Design of Tunnel and Underground Space
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Definitions

Rock – The mineral or organic (i.e. coal) matter that comprises the solid part of the Earth's crust excluding soil.

A natural aggregate of minerals that are connected by strong bonding or attractive forces.

Soil – Sediments and other unconsolidated accumulations of solid particles produced by the mechanical or chemical disintegration of rocks (Terzaghi, 1943)

Rock & soil mechanics – The theoretical and applied science of the mechanical behavior of rock and rock masses [soil]. It is the branch of mechanics concerned with the response of rock and rock masses [soil] to the force fields of its physical environment.

Geotechnical engineering – The art and science of solving insoluble problems armed with incomplete information, an inadequate budget and operating under unreasonable time (Raymond Seed, UC Berkeley, 1989)

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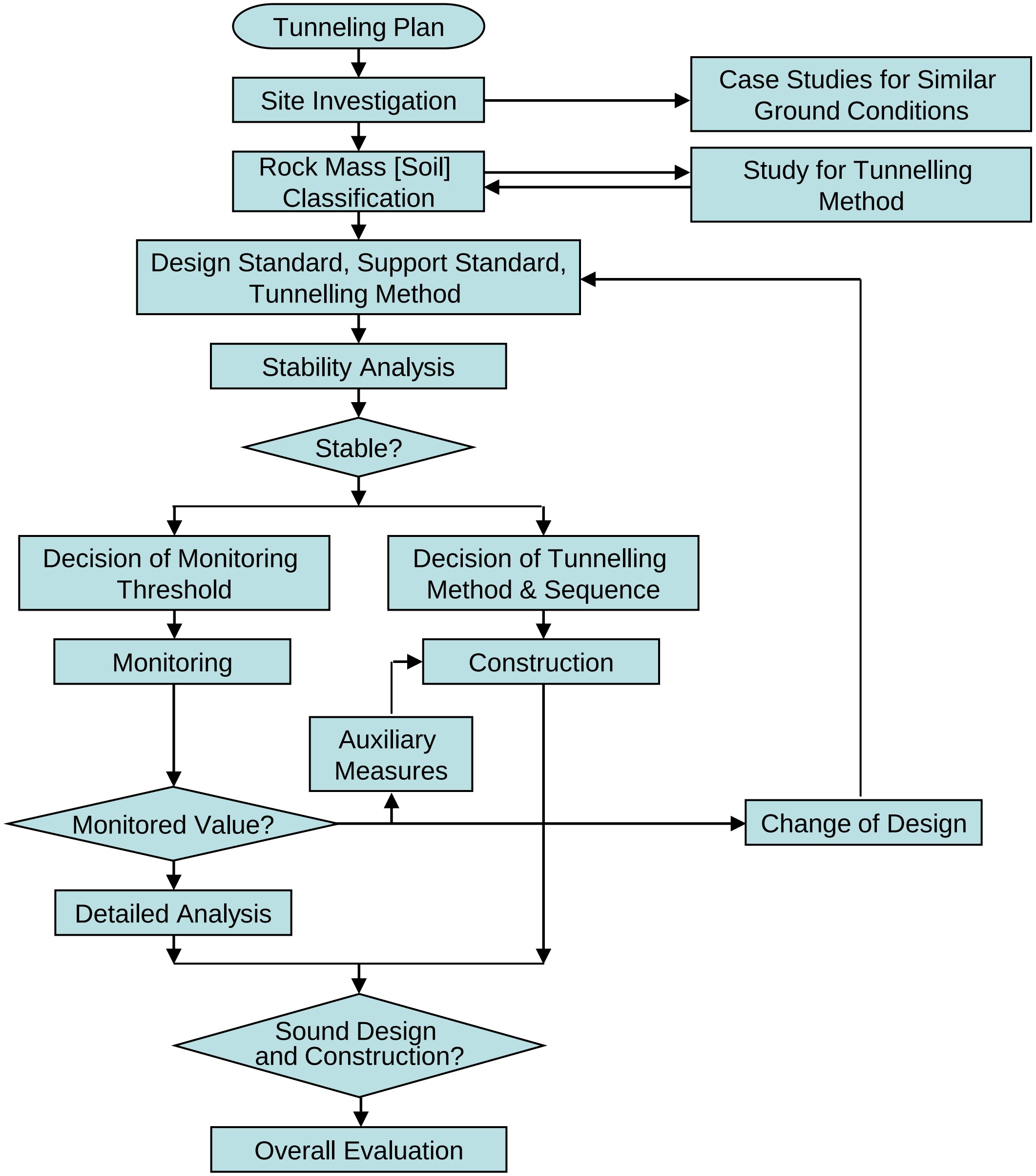
engineer (재능, 창조, 혁신) ← "genie" 〈〈French〉〉 재능이 있는 [Not from ["engine"]

Flow chart of tunnel design and construction



Introduction

1. History of tunnels

(1) Fundamental operations

a. Survey
b. Excavation of ground
c. Immediate support of ground
d. Permanent support of ground
e. Management of water
* Unexpected physical conditions → project impossible

(2) Relationship to mining

	Mining tunnels	Civil tunnels
Service life	Temporary (several decades)	Permanent (up to 10,000 years)
Access & usage	Trained personnel	General public
Length	Long (up to tens of kilometers)	Short (L < 10 km)
Ground condition	Known over years	Usually need site exploration
Depth	Deep	Shallow (D < 500 m)
Stress condition	Changing	Stable (steady)
Economy	Sensitive to profits	Fixed
Site	Ore location	Superior condition selected
Size	Minimum (~ 3 m)	Large
Community	Permanent	Temporary

トンネルができるまで
①準備
最初に測量をして、設備の配置を決めトンネル回りを整え、次にトンネルを掘るために使う機械を運びます。
Start
②掘る 削る
ドリルジャンボで岩に穴を開け、そこに火薬を入れて爆破します。
③ずり出し
掘っていく時にでる土や岩（ずり）はホイールローダーでダンプトラックに積込みトンネルの外へ出します。
Point!!
近くに住んでいる人になるべく迷惑にならないように、気をつけながら工事をしているよ。
④吹付コンクリート（1回目）
鋼製支保工建込
吹付コンクリート（2回目）
せっかく掘った穴がくずれないようにコンクリートを吹付けて固め、鋼製の支保工（トンネル内部を支える鉄でできたわく）を組み立て、さらにコンクリートを吹付けます。
⑤ロックボルト
ロックボルトをトンネル内部から外へ向けて埋込み、地山の強度を高め、地山と一体化します。
力
力
力
②からここまでの行程を繰り返してトンネルを掘り進みます。
⑥防水シート張り
トンネルの中の水もれを防ぐためにに防水シートを張ります。
Point!!
トンネル工事では山が崩れないようにするために色んな工夫をしているね。
⑦コンクリート覆工
支保工を補強して安全性を高めたり、コンクリート永久構造物として地山を支持する機能があります。
トンネル掘りはここでおしまい。ここからはそれぞれの専門家達にバトンタッチするんだ!
⑧舗装
一般にアスファルトよりも耐久性に優れ、明るい色のコンクリートを使用して舗装します。
⑨設備工事
トンネル内の照明などを設置します。
⑩完成
いよいよ完成!
トンネルの開通です。
Finish

Introduction

1. History of tunnels

(3) History

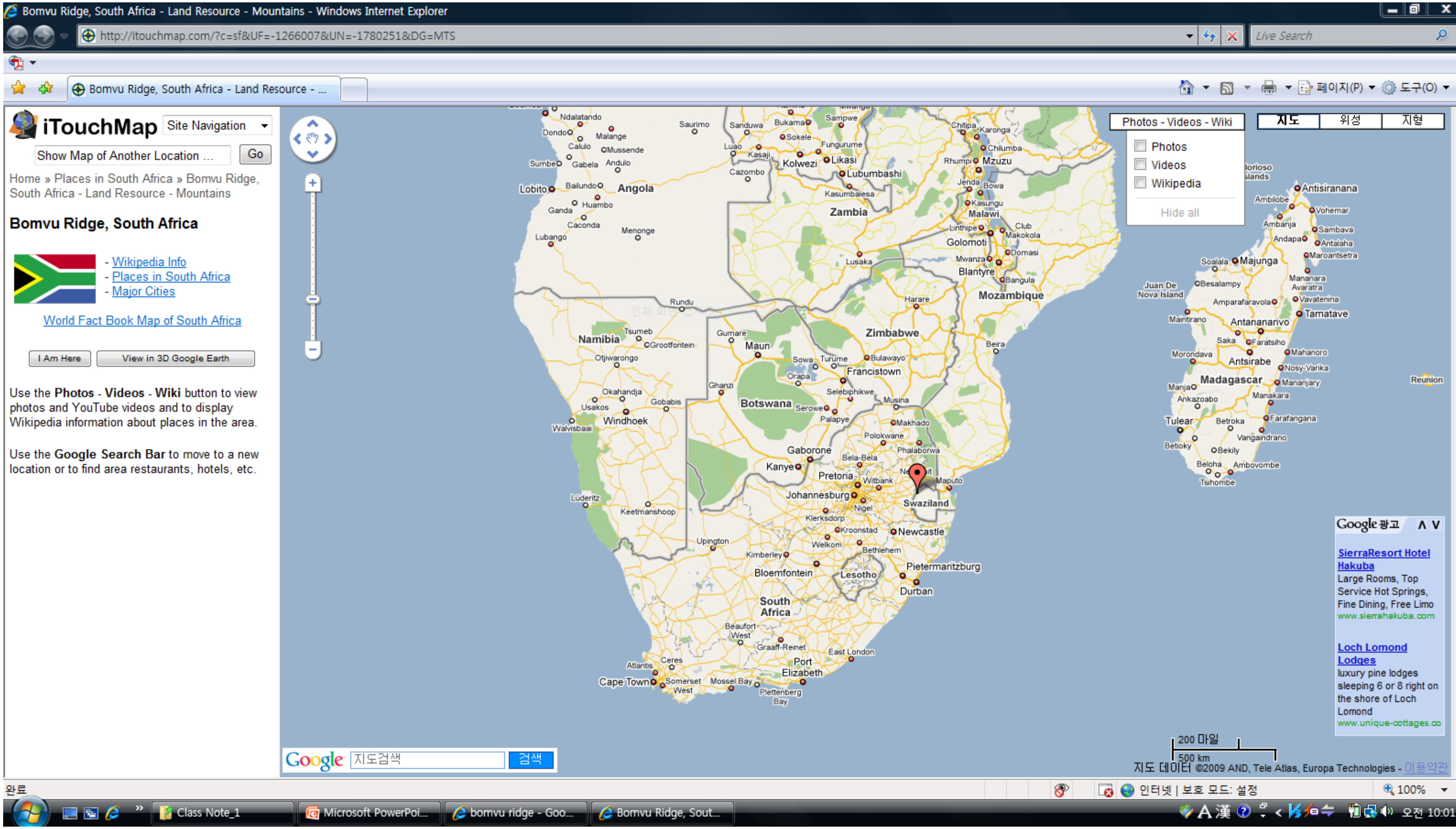
a. Purpose: Burial, attack, mineral and metals, transport (human & natural resources), shelter from water and fire (temperature)

b. Oldest: Bomvu Ridge in Swaziland in South Africa
40,000 BC (Neanderthal Man)
Hematite (blood stone) mine (for funeral and ornament)

c. Magnum Salalias Wieliczka Salt Mine (poland from 3,500 ~ 2,500 BC) Still operating
Underground Post Office and Church (100 km long)

* Methods: Wooden wedges in a hole → soaking → swelling
Fire setting

d. AD 41, Fucinus Tunnel (to drain Lake Fucino)
5.6 km long, 6 m high, 2.7 m wide
40 shafts
Took 11 years, 30,000 slaves
The averaged advance/working face = 7 cm/week


Bomvu Ridge, South Africa - Land Resource - Mountains - Windows Internet Explorer
http://itouchmap.com/?c=sf&UF=-1266007&UN=-1780251&DG=MTS
Live Search
Bomvu Ridge, South Africa - Land Resource - ...
페이지(P)
도구(O)
iTouchMap
Site Navigation
Show Map of Another Location ...
Go
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Bomvu Ridge, South Africa
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- Places in South Africa
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World Fact Book Map of South Africa
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500 km
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Google
지도검색
검색
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인터넷 | 보호 모드: 설정
100%
Class Note_1
Microsoft PowerPoi...
bomvu ridge - Goo...
Bomvu Ridge, Sout...
오전 10:01

Introduction

1. History of tunnels

(3) History

e. 1851 ~ 1875: “Great Bore” railroad tunnel
Through Hoosac Mountain in Massachusetts
7.6 km long, 7.3 m wide, 6.7 m high
Compressed air drill
Nitroglycerin (92% NG + 8% Nitrocellulose, 1875 Nobel)

f. 1960 ~ 1969: 13,000 km of tunnel worldwide
1970 ~ 1979: Double the length

* Breakthough
    - Dynamite
    - Hydraulic drilling machine and bit
    - Rock bolt (+ shotcrete)
    - TBM (Tunnel Boring Machine)
    - Grouting

Introduction

1. History of tunnels

(3) History

e. Current Projects

Nuclear waste repository (i.e. Nevada Yucca Mountin)

Underground oil & gas storage

CAES (Compressed Air Energy System)

Subways (Seoul, Tokyo, San Francisco, Washington DC, Paris, etc.)

Solan Tunnel in Korea (16.9 km railroad tunnel)

Inje Tunnel in Korea (21 km road tunnel)

* TBMs

345 m advance per week

Fucinus tunnel – 7 cm per week (30,000 workers)

Introduction

2. Functions and Requirements

(1) Factors

a. Situation: Mountain, hill, subaqueous, urban
b. Ground: Soft silt, hard rock
c. Dimensions and Geometry: Width, height, length, levels, gradients, curves ….
d. Structural form: Circle, horseshoe, rectangle, concrete, brickwork ….
e. Construction methods: Boring, blasting, cut & cover
f. Equipment: Ventilation, lighting, rail track ….

(2) Principal Functions

a. Transportation (to pass underneath obstacles, i.e., hill, mountain, river, city, building, etc.)
    People & goods – subways, railways, highways
    Water – canals, irrigation, hydroelectric power
b. Storage & plant
    Car parks
    Cavern storage of oil
    Underground power stations
    Disposal of radioactive waste
    Military stocks
c. Protection of people
    Shelters

Introduction

2. Functions and Requirements

(3) Situation

a. Mountain range

Preferable (high capital investment)
Depends on the traffic amount

b. Subaqueous

Bridge – the cheaper alternative
Cost effectiveness (for a long distance)
Foundation
Capacity
Efficient use of land

} Tunnel preferred
Can be very long to attain a flat gradient

c. Urban

Normally short – often cut-and-cover
Noise and vibration

Introduction

2. Functions and Requirements

(4) Subways (pedestrian & cycle)

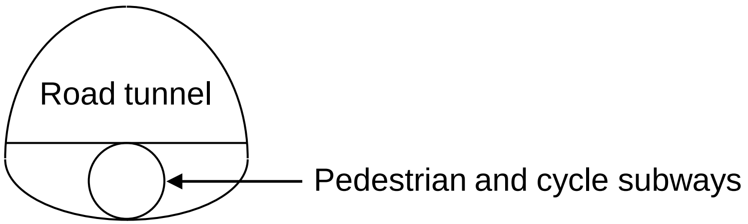
Relatively free gradient and curve

Decorative surface (wall) preferred

Minimum space requirement - 2 ~ 3 m high, 2 m width, 10% gradient, steps allows

Drainage (storage and pumping) system required

Lighting



(5) Railways

Typically, 5 mW x 7 mH for a single track

8.5 mW x 7 mH for a twin track

Gradient < 1% (~power, stop & start)

Curvature (~speed)

Introduction

2. Functions and Requirements

(6) Metro systems

Urban, subaqueous, hills
As shallow as practical (~ easy & rapid access)
Gradient can be greater (to transport people, i.e. 3.5%, electric power)
Cut & cover, NATM, TBM
Ventilation, lighting, fire, evacuation

(7) Highways

Gradient of 3.5 ~ 4.5% (up to 6.5%) (better ventilation at higher gradient)
Curvature 400 m in radius
Economy of dimensions (most important)
Shield drives, drill & blast, cut & cover, TBM …
Lighting
Ventilation
Drainage
Portals

(8) Water conveyance

Smoothness, water-tightness (pressure varies, i.e. turbines, aqueduct …)
Against contamination for drinking water
Access for inspection, maintenance, and repair

Introduction

2. Functions and Requirements

(8) Water conveyance

- Smoothness, water-tightness (pressure varies, i.e. turbines, aqueduct …)
- Against contamination for drinking water
- Access for inspection, maintenance, and repair
- Hydro-electric power
  - Free discharge
  - High pressure water tunnels (penstocks)
  - Machine halls (caverns in rock)

Quiet Through Tunnel, San Francisco, U.S.A.

Cross-Harbor Tunnel, Hong Kong


인천국제공항철도

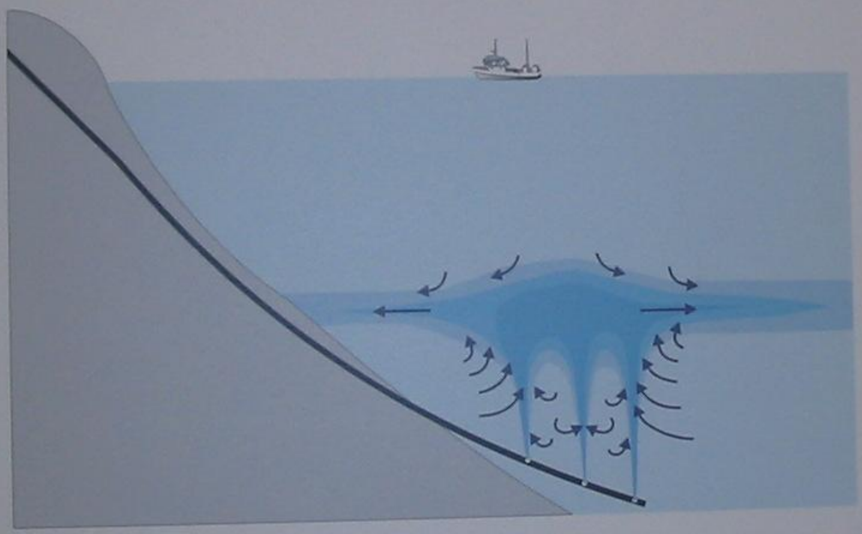
Underground Sewage Treatment Plant, Trondheim, Norway

Underground Sewage Treatment Plant, Trondheim, Norway

UTSLIPPSLEDNINGER

Fra utslippskum blir renset vann ført med 2 utslippsledninger til Trondheimsfjorden, Ledningene har en diameter på 800 mm. Utslippet skjer gjennom diffussorer på 48 – 65 m dybde, ca 180 m fra land. Diffussorene fordeler det rensede avløpsvannet i fjordens vannmasser slik at det oppnås en fortynning og innblanding.

En diffussor er et rør med en rekke mindre åpninger langs sidene eller i toppen av røret. Det gjør at utslippet fordeles i mange stråler, slik at innlagring skjer på 20 - 30 m dyp i sjøen.



Prinsipp. Utslippsledning med diffussor. Renset avløpsvann føres ut via mange hull i enden av utslippsledningen og fortynnes og innblandes i sjøen. Avløpsvannet innlagres på dypt vann under brakkvannslaget i overflata.

Bunn topografi ved utslippspunkt for Høvringen RA og Ladehammeren RA.

Underground Sewage Treatment Plant, Trondheim, Norway

H6 Sector Tunnel, Innsbruck, Austria

Hydro Power Plant, Trondheim, Norway

Cut & Cover Tunnel, H7 Sector, Innsbruck, Austria

Cut & Cover Tunnel, H7 Sector, Innsbruck, Austria

Cut & Cover Tunnel, H7 Sector, Innsbruck, Austria

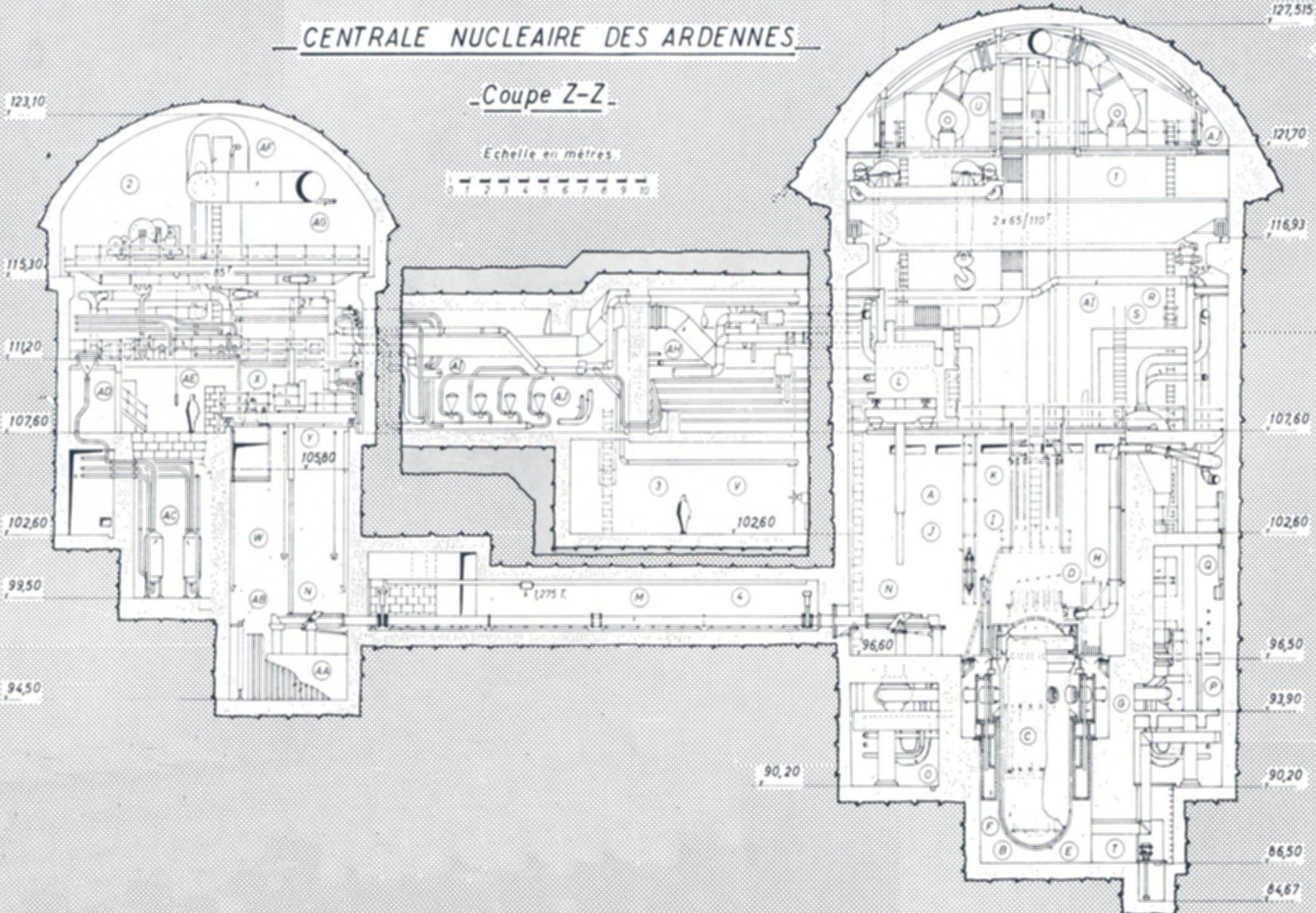
Austria (January 2006)

Metro Station, Athens, Greece (2005)

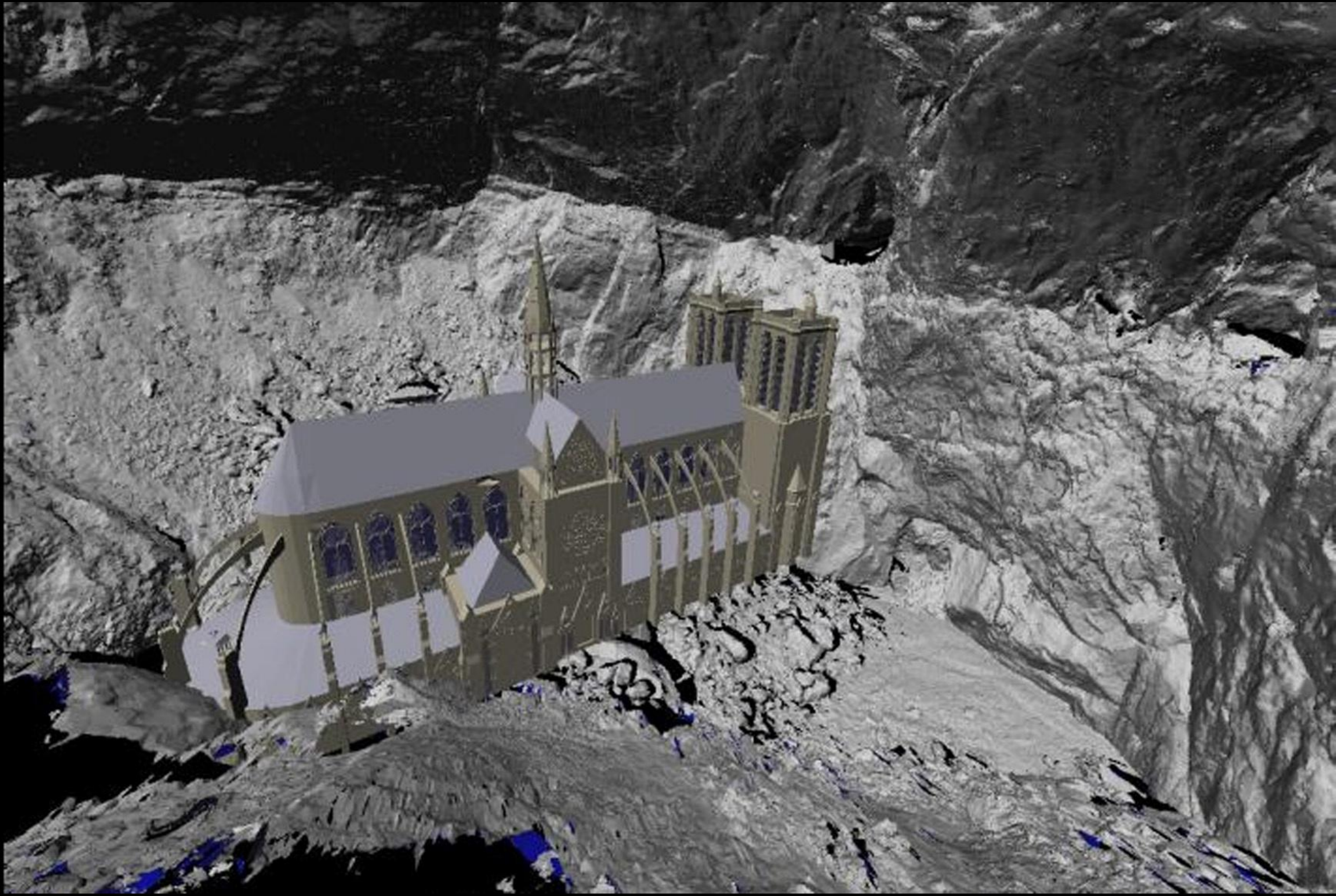
Metro Station, Athens, Greece (2005)

Metro Station, Istanbul, Turkey (2005)

A tunnel, Istanbul, Turkey (2005)



Underground Nuclear Power Plant, France (1992)



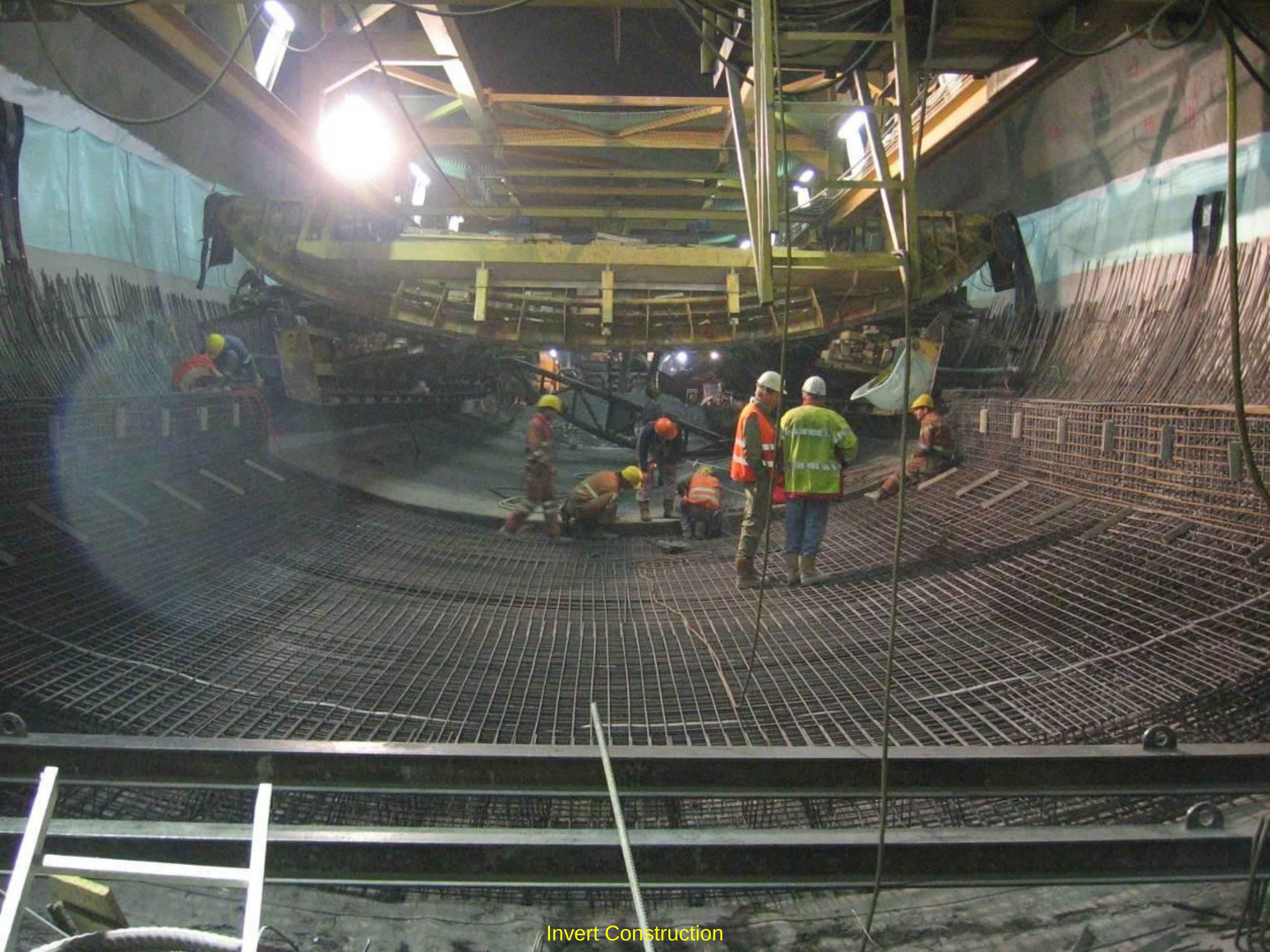
A conceptual view: Paris Cathedral in a limestone cave (By courtesy of Pierre Duffaut)

Metro Station, Kyoto, Japan (2003)

Metro Station, Kyoto, Japan (2003)

Automium, Brussels, Belgium (2006)

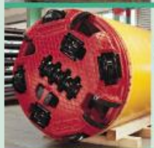
NATM tunnel construction, near Ulsan, Korea (2004)



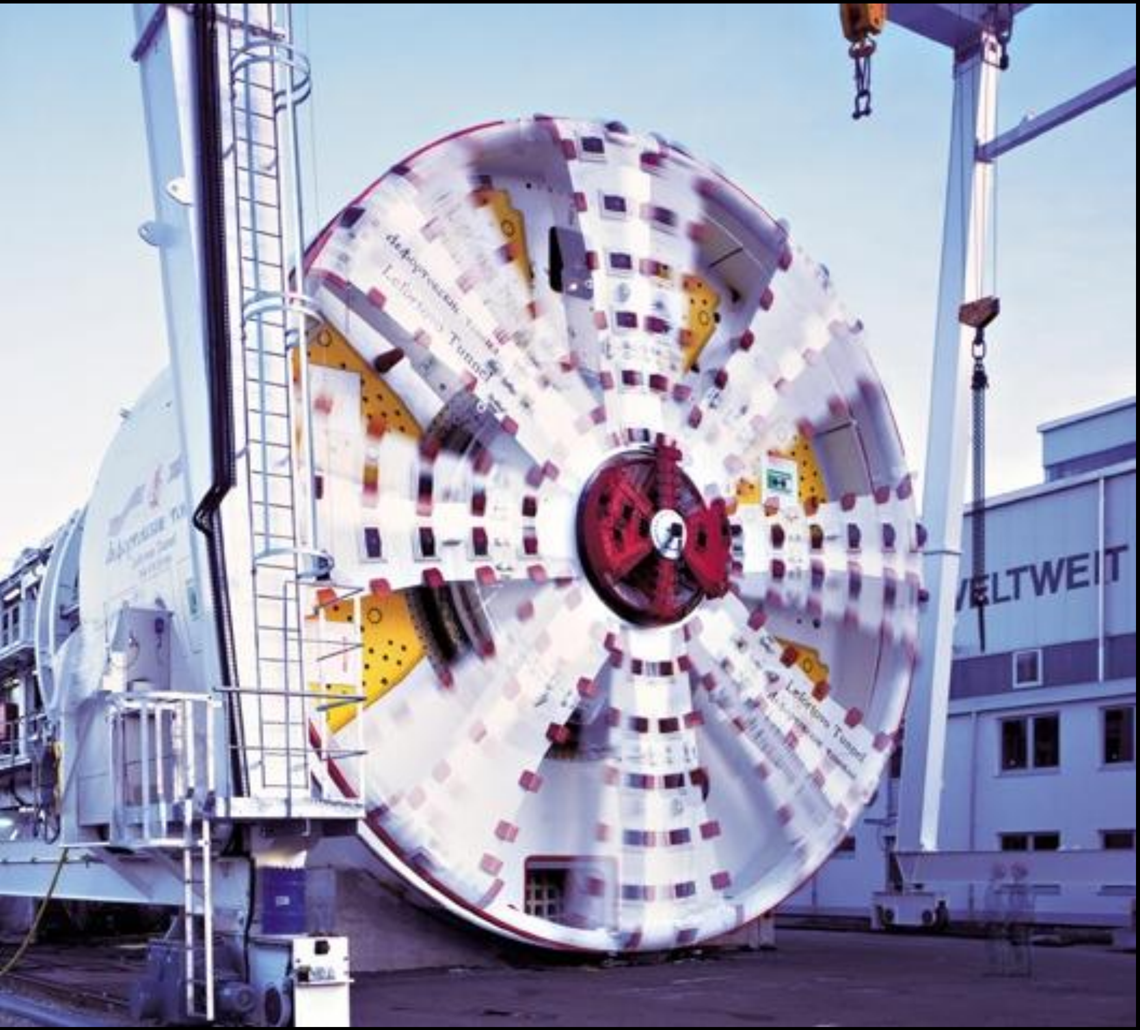
Invert Construction

Final Lining Installation

Survey in Construction

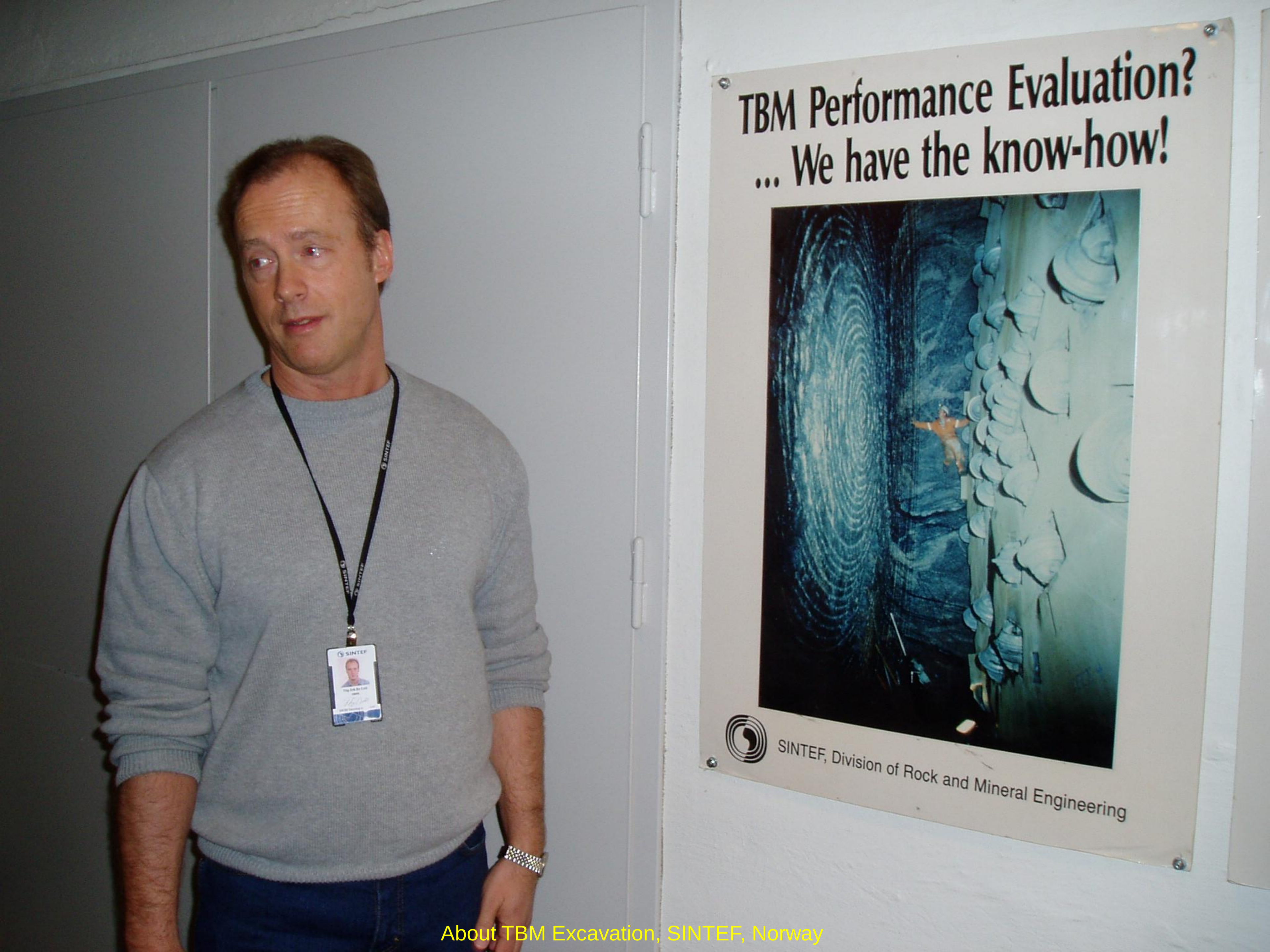
	Diameter		0mm -> 1,000mm -> 2,000mm -> 16,000mm
	Auger Drilling Machines		DN 150 – DN800
	AVN Micromachines		DN 250 – DN 2000
	Shields with partial face excavation	Pipe Jacking	DN 1200 – DN 3500
		Segmental Lining	DN 1800 – DA 12000
	EPB-Machines	Pipe Jacking	DN 1200 – DN 3000
		Segmental Lining	DN 1800 – DA 16000
	Mixshields	Pipe Jacking	DN 1600 – DN 3000
		Segmental Lining	DN 1800 – DA 15060
	Hard Rock-TBM		DN 1200 – DA 12500
	Hard Rock Gripper-TBM		DN 2200 – DN 10000

Excavation Machines



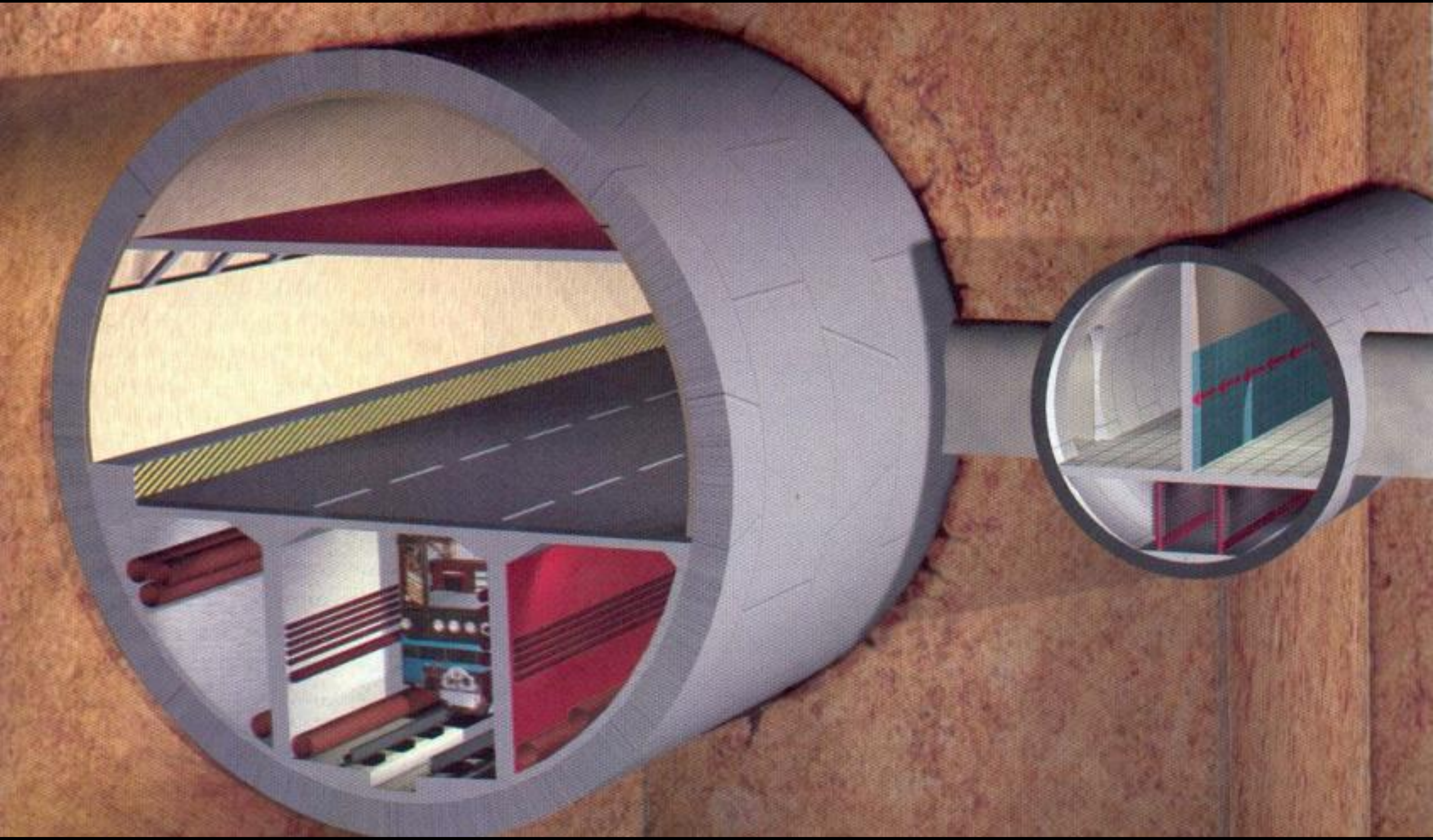
Soft Ground TBMs

Soft Ground TBMs, Hamburg, Germany

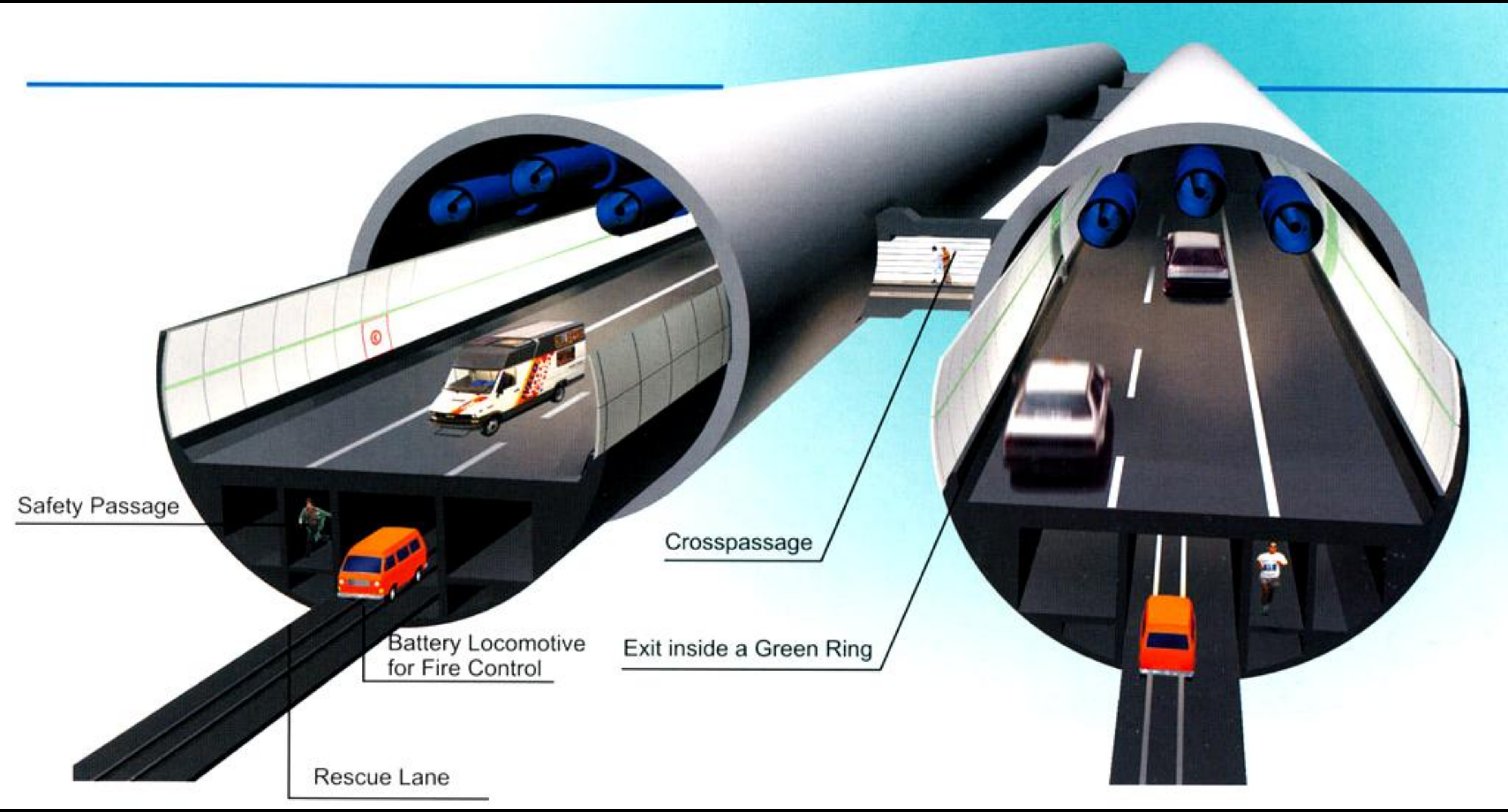


About TBM Excavation, SINTEF, Norway

Soft Ground TBMs, Hamburg, Germany



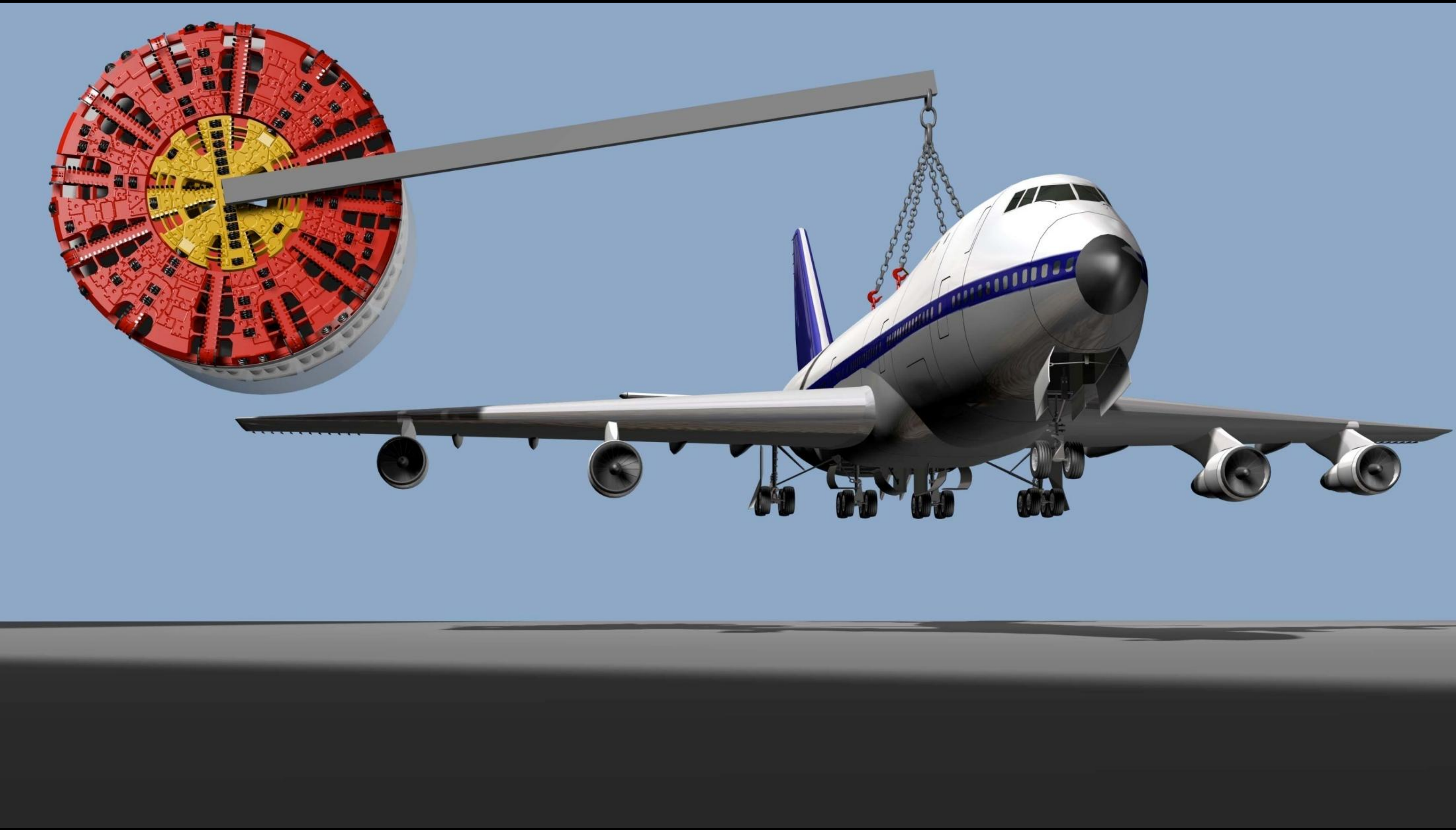
TBM Tunnel, Moscow, Russia



TBM Tunnel, Shanghai, China

TBM Tunnel, Shanghai, China

Highest torque ever installed in a TBM.
125,268 kNm, EPB-Shield M-30 Madrid.



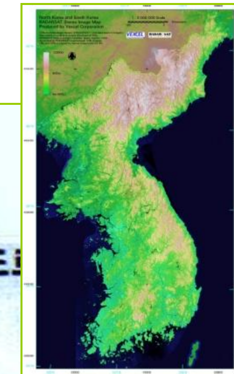
Hard Rock TBM

Hard Rock TBM

Completion of TBM excavation

Explosives Charging, Bul-Am Mt. Tunnel, near Tyoe-gye-won, Korea (2002)

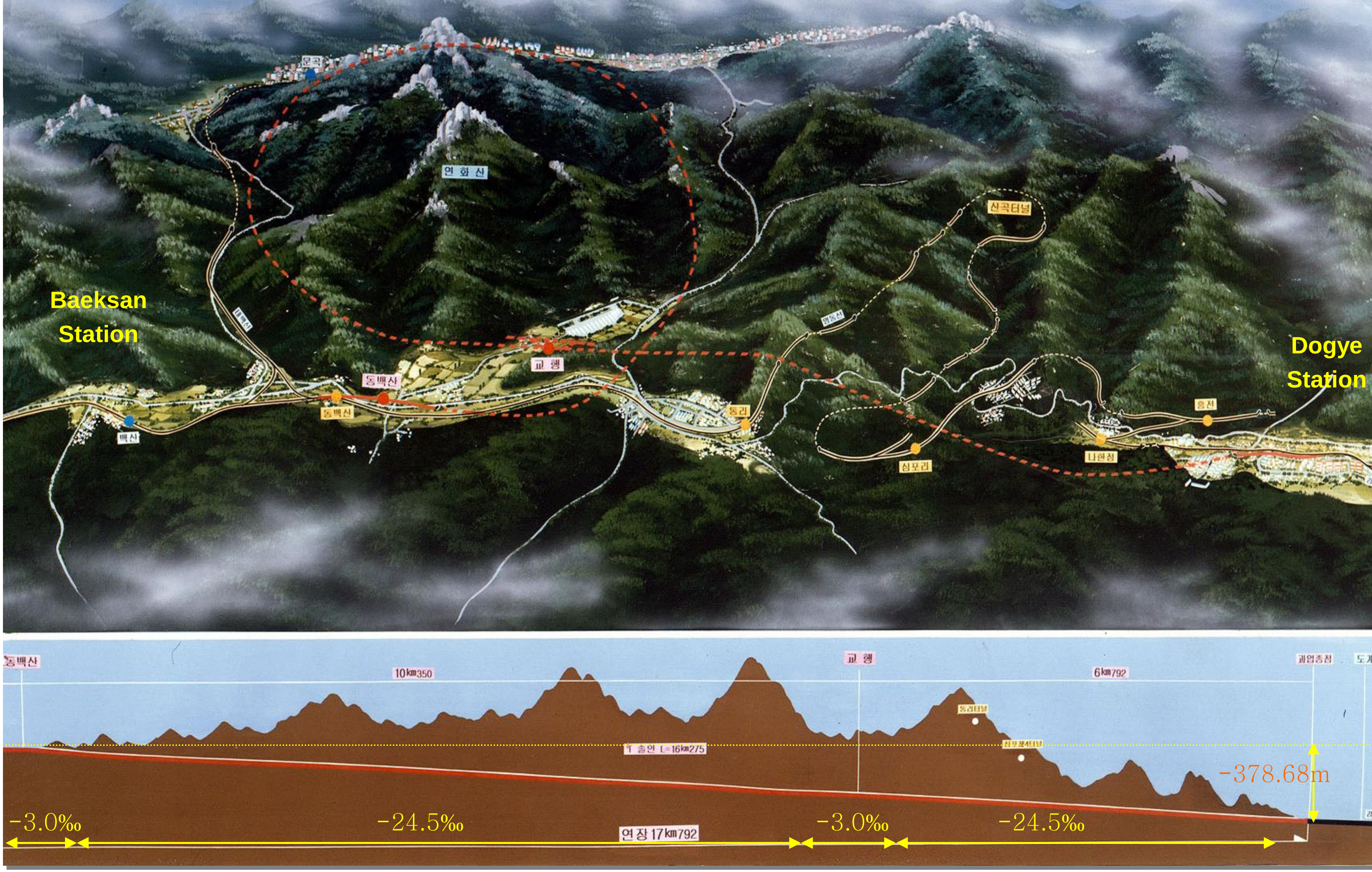
Drilling, Bul-Am Mt. Tunnel, near Tyoe-gye-won, Korea (2002)



- 1940.8 Incline installed
- 1963.5 Switch-back installed
- 1999. Loop-type tunnel started

Location: Gangwon-Do, Korea

Taebaek Mountains

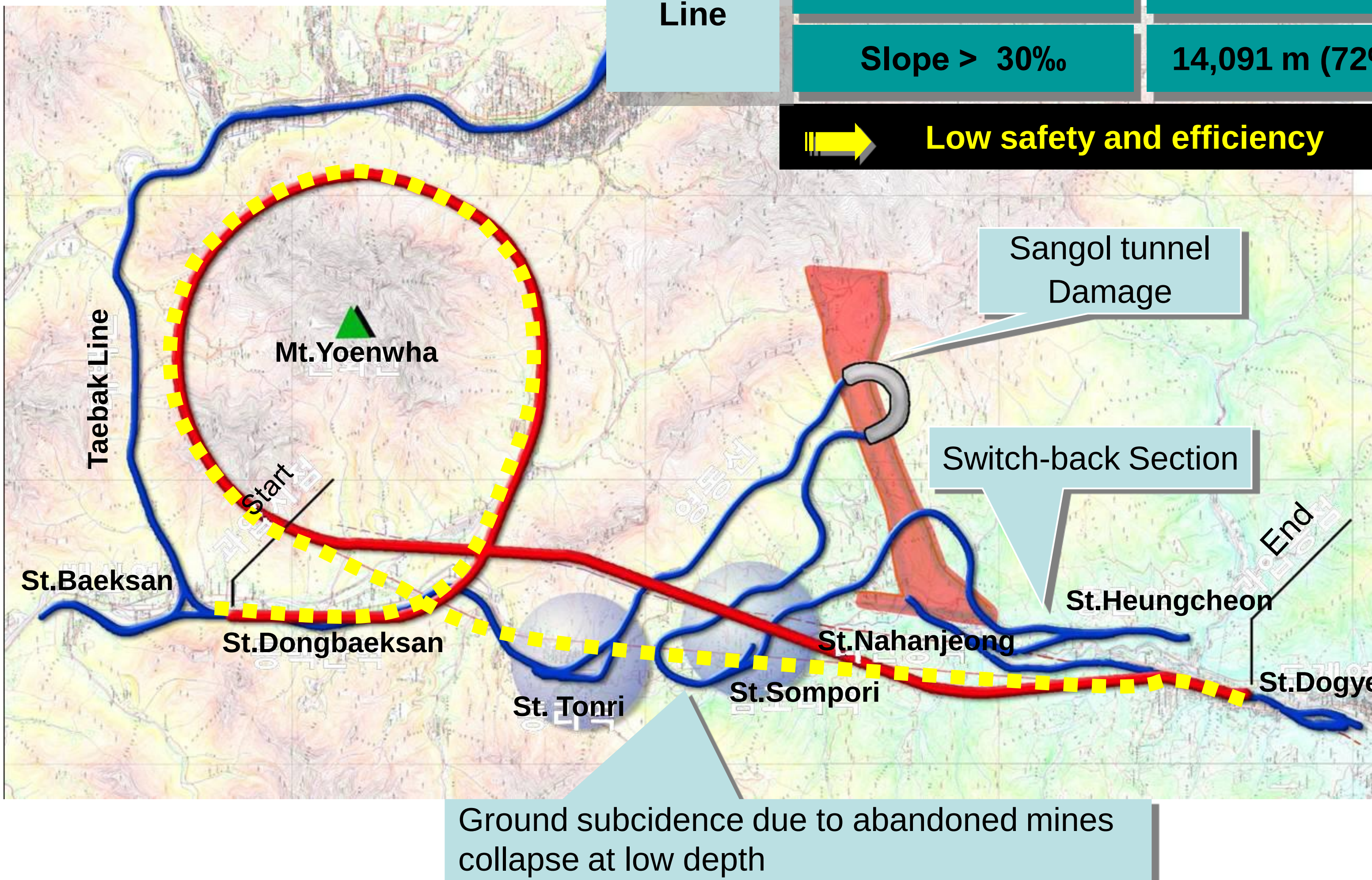


Location: Gangwon-Do, Korea
Taebaek Mountains

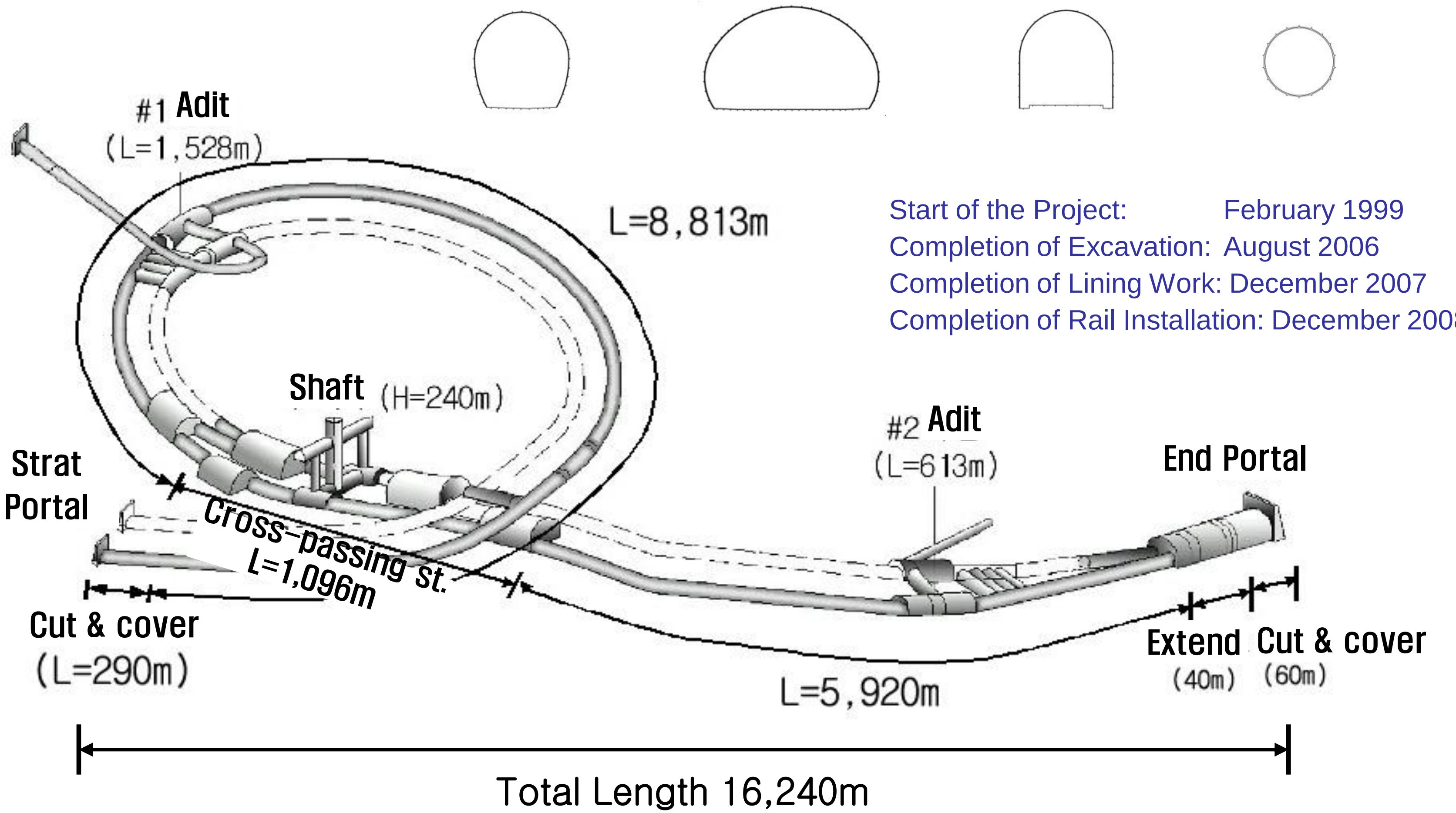
Solan Tunnel, Taebaek, Korea

Existing Line		
	Total Length	19,576 m
	Radius < 300m	7,253 m (37%)
	Slope > 30‰	14,091 m (72%)

Low safety and efficiency



Single Tunnel	Ext. Tunnel	Adit	Vent. Shaft
W7.6mXH7.8m	W17.7mXH10.5m	W7.6mXH10.5m	Ø6.5m



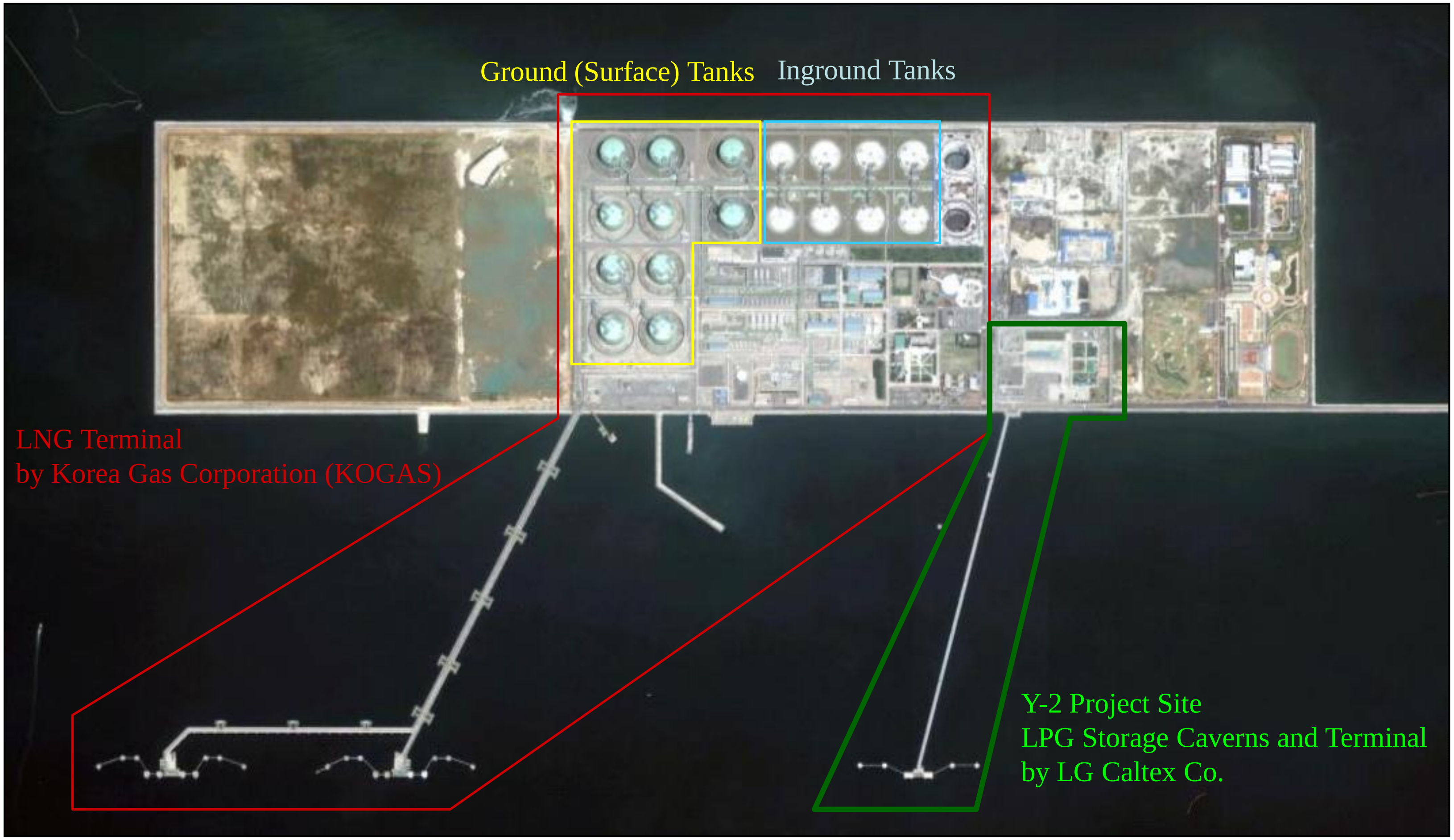
Start of the Project: February 1999
Completion of Excavation: August 2006
Completion of Lining Work: December 2007
Completion of Rail Installation: December 2008

Solan Tunnel, Taebaek, Korea

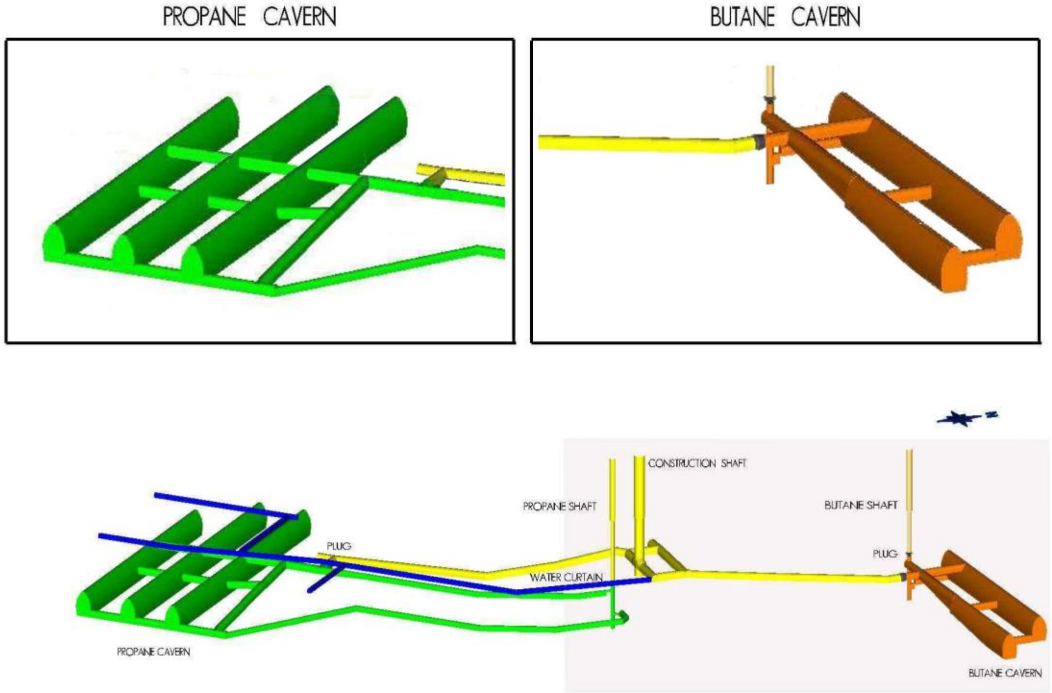
Y2 Project, LPG Storage Caverns, Incheon, Korea

Artificial Landfill Island, Incheon Metropolitan Area

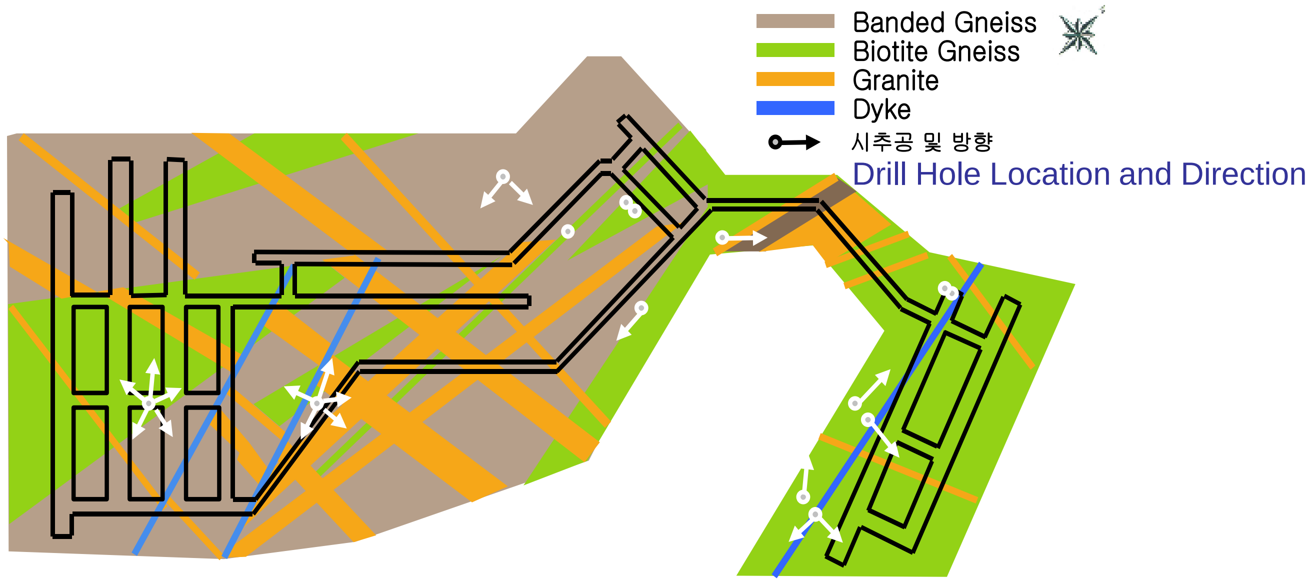
Y2 Project, LPG Storage Caverns, Incheon, Korea

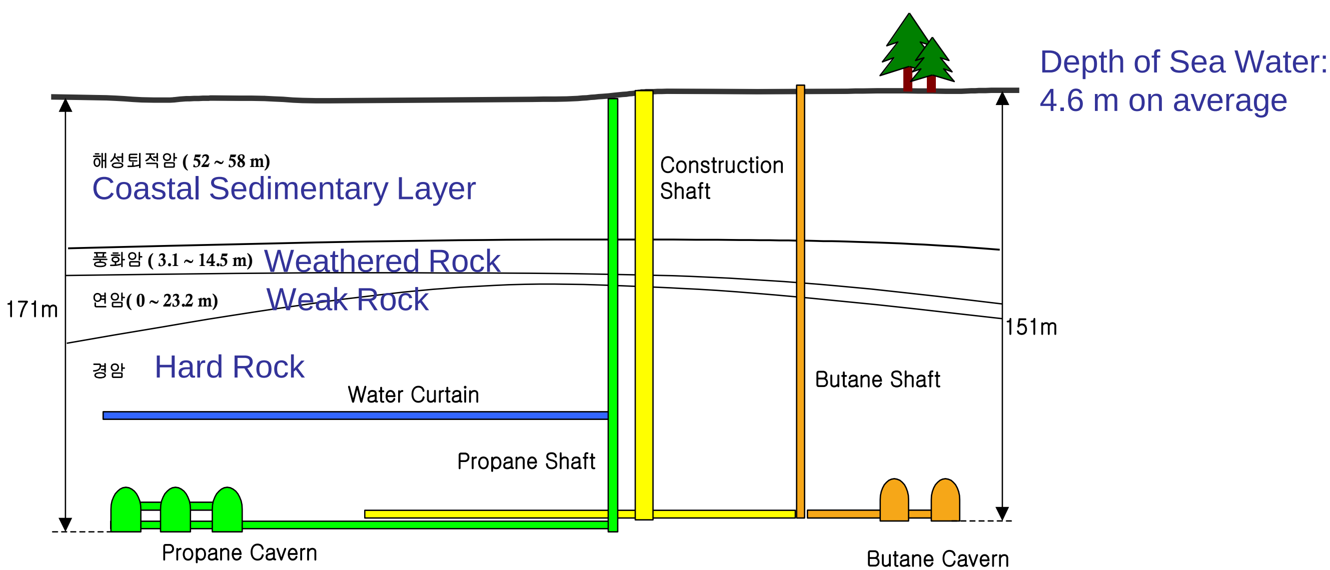


Artificial Landfill Island, Incheon Metropolitan Area



Y2 Project, LPG Storage Caverns, Incheon, Korea





Y2 Project, LPG Storage Caverns, Incheon, Korea

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