

Cut and Cover Tunnel

Construction of a station by cut & cover method



June 30th 2016 Lecture at Waseda Univ.

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Types of Tunnel & Construction Methods

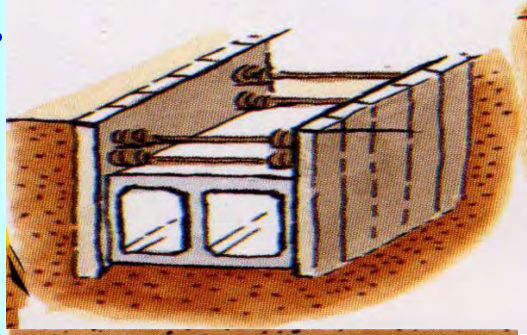
What's Tunnel?



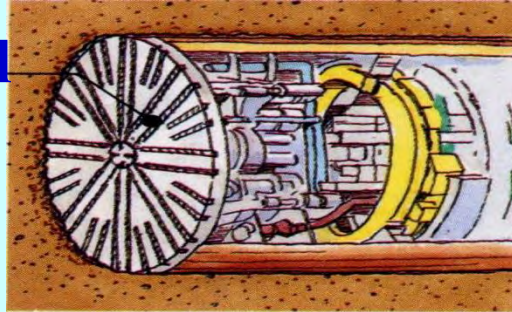
What's a tunnel made of ?

Types of Tunnel

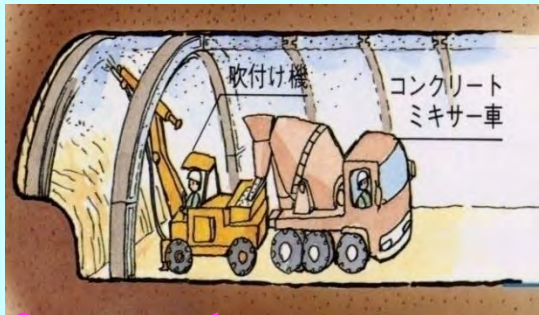
Cut & Cover
Tunnel



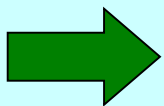
Shield Tunnel



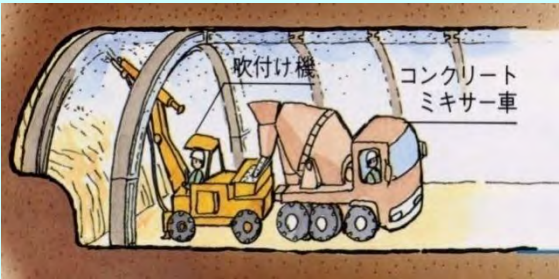
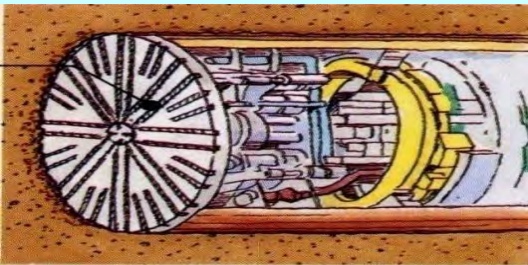
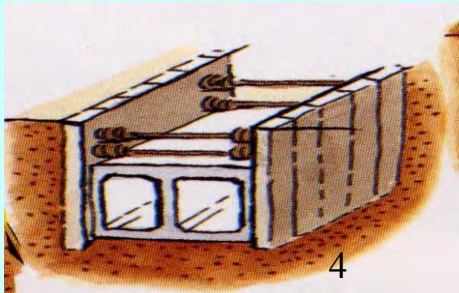
Mountain
Tunnel



Difference of ground
Difference of
construction method



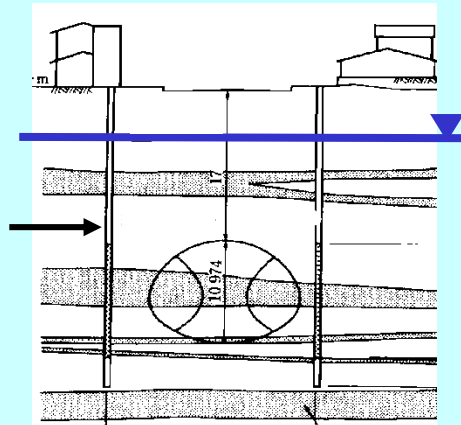
COMPARISON-1.Outline of construction methods

NATM	Shield	Cut & cover
<ul style="list-style-type: none">▪ <u>Shot Crete</u>, <u>Steel support</u>, <u>Rock Bolt</u>▪ Making full use of the natural support function of the surrounding ground▪ Prerequisite condition is that face remains standing when excavated	<ul style="list-style-type: none">▪ <u>Segmental Lining.</u>▪ The skin plate of the shield machine, outer backfill layer of the shield and the segmental support the wall of the tunnel.▪ Closed-type shield stabilizes the face using earth or slurry to counter earth or hydraulic pressure.	<ul style="list-style-type: none">▪ Earth-retaining wall, Main body▪ The ground excavated from the surface to build the tunnel at the desired depth. Then the excavated earth is brought back to restore the surface.
 <p>吹付け機 コンクリート ミキサー車</p>		 <p>4</p>

COMPARISON-2.Countermeasure for underground water

NATM	Shield	Cut & cover
<ul style="list-style-type: none">▪ When there is water inflow that affects the self-support of the face or stability of the ground during excavation, water sealing method such as by deep well, well point, or drainage tunnel is necessary.	<ul style="list-style-type: none">▪ Usually, closed type shield does not required countermeasure s, but the open type does.	<ul style="list-style-type: none">▪ Countermeasures such as deeper penetration of earth retaining wall, groundwater reducing method, soil improvement etc. are usually necessary to overcome boiling or heaving.

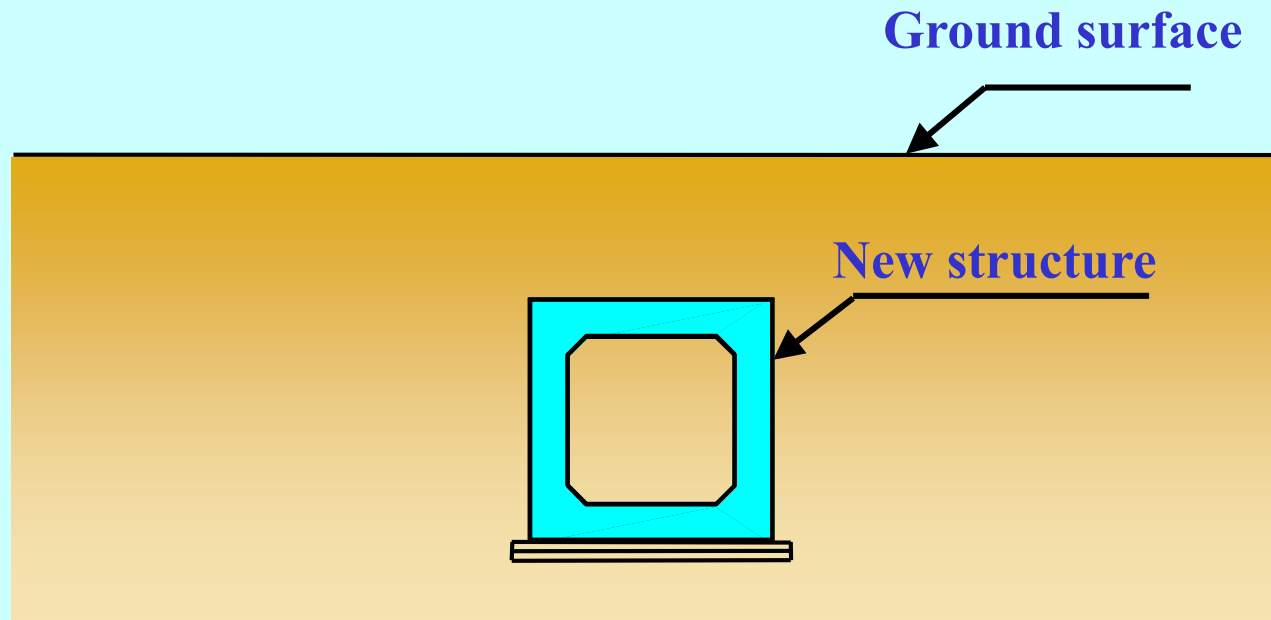
Deep well.



Natural water level.

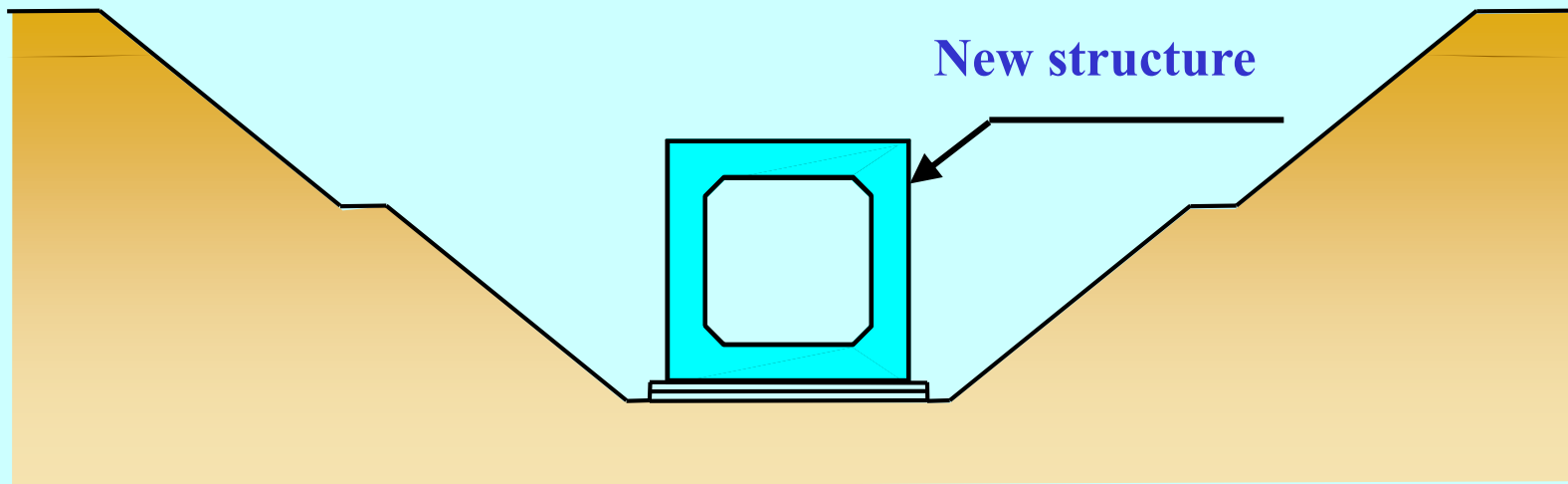
When a structure is needed to construct in underground, 1

If there is no limitation of the ground surface and surroundings,



When a structure is needed to construct in underground, 2

If there is no limitation of the ground surface and surroundings,

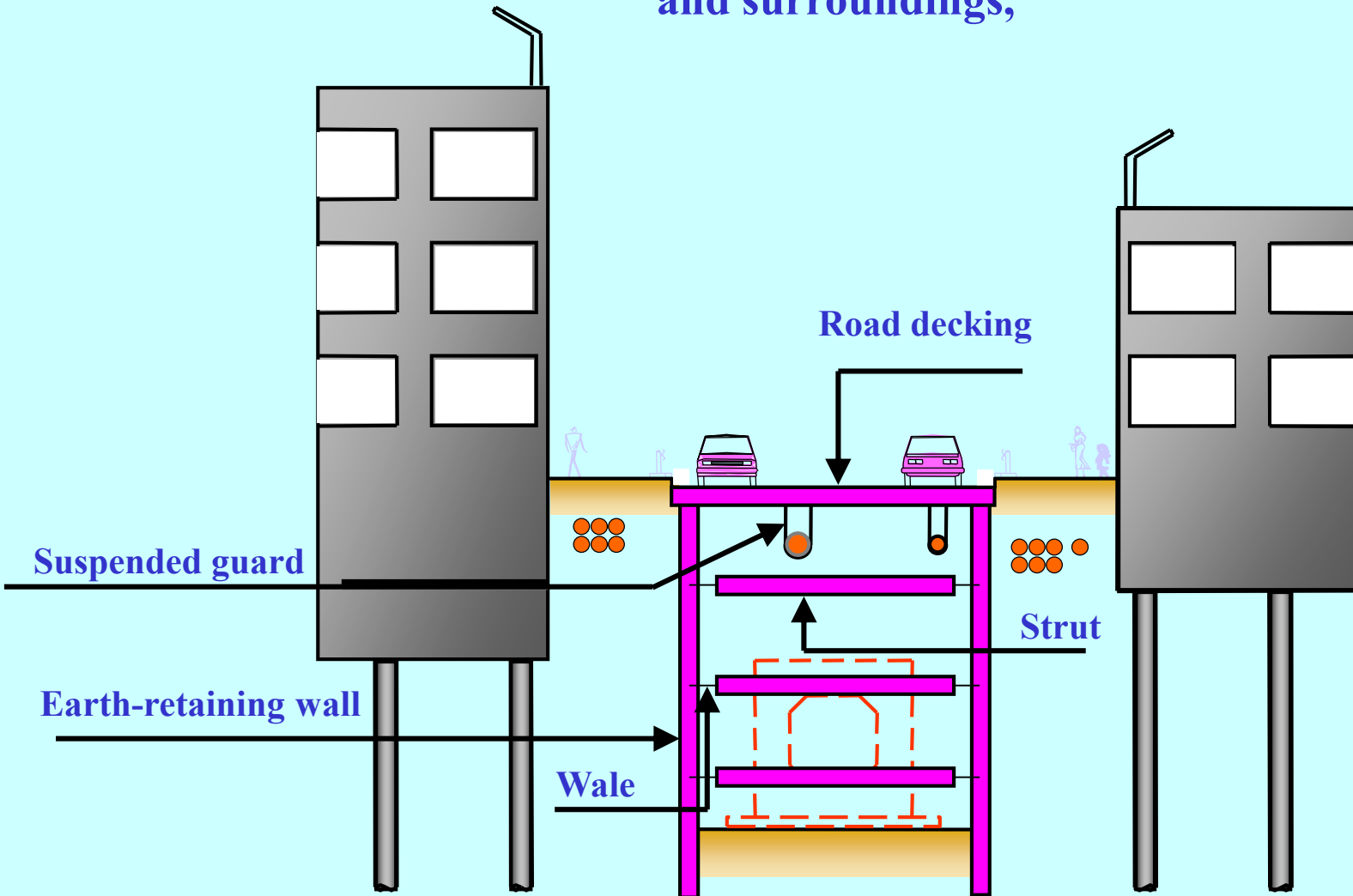


⇒ Open cut method

Cheaper, Faster

When a structure is needed to construct in underground, 3

If there is limitations of the ground surface and surroundings,



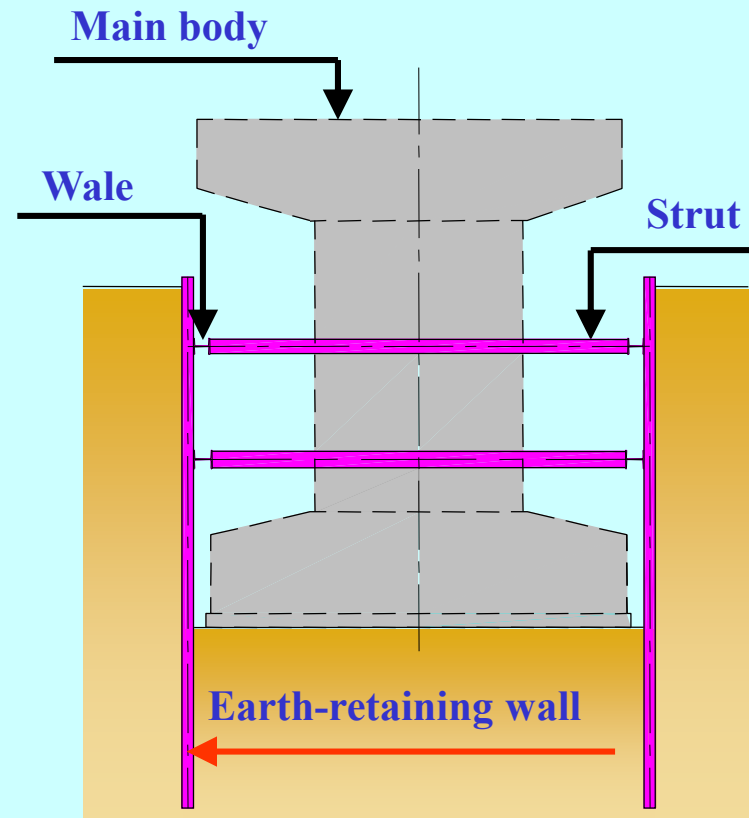
What 's an earth-retaining structure?

>Prevent the collapse of surrounding ground and inflow of ground water.

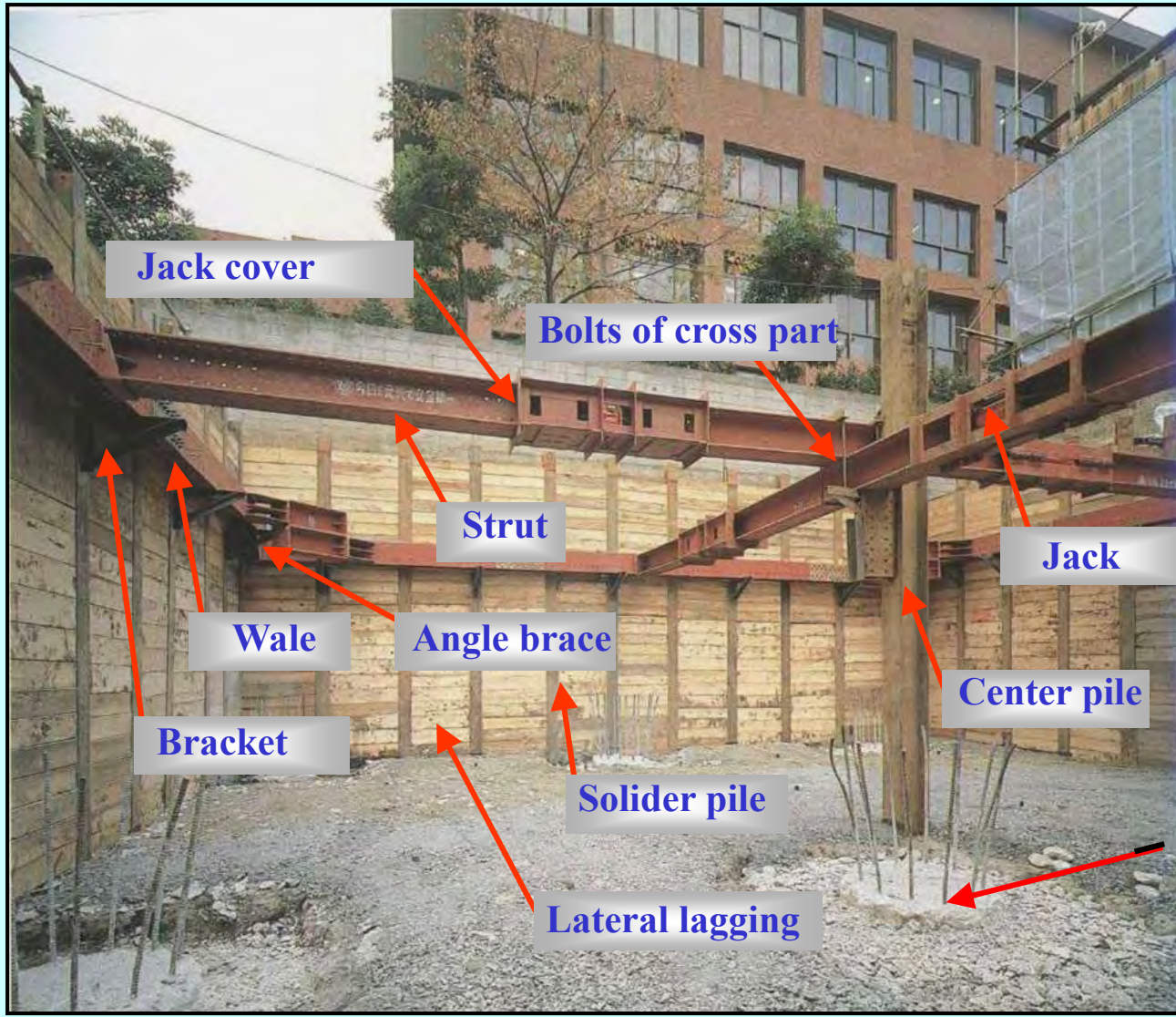
>Compose with retaining wall and support (Strut, wale)

>The structures and construction works are called Earth-retaining structure and earth-retaining support.

An example of retaining wall



Composition of earth-retaining structure (Soldier pile with lateral lagging)



Jack cover

Bolts of cross part

Strut

Jack

Wale

Angle brace

Center pile

Bracket

Soldier pile

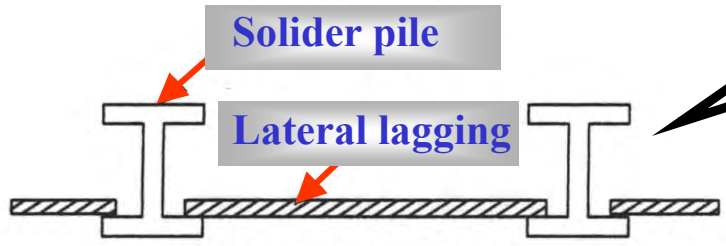
Pile heading

Lateral lagging

Types of earth-retaining wall - 1

An easy method
Cheap
Fast

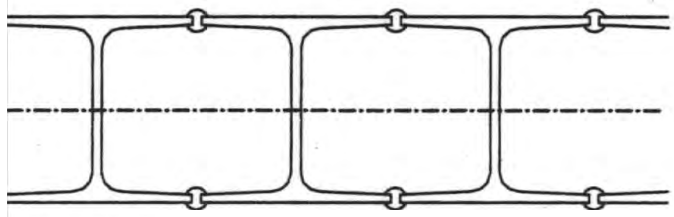
Weak
For shallow tunnel
>-20m



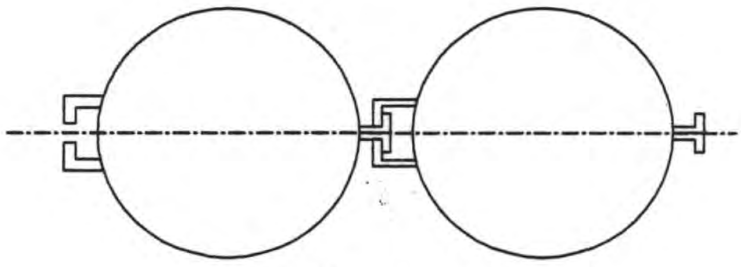
(a) Soldier pile with lateral lagging



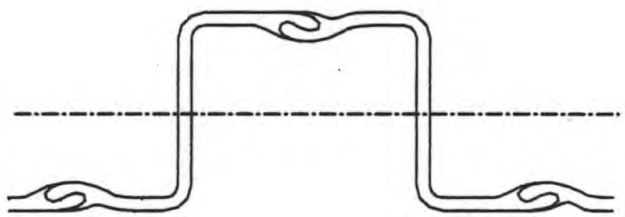
U shaped steel sheeting pile



H shaped steel sheeting pile



(b) Steel pipe sheeting

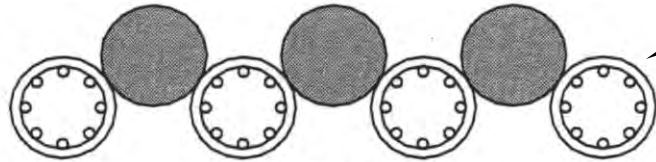


Z shaped steel sheeting pile

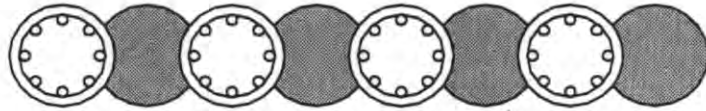
(c) Steel pile sheeting

Types of earth-retaining walls - 2

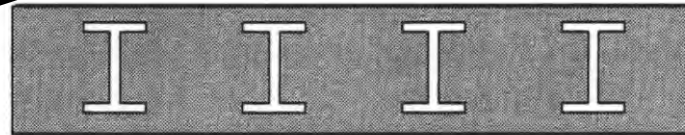
An advanced technology Rigid, Strong
Large scale For deep tunnel
Expensive Colum-type: >-50m
Long time Diaphragm wall: >-150m



Staggered layout



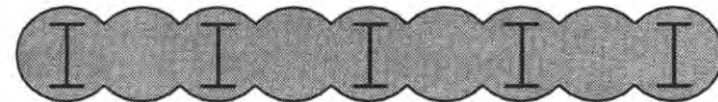
Overlapping layout



(f) Slurry solidified diaphragm wall



Installed in every hole



Installed in alternate hole

(g) Soil-cement diaphragm wall



(e) Underground diaphragm wall

Execution of earth-retaining wall

Soil-cement diaphragm wall

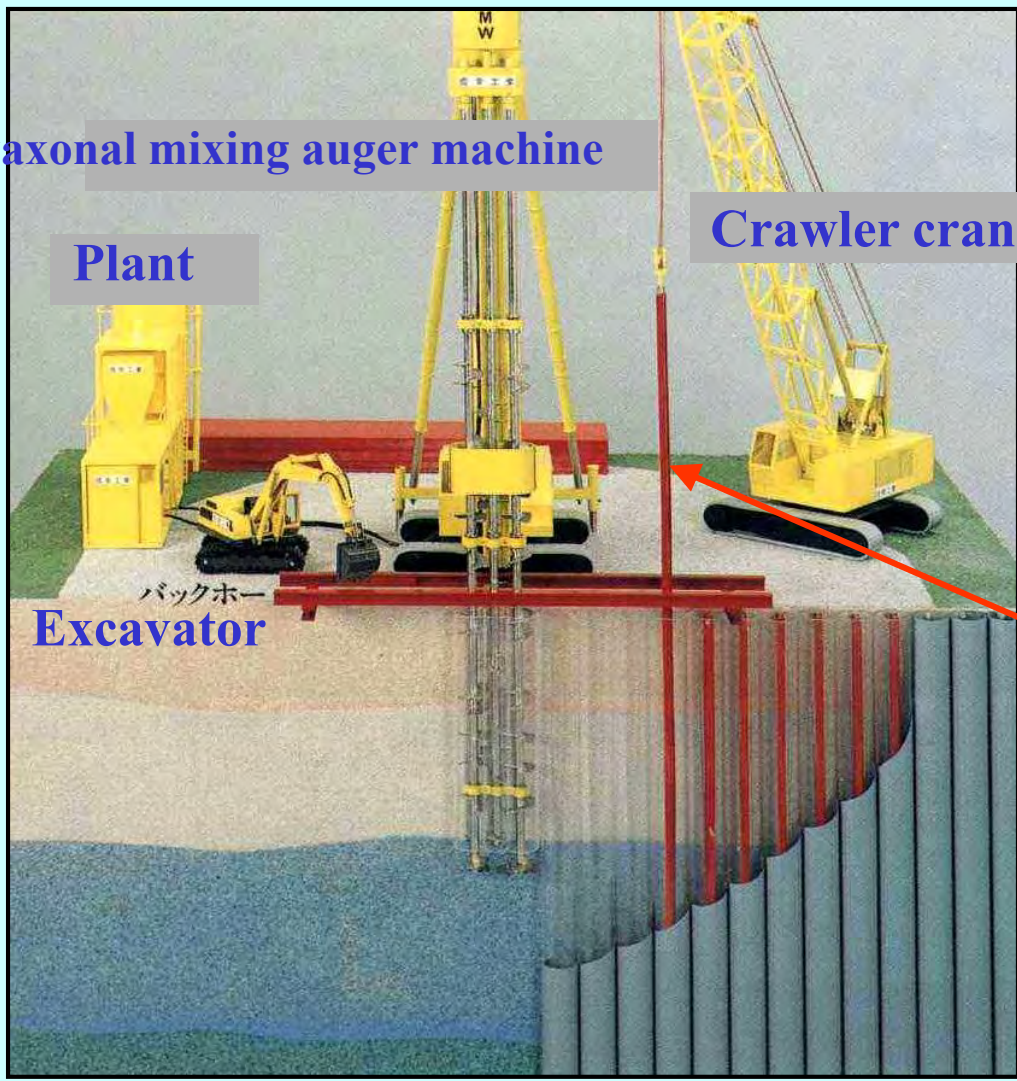
SMW polyaxonal mixing auger machine

Plant

Crawler crane

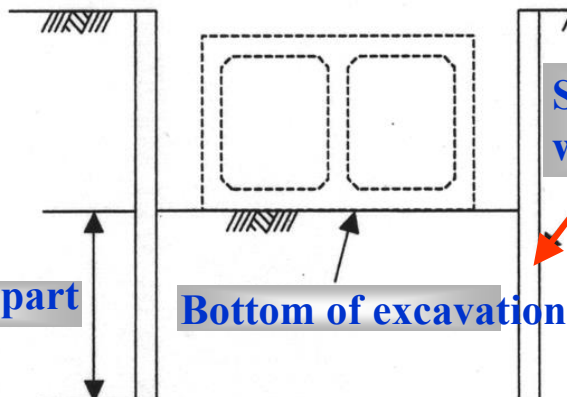
バックホー
Excavator

Corer material
(H-shaped steel)

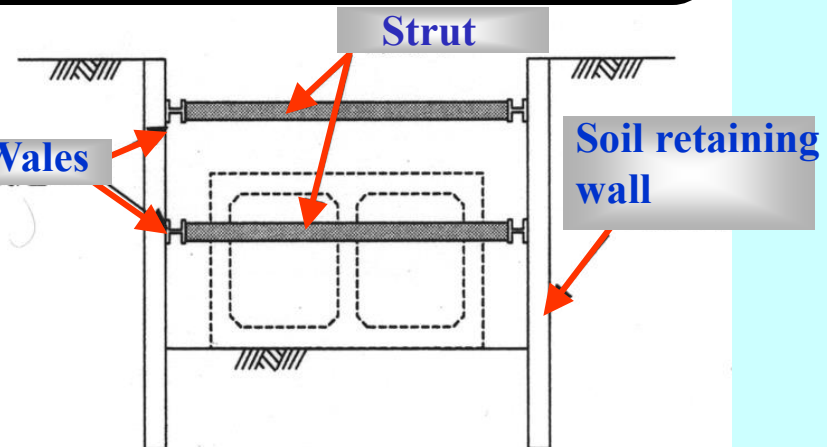


Types of support methods- 1

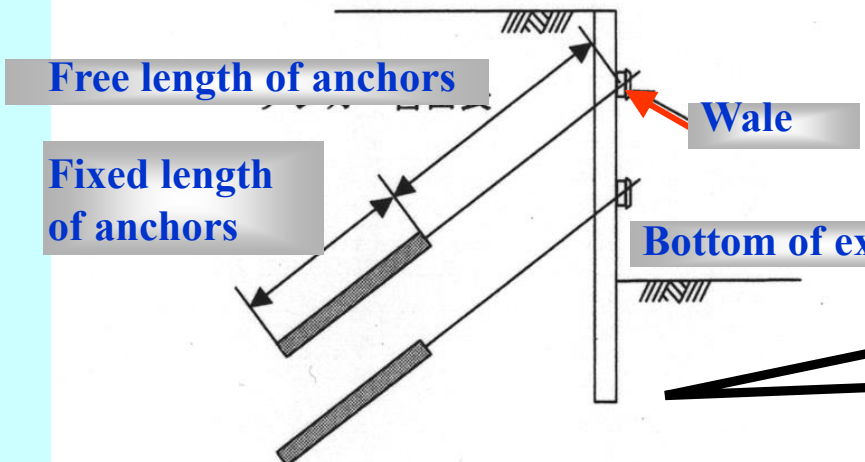
An easy method
 Cheap
 Fast
 For shallow tunnel
 Useful underground space



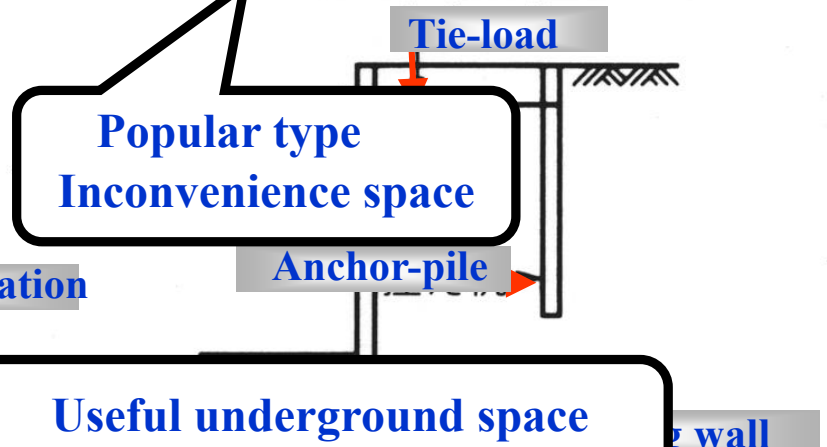
(a) Unbraced soil retaining work



(b) Strut type soil retaining work



(c) Ground anchor soil retaining work



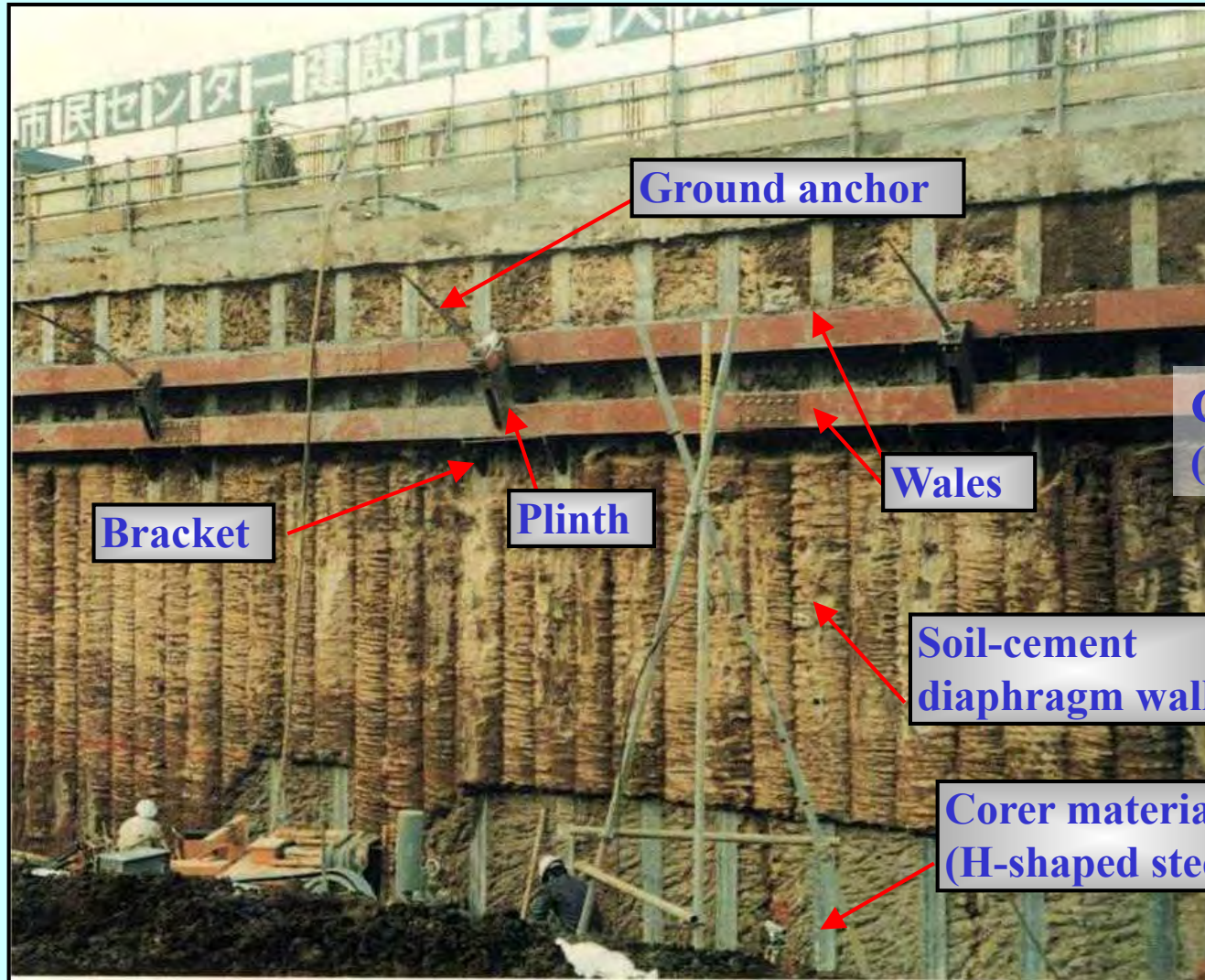
Popular type
 Inconvenience space

Useful underground space
 Land behind the wall is needed

(d) Tie-load with anchor-pile type soil retaining work

Types of support methods- 2

Soil-cement diaphragm wall

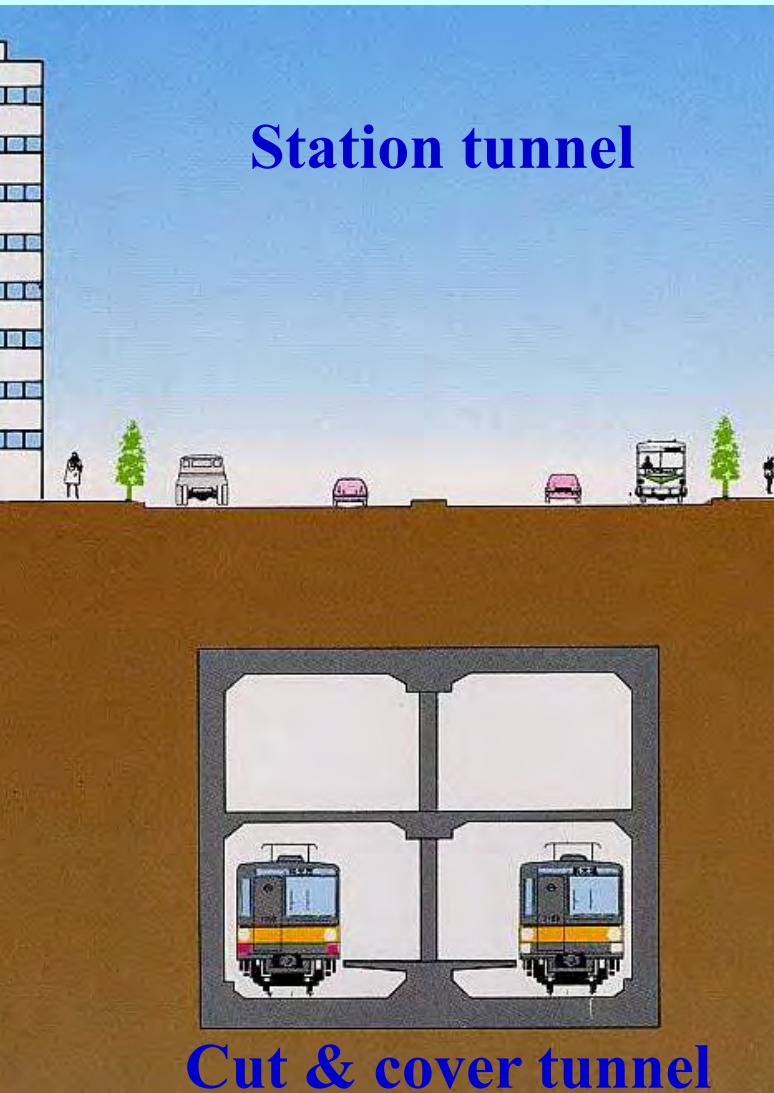


Procedure of cut and cover method

Presented by Tokyo Metro Co.,Ltd.

Standard Structure of a Tunnel

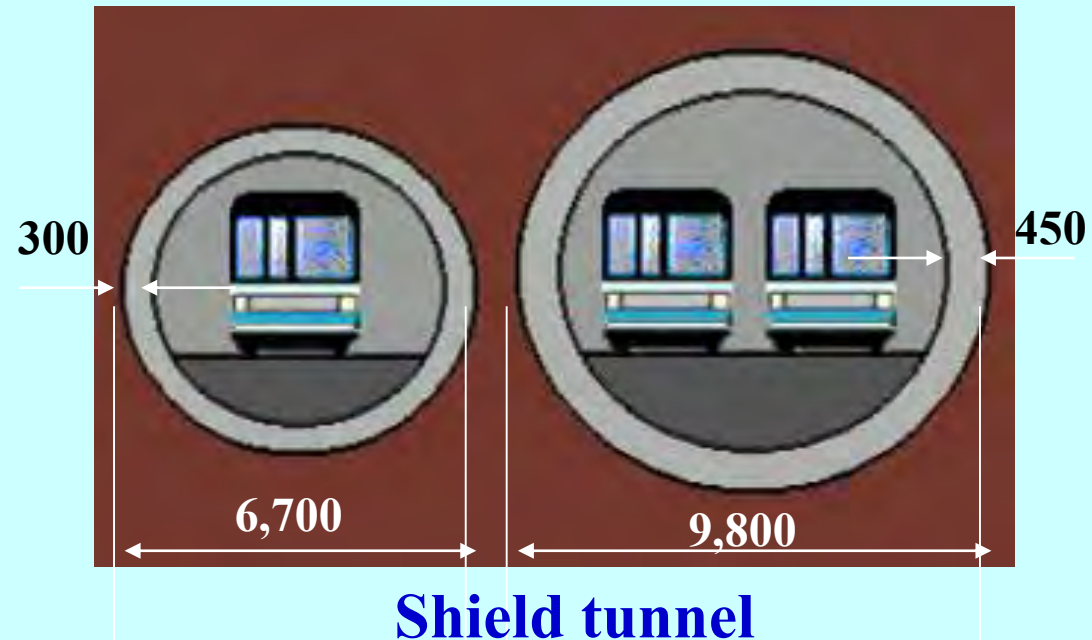
Station tunnel



Running tunnel

Single track

Double track



Cut & cover method

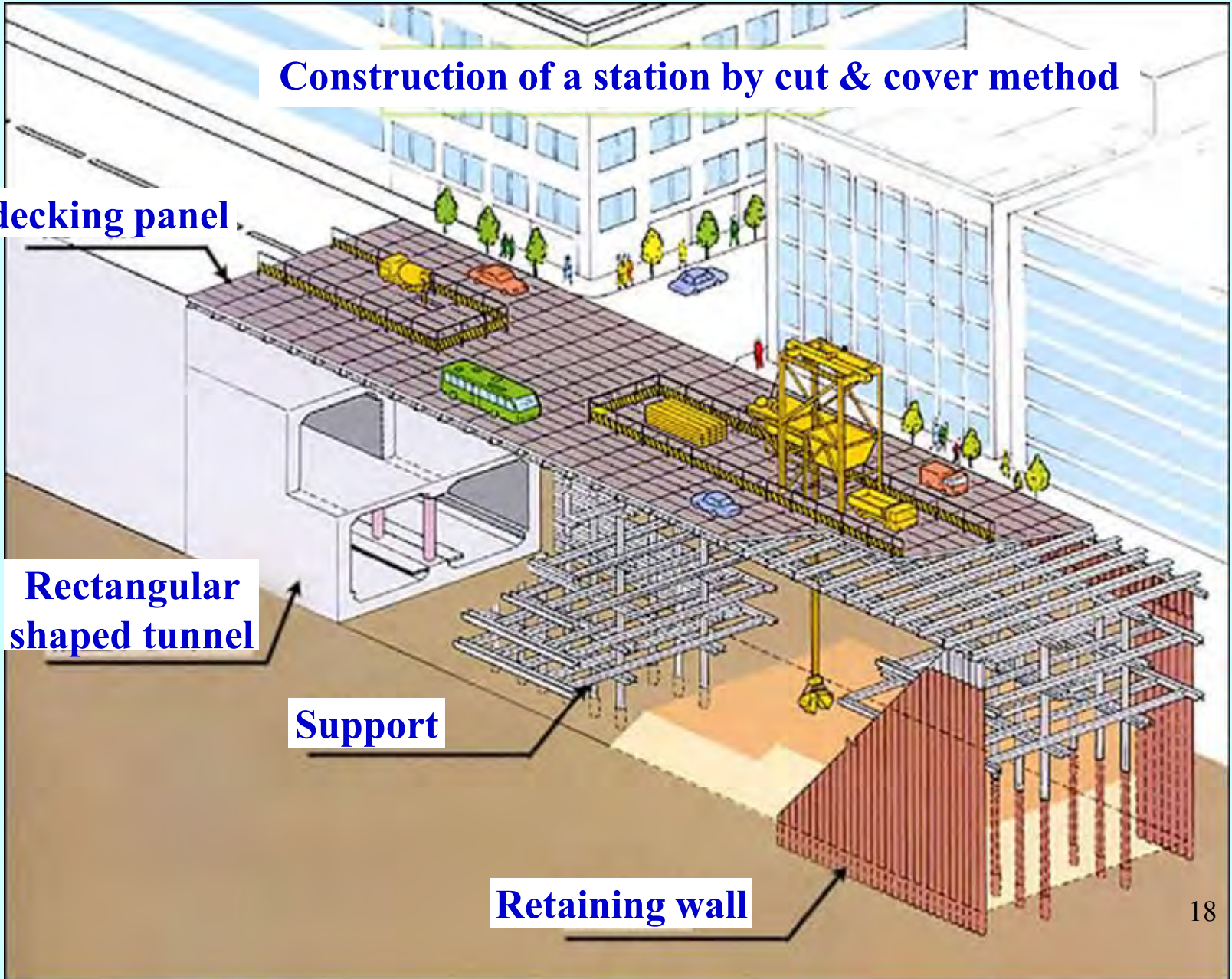
Construction of a station by cut & cover method

Road decking panel

Rectangular shaped tunnel

Support

Retaining wall



Construction Methods of Cut & Cover Tunnel

Standard Construction method

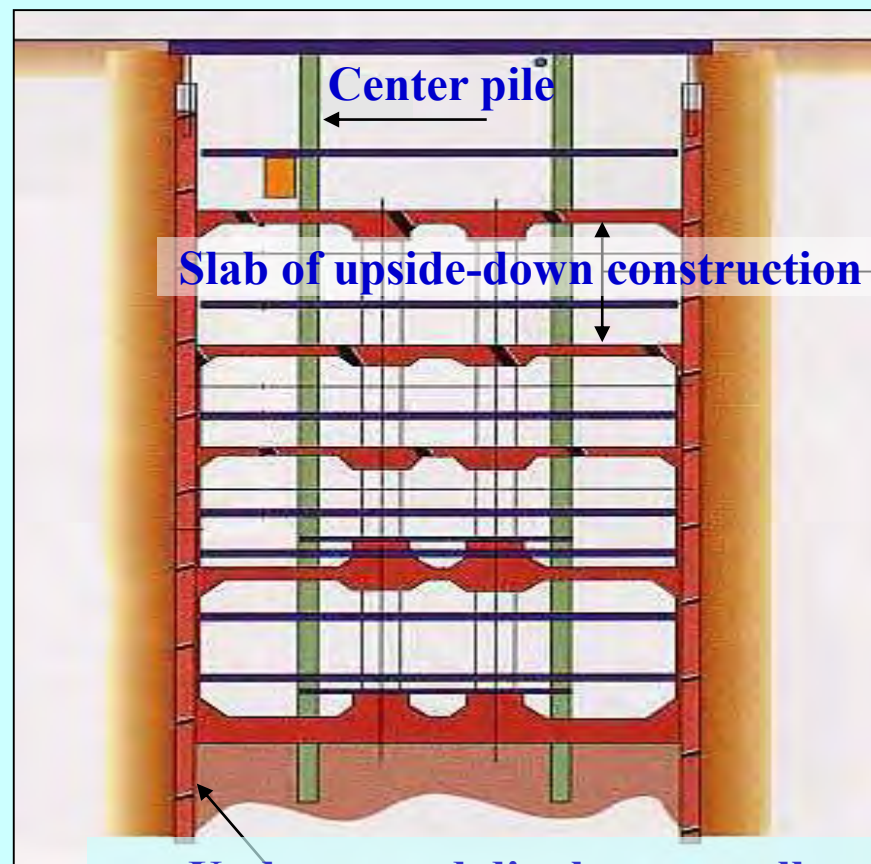
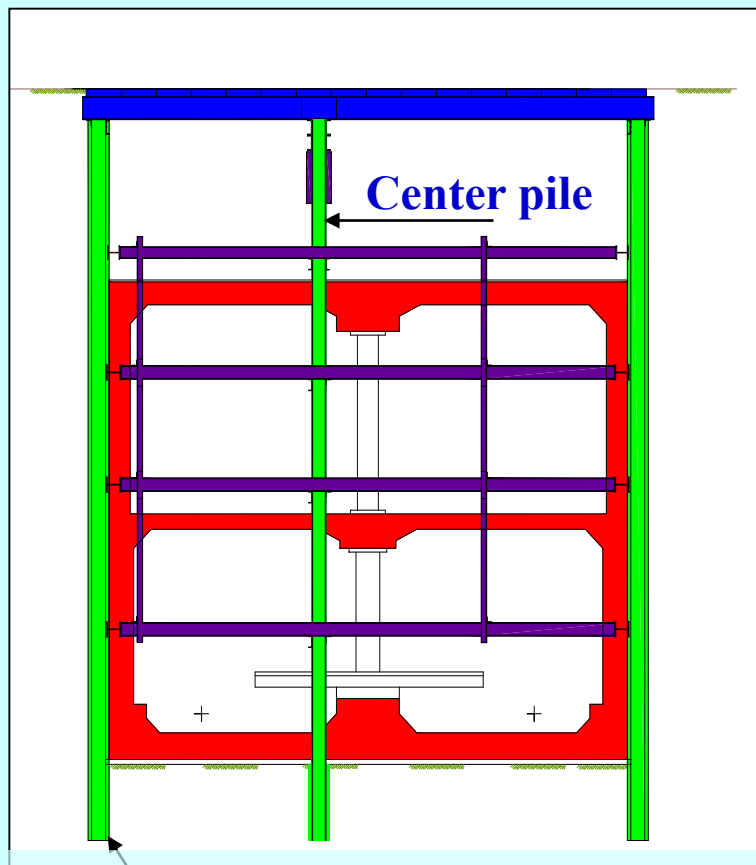
Upside-down Construction method

Stiff ground

(Simple procedure)

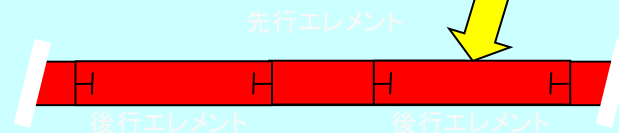
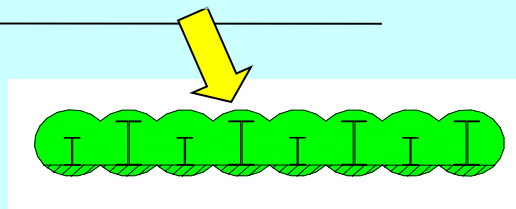
Soft ground

(Complex procedure)



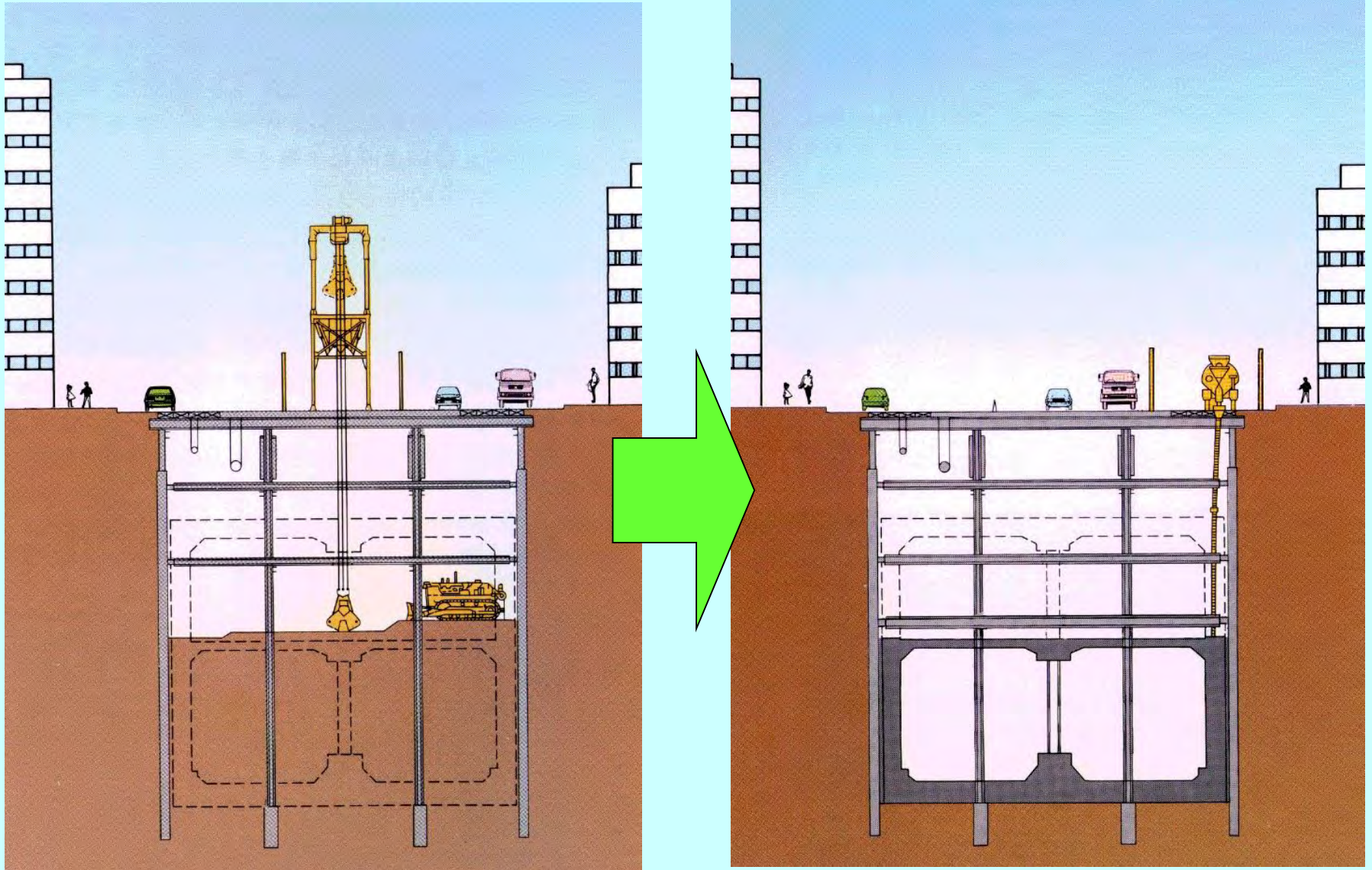
Column-type underground diaphragm wall

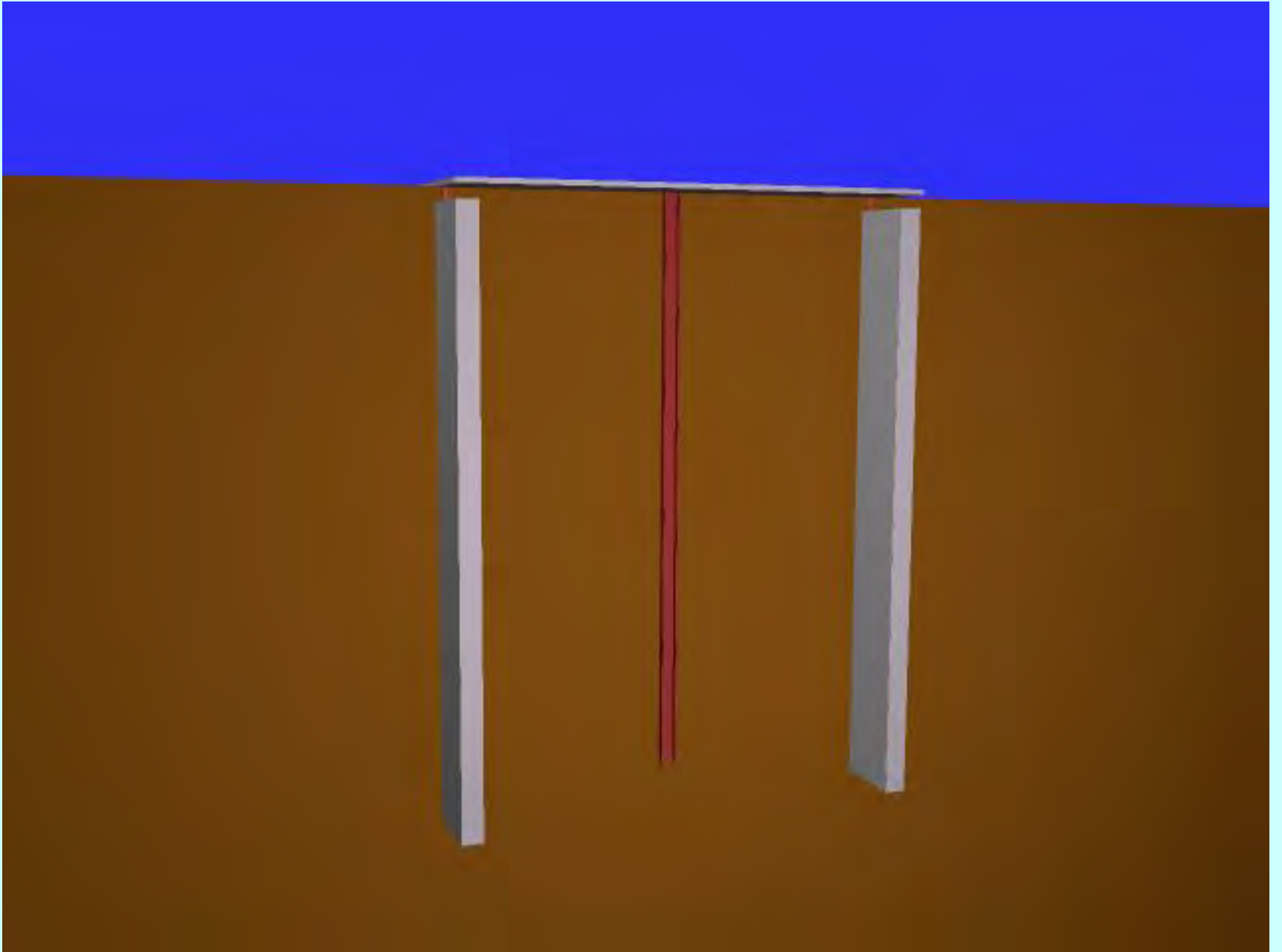
Underground diaphragm wall

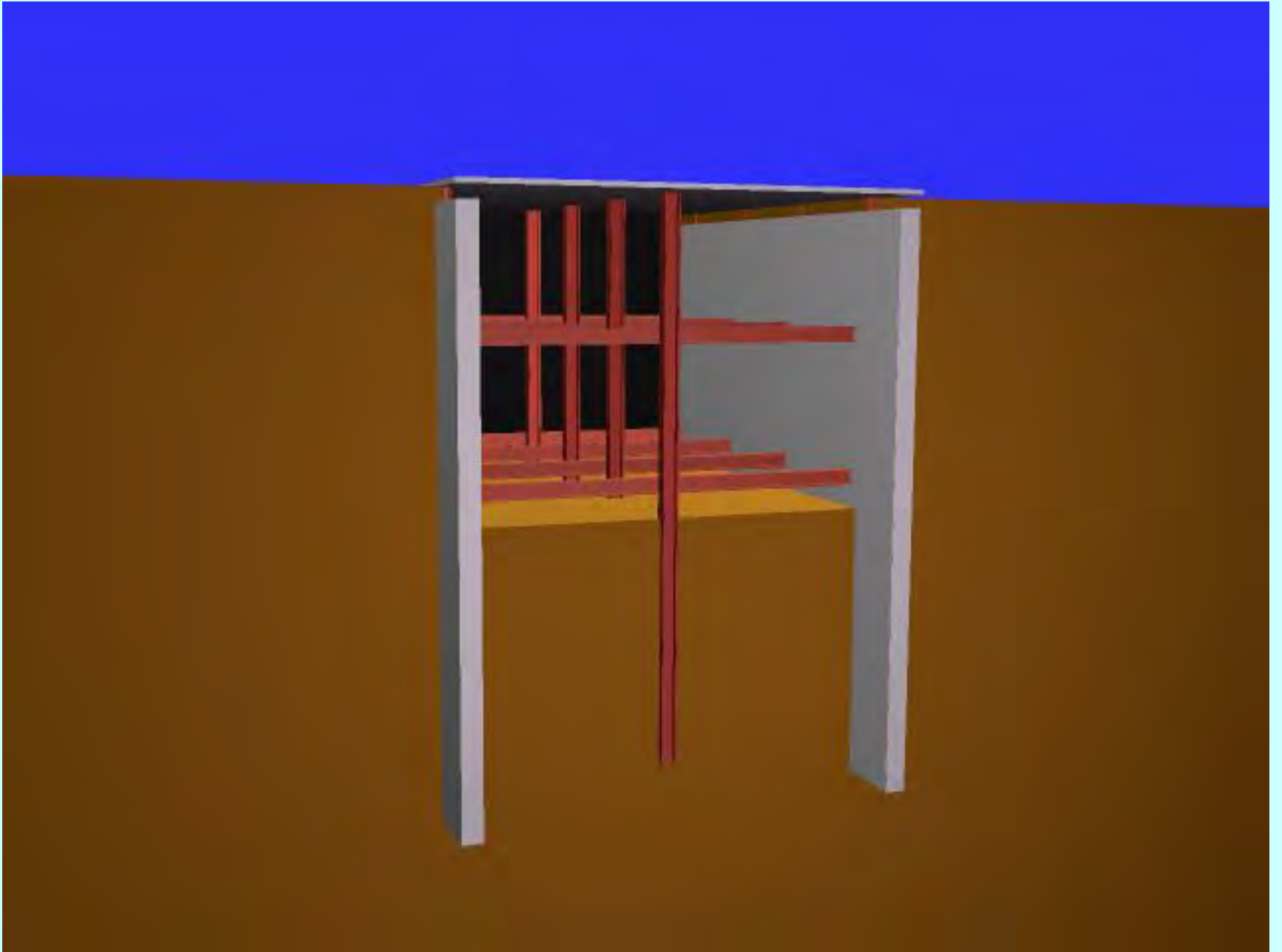


Standard construction method

Excavate from surface to bottom. Then, construct the body.



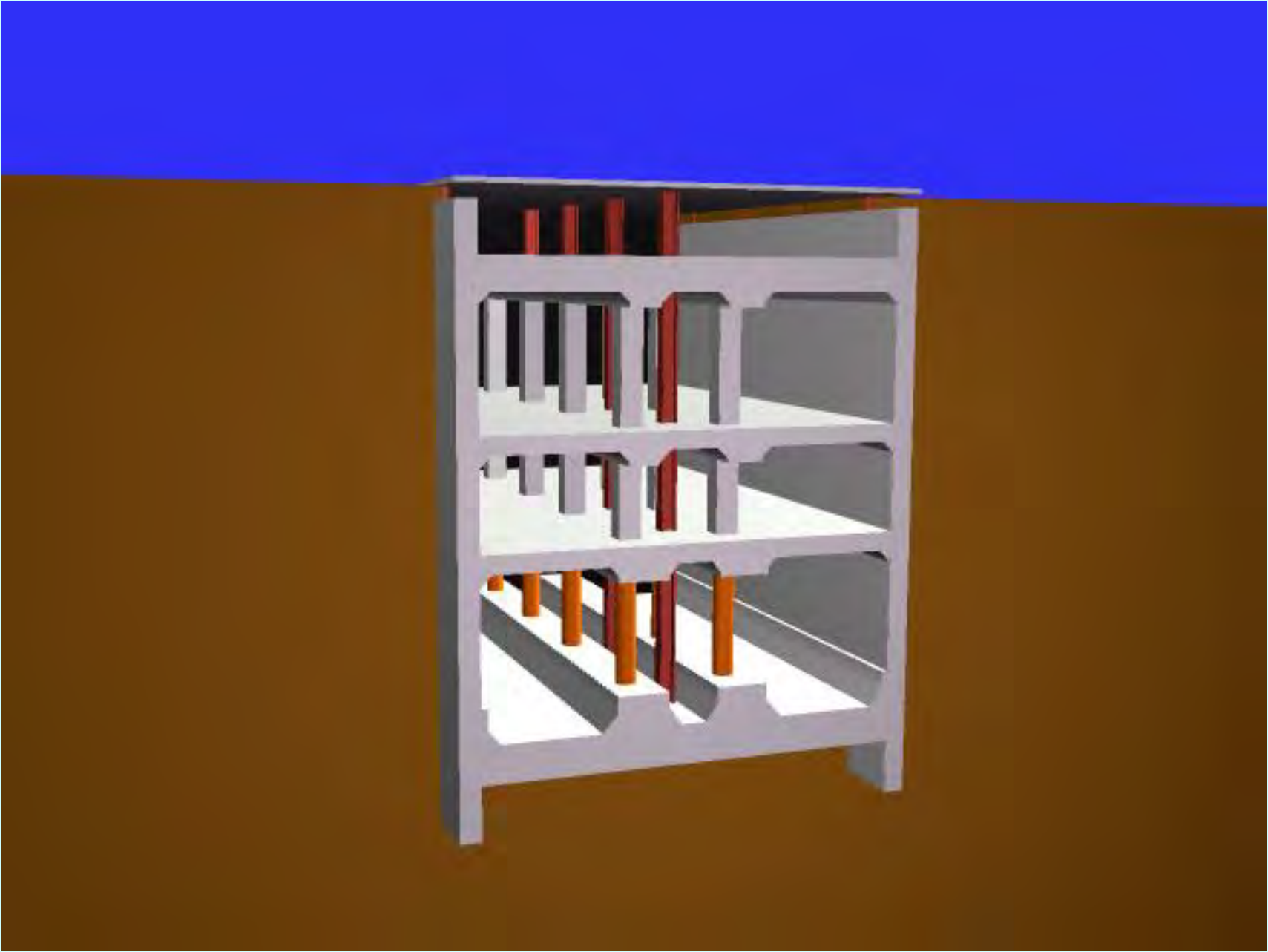


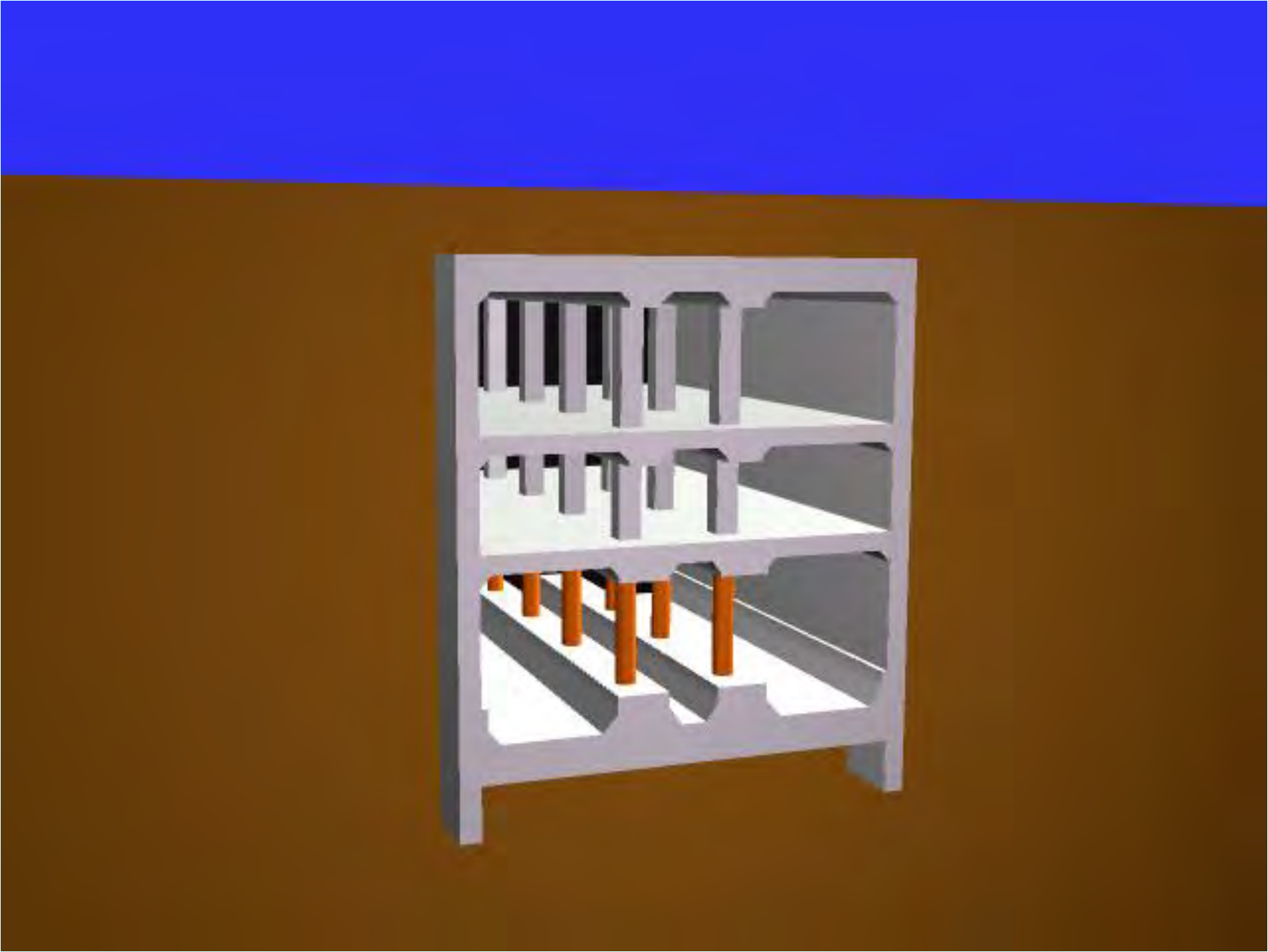












Upside-down Construction Method

- A slab is constructed in advance, because it is used for a high-rigid strut restraining deformation of the retaining wall.
- The method is applied in the case of construction in the soft ground or with deep excavation.
- If the upper floor slab is constructed by the method, it is advantageous to back fill in early stage.



10:40~12:10

Road decking panel

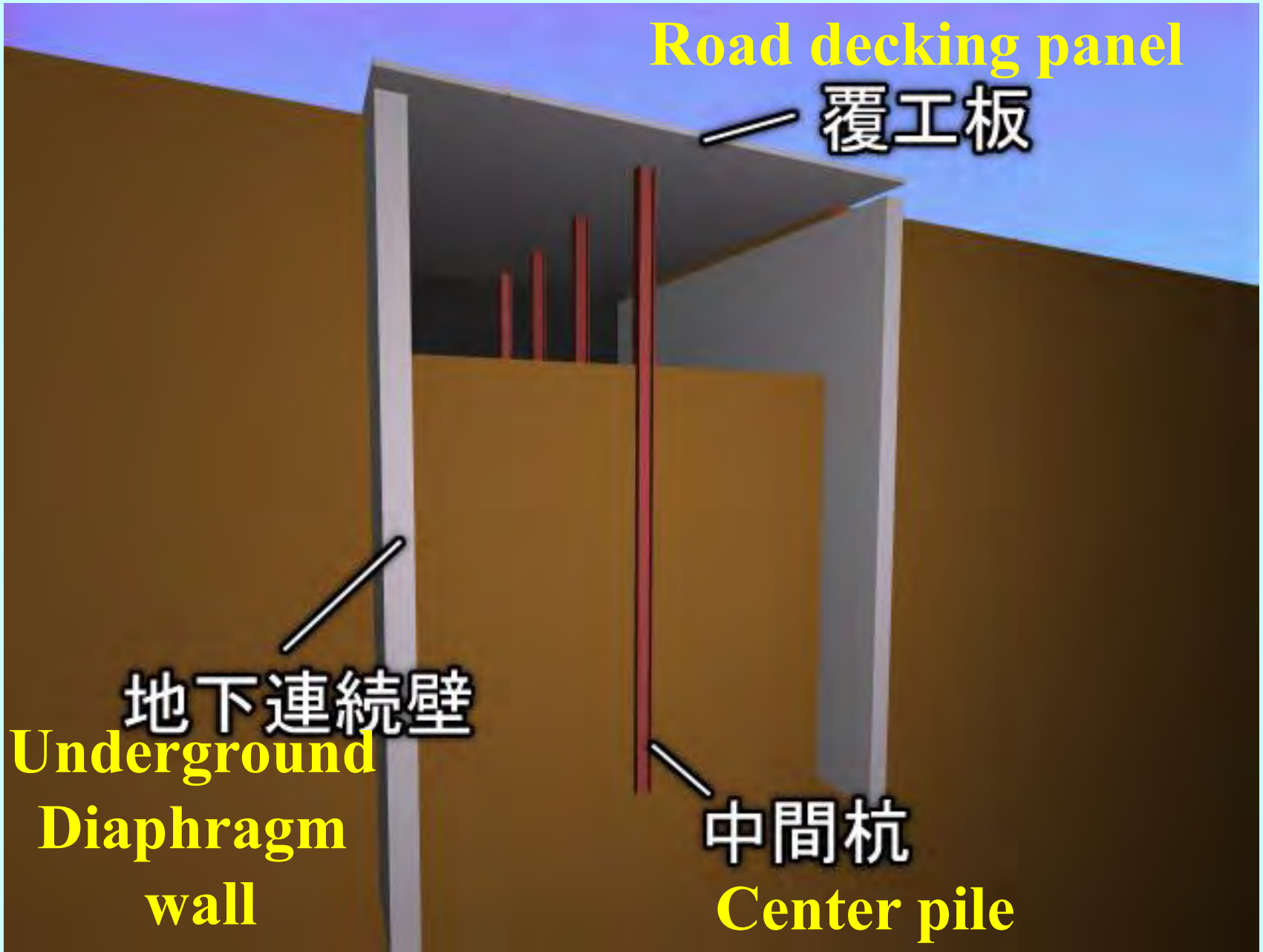
覆工板

地下連続壁

Underground
Diaphragm
wall

中間杭

Center pile





上床版

Upper
Floor Slab

Construction
of the upper
floor slab

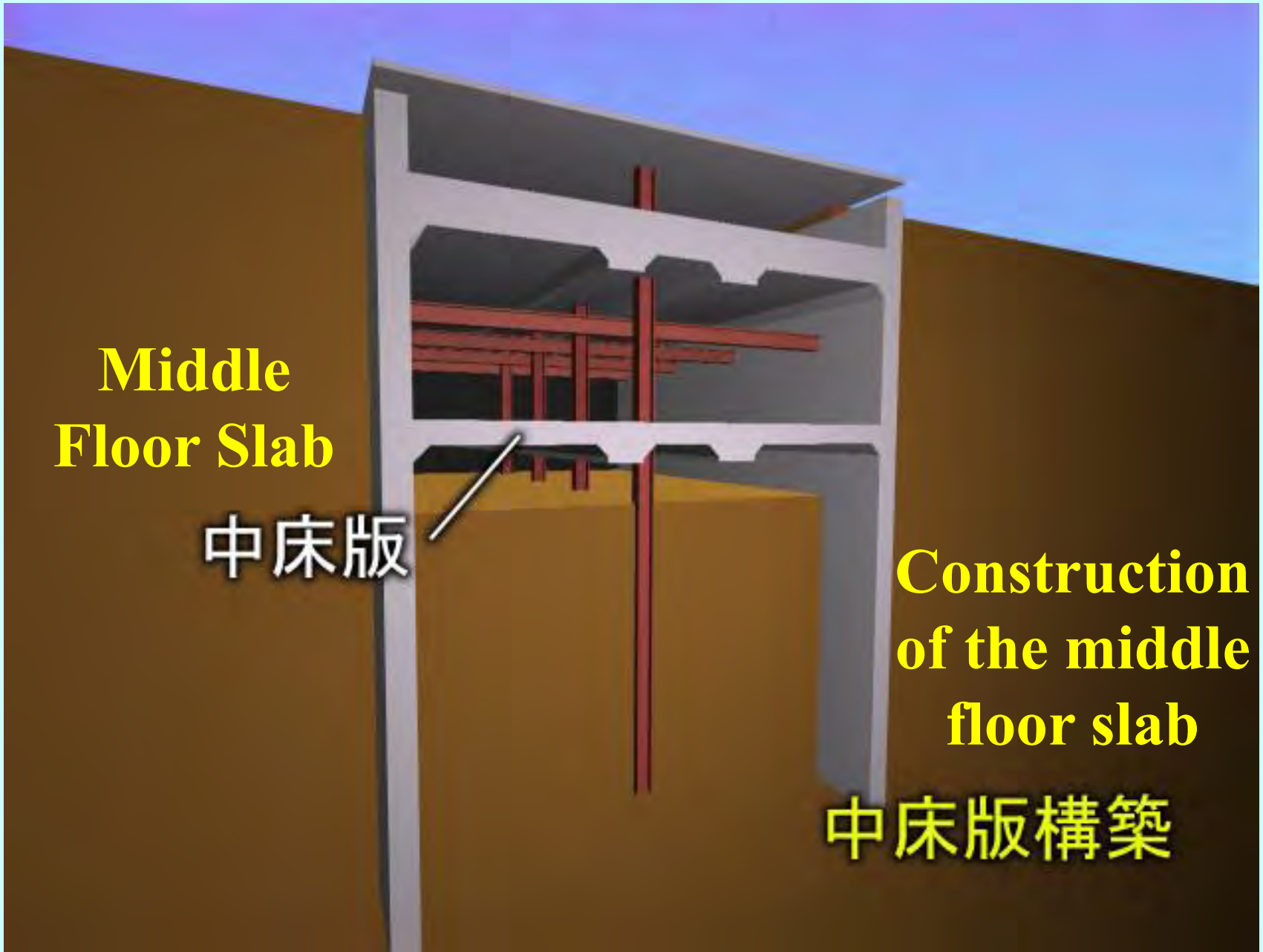
上床版構築

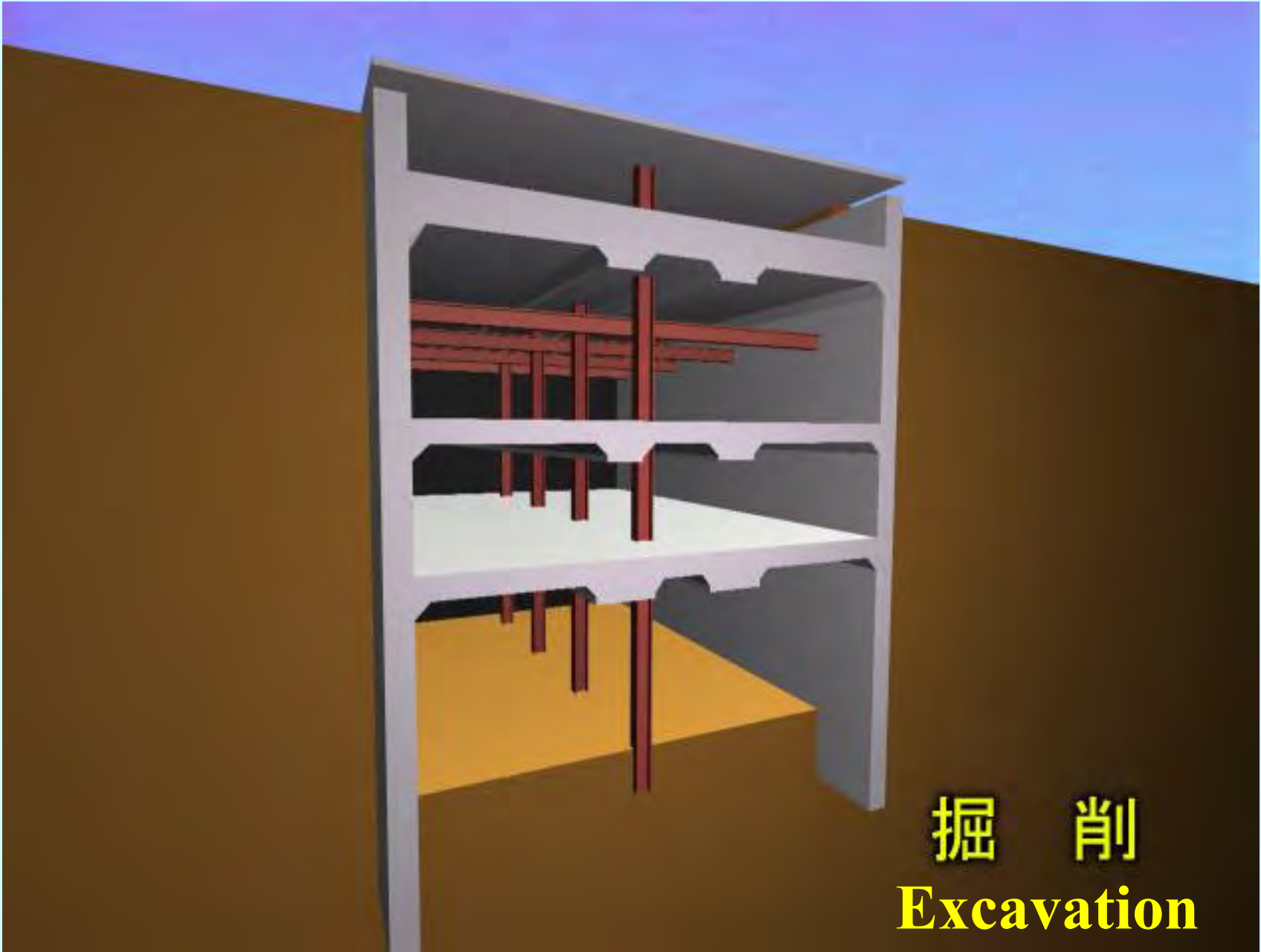
**Middle
Floor Slab**

中床版

**Construction
of the middle
floor slab**

中床版構築





掘削
Excavation

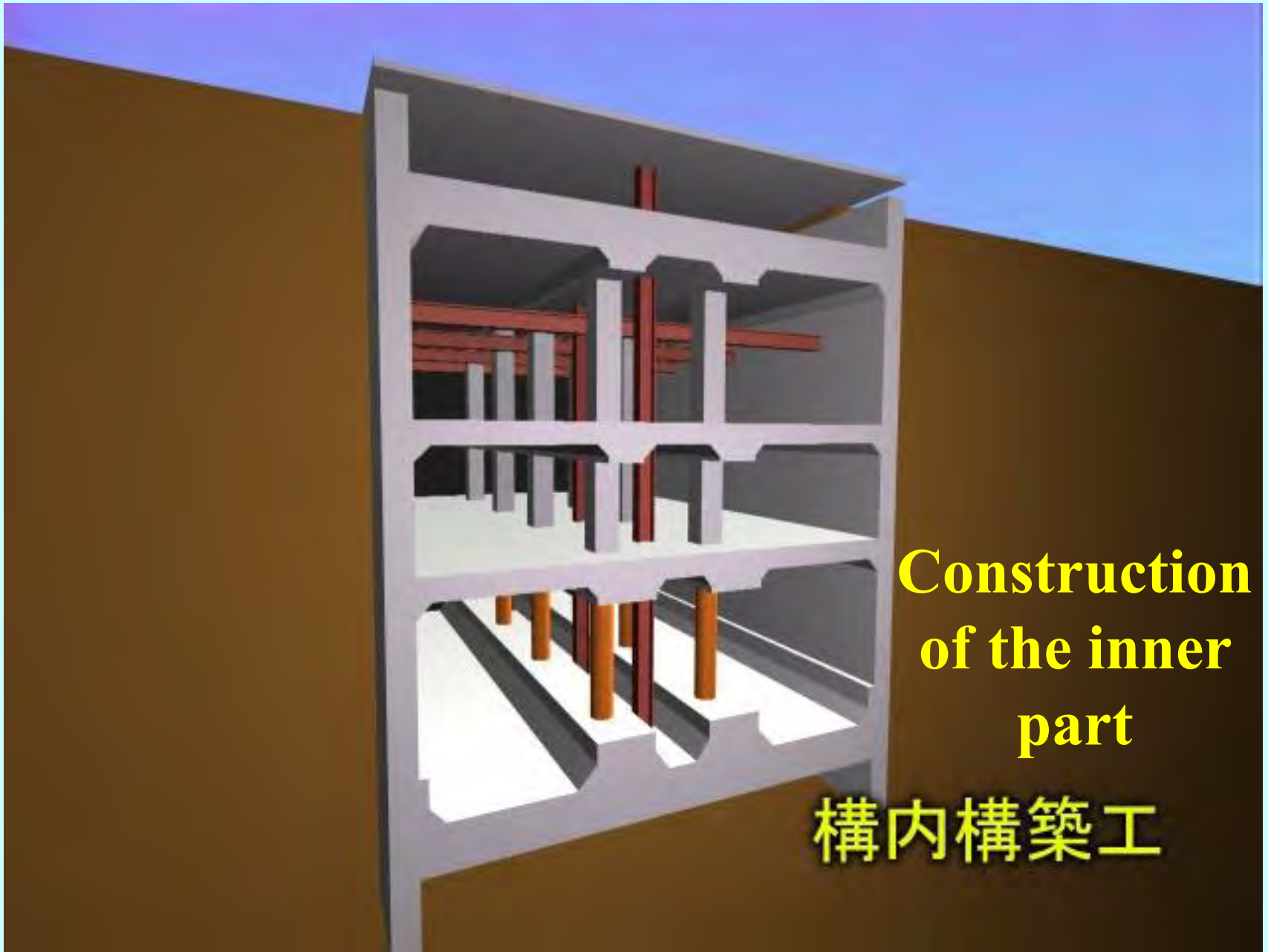


Base Slab

下床版

**Construction
of the base
slab**

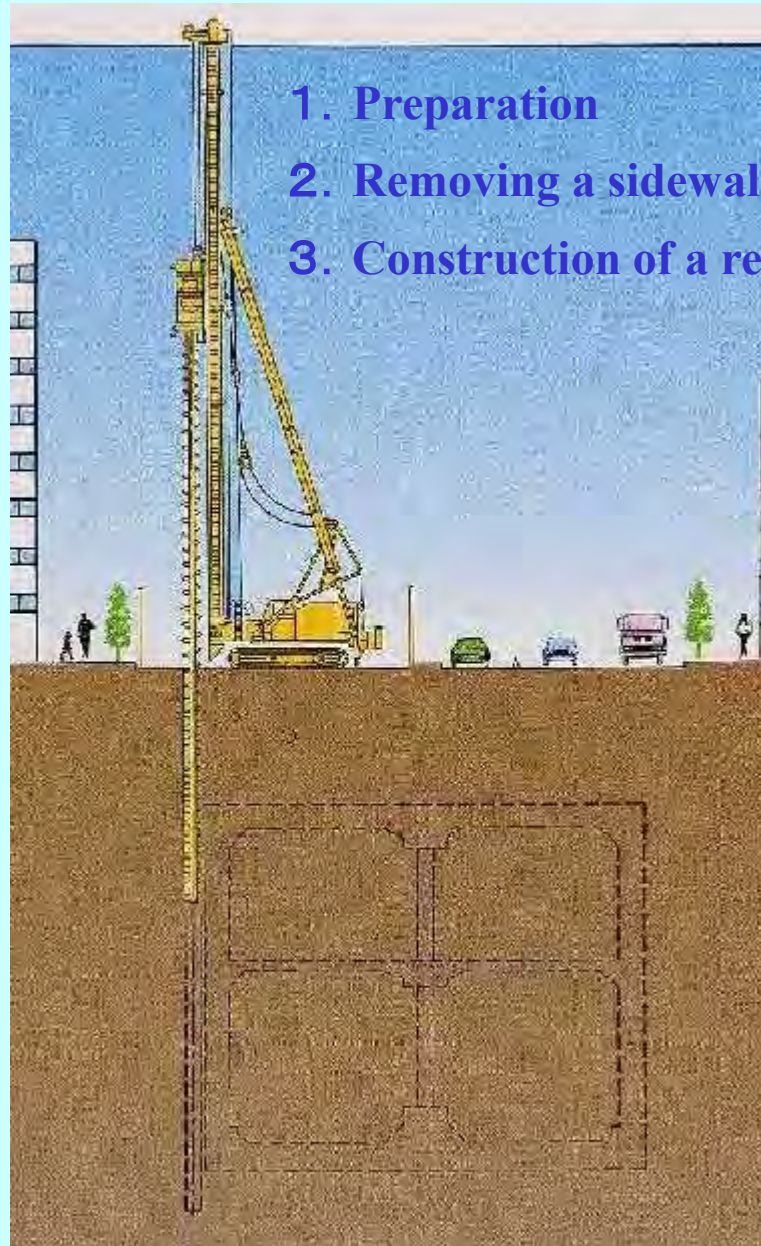
下床版構築



**Construction
of the inner
part**

構内構築工

Procedure 1 of a cut & cover method-1

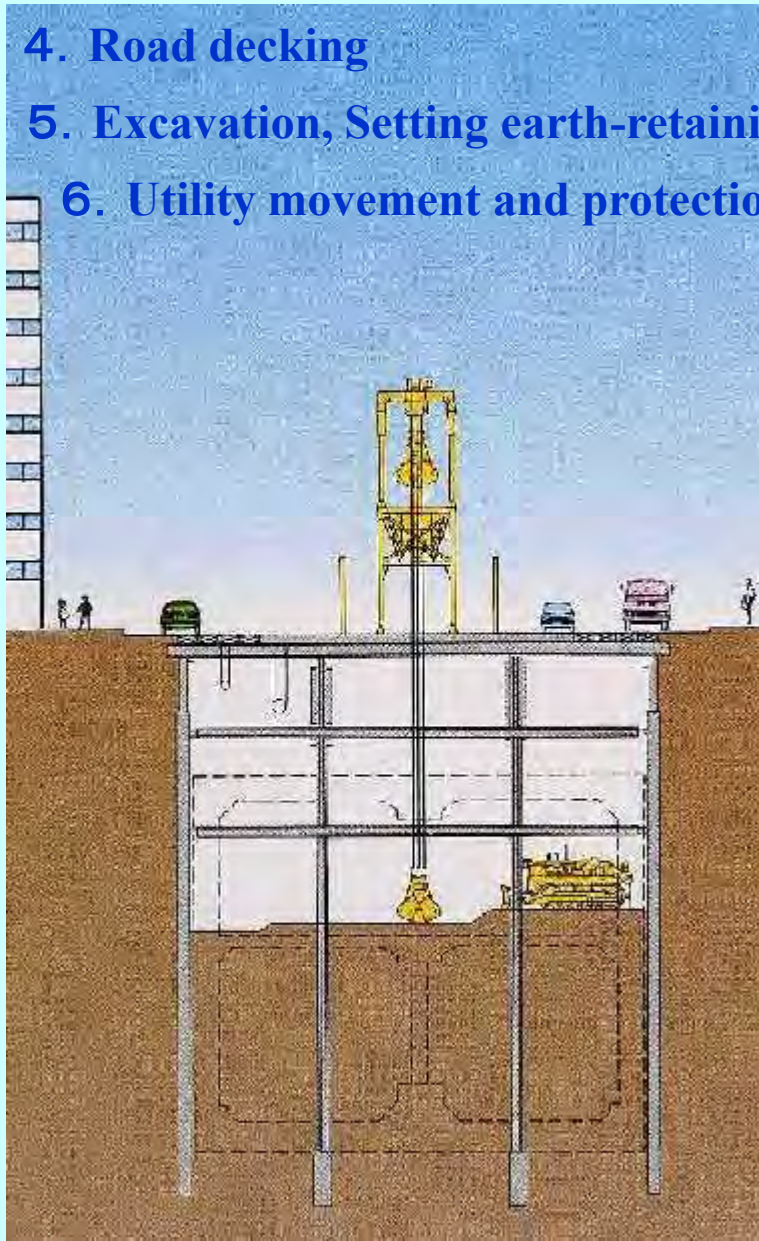


Procedure 2 of a cut & cover method-2

4. Road decking

5. Excavation, Setting earth-retaining support

6. Utility movement and protection



Excavation under a road decking



Carrying out the muck-1.



Carrying out the muck-2.

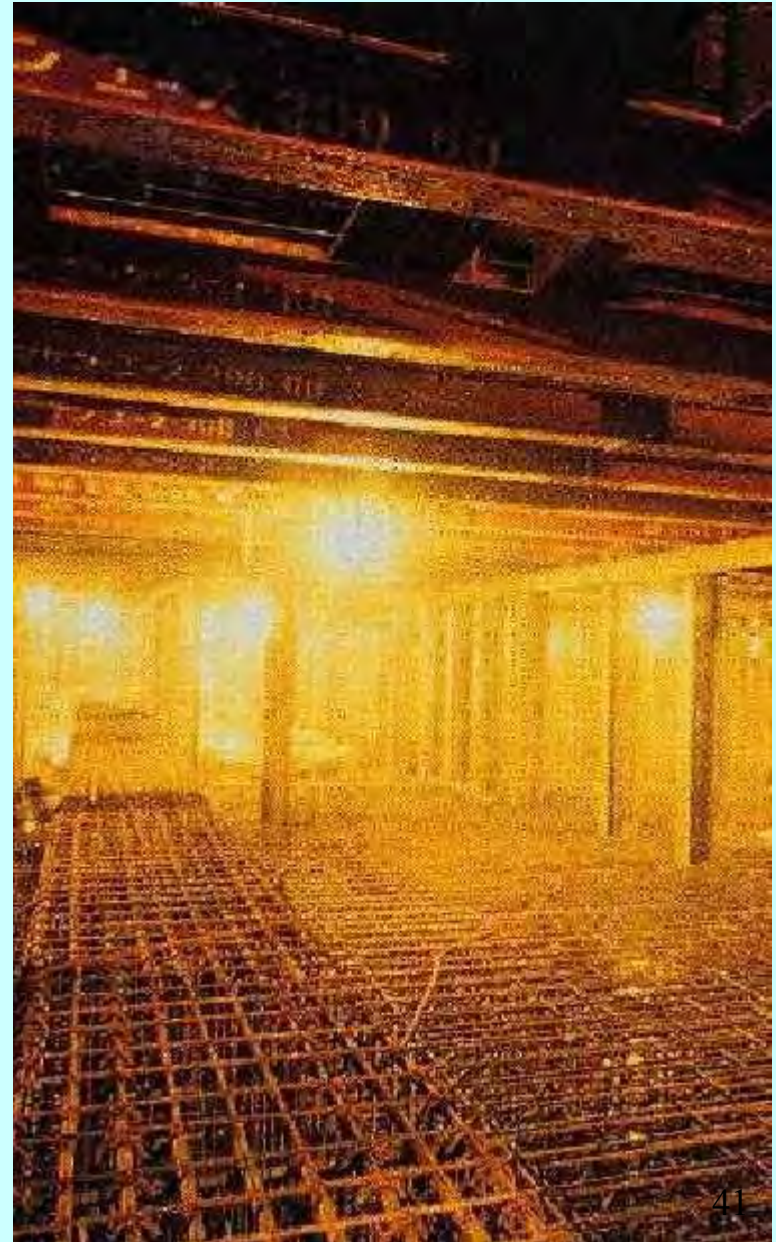
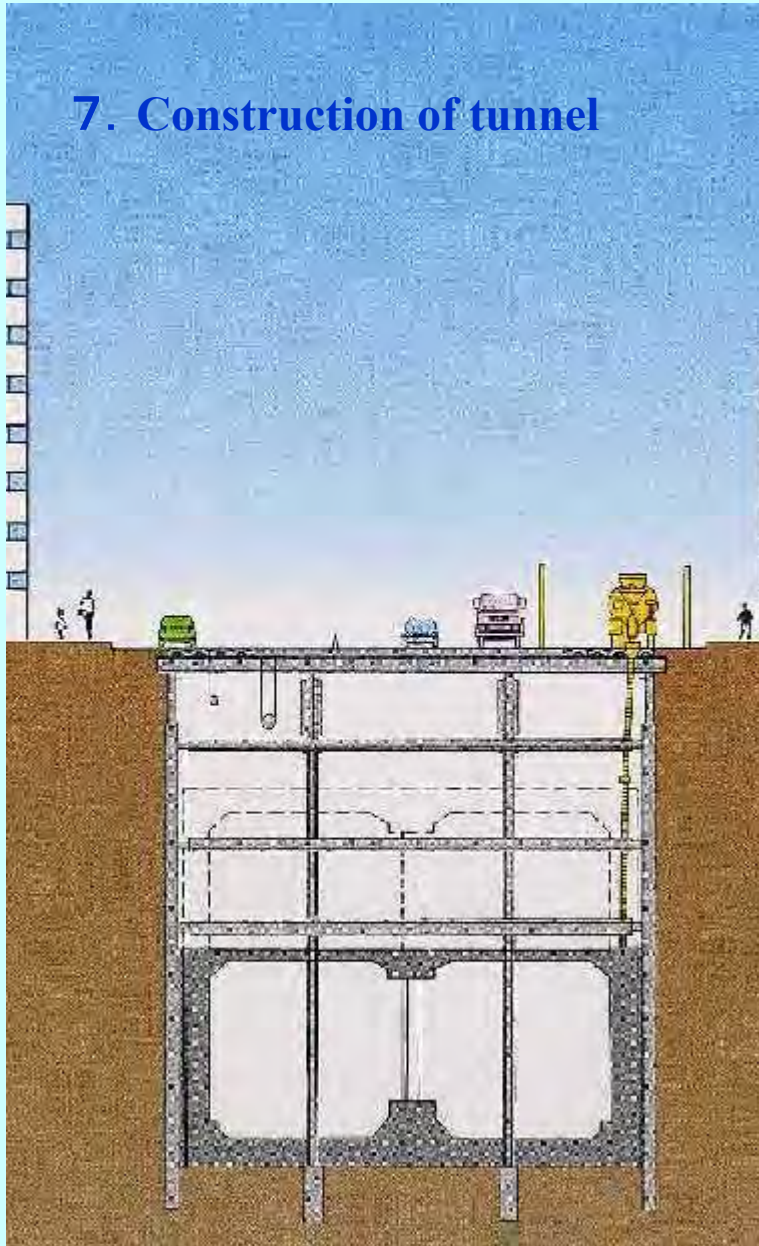


Setting supports, Slab of upside-down construction



Procedure 3 of a cut & cover method-3

7. Construction of tunnel

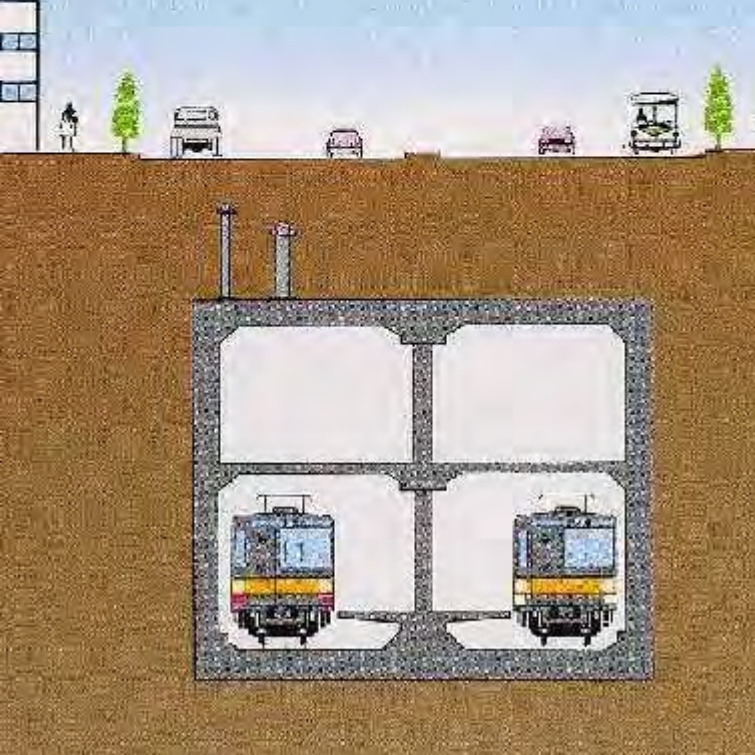


Placing concrete



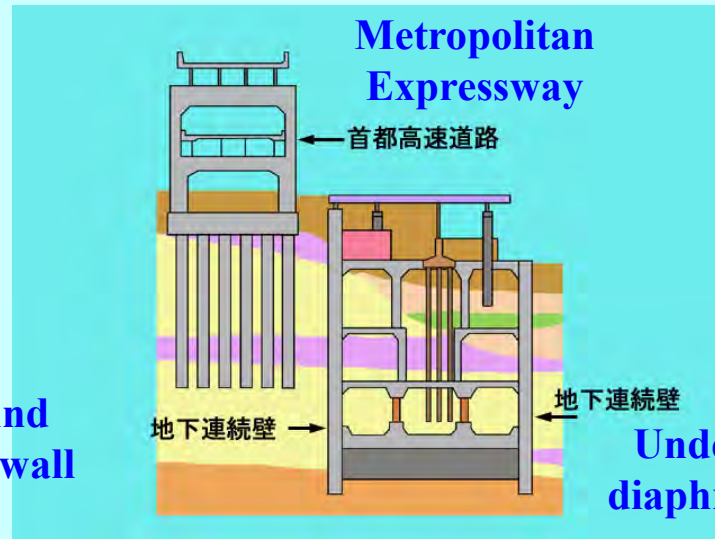
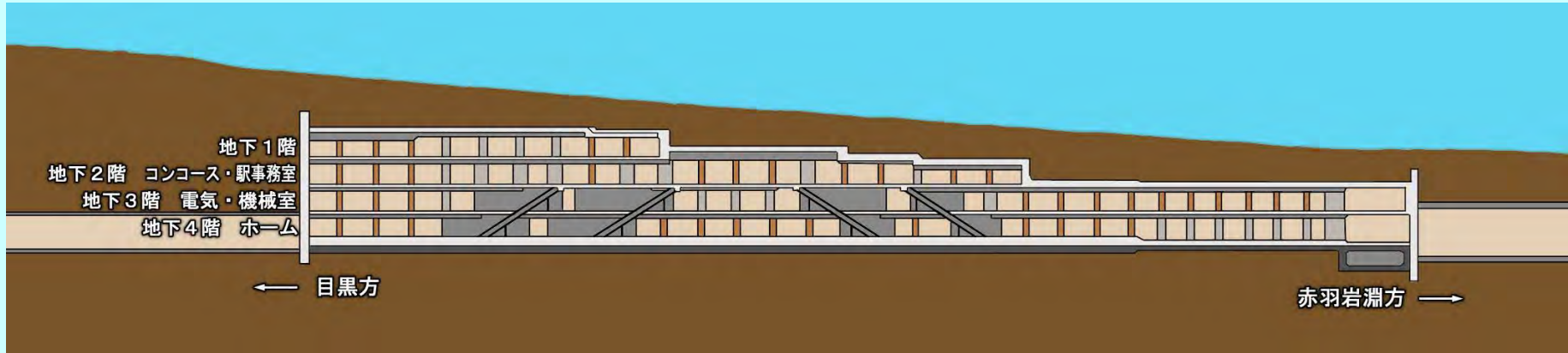
Procedure of a cut & cover method-4

8. Restoration of the utilities
9. Back filling
10. Removal of the road decking
11. Removal of heading part of piles
12. Restoration of the road
13. Setting facilities



An example of the special cut & cover method

Nanboku line Roppongi-ichome station

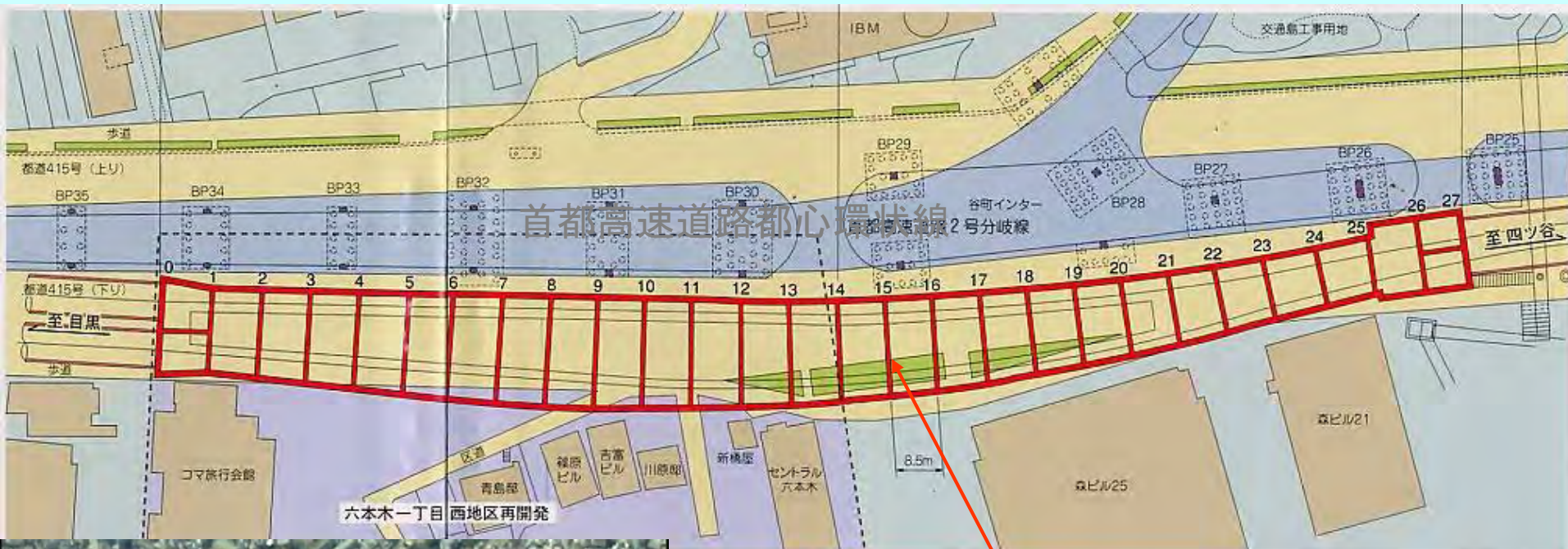


Underground diaphragm wall

Underground diaphragm wall

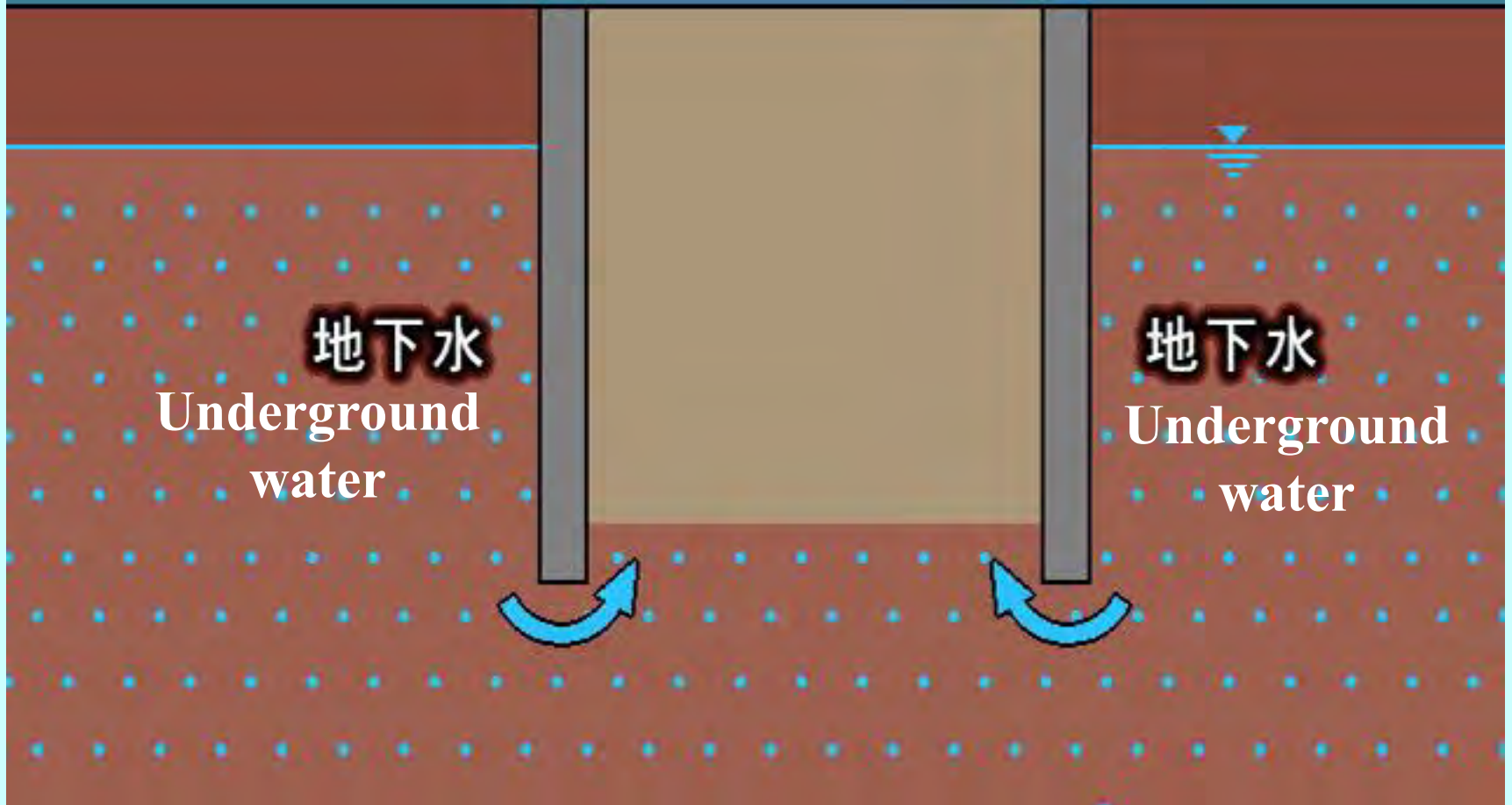
Viaduct of Metropolitan Expressway is close to new station.

Plan view of the Roppongi-ichome station



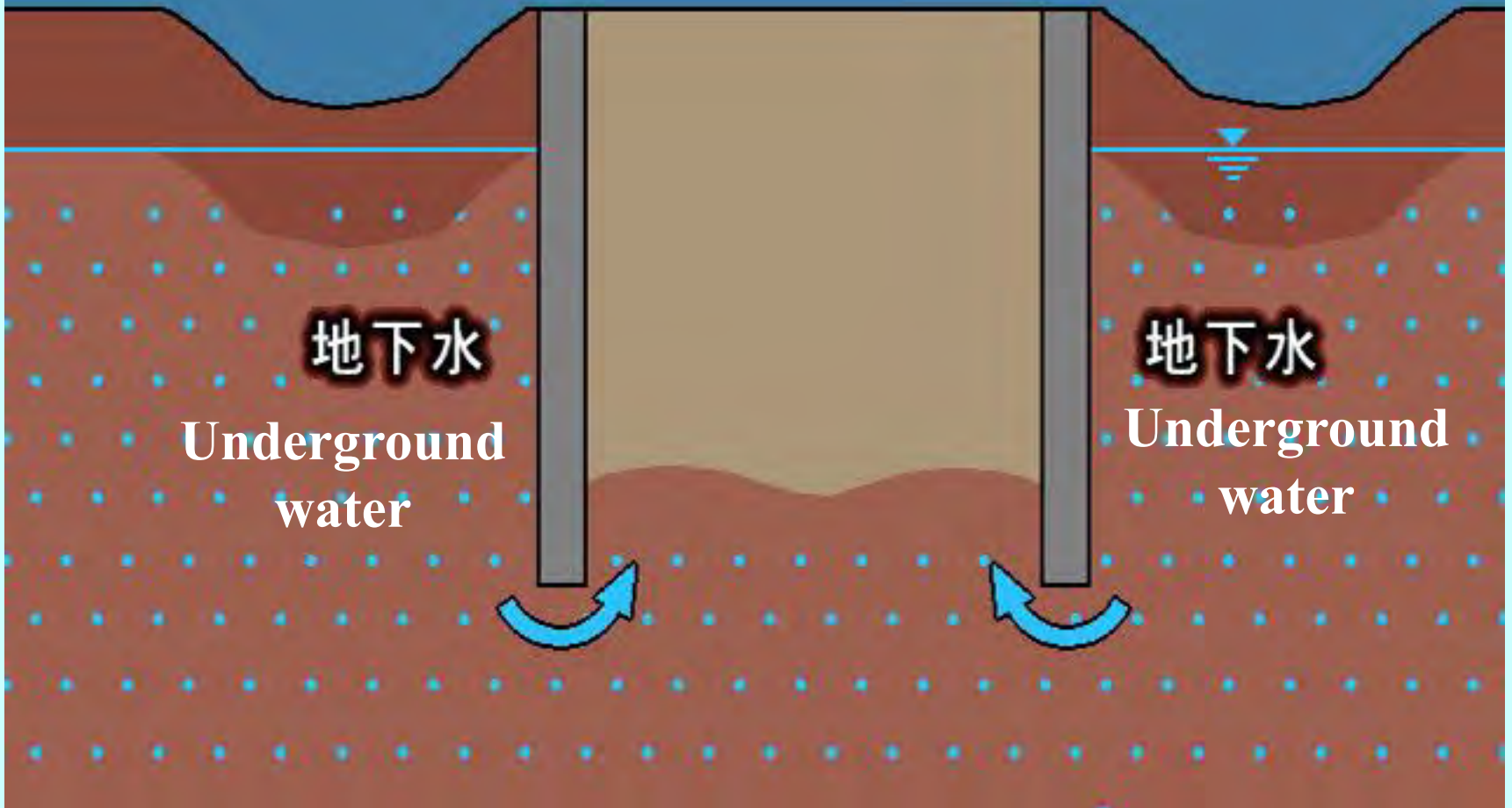
**Cross underground
Diaphragm wall**

In the case of existing underground water with high pressure, if you excavate lower part of below underground water level,

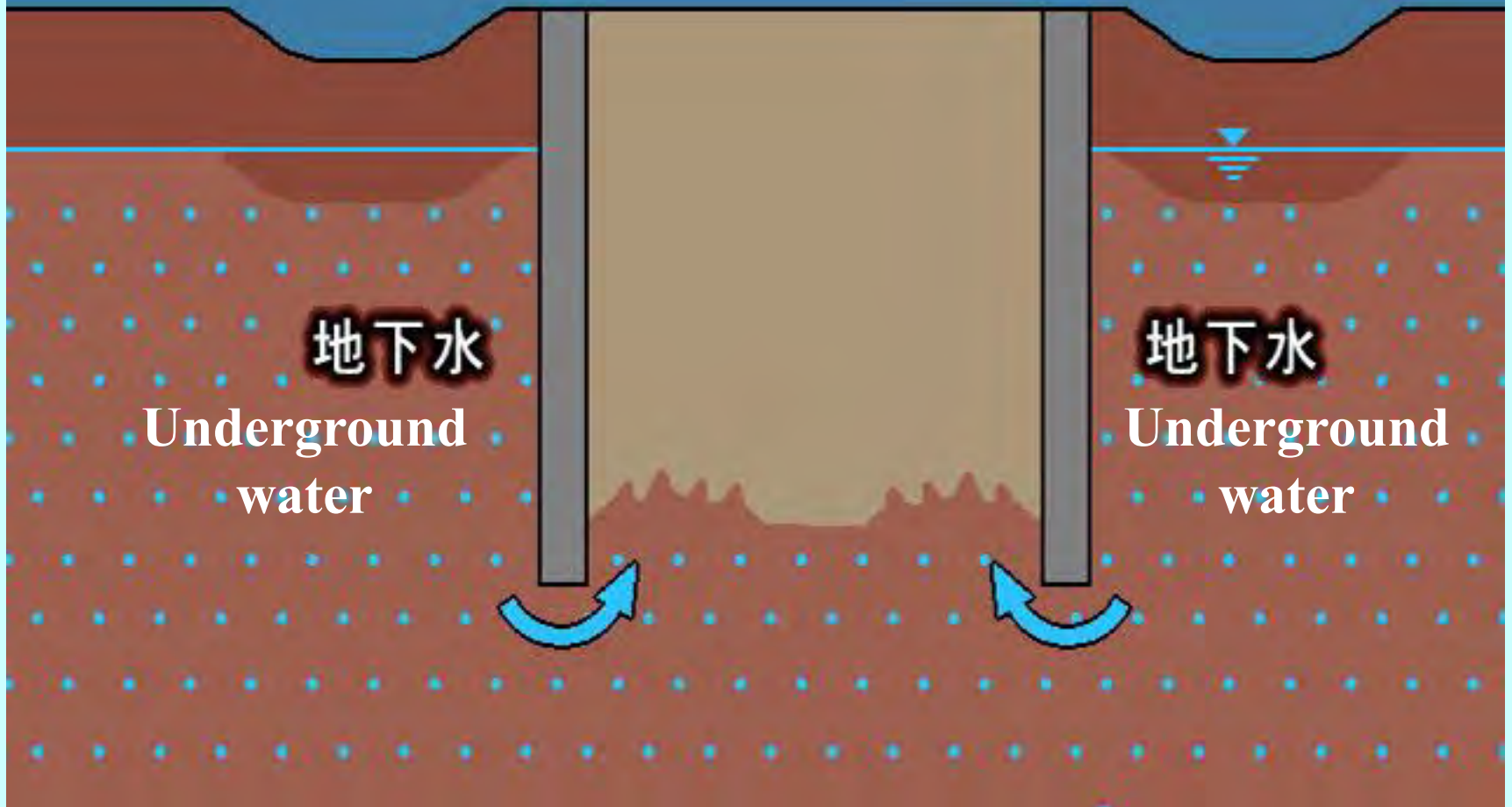


The bottom surface of the cutting heaves
due to pressure of underground water.

heaving



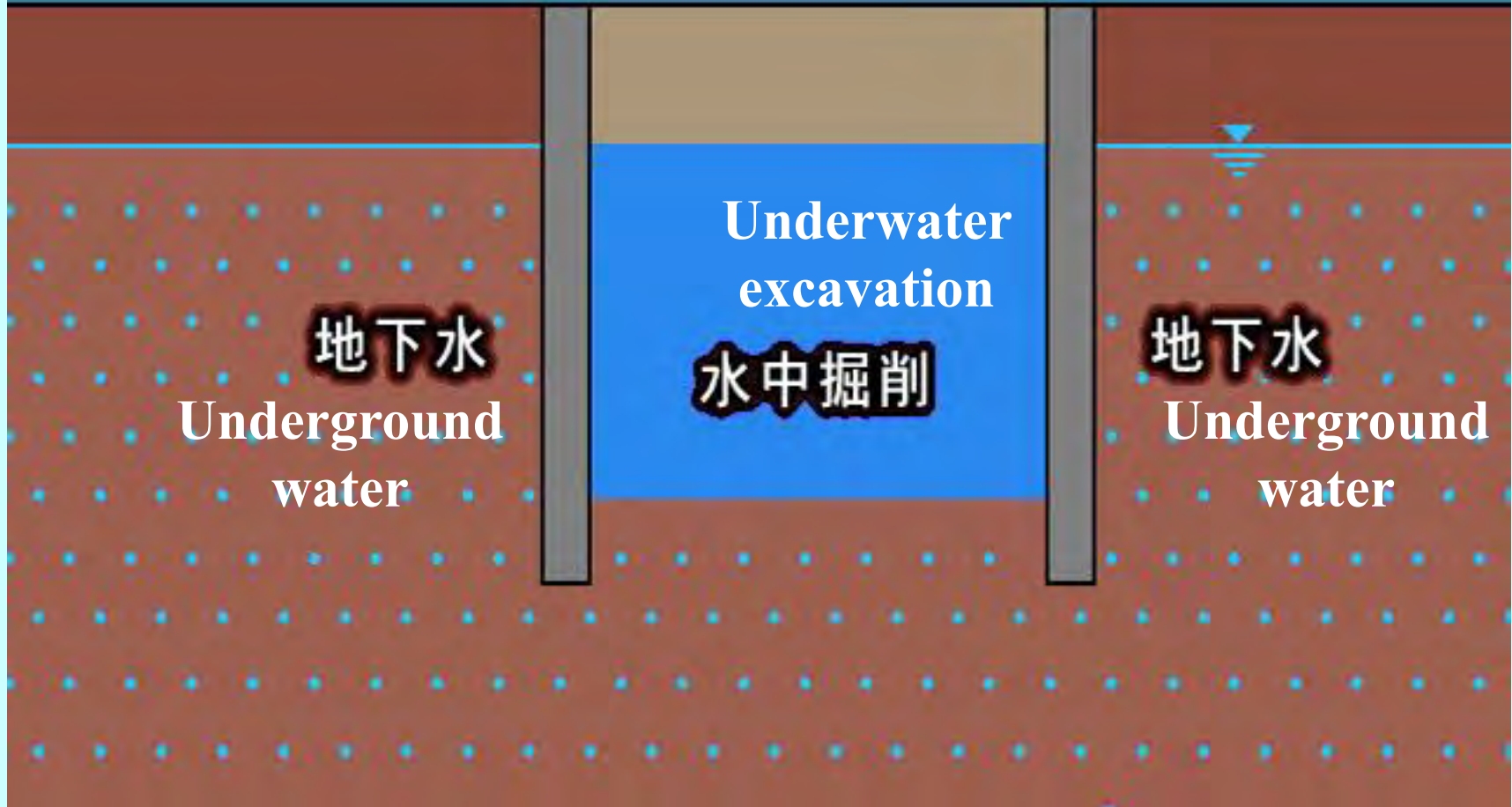
When base of excavation is broken, large deformation of the surrounding ground occurs



Underwater Excavation Method

Pour water to underground water level

and excavate with keeping water pressure balance



Underwater Excavation Method

バケットによる工法

Underwater excavation

Underwater concrete

水中掘削

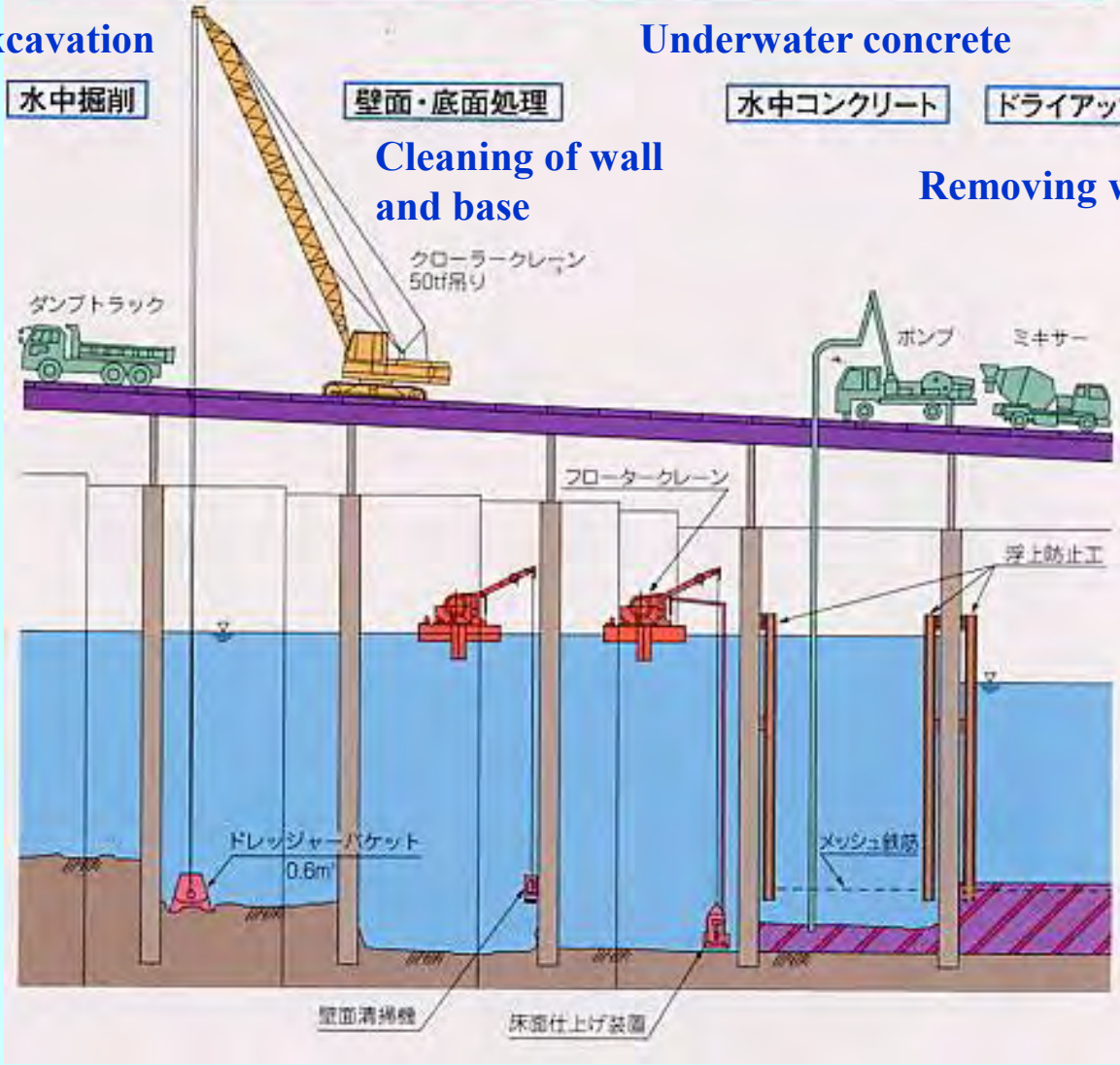
壁面・底面処理

水中コンクリート

ドライアップ

Cleaning of wall and base

Removing water



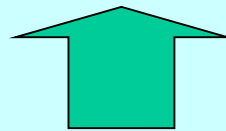
6:20~10:39

Change of a cut & cover method

Back ground

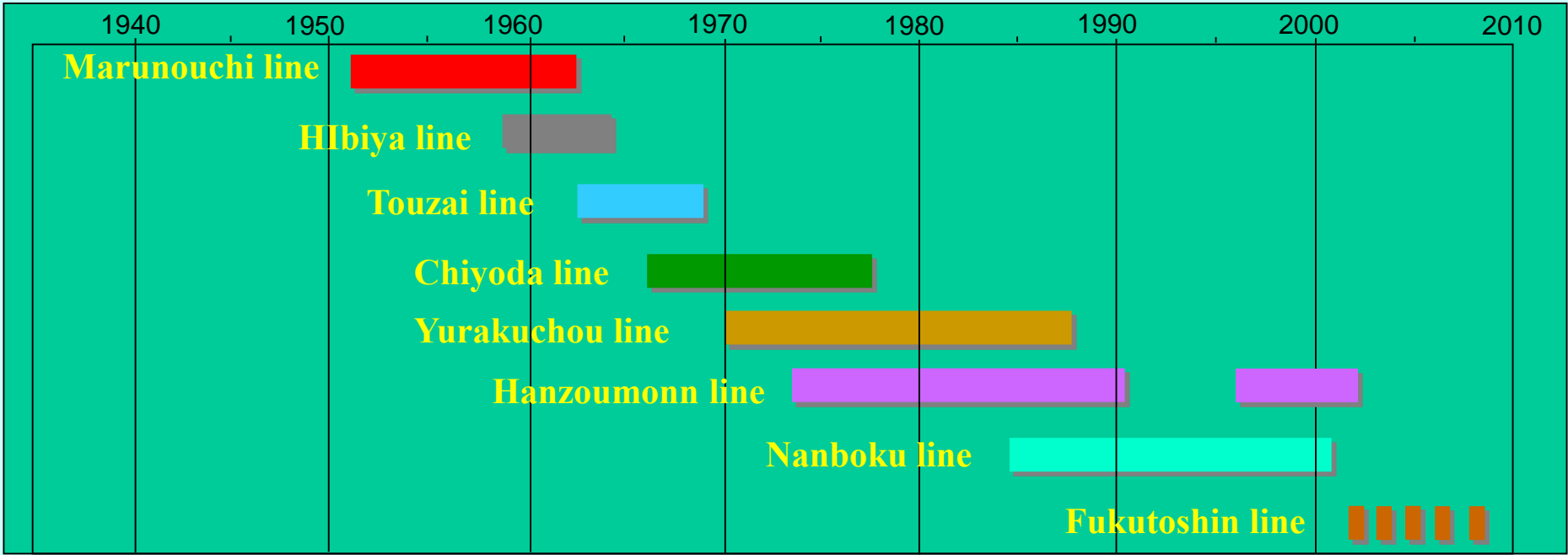
- >Environment Preservation
(Noise, Vibration,
Lowering of ground water level)
- >Larger and deeper of structures
- >Mechanization of construction
- >Enlargement of traffic on the road

- >Low noise construction method,
Low vibration construction method.
- >Improvement of preventing water leakage
capacity.
- >Keep of a space for construction.
- >Countermeasure of a heavy load.



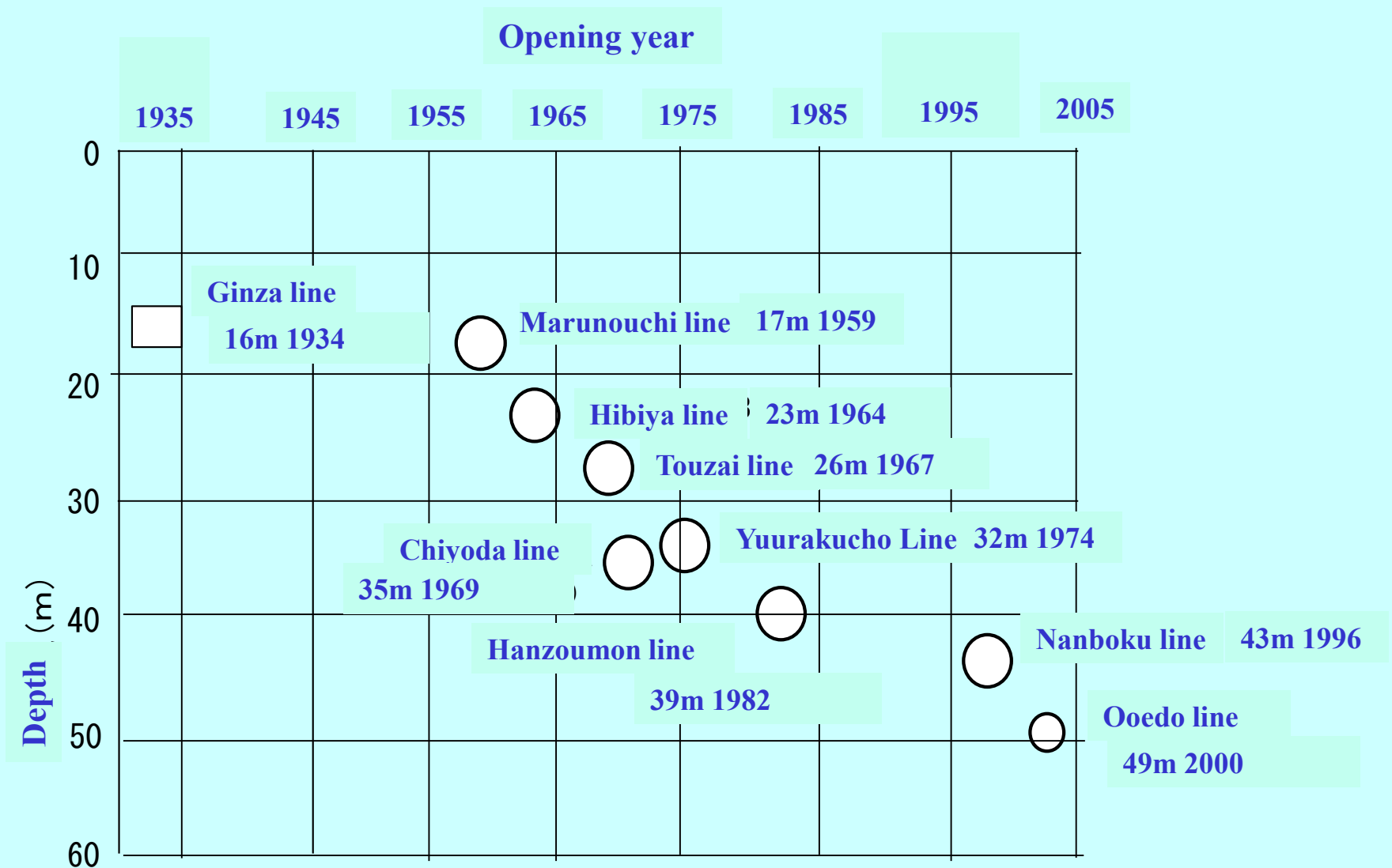
Technological innovation

Change of a cut & cover method



- Soldier pile with lateral lagging method**
 Driven pile / Bored pile
- Column-type underground diaphragm wall**
 Single axis, Reinforcing bar basket / Single axis, H-shape steel / Multi axes, H-shape steel
- Underground diaphragm wall**
 The I.C.O.S. method / Reinforcing bar basket / Steel material / Combined use of temporary wall
- Support**
 A thirty-centimeter square piece of lumber
 Wooden / Pine log / Steel material / Ground anchor
- Road decking**
 Wooden / Steel

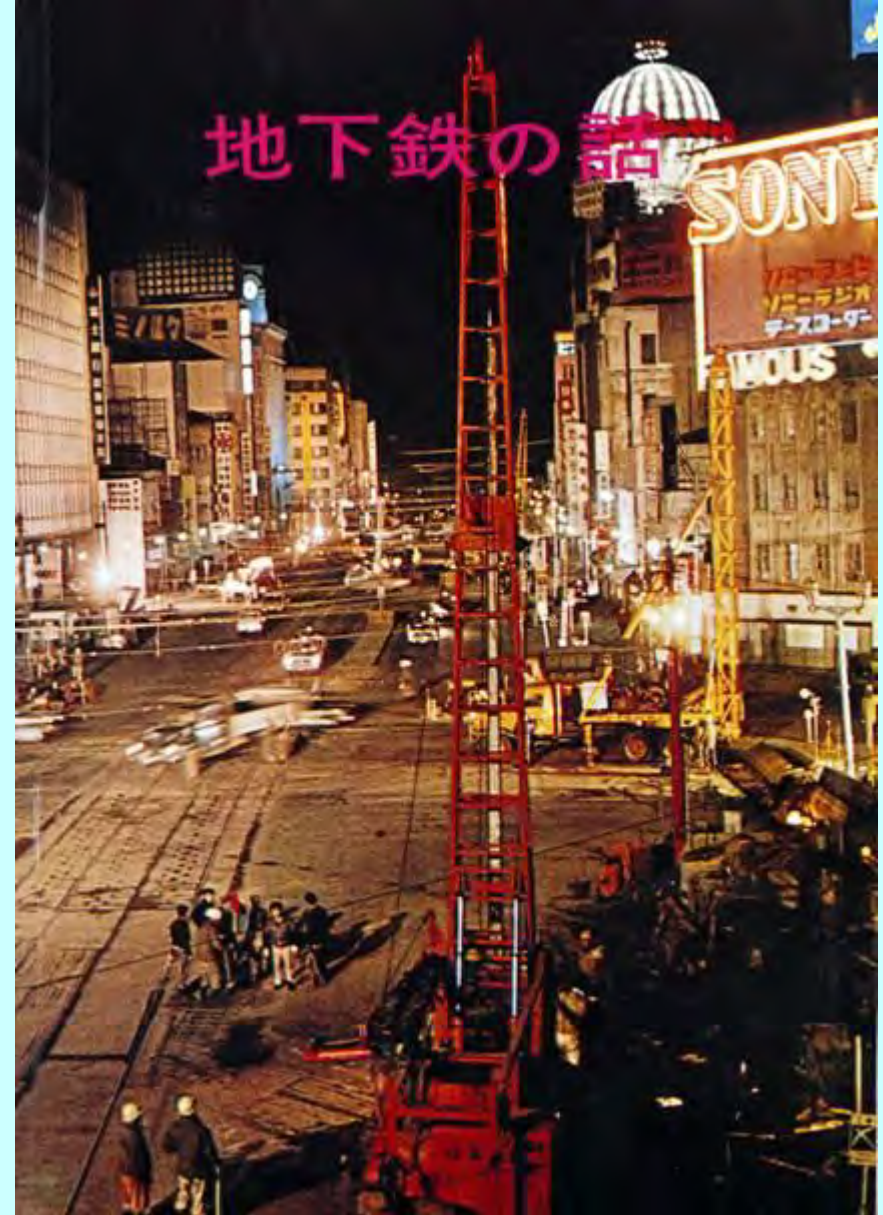
A record of subways in Tokyo



Pile driving (Single pile)



Marunouchi line

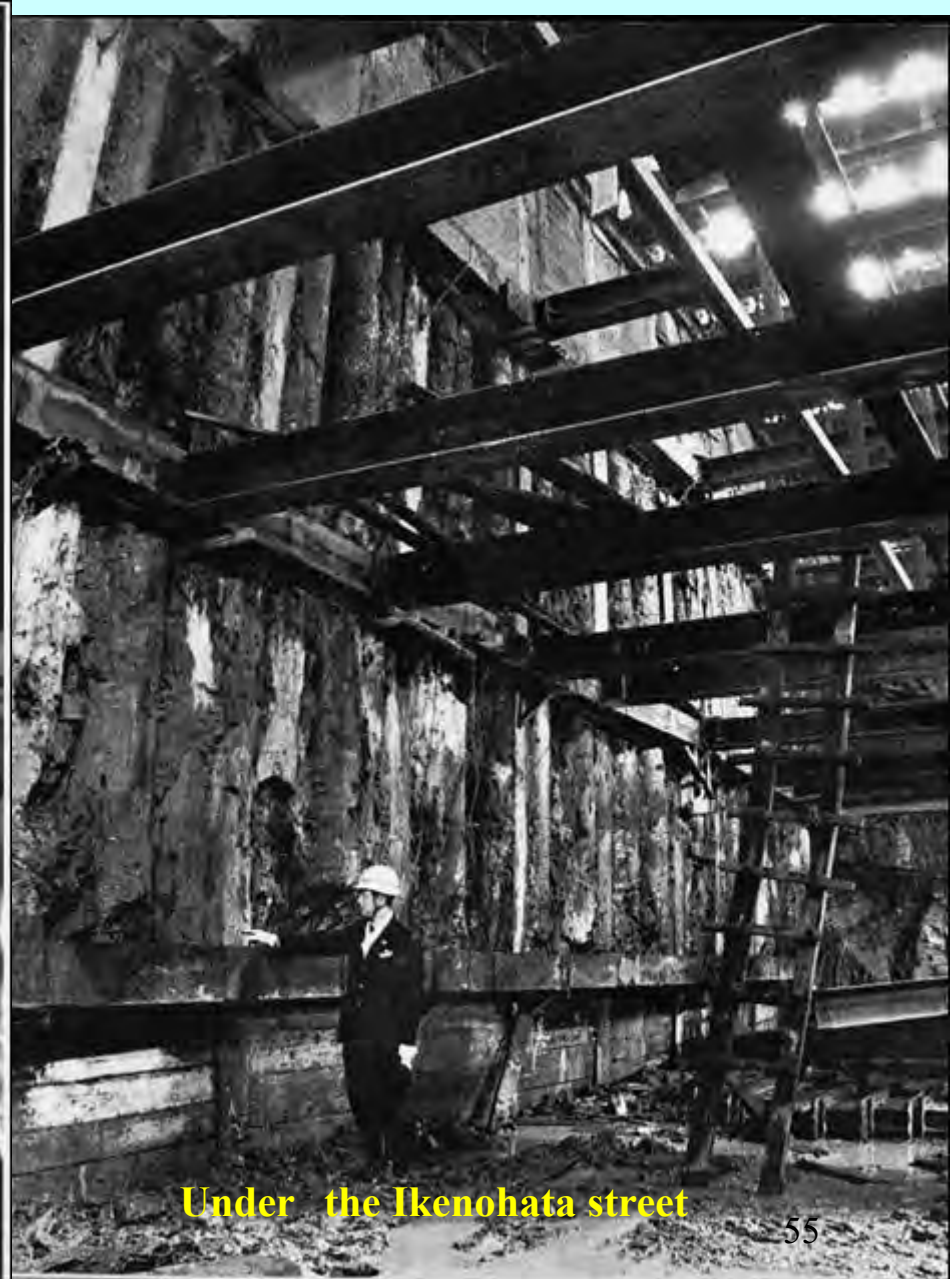


Hibiya line

Piles of column-type underground diaphragm wall (Chiyoda line)

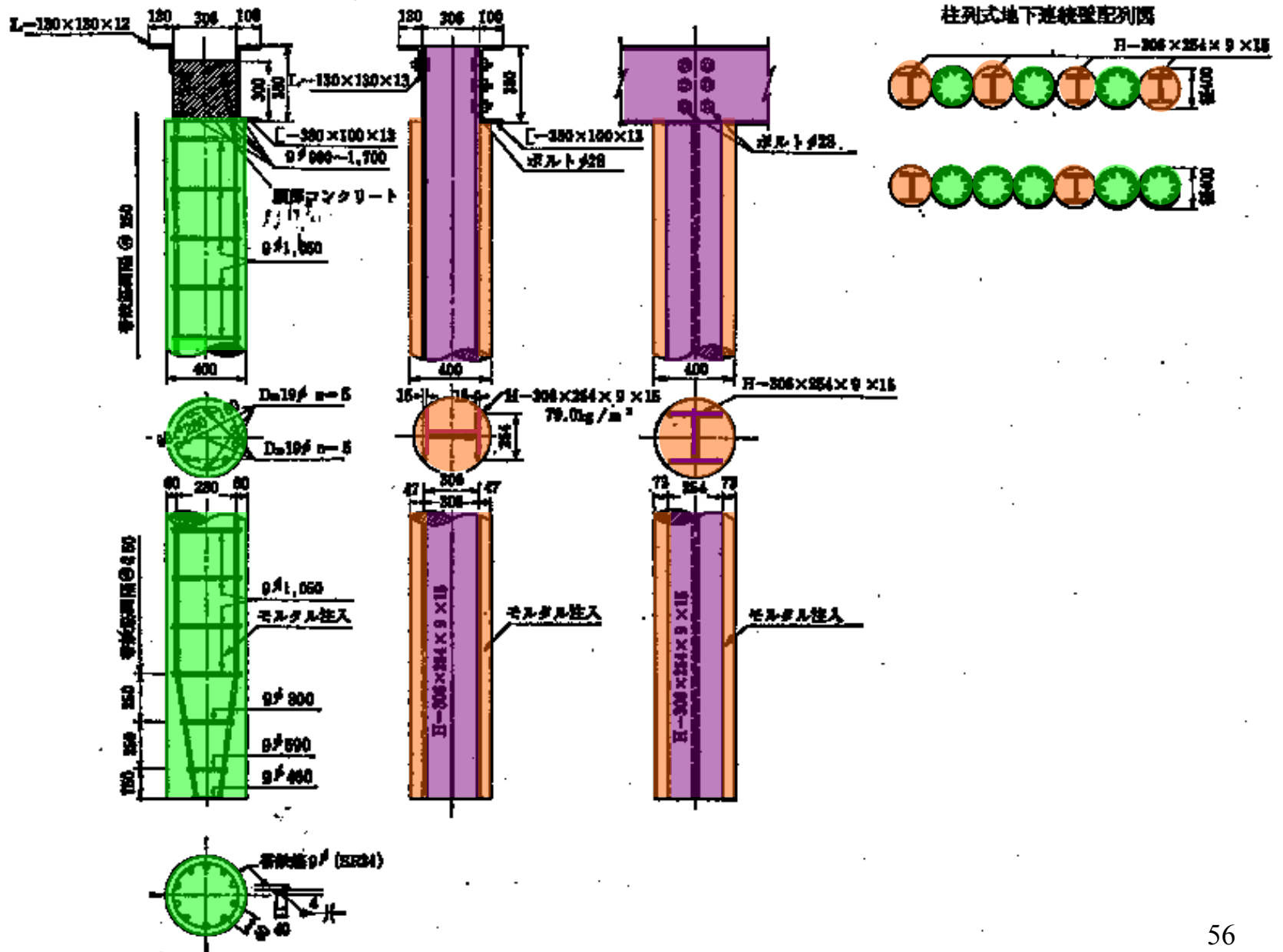


Under the Shinobazu street



Under the Ikenohata street

Column-type underground diaphragm wall



Pile of Column-type underground diaphragm wall



Borehole by multi-axes auger

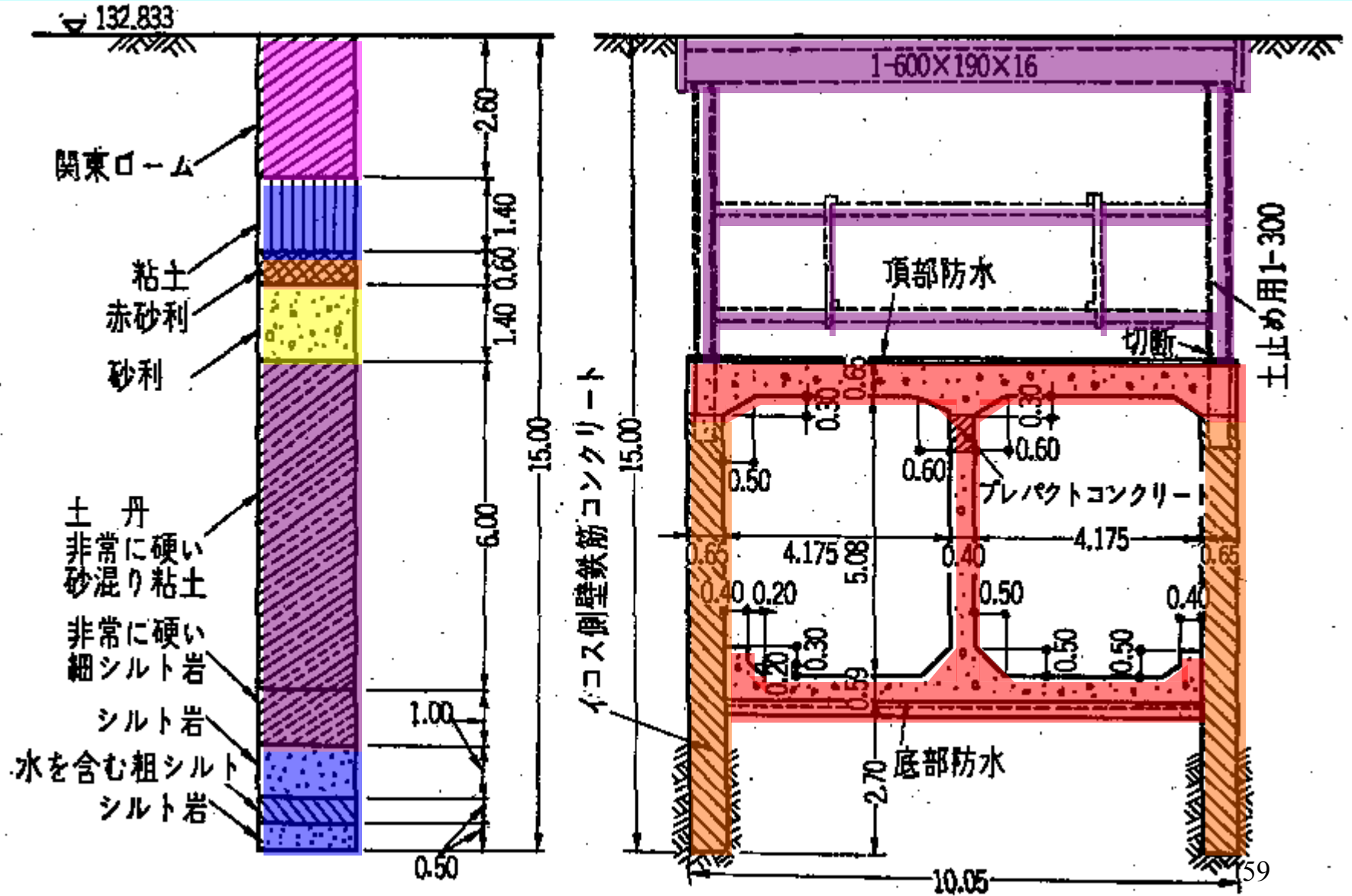
**Yurakucho line,
Toyosu**

Underground diaphragm wall



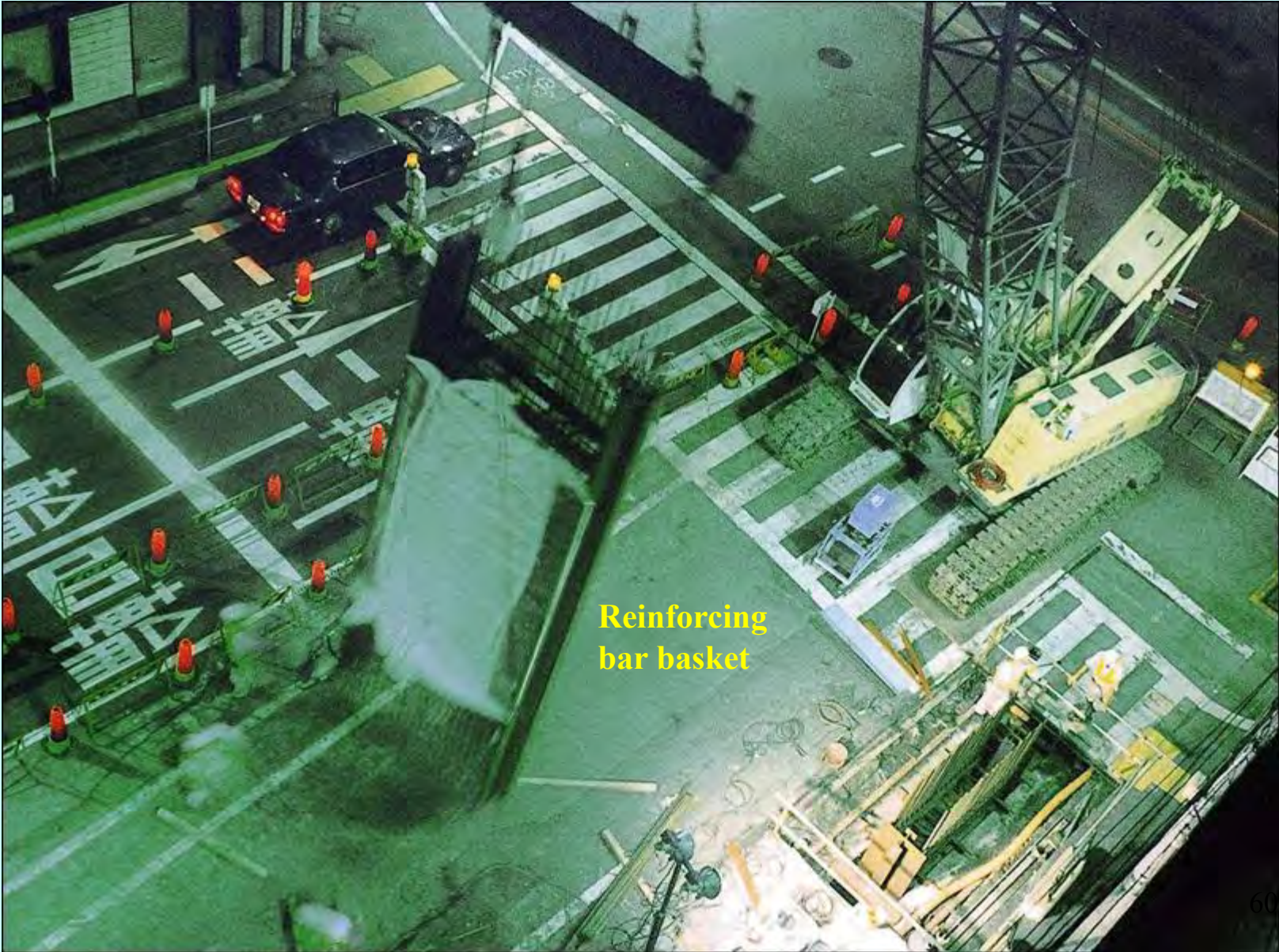
**The I.C.O.S. method (Reinforcing bar basket)
(Marunouchi line, Hounannchou)**

Cross section of the I.C.O.S. method (Marunouchi line, Hounannchou)



Underground diaphragm wall

Hanzoumon line, Sumiyoshi station



Support (Strut, Wale) (Wooden support)



Pine log Wooden support (Marunouchi line)

Support (Strut, Wale) (Wooden support)



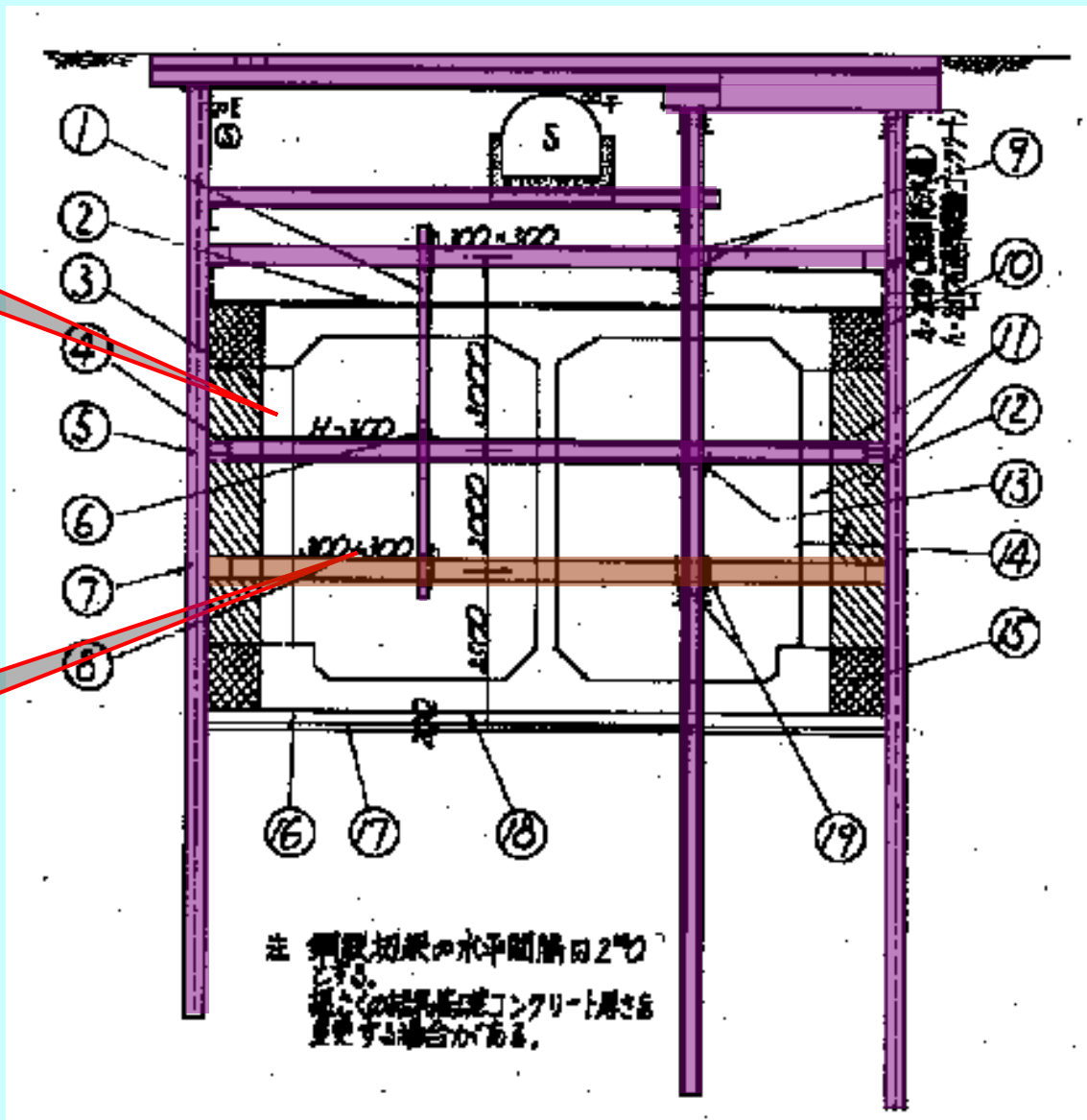
A thirty-centimeter square piece of lumber

Wooden support (Marunouchi line)

Support (H-shaped steel and wooden support) (Hibiya line, Kamiyachou)

Steel strut

Wooden strut

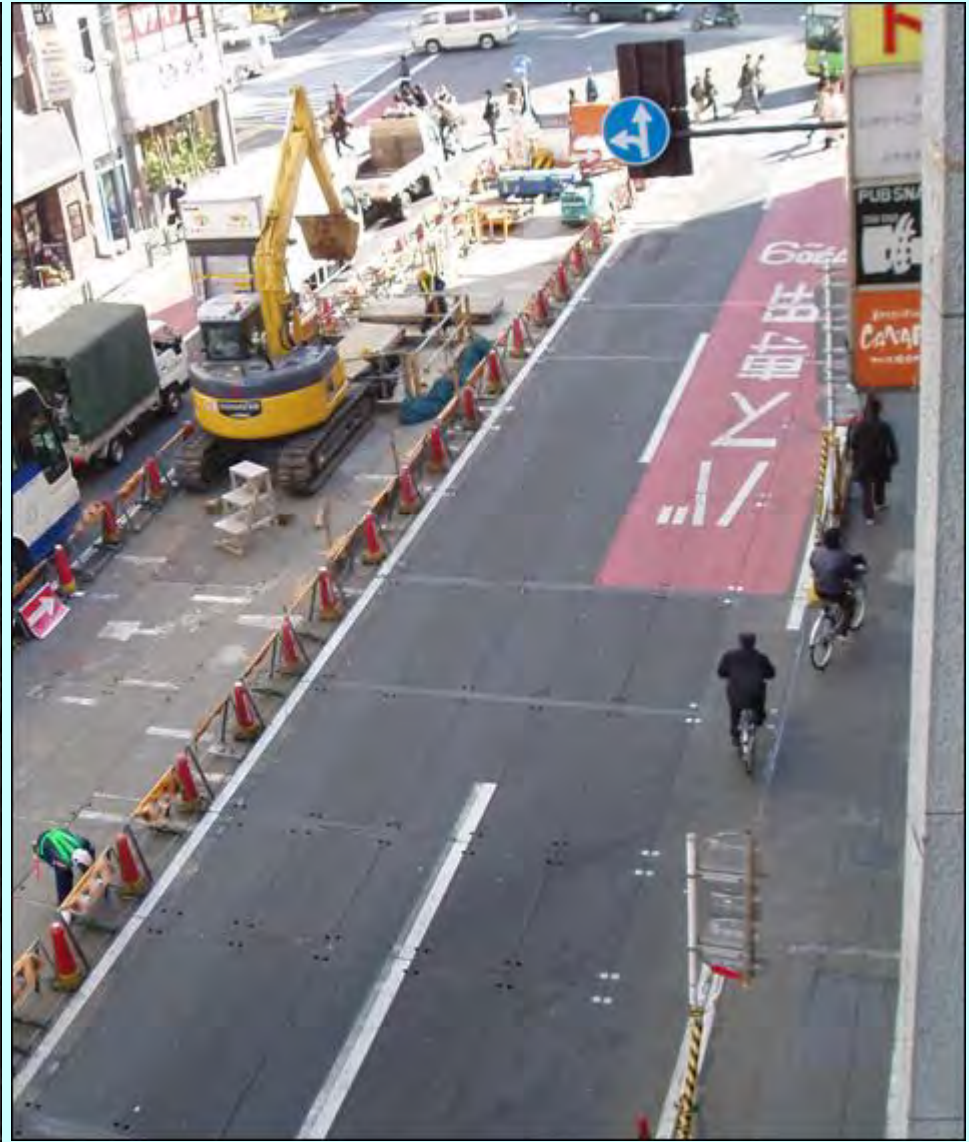


All steel supports (Hibiya line)



For engineer, it is important to feel at a glance that the support system has good balance or not, stable or unstable.

Road decking (Road decking panel)



Road decking Panel (2m, Touzai line, Nihonbashi)

Road decking Panel (13m, Fukutoshinn line, Shinjuku)

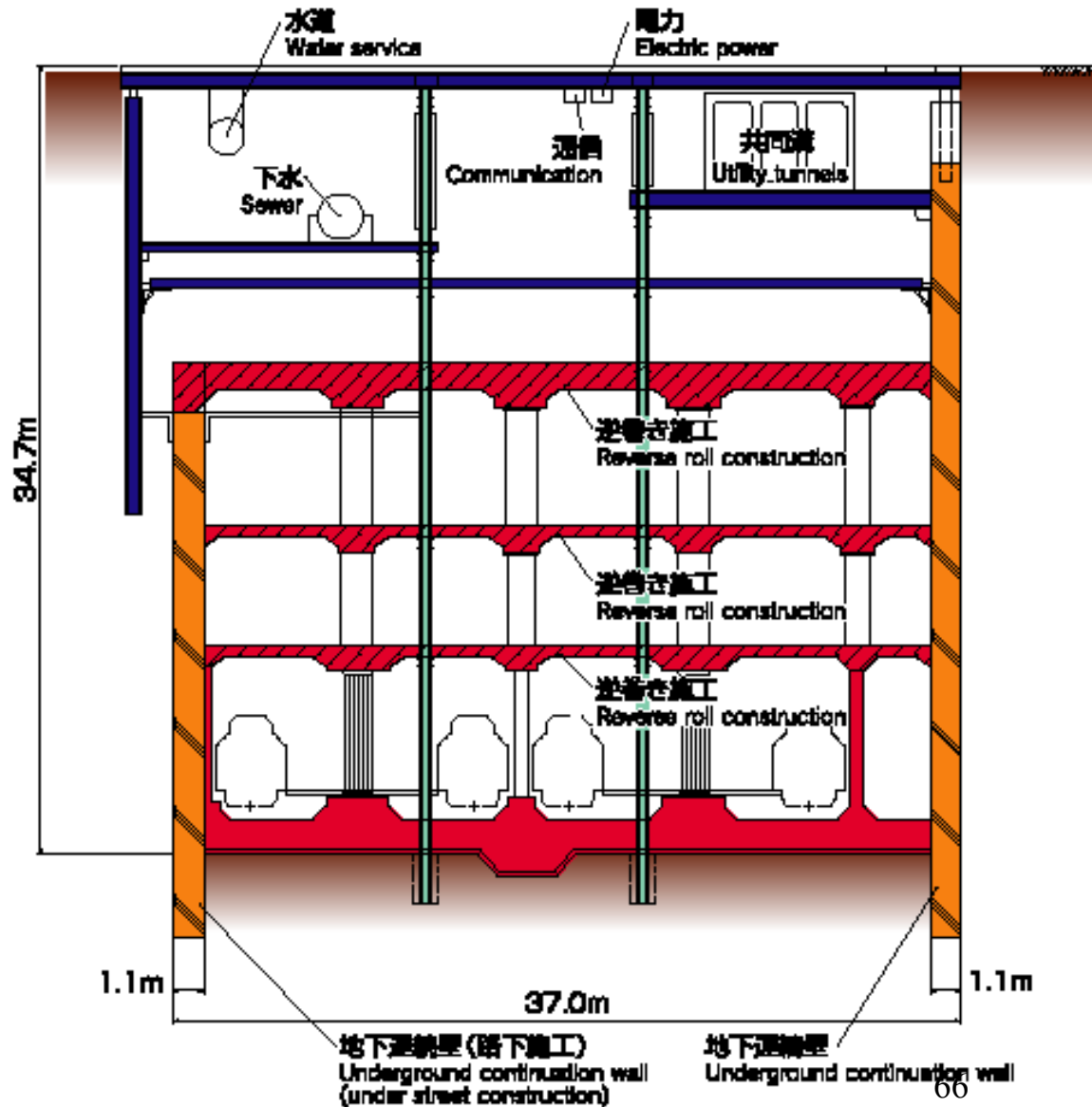
Large-scale excavation work

Large-scale excavation work

North-south line operation

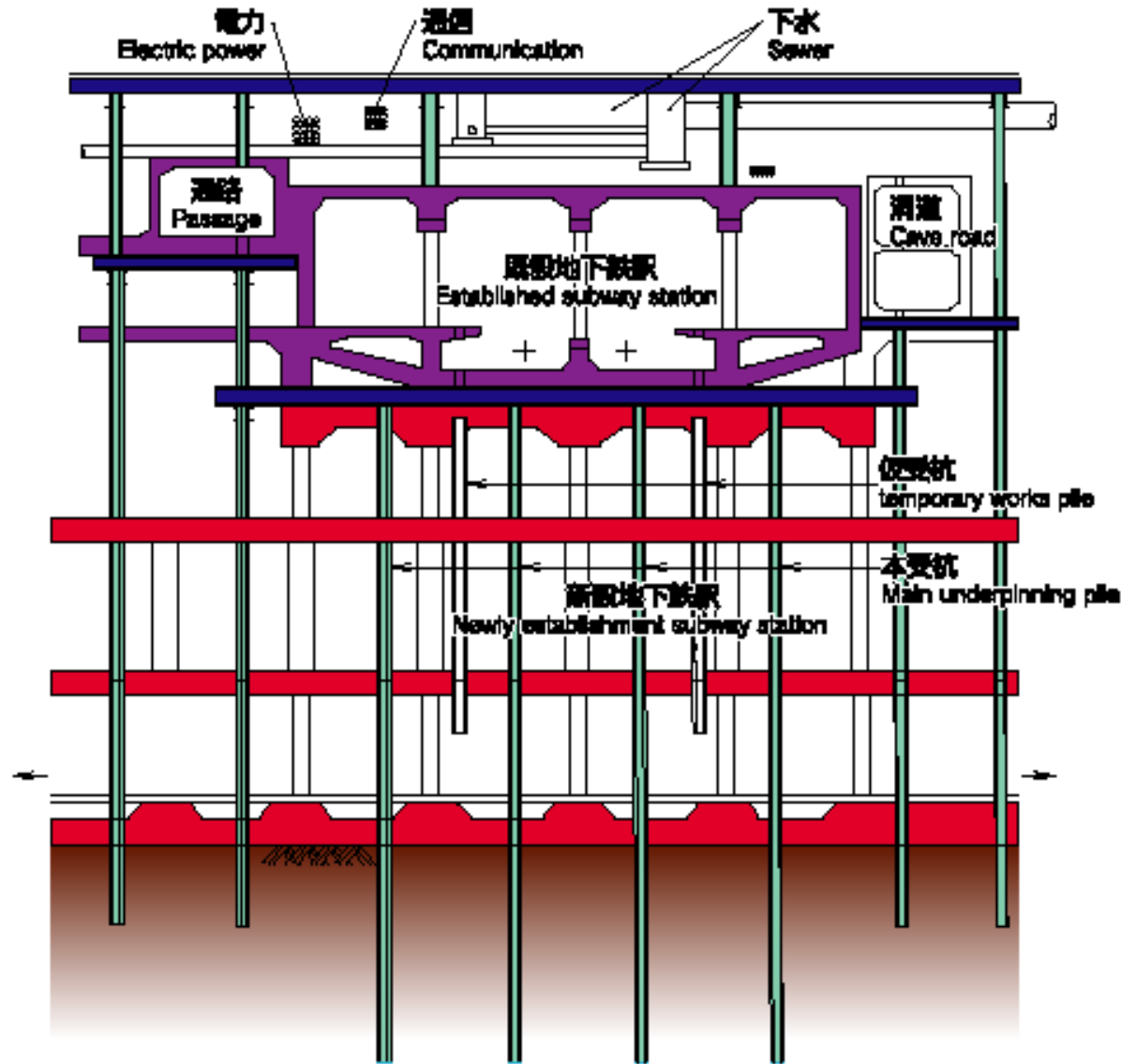


17:16~19:09



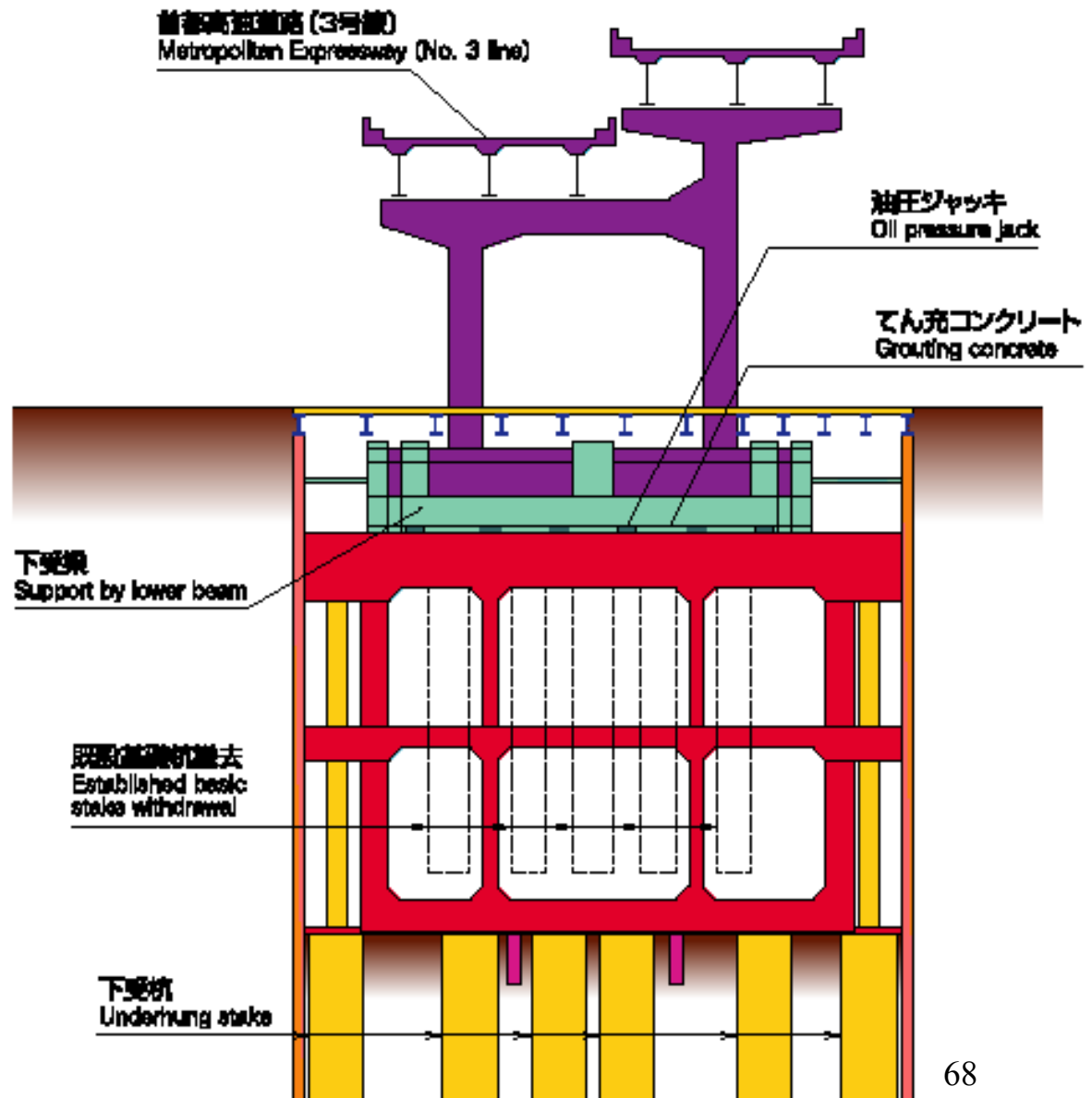
The underpinning method of construction at crossed subway

Hanzomon line operation



Construction directly under a highway (underpinning method of construction)

North-south line operation



Design of Temporary Structure for Cut & Cover Method

What's the temporary structure ?

Earth-retaining wall

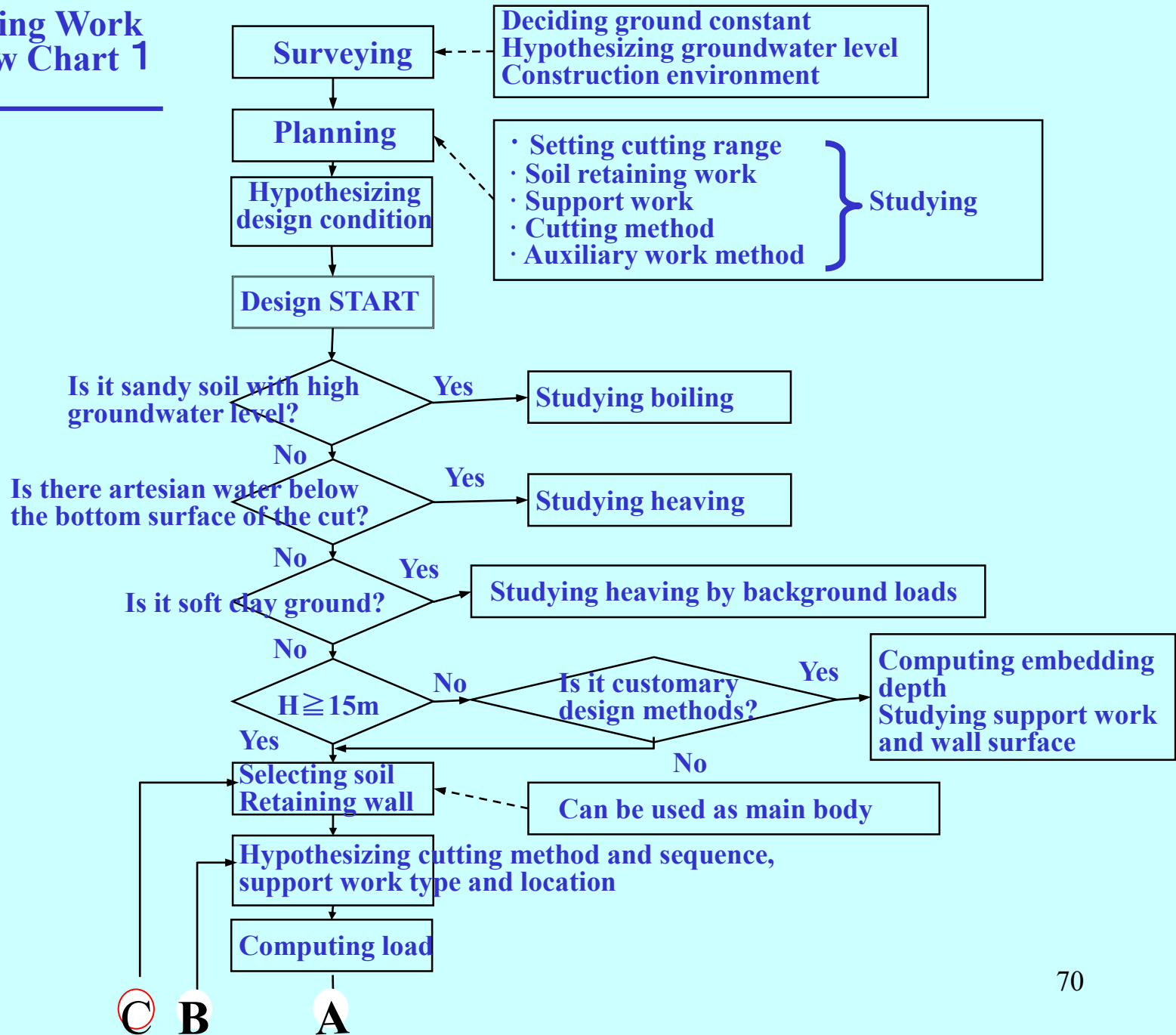
Strut

Wale

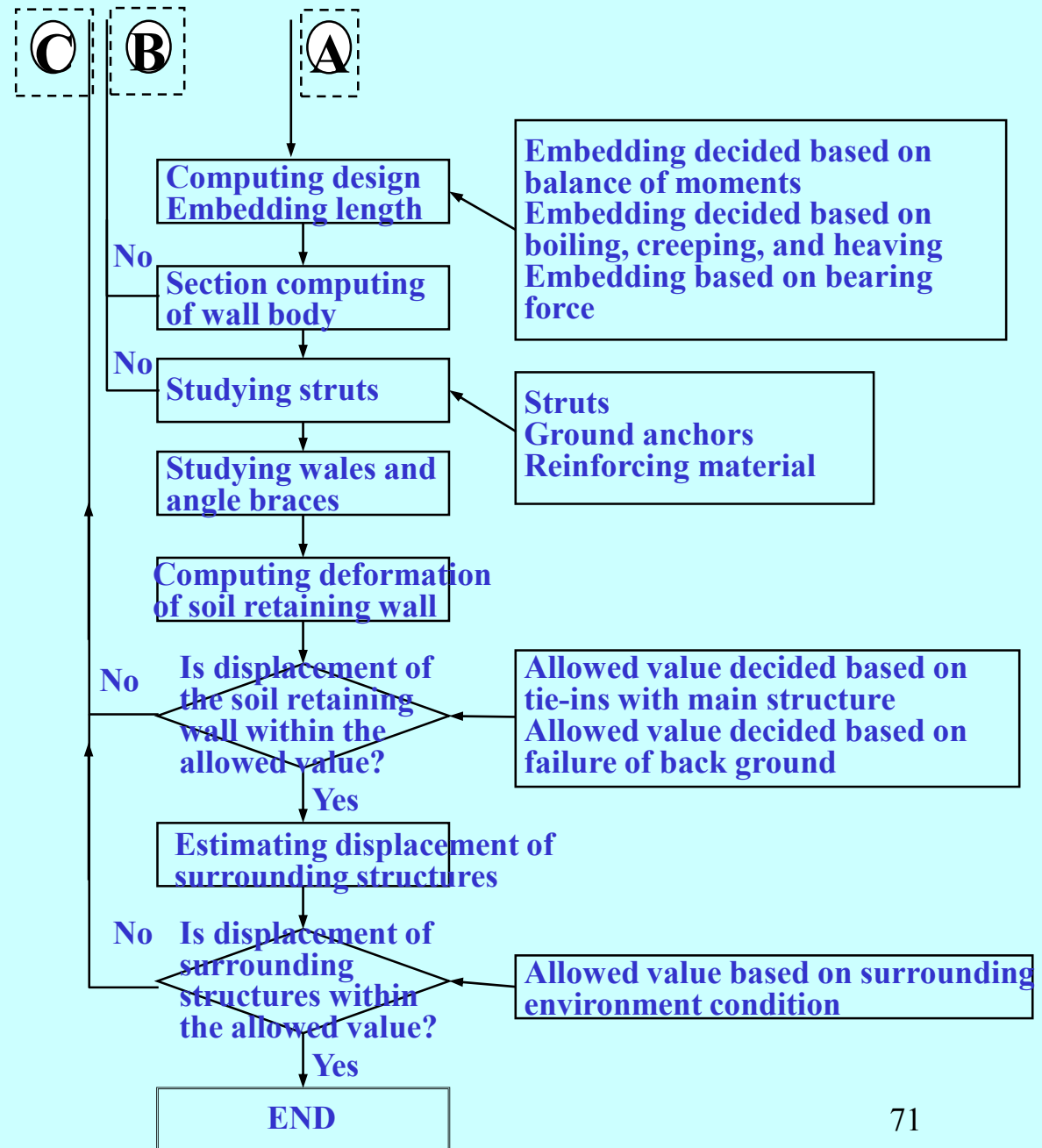
Bottom ground improvement

etc

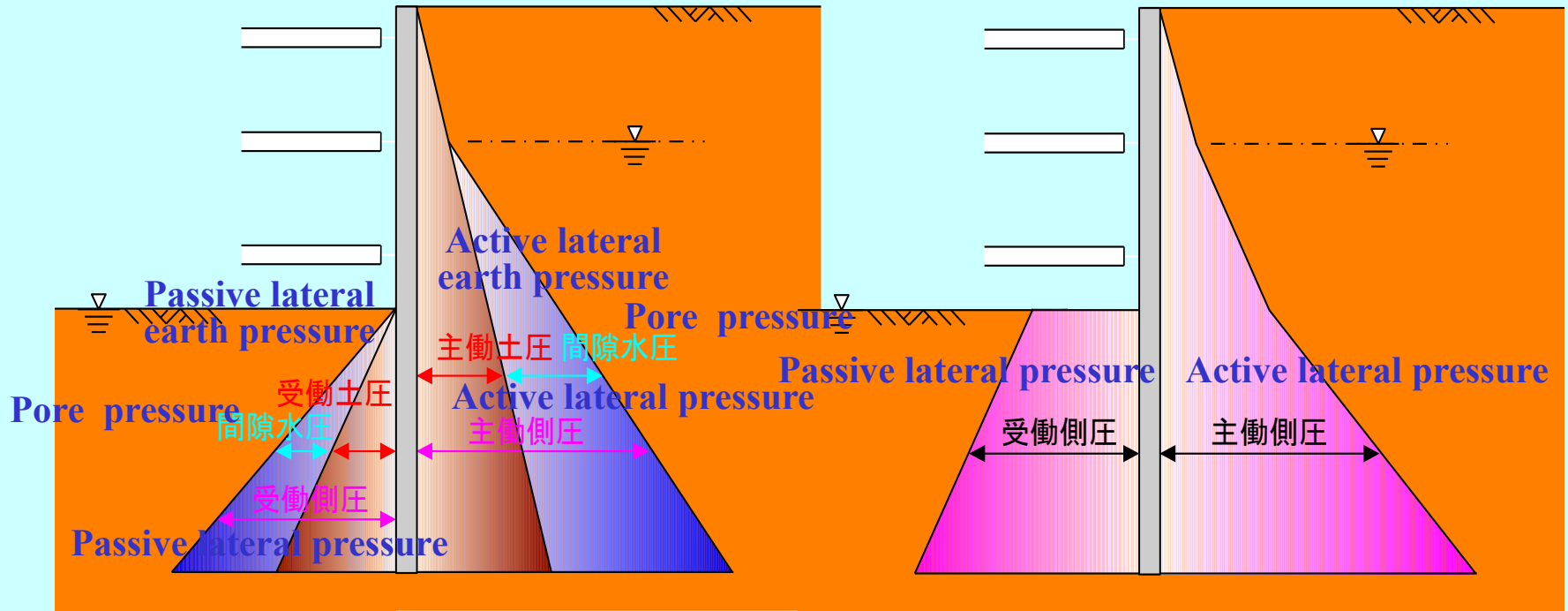
Soil Retaining Work Design Flow Chart 1



Soil Retaining Work Design Flow Chart 2



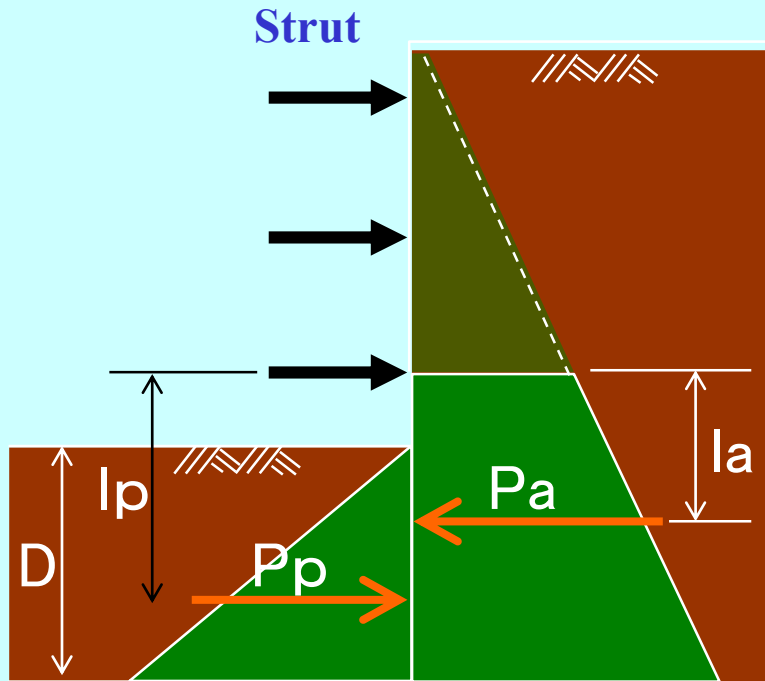
Schematic drawings of Lateral pressure



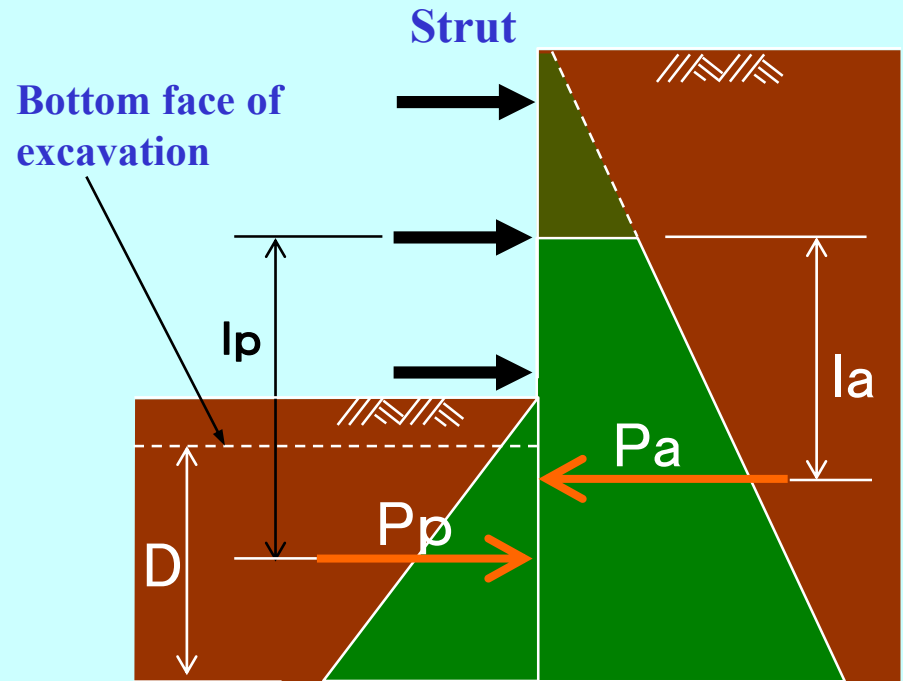
Sandy soil

Clayey soil

Depth of embedment



(a) At the end of excavation

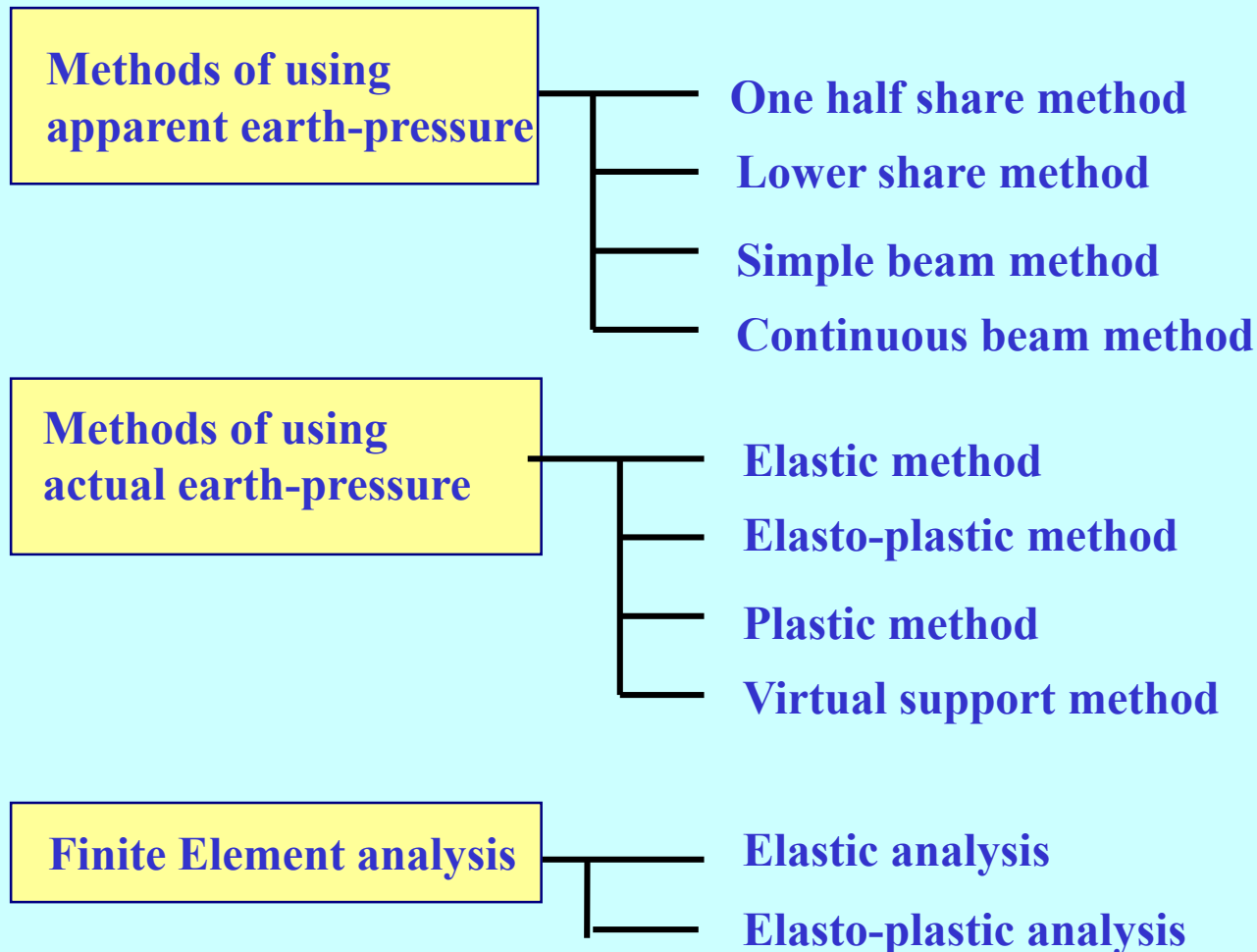


(b) Before placing of the lowest strut

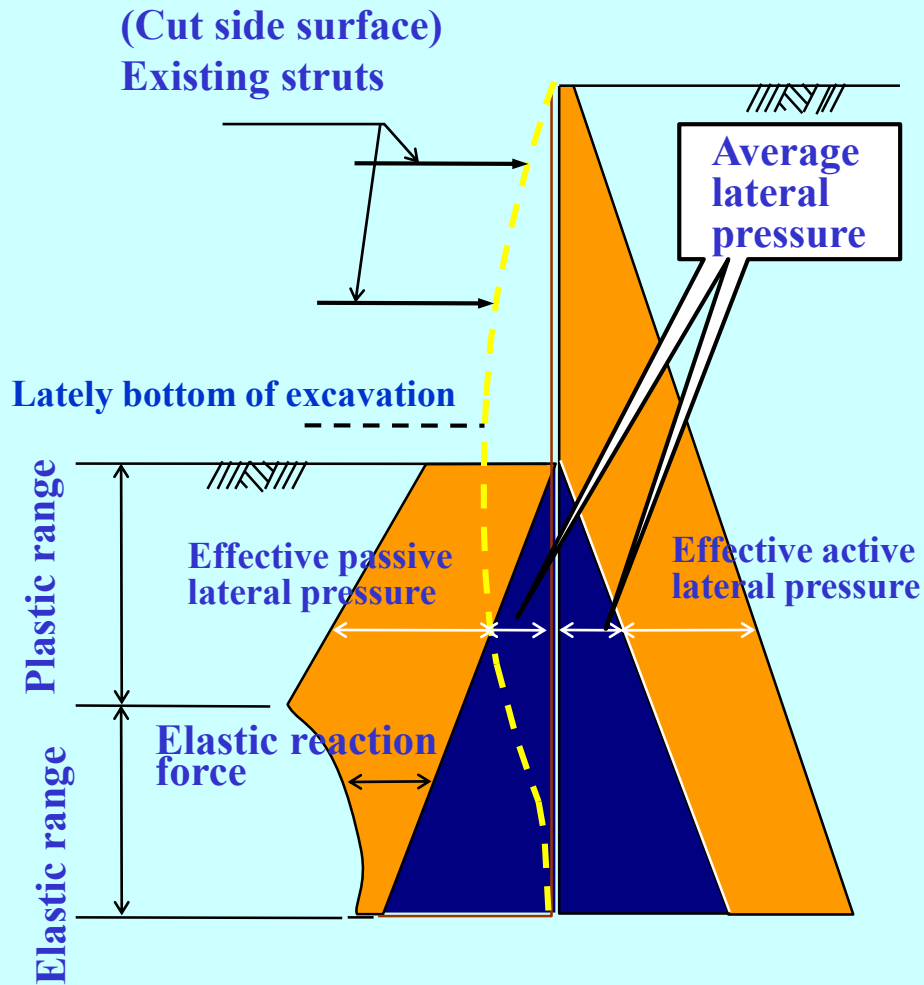
An equation for calculating a design depth of embedment

$$(l_p \cdot P_p = 1.2 \cdot l_a \cdot P_a \quad : \text{depth of embedment})$$

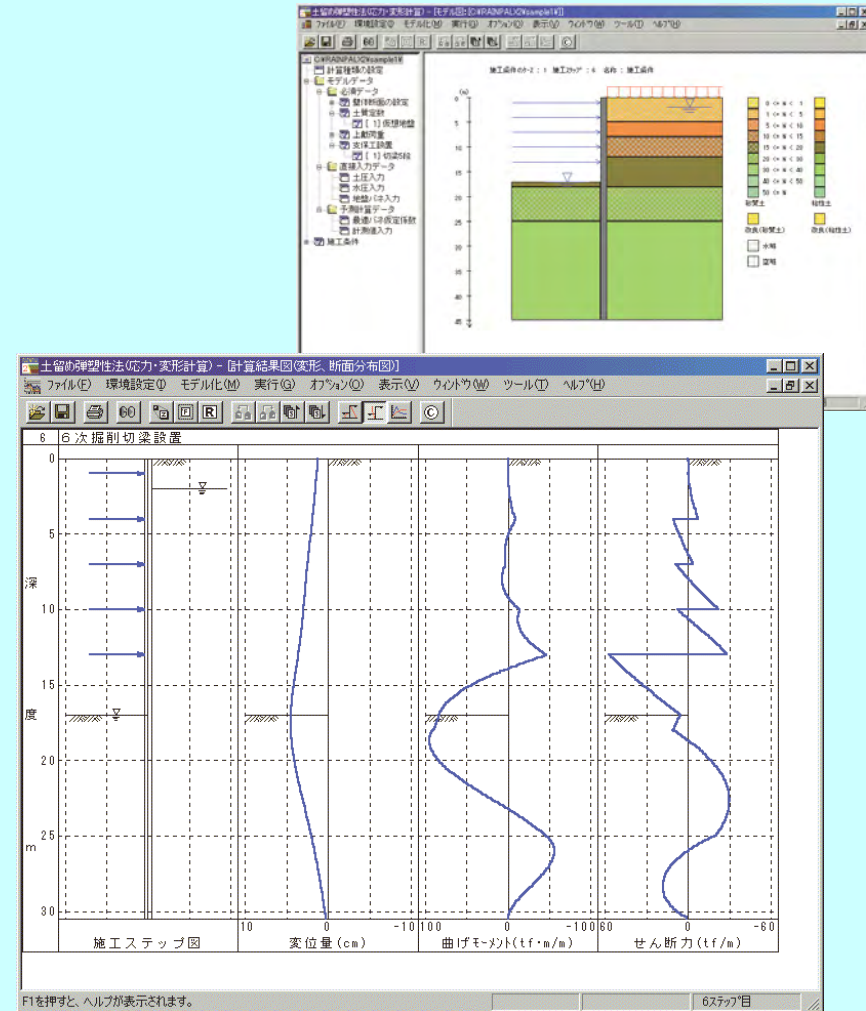
Calculation methods of wall section



Stress calculation by Elasto-plastic method

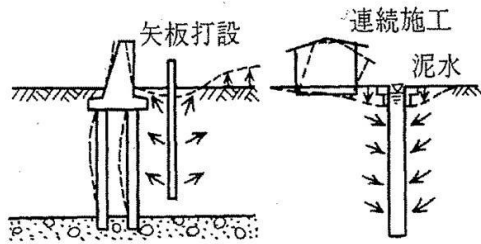


Equal lateral pressure explanatory figure

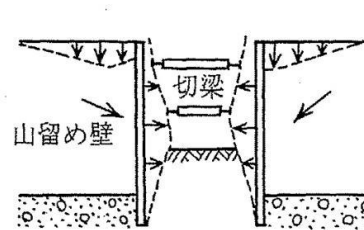


An Example of calculation results of stress.

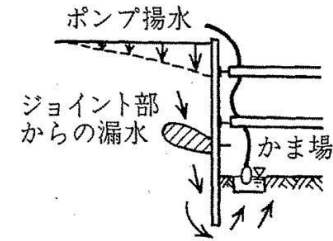
Factors of ground deformations surrounding retaining walls



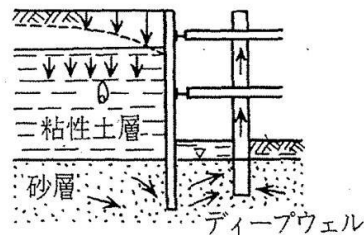
① 山留め壁施工に伴う地盤変位



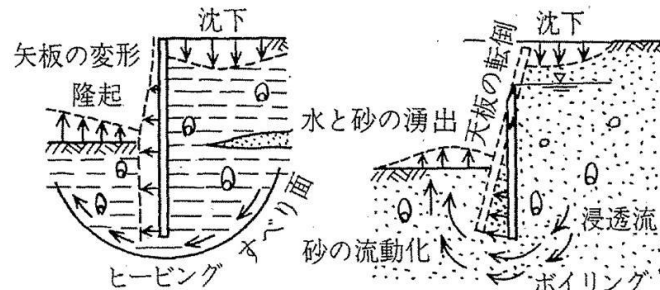
② 掘削に伴う山留め壁の変形による地盤変位



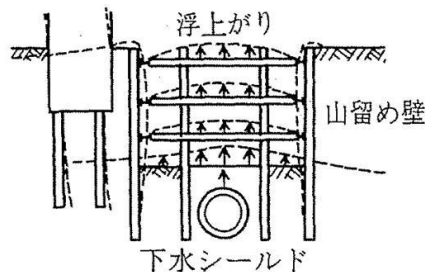
③ 根切りに伴う地下水湧出による地盤変位



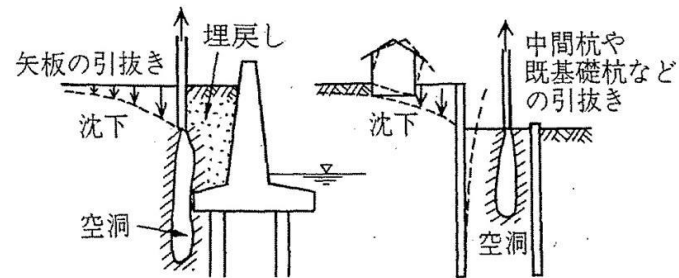
④ 排水に伴う地下水位低下による粘性土の圧密沈下



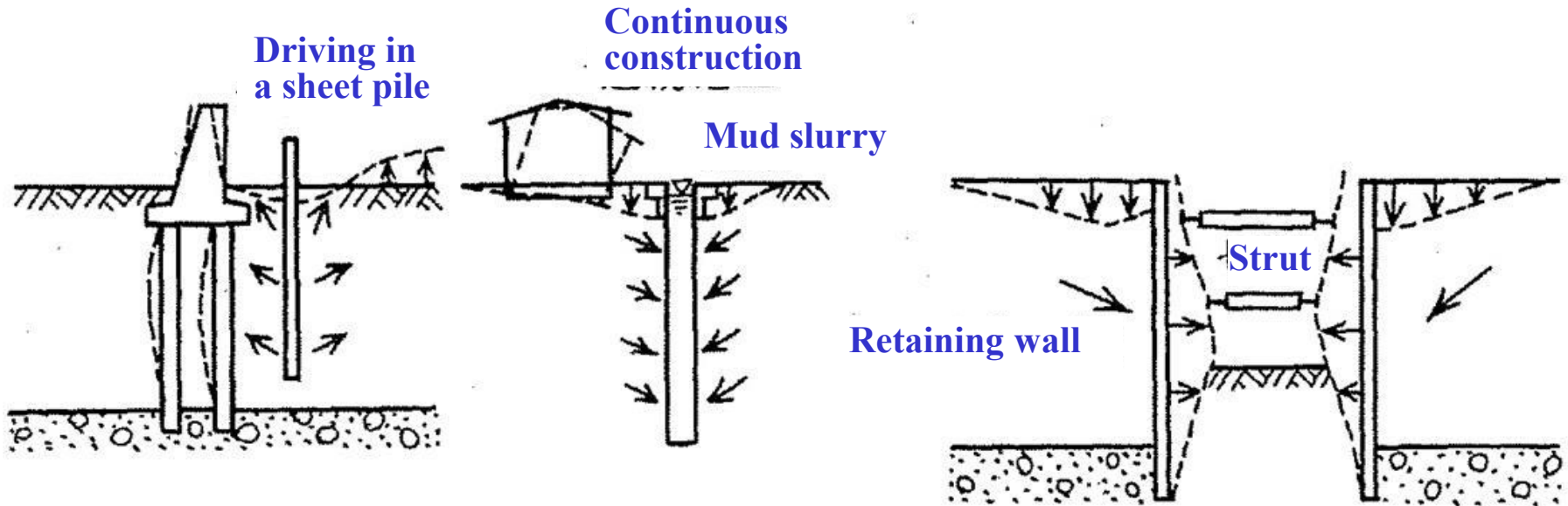
⑤ ヒービングやボーリングによる地盤変位



⑥ 根切りに伴う地盤の浮上がり

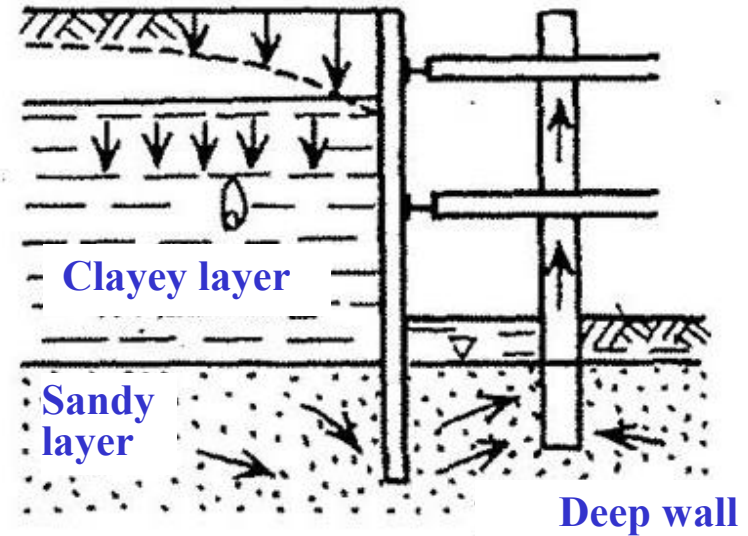
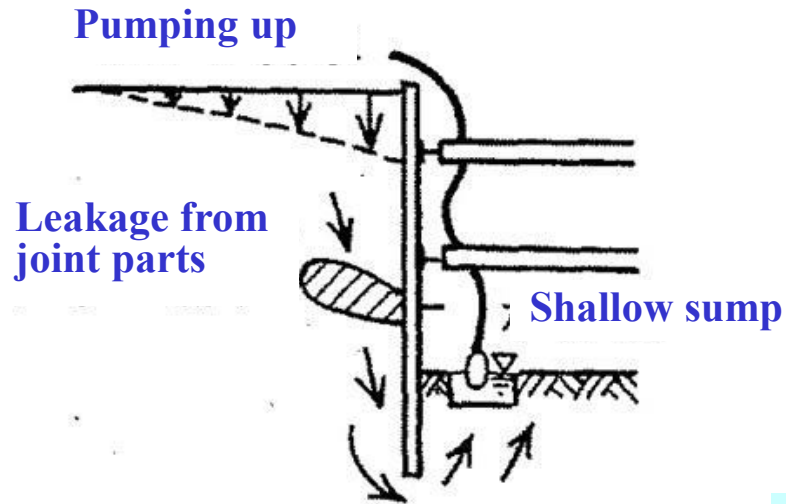


⑦ 切梁や山留め壁撤去に伴う地盤変位



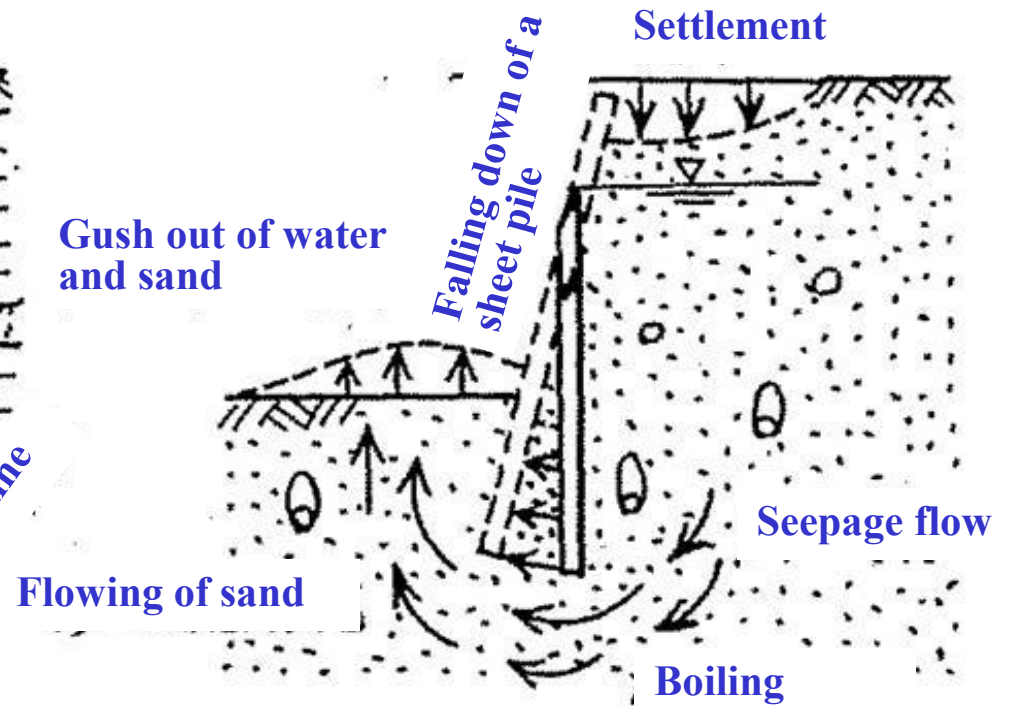
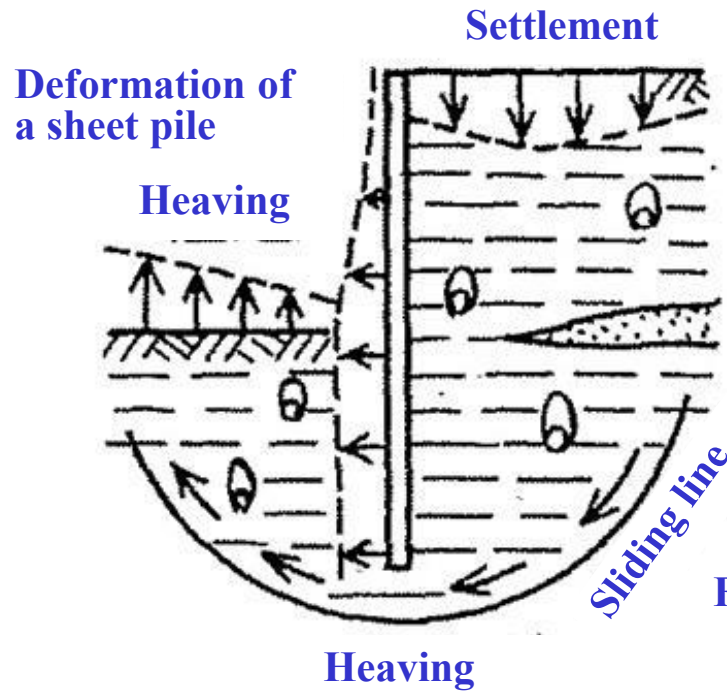
1. Ground deformation due to placing a retaining wall.

2. Ground deformation due to deforming of retaining walls with the excavation.

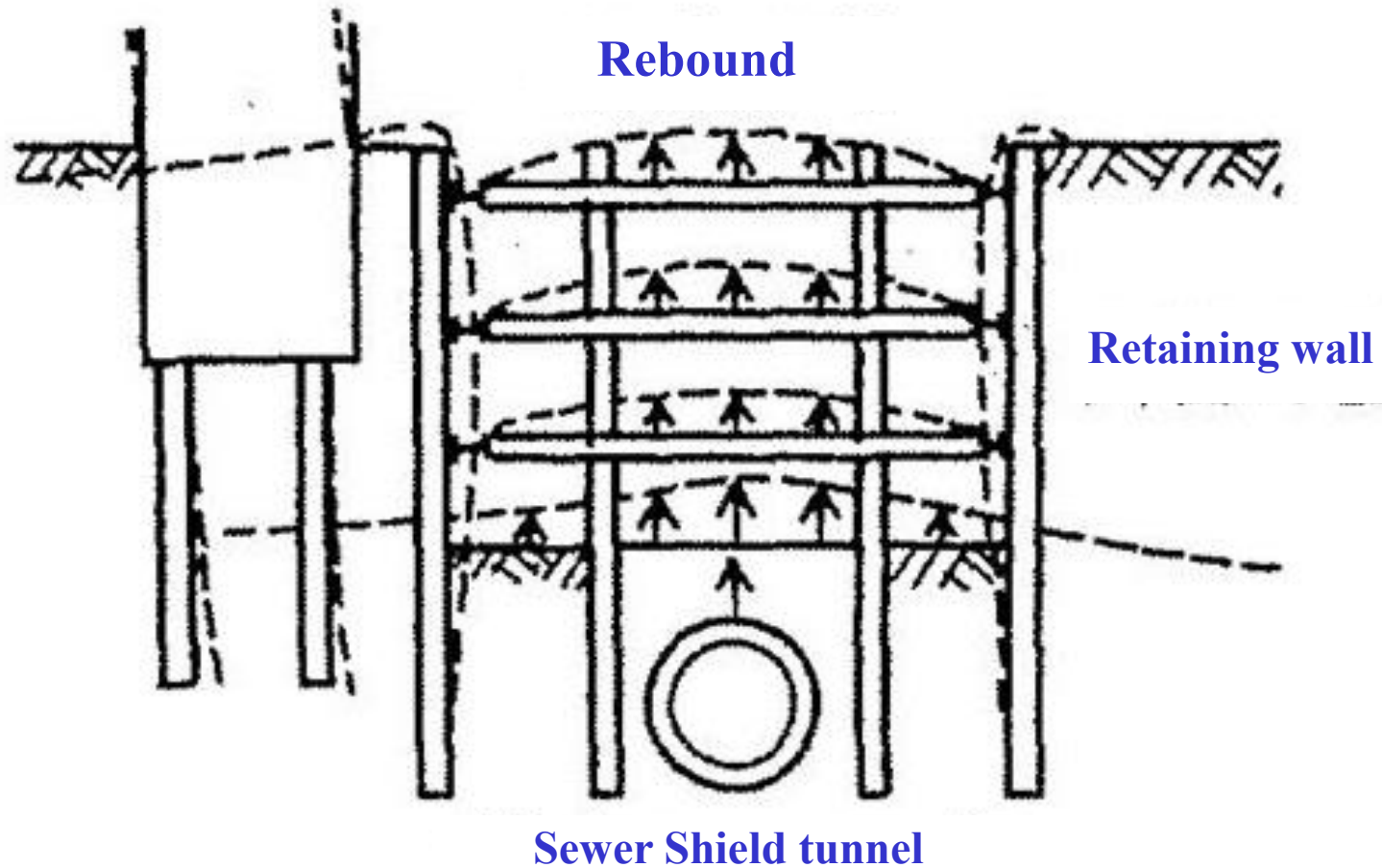


3. Ground deformation due to welling up underground water with the excavation of excavation.

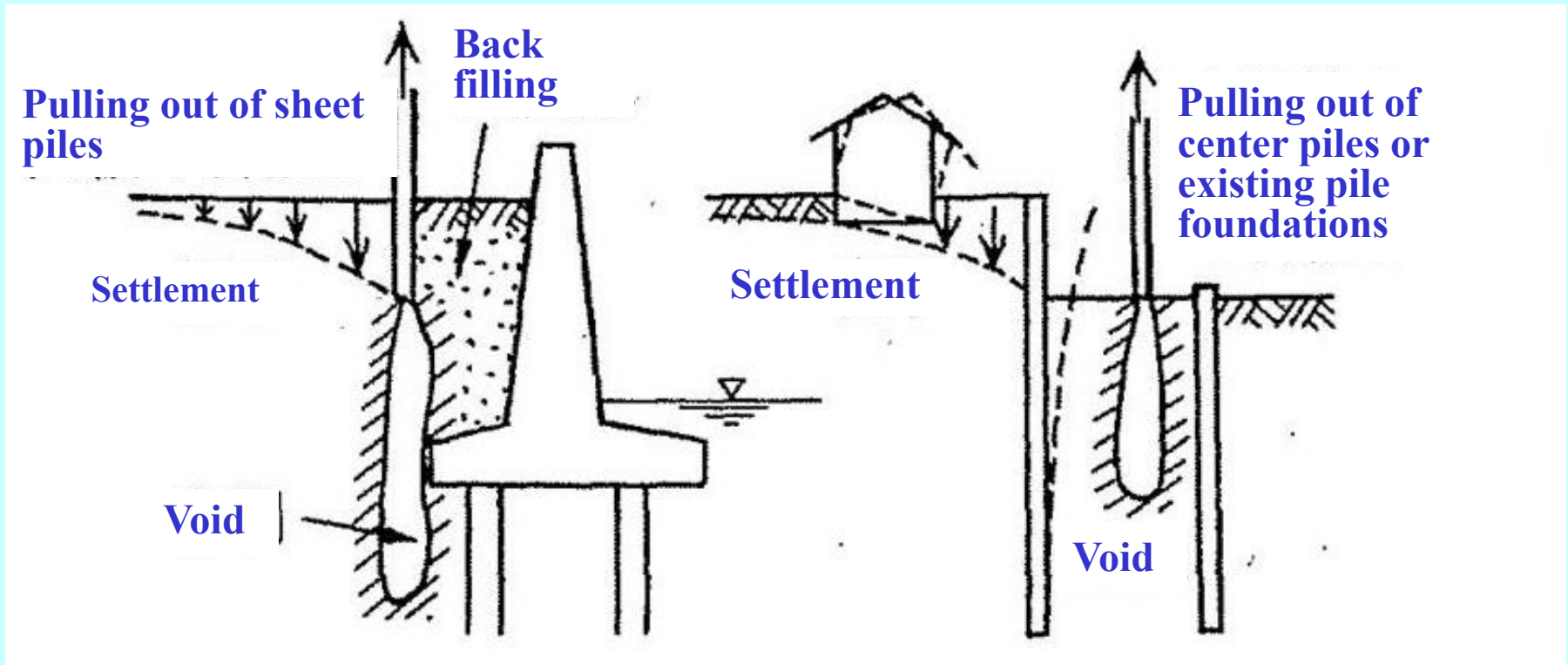
4. Settlement due to consolidation of clayey layer with lowering of the underground water level by draining.



5. Ground deformation due to heaving or boiling.

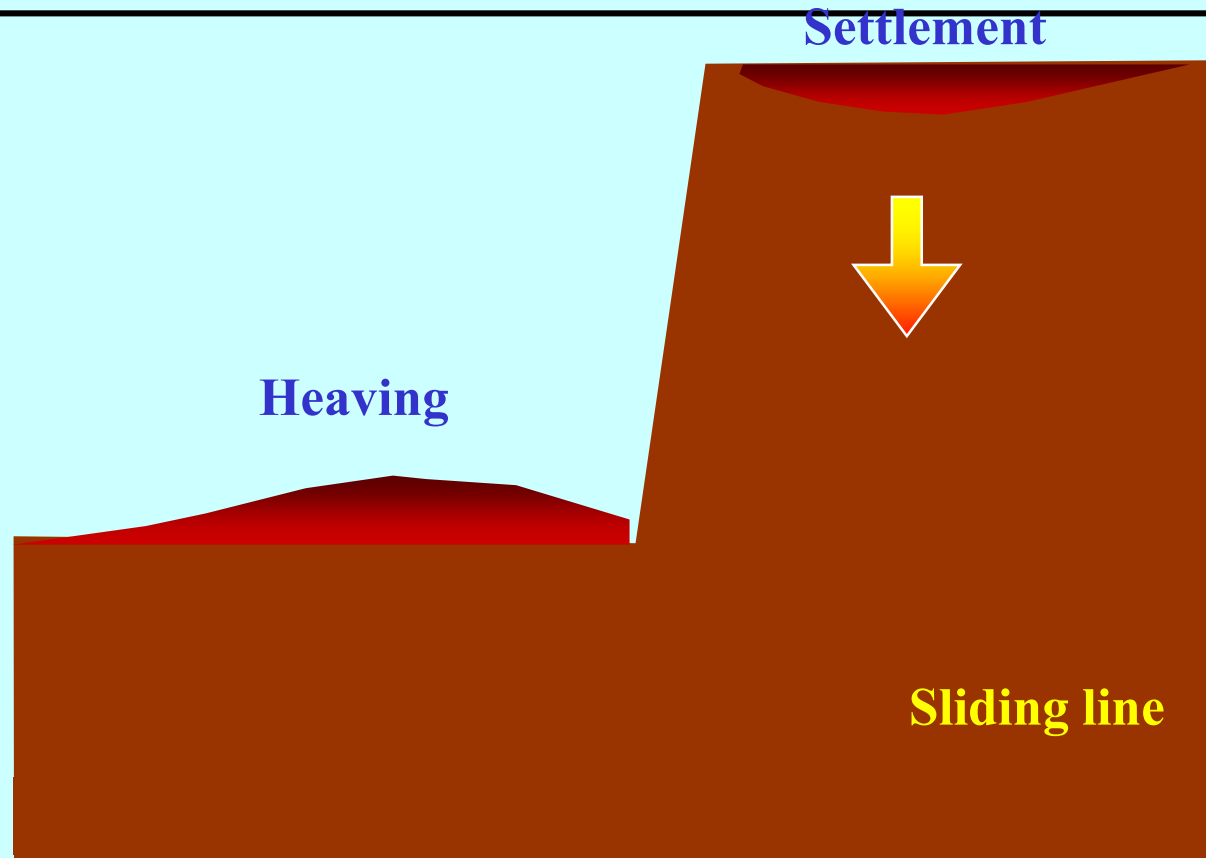


6. Ground deformation due to rebound of ground with the excavation.



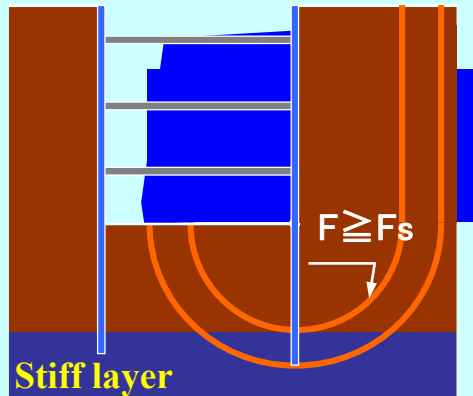
7. Ground deformation due to removal of struts or retaining walls.

Heaving

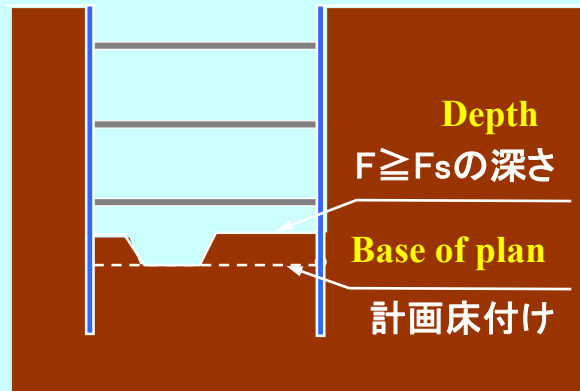


Heaving: The phenomenon is that the bottom surface of the cutting heaves remarkably , because the soil of behind a retaining wall moves to the excavation side in the soft clay ground due to excavation.

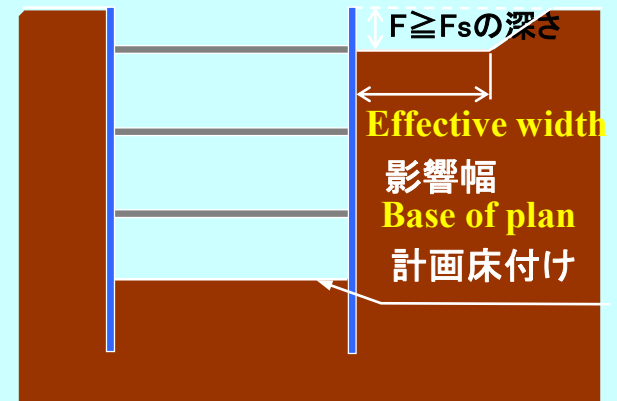
Examples of countermeasures for a heaving



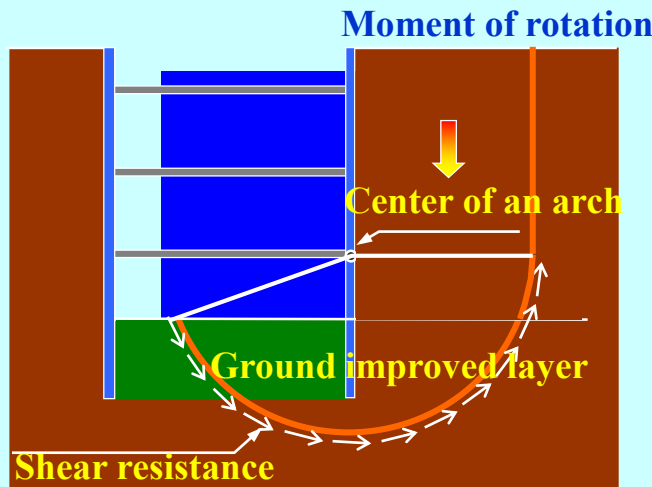
1. Increasing the length of the embedded part



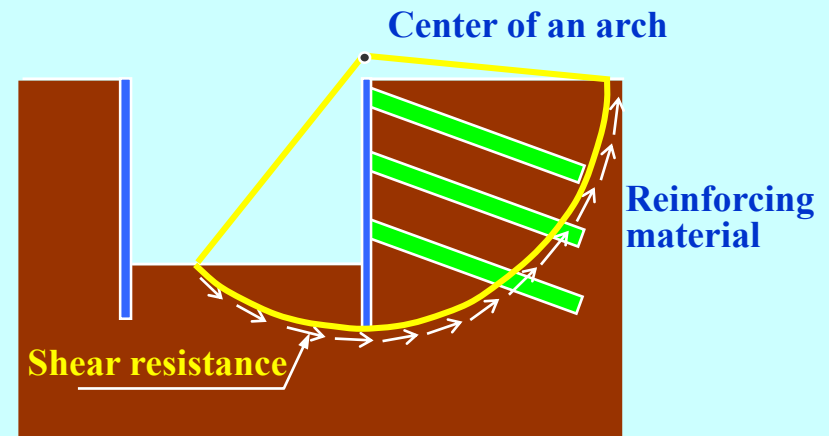
2. Change of excavation procedure



3. Removing the soil of behind a retaining wall



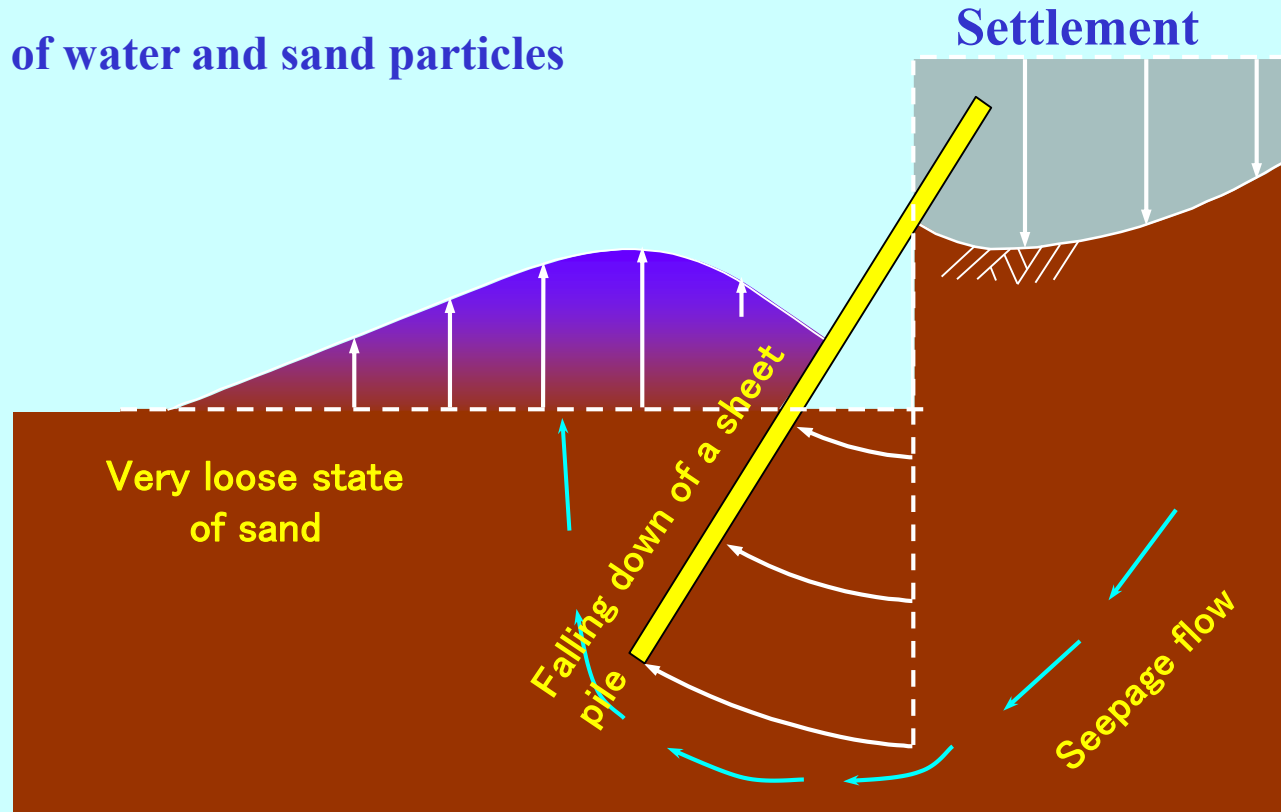
4. Ground improvement method



5. Reinforced soil method

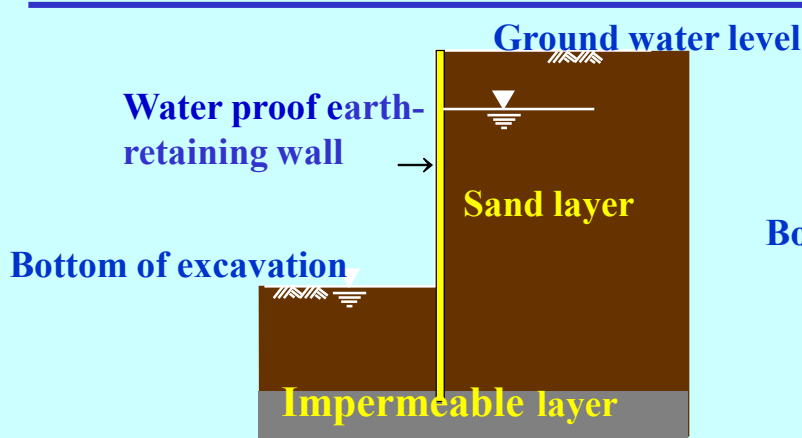
Boiling

Blowing out of water and sand particles

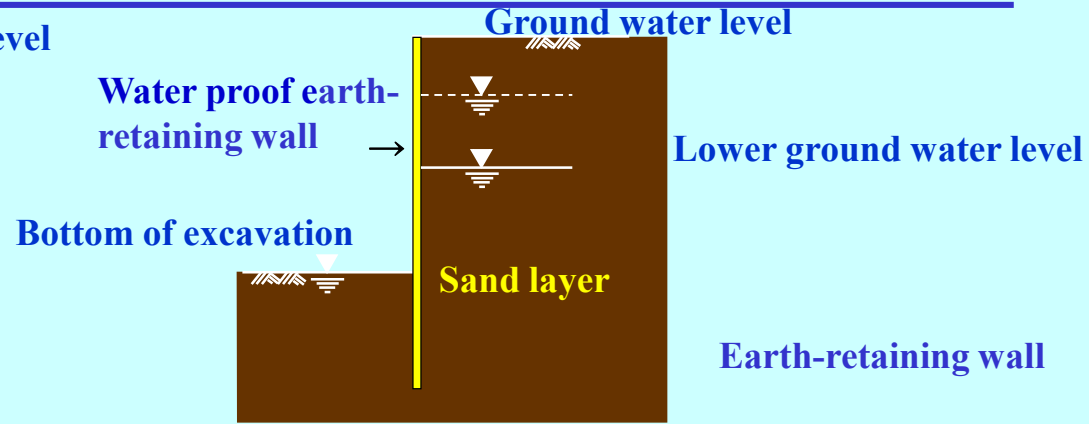


Boiling: The phenomenon is that the ground at bottom of excavation liquefies and the sand particles blow out in the sandy ground due to seepage force in the sandy ground.

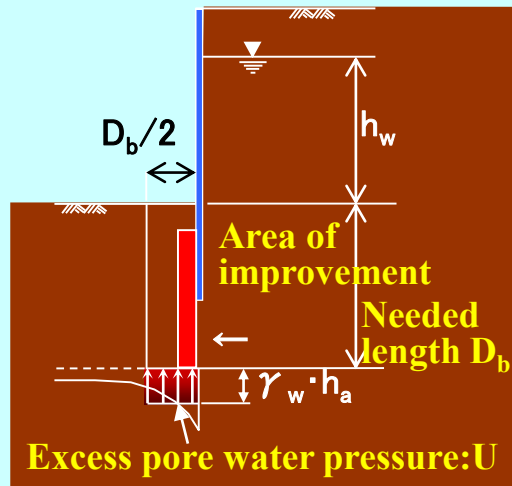
Examples of countermeasures for a boiling



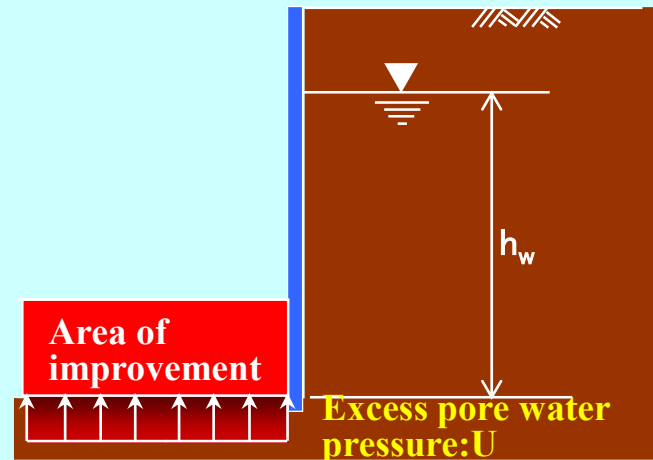
1. Increasing the length of the embedded part



2. Groundwater decline

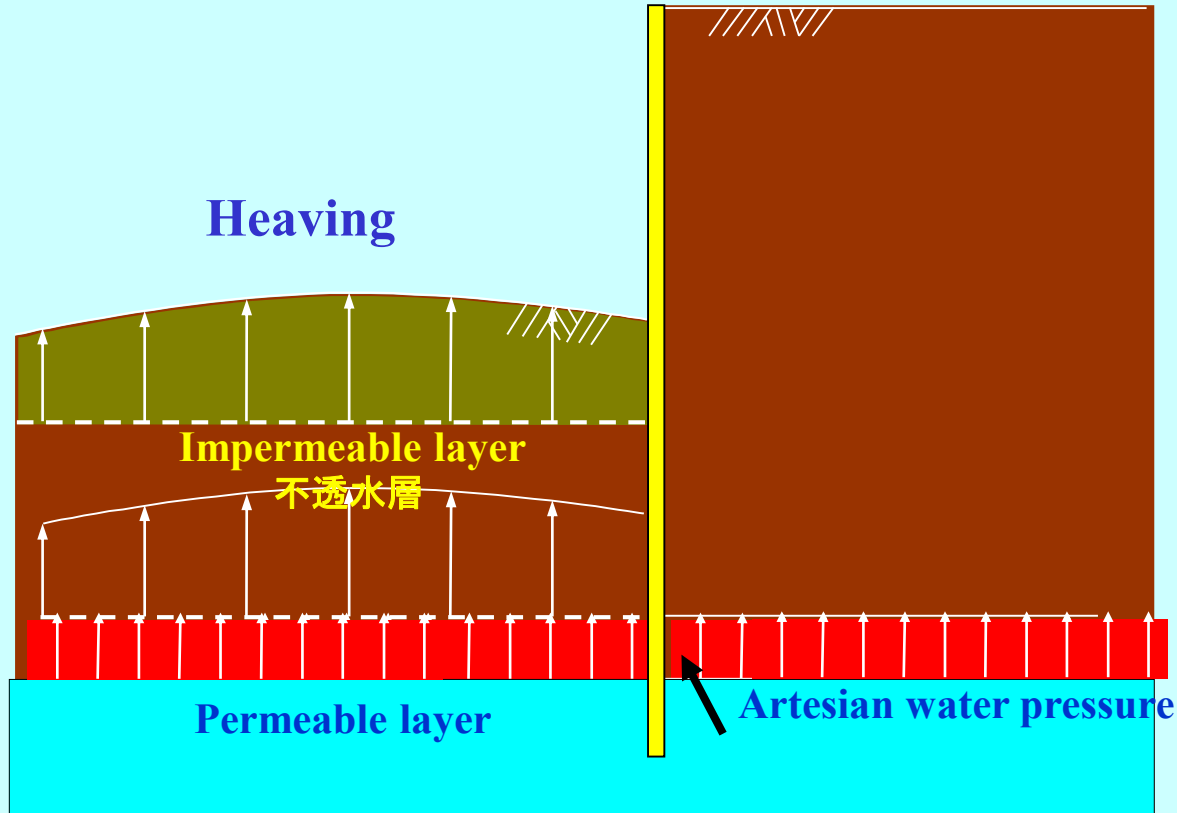


3. Making water prevent walls by grouting method



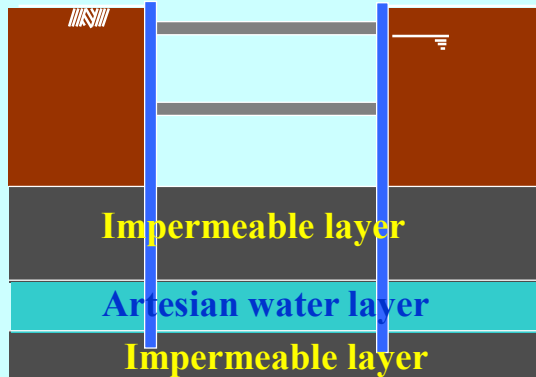
4. Making an impermeable layer by grouting method

Heaving

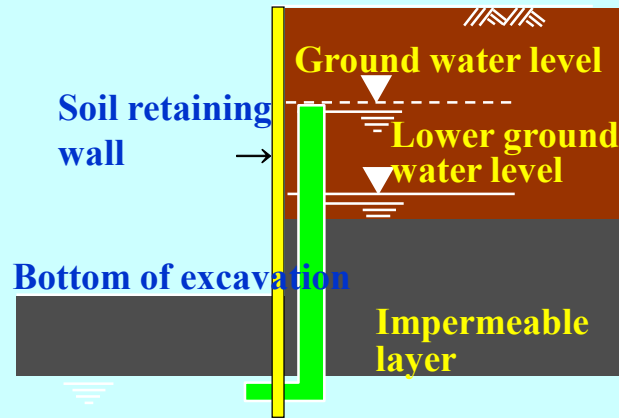


Heaving: The phenomenon is that the ground at bottom of excavation swell up due to the upward water pressure by artesian water in a permeable layer below an impermeable layer. Heaving occurs when the upward force become lager than a resistance force of upper ground.

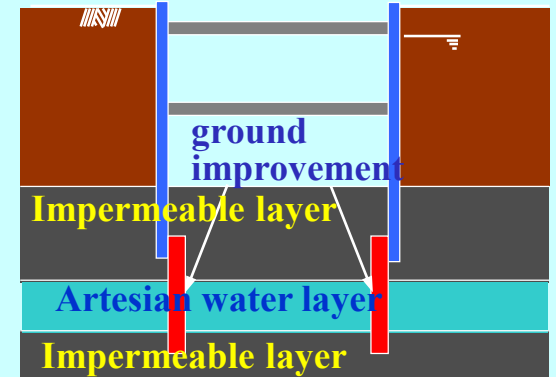
Examples of countermeasures for a heaving



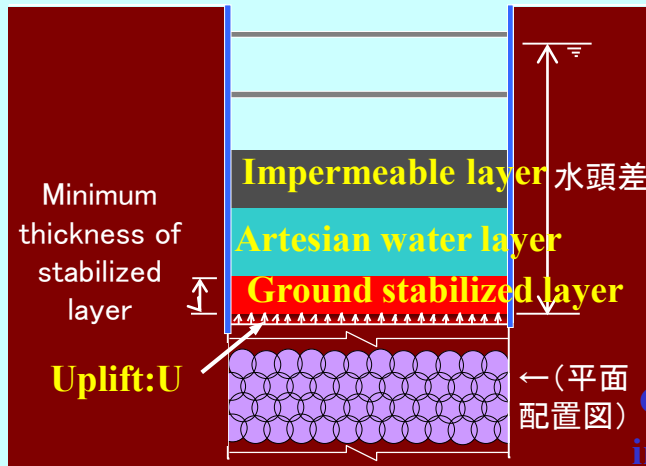
1. Set soil retaining wall in an impermeable layer



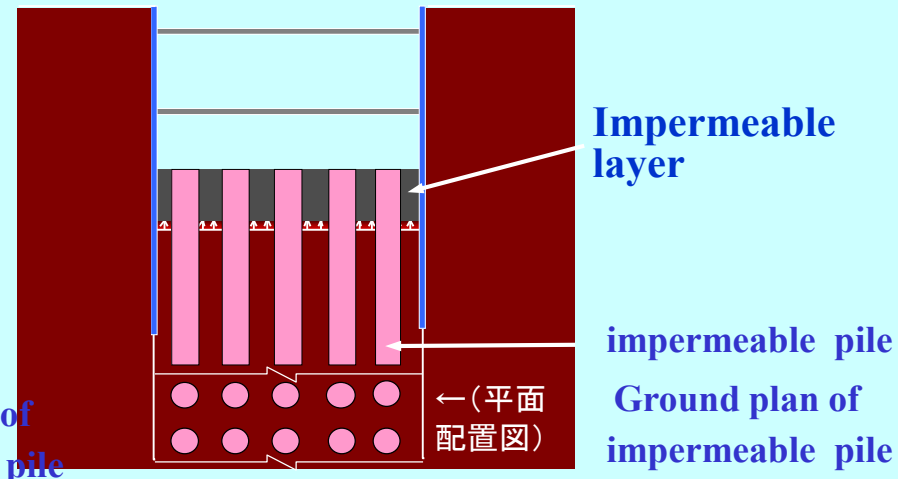
2. Groundwater decline



3. Making water prevent walls by ground stabilization method



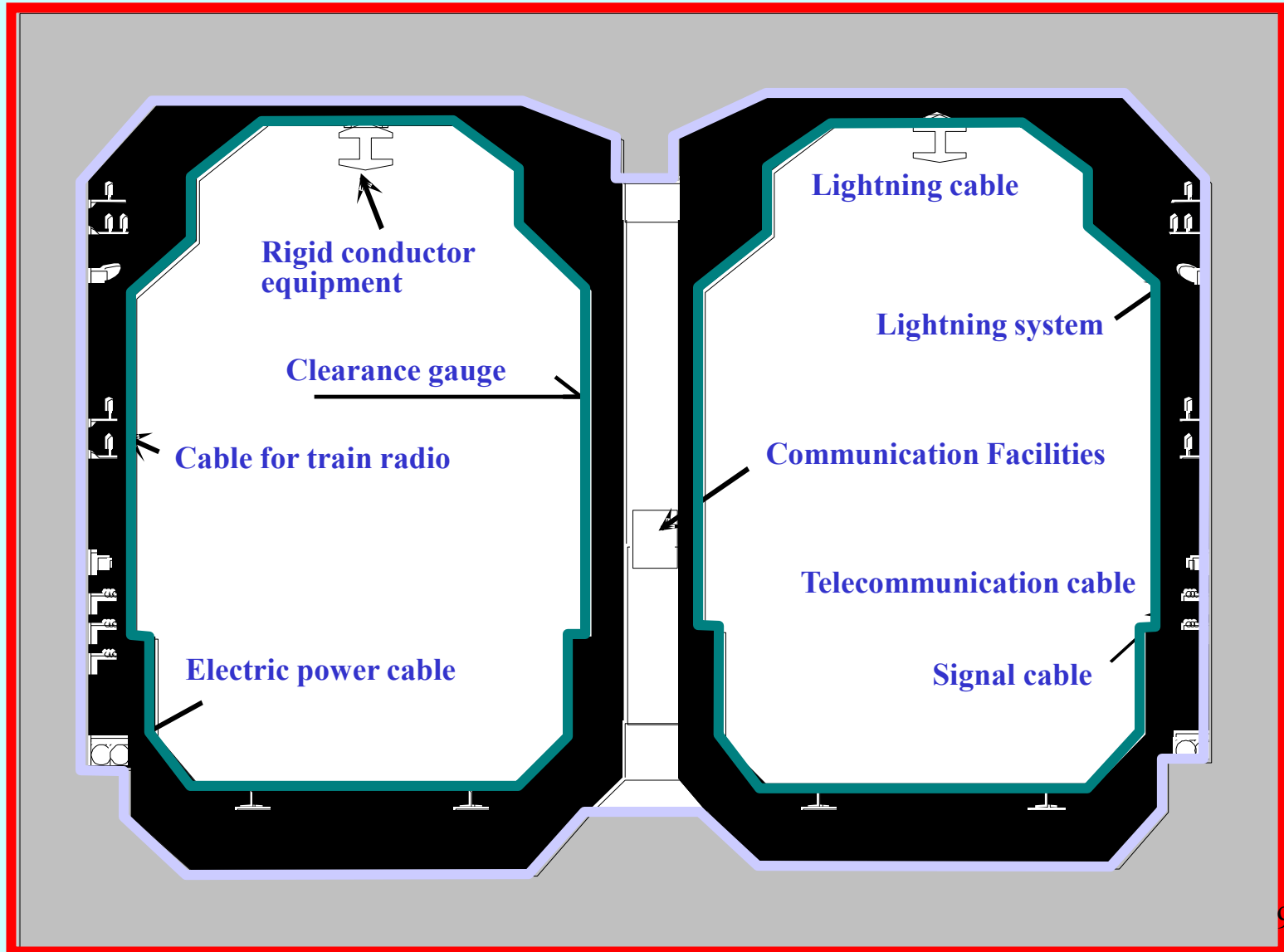
4. Making an impermeable layer by ground stabilization method



5. Pile type ground stabilization

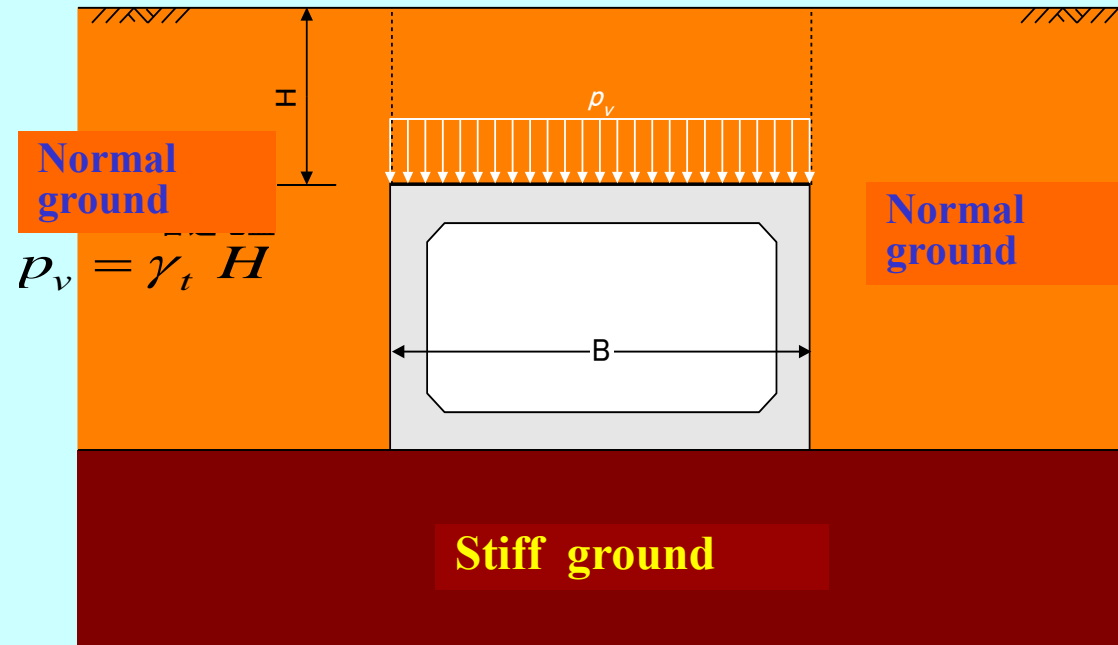
Design procedure for body parts of cut & cover method

An example: A Cross section of railway tunnel



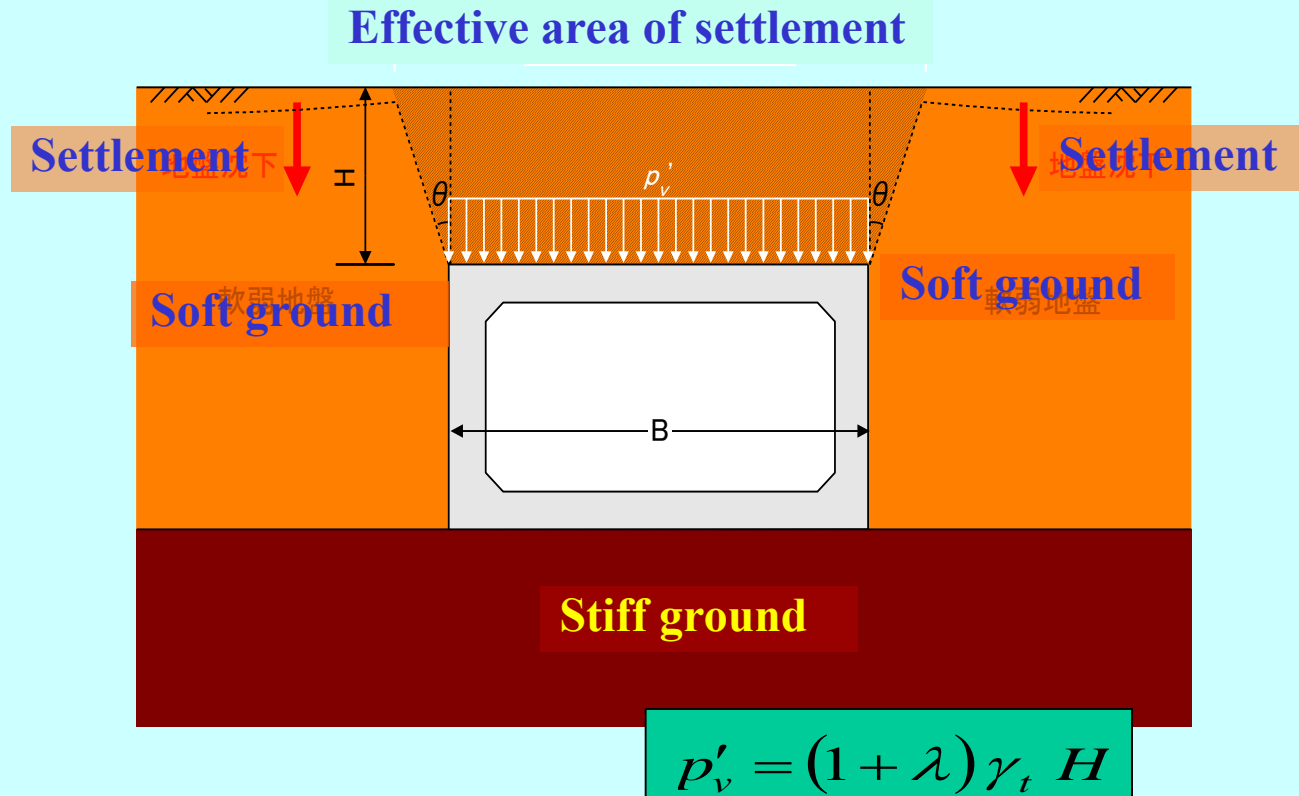
Vertical earth pressure under the general condition

Vertical earth pressure



- p_v : Vertical earth pressure
- γ_t : Wetting unit weight of the soil at upon the tunnel
- H : Overburden

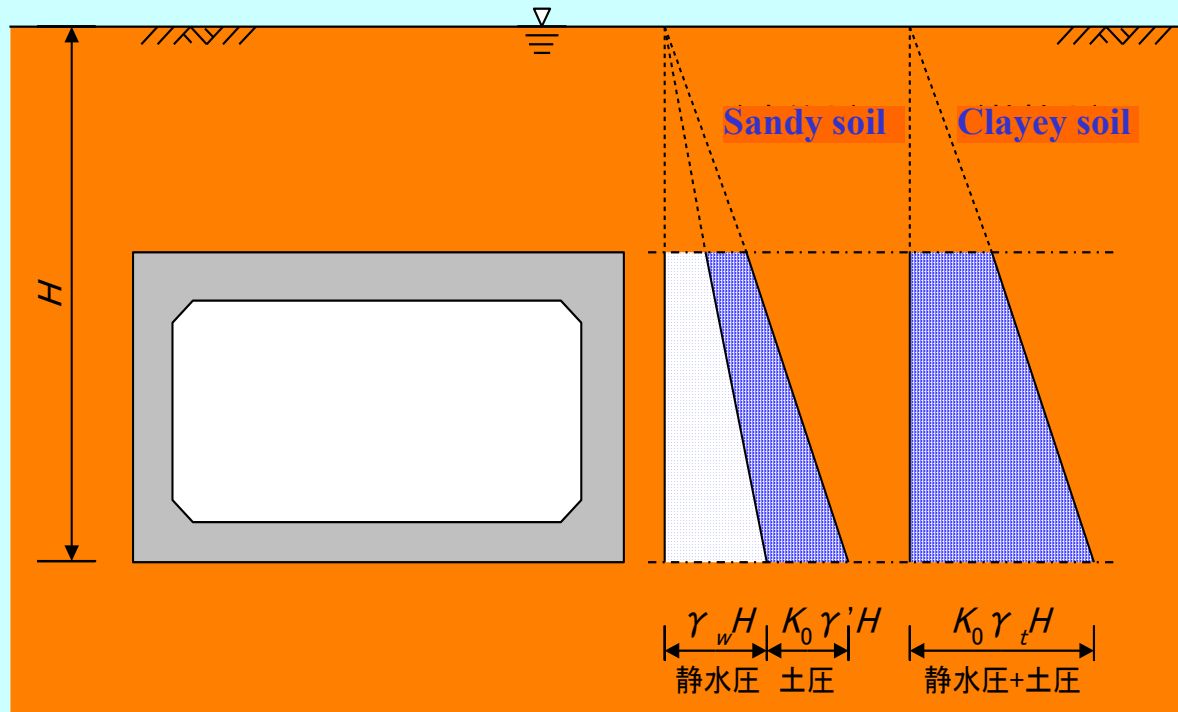
Vertical earth pressure under the condition with settlement of the surrounding ground



- p'_v : Vertical earth pressure
- λ : Extra coefficient
- $\lambda = \tan \theta \cdot H/B$
- γ_t : Wetting unit weight of the soil at upon the tunnel
- H : Overburden
- $\tan \theta$: Effective area (usually 0.25)
- B : Width of the tunnel

Lateral earth pressure

Earth pressure by permanent load

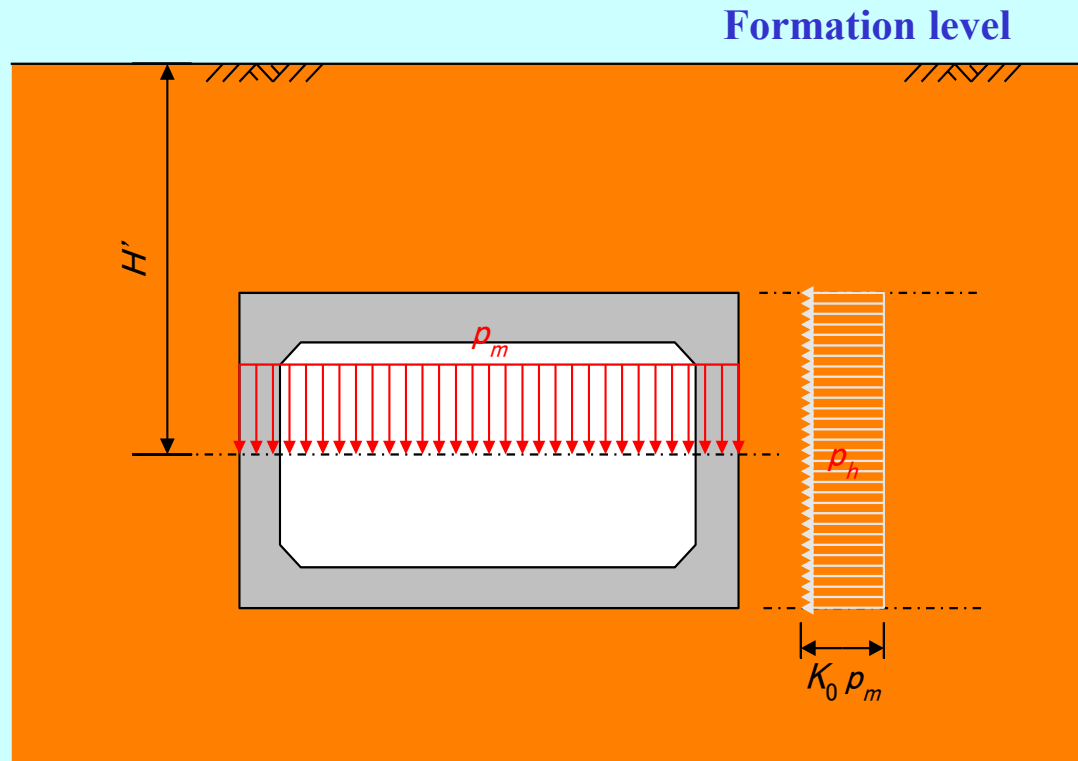


$$p_0 = K_0 \gamma_t H$$

- p_v' : Vertical earth pressure
- λ : Extra coefficient
- $\lambda = \tan \theta \cdot H/B$: Wetting unit weight of the soil at upon the tunnel
- γ_t : Overburden
- H : Effective area
- $\tan \theta$: Width of the tunnel
- B :

Lateral earth pressure

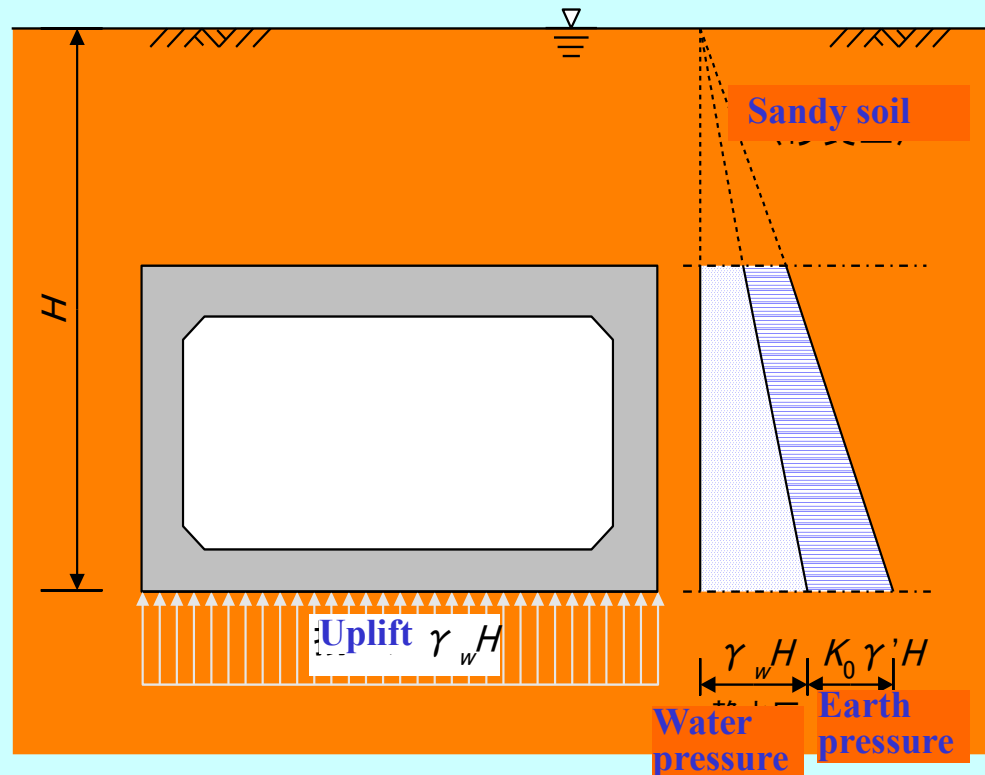
Earth pressure by variable load



$$p_h = K_0 p_m$$

- p_h : Lateral earth pressure by variable load
- p_m : Vertical earth pressure at at one half height of the tunnel for calculation of bending moment
- H' : Depth at one half height of the tunnel

Uplift



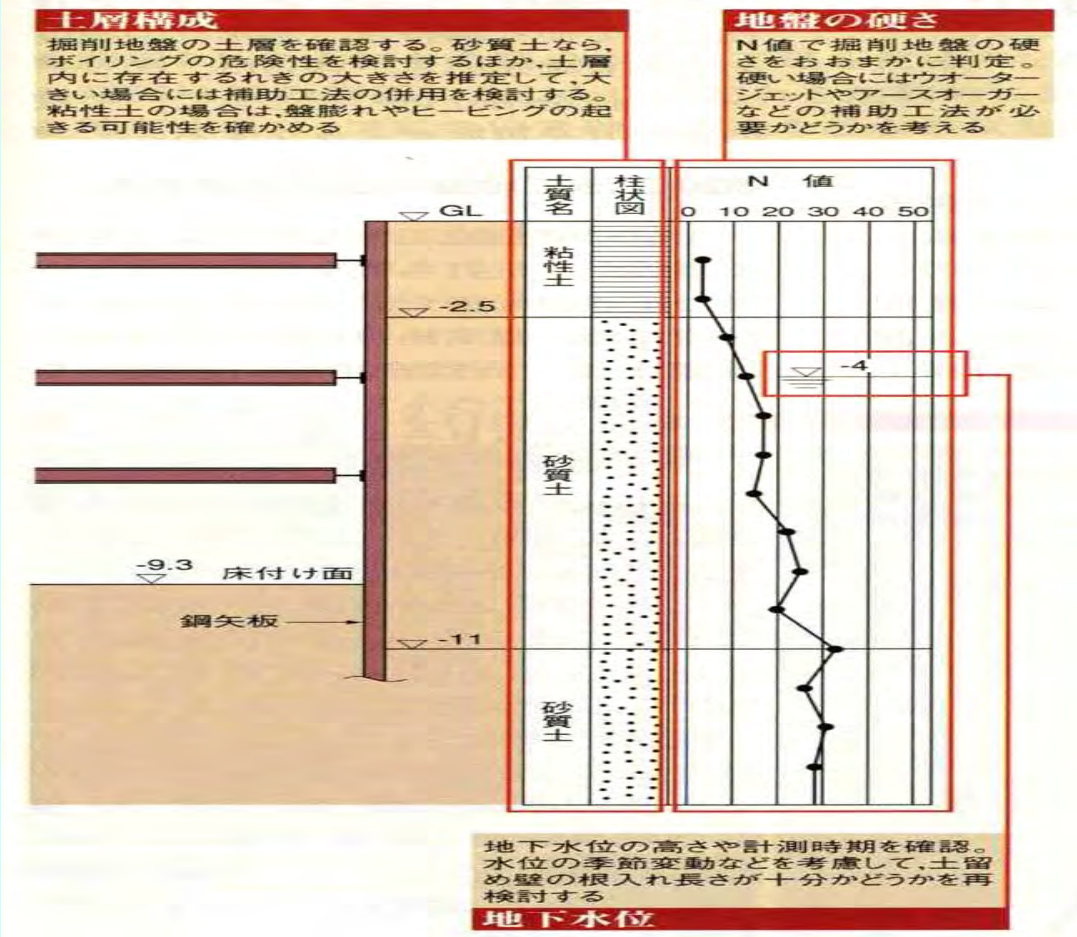
When ground water has artesian water power, special considering is necessary.

Additions

Point1 Check on design conditions

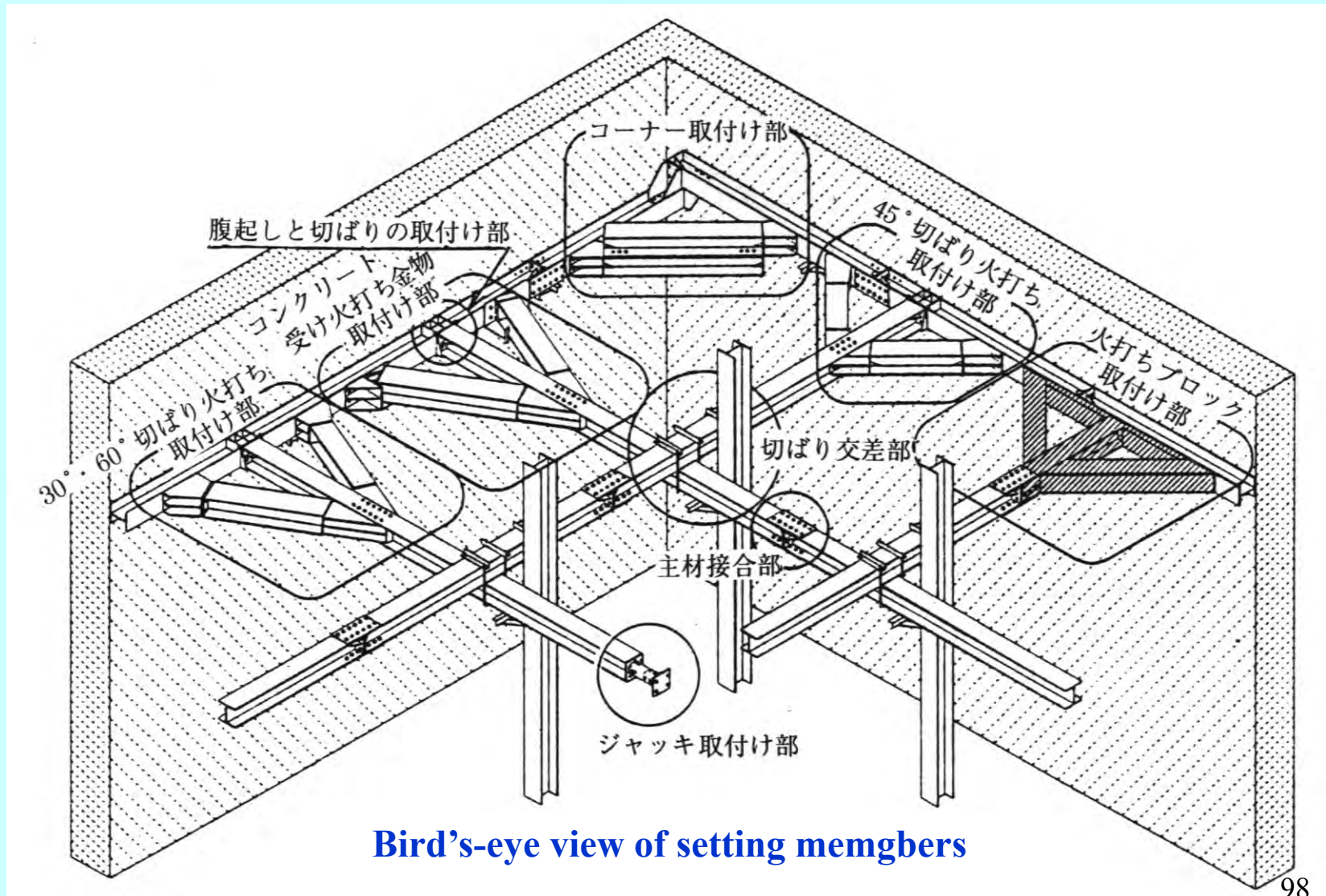
Is there any deference between conditions of design and it of construction site?

- Deference of underground water level.
(Observation of the underground water level)
- Deference of ground layer composition.
(Observing appeared soils with excavation.)



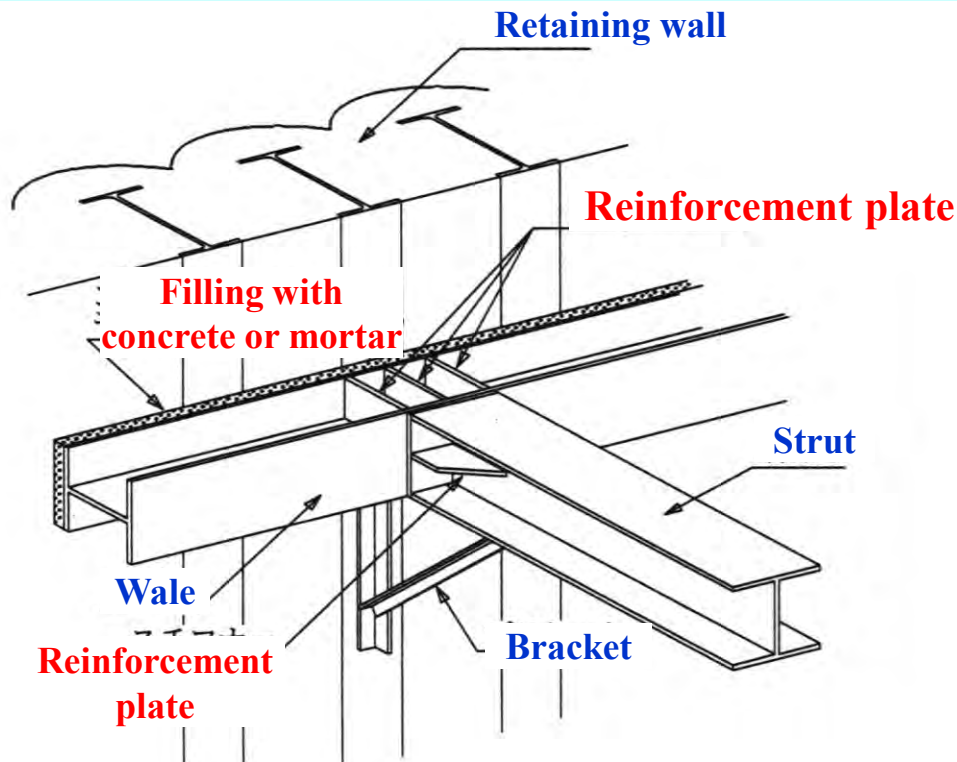
Point2 Check on setting of members

Make sure to set members.

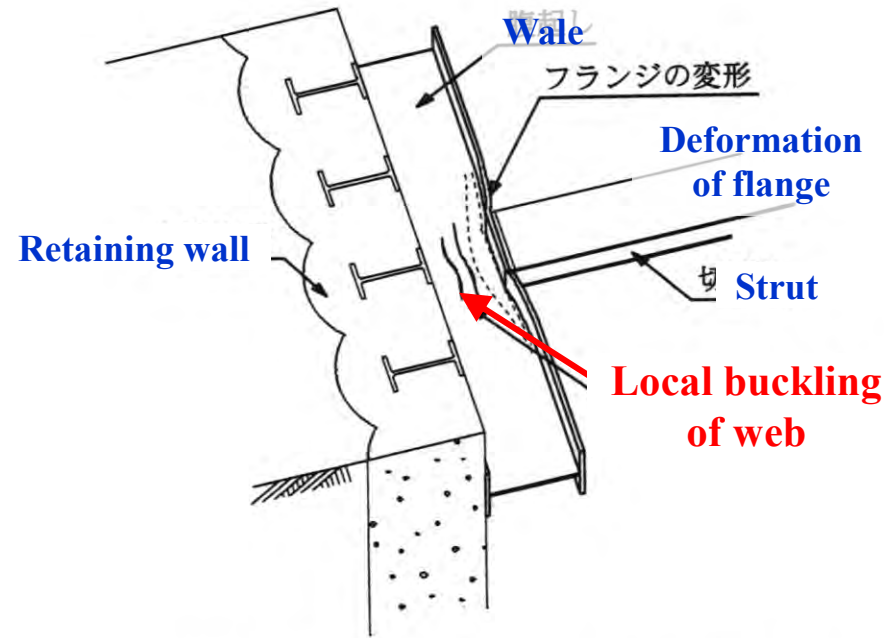


Important notice No.1 of setting members

- >For transmitting load to a wale equally, fill in voids between a retaining wall and wale.
- >For preventing a local buckling and deformation, reinforcement plate is placed at the joint between a wale and strut .



Explanation drawing
Structural examples of the
joint between a strut and wale

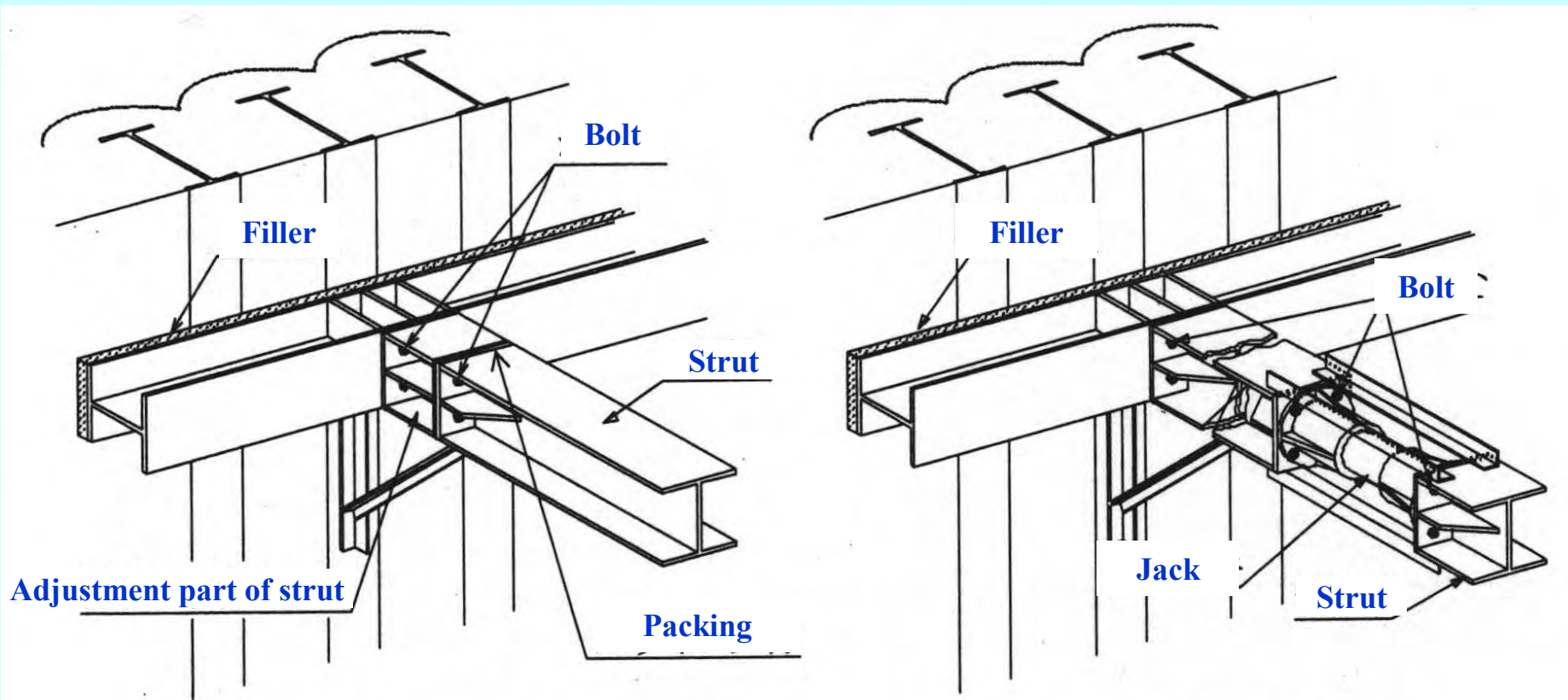


Explanation drawing
Local buckling at joint
between wale and strut

部破壊

Important notice No.2 of setting members

> Touch the strut to the wale without looseness at the joint.



(a) Case of using adjustment parts

(b) Case of using jacks

Explanation drawing Structural examples of the joint between a strut and wale

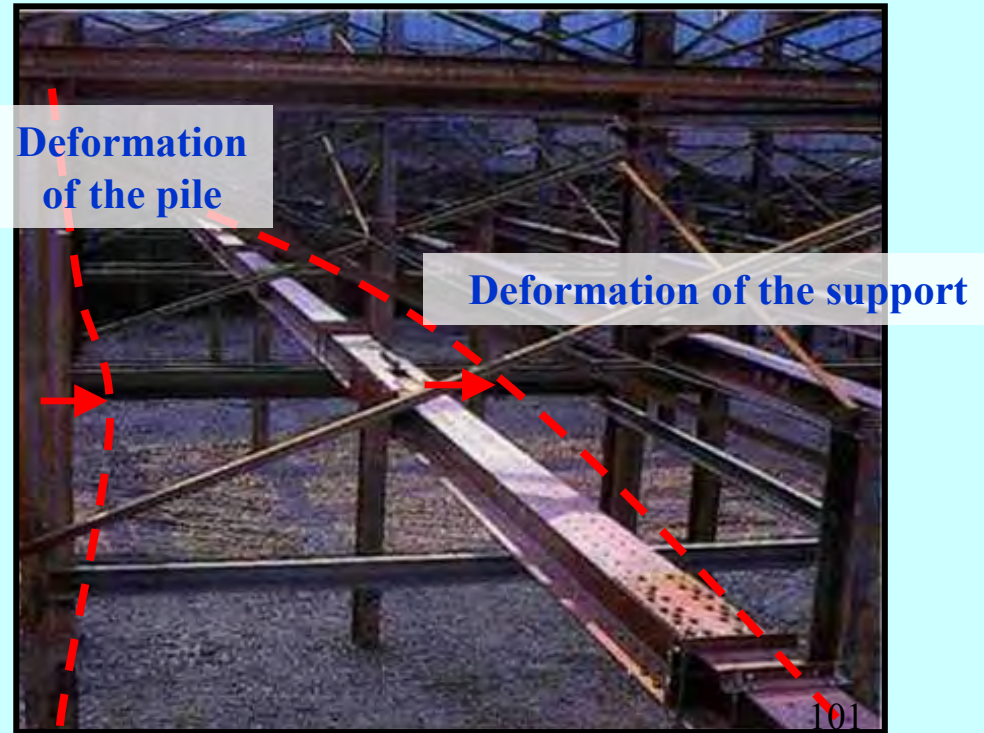
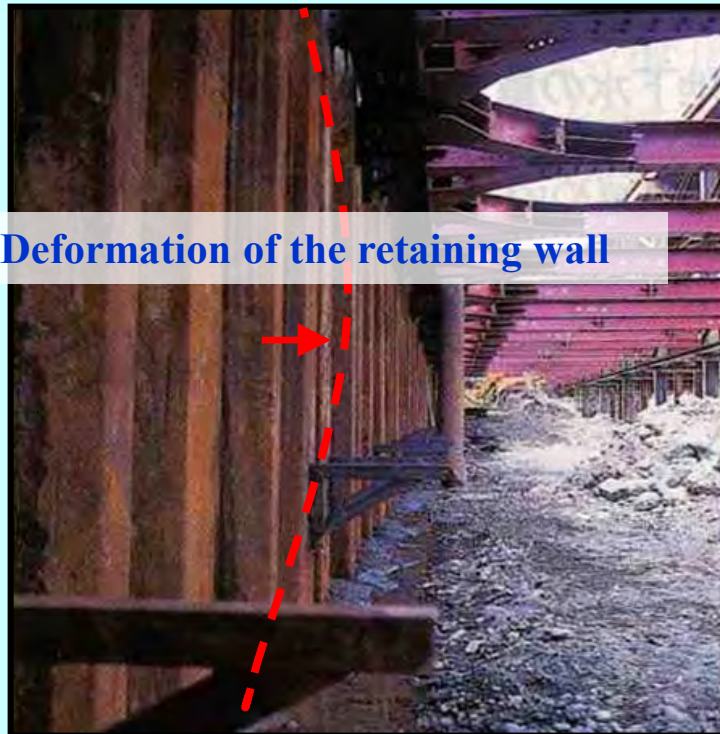
Point3 Deformation of members

Is there some deformation of retaining walls, supports and piles?

>Check up deformation or bend of the wall. ➡ same as design values?

>Is there break, winding, bending of supports?

➡ Increase of earth pressure, lack of reinforcement for support members.



Point4 Check on looseness or drop of bolts

Do bolts come loose? Do bolts come out?

>The place on which shaking, vibration or deformation are given to happen.

➡ Check on looseness of bolts and deformation of steel materials by observation.

>Is there break, winding, bending of supports?

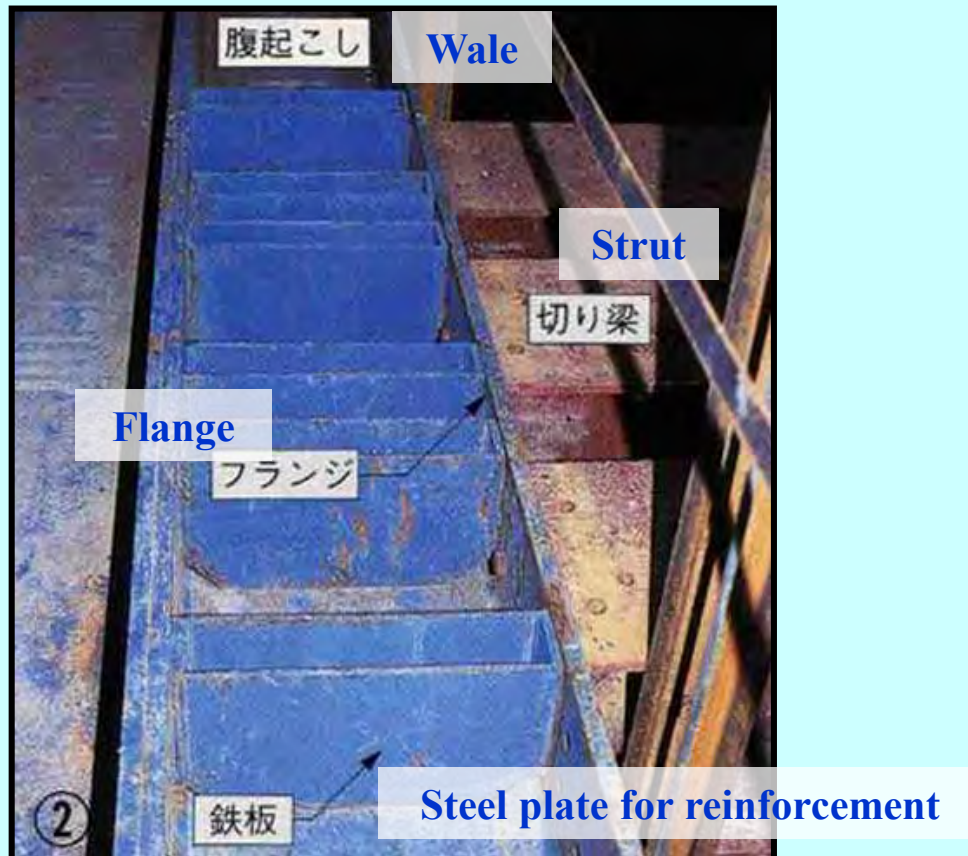
➡ Increase of earth pressure, lack of reinforcement for support members.



Point5 Check on local buckling of steel members

Do steel members deform with buckling?

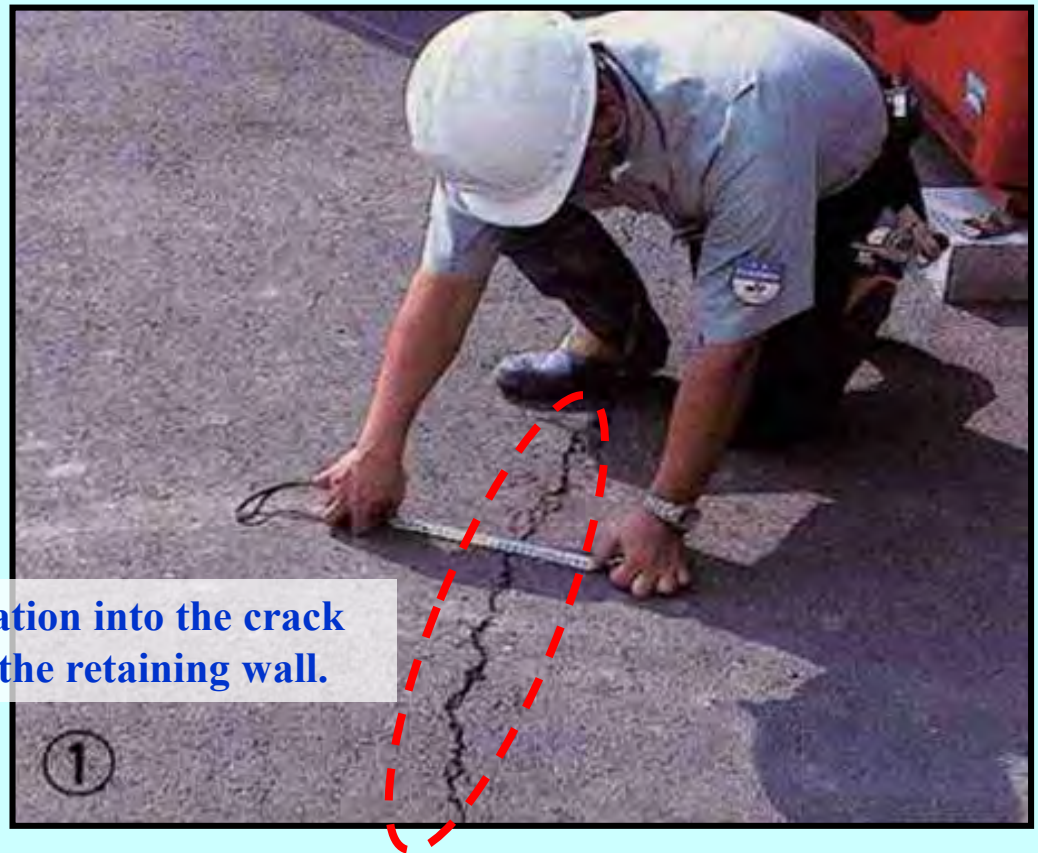
- > Check on the parts on which loads act concentratedly.
- > Are steel members reinforced?



Point6 Check on deformation of surrounding ground and adjacent structures

Are there any cracks behind retaining walls?
Are there any deformation in the structure?

- > Are cracks growing?
- > Try to find the cause:
 - Situation of work in the site.
 - Deformation of a retaining wall
 - leakage from a wall
 - Movement of a heavy machine
 - machine
 - etc.



Investigation into the crack behind the retaining wall.

Point7 Check on leakage of water from walls

Are earth and sand mixed with leakage of water?

➤ A void in the ground is growing due to flowing out of soil particles.

➔ Develop into a cave-in in the road



Point8 Check on spring water from base of the excavation

Does water spring from a base of excavation?

➔ Piping, Boiling

- Observation on the surrounding of piles and retaining walls.
- Need care to the spring water raising a cloud of soil particles!



All steel supports (Hibiya line)



For engineer, it is important to feel at a glance that the support system has good balance or not, stable or unstable.

My advice for engineer (on a construction site)

1. Feel strangeness at a glance. ➡ >Knowledge, Experience
(look at various construction sites.)

2. Think ahead. ➡ >Predict possible troubles. ➡ >Avoid troubles.
>Preparation for taking countermeasures to the troubles.

3. Simple is the best. ➡ >Complexness causes accidents.

4. Time is money. ➡ >Decide quickly how to cope with a trouble
when it happen.
>Buy time.
>After that, modified the countermeasure with observing the situation.

(If the possibility that a countermeasure will succeed is over 50%,
you have to go ahead.)

5. Imagination is very important. ➡ >Image what's happen and how
does it happen in the blind spaces.