O \rightarrow CuSO_4 + 17FeSO_4 + 8H_2SO_4$
黄鉄鉱　硫酸第二鉄　硫酸銅　硫酸第一鉄　硫酸

$PbS + 4Fe_2(SO_4)_3 + 4H_2O \rightarrow PbSO_4 + 8FeSO_4 + 4H_2SO_4$
方鉛鉱　硫酸第二鉄　硫酸鉛　硫酸第一鉄　硫酸

$ZnS + 4Fe_2(SO_4)_3 + 4H_2O \rightarrow ZnSO_4 + 8FeSO_4 + 4H_2SO_4$
閃亜鉛鉱　硫酸第二鉄　硫酸亜鉛　硫酸第一鉄　硫酸

$HgS + 4Fe_2(SO_4)_3 + 4H_2O \rightarrow HgSO_4 + 8FeSO_4 + 4H_2SO_4$
辰砂　硫酸第二鉄　硫酸水銀　硫酸第一鉄　硫酸

H_2O and O_2 play important roles in acidification and producing acid water containing heavy metals

重金属を含む酸性水の発生

http://www.cbr.mlit.go.jp/tajimi/suishitsu/information/i030805/p10shingi_shiryo.pdf

4. Countermeasures for Water Contamination

- The most important point of considering countermeasures is to avoid producing contaminated water.
- Wastewater which is produced unavoidably should be treated appropriately.

4. Countermeasures (1)

Pollutant	To avoid producing	Appropriate treatment
SS from Soil	• Avoiding soil erosion ✓ Covering by sheet ✓ Drainage trench	Solid – Liquid Separation by installing settling pond or treatment plant.
Alkaline from Cement	• Controlling the quantity of water with concrete works	Neutralization by treatment plant.
Metals from Cement	• Selecting cement material with little possibility of elution	Solid – Liquid Separation by treatment plant.
Acid, Alkaline, Metals from Groundwater	• Grouting • Water – tight structure	Solid – Liquid Separation by treatment plant.

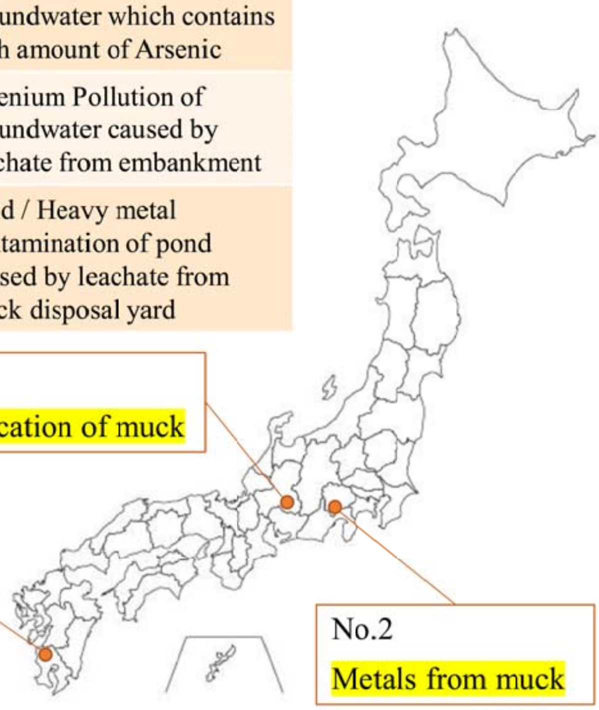
4. Countermeasures (2)

Pollutant	To avoid producing	Appropriate treatment
Metals from Rock, Soil	• Avoiding exposure to rainwater and groundwater ✓ impermeable liner such as sheet and clay ✓ Compaction	Solid – Liquid Separation by treatment plant.
Acid from Rock, Soil	• Avoiding exposure to rainwater, groundwater and Oxgen ✓ impermeable liner such as sheet and clay ✓ Compaction	Neutralization, Solid – Liquid Separation by treatment plant.

4. Countermeasures (3)

5. Japan's Experiences of Water Pollution Caused by Tunnel Projects

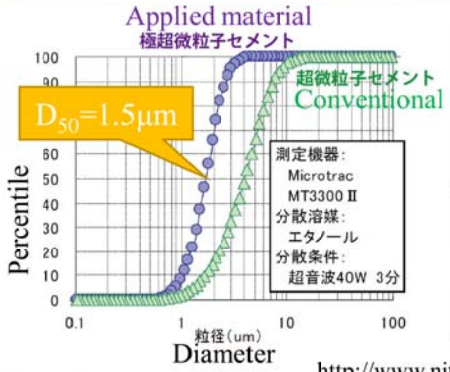
No.	Project	Name of tunnel	Length	Direction	Problem
1	Hokusatsu Odan Expressway	Hokusatsu tunnel	4,850m	2-way	Large inflow of groundwater which contains high amount of Arsenic
2	Chubu Odan Expressway	Kazone 4th tunnel	1,852m	2-way	Selenium Pollution of groundwater caused by leachate from embankment
3	Tokai-Kanjo Expressway	-	-	2-way	Acid / Heavy metal contamination of pond caused by leachate from muck disposal yard



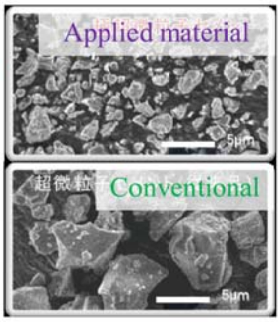
5.1 Large inflow of groundwater which contains high amount of Arsenic

- Project
  - Hokusatsu Odan Expressway Hokusatsu Tunnel L=4,850m
- Problems
  - Maximum 1,200t/hour of inflow occurred during construction.
  - One of the section yielded 300t/hour inflow with high amount of arsenic, 0.16mg/L (Japanese environmental quality standard is 0.01mg/L).
- Countermeasures and final settlement
  - During excavation phase, Wastewater treatment plant was installed. Wastewater was treated by coagulation-flocculation process.
  - To Reduce the amount of inflow, grouting with ultrafine particle cement (mean grain size is 1.5μm) was applied. Coefficient of permeability was improved $4*10^{-4}$cm/sec to $4*10^{-6}$cm/sec, and inflow was reduced to 40t/hour.

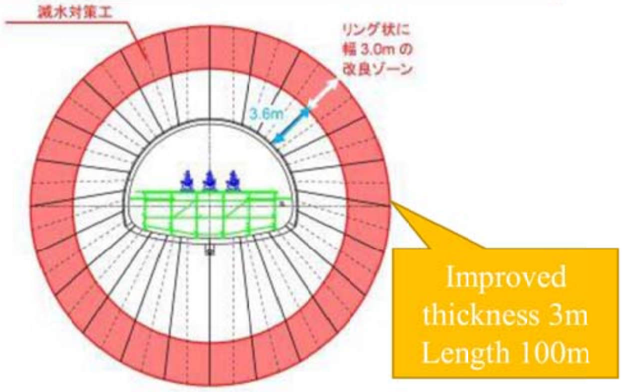
5.1 Large inflow of groundwater which contains high amount of Arsenic



Grouting material



http://www.nittoc.co.jp/technology/0627.html



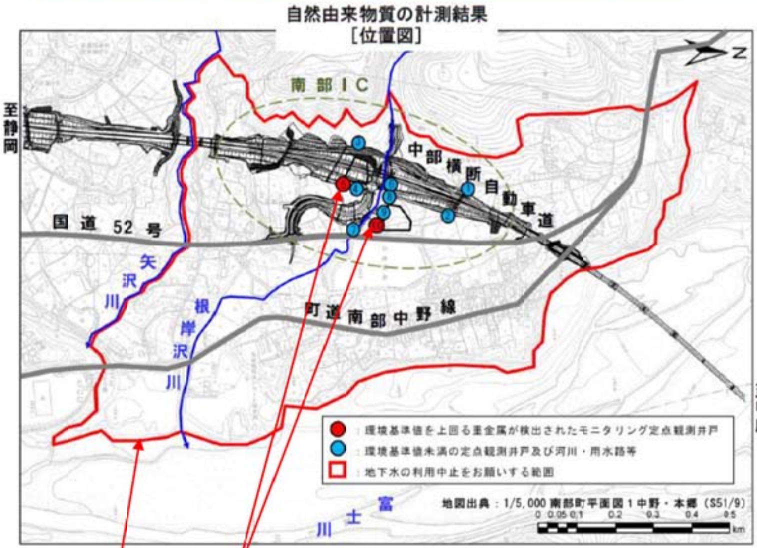
Coefficient of permeability was improved $4*10^{-4}$ to $4*10^{-6}$cm/sec, inflow was reduced from 300t/h to 40t/h

http://www.kumagaigumi.co.jp/press/2016/pr_170125_1.html

5.2 Selenium Pollution of groundwater caused by leachate from embankment

- Project
  - Chubu Odan Expressway Kazone 4th tunnel
- Problems
  - Groundwater was polluted by leachate from embankment which was constructed of tunnel muck. The leachate contained high amount of Selenium resulting from improper construction work.
  - The maximum level of Selenium detected from observation well was 0.15mg/L (Japanese standard is 0.01mg/L).
- Countermeasures and final settlement
  - As a temporary measure, covering the embankment by sheet to prevent rainwater permeation.
  - As a permanent measure, containment was applied to prevent the migration of contaminants in groundwater.

5.2 Selenium Pollution of groundwater caused by leachate from embankment

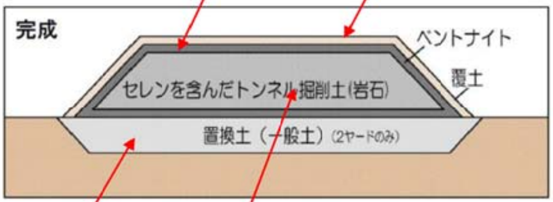


Excess of the environmental standard

Use of well water was banned for more than a year, at most 180 wells had been affected.

Soil covering

Clay



Muck (containing Selenium)

Replacement of soil (polluted zone)

Permanent countermeasure

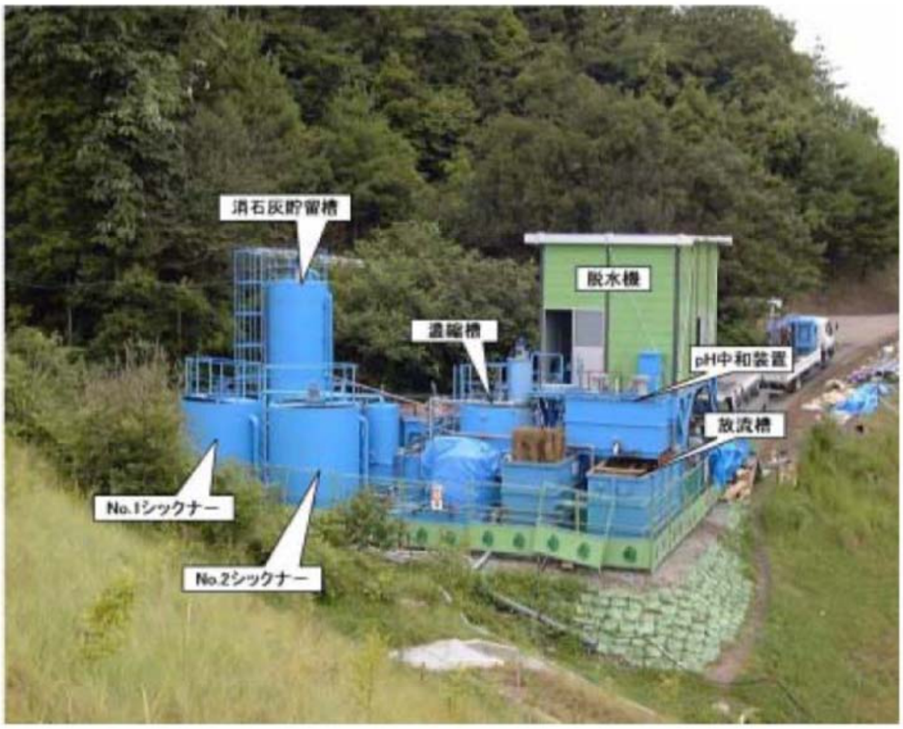
http://www.ktr.mlit.go.jp/ktr_content/content/000085393.pdf

http://www.ktr.mlit.go.jp/ktr_content/content/000088912.pdf

5.3 Acid / Heavy metal contamination of pond caused by leachate from muck dissposal yard

- Project
  - Tokai-Kanjo Expressway (from disposal yard)
- Problems
  - From muck disposal yard, acid leachate was produced due to the chemical reaction of iron pyrite contained in mudstone.
  - The acid Leachate discharged into a Shin-Takigahora pond, many fish were killed. The drainage contains heavy metals.
- Countermeasures and final settlement
  - Leachate treatment plant was installed to neutralize and remove heavy metals.
  - Dredging the sediment of detention pond of the disposal yard.
  - Soil covering of the disposal yard to prevent rainfall permeation.
  - Diversion of the treated effluent to downstream tributary where large amount of water discharges.

5.3 Acid / Heavy metal contamination of pond caused by leachate from muck dissposal yard



Leachate treatment plant

http://www.cbr.mlit.go.jp/tajimi/suishitsu/information/i030805/p10shingi_shiryo.pdf

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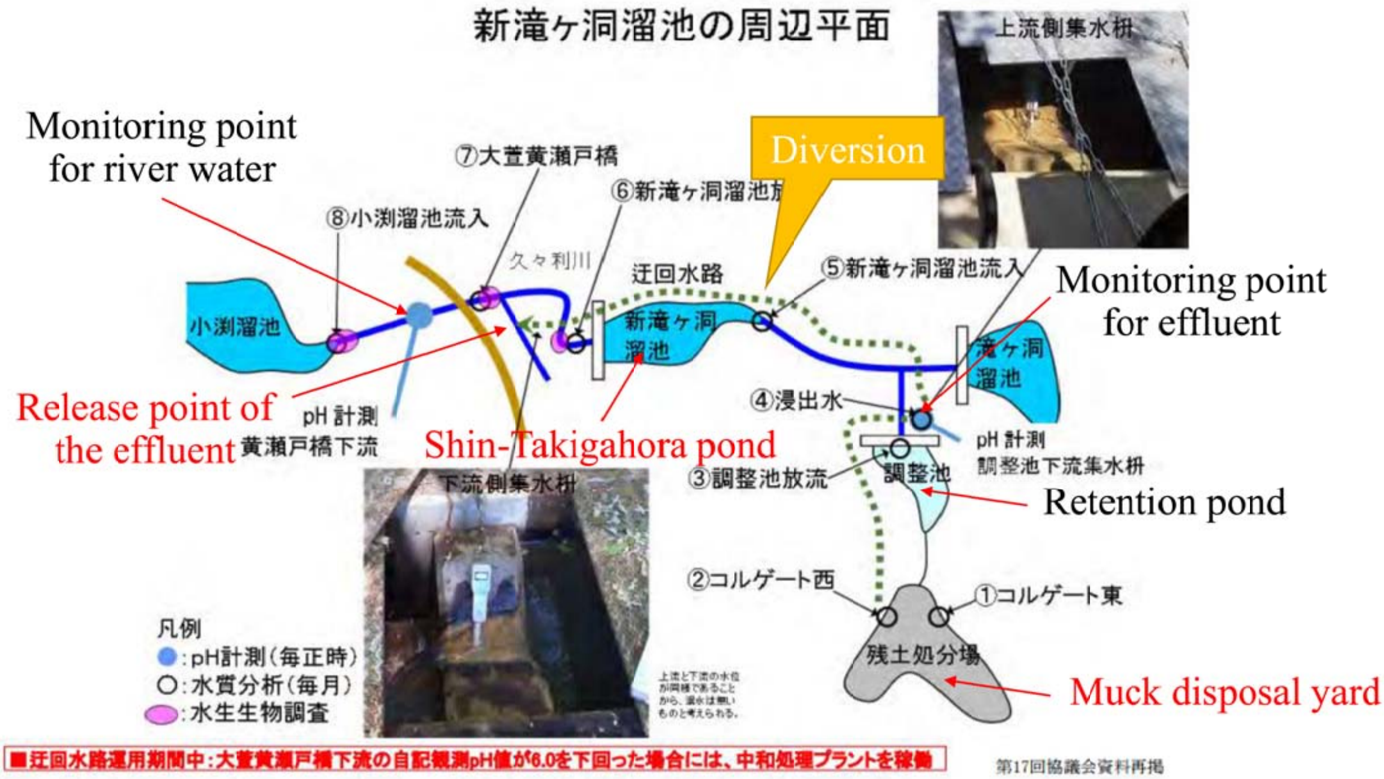
5.3 Acid / Heavy metal contamination of pond caused by leachate from muck disposal yard



http://www.cbr.mlit.go.jp/tajimi/suishitsu/information/20170207/pdf/20170207_1_suishitsu_19_2.pdf

6.Conclusion

- It is not rare that heavy metals originating from nature could be contaminants.
- Until completing the whole process of excavating the tunnel, it is impossible to predict precisely whether there will be a need for taking countermeasure or not.
- It is important to continue judging by observation and monitoring through construction phase.
- The most important point of considering countermeasures is to avoid producing contaminated water.

Muchas gracias !