Cut and Cover Tunnel

Construction of a station by cut & cover method

Road decking panel

Rectangular shaped tunnel

Support

Retaining wall

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Shinji KONISHI
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

<table>
<thead>
<tr>
<th>NATM</th>
<th>Shield</th>
<th>Cut &amp; cover</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shot Crete, Steel support, Rock Bolt</strong></td>
<td><strong>Segmental Lining.</strong></td>
<td><strong>Earth-retaining wall, Main body</strong></td>
</tr>
<tr>
<td><strong>Making full use of the natural support function of the surrounding ground</strong></td>
<td><strong>The skin plate of the shield machine, outer backfill layer of the shield and the segmental support the wall of the tunnel.</strong></td>
<td><strong>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.</strong></td>
</tr>
<tr>
<td><strong>Prerequisite condition is that face remains standing when excavated</strong></td>
<td><strong>Closed-type shield stabilizes the face using earth or slurry to counter earth or hydraulic pressure.</strong></td>
<td></td>
</tr>
</tbody>
</table>

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![NATM Image](image1.png)

![Shield Image](image2.png)

![Cut & cover Image](image3.png)
### COMPARISON-2. Countermeasure for underground water

<table>
<thead>
<tr>
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<th>Shield</th>
<th>Cut &amp; cover</th>
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</thead>
<tbody>
<tr>
<td>• 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.</td>
<td>• Usually, closed type shield does not required countermeasure s, but the open type does.</td>
<td>• Countermeasures such as deeper penetration of earth retaining wall, groundwater reducing method, soil improvement etc. are usually necessary to overcome boiling or heaving.</td>
</tr>
</tbody>
</table>

![Natural water level and deep well diagram](image-url)
When a structure is needed to construct in underground,

If there is no limitation of the ground surface and surroundings,
When a structure is needed to construct in underground,

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, if there are limitations of the ground surface and surroundings,

- **Road decking**
- **Suspended guard**
- **Earth-retaining wall**
- **Strut**
- **Wale**
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.
Composition of earth-retaining structure (Solider pile with lateral lagging)
Types of earth-retaining wall - 1

(a) Solid pile with lateral lagging

(b) Steel pipe sheeting

(c) Steel pile sheeting

An easy method  Weak
Cheap  For shallow tunnel
Fast  >-20m

U shaped steel sheeting pile
H shaped steel sheeting pile
Z shaped steel sheeting pile
Types of earth-retaining walls - 2

(d) Column-type underground diaphragm wall

(e) Underground diaphragm wall

(f) Slurry solidified diaphragm wall

Installed in every hole

Installed in alternate hole

(g) Soil-cement diaphragm wall

Staggered layout

Overlapping layout

An advanced technology

Rigid, Strong

Large scale

For deep tunnel

Expensive

Colum-type: >-50m

Long time

Diaphragm wall: >-150m

For deep tunnel

Colum-type: >-50m

Large scale

Expensive

Rigid, Strong
Execution of earth-retaining wall

Soil-cement diaphragm wall

SMW polyaxonal mixing auger machine

Plant

Crawler crane

Excavator

Corer material (H-shaped steel)
Types of support methods - 1

(a) Unbraced soil retaining work
- Embedded part
- Bottom of excavation
- Free length of anchors
- Fixed length of anchors

(b) Strut type soil retaining work
- Soil retaining wall
- Wales
- Wale
- Strut
- Tie-load
- Anchor-pile

(c) Ground anchor soil retaining work
- Bottom of excavation
- Land behind the wall is needed

(d) Tie-load with anchor-pile type soil retaining work
- Useful underground space
- Inconvenience space

An easy method
- Cheep
- Fast

For shallow tunnel
- Useful underground space
Types of support methods - 2

Soil-cement diaphragm wall

- Ground anchor
- Bracket
- Plinth
- Wales
- Soil-cement diaphragm wall
- Corer material (H-shaped steel)
Procedure of cut and cover method

Presented by Tokyo Metro Co., Ltd.
Standard Structure of a Tunnel

**Station tunnel**

- Cut & cover tunnel

**Running tunnel**

- Single track
  - Single track tunnel: 300m, 6,700mm
- Double track
  - Double track tunnel: 450m, 9,800mm

**Shield tunnel**
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

Stiff ground

(Simple procedure)

Center pile

Column-type underground diaphragm wall

Underground diaphragm wall

Upside-down Construction method

Soft ground

(Complex procedure)

Center pile

Slab of upside-down construction

Underground diaphragm wall

Upside-down construction method

Standard Construction method
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.
Road decking panel

Underground Diaphragm wall

Center pile
Upper Floor Slab

Construction of the upper floor slab
Middle Floor Slab

Construction of the middle floor slab
Base Slab Construction of the base slab
Construction of the inner part

構内構築工
Procedure 1 of a cut & cover method-1

1. Preparation
2. Removing a sidewalk
3. Construction of a retaining wall
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

7. Construction of tunnel
Placing concrete
Procedure of a cut & cover method

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

Metropolitan Expressway

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

Underground water

Underground water
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

Underwater excavation

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**

- **1940**
  - Marunouchi line
  - HiBiya line
  - Touzai line
  - Chiyoda line
  - Yurakuchou line
  - Hanzoumon line
  - Nanboku line
  - Fukutoshin line

- **1950**
- **1960**
- **1970**
- **1980**
- **1990**
- **2000**
- **2010**

**Notes:**
- **Soldier pile with lateral lagging method**
- **Driven pile**
- **Bored pile**
- **Column-type underground diaphragm wall**
- **Single axis, Reinforcing bar basket**
- **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**
- **Road decking**
  - **Wooden**
  - **Steel**
  - **52**
A record of subways in Tokyo

Ginza line 16m 1934
Marunouchi line 17m 1959
Hibiya line 23m 1964
Touzai line 26m 1967
Chiyoda line 35m 1969
Yuurakucho Line 32m 1974
Hanzoumon line 39m 1982
Nanboku line 43m 1996
Ooedo line 49m 2000
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

Reinforcing bar basket
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)
Steel strut

Wooden strut

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

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

Surveying

Planning

Hypothesizing design condition

Design START

Deciding ground constant
Hypothesizing groundwater level
Construction environment

· Setting cutting range
· Soil retaining work
· Support work
· Cutting method
· Auxiliary work method

Studying

Is it sandy soil with high groundwater level?

Yes

Studying boiling

No

Is there artesian water below the bottom surface of the cut?

Yes

Studying heaving

No

Is it soft clay ground?

Yes

Studying heaving by background loads

No

H ≥ 15m

Yes

Selecting soil Retaining wall

No

Is it customary design methods?

Yes

Computing embedding depth
Studying support work and wall surface

No

Can be used as main body

Hypothesizing cutting method and sequence, support work type and location

Computing load
Soil Retaining Work Design Flow Chart 2

Computing design
Embedding length

No
Section computing of wall body

No
Studying struts

Studying wales and angle braces

Computing deformation of soil retaining wall

No
Is displacement of the soil retaining wall within the allowed value?

Yes
Estimating displacement of surrounding structures

END

No
Allowed value decided based on tie-ins with main structure
Allowed value decided based on failure of background

Embedding decided based on balance of moments
Embedding decided based on boiling, creeping, and heaving
Embedding based on bearing force

Struts
Ground anchors
Reinforcing material

Allowed value based on surrounding environment condition
Schematic drawings of Lateral pressure

Sandy soil

Clayey soil

- Passive lateral earth pressure
- Active lateral earth pressure
- Pore pressure

主働土圧
主働側圧
間隙水圧
受働側圧
間隙水圧
受働土圧
Depth of embedment

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

- Methods of using apparent earth-pressure
  - One half share method
  - Lower share method
  - Simple beam method
  - Continuous beam method

- Methods of using actual earth-pressure
  - Elastic method
  - Elasto-plastic method
  - Plastic method
  - Virtual support method

- Finite Element analysis
  - Elastic analysis
  - Elasto-plastic analysis
Outline of a simple beam method

Active earth pressure, water pressure for calculation of a section

Virtual support

Passive lateral earth pressure
Passive lateral water pressure

Virtual support: An action point of the resultant passive lateral force $P_p$ against balanced depth $D$ of embedment.
Stress calculation by Elasto-plastic method

(Cut side surface)  
Existing struts

(Lately bottom of excavation)

Plastic range

Elastic range

Effective passive lateral pressure

Effective active lateral pressure

Elastic reaction force

Average lateral pressure

Equal lateral pressure explanatory figure

An Example of calculation results of stress.
Factors of ground deformations surrounding retaining walls
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: 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

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Stiff layer

F ≥ Fs

Depth

Effective width

Base of plan

Moment of rotation

Center of an arch

Reinforcing material

Ground improved layer

Center of an arch

Shear resistance

Ground improved layer

F ≥ Fsの深さ

影響幅

ベースの計画

仕切床付け

基準層

応力

変位

抵抗
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 water well

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

\[ \gamma_w h_a \]

\[ \frac{D_b}{2} \]

\[ h_w \]

\[ \text{Excess pore water pressure: } U \]
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

- Rigid conductor equipment
- Clearance gauge
- Cable for train radio
- Electric power cable
- Lightning cable
- Lightning system
- Communication Facilities
- Telecommunication cable
- Signal cable
Vertical earth pressure under the general condition

Vertical earth pressure

\[ p_v = \gamma_t H \]

- \( p_v \) : Vertical earth pressure
- \( \gamma_t \) : Wetting unit weight of the soil at upon the tunnel
- \( H \) : Overburden
Vertical earth pressure under the condition with settlement of the surrounding ground

\[ p'_v = (1 + \lambda) \gamma_t H \]

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

(usually 0.25)
Lateral earth pressure

Earth pressure by permanent load

\[ p_0 = K_0 \gamma_t H \]

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

Earth pressure by variable load

\[ \rho_h = K_0 \rho_m \]

\( \rho_h \) : Lateral earth pressure by variable load

\( \rho_m \) : 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
When ground water has artesian water power, special considering is necessary.
Additions
Point 1  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.)
Point 2  Check on setting of members

Bird’s-eye view of setting memgbers
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.

Examination drawing
Local buckling at joint between wale and strut

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

Examination drawing
Local buckling of web

Examination drawing
Filling with concrete or mortar

Examination drawing
Deformation of flange
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
Point 3  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.
Point 4  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.
Point 5  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?
Point 6  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
  etc.

Investigation into the crack behind the retaining wall.
Point 7  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 our of soil particles.

  Develop into a cave-in in the road
Point 8  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!

![Image 2](image2.png)

![Image 3](image3.png)
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.)


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.