CT3300 – Use of Underground Space

Basement Structures

Delft University of Technology/Lectures CT3300
dr.ir. Wout Broere

Basement Structures

- What are basement structures?

- Possibilities for utilisation
- Motives for building underground
- Safety aspects
- Construction techniques
- Cost factors

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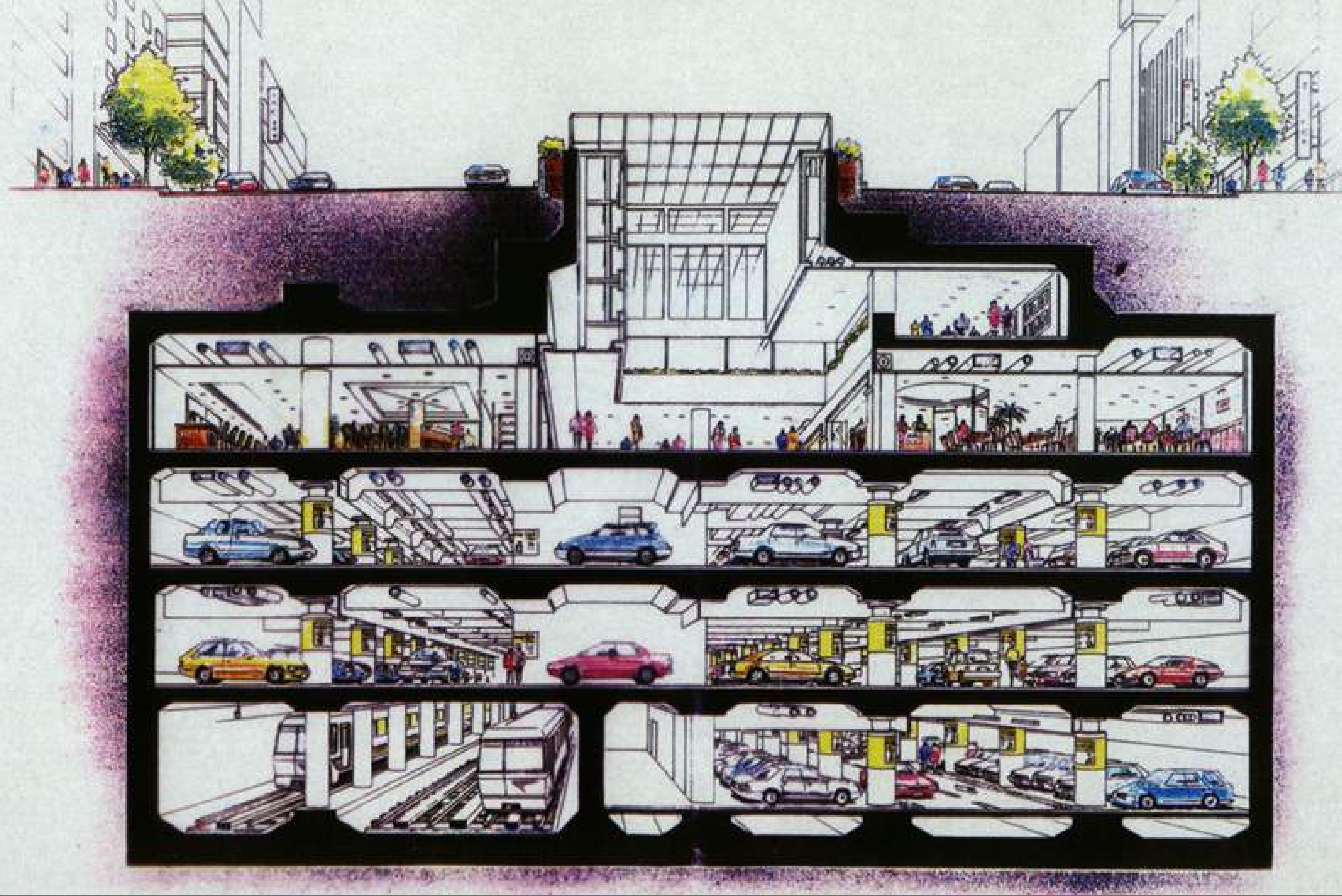
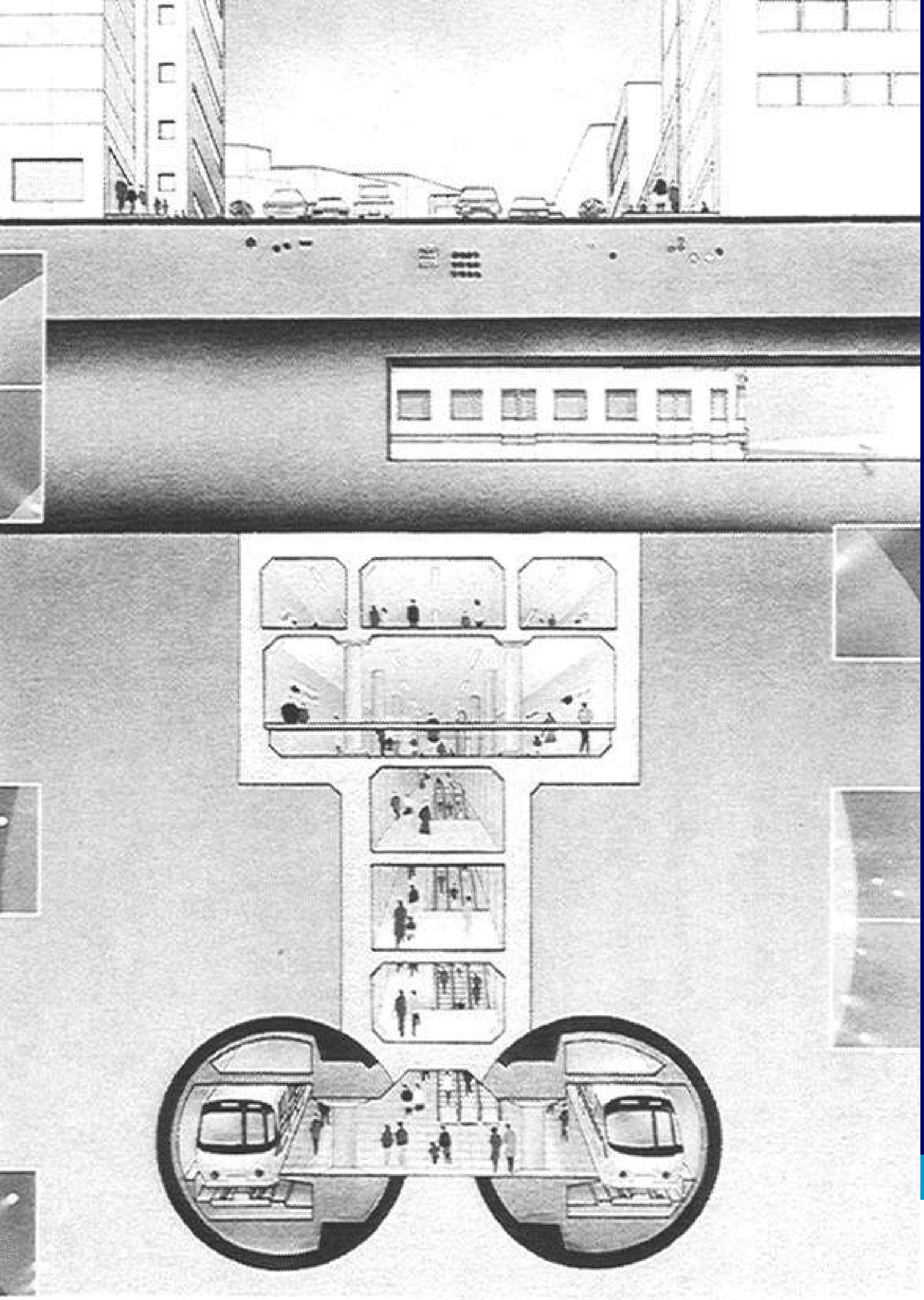
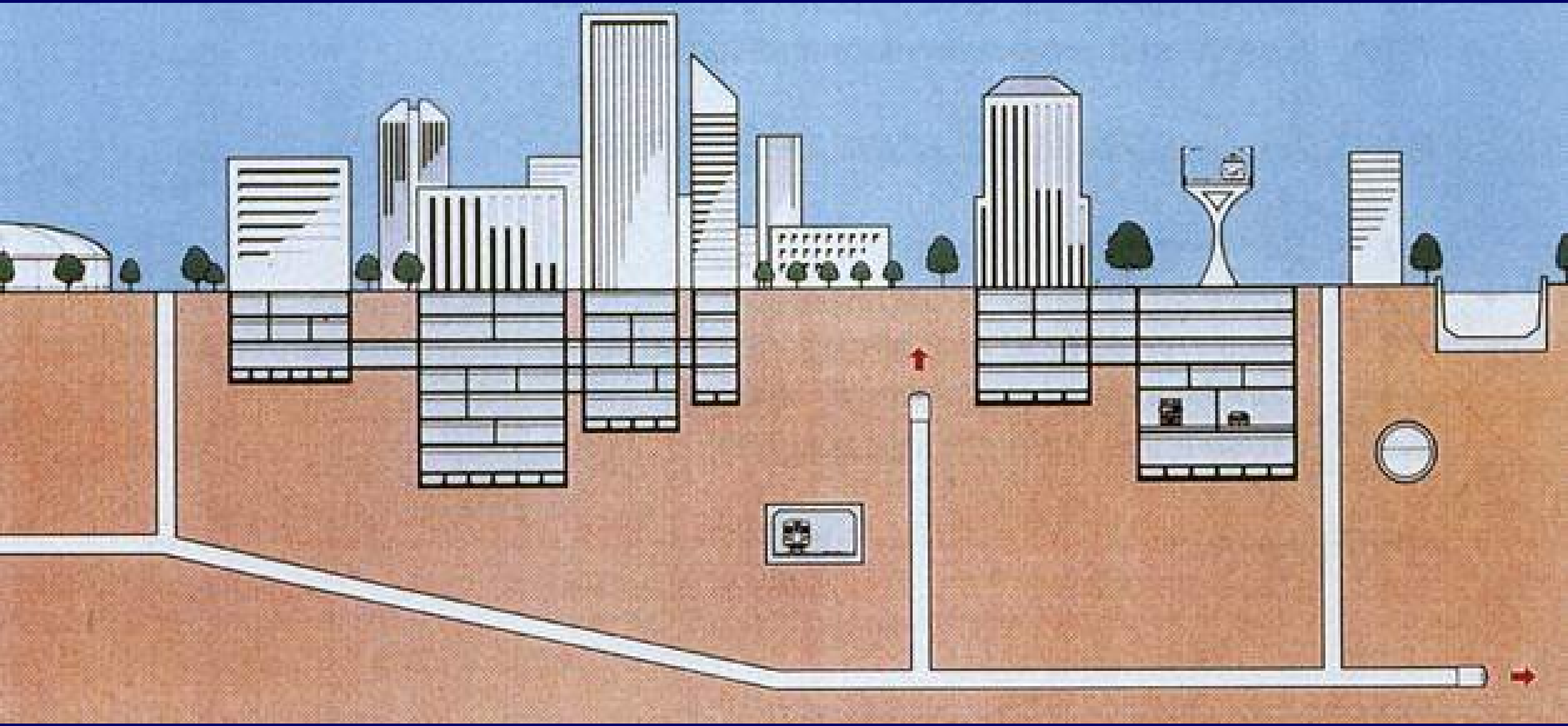




Basement Structures



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Present Situation in Underground Construction

In the Netherlands underground construction is interesting because of the following reasons:

- Energy savings
- Protection / for safety reasons
- Integration in environment / landscape
- Mixed use of land
- Cultural heritage conservation
- Limitation of hindrance

Primary Function Types

- Residential
  - Climate
  - Safety
- Business
  - Offices
  - Shops
  - Industrial facilities
- Recreation
  - Sports
  - Musea
  - Education
  - Religion
  - Theaters
- Storage
  - Water
  - Gas
  - Hazardous waste
- Transportation
  - Railway
  - Metro
  - Cars
  - Parking
  - Goods
- Pipelines & Utilities
  - Transport
  - Waste water / sewage
  - Water
  - Gas
  - Cables

Motives

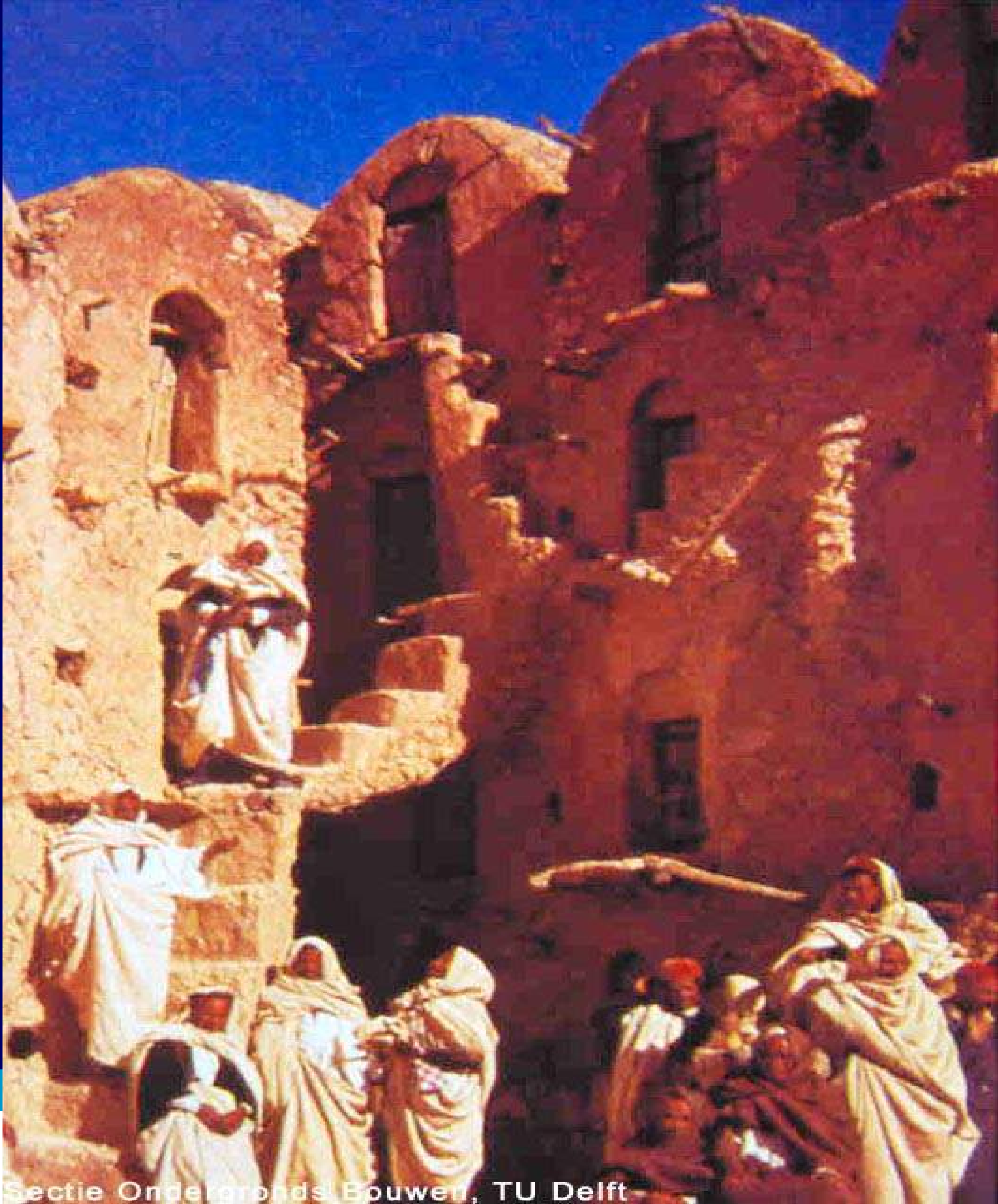
Driving forces

Driving factors for underground building construction:

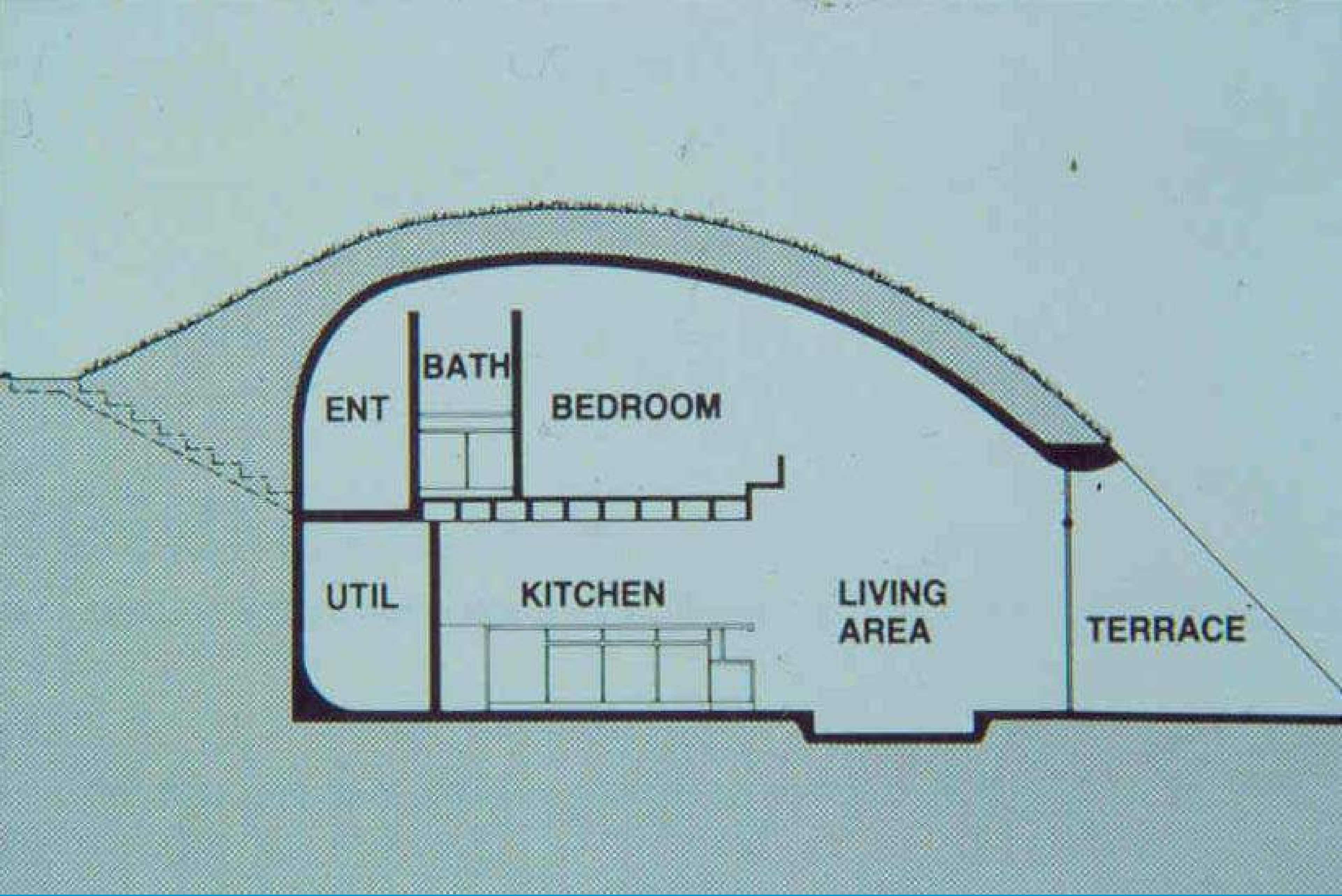
- Growing quality awareness
- Growing pressure on available (urban) space
- Growing mobility
- Large economic growth / prosperity
- Technological progress
- Active government / political pressure / side effect of policy
- Environment

Residential

- Climate
- Shelter



Capadocia, Turkey


BATH
ENT
BEDROOM
UTIL
KITCHEN
LIVING
AREA
TERRACE

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House Pembrokeshire, Wales


Reitmans
12/11/2004


GARAGE
Niveau Ste-Catherine
12/11/2004

La ville intérieure, au cœur du centre-ville

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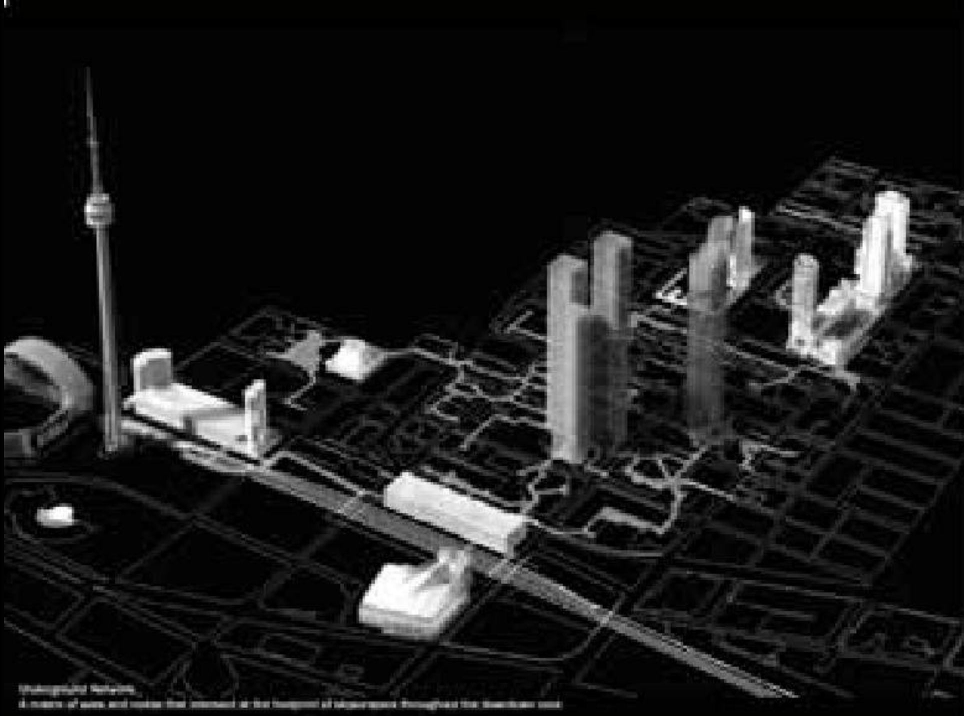
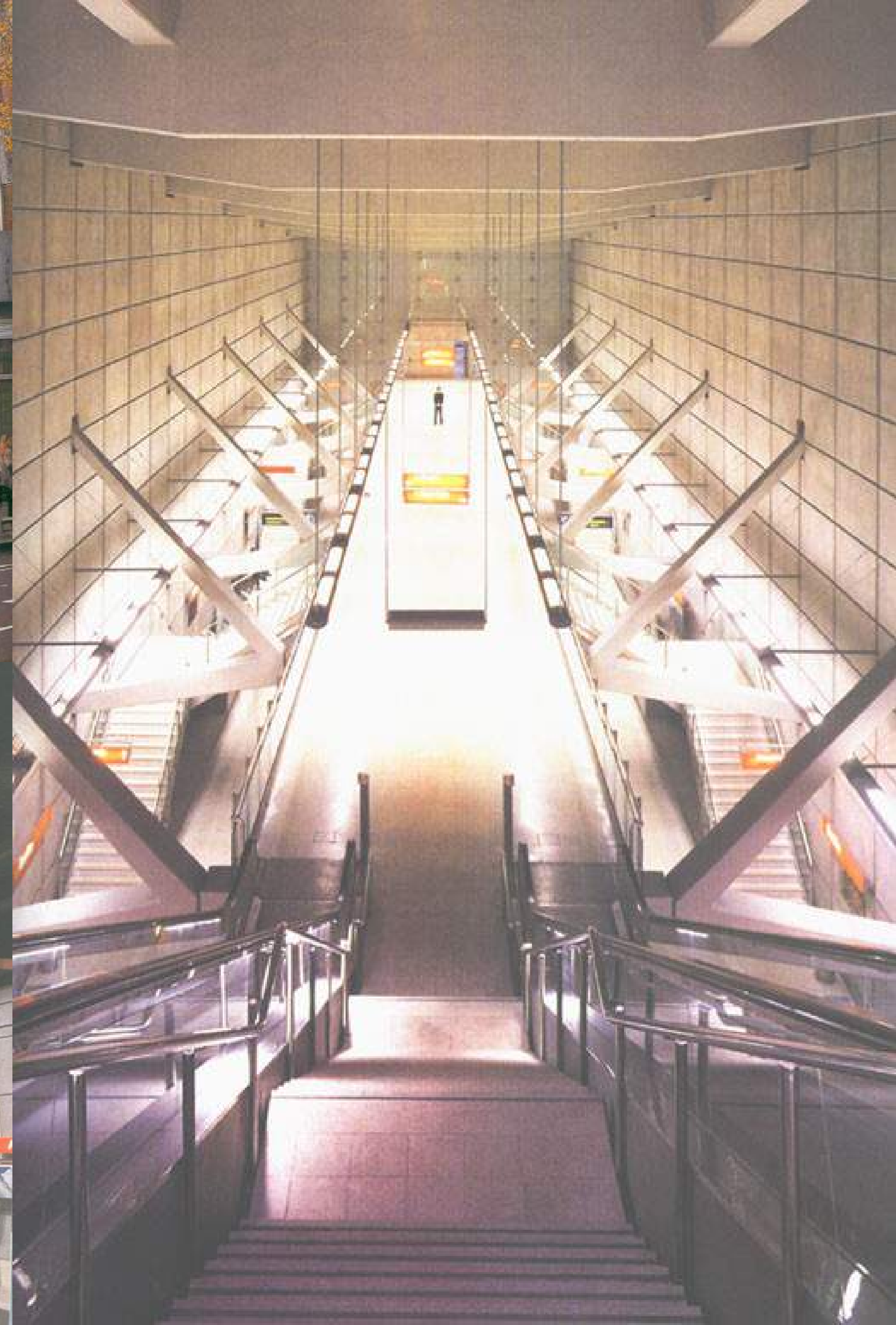



Ottawa

Koopgoot, Beursplein Rotterdam

TGV Lille

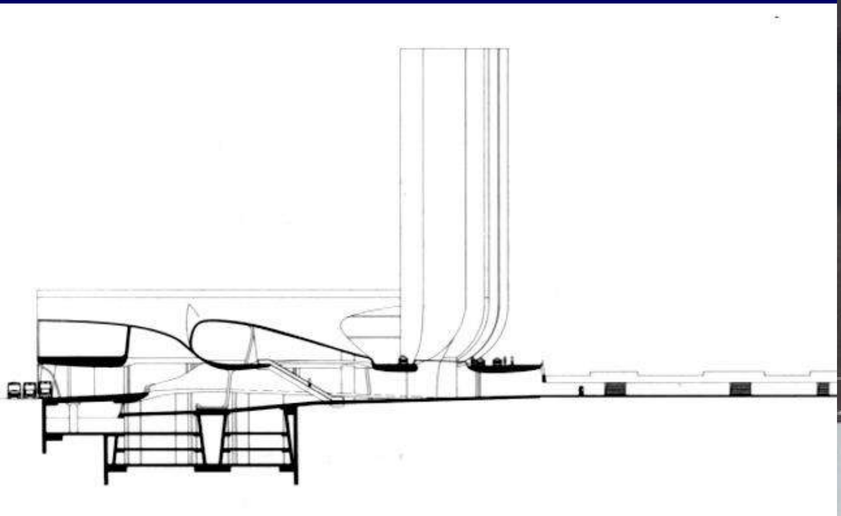


Metro Bilbao, Spain

Metro station Canary Warf London, UK

Mass Transit
Arnhem Central Station

- Multi modal public transport transit point
- Shopping, offices, residential functions



Arnhem Centraal: Parking

Amsterdam: Mechanized parking

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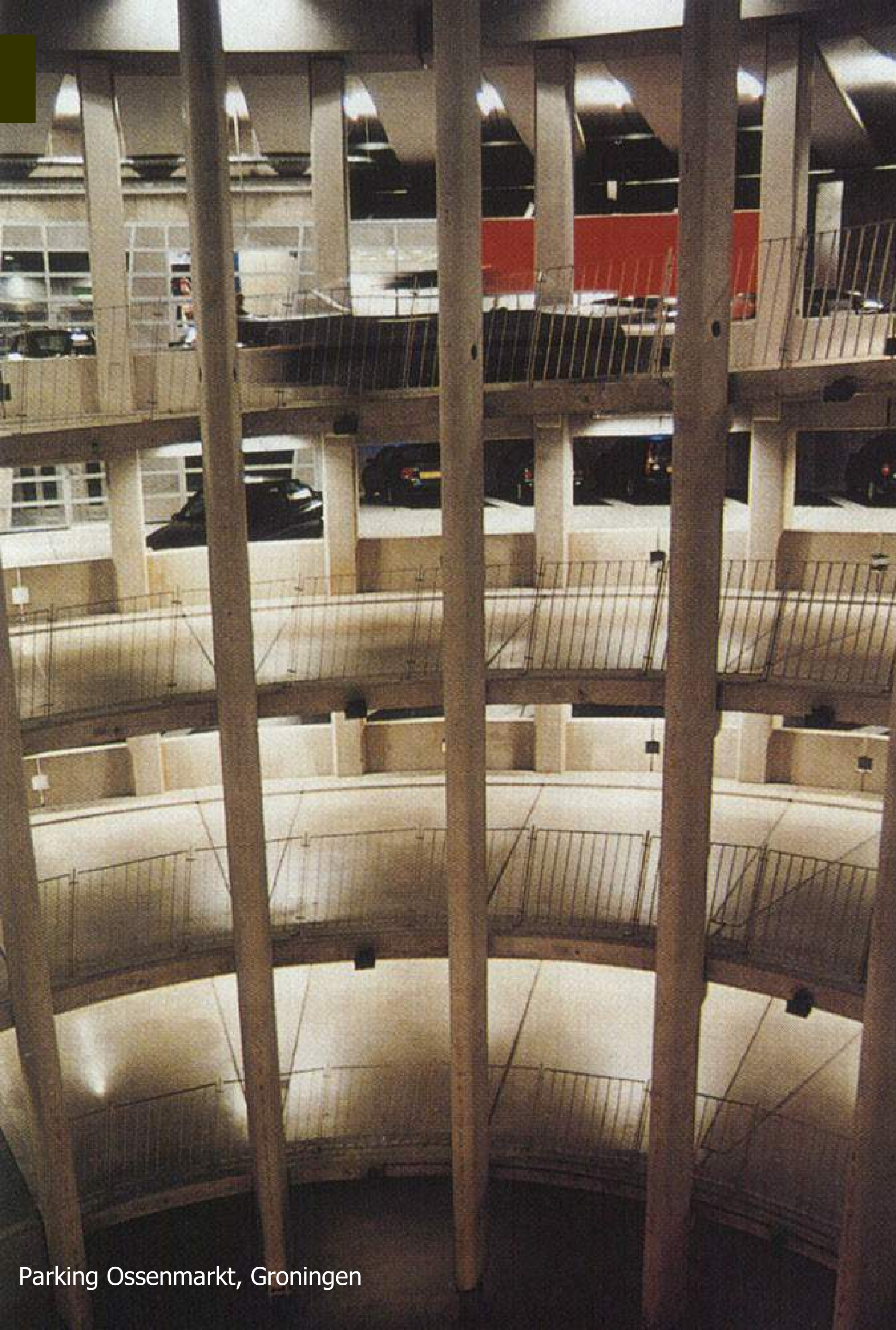
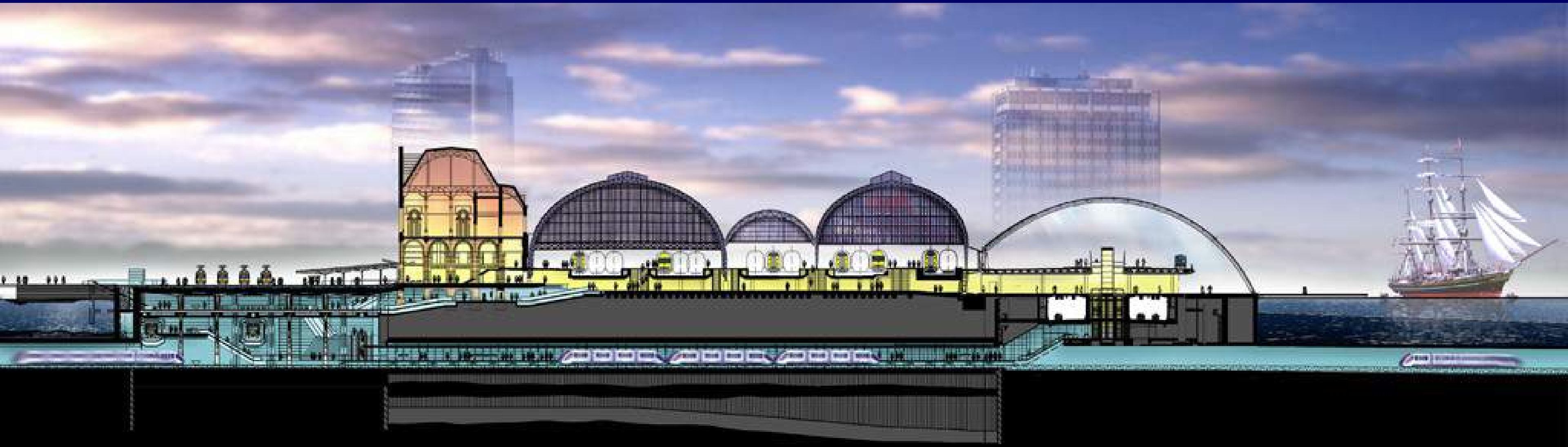


Parking Ossenmarkt, Groningen

Parkeergarage Laakhaven, Den Haag



huidige situatie

nieuwe situatie

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ESPIRITO SANTO
AGÊNCIA DO PARQUE DAS NAÇOES
Sectie Ondergronds Bouwen, TU Delft

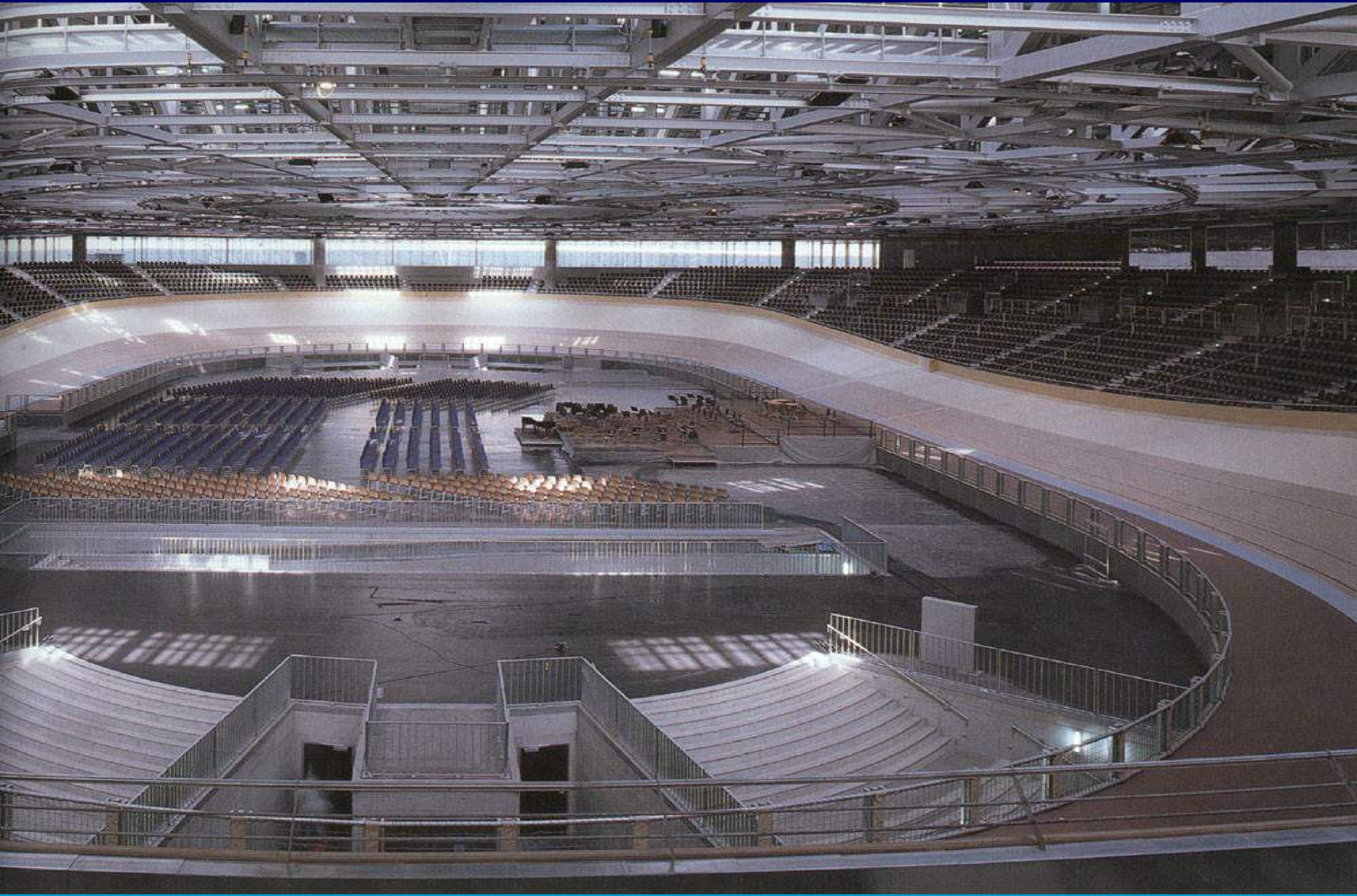
Lissabon

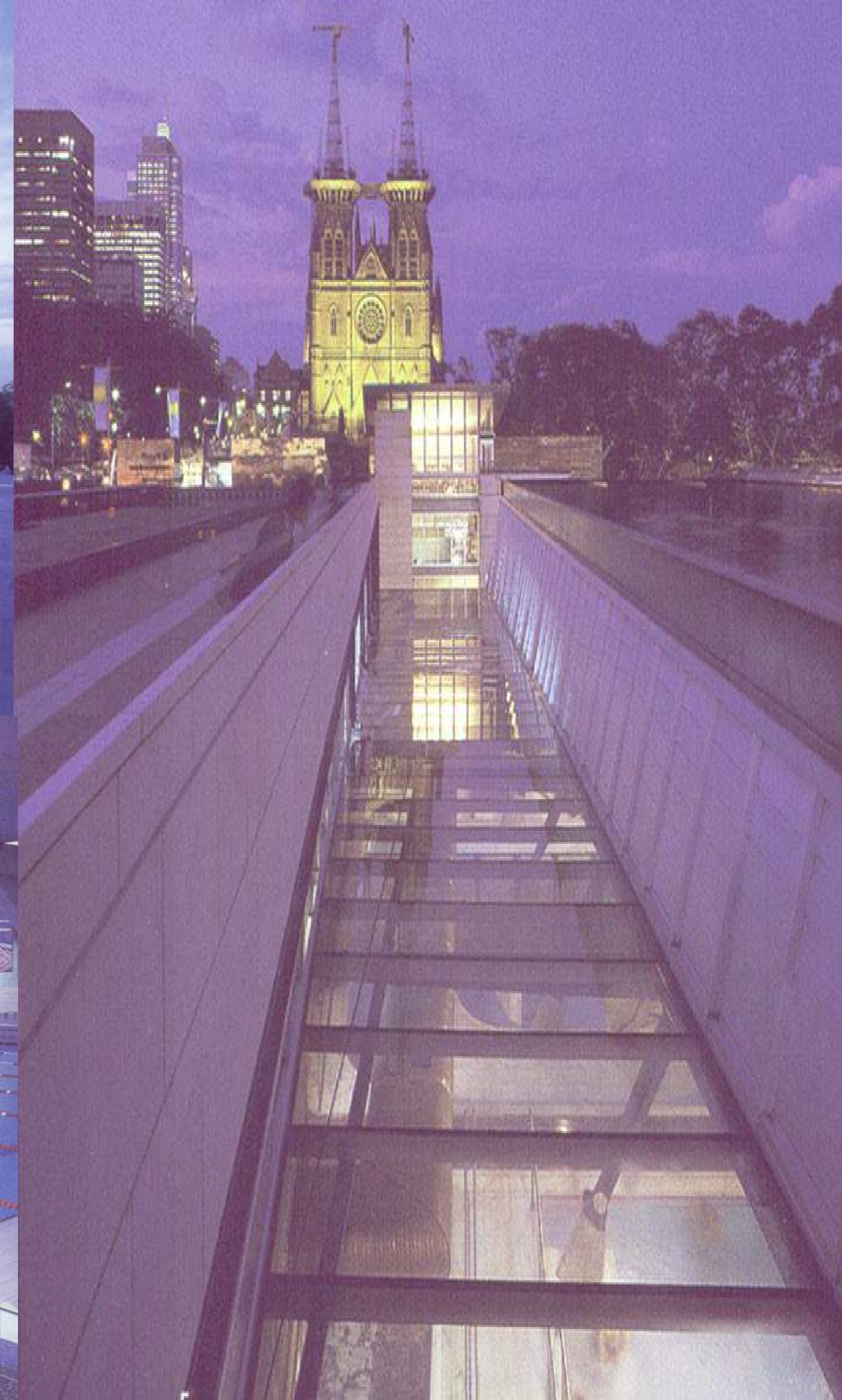
Metrostation Meteor Lissabon, Portugal

Lyon

Sectie Ondergronds Bouwen, TU Delft

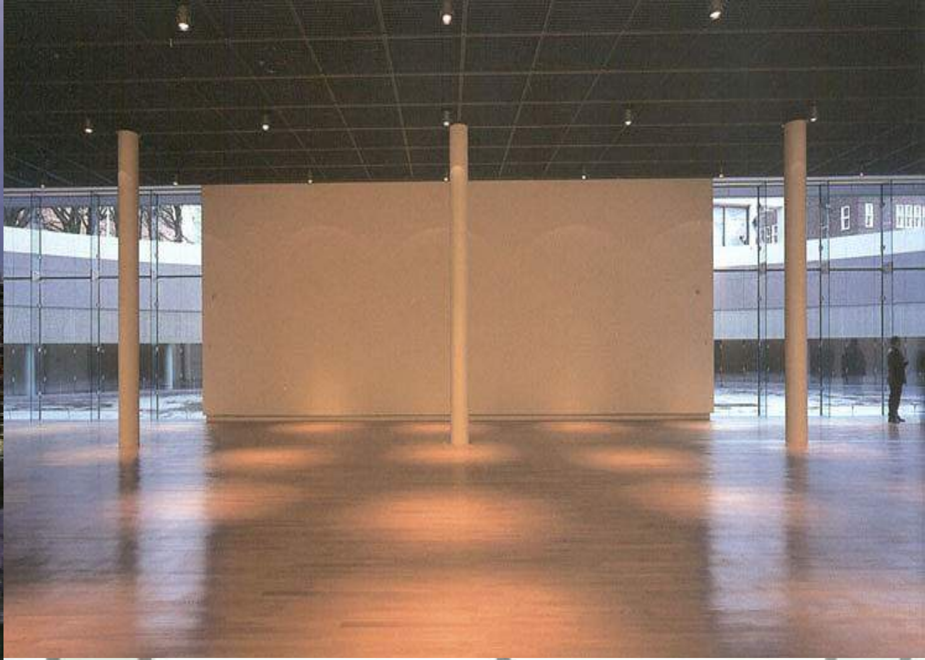
TU Delft





Sports complex Sydney, Australia


Spa, Vals, Schweiss

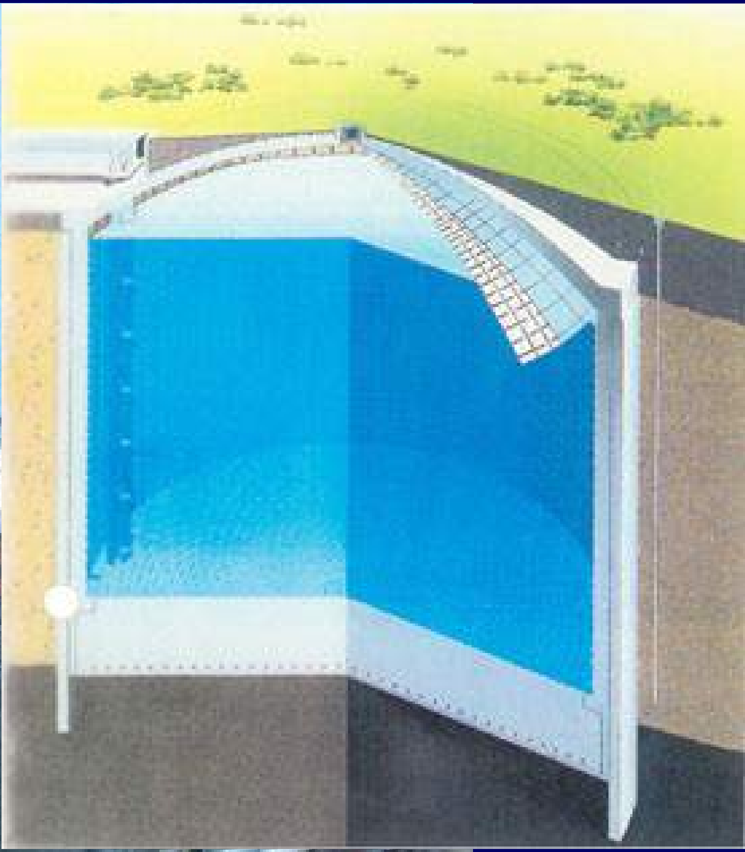


Van Gogh Museum, Amsterdam

Museum “Beelden aan Zee”, Scheveningen

Villa Maliebaan, Utrecht

Underground Storage



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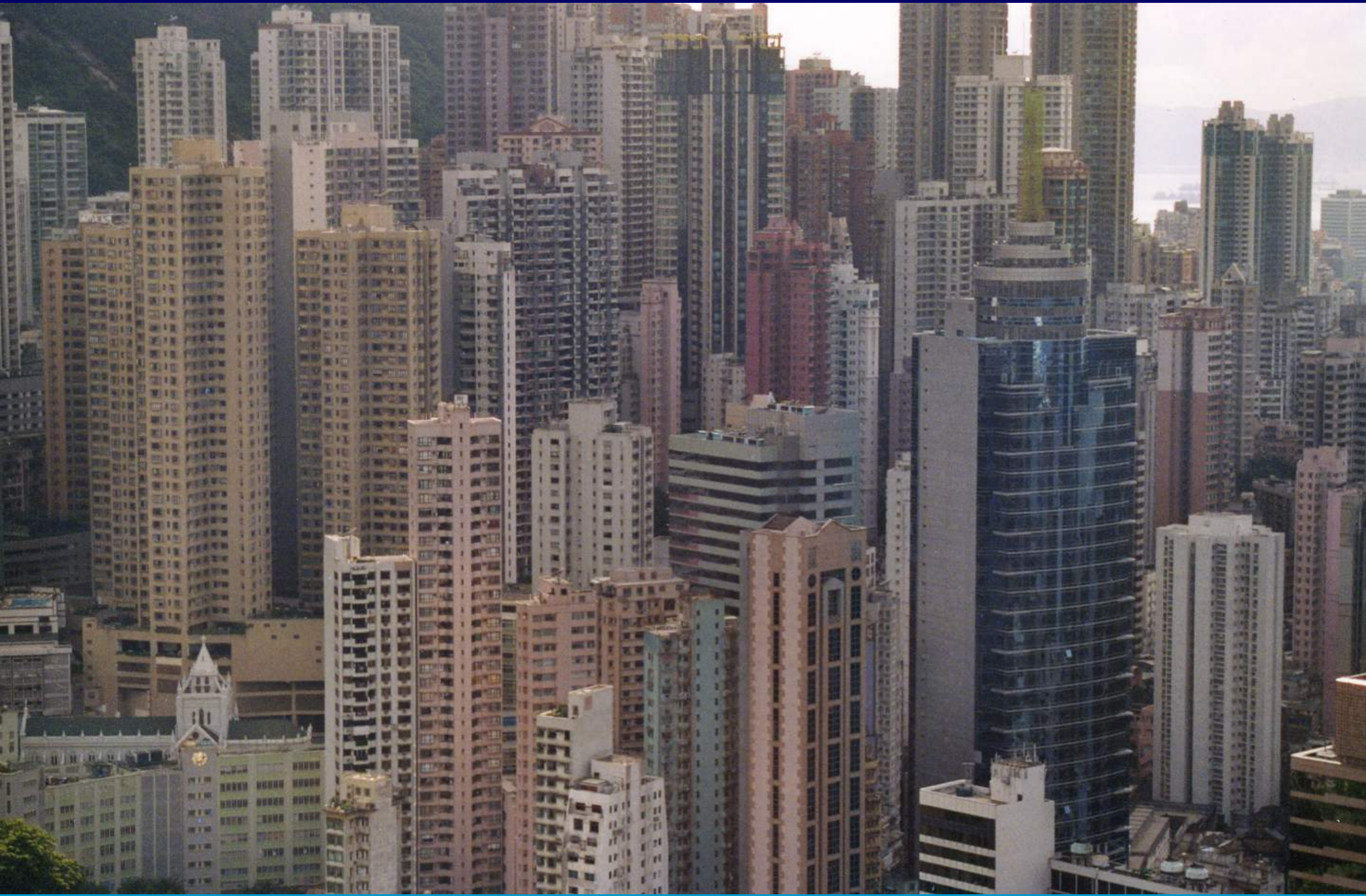

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Function Changes

Utrecht

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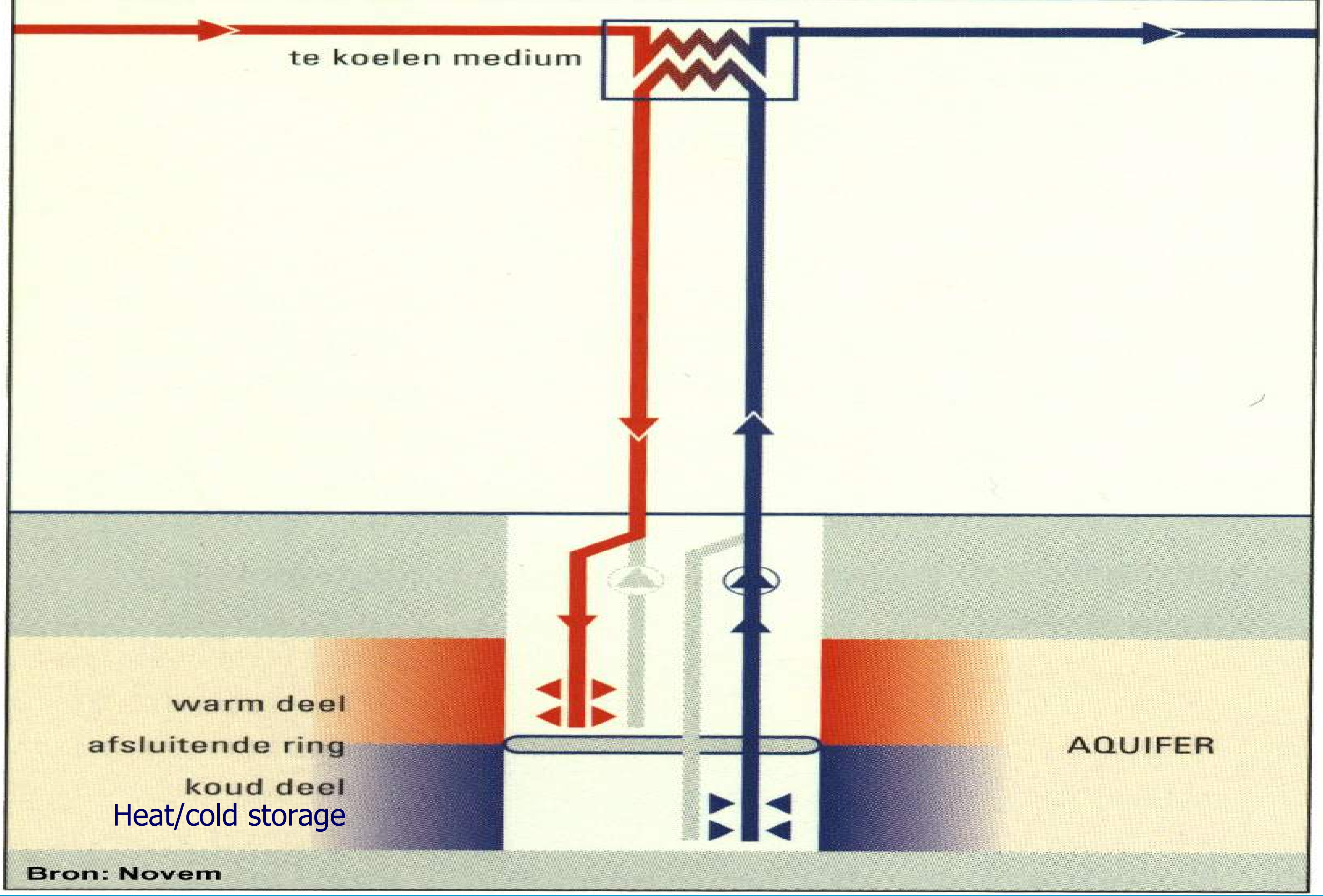
TunFun, Amsterdam



Heat/cold storage

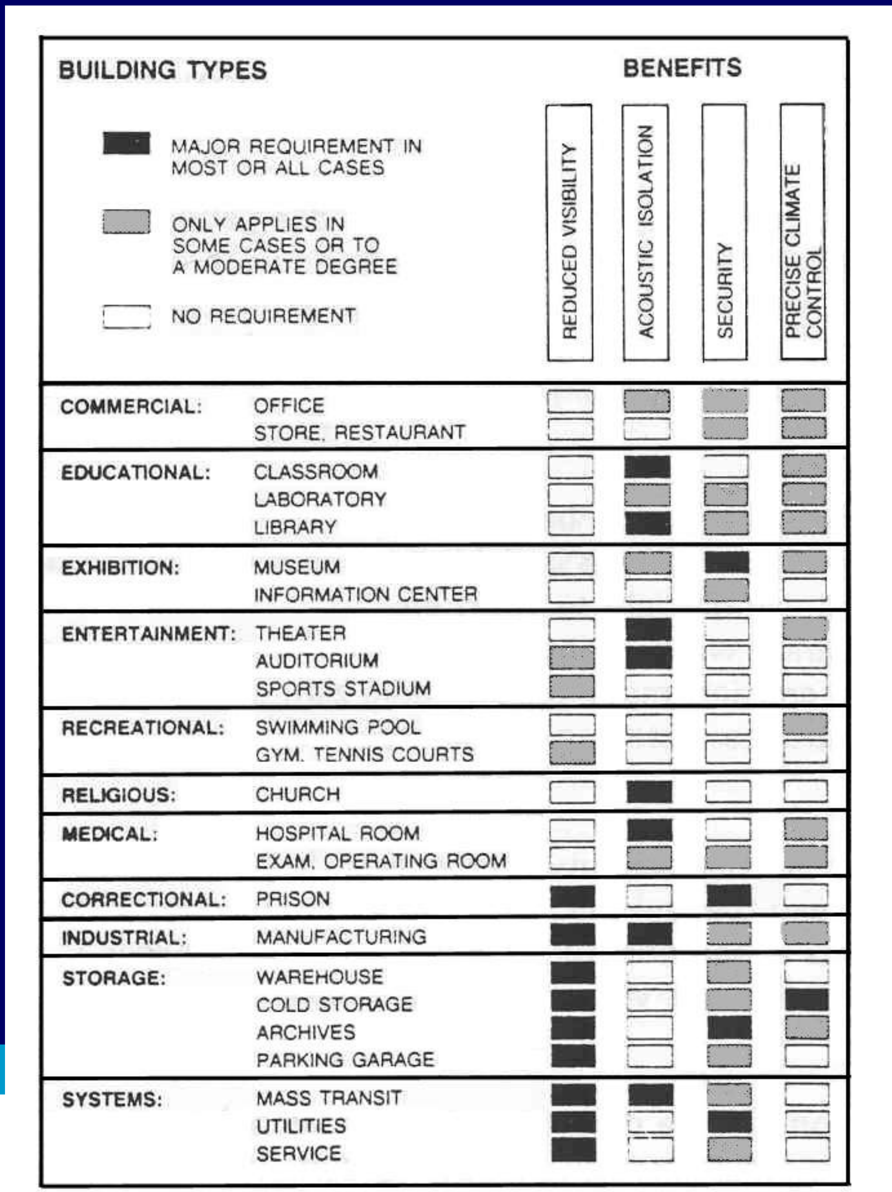
Possible Functions of Buildings under the Ground

Most advantages of underground buildings are independent of the functions of these buildings and do not depend on the functions above

Some advantages are tangible:

- Limited daylight illumination
- Good sound insulation
- Easier security possibilities
- Good warmth / cold insulation

Advantages of underground constructions for different utilization functions



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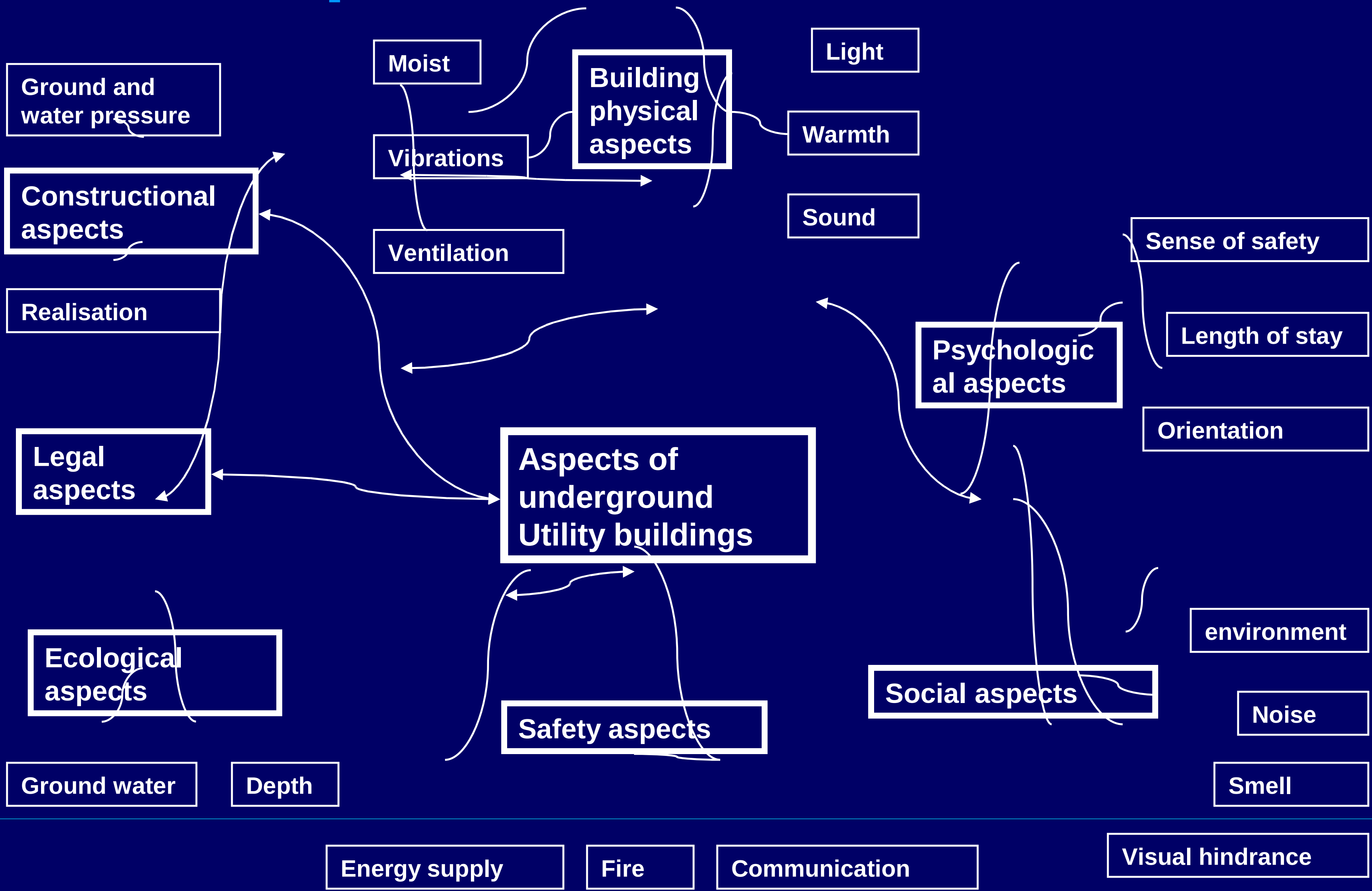
Depth Dependency of Functions

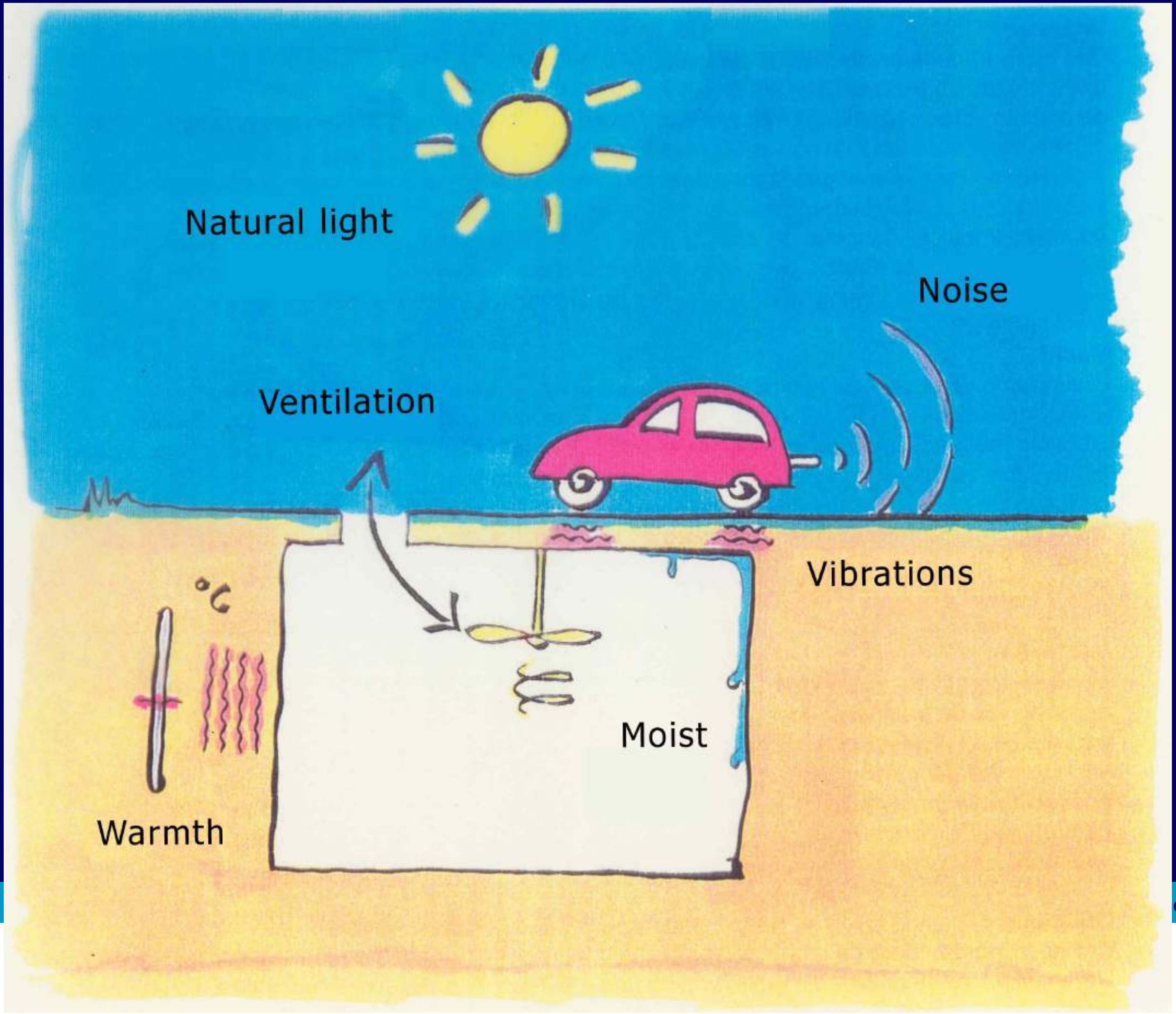
	FUNCTION	1st layer	2nd layer	more layers
1	Offices	*		
2	Restaurant	*	*	
3	Laboratory	*	*	*
4	Library	*	*	*
5	Theater	*	*	*
6	Sports accomodation	*	*	*
7	Swimming pool	*	*	*
8	Church	*		
9	Surgery room	*	*	*
10	Prison	*	*	*
11	Factory	*	*	*
12	Warehouse	*	*	*
13	Cold storage	*	*	*
14	Archives	*	*	*
15	Parking garage	*	*	*
16	Installation room	*	*	*
17	Department store	*	*	*

Mind Map

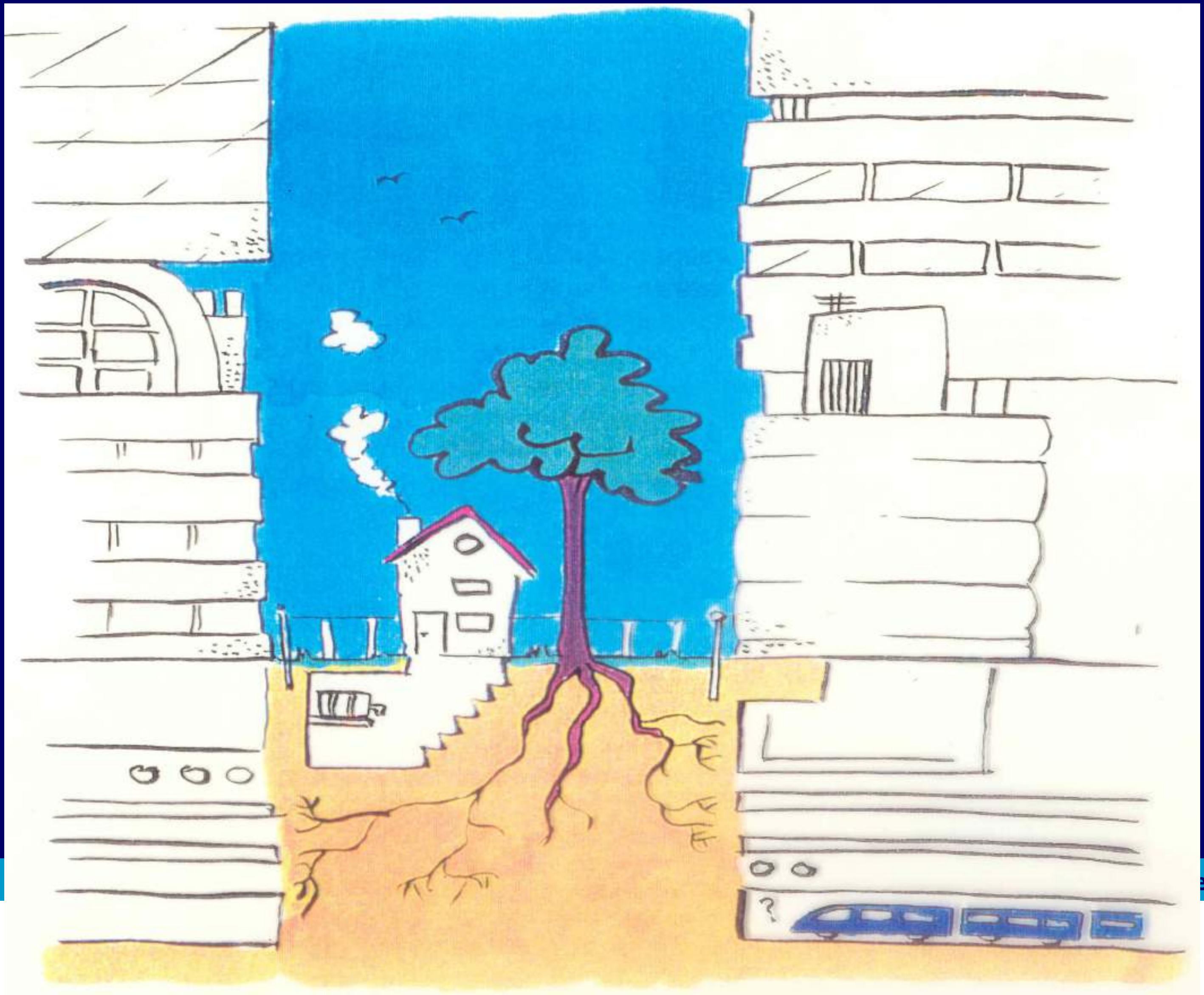


Ground and water pressure
Moist
Building physical aspects
Light
Vibrations
Warmth
Constructional aspects
Sound
Ventilation
Sense of safety
Realisation
Length of stay
Psychological aspects
Orientation
Legal aspects
Aspects of underground Utility buildings
environment
Ecological aspects
Social aspects
Noise
Safety aspects
Ground water
Depth
Smell
Energy supply
Fire
Communication
Visual hindrance

Physical Aspects of Underground Constructions



Legal Aspects



Safety aspects

- Sense of security
- Fire safety
- Security against trespassers
- Subdivision
- Connections between different storeys
- Exits and escape routes
- Social safety

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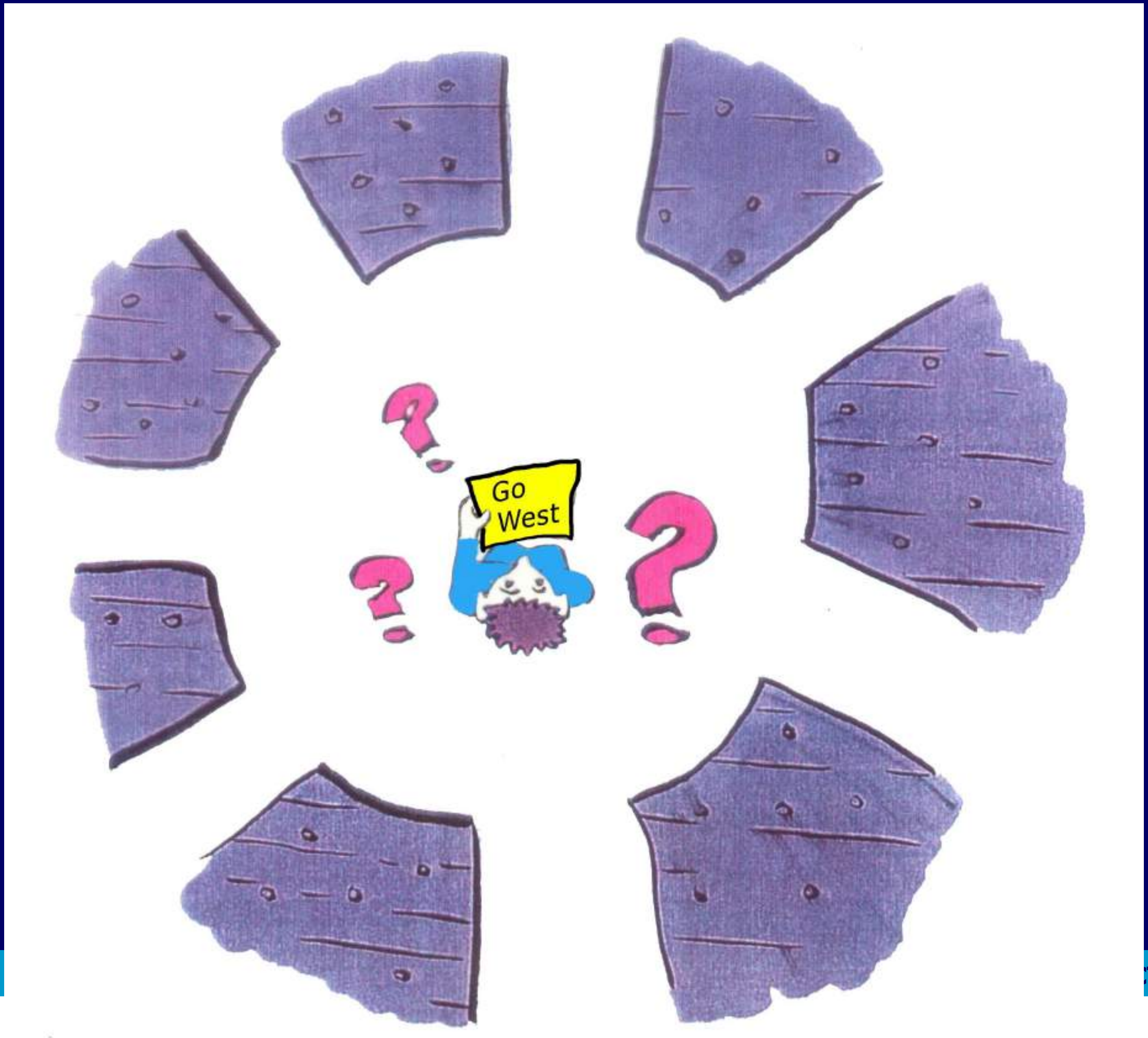
Difficulties with Orientation in Underground



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Where are the trains ?

Sense of insecurity and lack of orientation by a space with obstacles, unclear routing, artificial light.

Pleasant safe space by a clear routing, lots of open spaces, natural daylight entry and the use of bright materials

Application of natural daylight and artificial light

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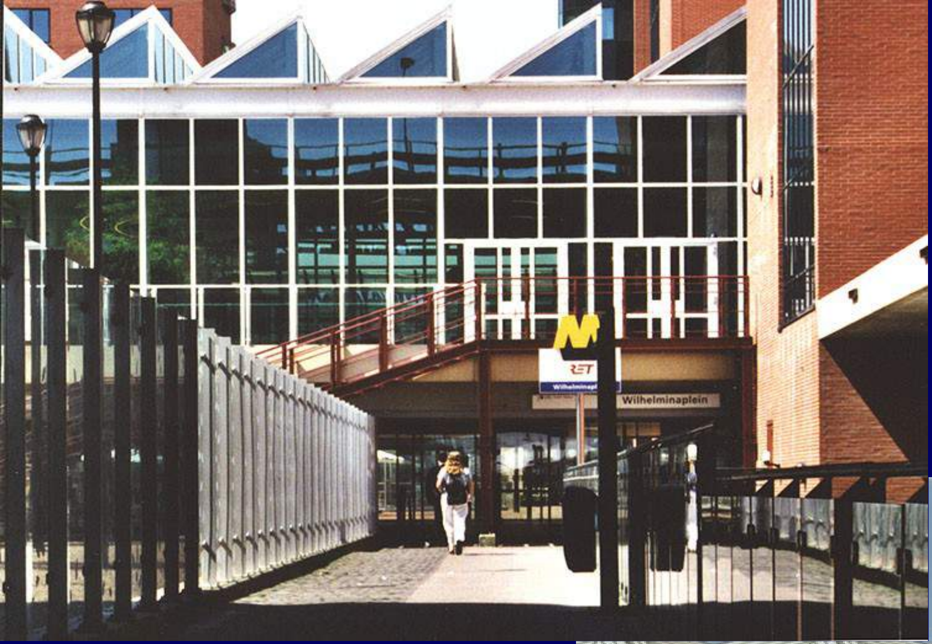
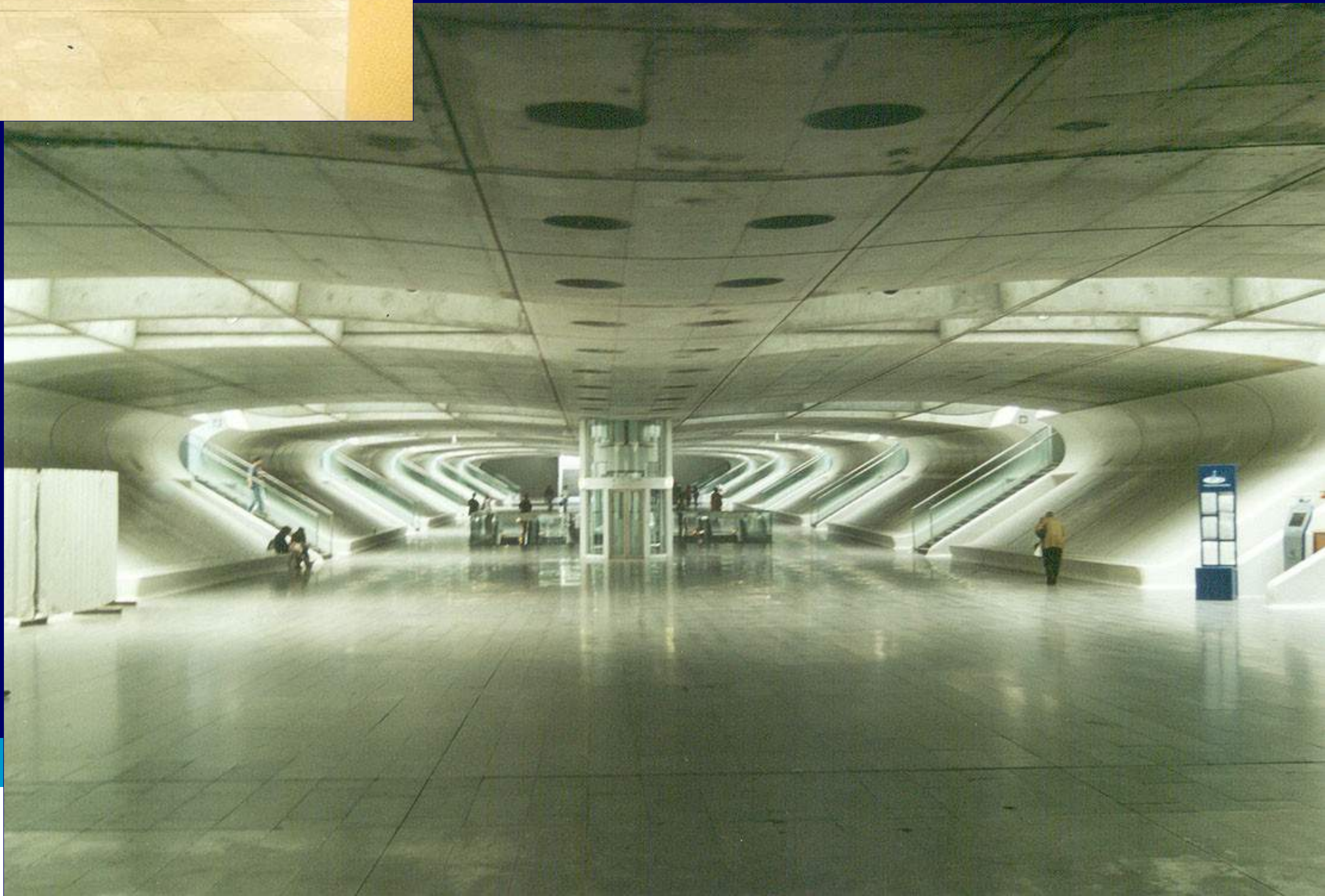
Clear lines of sight

Daylight, lack of sharp contrast



Entrance

Clear lines of sight

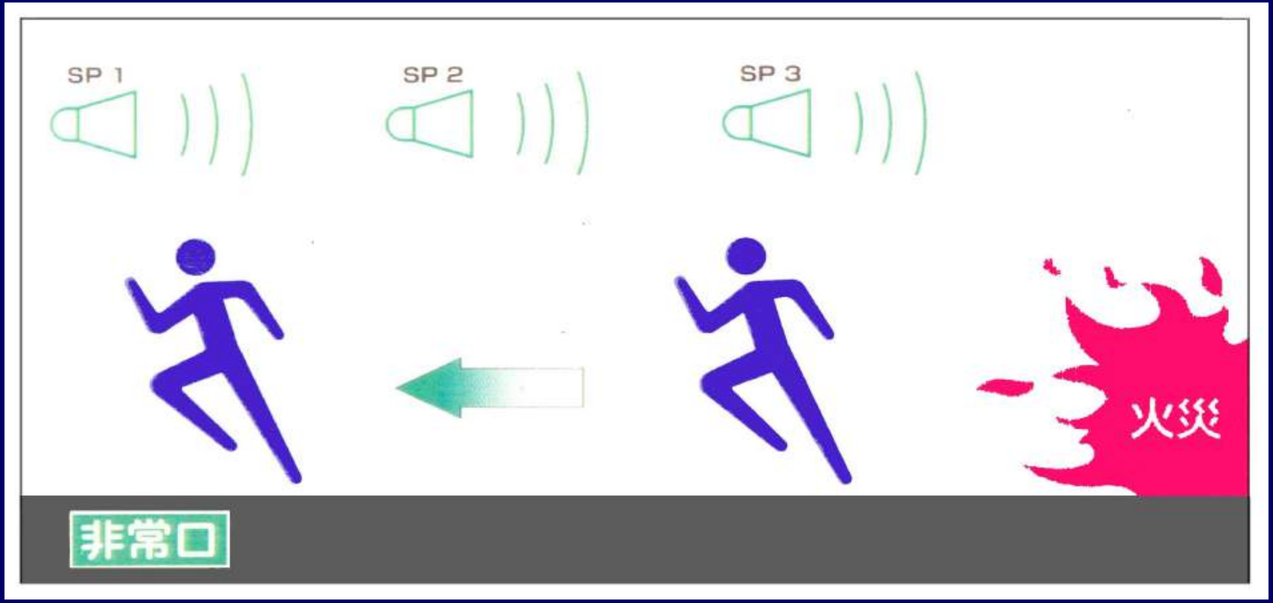


Clear lines, open space

Daegu Subway

February 18, 2003

Safety measure:
direction by light



Safety measure:
direction by sound

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Design process

Design of underground structures is an iterative process.

The following plays a role in the design process:

- design criteria for the basement itself;
- buildings on top of the construction;
- soil profile;
- environment.

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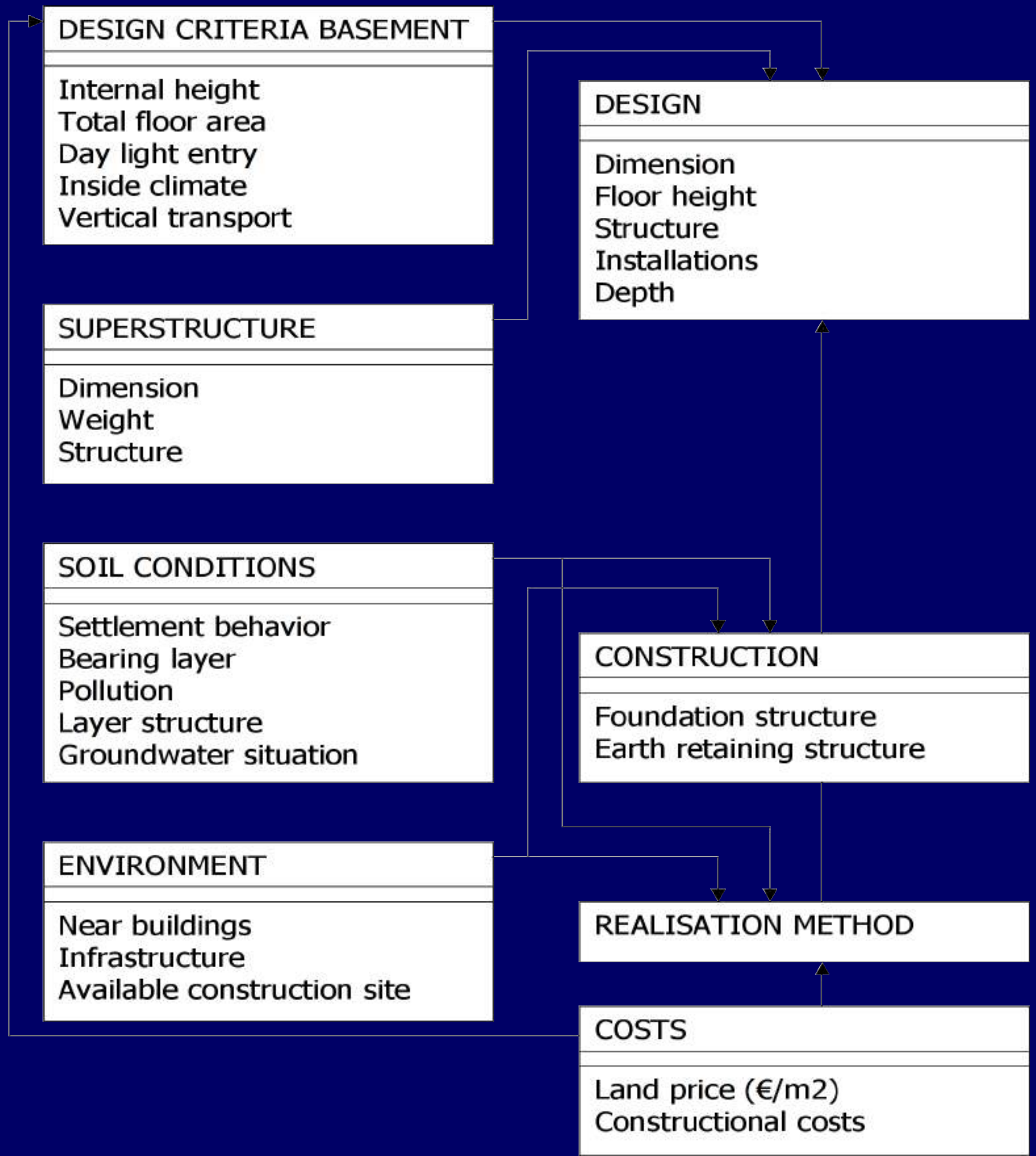
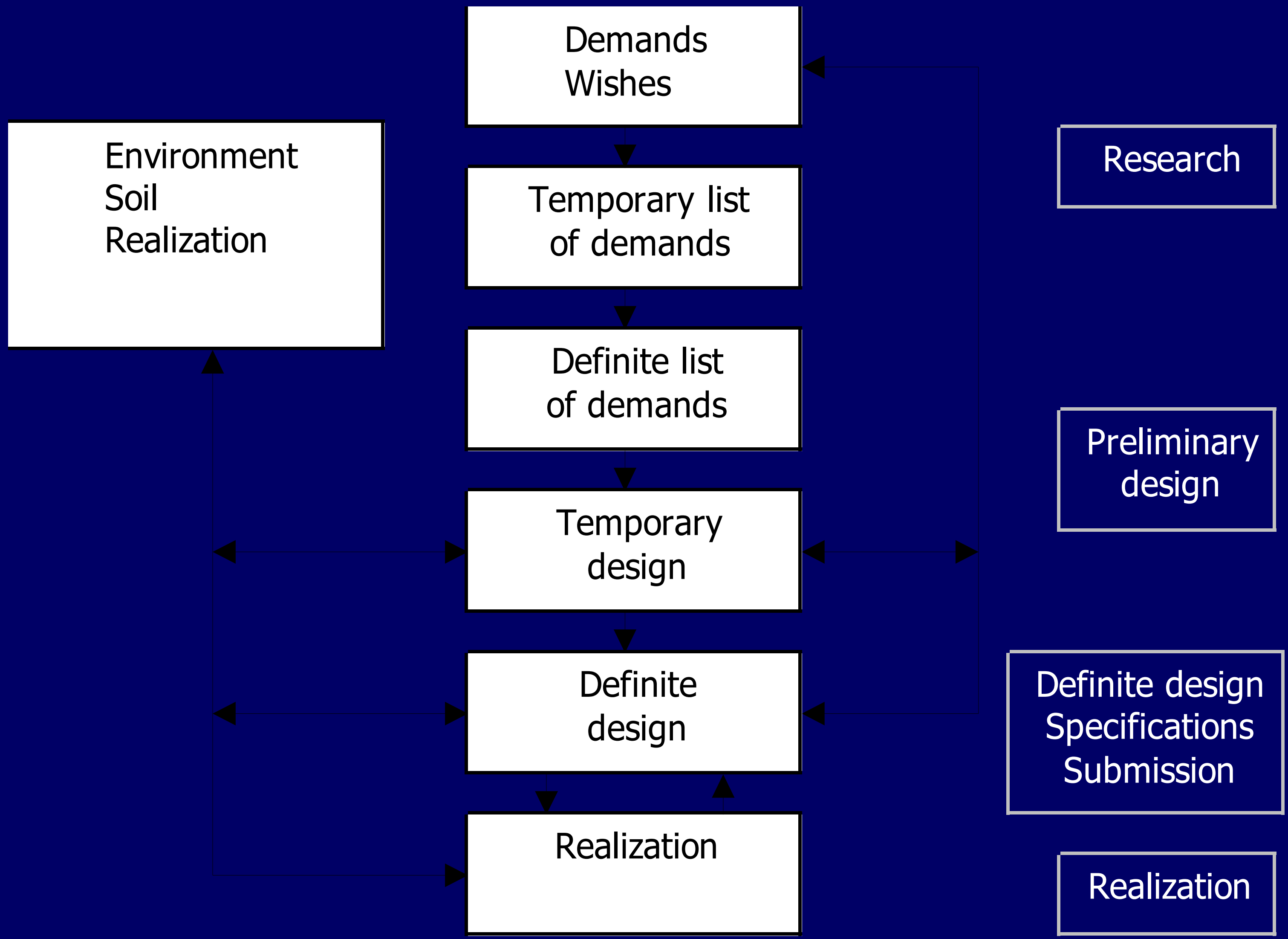
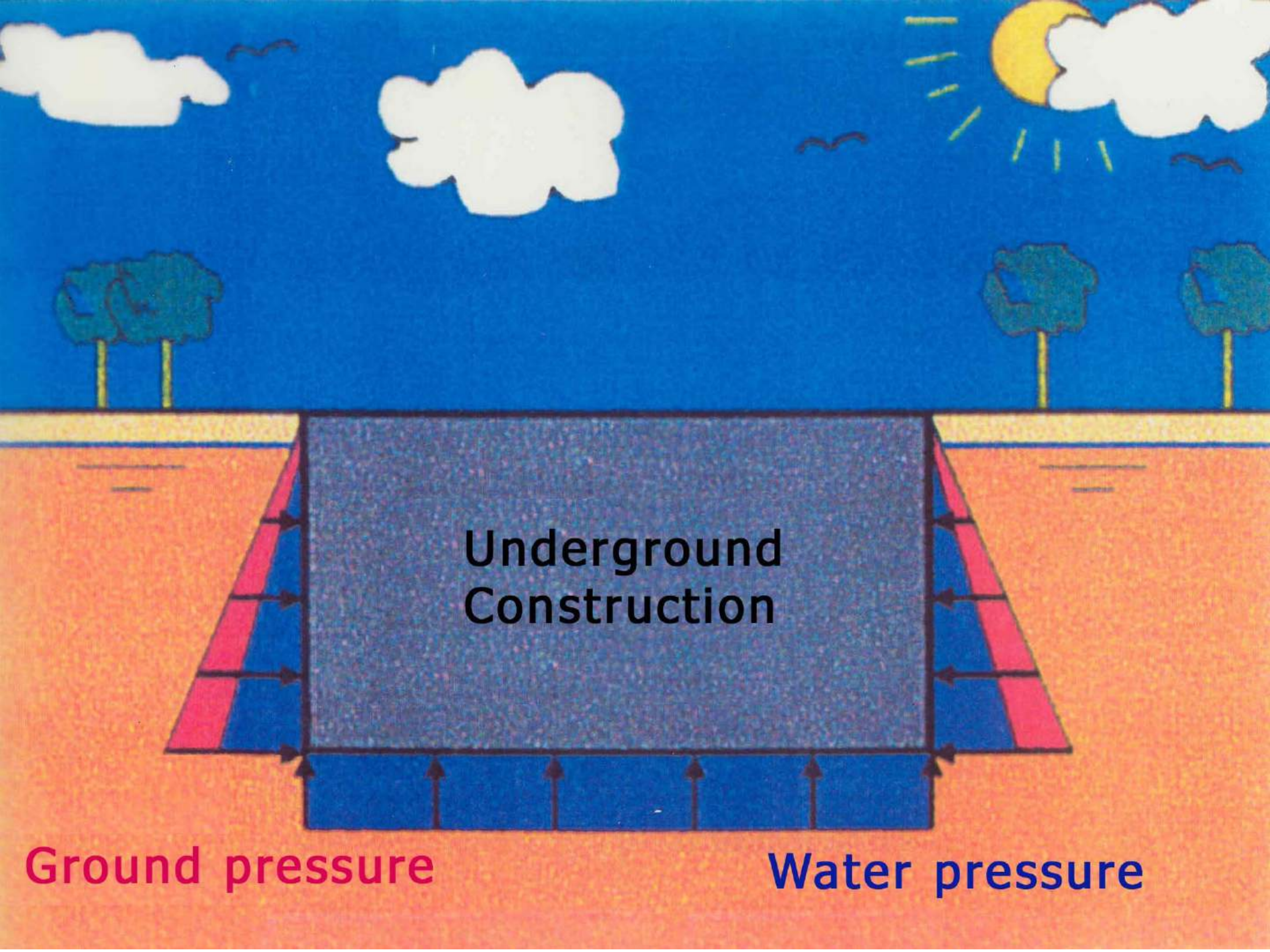
Design of Basement Structures
Classical Way

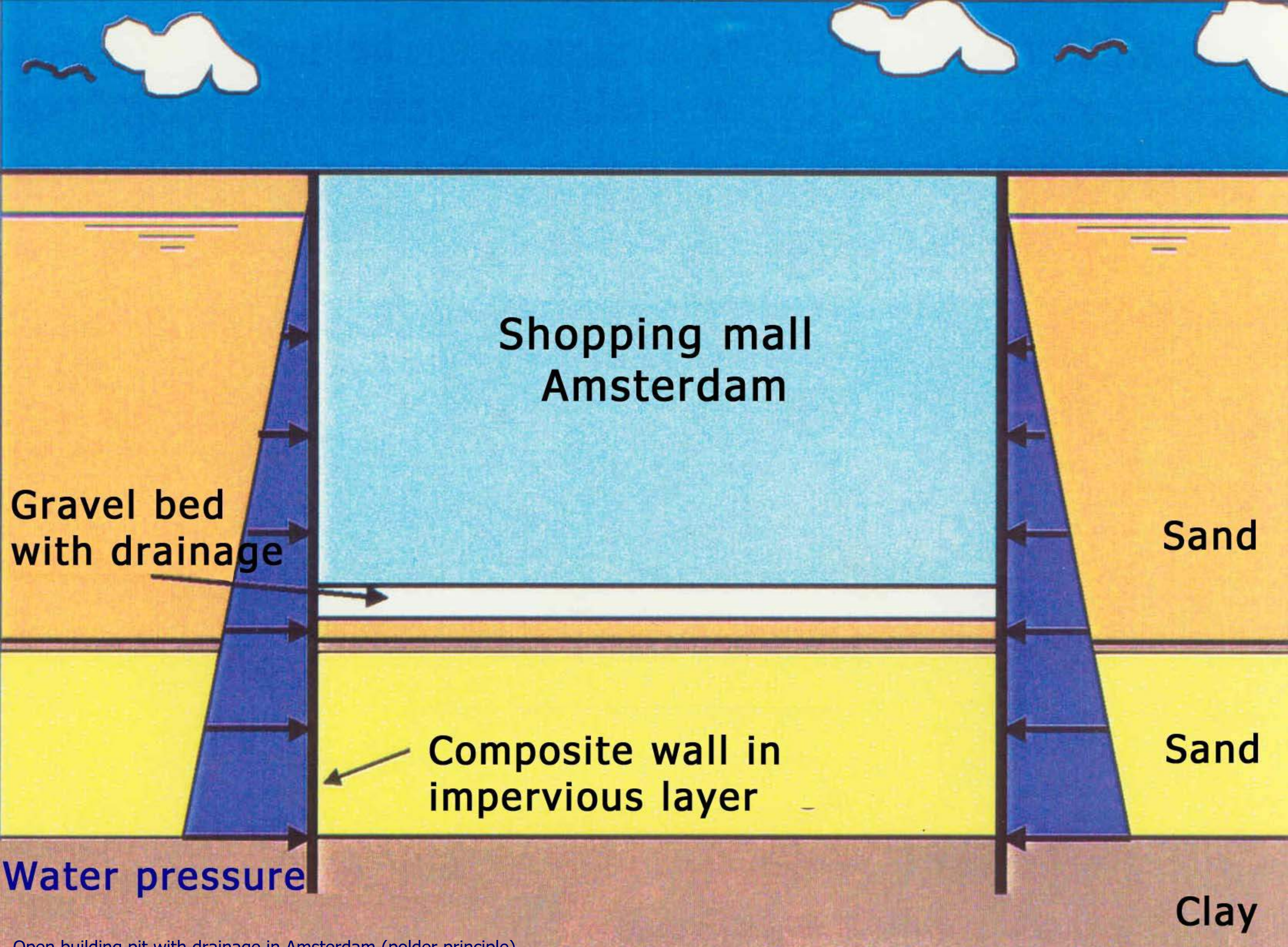


Design of Basement Structures

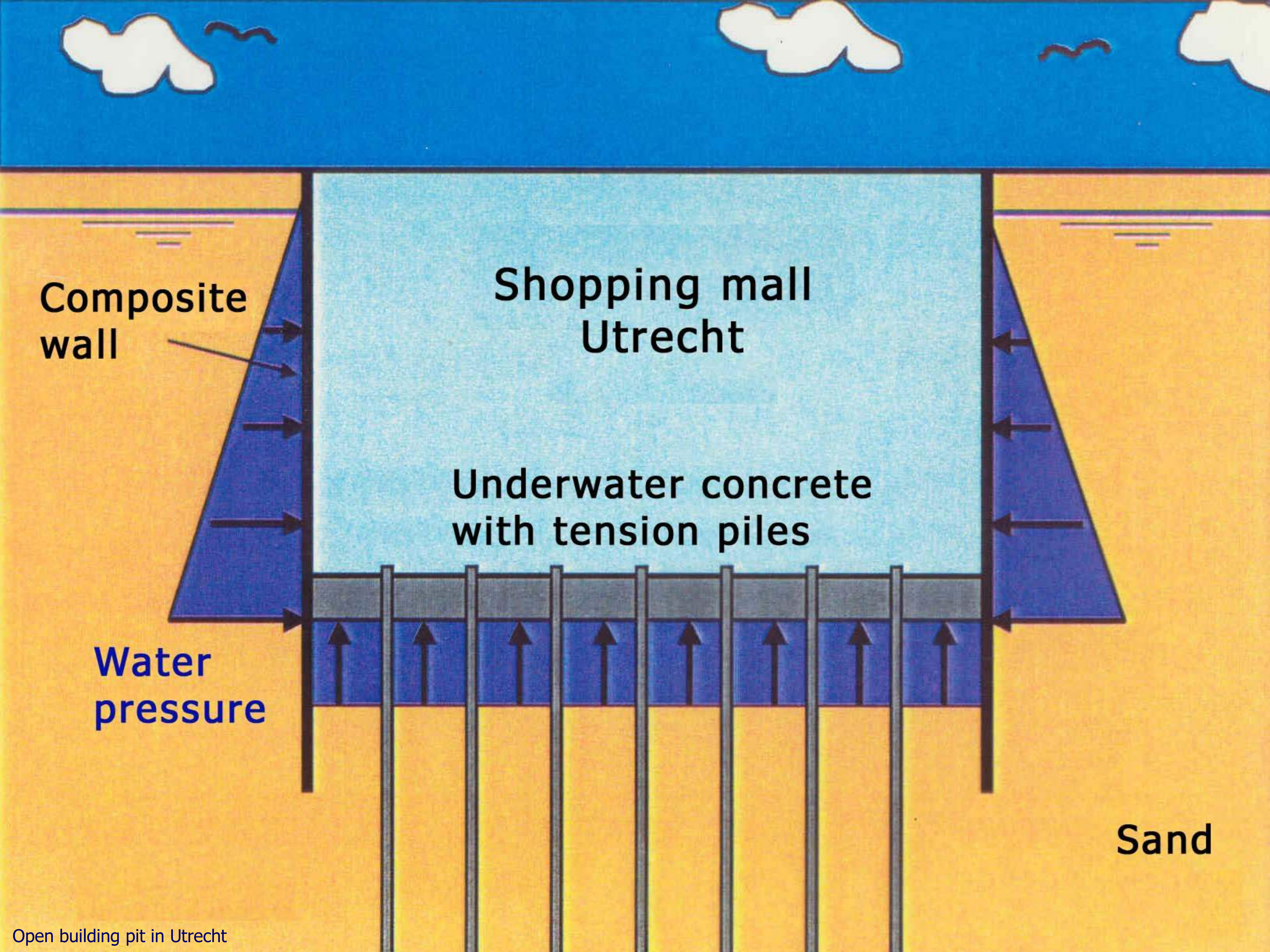
Iterative Process



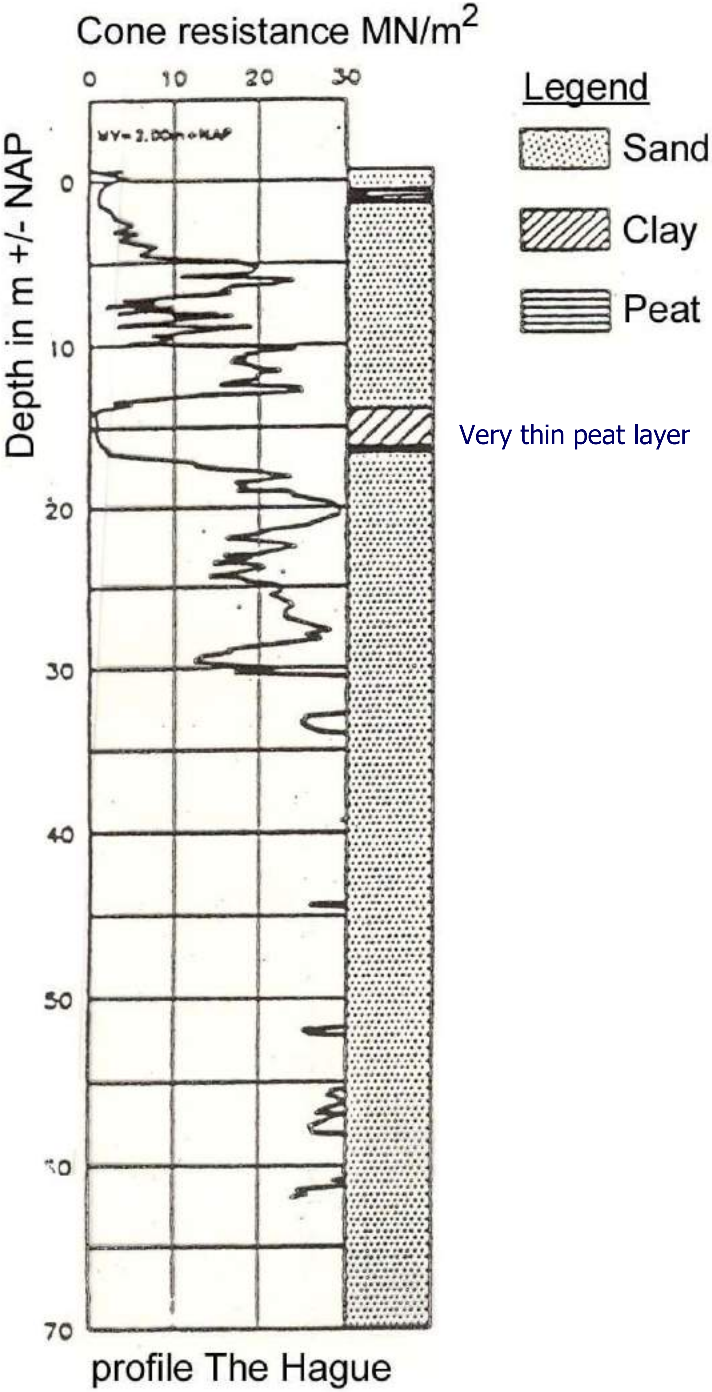

Underground
Construction
Ground pressure
Water pressure

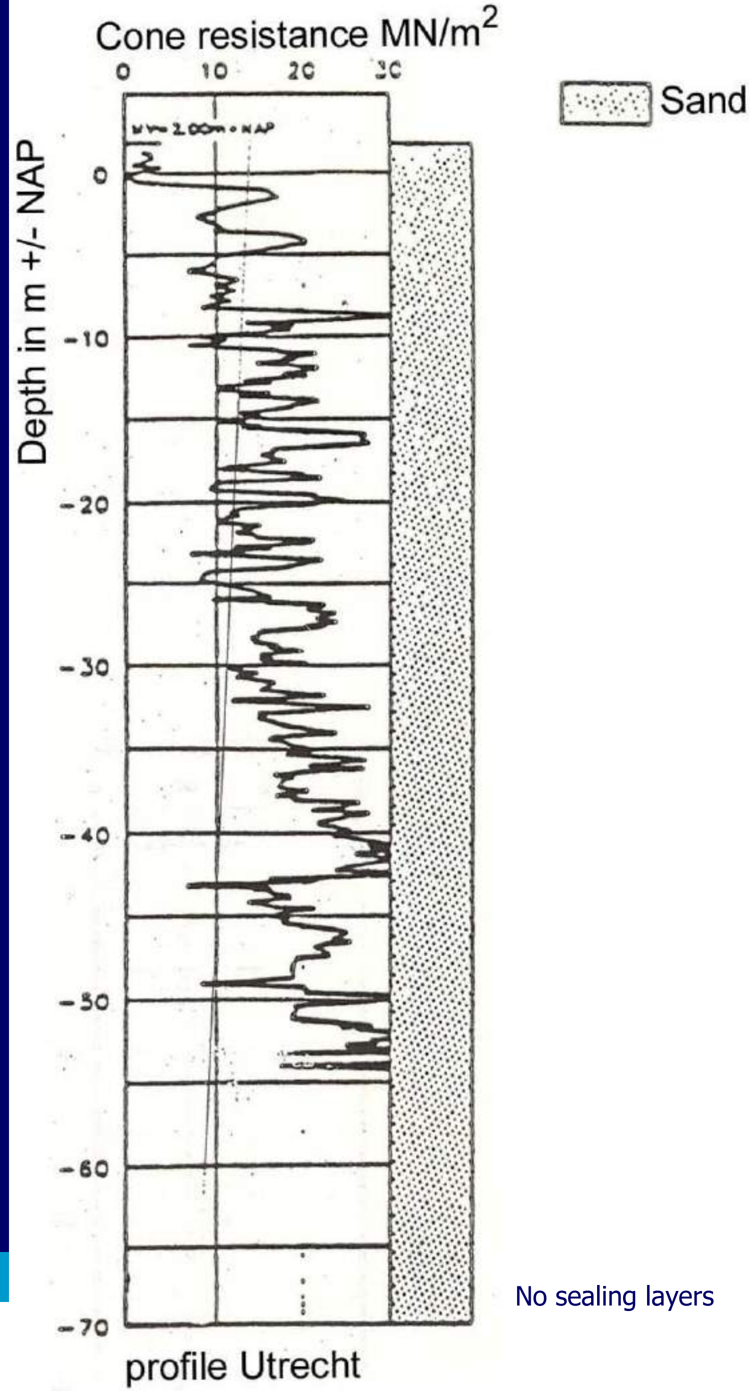


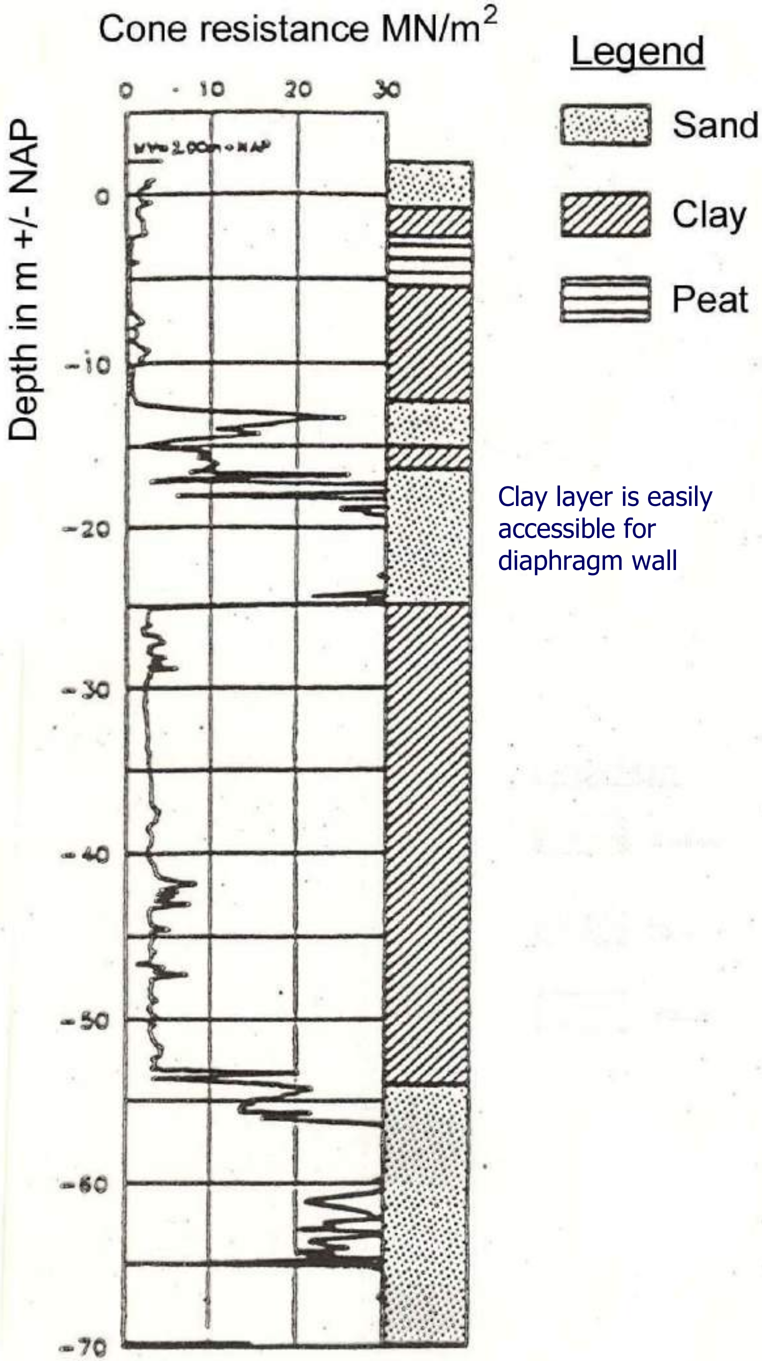
Open building pit with drainage in Amsterdam (polder principle)



Open building pit in Utrecht

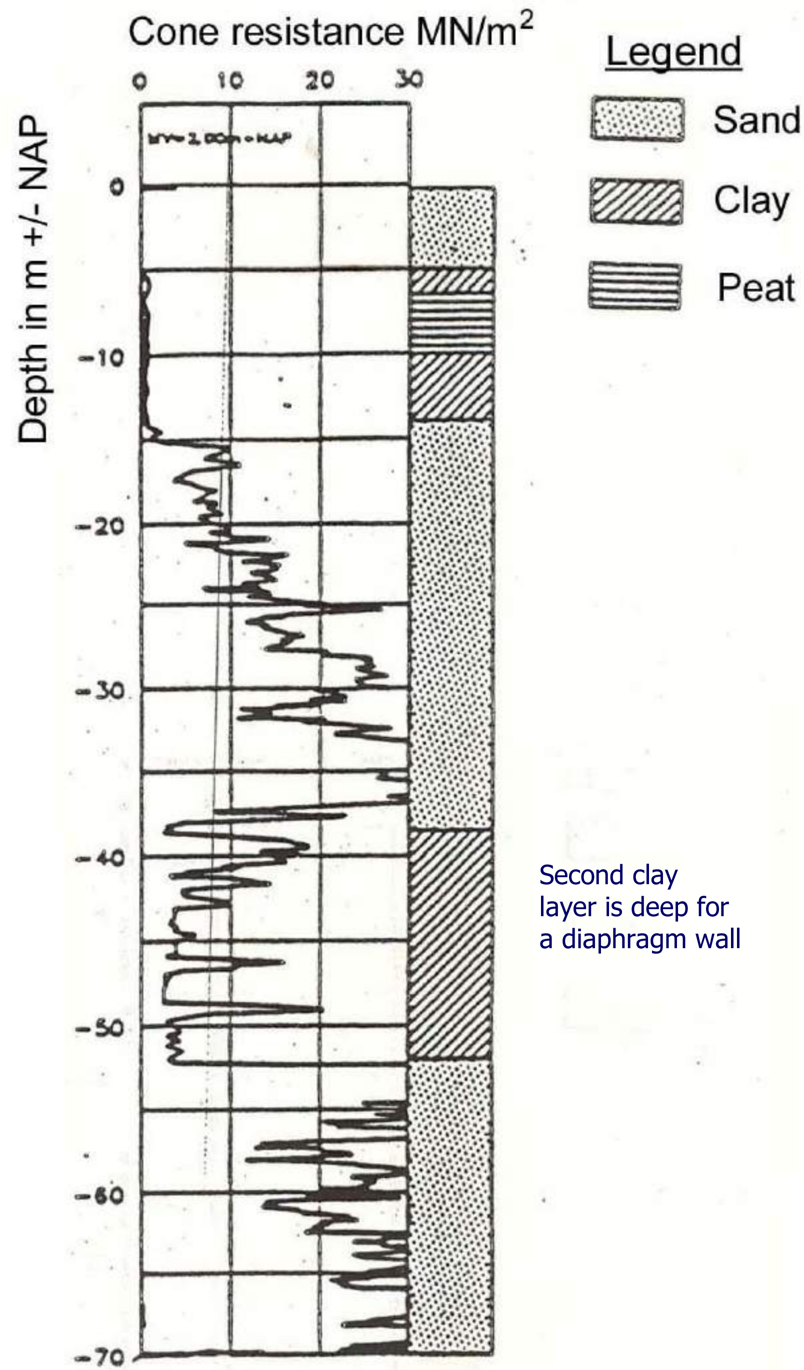

Cone resistance MN/m2
0 10 20 30
Depth in m +/- NAP
0
10
20
30
40
50
60
70
Legend
Sand
Clay
Peat
Very thin peat layer
profile The Hague


Cone resistance MN/m2
0 10 20 30
Depth in m +/- NAP
0
-10
-20
-30
-40
-50
-60
-70
Sand
No sealing layers
profile Utrecht



profile Amsterdam

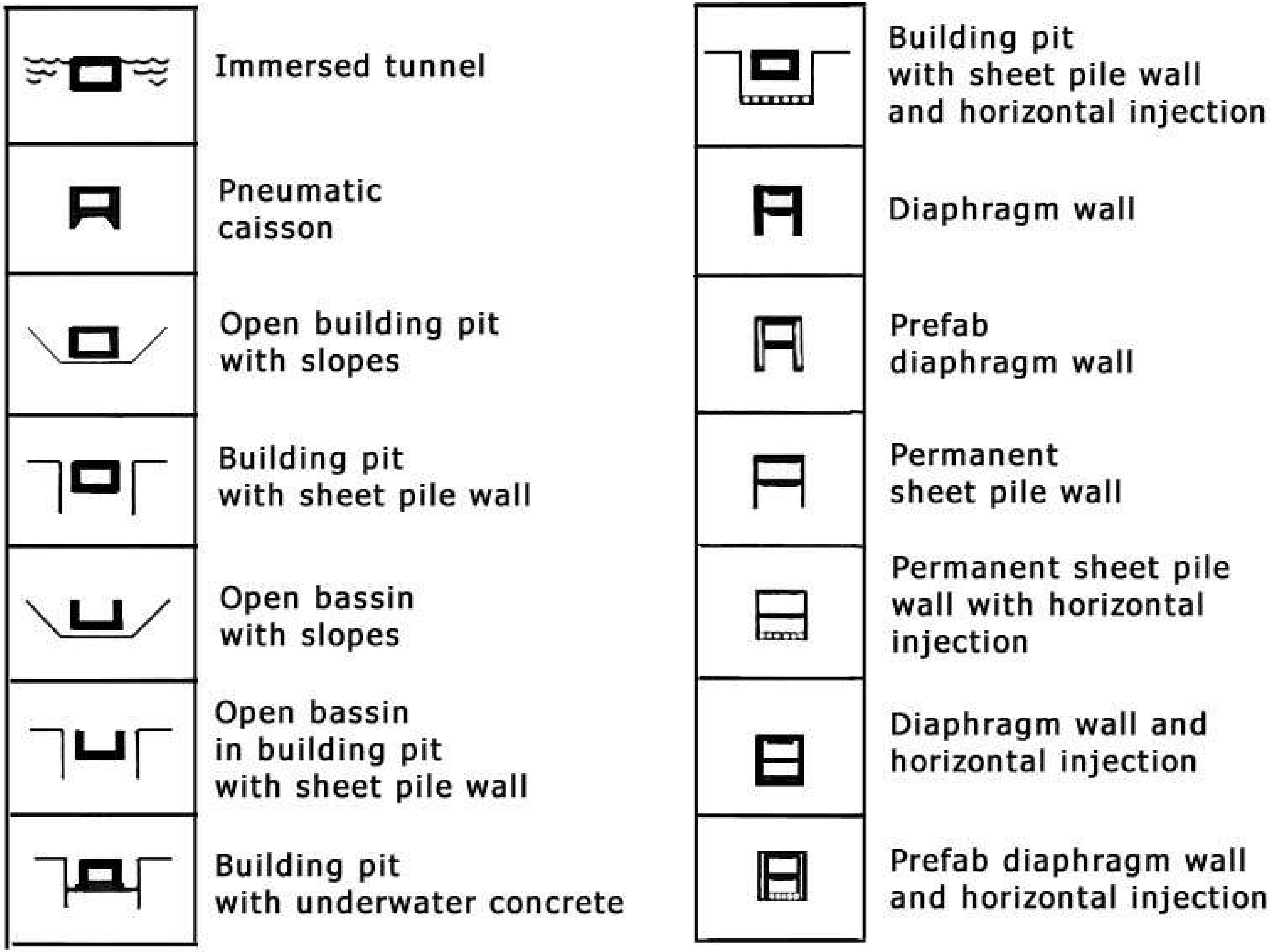
Clay layer is easily accessible for diaphragm wall



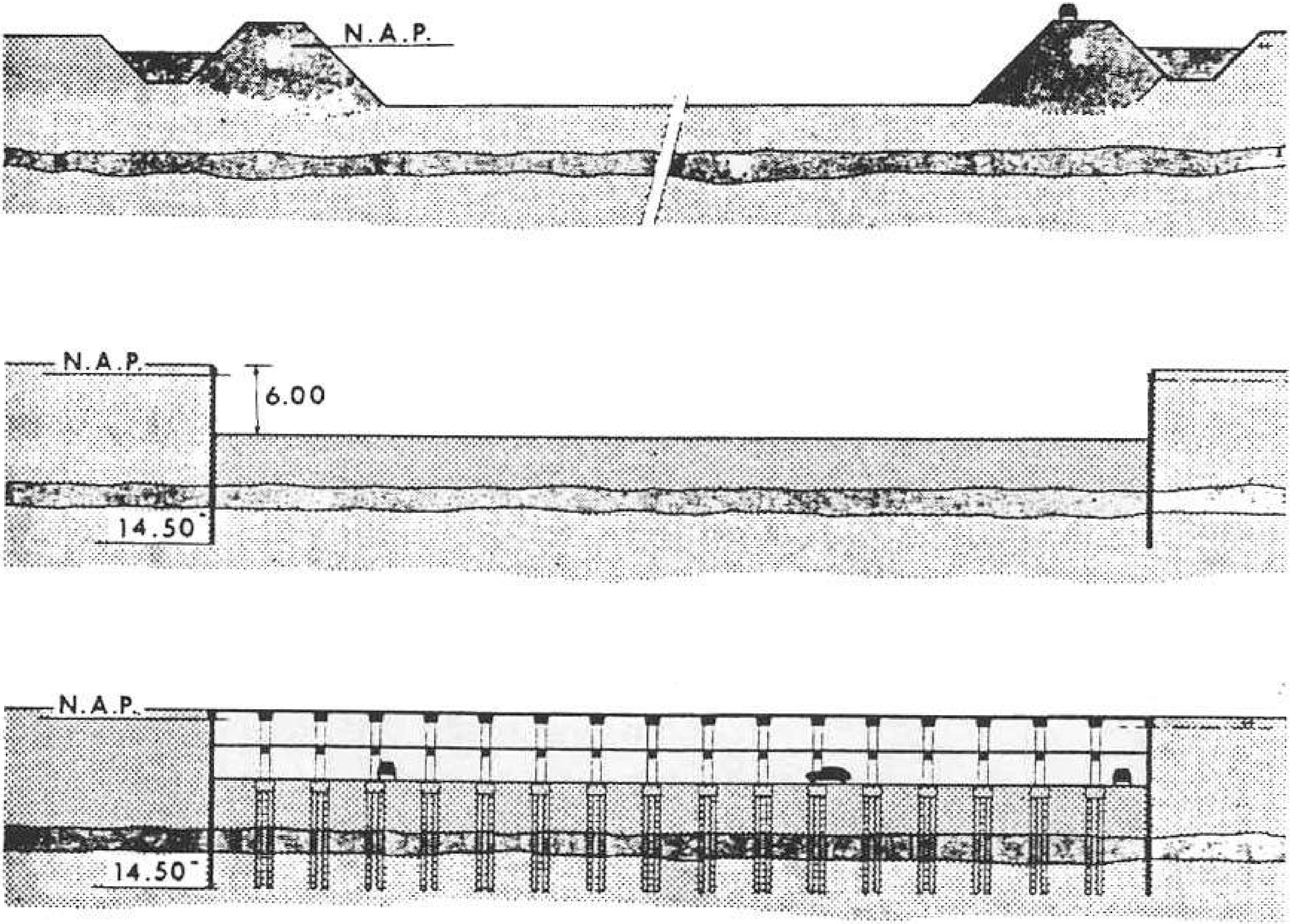
profile Rotterdam

Second clay layer is deep for a diaphragm wall

Both profiles have sealing layers

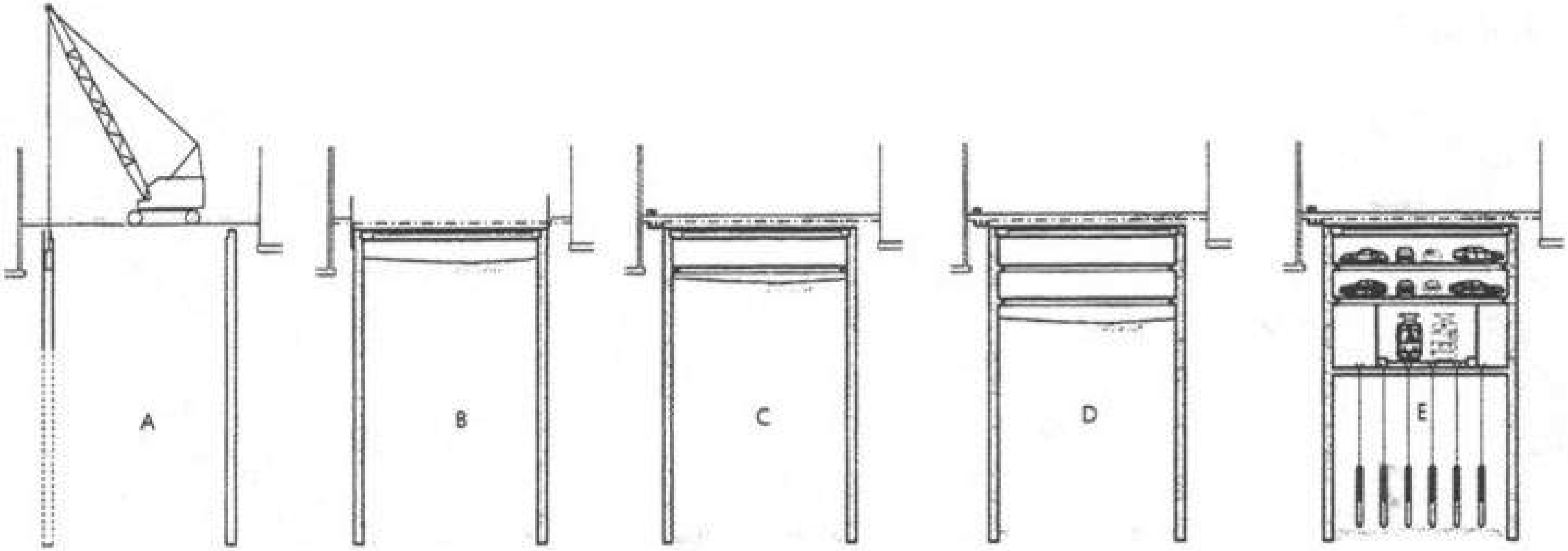


Immersed tunnel
Pneumatic caisson
Open building pit with slopes
Building pit with sheet pile wall
Open bassin with slopes
Open bassin in building pit with sheet pile wall
Building pit with underwater concrete
Building pit with sheet pile wall and horizontal injection
Diaphragm wall
Prefab diaphragm wall
Permanent sheet pile wall
Permanent sheet pile wall with horizontal injection
Diaphragm wall and horizontal injection
Prefab diaphragm wall and horizontal injection



Basement structures built with the traditional polder principle

Cut and Cover (Top-Down) Construction Phases



Building from ground level:

A constructing diaphragm walls
B excavating and building roof structure

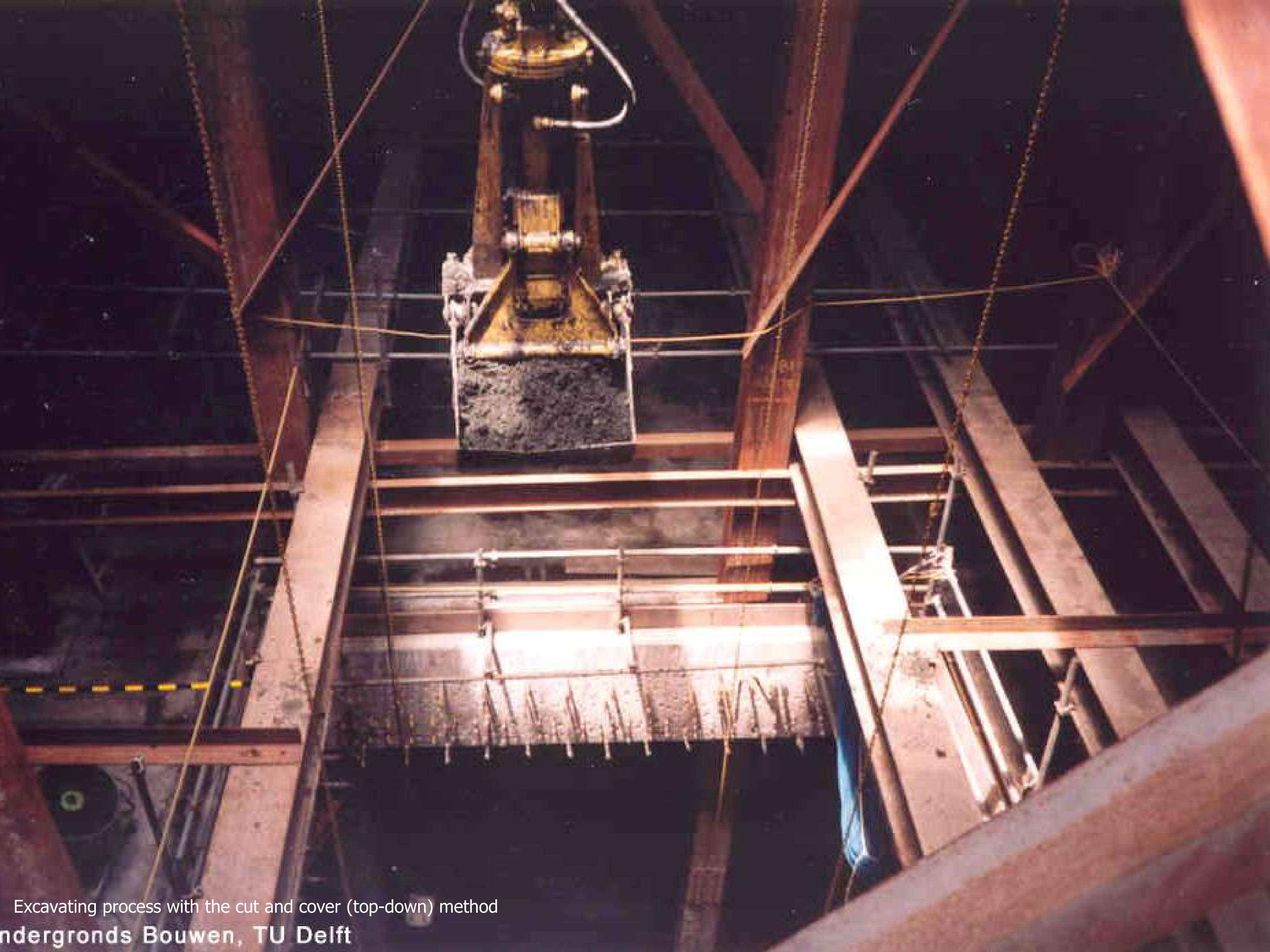
Building below the roof:

C excavating and building floor -1
D excavating and building floor -2
E excavating and building floor -3

Cut and Cover (Top-Down) Method

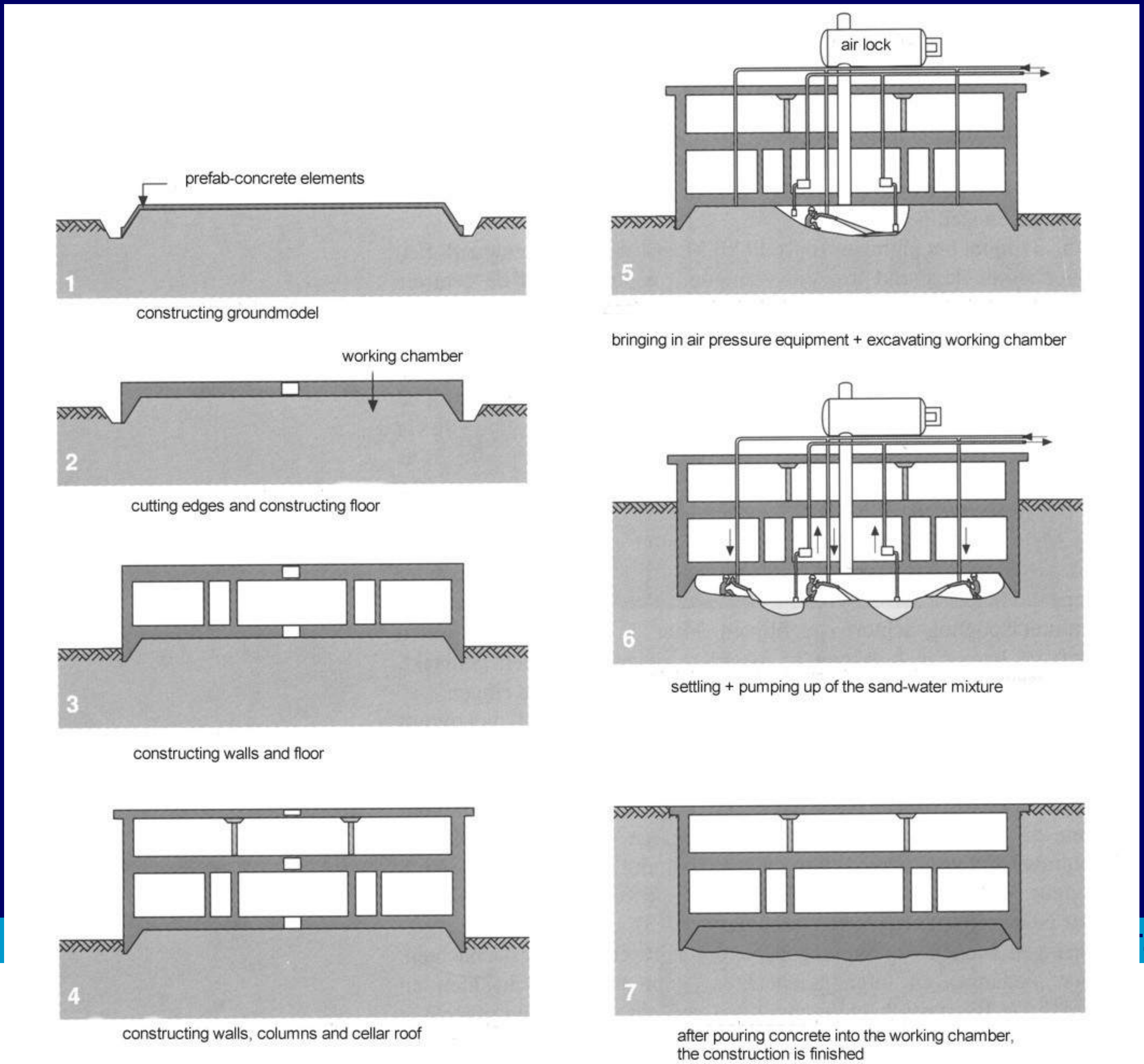
- First the roof of the building pit is constructed together with the walls, to continue the activities on the surface
- When a building pit over a long time period is not possible
- Difficult logistics

Minimal hindrance for the traffic with the use of the cut and cover method



Excavating process with the cut and cover (top-down) method

Pneumatic Caisson Method

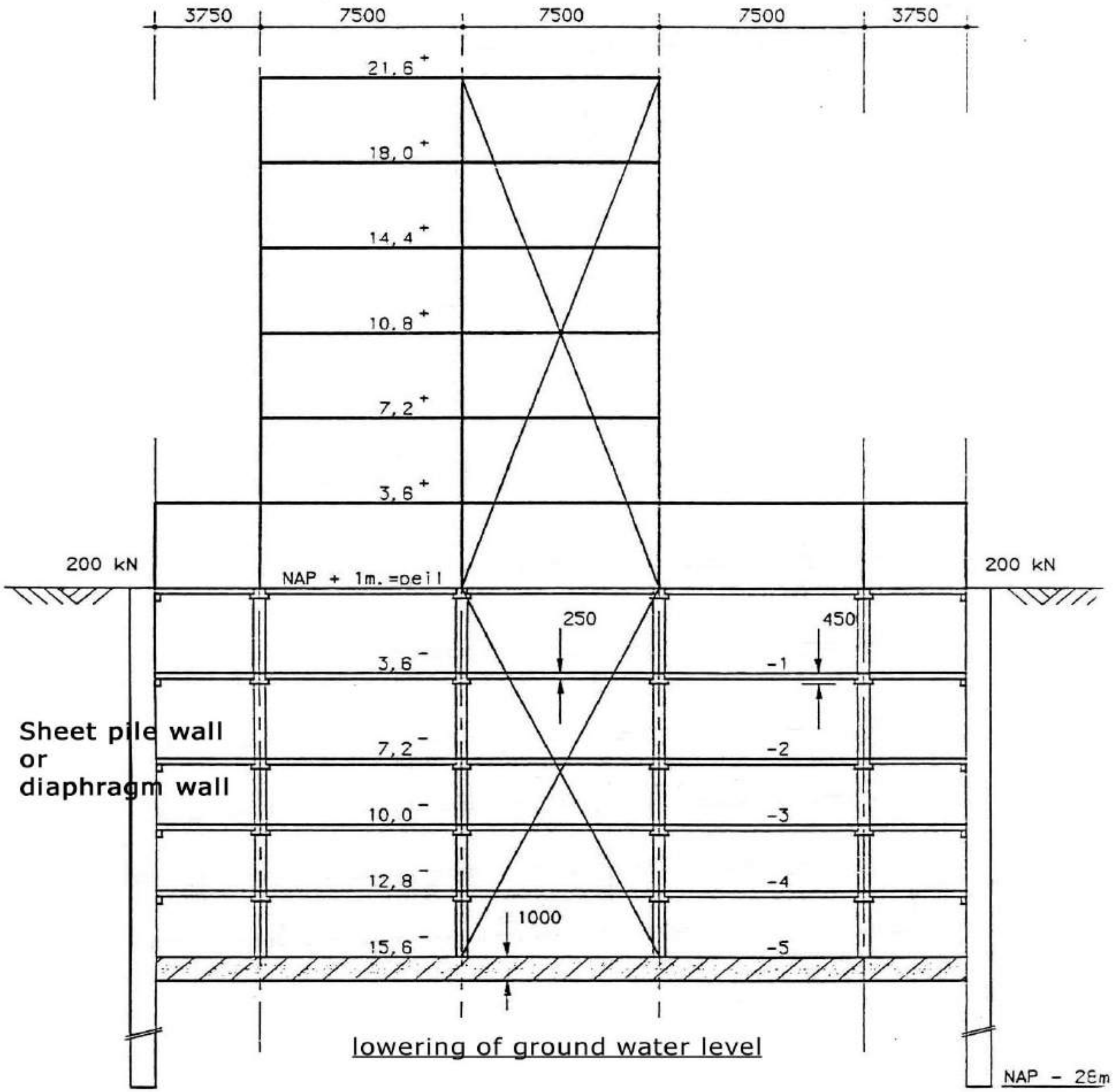


Pneumatic Caisson

- Construction above/on the ground level
- Excavation underneath the construction (control of groundwater by air pressure)
- Limited depth because of working under pressure
- No dewatering necessary
- Hindrance because construction on street level
- Bearing capacity of foundation layer must be good

Construction of a caisson

Caisson underground after sinking



Situation : Amsterdam
Ground retaining : Sheet pil wall/ diaphragm wall
Horizontal barrier : -Natural closing layer
-Floating foundation

Construction in Amsterdam with diaphragm or sheet pile wall and floating foundation

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Vertical Building Pit Boundaries

Slopes

- dewatering necessary
- large space necessary

Steel sheet pile wall or combi-walls

- many different combinations and strengths
- easy, fast building
- limited lengths of elements
- hindrance caused by vibrations and noise
- wall is relatively weak -> danger of settlements
- wall elements can possibly be reused

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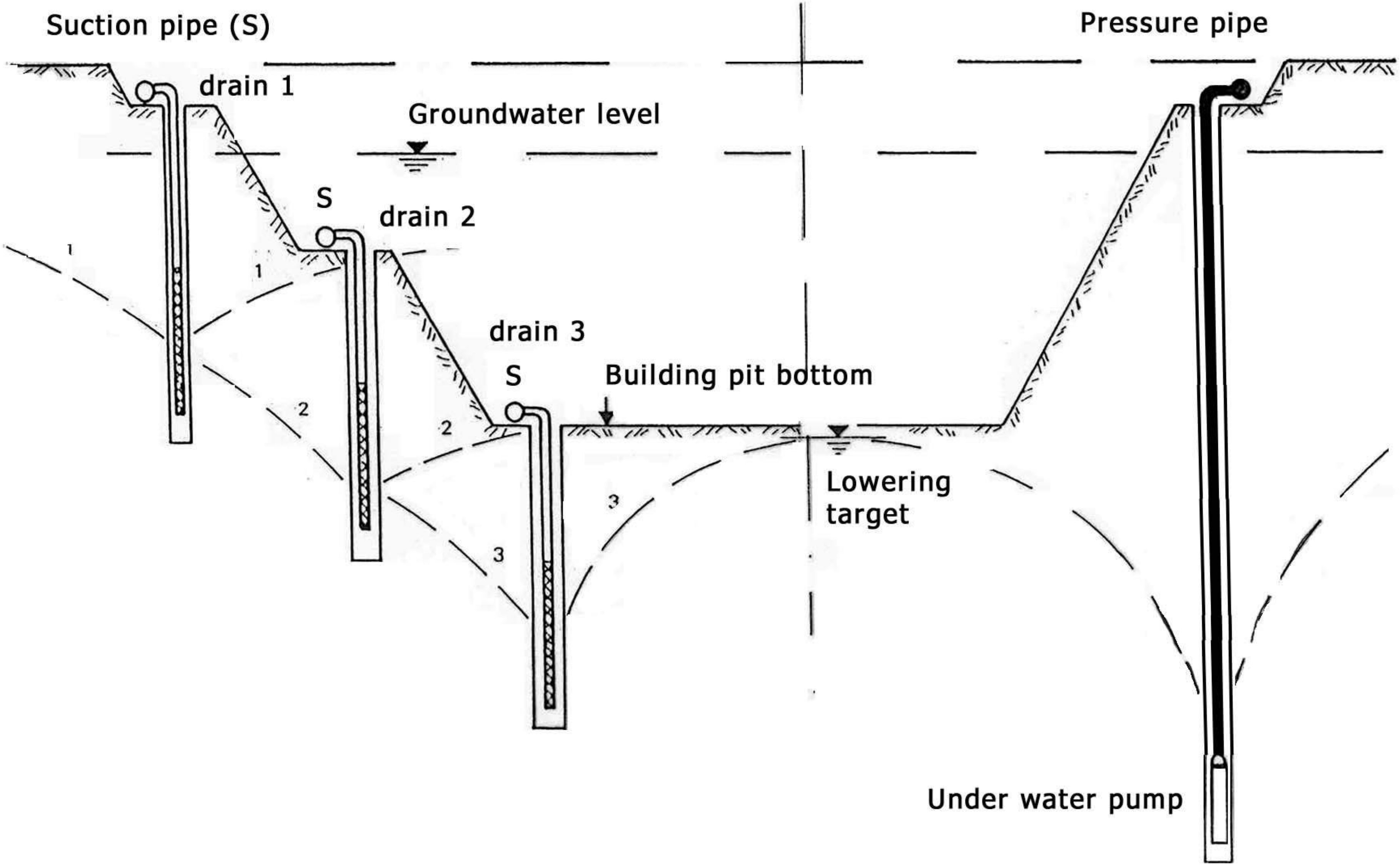
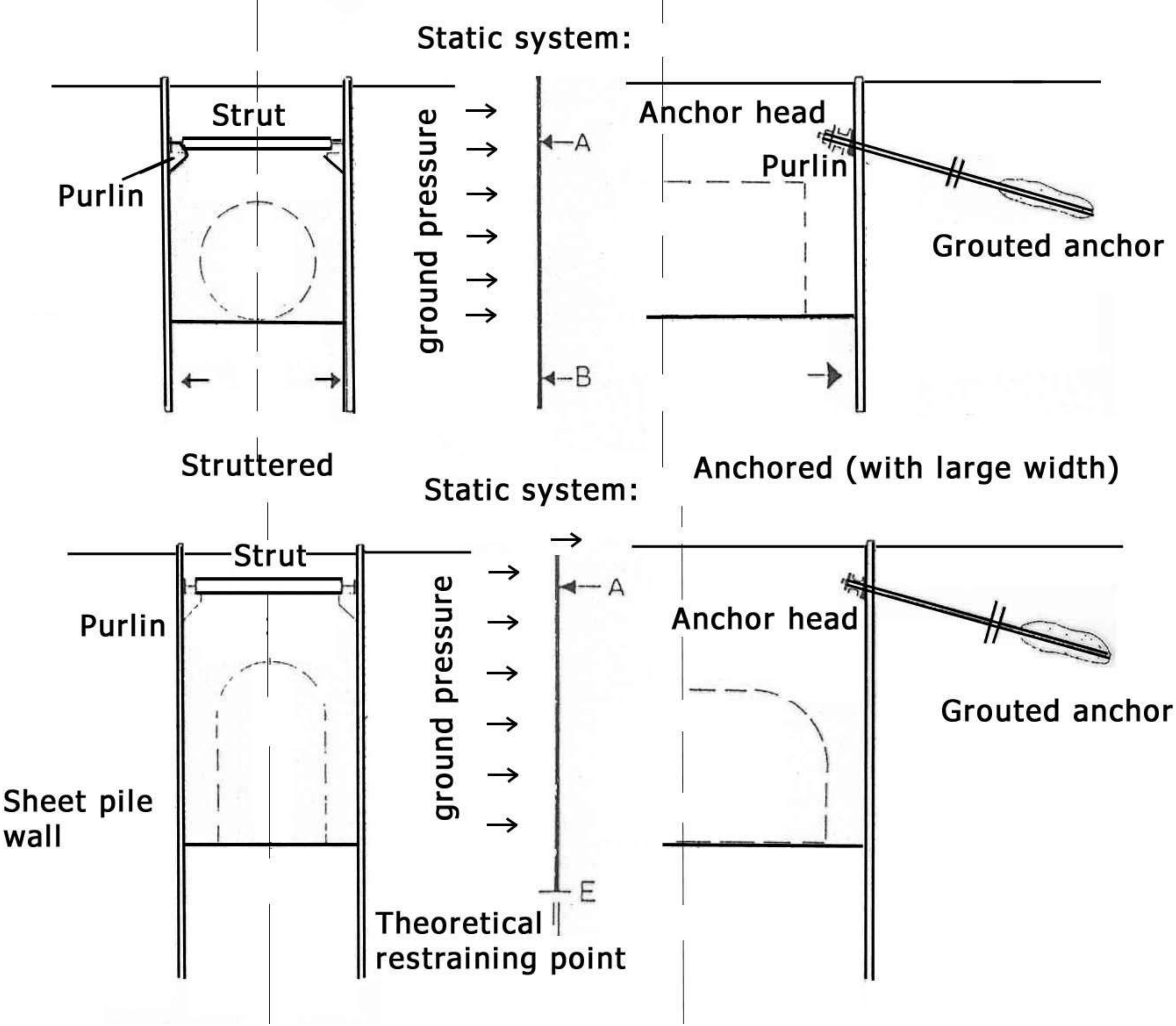
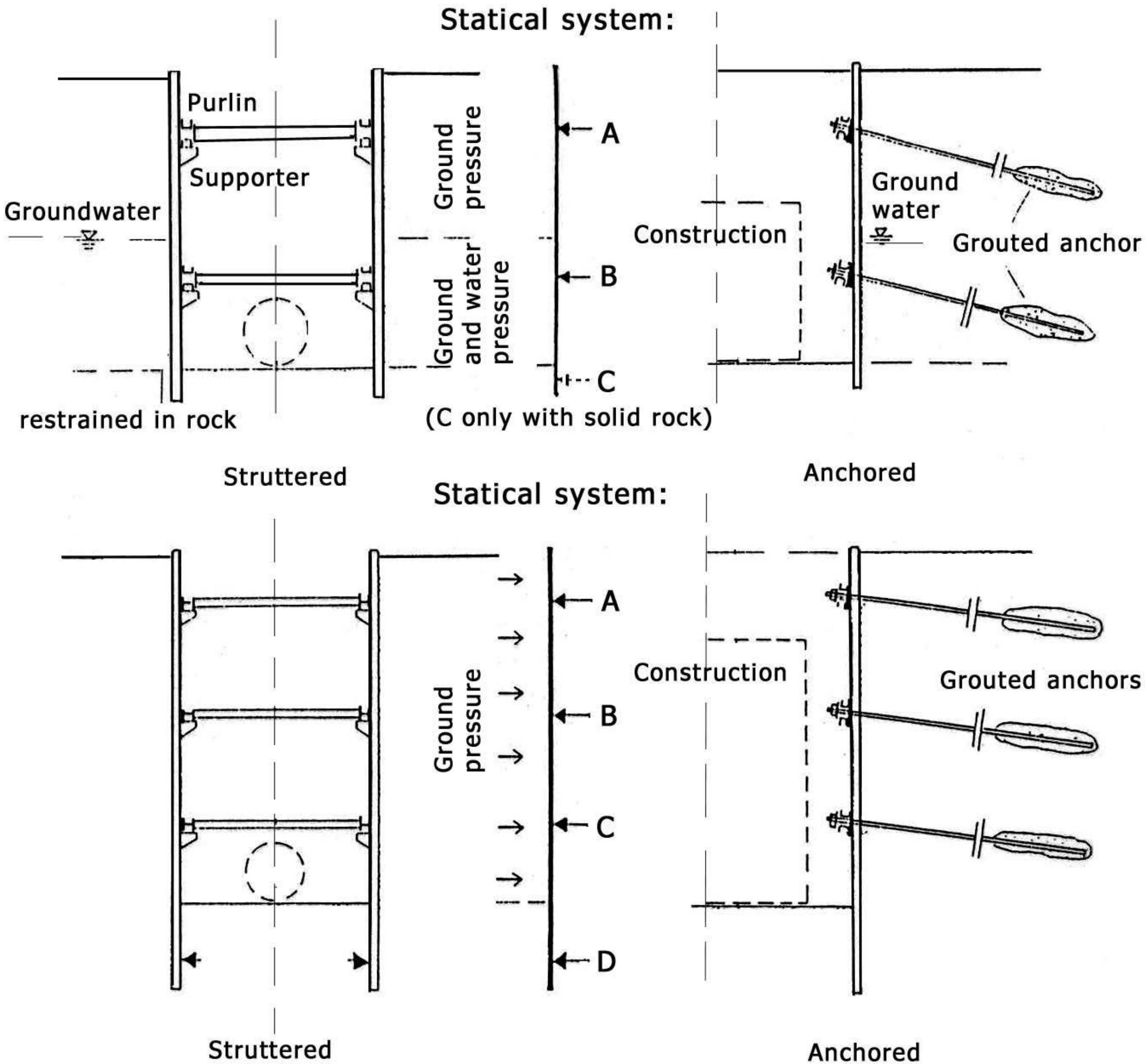


Drainage of a building pit with suction pipes or pressure pipes

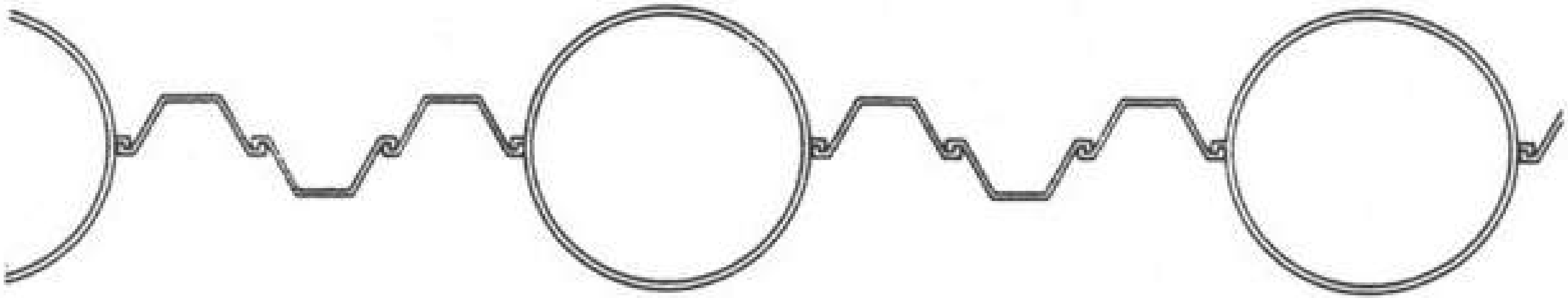


Static system:
Strut
Purlin
ground pressure
A
B
Anchor head
Purlin
Grouted anchor
Struttered
Anchored (with large width)
Static system:
Strut
Purlin
ground pressure
A
Anchor head
Grouted anchor
Sheet pile wall
E
Theoretical restraining point



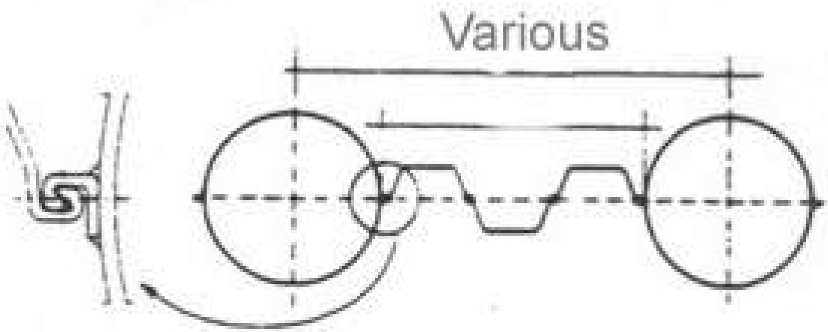
Multiple use of struts and anchors

A lot of struts can be used to keep the building pit stable (note the jack)



A combination-wall (combi wall) is stronger than a sheet pile wall

Mostly sheet piles shorter than tubular piles



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Diaphragm walls/bored piles wall

Wall, which is formed in the ground by removing the soil and replacing it by slurry (bentonite-clay). After placing of a reinforcement cage, the slurry is in turn replaced by concrete.

- Can be part of final construction
- Stiff wall
- Can be used for cut-and-cover (top-down) method
- Long construction time and expensive
- In the Netherlands max. depth 50 m; in other areas depths up to 100 m possible

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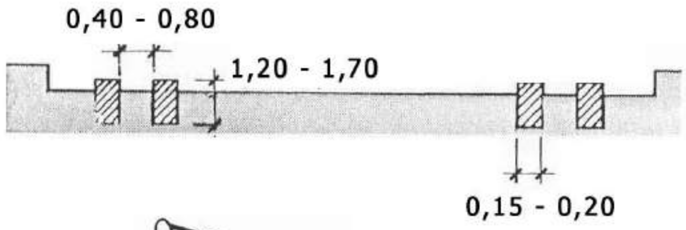
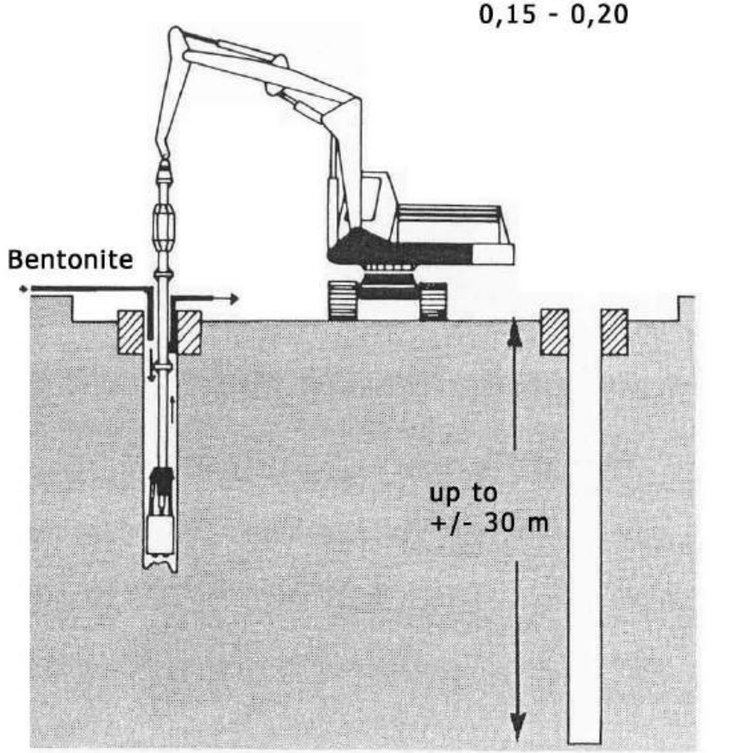
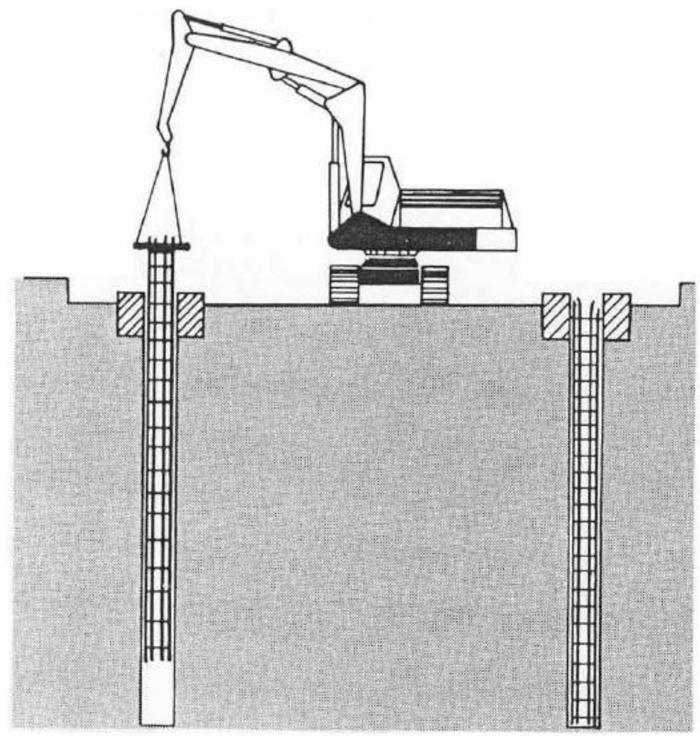


a) Installation of the guide walls, which will provide an obstacle free vertical excavation of the diaphragm wall

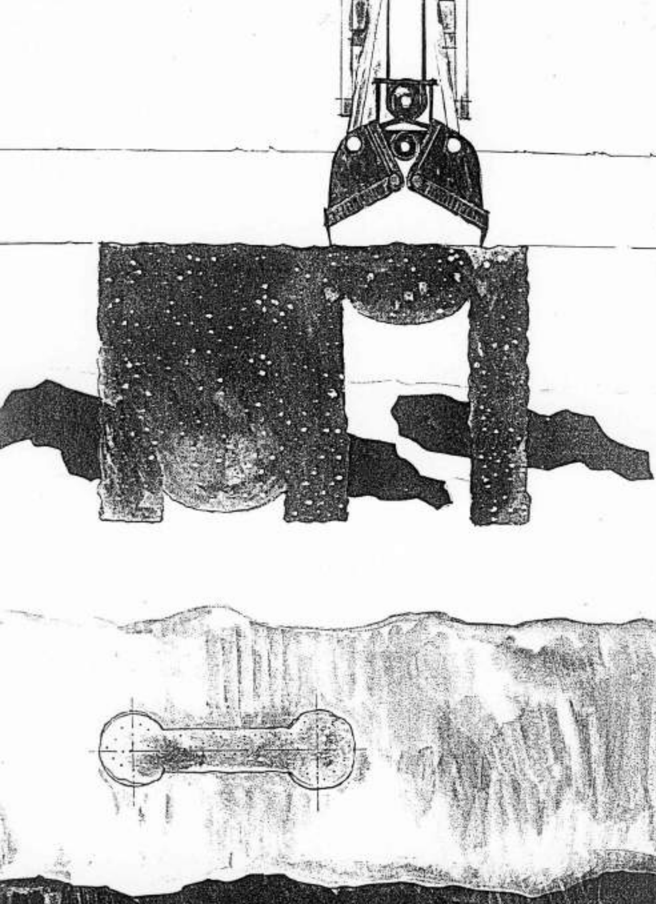


b) During the excavation a bentonite suspension is pumped into the hole, which stabilises the hole and makes it watertight

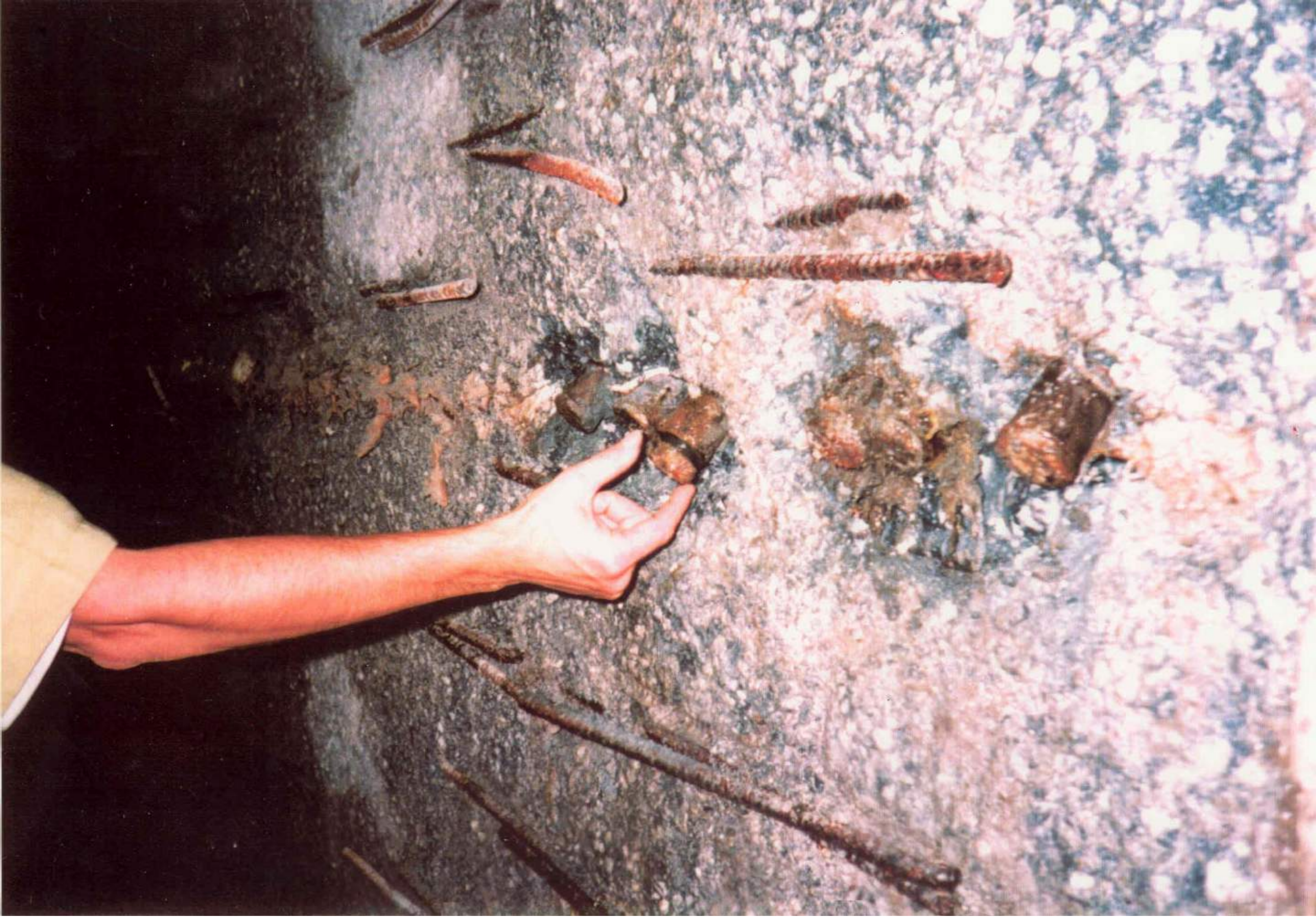


c) After the excavation of the hole, the reinforcement cage is let down by a crane in one section (length 2,5 - 6,0 m) of the diaphragm wall

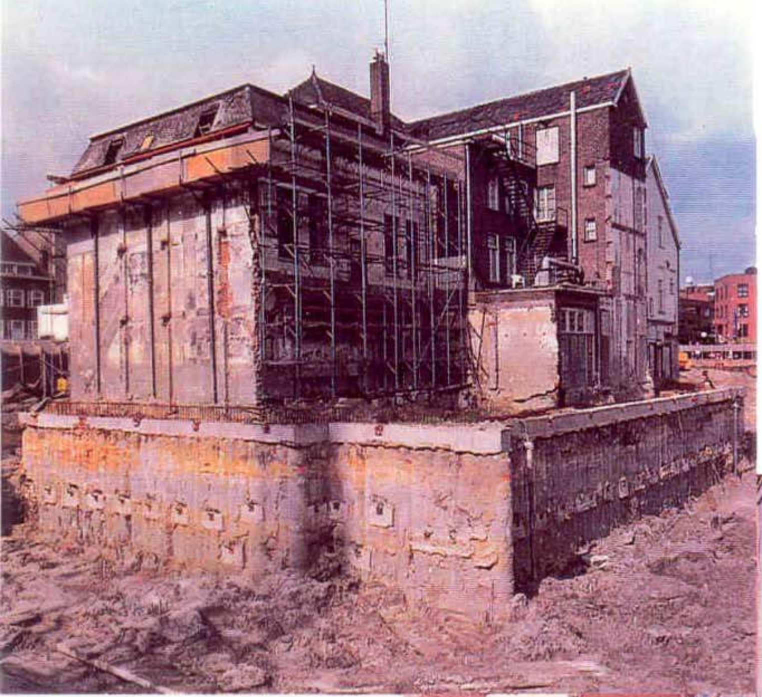
Realization of a diaphragm wall



Grab of an diaphragm wall excavating machine



Diaphragm wall at 25 meter minus (connection screw housing and starter bars)



Building pit with diaphragm wall, with anchors

MIP (mixed in place) machine
(wet and dry method)

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Mixed in place, strengthened by steel profiles

Auger pile wall (no slurry)

- No slurry used
- Stiff construction, less settlements and less damage on marginal property
- Bearing capacity for superstructure
- Suitable for cut-and-cover method
- Extended construction period

In case of water-retaining function, be carefull!!!!!!

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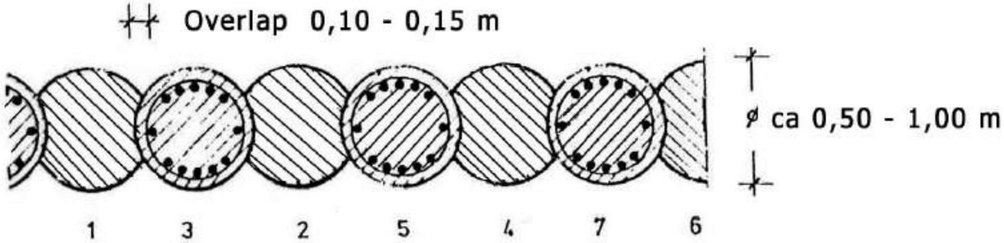
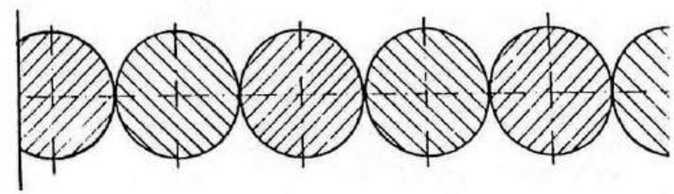
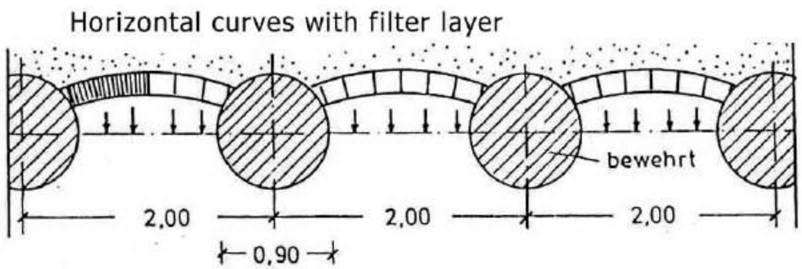


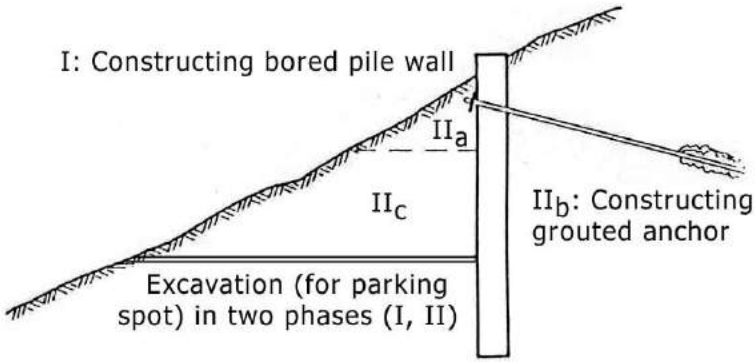
a) Overlapping bored pile wall



b) Discrete bored pile wall (every pile is reinforced)



c) Seperate bored pile wall (with possibility for pendulate and seepage water to flow through)



d) Large bored pile wall for stability at an excavation

Different types of bored pile walls (no slurry)

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Building pit with auger pile wall

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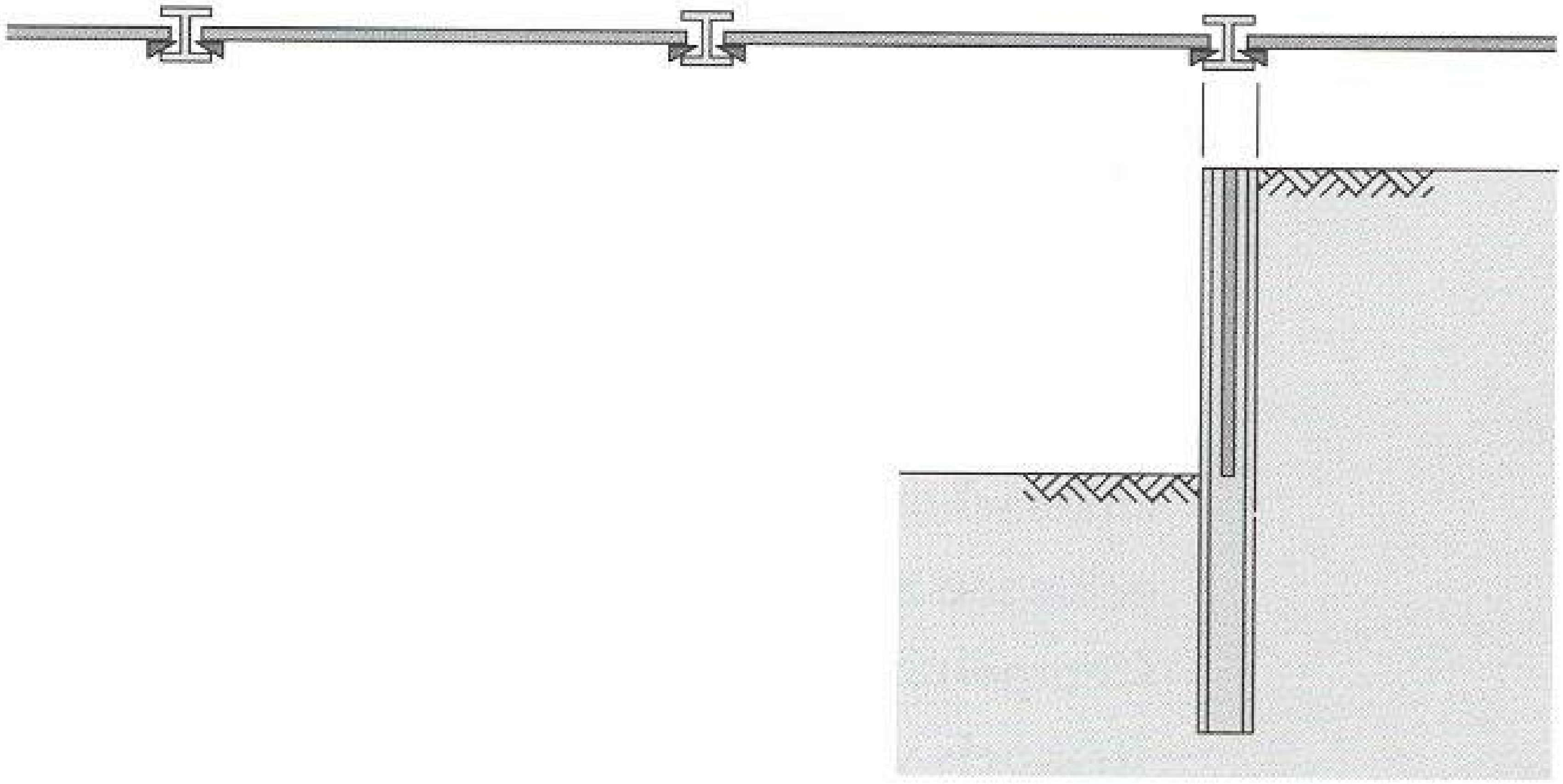
Berliner Wall (Berliner Verbau)

- Vertical steel profiles with wooden beams or shelves
- No water retaining capability
- Low retaining height



Berliner wall (where possible very economical)

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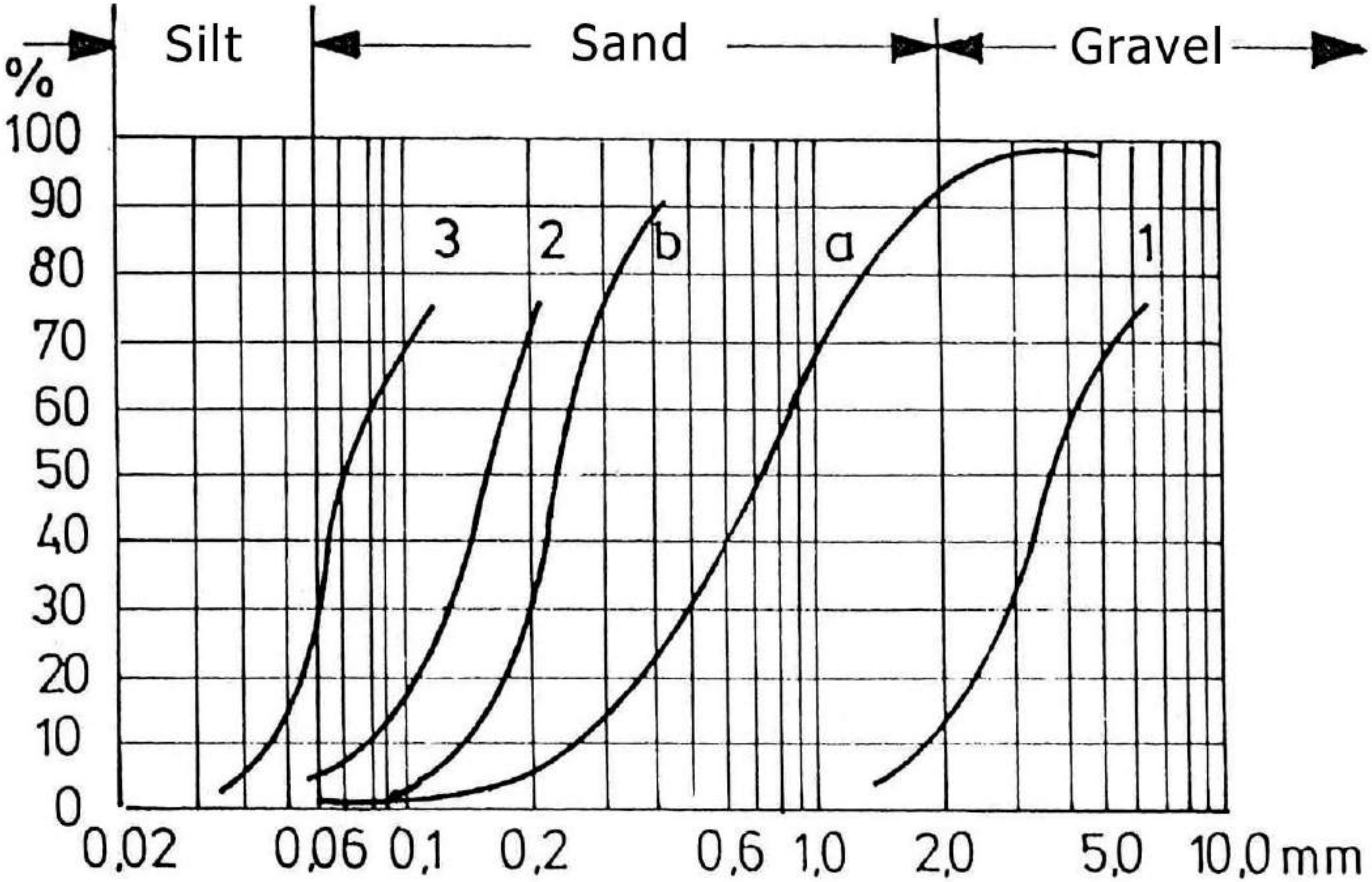
Walls by Chemical Injection

- Existing soil is mixed in place with chemicals
- Method especially suitable for securing stability of marginal properties
- Possibility to make retaining wall underneath marginal structure in case of lack of space
- Also water retaining
- Only suitable in “sandy” material
- Not possible in case of strong groundwater flows



Range of use of chemical injection in soil:

1 = Limit for cement injection
2 = Limit for the use of the Joosten method
3 = Limit for the use of the Monodur method
a = Cube compression strength 4,8 N/mm2
b = Cube compression strength 3,5 N/mm2

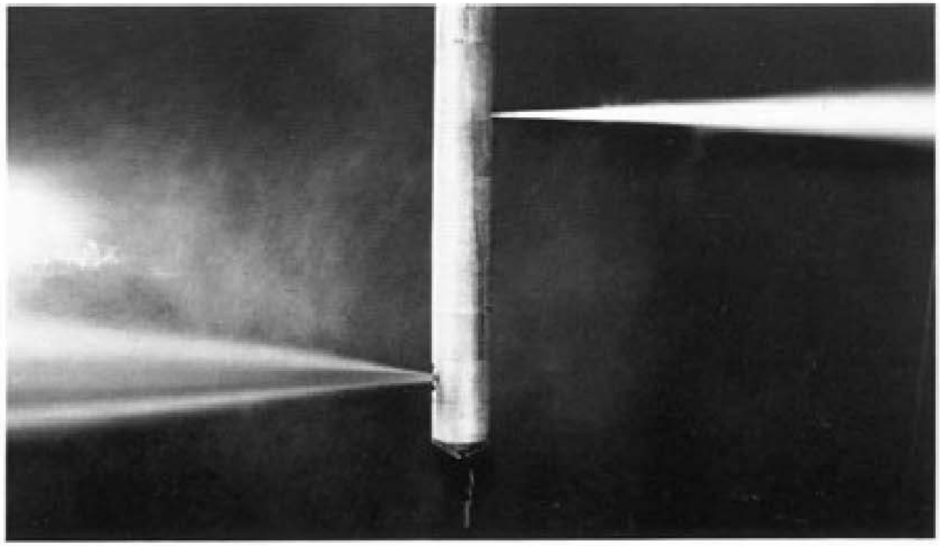
The range of suitability of chemical injection in different types of soil

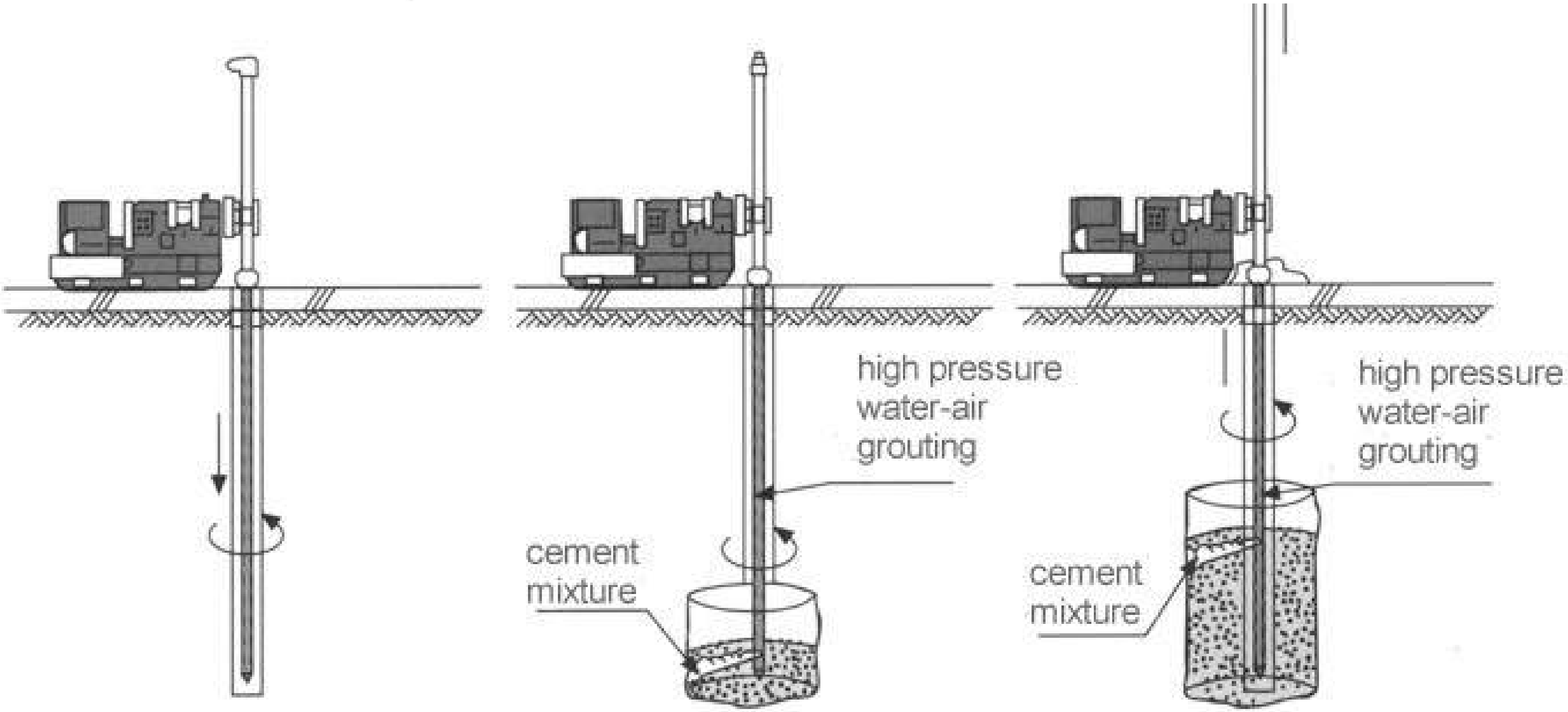
Jet Grouting Wall (VHP)

- Wall made with jet grout columns
- Very High Pressure (VHP) grouting
- Suitable as a ground and water retaining structure and as a reinforcement for major structures
- For almost all soil conditions
- Temporary and final construction
- Relative new technique in the Netherlands

Jetting

A high speed water and air jet is forced out of the upper nozzle and at the same time cement slurry is jetted from the lower nozzle in the opposite direction to supplement the water-air jet function with the formation of a grouted mass and to balance the pressure inside the monitor.





Carving cannot be made only by applying high pressure to the water. The water to be injected must be surrounded by an air jet. From the Fig. 1 it can be seen that the carving ability of water has been remarkably improved by combined use of an air jet.

Another feature is that a jet air pushes the carved soil up onto the surface. Therefore, the soil is replaced with grouting solution in the most favorable manner.

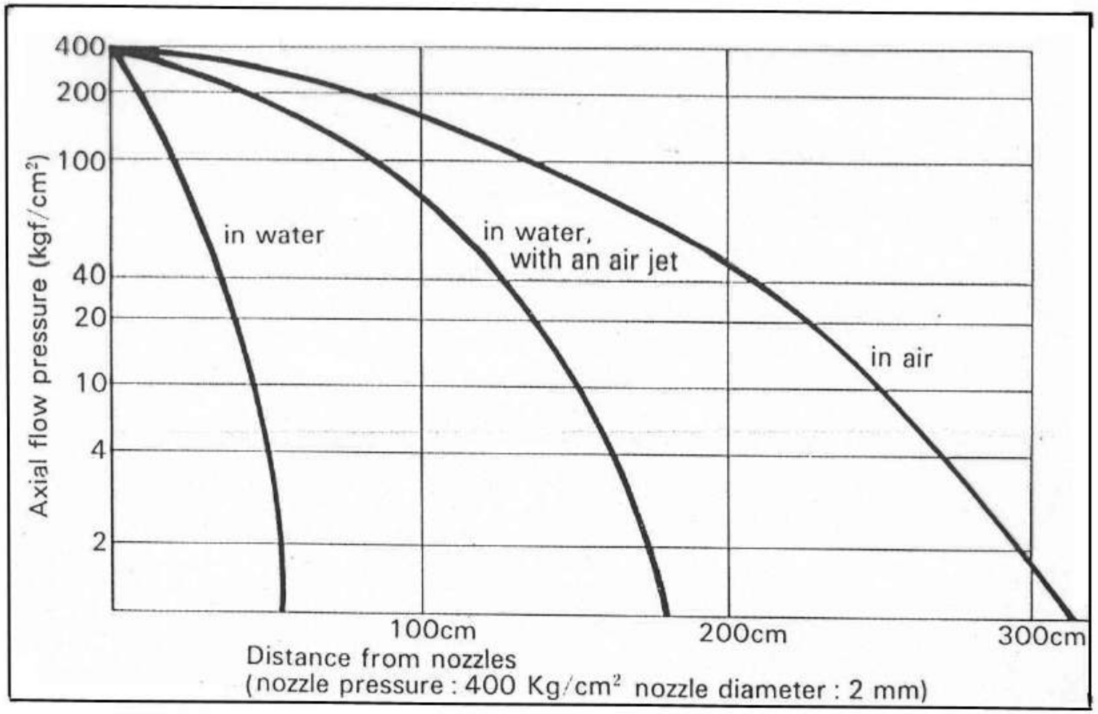
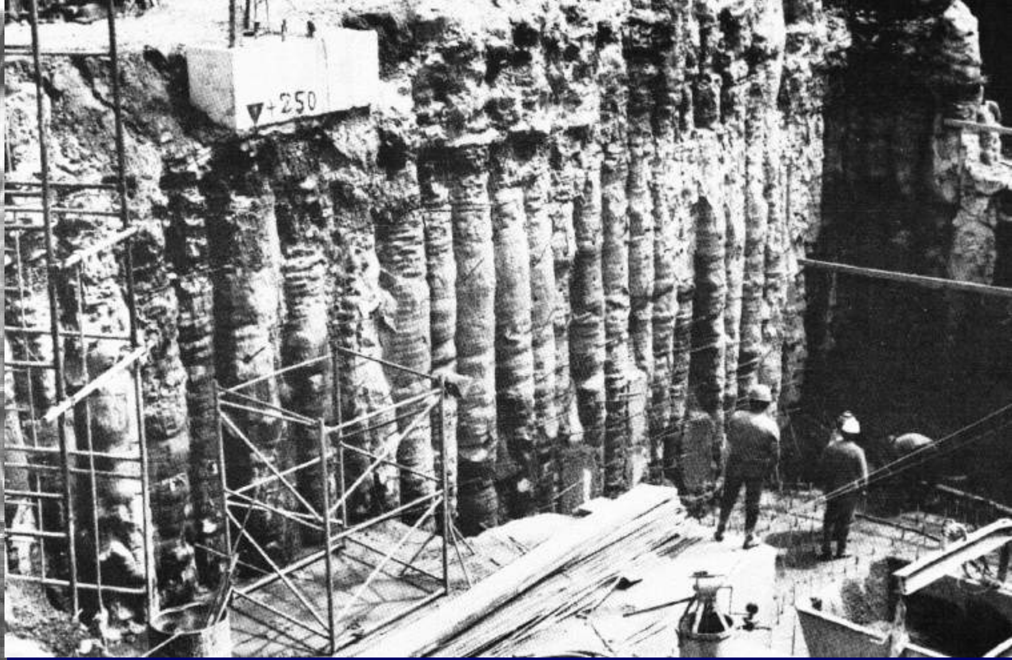


Fig.1 Relationship between water jet's axial flow pressure and its distance from the nozzle.

The effect of the combined use of an air jet and a water jet



Result of jet grouting: a column and a wall

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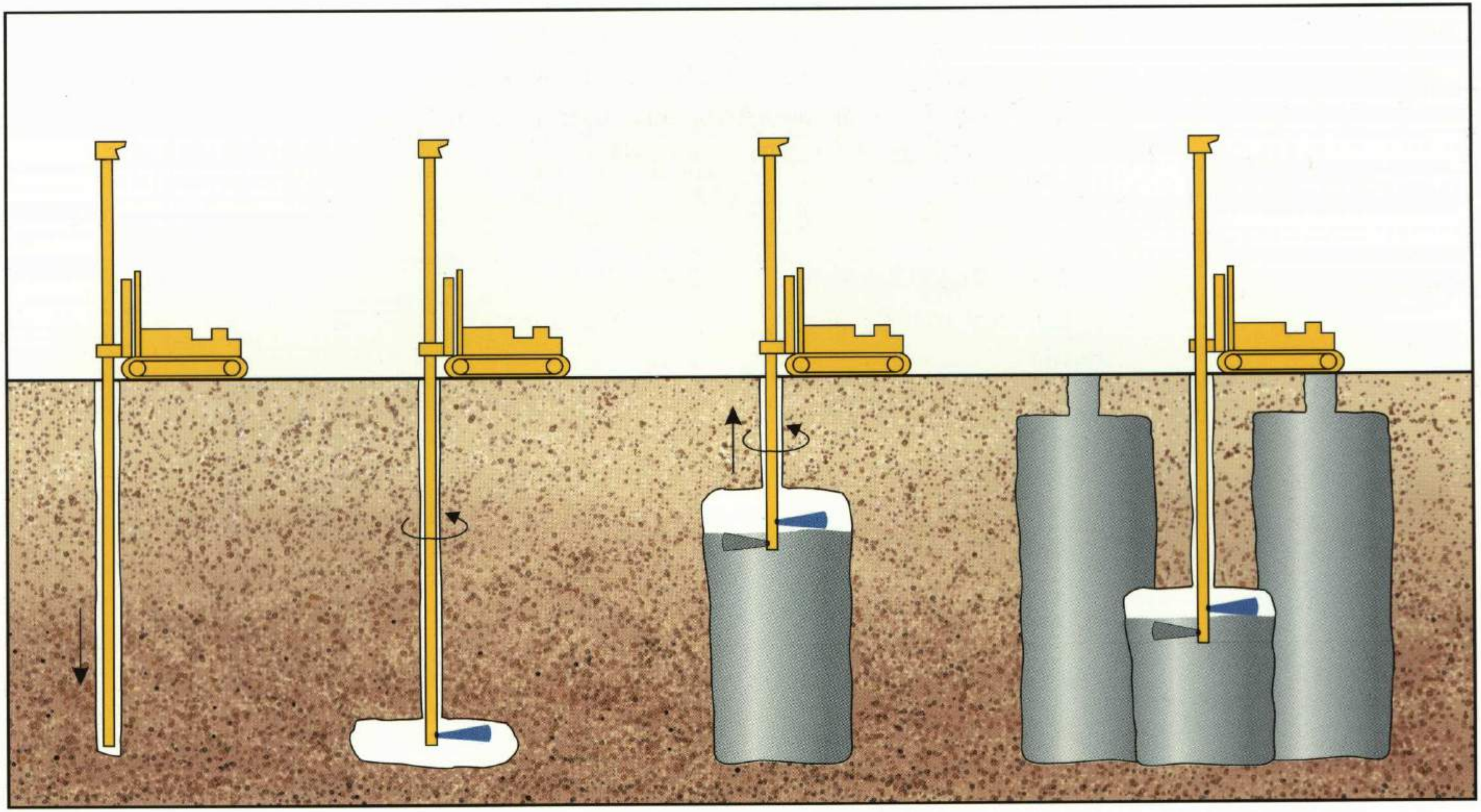


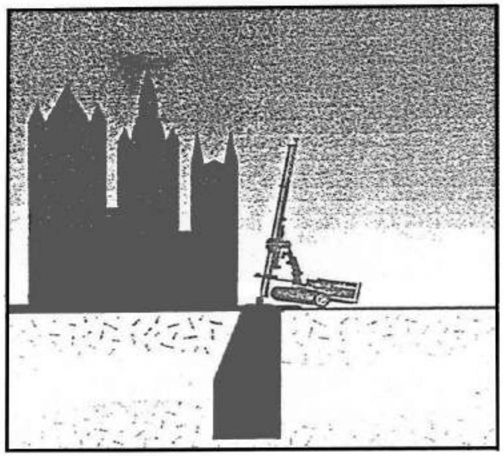
Boring

Soil erosion

Soil erosion and grout injection

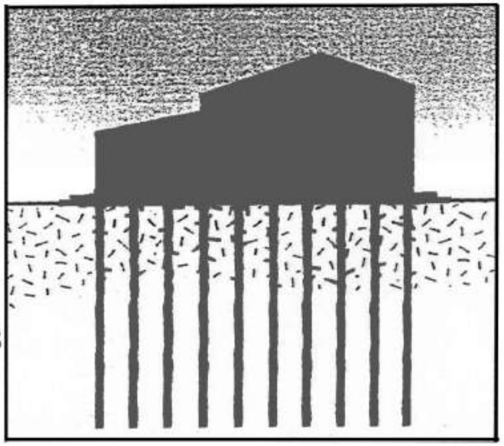
Connection of several Jet grouting columns

Support
- Support of structures in danger of settlement (f.i. old churches)
- Support of existing structures to increase bearing force during renovation
- Support for constructing cellars under existing structures
- Support of buildings near a building pit in narrow spaces



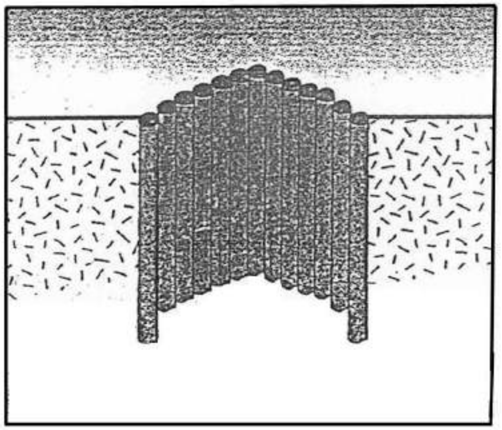
Sanitation
- Stabilising all types of foundations

Sealing
- Bottom sealing of building pits
- Sealing walls of building pits
- Sealing walls for controlling ground water
- Closure of connected sheet piles
- Closure of gaps in bored pile walls



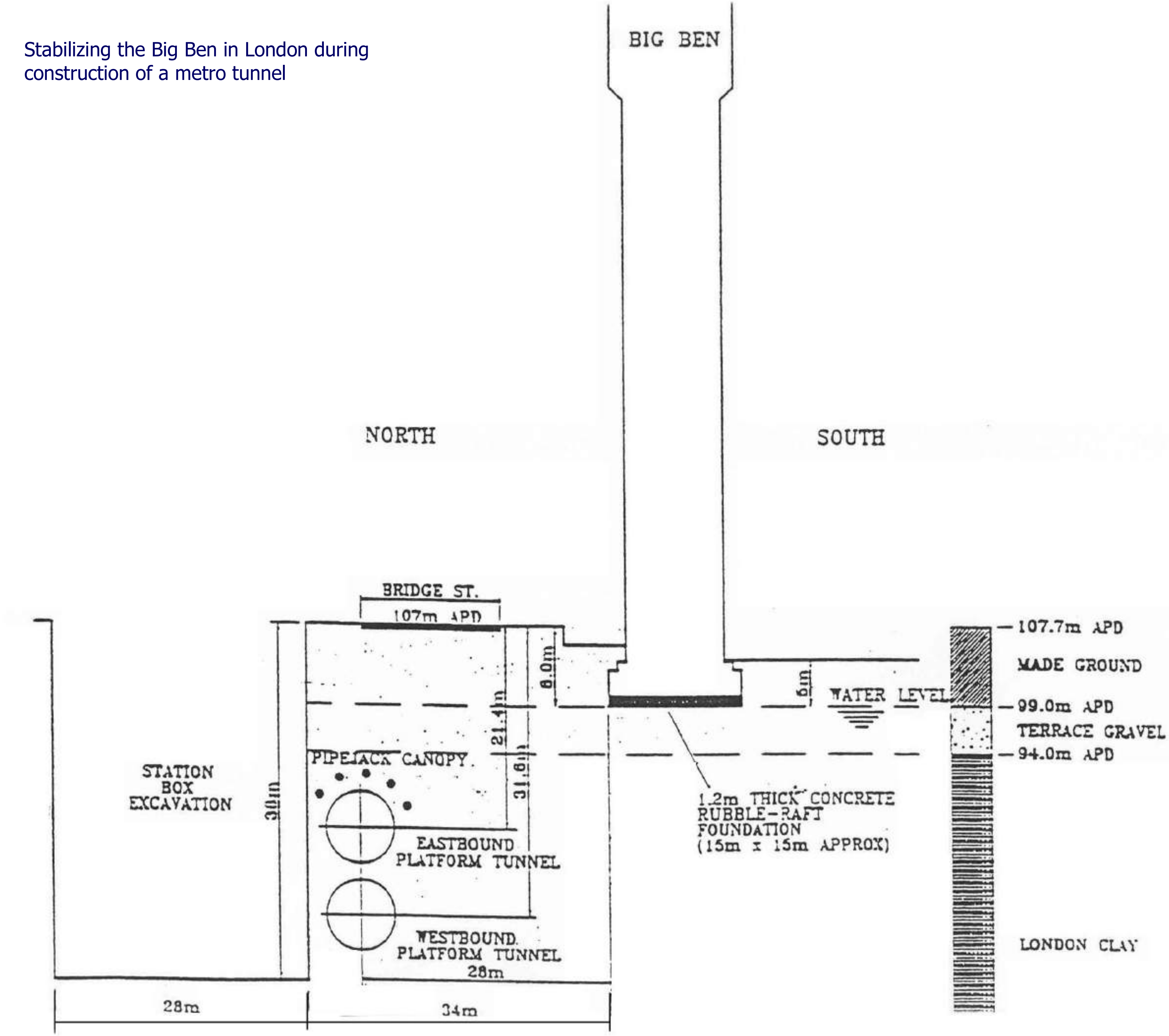
New estate
- Realization of foundations in difficult narrow places

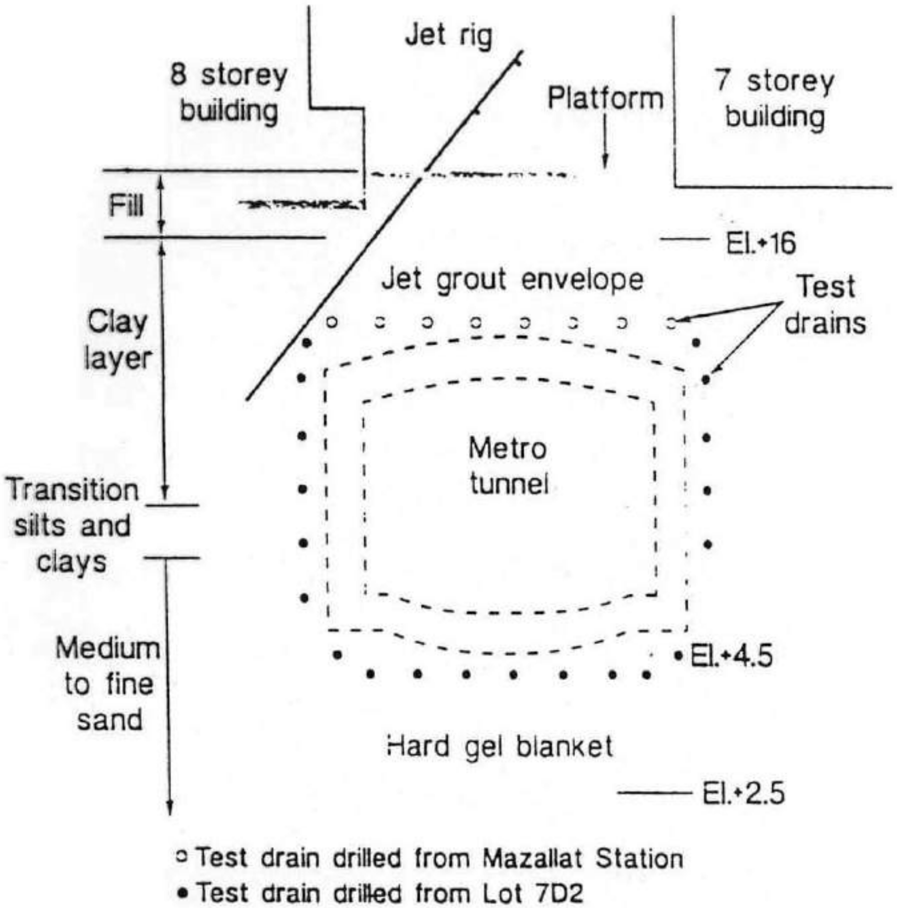
Tunnelling
- Construction of underground arches
- Construction of arches from surface
- Prevention of settlement of nearby buildings

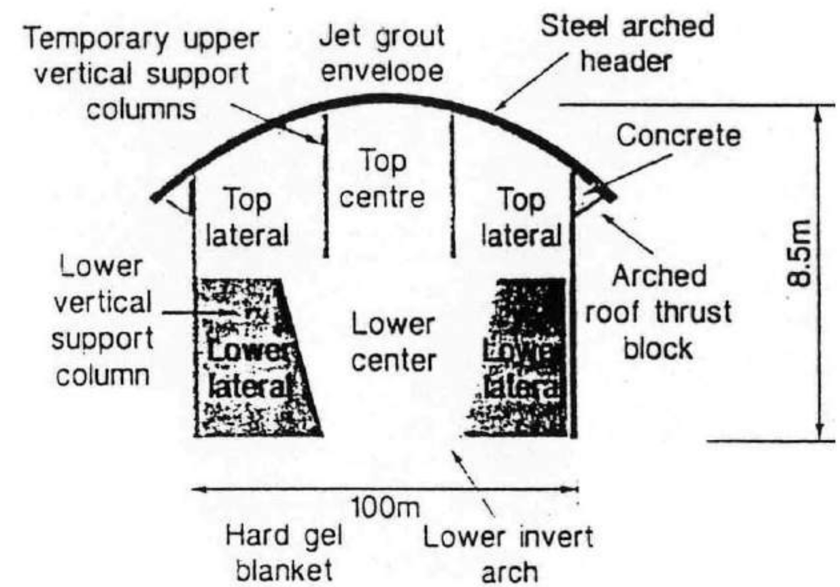


Different applications of jet grouting (VHP) techniques

Stabilizing the Big Ben in London during construction of a metro tunnel



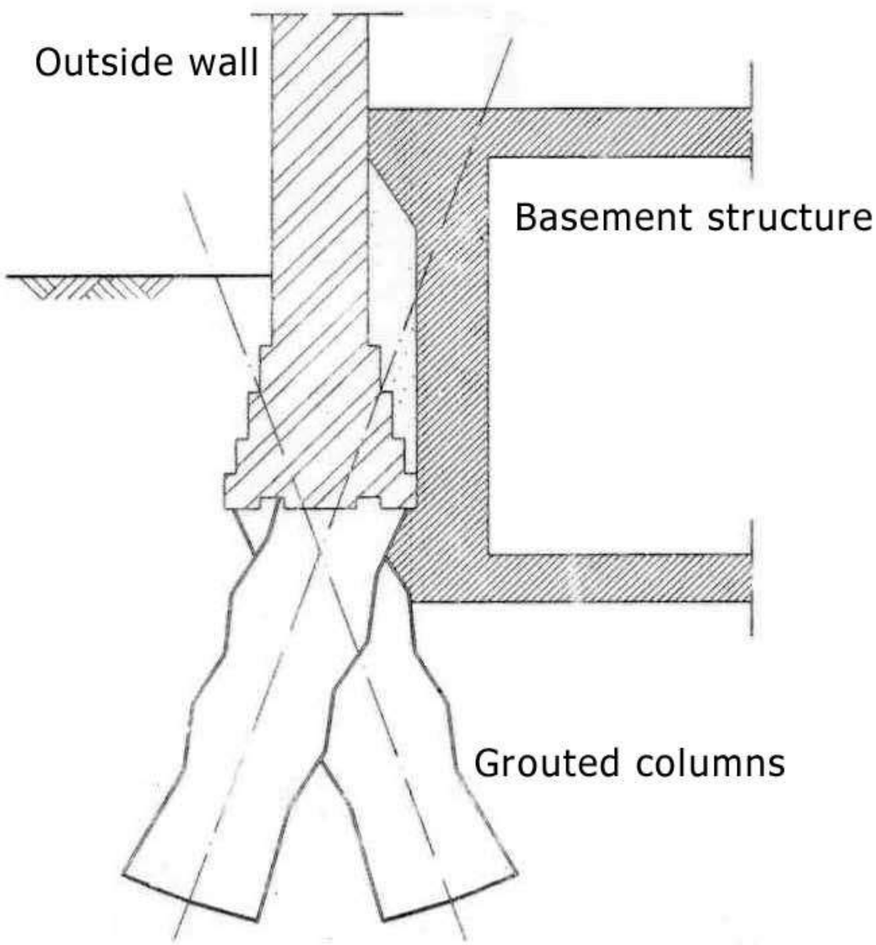




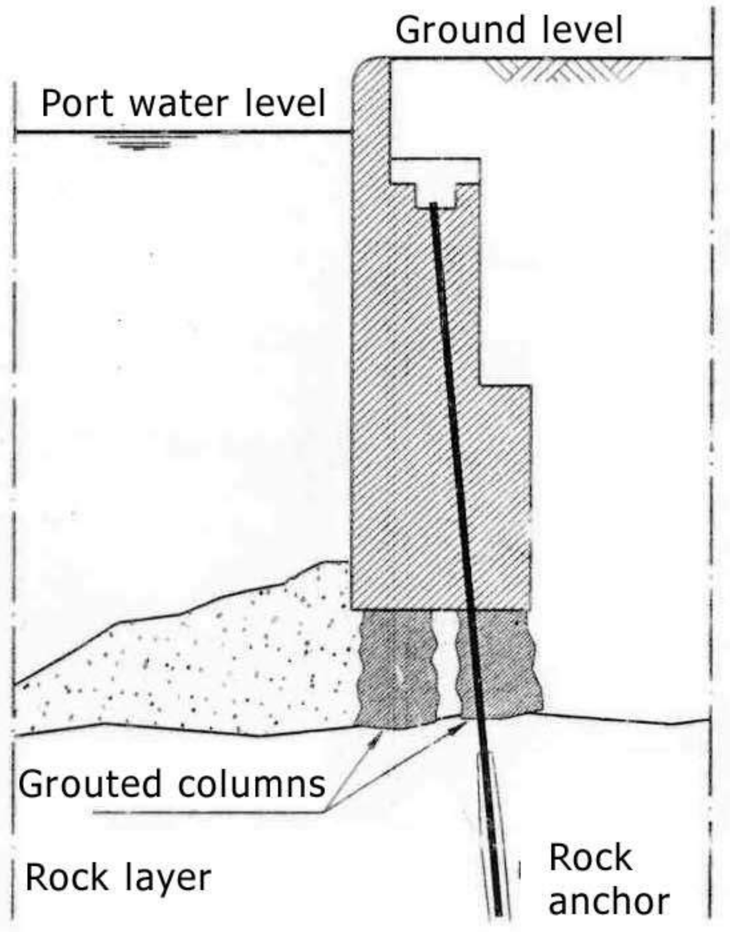
Stage 1. Excavate and support top centre gallery for entire tunnel length.
Stage 2. Alternately excavate and support top lateral headings, 2-3m at a time.
Stage 3. Remove upper temporary vertical support columns.
Stage 4. Excavate lower centre heading, 2-3m in advance of excavation of lower lateral headings. Simultaneously install lower vertical support columns.
Stage 5. Excavate lower arched invert.

Two stage ground treatment stabilised the ground

Stabilizing the ground through application of Jet grouting (VHP)



Support of "Huis van Brecht"



Support of quay wall

Examples of application of jet grouting (vhp) (1)

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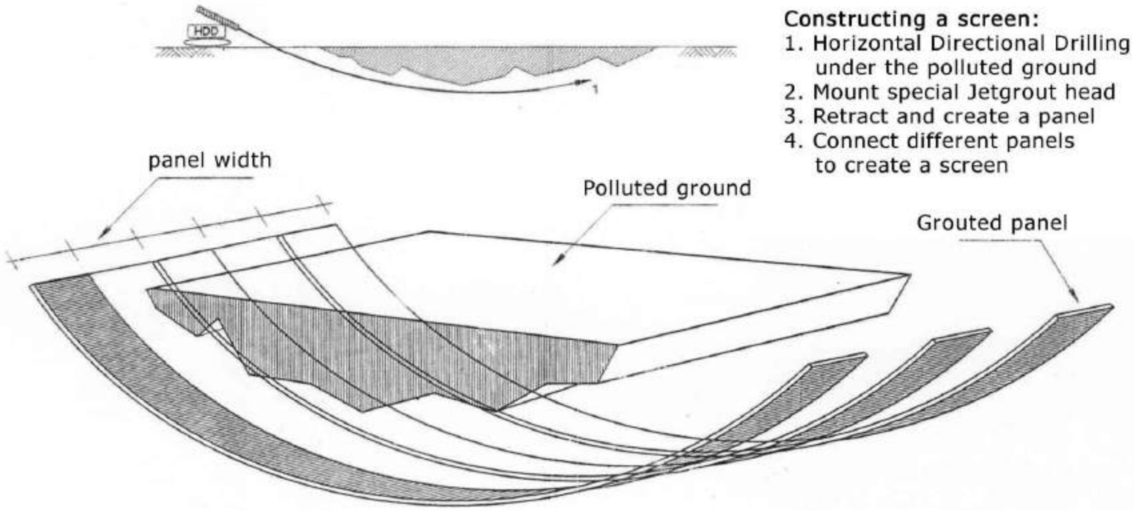
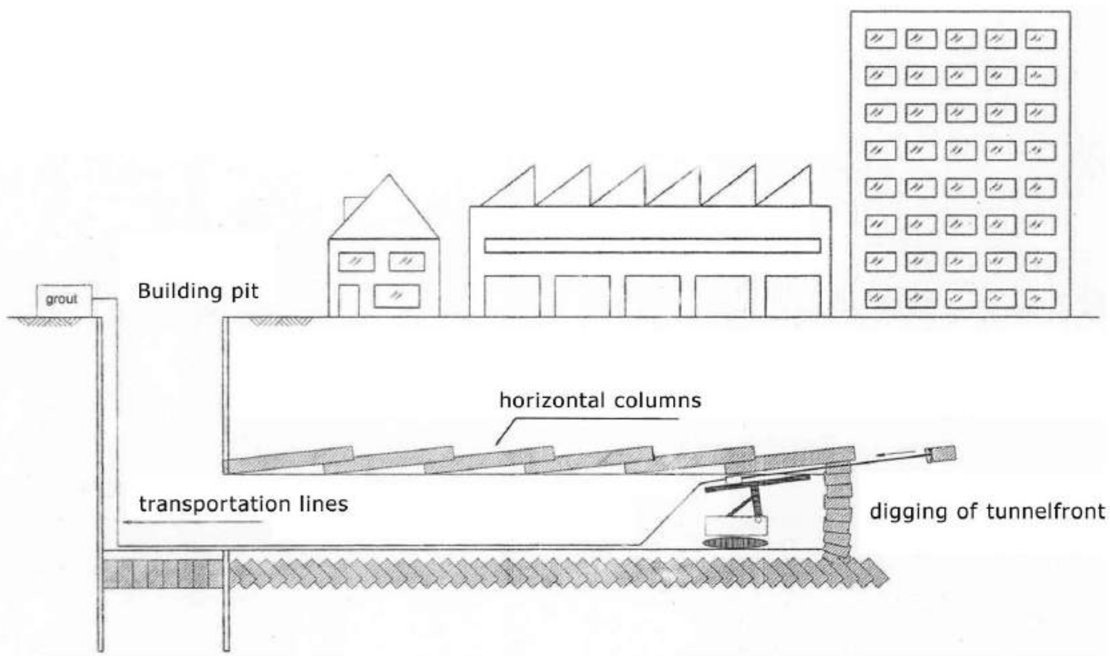


Isolating polluted ground through Jetgrouting

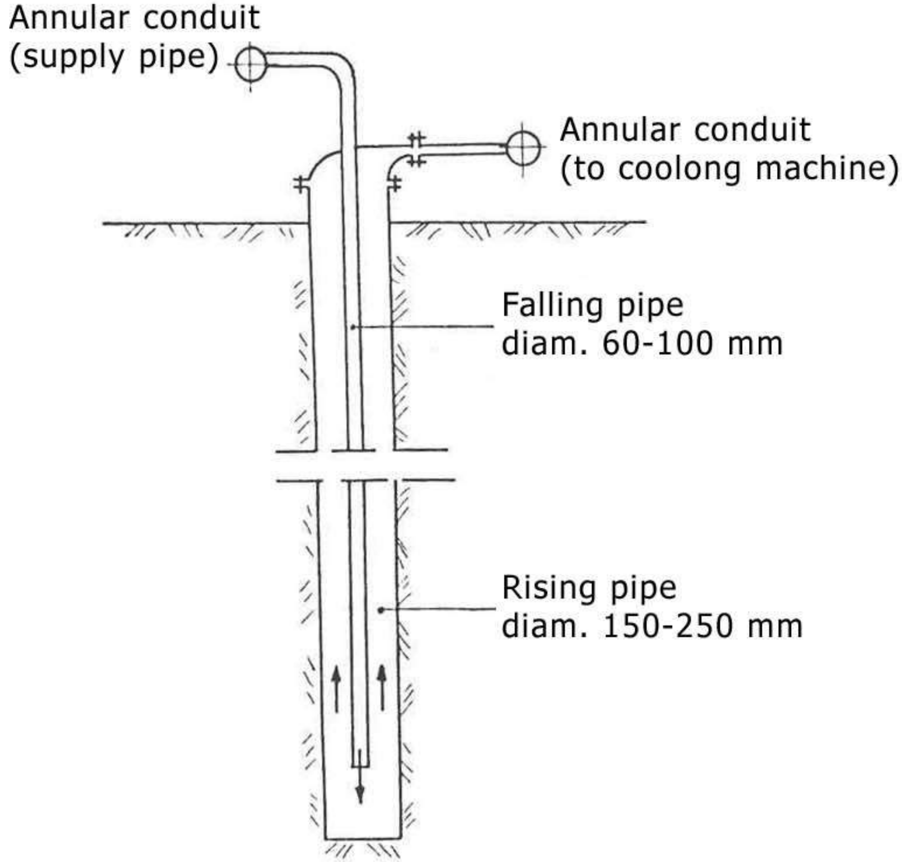


Method of constructing tunnels through horizontal Jetgrouting

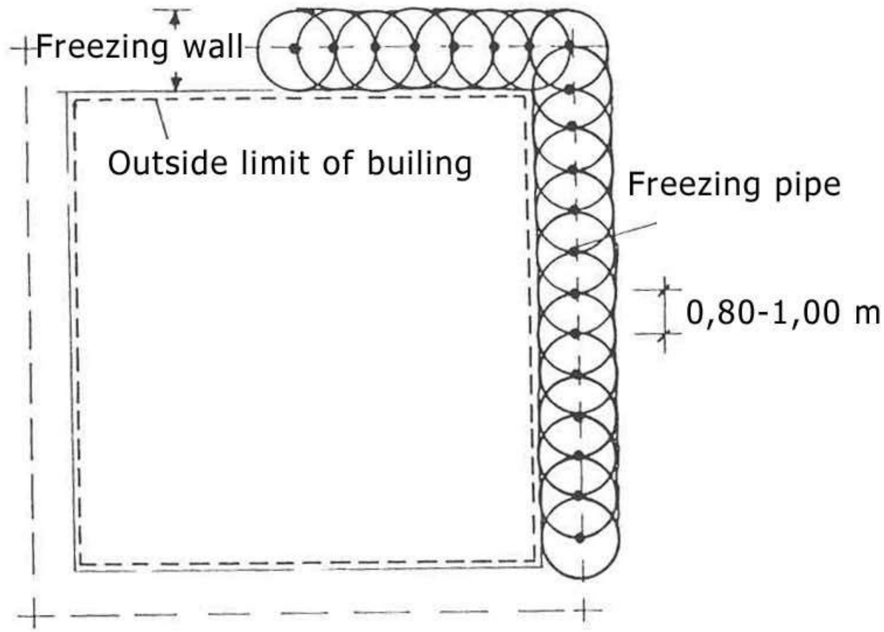
Examples of application of grouting

Soil Freezing

- Wall construction by means of freezing of moisture and water in the soil
- Water and earth retaining structure
- Relatively independent of soil type and conditions
- Environmentally safe
- Deformations because of freezing and thawing (swell)
- Only temporary constructions
- Not suitable in (strong) groundwater flows



Freezing pipe



Placing of the freezing pipes in the ground

The construction of a freezing wall

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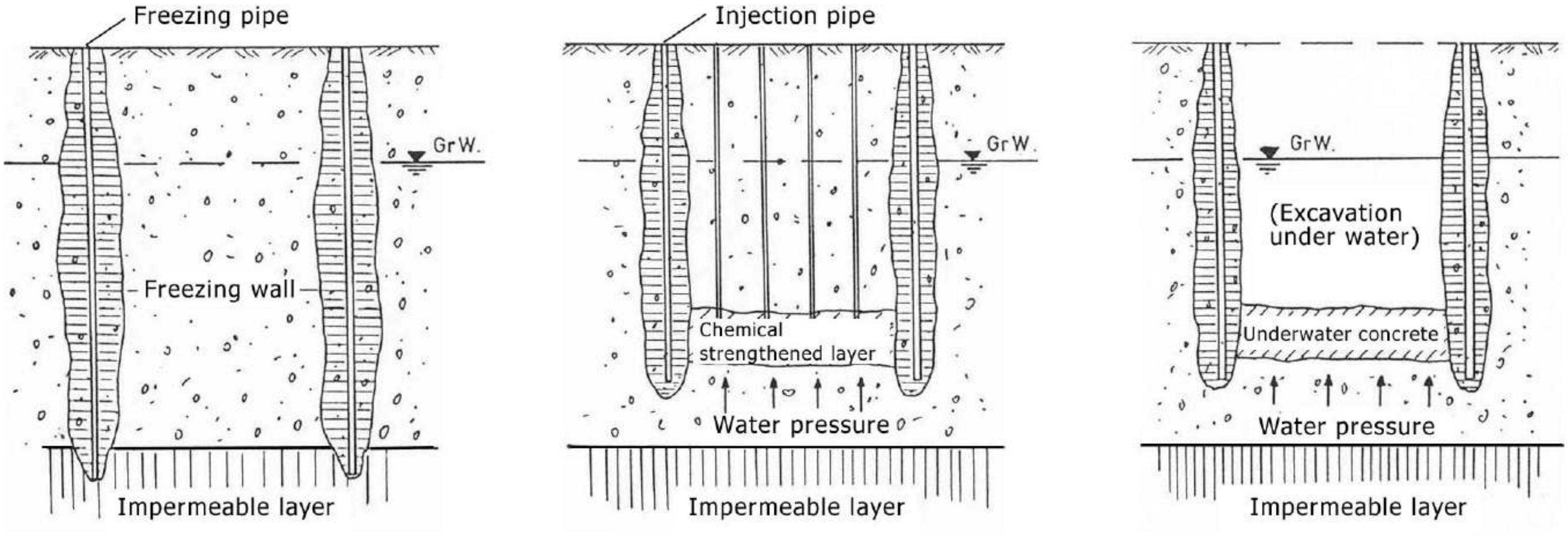


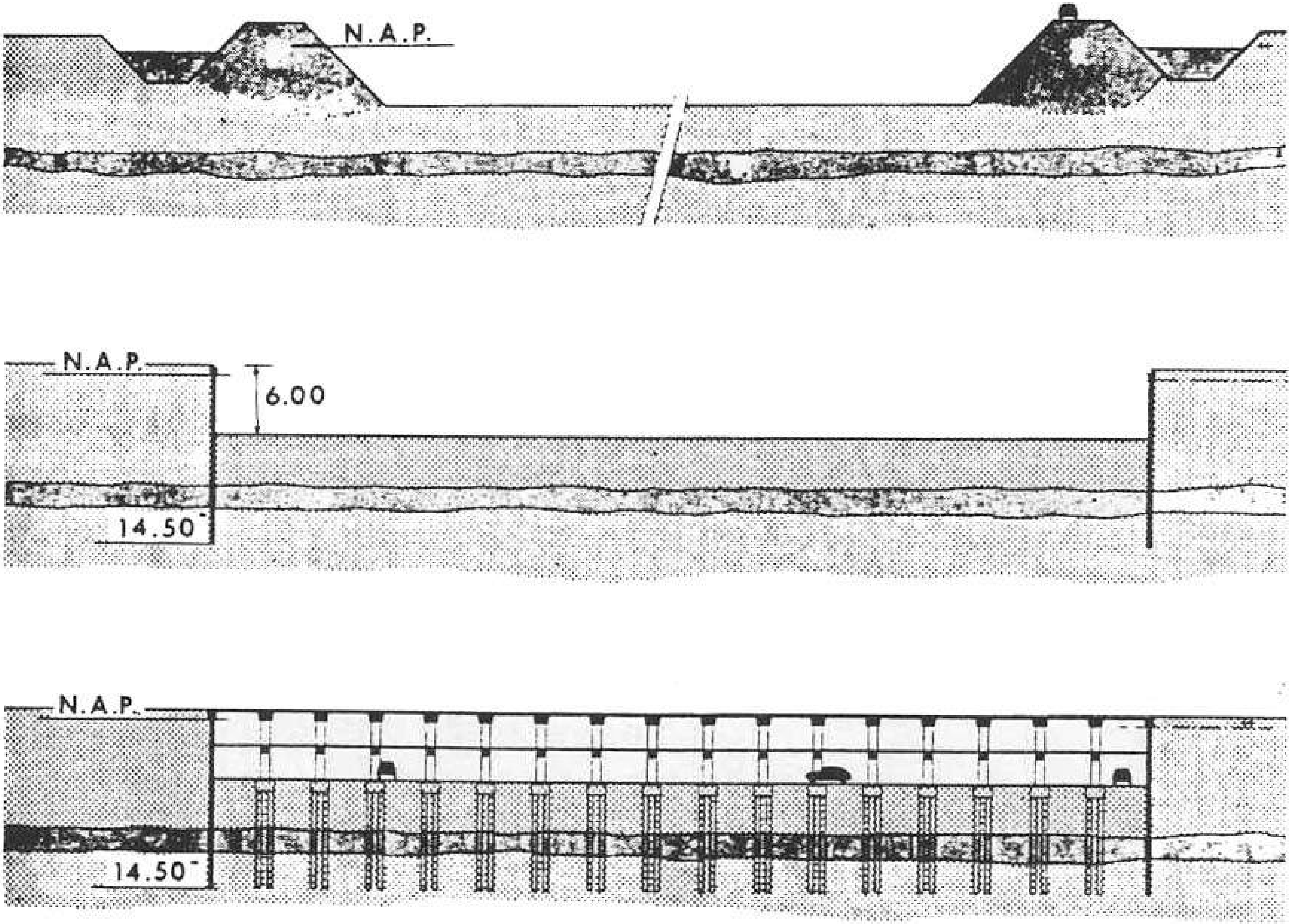
a) Construction of freezing walls into impermeable layer

b) Sealing of the building pit bottom by a chemical injected layer

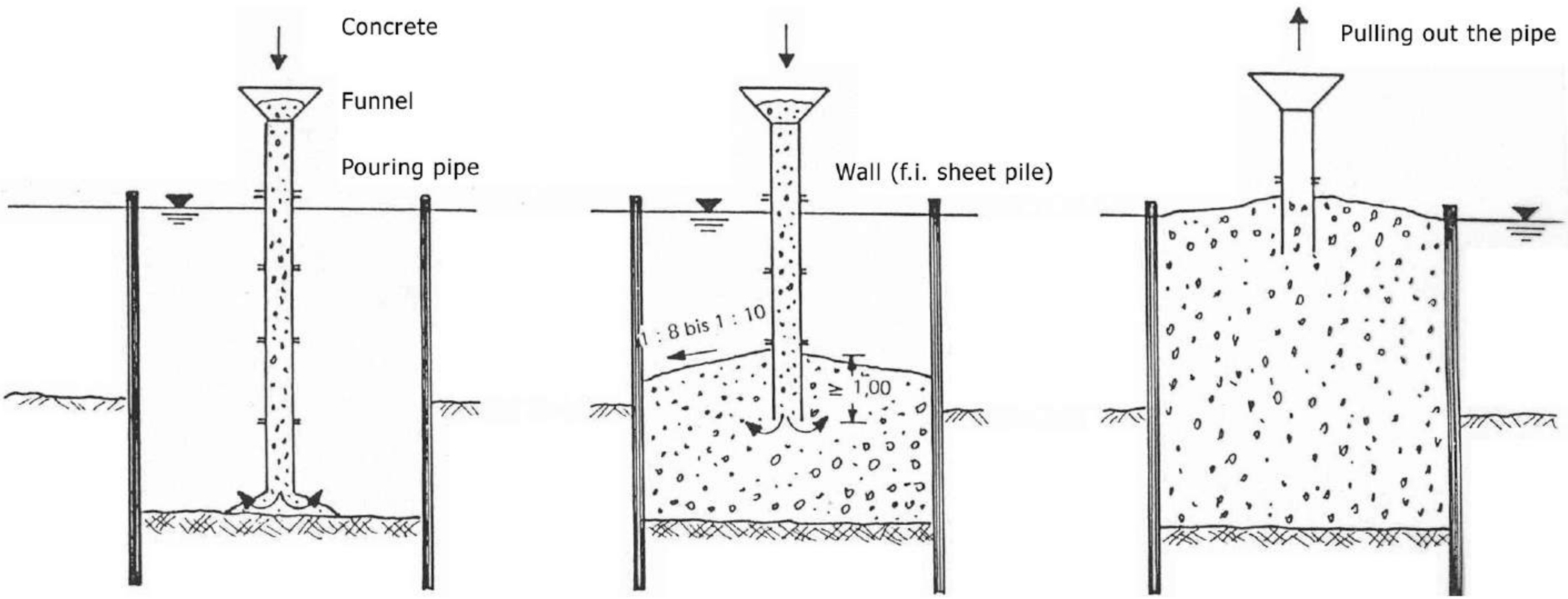
c) Construction of a watertight building pit with underwater concrete

Horizontal Boundaries

- Polder
- Open building pit with dewatering
- Natural impermeable layer
- Underwater concrete
- Horizontal chemical injection
- Jet grouting (VHP)



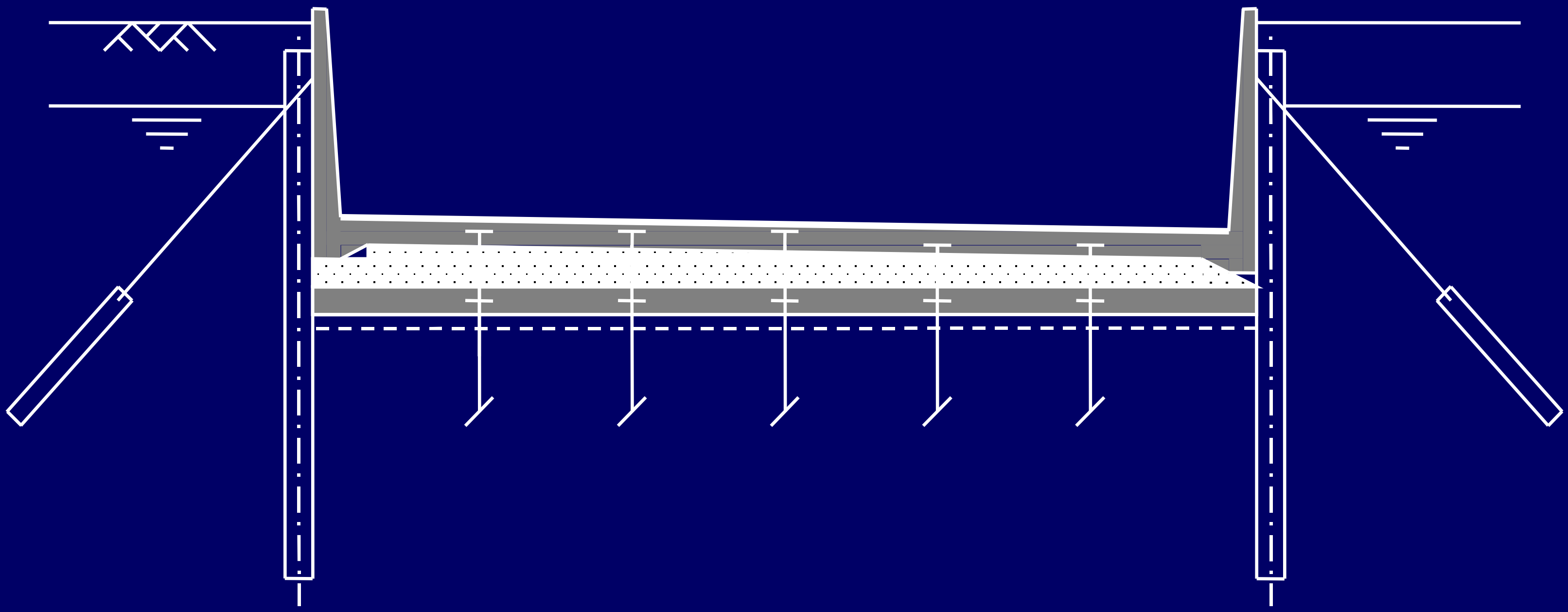
Basement structures built with the traditional polder principle



Pouring concrete under water with a funnel

Pouring underwater concrete

Underwater and Structural Concrete



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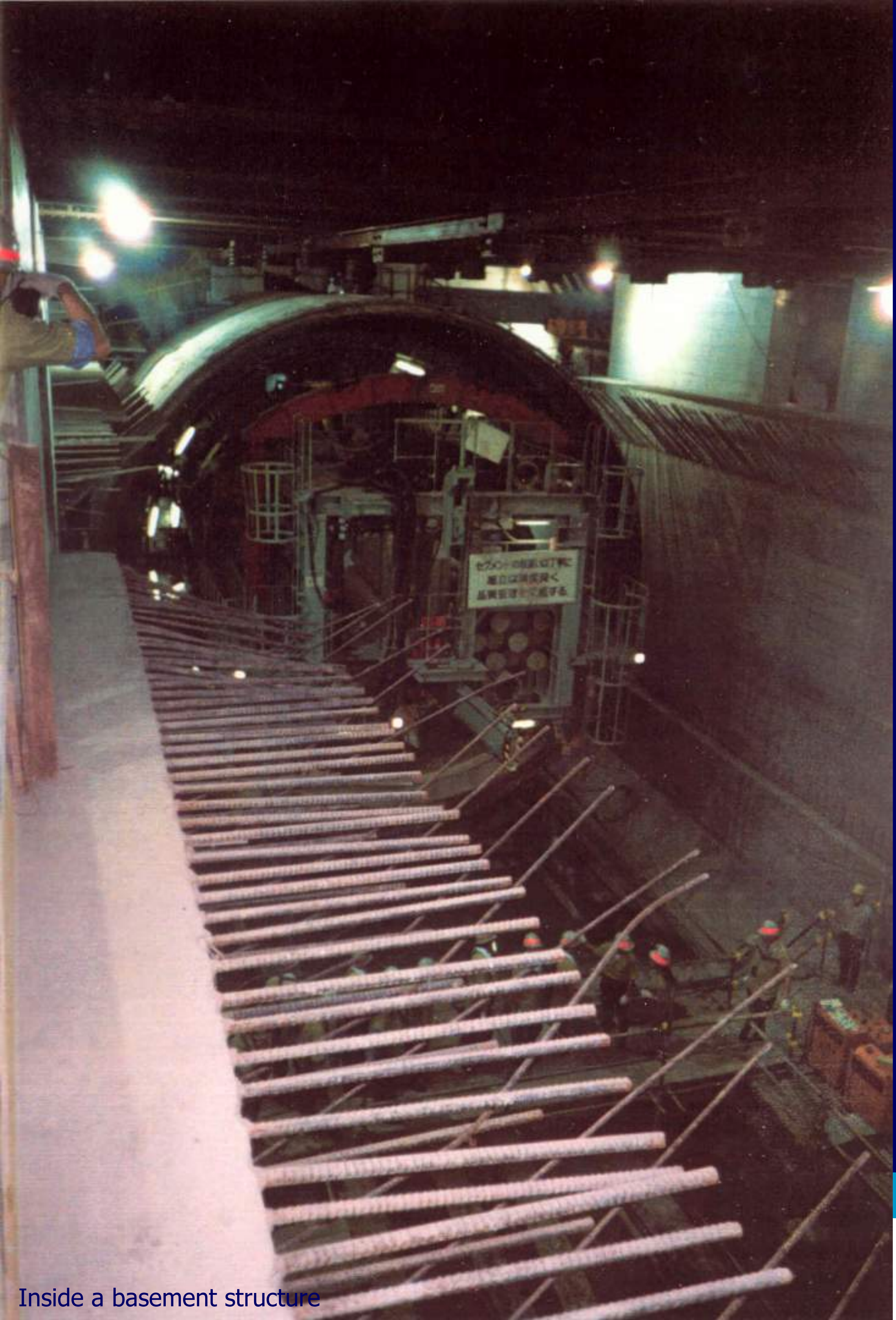
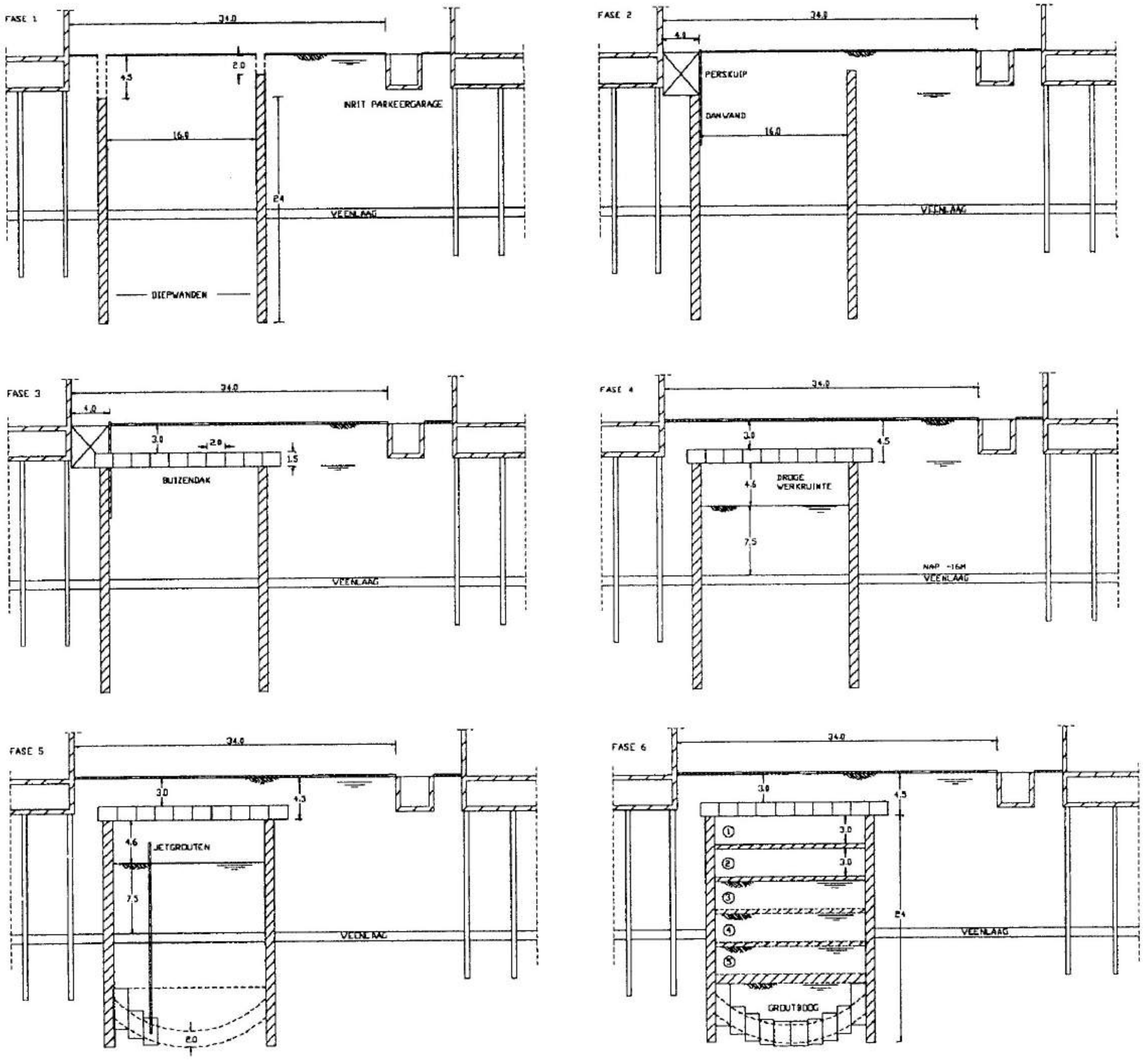

Inside a basement structure



Cut and Cover:
Combining construction techniques

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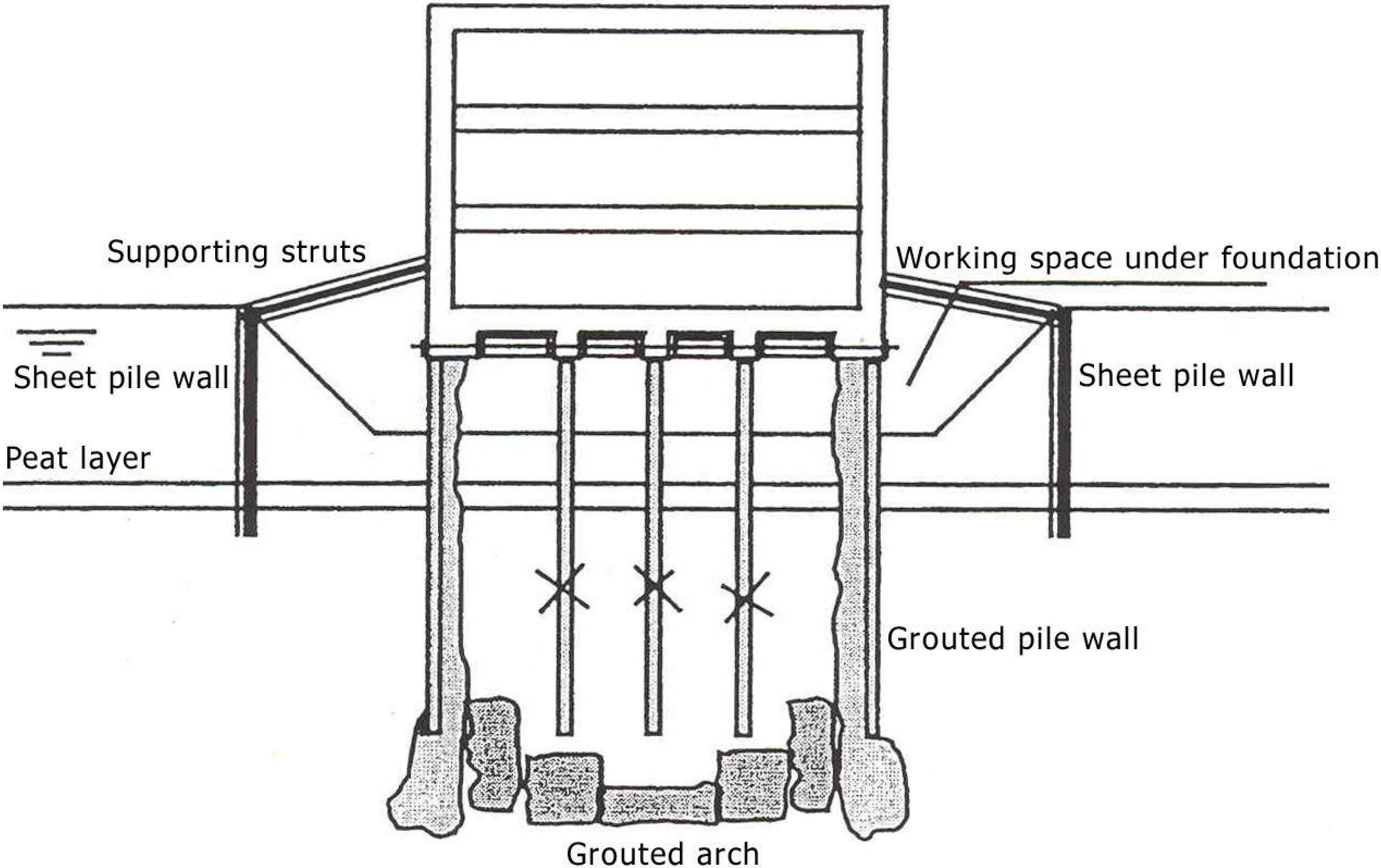
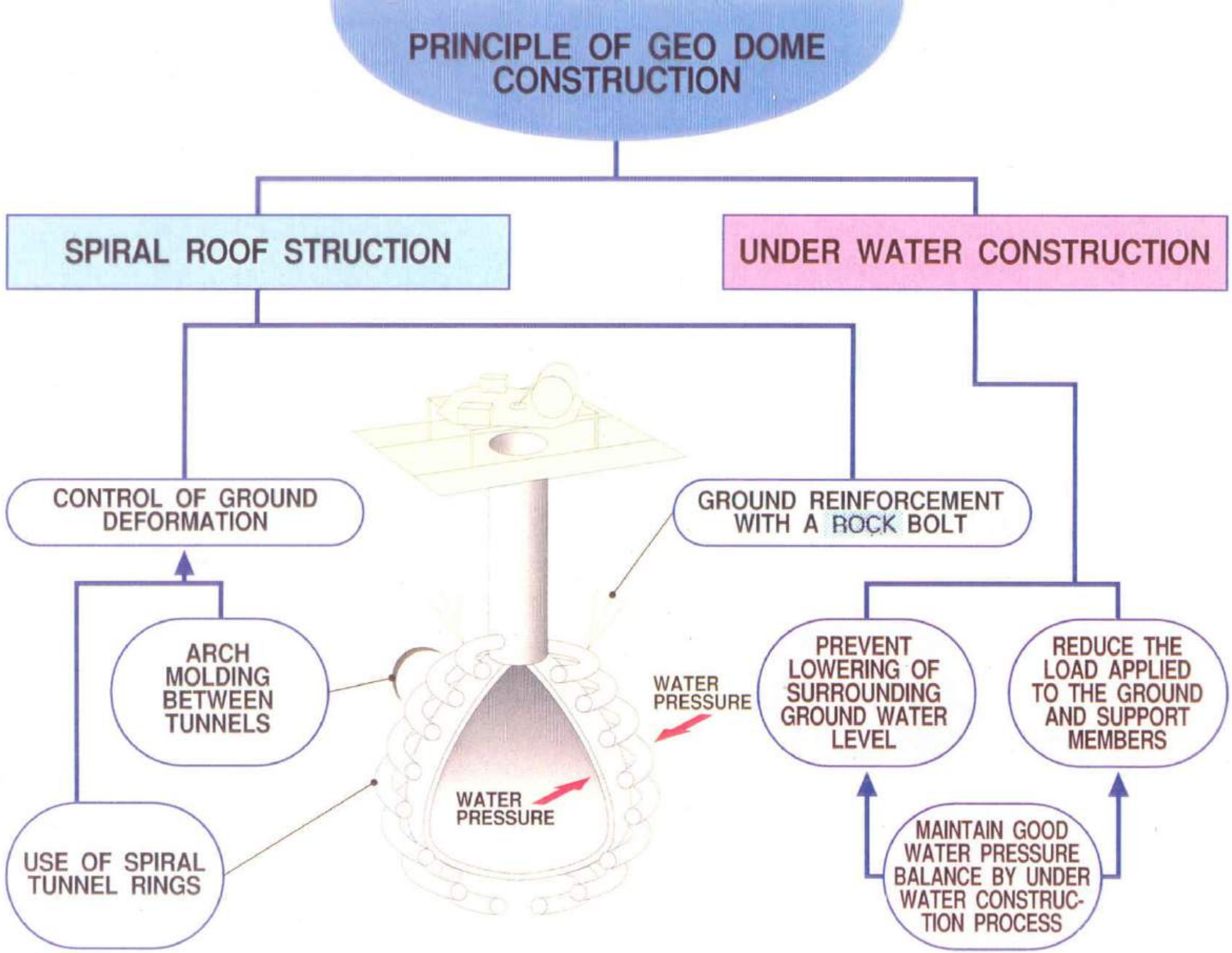
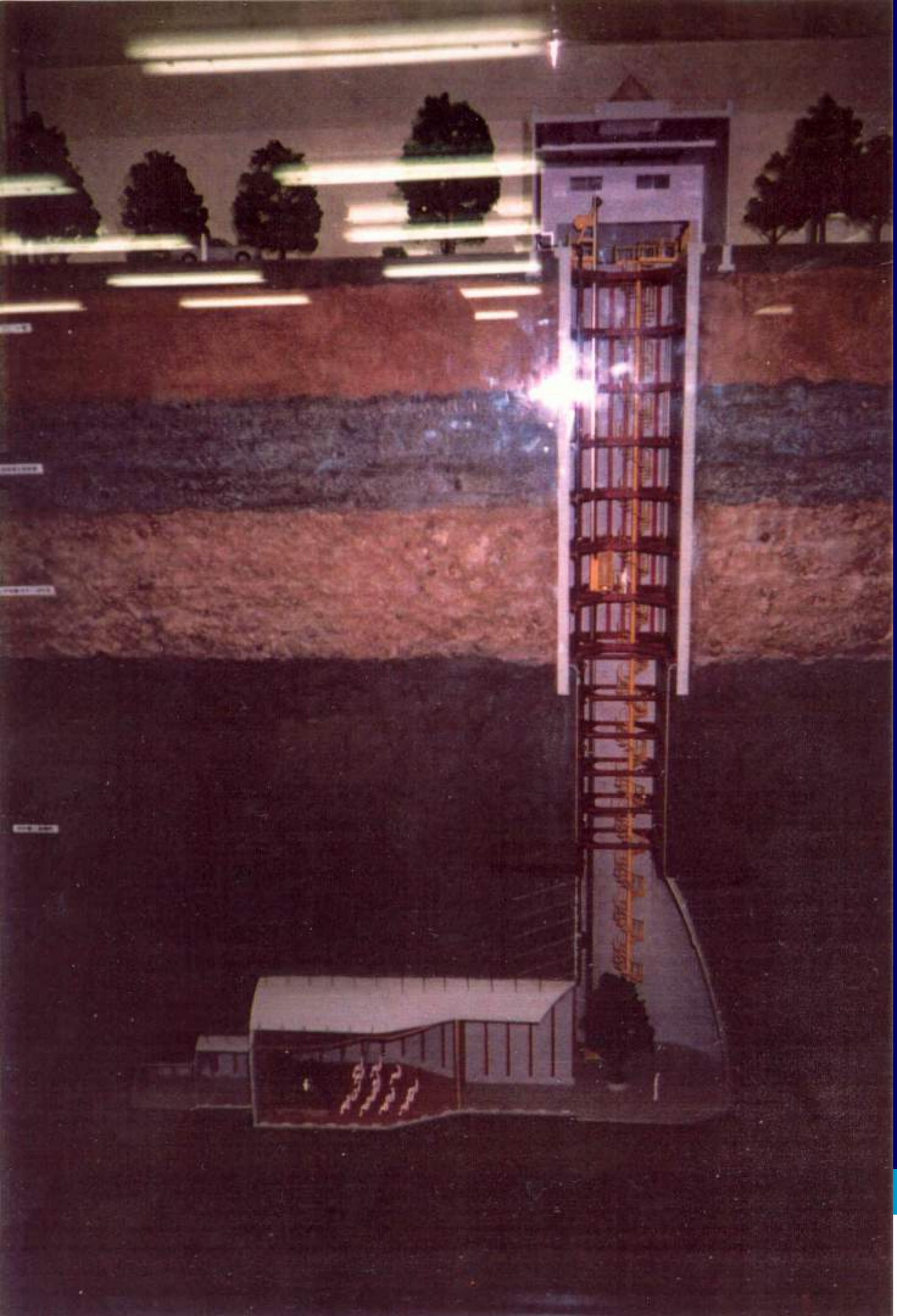


Construction under an existing building, founded on piles



Capable of building a large space having a diameter of 50m in underground at a great depth.

Underground constructions: Geo dome construction

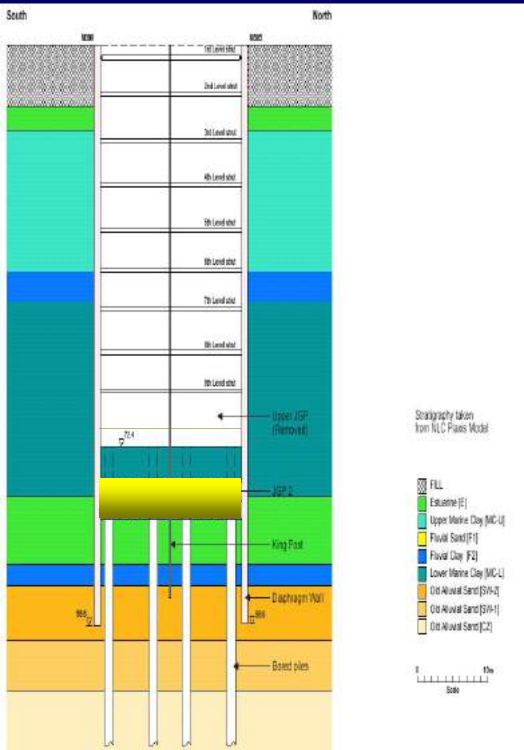


Underground constructions:
Underground theatre

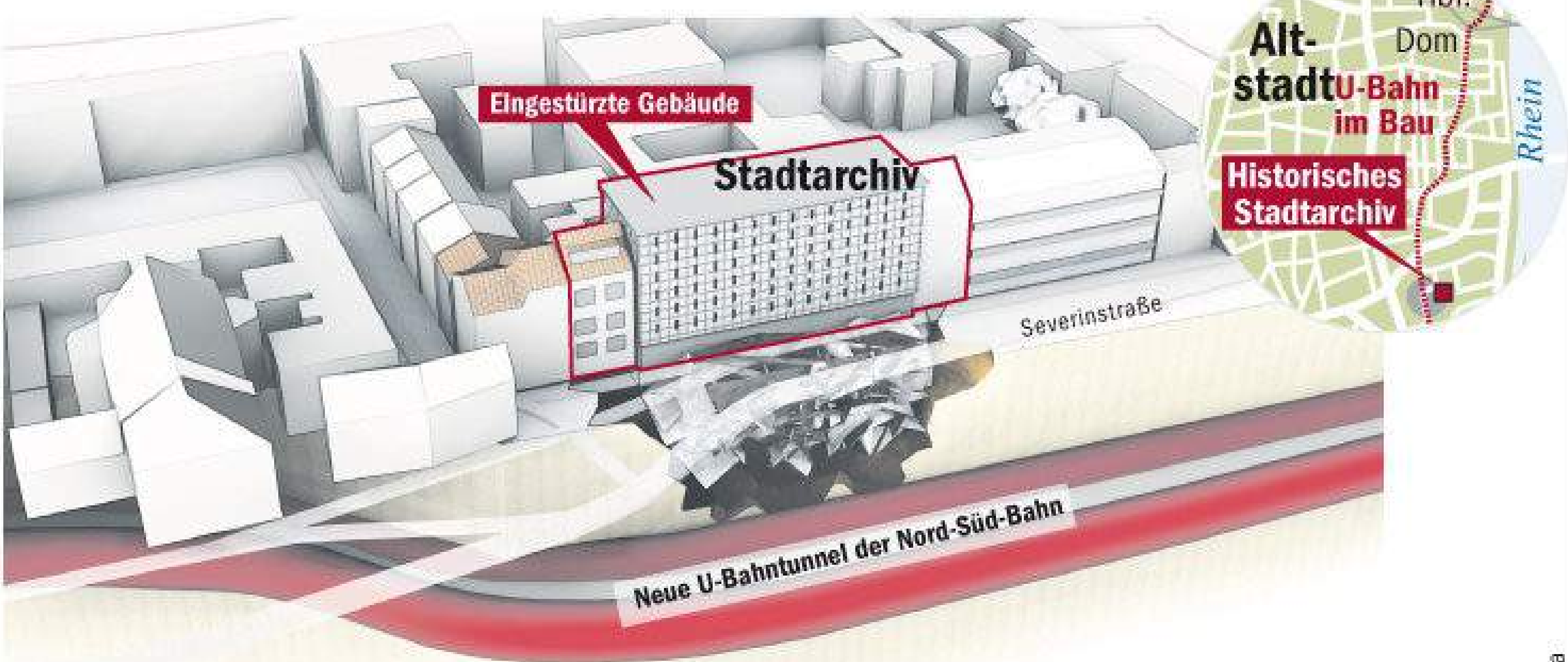
Model of a dome (Japan)

Construction Failures

- Designing on strength
- Designing on (water)pressure
- Failures:
  - Wilhelmina station (high pressure grouting)
  - Botlek utility tunnel (starting zone constructed with weak concrete and after that freezing techniques have been used)
  - The Hague Metroline (high pressure grouting)


South
North
Upper JGP (Removed)
JGP 2
King Post
Diaphragm Wall
Bored piles
Stratigraphy taken from NLC Plaxis Model
FILL
Estuarine [E]
Upper Marine Clay [MC-U]
Fluvial Sand [F1]
Fluvial Clay [F2]
Lower Marine Clay [MC-L]
Old Alluvial Sand [SW-2]
Old Alluvial Sand [SW-1]
Old Alluvial Sand [CZ]
Scale

DER EINSTURZ DES KÖLNER STADTARCHIVS



adtarchiv wird
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Grafik: Jutta Setzer, Hergang: dpa




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Temporary structures

Temporary structures will be replaced by permanent structures. Design required for both stages.

Standards, specifications and boundary conditions are not always the same for temporary works and permanent construction and a transition period between the two exists

Multi-criteria Matrix Method

- Selection based on experience of the designer
- Assisted by the multi criteria method in case of more difficult problems with more variables

Combination of building pit borders	HORIZONTAL					Remarks on vertical building pit border
	A No closing layer with dewatering (temporary)	B Natural closing layer (temporary/ definite)	Artificial closing layer			
			C Underwater concrete	D Chemical injection (temporary)	E Jetgrouting (temporary/ definite)	
1 Slopes	1A	X	X	X	X	
2 Sheet pile - / Combined wall	2A	2B	2C	2D	2E	
3 Diaphragm - / Bored pile wall	3A	3B	3C	3D	3E	
4 Screwed pile wall (without slurry)	4A	4B	4C	4D	4E	
5 Chemical injected wall	5A	5B *	5C *	5D *	5E *	stabilising and/or watertight
6 Berliner wall	6A	X	X	6D *	6E *	depends on soil type. Not watertight
7 Jetgrouting	7A	7B	7C *	X	7E *	stabilising and/or watertight
8 Freezing wall						
9 Pneumatic caisson	9					horizontal/ vertical border
Remarks concerning horizontal building pit border		Definite closing layer = polder principle		Depends on soil type, injectability		* : Special or local application X : Not or hardly applicated

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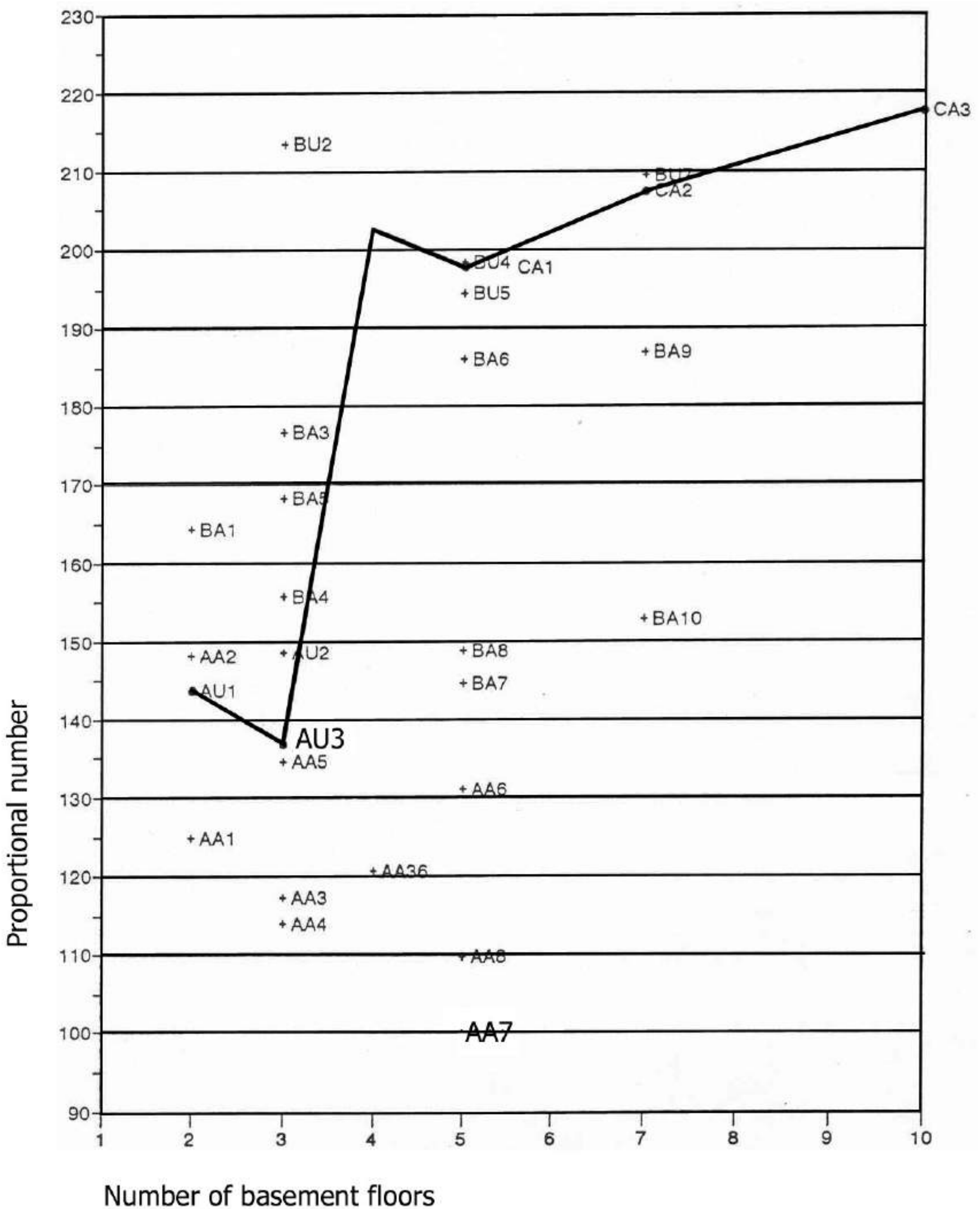
	CRITERIA								
Combination	Construction depth			Disruption ground water level	Hindrance neighbours	Nearby buildings	Disruption infra. above ground level	Small working ground	Environ-ment
	> 20 m	5-20 m	< 5 m						
1A Slope/ Dewatering	1	1	5	1	5	1	1	1	5
2A Sheet pile wall/ dewatering	1	3	5	1	2	1	3	4	4
2B Sheet pile wall/ closing layer	2	5	5	5	2	2	3	4	4
2C Sheet pile wall/ underwater concrete	2	3	3	5	2	2	3	3	4
2D Sheet pile wall/ chemical injection	1	2	2	5	2	2	3	4	1
2E Sheet pile wall/ Jetgrouting	1	2	2	5	2	2	3	4	3
3A Diaphragm wall/ dewatering	1	2	2	1	4	3	5	2	3
3B Diaphragm wall/ closing layer	5	4	2	5	4	5	5	2	3
3C Diaphragm wall/ underwater concrete	5	2	1	5	4	5	3	2	3
3D Diaphragm wall/ chemical injection	1	2	1	5	4	5	3	2	1
3E Diaphragm wall/ Jetgrouting	1	2	2	5	3	3	3	2	3
4A Screwed pile wall/ dewatering	1	2	2	1	4	3	5	2	3
4B Screwed pile wall/ closing layer	1	4	2	5	4	5	5	2	3
4C Screwed pile wall/ underwater conc.	1	2	1	5	4	5	3	2	3
4D Screwed pile wall/ chemical injection	1	2	1	5	4	5	3	2	1
4E Screwed pile wall/ Jetgrouting	1	2	2	5	3	3	3	3	3
5A Chemical injection/ dewatering	1	1	1	1	5	5	1	4	1
6A Berliner wall/ dewatering	1	1	4	1	3	1	1	3	4
7A Jetgrouting/ dewatering	1	1	1	1	4	2	3	3	3
7B Jetgrouting/ closing layer	1	1	1	5	4	3	3	3	3
9 Caisson (pneumatic)	2	3	1	5	1	5	2	5	5
Remarks	Complexity technical realization				Sound/ visual	Vibration/ Deformation	Diff. with cut-and-cover method		

Case number	Layers	Model	Remarks	Realization time in weeks			Total time rough structure in months
				Ground retaining Excavation Foundation	Floors Basement	Total rough structure	
AA1	2	Sheet pile wall		10	10	20	7
BA1	2	Screwed pile wall		21	8	29	10
AA2	2	Sheet pile wall	Underwater concrete	22	9	31	11
AA3	3	Sheet pile wall		24	12	36	13
BA3	3	Screwed pile wall		31,5	12	43,5	16
AA4	3	Sheet pile wall	Polder principle	17,5	12	29,5	11
BA4	3	Screwed pile wall	Polder principle	32	12	44	16
AA5	3	Sheet pile wall	Underwater concrete	26,5	13	39,5	14
BA5	3	Screwed pile wall	Underwater concrete	34	13	47	17
AA6	5	Sheet pile wall	Piles to -50 m	42,5	20	62,5	23
BA6	5	Diaphragm wall	Piles to -50 m	54	20	74	27
AA7	5	Sheet pile wall	Polder principle	25	20	45	16
BA7	5	Diaphragm wall	Polder principle	34,5	20	54,5	20
AA8	5	Sheet pile wall	Floating foundation	20,5	20	40,5	15
BA8	5	Diaphragm wall	Floating foundation	30	20	50	18
CA1	5	Caisson		-	-	48	17
BA9	7	Diaphragm wall	Piles to -50 m	67	28	95	34
BA10	7	Diaphragm wall	Floating foundation	35	28	63	23
CA2	7	Caisson		-	-	63	23
CA3	10	Caisson		-	-	87	32
AU1	2	Sheet pile wall	Underwater concrete	21,5	9	30,5	11
AU2	3	Sheet pile wall	Chemical injection	22	15	37	13
BU2	3	Diaphragm wall	Chemical injection	29,5	15	44,5	16
AU3	3	Sheet pile wall	Underwater concrete	33,5	13	46,5	17
BU4	5	Diaphragm wall	Chemical injection	50	23	73	26
BU5	5	Diaphragm wall	Floating foundation	36	23	59	21

Construction time of different construction methods

Case number	Location	Model	Remarks	Layers	Proportion	Accuracy
AA1	Amsterdam	Sheet pile wall		2	125	10
AA2	Amsterdam	Sheet pile wall	Underwater concrete	2	148	10
AA3	**Amsterdam**	**Sheet pile wall**		3	**117**	10
AA4	**Amsterdam**	**Sheet pile wall**	**Polder principle**	3	**114**	10
AA5	Amsterdam	Sheet pile wall	Underwater concrete	3	135	10
AA3/6	Amsterdam	Sheet pile wall		4	120	15
AA6	Amsterdam	Sheet pile wall		5	131	20
AA7	Amsterdam	Sheet pile wall	Polder principle	5	100	20
AA8	Amsterdam	Sheet pile wall	Floating foundation	5	110	20
AU1	Utrecht	Sheet pile wall	Underwater concrete	2	144	10
AU2	Utrecht	Sheet pile wall	Chemical injection	3	149	10
AU3	**Utrecht**	**Sheet pile wall**	**Underwater concrete**	3	**137**	10
BA1	Amsterdam	Screwed pile wall		2	164	10
BA3	**Amsterdam**	**Screwed pile wall**		3	**177**	10
BA4	**Amsterdam**	**Screwed pile wall**	**Polder principle**	3	**156**	10
BA5	Amsterdam	Screwed pile wall	Underwater concrete	3	168	10
BA6	Amsterdam	Diaphragm wall		5	186	20
BA7	Amsterdam	Diaphragm wall	Polder principle	5	145	20
BA8	Amsterdam	Diaphragm wall	Floating foundation	5	149	20
BA9	Amsterdam	Diaphragm wall		7	187	25
BA10	Amsterdam	Diaphragm wall	Floating foundation	7	153	25
BU2	Utrecht	Diaphragm wall	Chemical injection	3	214	10
BU4	**Utrecht**	**Diaphragm wall**	**Chemical injection**	5	**198**	20
BU5	Utrecht	Diaphragm wall	Floating foundation, chemical injection	5	195	20
BU7	Utrecht	Diaphragm wall	Chemical injection	7	210	25
CA1	Amsterdam	Caisson		5	198	10
CA2	Amsterdam	Caisson		7	208	10
CA3	**Amsterdam**	**Caisson**		10	**218**	10

Overview proportional costs by building method



Proportion of costs with construction
of deep basement structures in Utrecht

KIVI "Op naar de diepte" 1994

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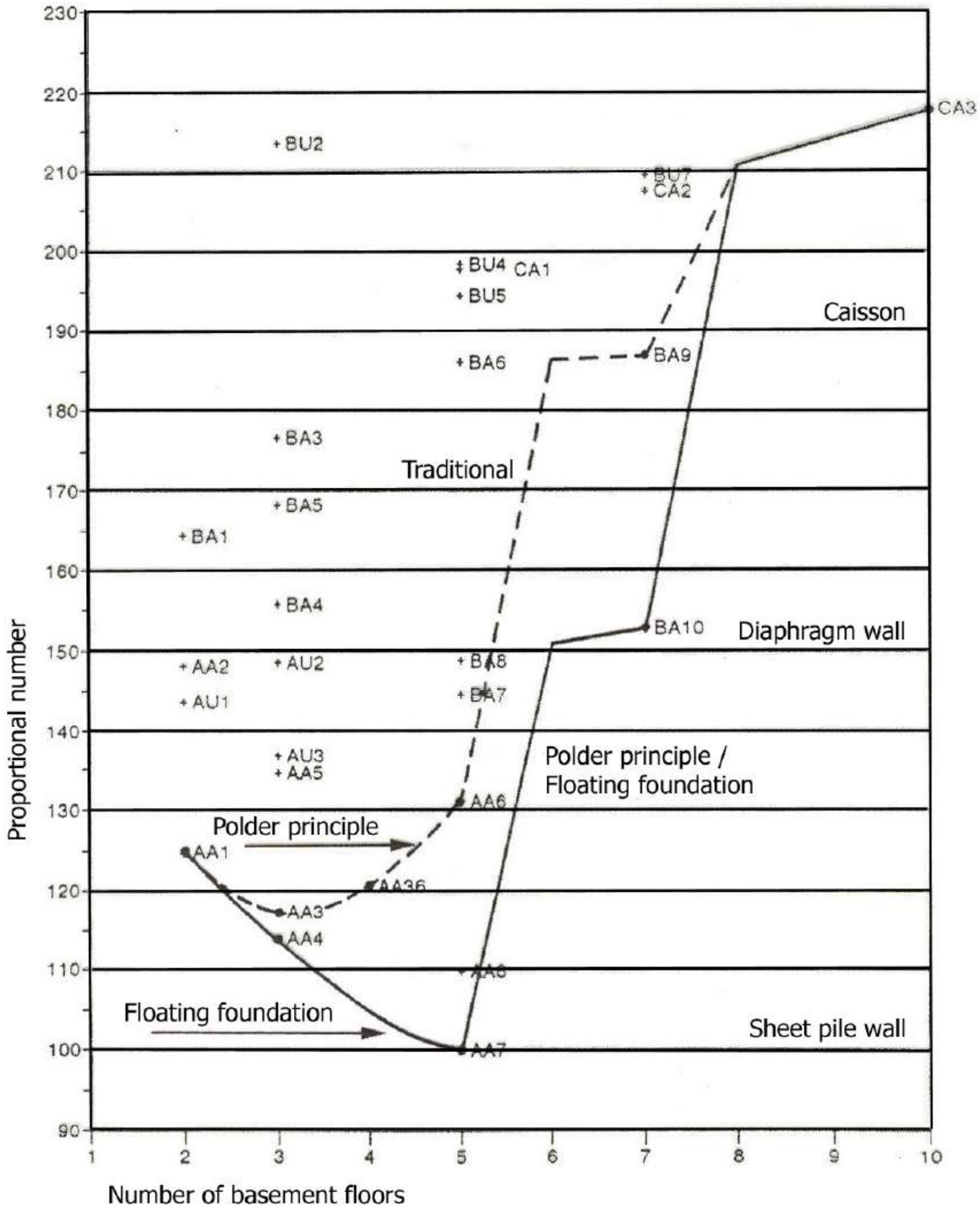
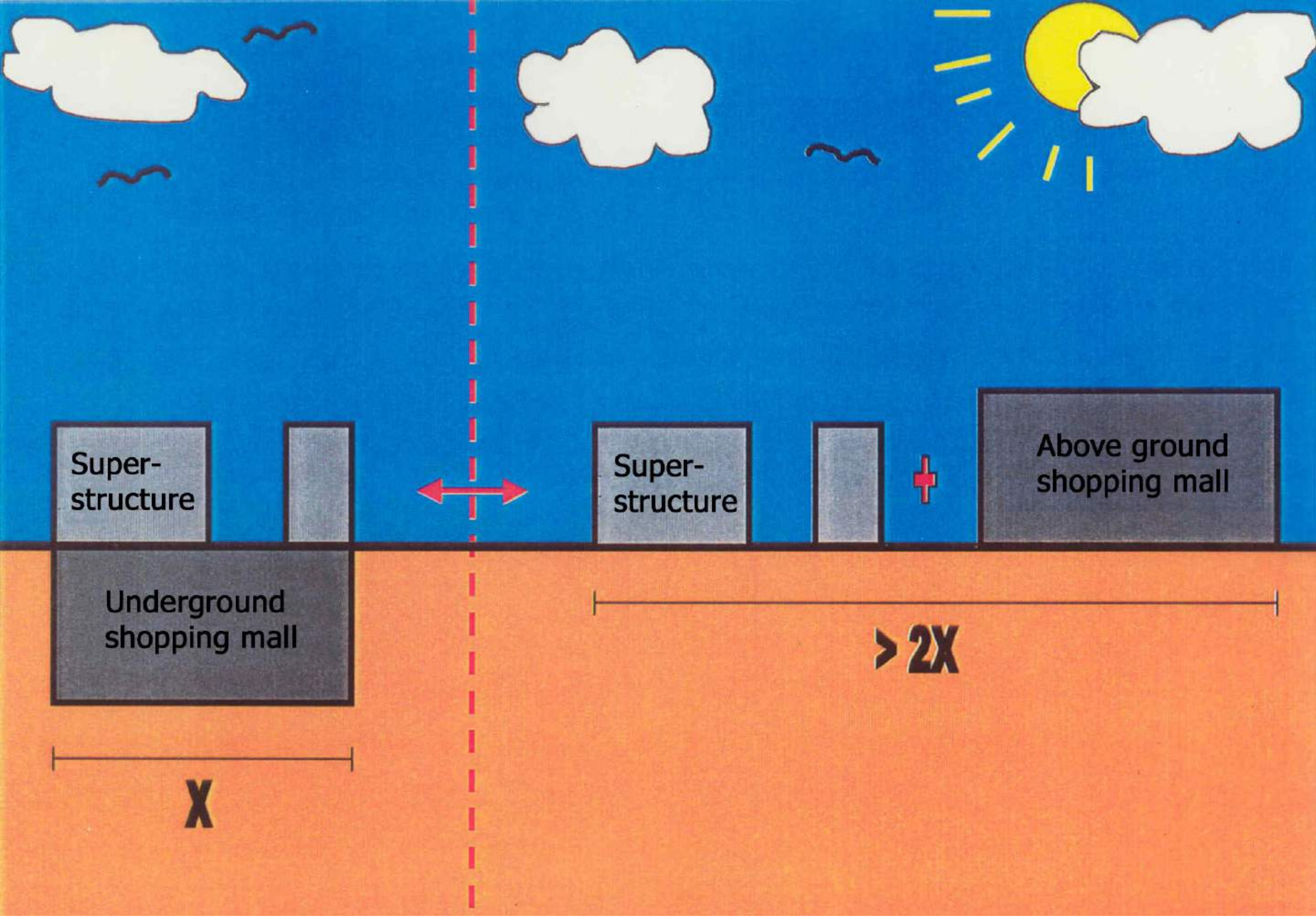


Proportion of costs with construction
of deep basement structures in Amsterdam

KIVI "Op naar de diepte" 1994

TUDelft



More effective use of space by underground building *(Hanusch en van Dongen 1998)*