

Tunneling methods for Underground Construction

Retaining wall

- **Cut-and cover tunnel(開削工法)** DPW, SPW
 Cheap for shallow but expensive for deep tunnel
subway stations, utility tunnels(共同溝)

- **Shield tunnel(シールドトンネル工法)**
 Standard methods of urban tunnel in Japan

why?

- **Mountain tunneling(山岳工法)**

Conventional methods

NATM (New Austrian Tunneling method)

Cheaper than Shield T., but not applicable in soft ground

Design: Empirical,

Applicable to Unconsolidated ground (cemented gravel and sand) with reinforcement or/and improvement

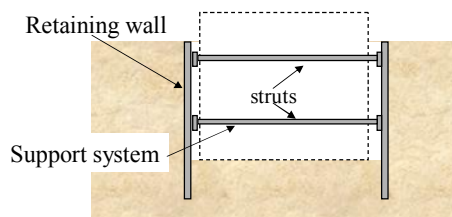
2007/1/31

1

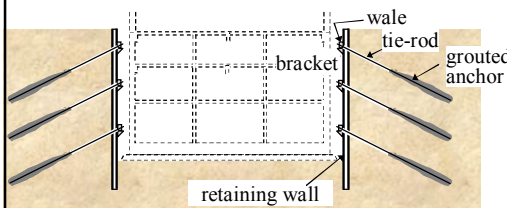
Cut & Cover Tunnelling - Open Deep Excavation -



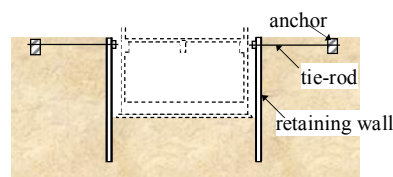
(a) Slope open cut without support



(b) Retained wall open cut



(c) earth anchor (grouted anchor)

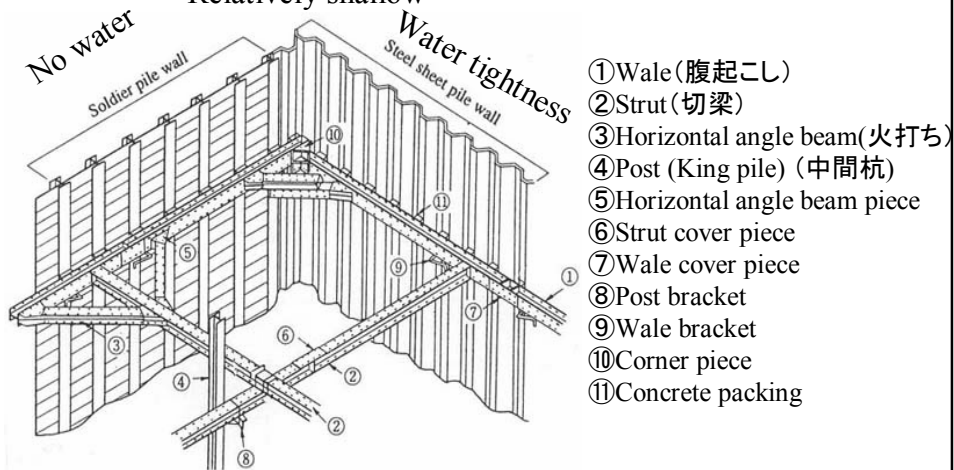


(d) Plate anchor (Tie-rod anchor) 2

Steel sheet pile wall and soldier pile wall

鋼製矢板壁と親杭横矢板壁

Relatively shallow



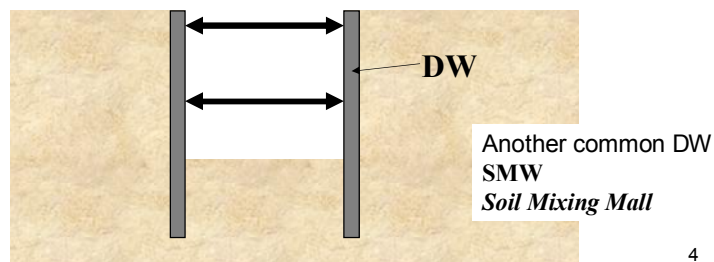
2007/1/31

3

Diaphragm Wall

(地中連続壁: 連壁)

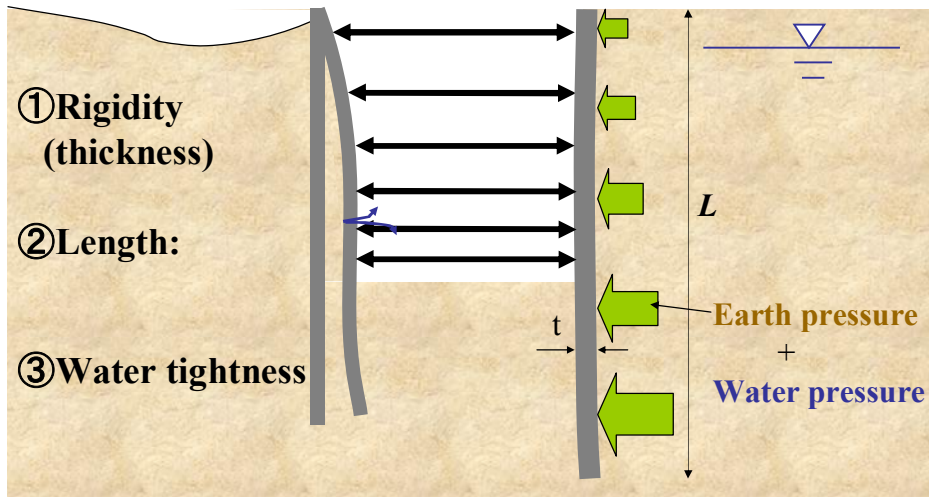
- Commonly used retaining wall in open **deep** excavations of **soft soil** for constructing underground structures
ex) subway station, basement, underground complex, etc
- Cast-in-place concrete wall in the ground



2007/1/31

4

Requirements of retaining wall in deep excavation of soft soil

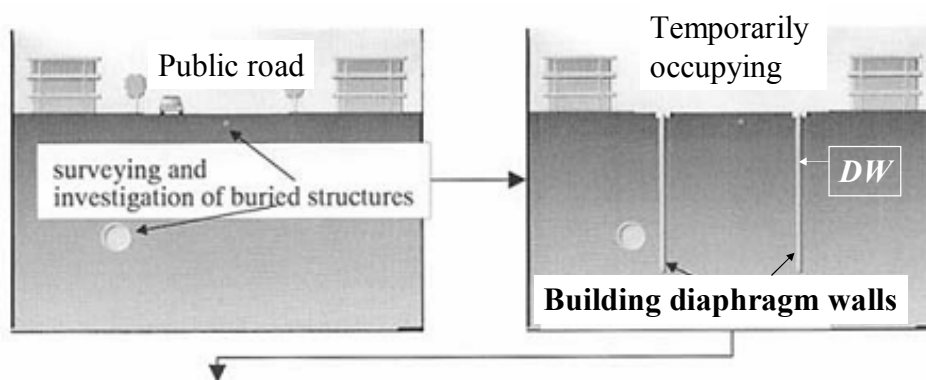


2007/1/31

RC DM can satisfy these conditions flexibly because it is cast in the ground.

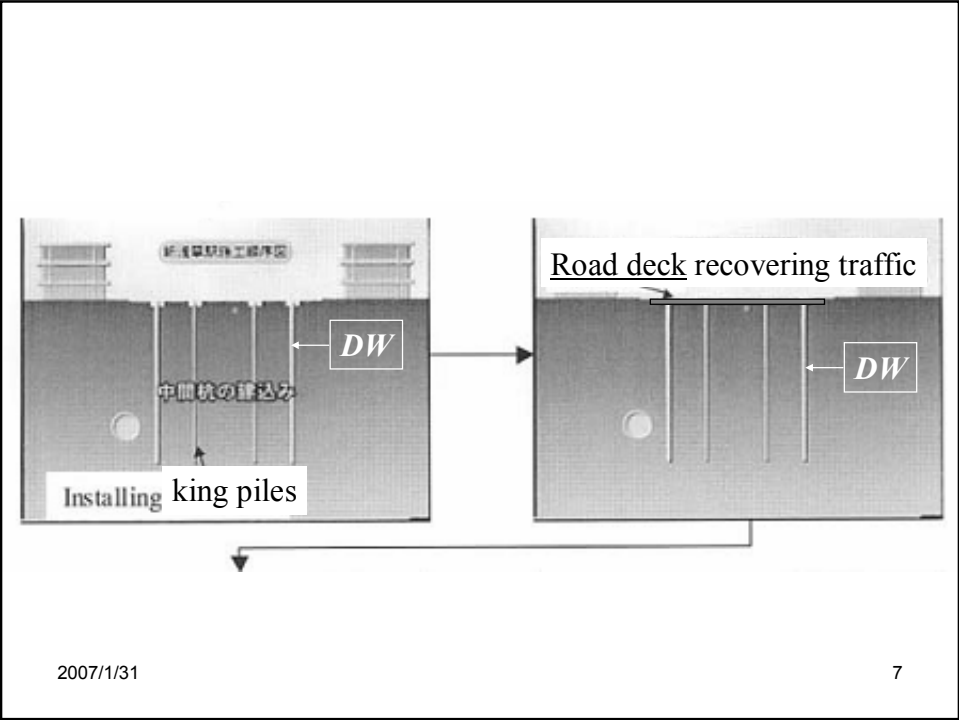
5

Construction procedure of subway station using cut-and cover tunneling methods

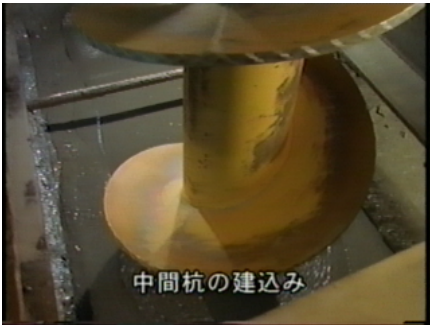


2007/1/31

6



**Typical sequence of strutted wall excavation
in urban area
installation of king piles**



drilling a hole



Installing a king pile

2007/1/31

8

Typical sequence of strutted wall excavation in urban area road decking



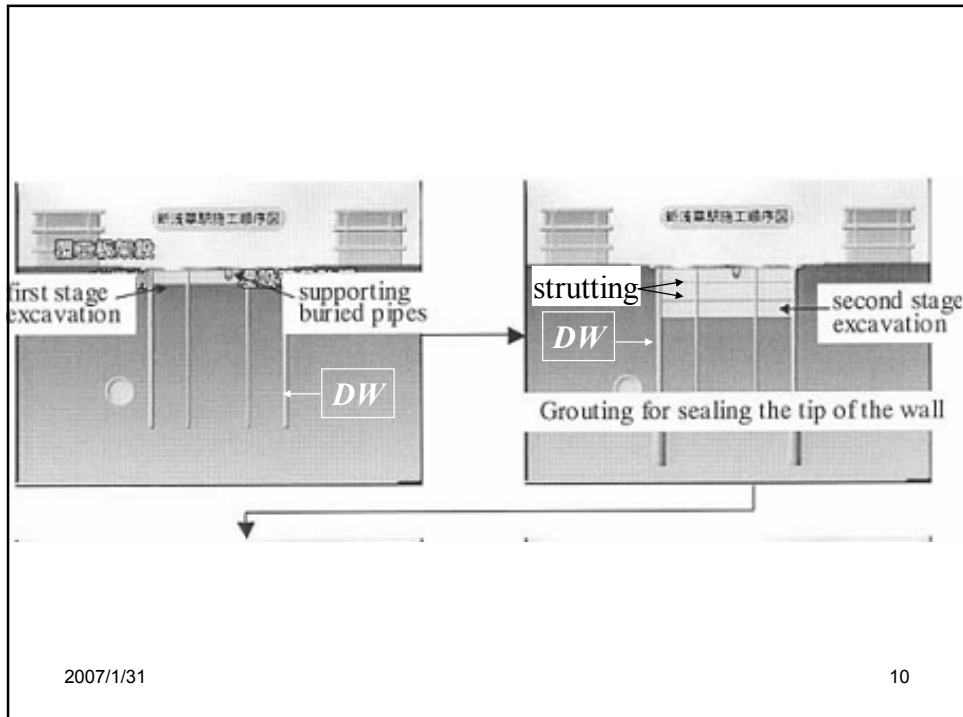
strutting first level



placing deck plates

2007/1/31

9



2007/1/31

10

**Typical sequence of strutted wall excavation
in urban area**
safety measures for buried structures



temporary supports for buried pipes

2007/1/31

11

**Typical sequence of strutted wall excavation
in urban area**
second stage excavation



excavation by backhoe



scraping by bulldozer

2007/1/31

12

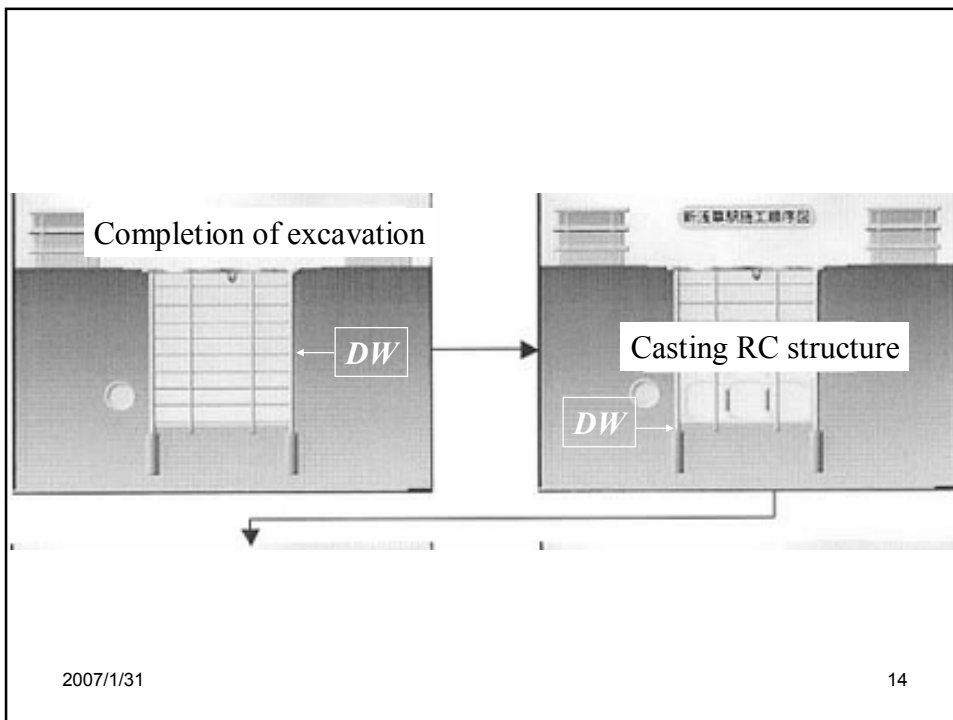
**Typical sequence of strutted wall excavation
in urban area
second stage excavation**



Lifting excavated soil by crab shell

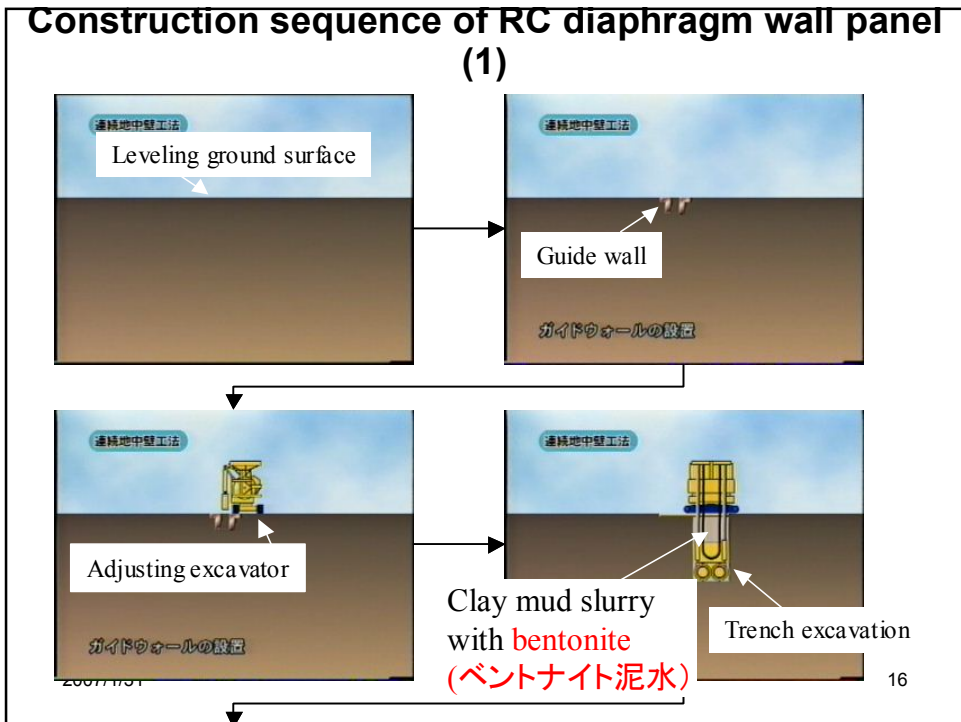
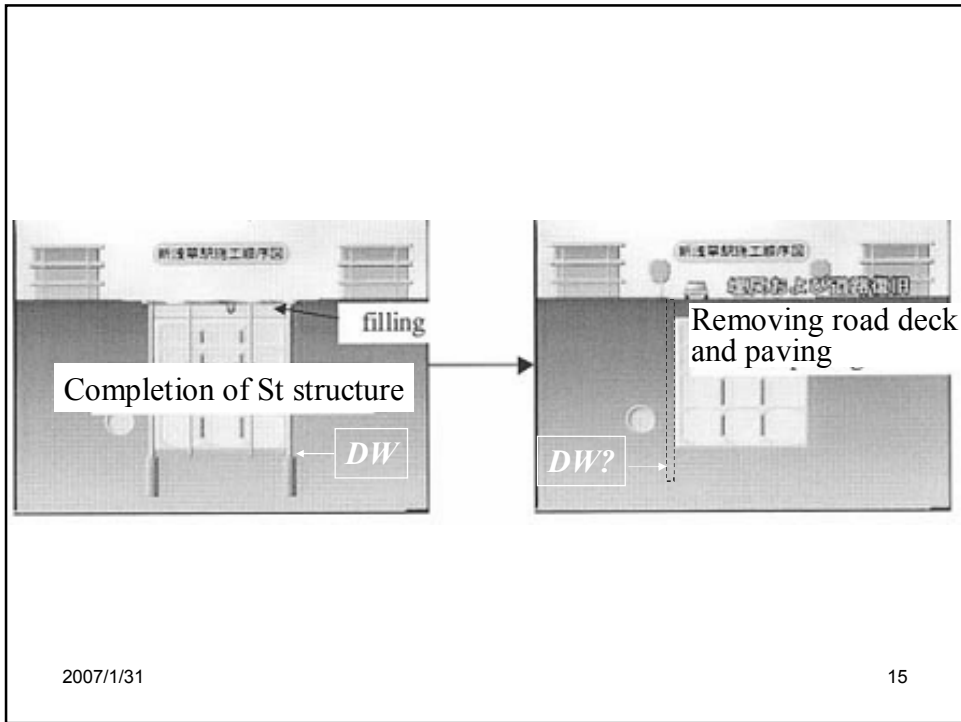
2007/1/31

13

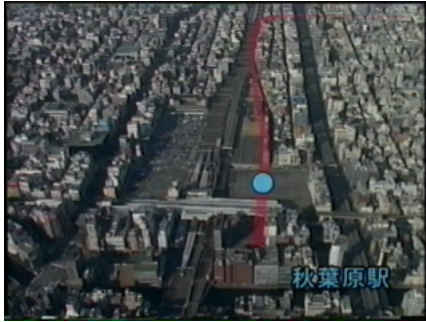


2007/1/31

14



Construction sequence of RC diaphragm wall panel working space



relatively large space needed

2007/1/31

17

Construction sequence of RC diaphragm wall panel trench excavation



excavation machine



horizontal axes rotary cutter

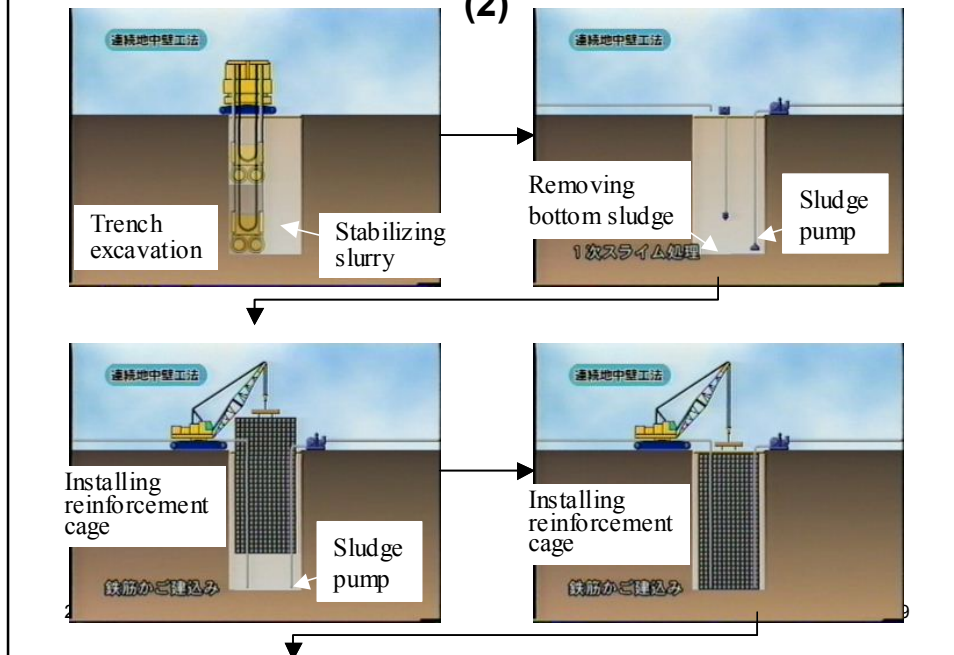


Clay mud slurry

2007/1/31

18

Construction sequence of RC diaphragm wall panel (2)



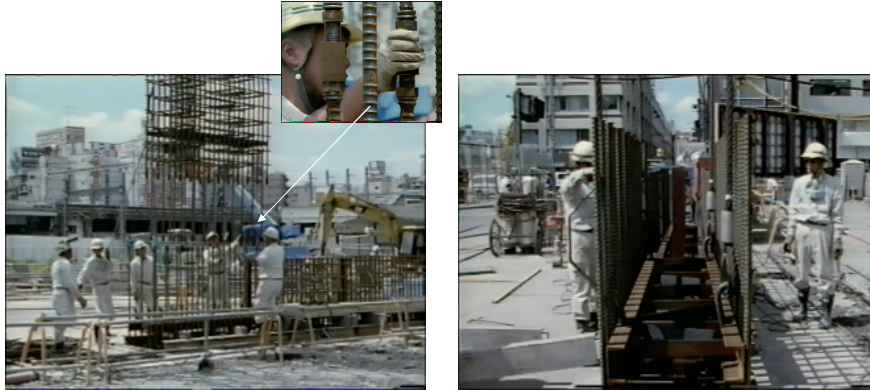
Construction sequence of RC diaphragm wall panel installation of reinforcement cage



2007/1/31

20

Construction sequence of RC diaphragm wall panel installation of reinforcement cage



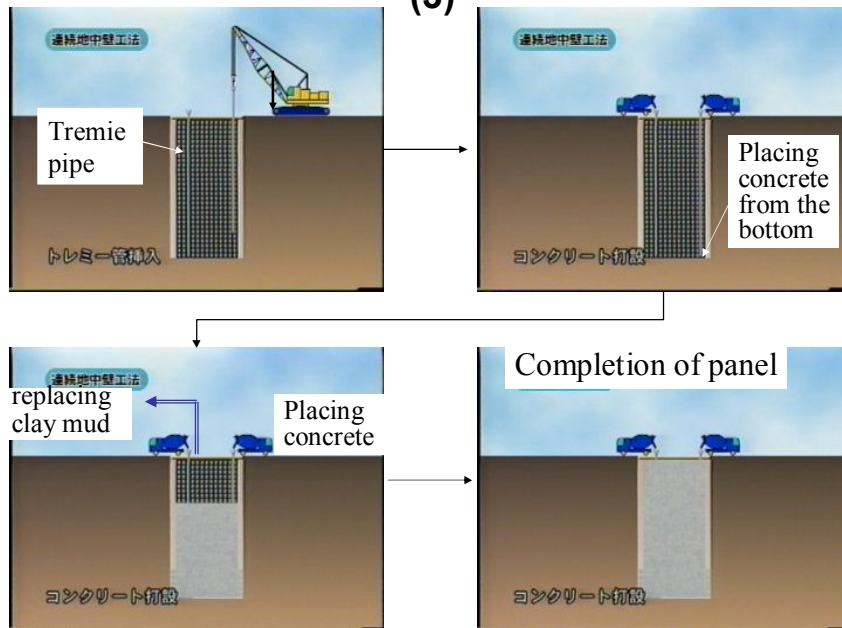
vertical connection of cages

horizontal connection

2007/1/31

21

Construction sequence of RC diaphragm wall panel (3)



Construction sequence of RC diaphragm wall panel treatment plant



clay mud treatment



mud slurry separation plant

2007/1/31

23

Construction sequence of RC diaphragm wall panel mud slurry is separated from excavated soil



Water content of excavated soil is reduced so that it can be disposed as construction waste



2007/1/31

24

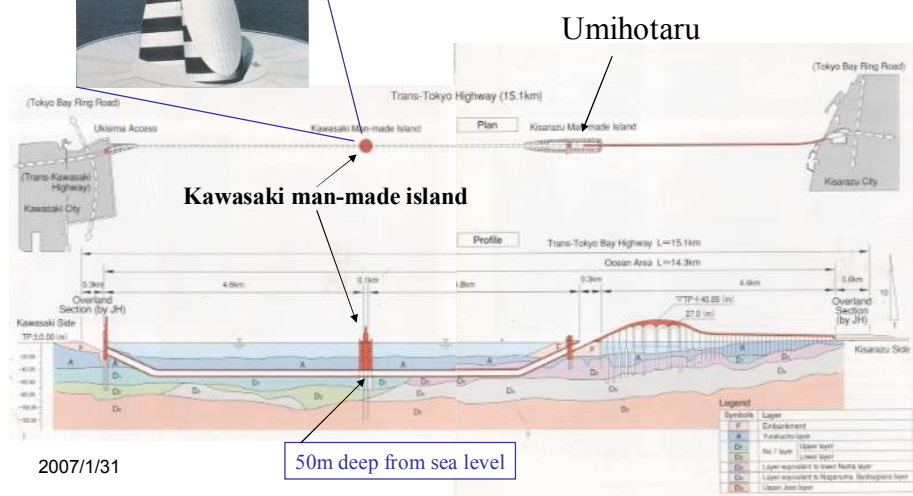
Application of DW Trans-Tokyo Bay Highway (Aqua-line)

Trans-Tokyo Bay Highway project(1966)
JSCE, JH & TTBH Corporation



Cross section and plan of TTBH

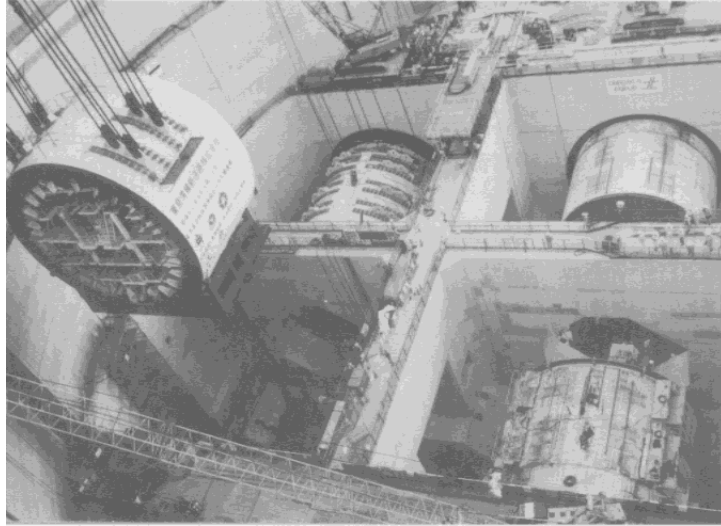
Tower of wind (風の塔)



2007/1/31

50m deep from sea level

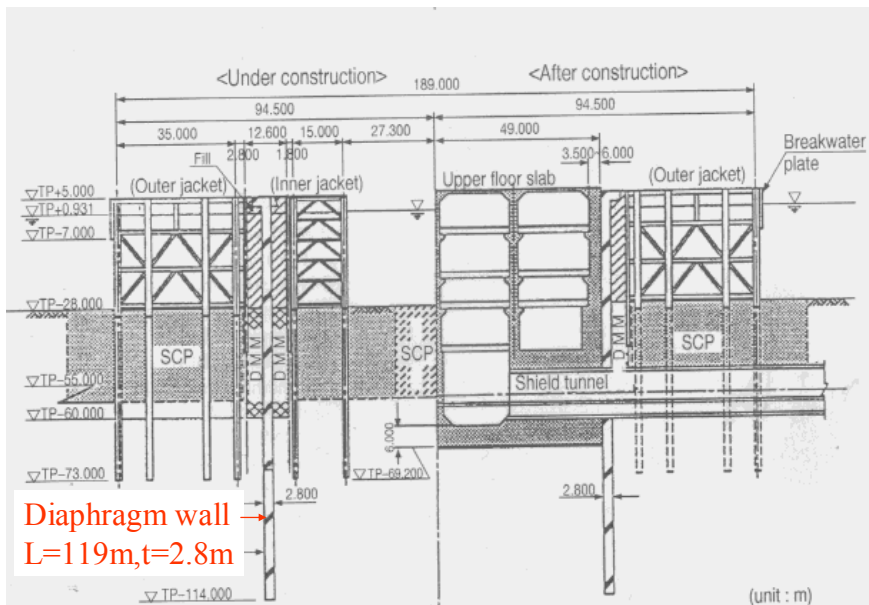
Kawasaki man-made island as launching shaft of shield tunnels



2007/1/31

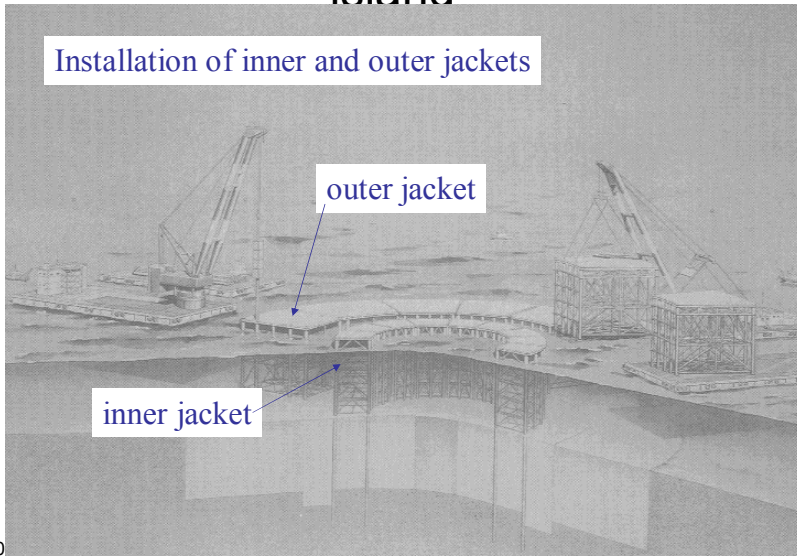
27

Kawasaki man-made island



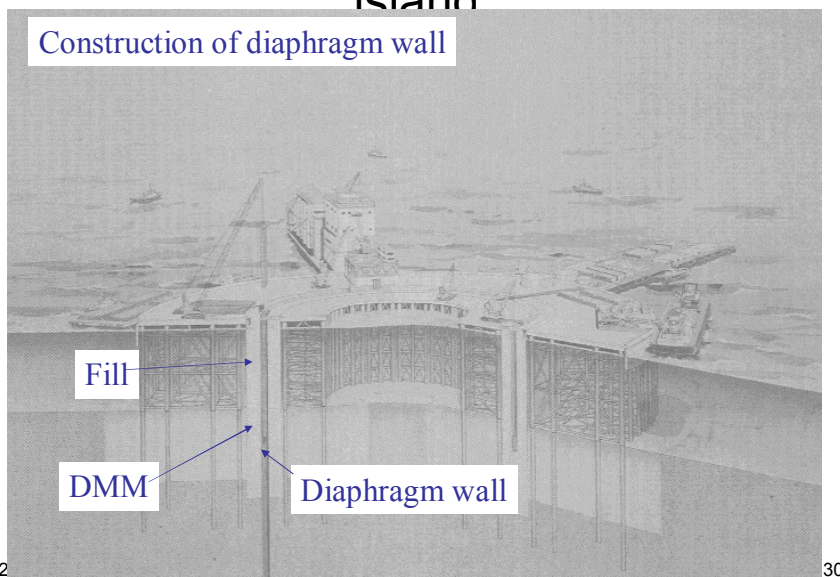
Construction of Kawasaki man-made island

Installation of inner and outer jackets



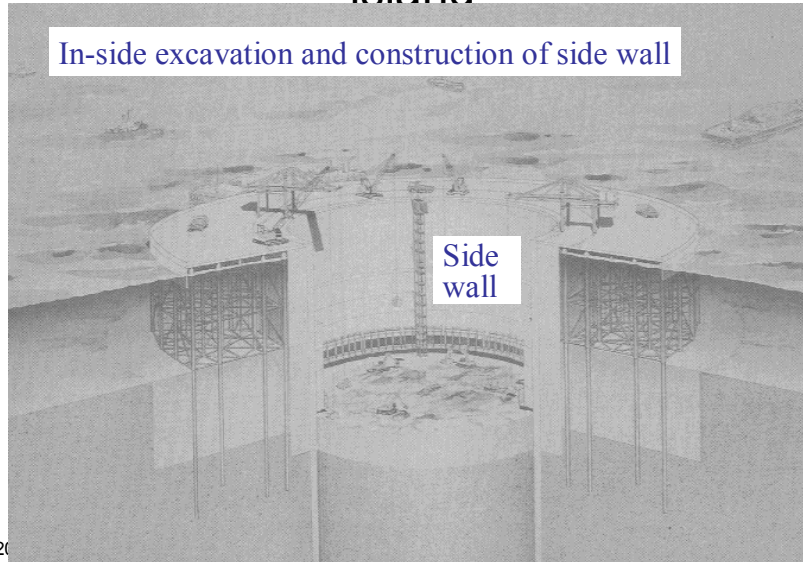
Construction of Kawasaki man-made island

Construction of diaphragm wall



Construction of Kawasaki man-made island

In-side excavation and construction of side wall

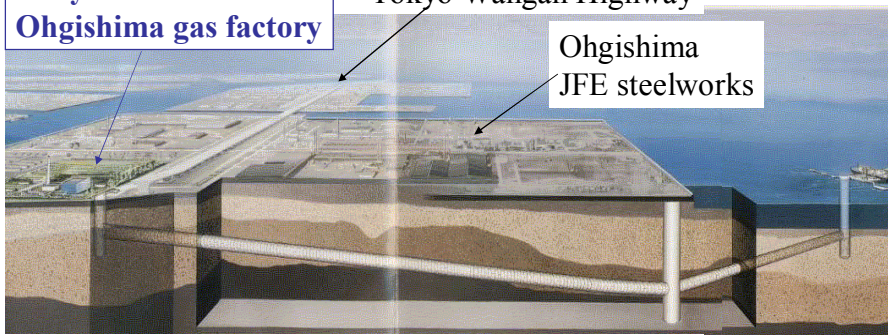


Ohgishima Gas Terminal

Tokyo Gas
Ohgishima gas factory

Tokyo Wangan Highway

Ohgishima
JFE steelworks

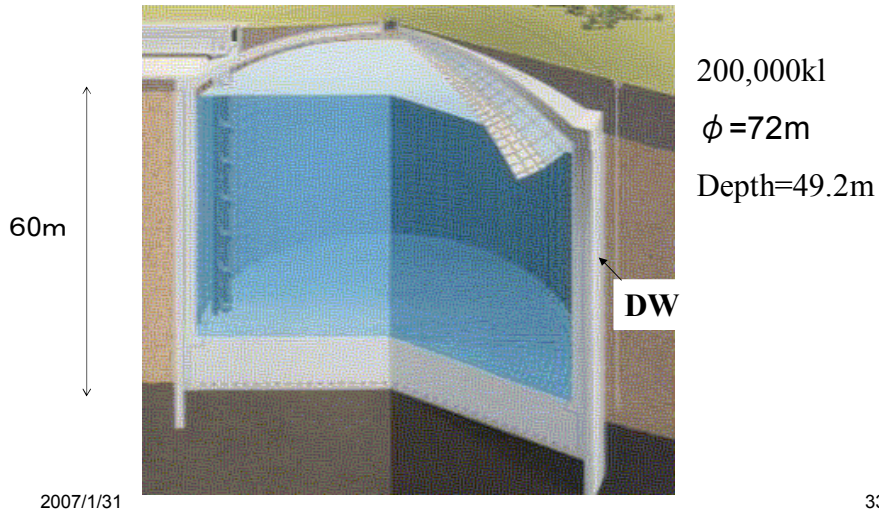


Main facility of gas factory: LNG storage tank
LNG: boiling point=-162°C

2007/1/31

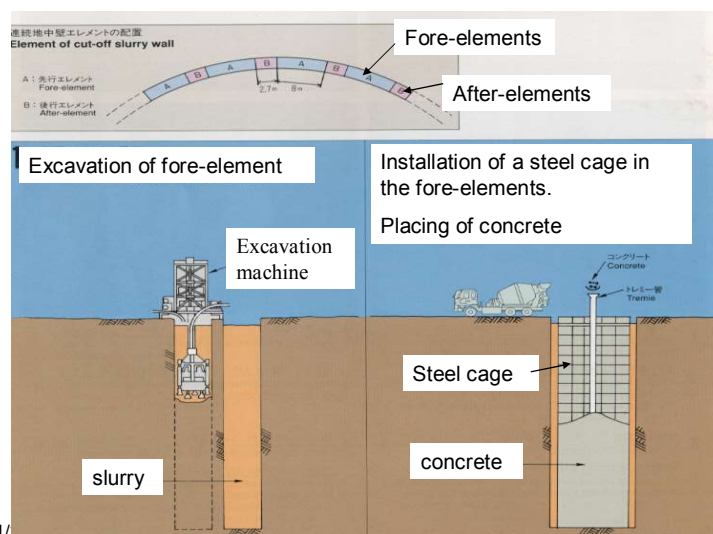
32

In-ground storage tank for LNG



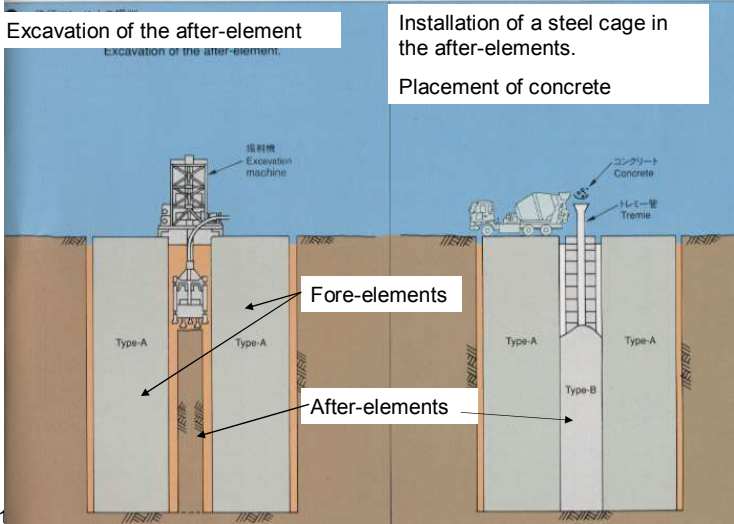
33

Construction sequence Diaphragm wall



34

Construction sequence Diaphragm wall

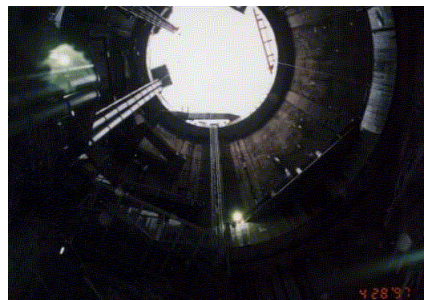


Excavation for in-ground tank



t=2m
+
3D effects
↓
No struts
↓
Precise
construction
Required.

Circular shaft t=800mm, Depth=73m



No lateral movement, but

large heave at the bottom ← Swelling due to unloading

2007/1/31

37

Shield tunneling methods シールドトンネル工法

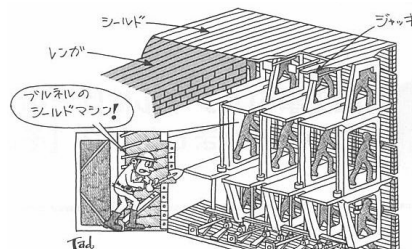
*First Shield T by Brunel
applied to Thames River Tunnel
ブルネイの世界最初のシールド*



Two Brunels
Father: Marc Isambard Brunel
Son: Isambard Kingdom Brunel
フランス人ブルネイ1818年
テムズ川の川底トンネル工事で発明。
1824から幾多の事故にあい1841年完成

Hint of invention (発明のヒント)
Shipworm making hole in wood
(木に穴を開けるフナクイ虫の特性)

- ①stiff shell (丈夫な殻で体を保護)
- ②conveying wood cut backward(穴を掘り進むにつれて、削った木を後方に送り出す)
- ③protecting excavated hole by smearing body fluid (取った穴はすぐ、体液によって膜はりをして、穴が崩れないように保護する)



「大深度地下利用」国土庁パンフレット

3

Types of Shield machine(シールド工法の種類)

最新シールドトンネル」日経BP社(1994)



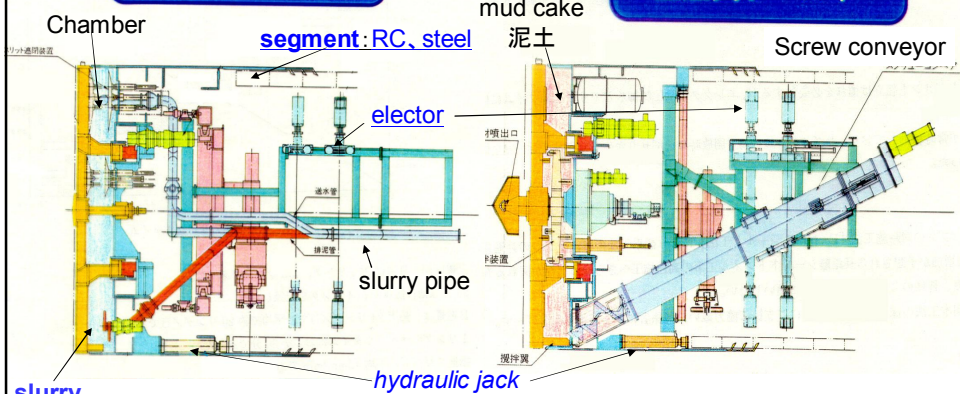
Slurry shield・Earth balance shield

Slurry Shield Commonly used machine in Japan

泥水式シールド

Earth Balance Shield

土圧式シールド

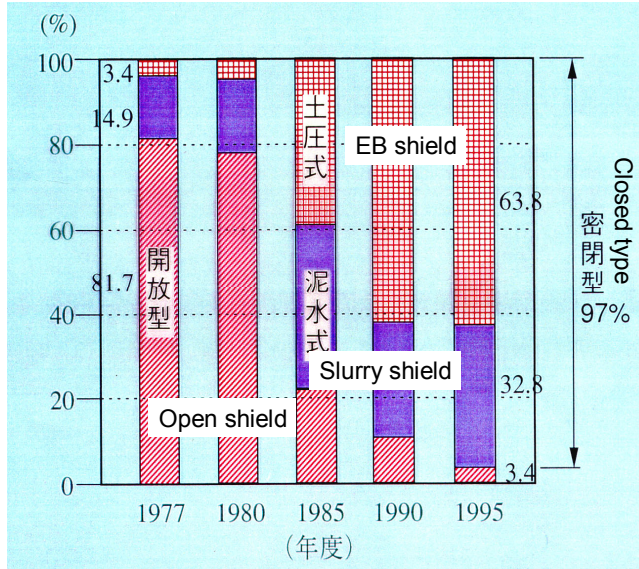


Earth & water P balanced by slurry pressure in the chamber;
Excavated soils conveyed with slurry in a form of liquid 液体状

Earth & water P balanced by mud pressure in the chamber;
Excavated soils removed by screw conveyor and normal conveyor as solid

History of shield

最新シールドトンネル 日経BP社 (1994)



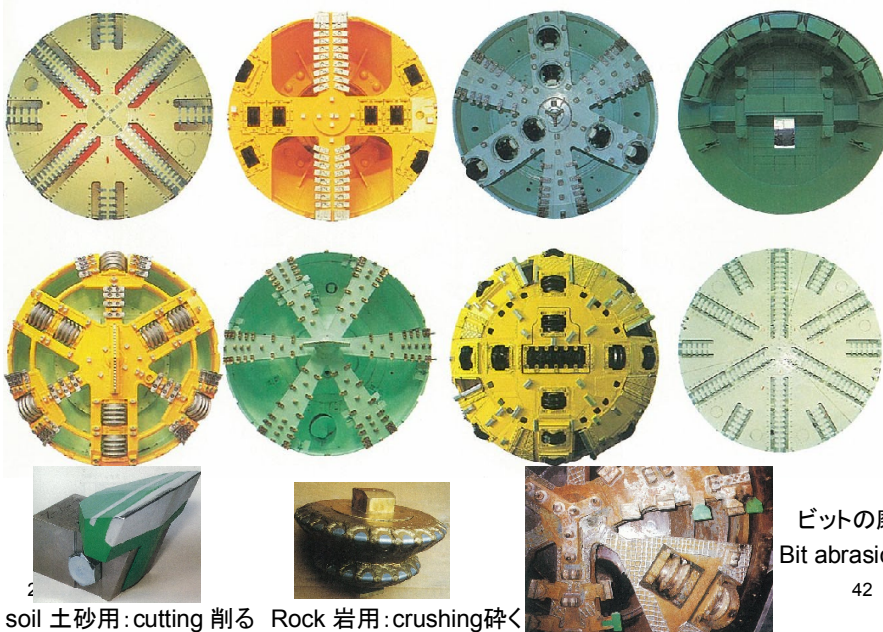
Inside of Shield T.
シールドトンネル内



RC segments
RCセグメント

41

Shield face and bit シールド盤面とビット

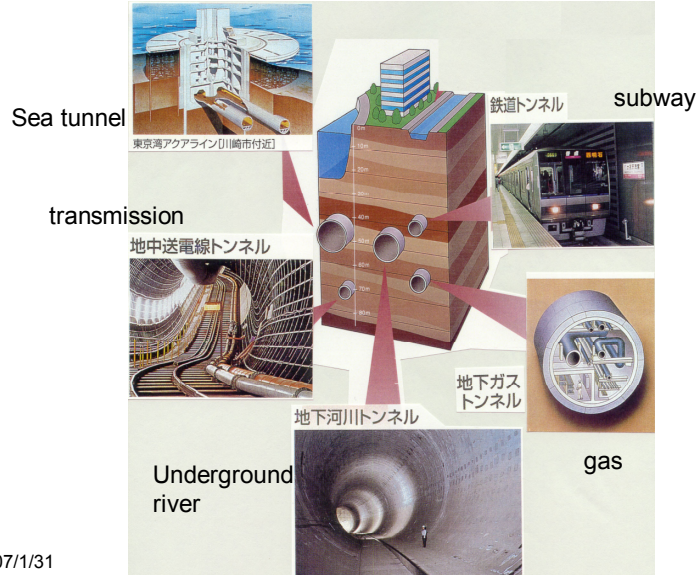


soil 土砂用: cutting 削る Rock 岩用: crushing 砕く

ビットの磨耗
Bit abrasion

42

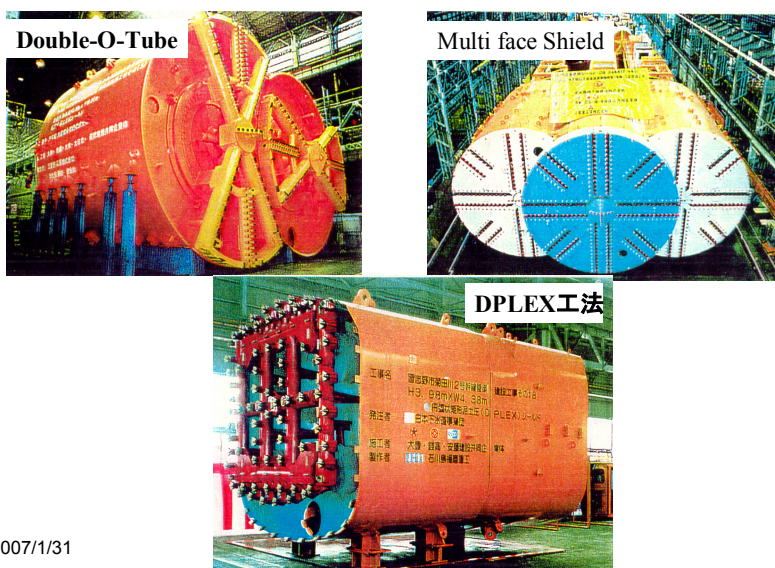
Application of shield tunnels シールド工法の適用



2007/1/31

43

Unconventional S machine 特殊なシールド工法



2007/1/31

44

Mountain tunneling methods

山岳トンネル工法

Classification of MT : difference of lining system

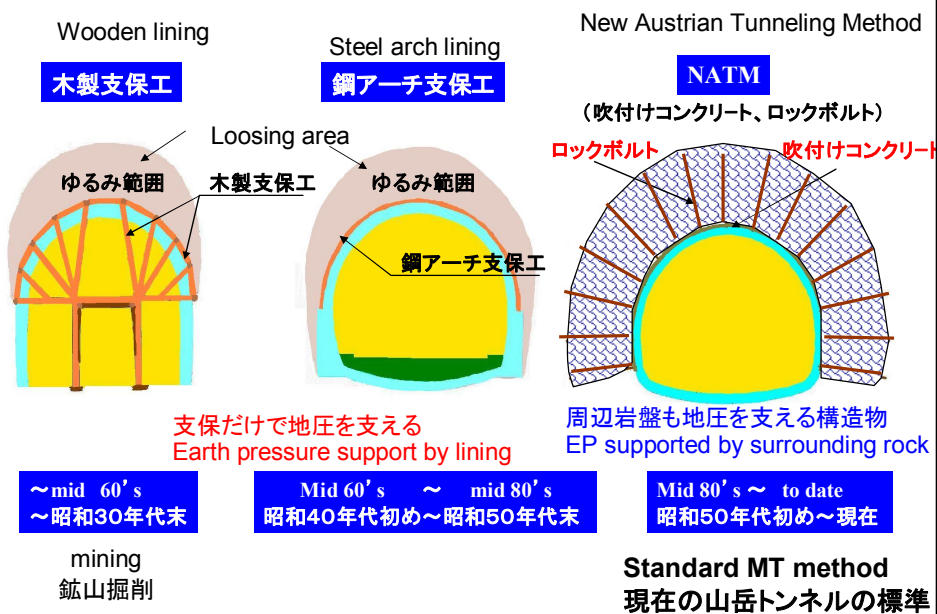
山岳(岩)トンネルの差: 支保工の差

- Open unsupported 素掘り(支保工なし): 有史以前から
from prehistoric time
- Wooden lining 木製支保工: mining 鉱山
- Steel lining 鋼製支保工
- RC lining
- NATM(shotcrete +rock bolts:吹き付けコンクリート+ロックボルト)
- Steel lining or RC lining+NATM 鋼製or RC支保工とNATM併用

2007/1/31

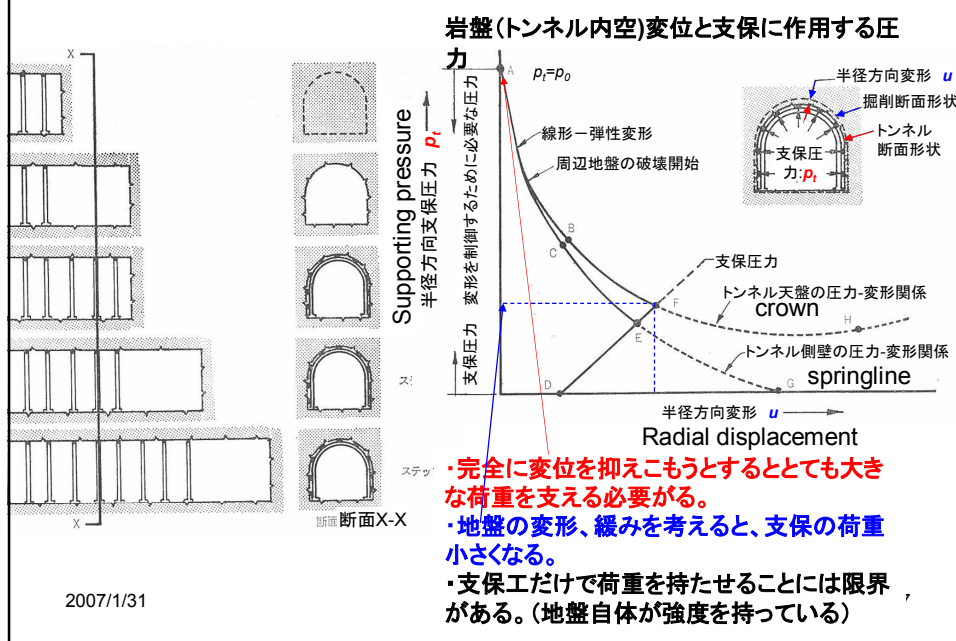
45

Historical change of MT



Construction sequence and change of tunnel cross section

山岳トンネルにおける施工過程と断面変位 参10)



Excavation method in MT

山岳トンネルの掘削方法

Depending on condition of rock (hardness, crack) and water
岩の状態(硬さ、亀裂)、水条件によって

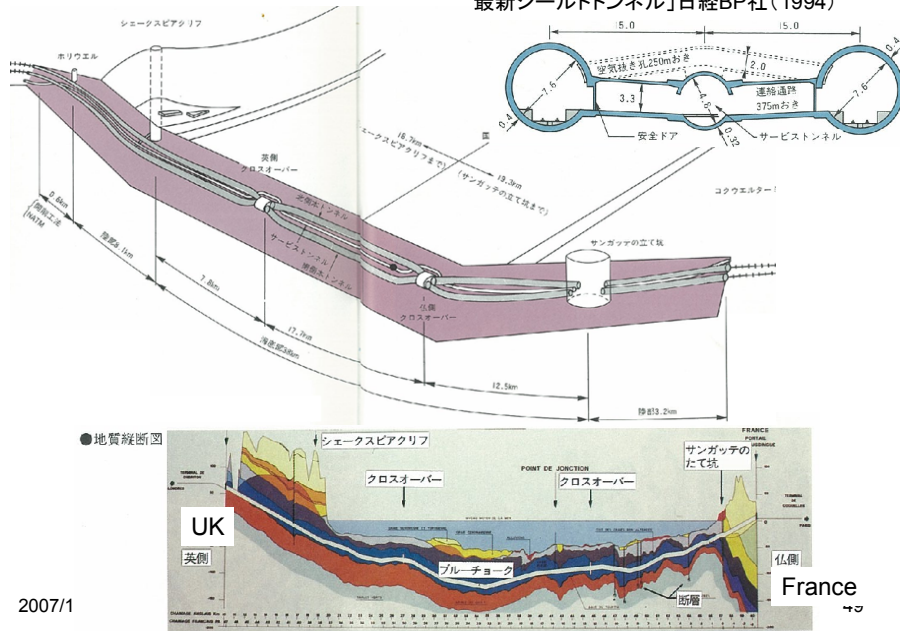
- Machine 機械堀
- TBM (Tunnel boring machine)
reaction for advancing TBM by gripper
シールドとの違い: 反力はマシン自身でとる
安全、施工速度: Euro tunnel、神流川発電所の圧力管
- Dynamite 発破(ダイナマイト)掘削
硬い岩では一般的、一番経済的
hard rock, economical

2007/1/31

48

Euro tunnel 英仏海峡(ドーバー)トンネル

最新シールドトンネル」日経BP社(1994)

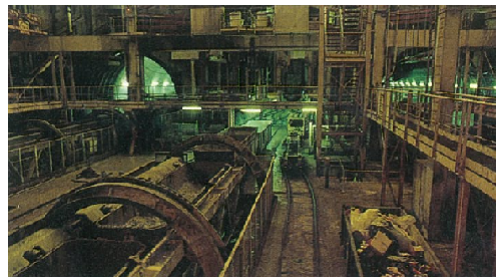


2007/1

英仏海峡トンネルの建設



英国シェークスピアから掘り進んだTBMのホリウエル立て坑への到達



フランスサンガッテ立坑、両側:本トンネル 中央:サービストンネル




フランス海底部を掘ったTBM
川崎重工
外径:8.78m、長さ:13.7m
総重量:900ton、
トルク:11,500tf

50

Construction of large UG space by NATM


NATMを使った大規模空洞の建設
<http://www.tepco.co.jp/kanna-gawaindex-j.html>

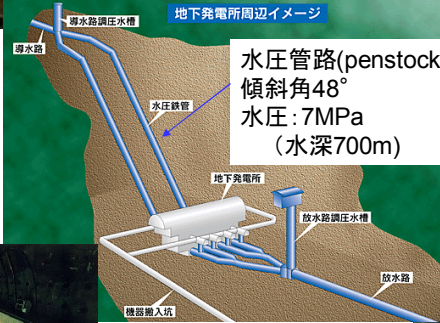
Upper dam
Rockfill



Pumped storage type
Power plant

Lower dam
Gravity concrete



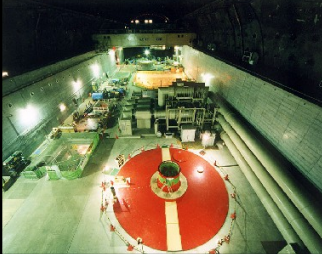


地下発電所周辺イメージ

水圧管路(penstock)
傾斜角48°
水圧: 7MPa
(水深700m)

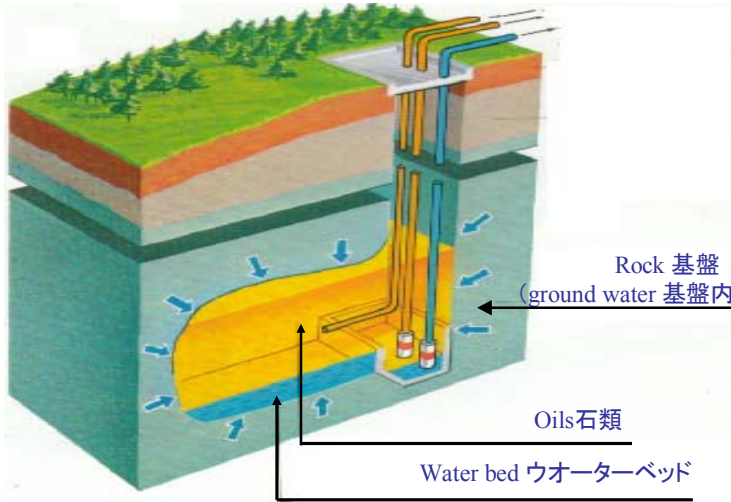
放水器調圧水槽
放水器
機器搬入坑

Kannagawa PP
神流川揚水式発電所



Underground power plant
地下発電所:
Depth 地下500m
H52m、W32m、L216m

Storage of oils in rock (Principle of water sealing) 石油類の岩盤内貯蔵(水封方式の原理)



Rock 基盤
(ground water 基盤内地下水)

Oils 石油類

Water bed ウォーターベッド

2007/1/31

52

LPG storage in rock formation using water sealing 液化プロパンガスの岩盤備蓄

Deference betw. LPG and oil

- 蒸気圧(vapor pressure)
(1MPa、100m water height)
- Volume deference bew. liquid and gas =>250times

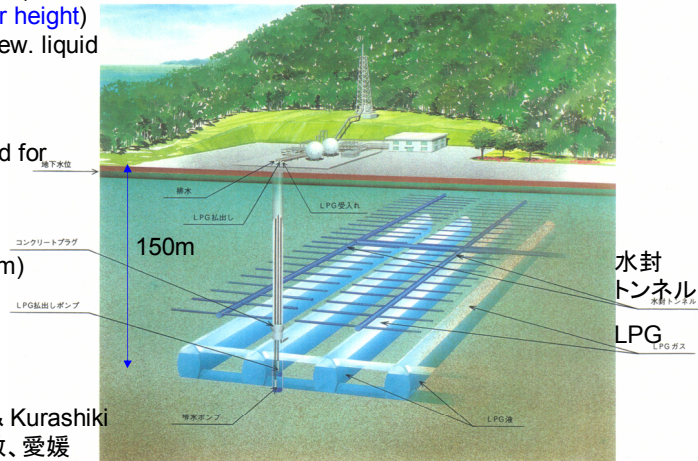
Under normal temp
Large pressure required for storing LPG

参考: 気化温度(1気圧)
Vapor temp.(under 1atm)
Methane: -161.5°C
Ethane: -88.6
Propane: -42.1
Butane: -0.5

Pilot plants: Ehime & Kurashiki
実証施設建設中-倉敷、愛媛

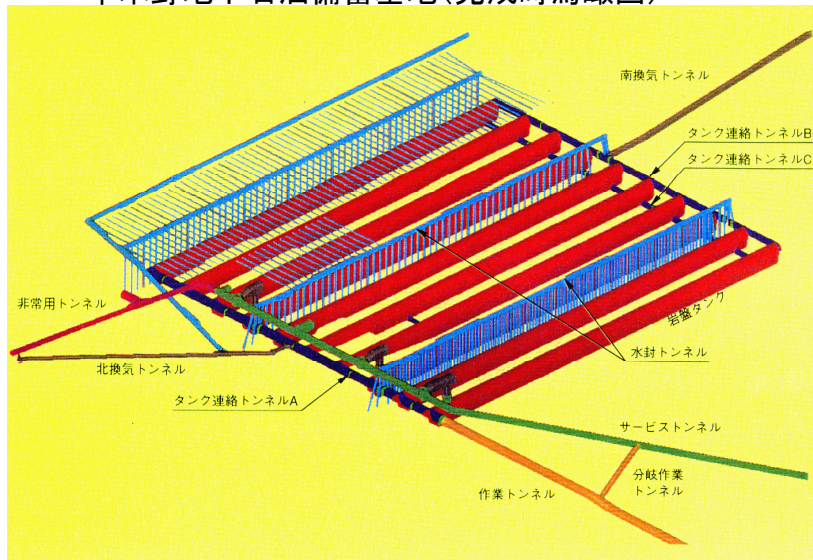
2007/1/31

石油公団:LPG地下備蓄技術実証プラント、1990.



53

Storage of crude oils in rock at Kuhikino 串木野地下石油備蓄基地(完成時鳥瞰図)



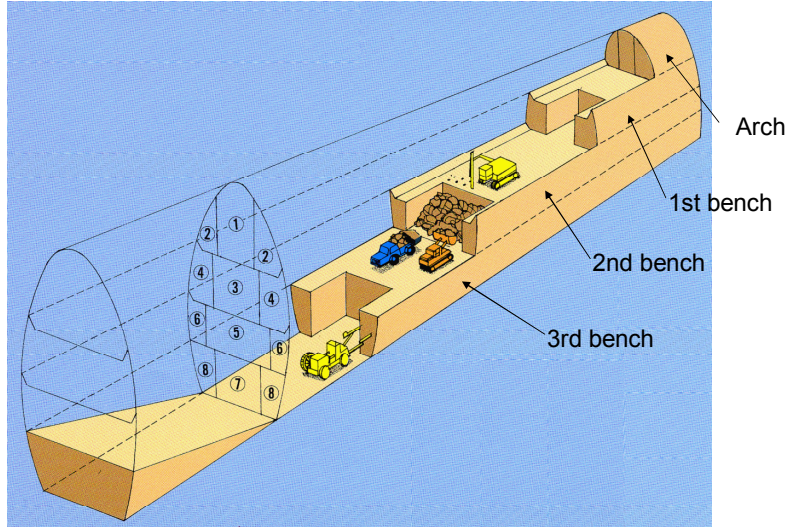
2007/1/31

日本地下石油備蓄(株): 串木野地下石油備蓄基地 工事記録(岩盤土木)、1994.

54

Sequence of tunnel excavation

空洞掘削順序図



2007/1/31

清水建設他JV: 串木野地下石油備蓄基地建設工事の概要 (パンフレット)、1990.

55

Construction of oil storage tunnel at Kushikino

串木野地下石油備蓄基地建設工事(施工時写真-1)

清水建設提供



アーチ部掘削 Arch

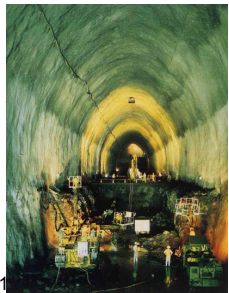


第1段ベンチ掘削
1st bench

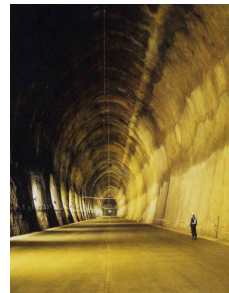


第2段ベンチ掘削

2nd bench

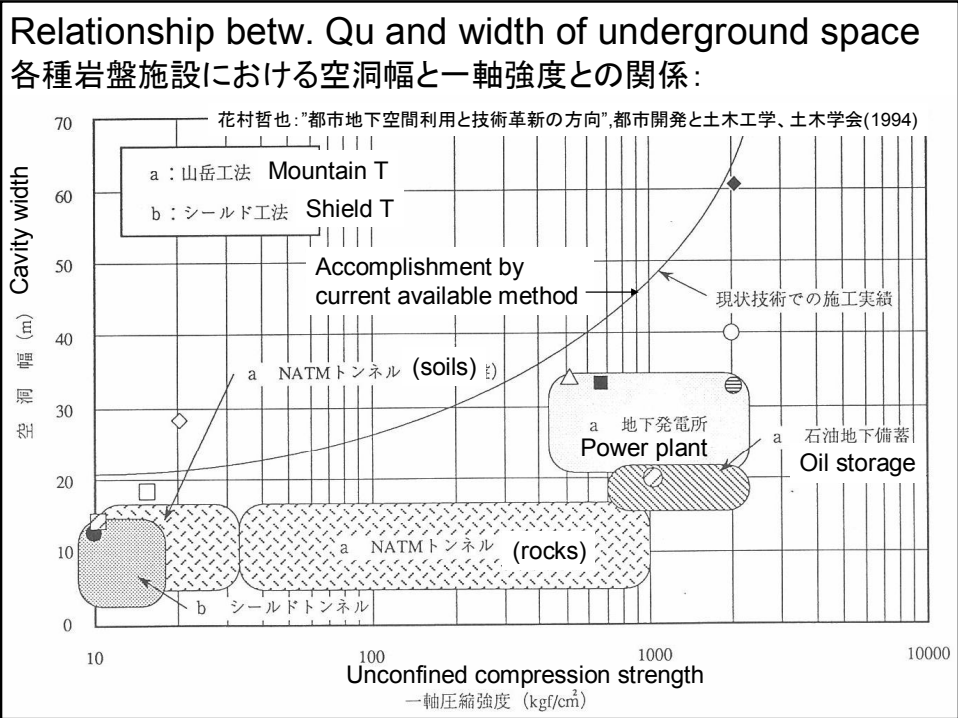


第3段ベンチ掘削
3rd bench



完成
completion
56

2007/1

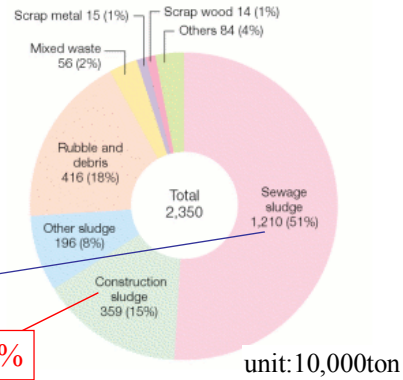


前頁の凡例

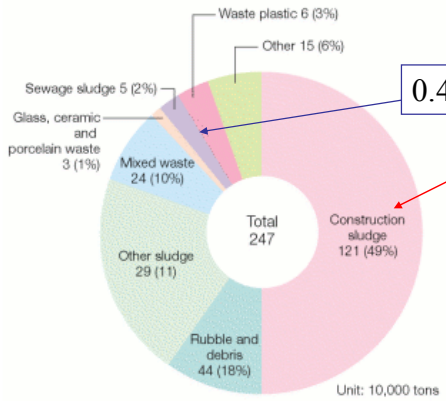
□ ランツベルク地下駐車場	ドイツ	● 京葉線東京駅	日本 (東京都)
◇ ミラノトンネル (補助工法付)	イタリア	▣ 東名所領トンネル (3車線)	日本 (静岡県)
△ チラタ地下発電所	インドネシア	⊗ 菊間地下石油備蓄基地	日本 (愛媛県)
■ ヴァルデックII地下発電所	ドイツ	⊕ 今市地下発電所	日本 (栃木県)
◆ ユービクアイスホッケーアリーナ	ノルウェー	○ スーパーカミオカンデ	日本 (岐阜県)

Industrial waste in Tokyo 2002

Volume of industrial waste by type in Tokyo (FY2002)



Volume of final disposal of industrial waste by type in Tokyo (FY2002)



0.4%

34%

(<http://www2.kankyo.metro.tokyo.jp/kouhou/env/eng/pdf/08.pdf>)

unit: 10,000ton

Unit: 10,000 tons

Site visit Jan. 31
O-hashijunction

Central Circular Route Shijuku line

首都高速中央環状新宿線
大橋ジャンクション

Way to the site

Taking the train to Futagotamagawa St. at 14:11 Midorigaoka St.
 緑が丘14:11発 二子多摩川14:21着
 Changing the train bound for Shibuya at 14:24
 二子多摩川14:24発 渋谷方面
 Taking off the train at Ikejirio-hashi St. 14:35
 池尻大橋下車 14:35

Central Circular Route(首都高速中央環状線)



Current highway system of Metropolitan Tokyo

Many radiating highways
Uncompleted circular highway

多数の放射状高速
中途半端な環状高速の完成

Central Circular Route

(首都高中央環状線)

Tokyo-Gaikan Exp.way

(東京外郭自動車道)

Kenoh Exp. way

(圏央道)



Underground (tunnel)

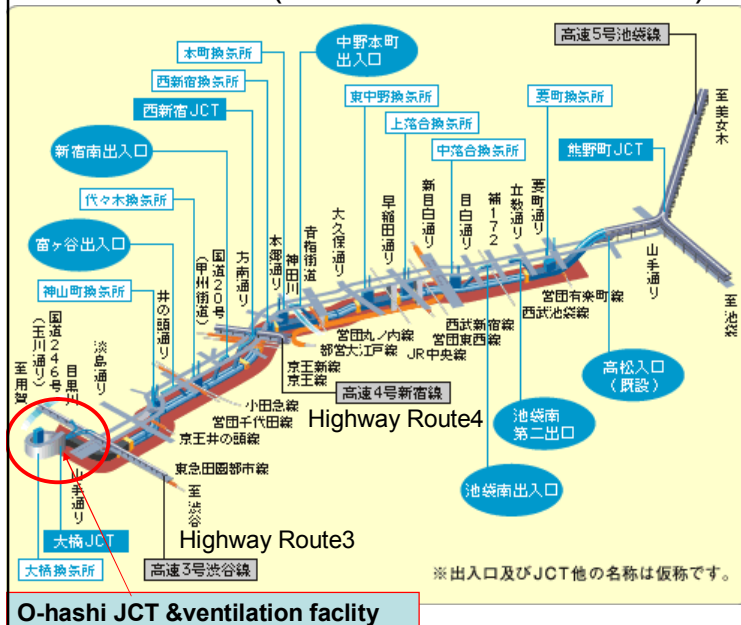
Large cross-section,

Deep

Interchange, Junction

61

Central Circular Route Shijuku line (首都高速中央環状新宿線)

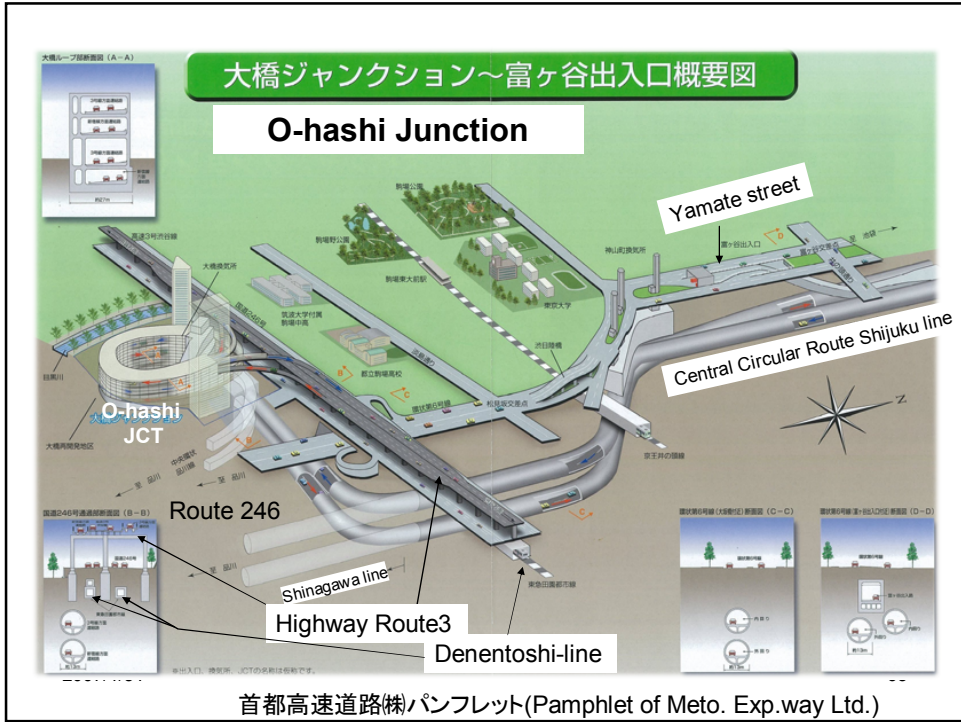


Underground Expressway underneath the Yamate street
山手通り下
ほぼ地下高速道路

Constructed by Shield tunnels & Cut&cover tunnel construction method

・シールドトンネル
・開削

62



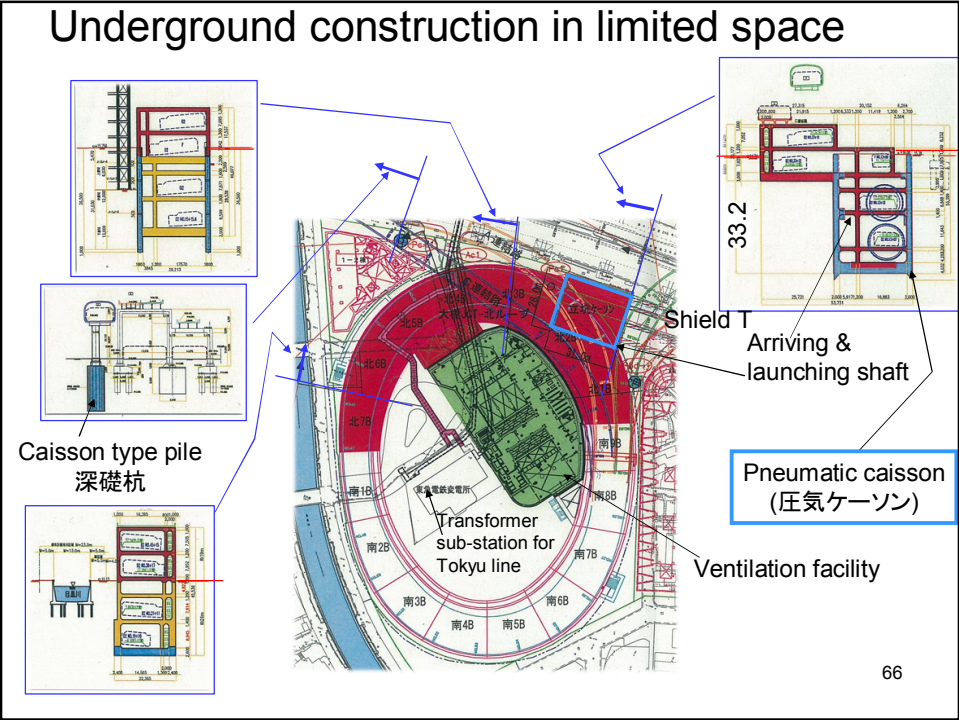
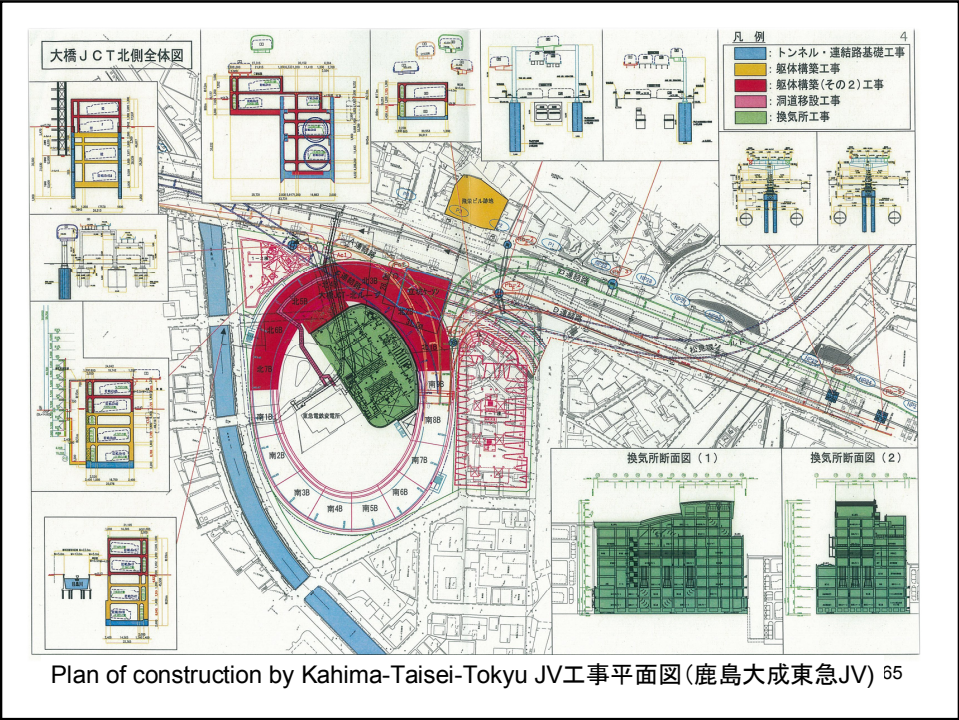
Underground construction in limited space

限られたスペースでの地下工事



2007

64

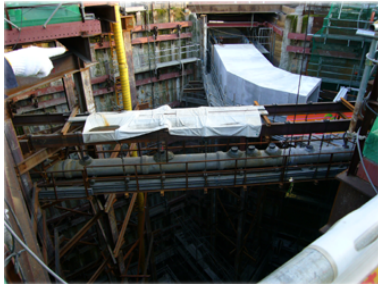




Pit for caisson type pile foundation



Retaining wall system by ground anchors



Transmission lines from Tokyu transformer sub-station
2007/1/31



Arriving & launching shaft

67



Super-structure of loop roadways of the JCT



2007/1/31

Inside of the super-structure of loop roadways of the JCT

68