CT3300 – Use of Underground Space

Lecture 2: The Subsoil

Delft University of Technology/Lectures CT3300

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Delft University of Technology

Overview

- Also see the reader *Underground Space Technology*
- Focus on:
    - Heterogeneous build-up of the underground: origin, structure and quality
    - Variation in groundwater levels, pore pressures, quality of the groundwater; in time, place and special circumstances
    - Deformation of underground structures depending on: applied construction techniques, external influences and actual status
    - Risk: settlements
    - Sustainability, ecology

Geological Periods

Outline of geological periods

Eon	Era	period	Age		Start (in mln years)
Fanerozoic	Cainozonic	Quartenary	Holocene - Alluvium		-0.01
			Pleistocene - Dilivium		-3.5
		Tertian	Above (Neogene)	Pliocene	-7
				Miocene	-26
			Under (Palaeogene)	Oligocene	-37
				Eocene	-53
				Palaeocene	-65
	Mesozonic	Cretaceous	Above		
			Under		-136
		Jurassic	Malm		
			Dogger		
			Lias		-195
		Triassic	Keuper		
			Muschellime		
			(colourful) sandstone		-225
	Paleozonic	Permian	Zechstein		
			Rotliegendes		-280
		Carbinoferious	Above		
			Under		-345
		Devonian			-395
		Silurian			-435
		Ordovician			-500
		Cambrian (since the Cambrian a lot of fossils)			-570
Azoic cryptozoic = Precambrian	Proterozonic	Further classified on the basis of pleat (plooiings) phases			
	Archeozonic (Archeic)	(Oldest remains of algae and bacteria 3000 mln years)			
		oldest dated rock			-3500
	No information known: On the existence of lead isotopes in the earth's rock and meteorites the age of the earth crest can be determined on				-4500

In The Netherlands (as in most delta's) Holocene era most important

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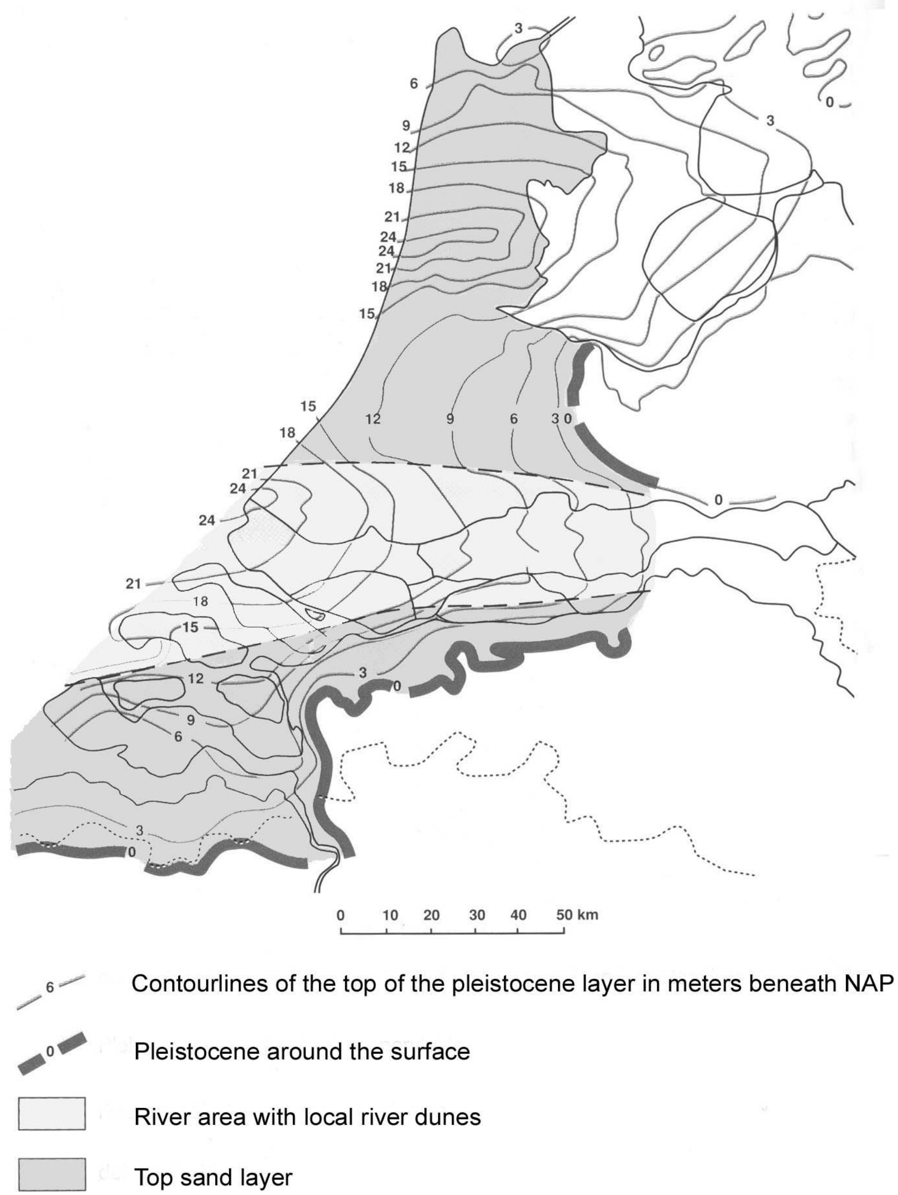
Depth of Pleistocene



Thickness of the Holocene - or - depth of the Pleistocene layers in the Netherlands in m. beneath NAP

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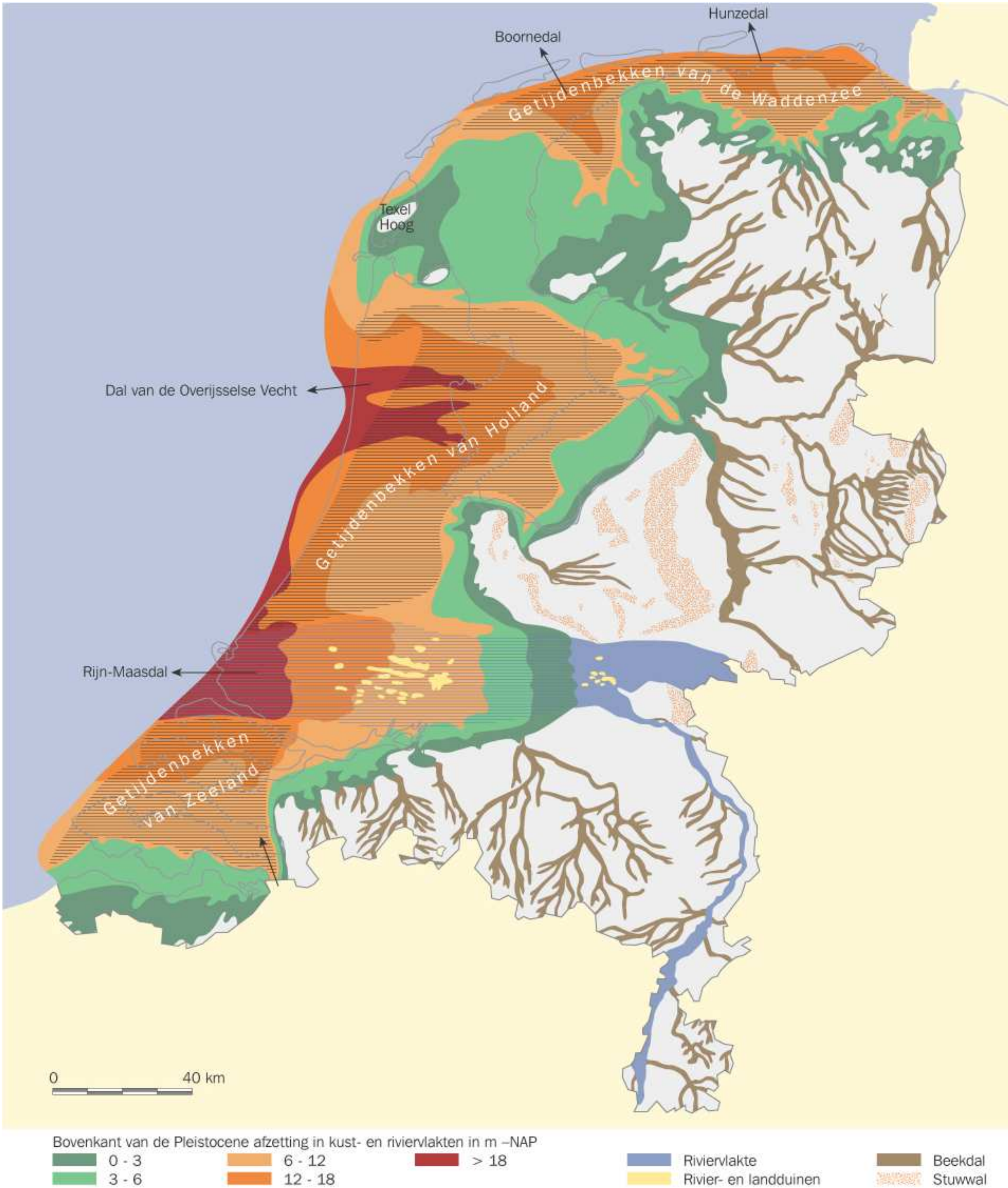

Top of the Pleistocene Layer

(De Ondergrond van Nederland TNO/NITG)

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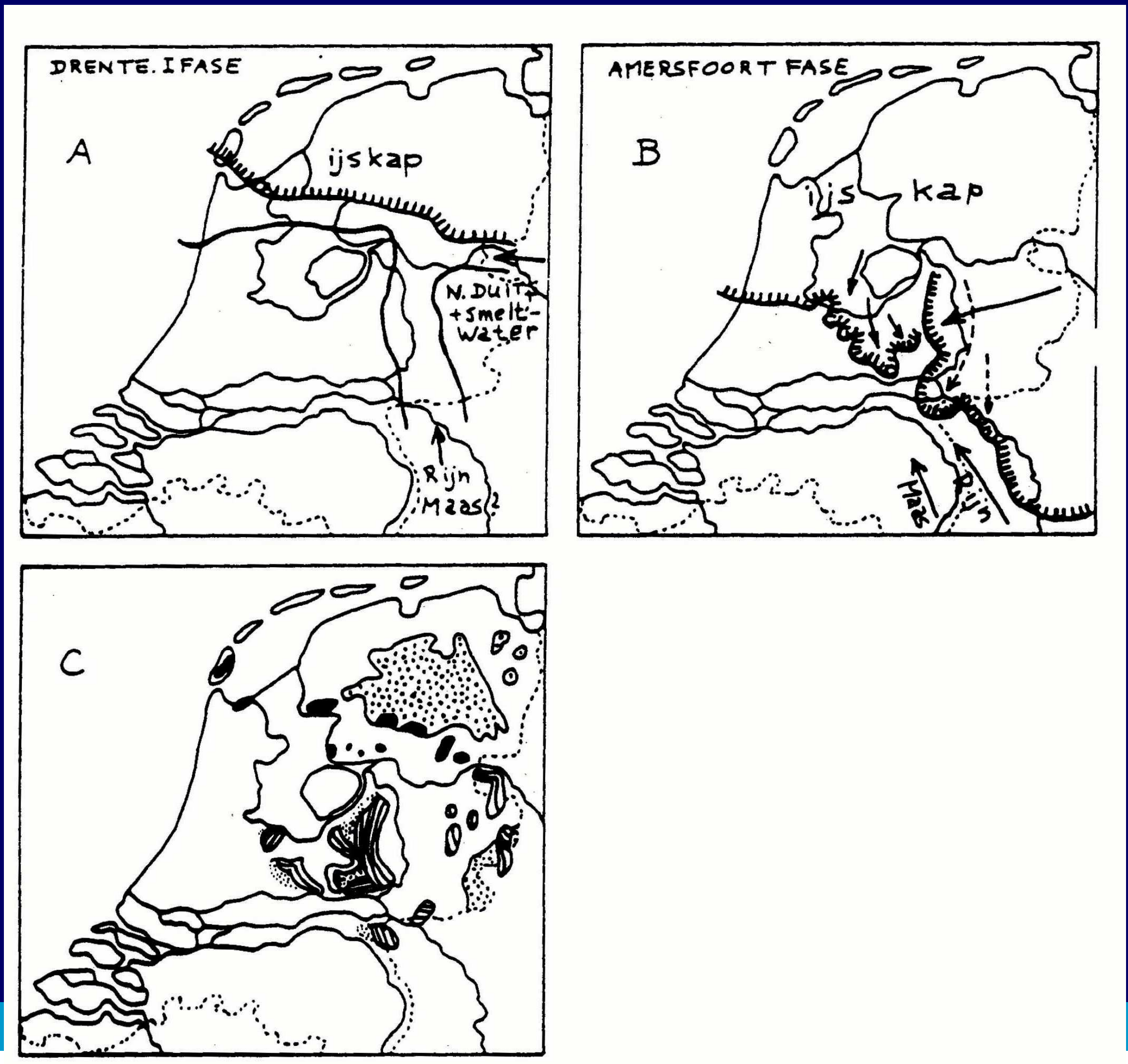
Formation Era

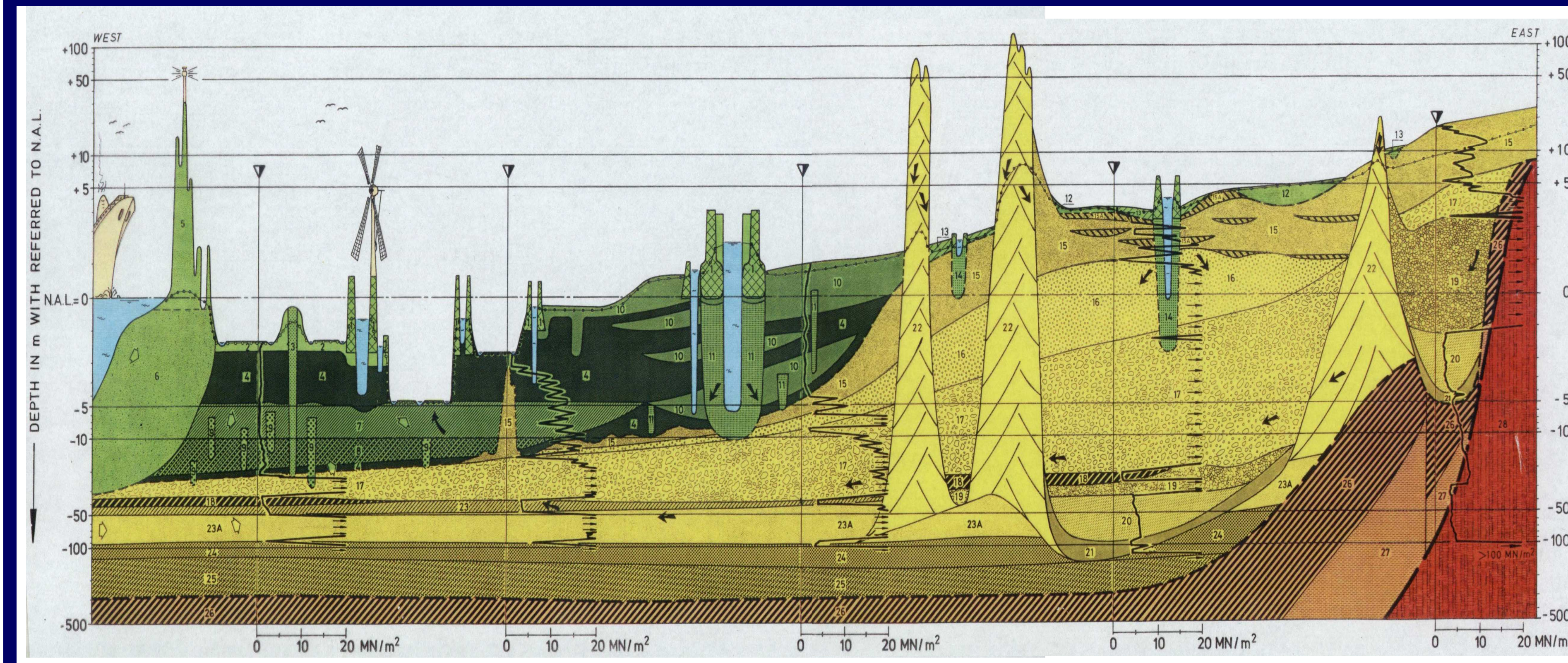


Obtrusive land ice (Saalien)
A. Drenthe
B. Amersfoort phases
C. Glacial deposits

Geology of the Netherlands

West

East



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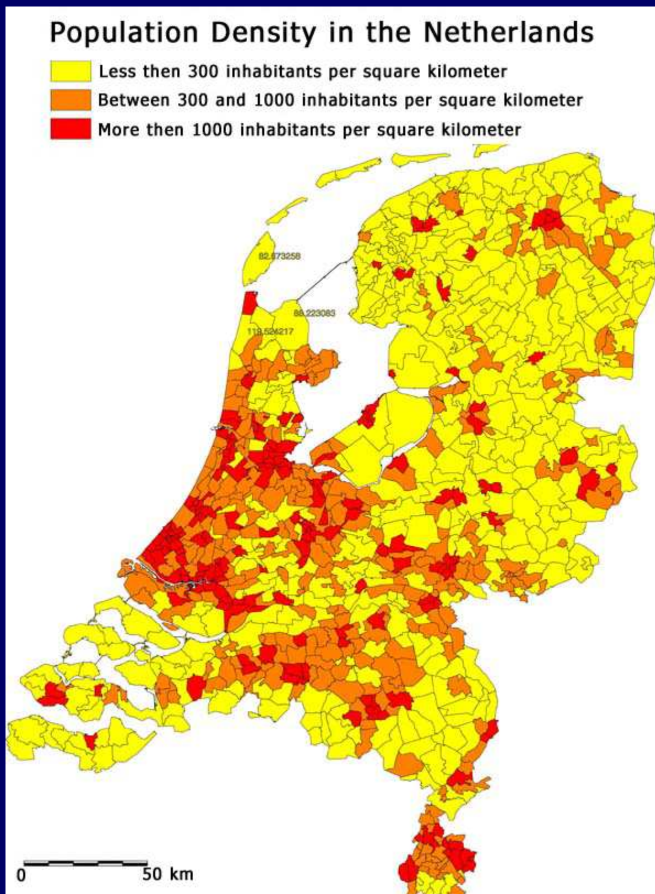
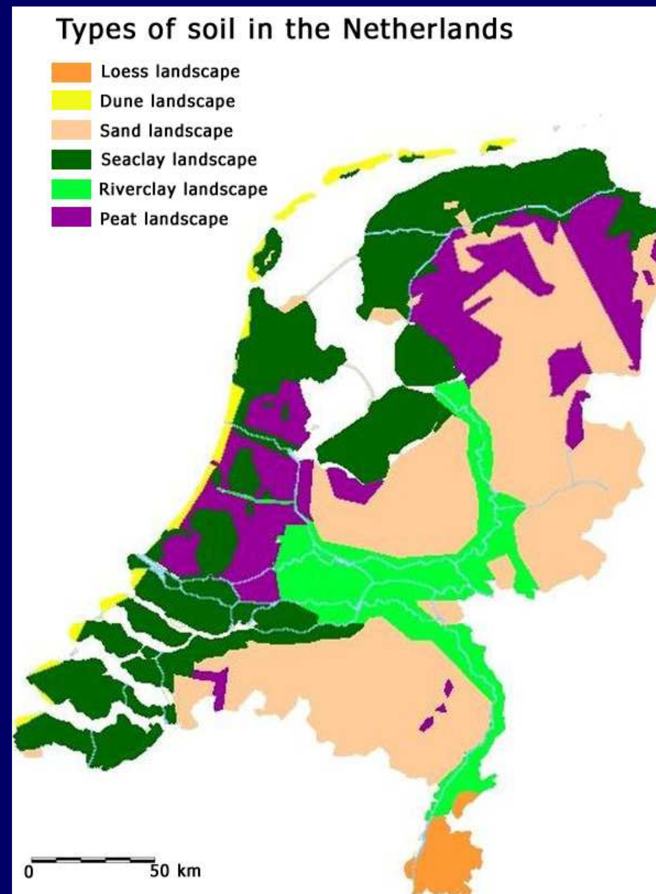
Geology of the Netherlands





Functions of the Underground

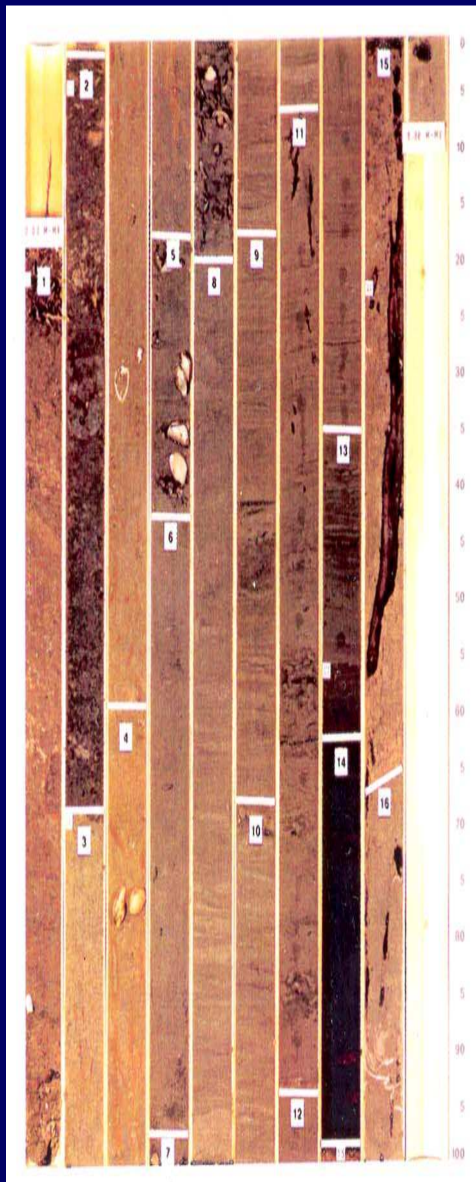
- Natural functions
  - Flora
  - Fauna
  - Groundwater (storage, cleaning)

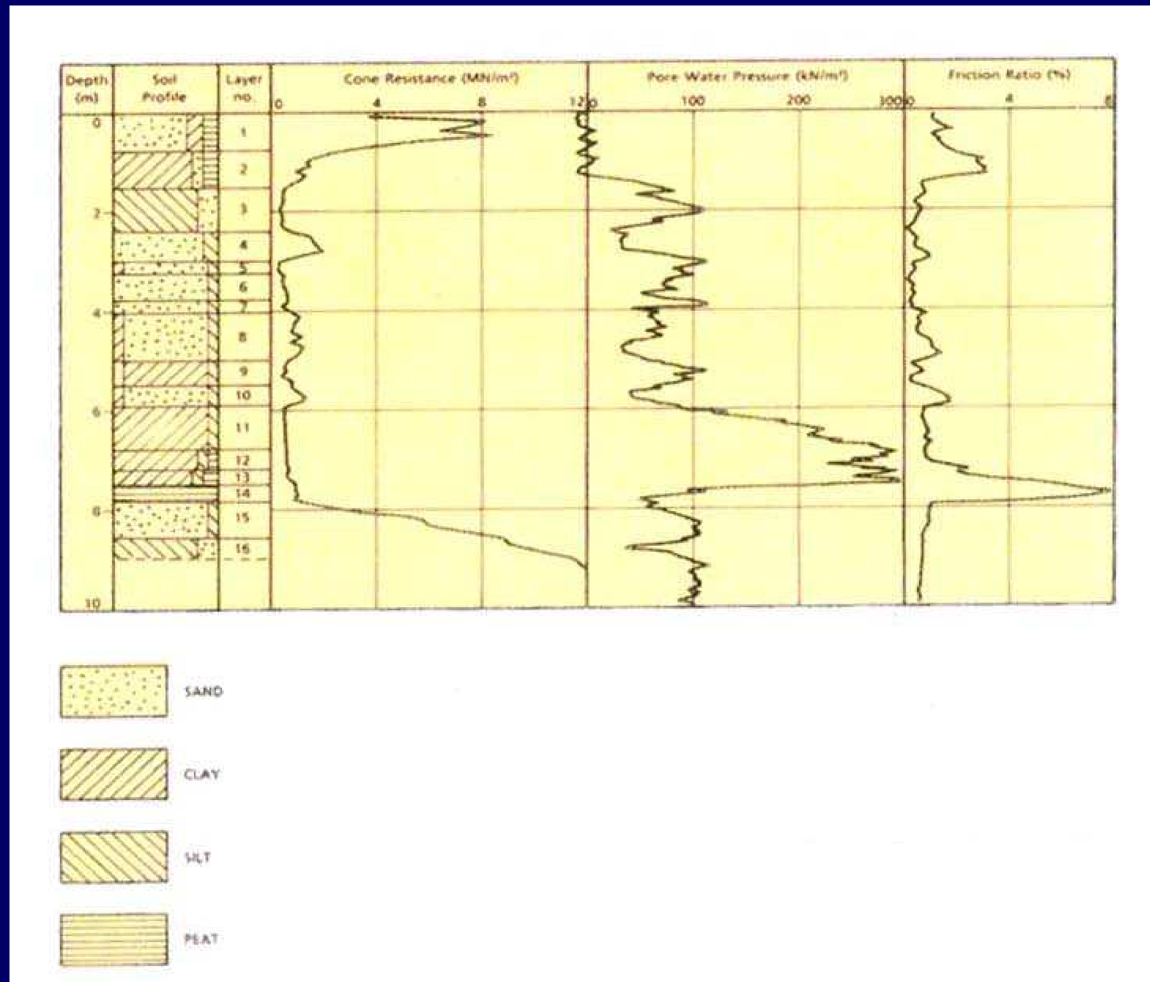
- Artificial functions
  - Infrastructure
  - Buildings/constructions
  - Groundwater mining
  - Supply of raw materials
  - Storage of contaminants
  - Heat – cold storage and supply

Underground Space is not unlimited

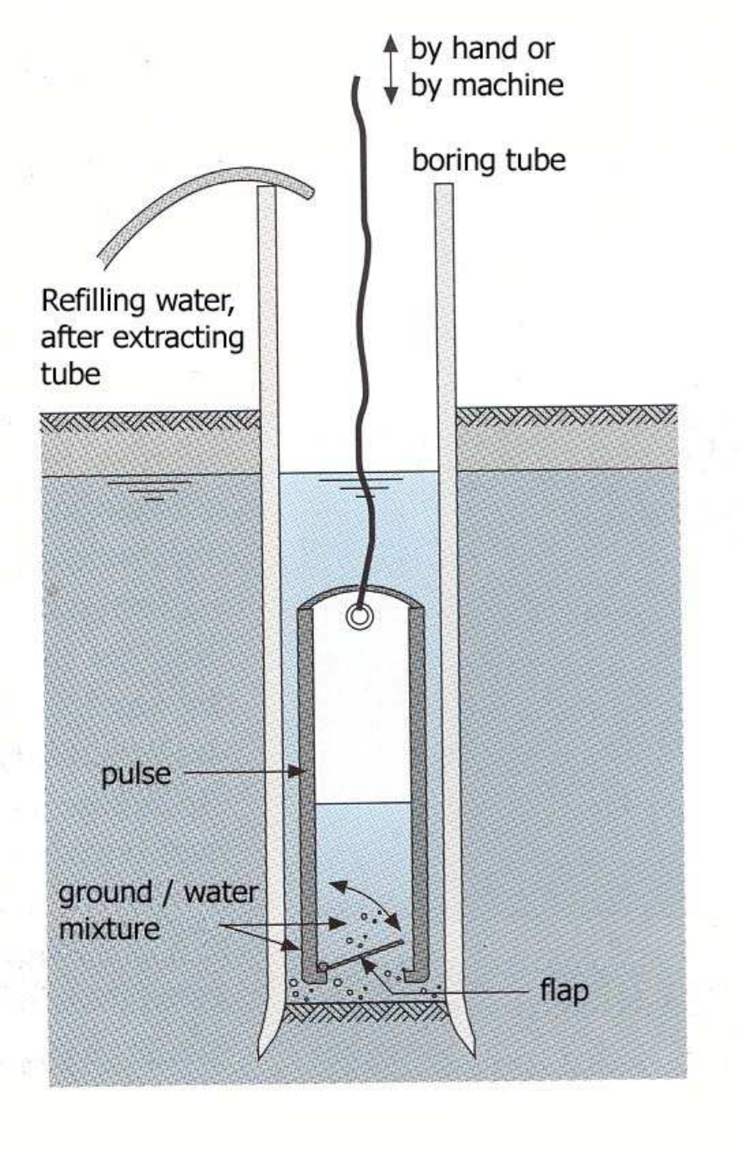
Soil Profile from a Boring

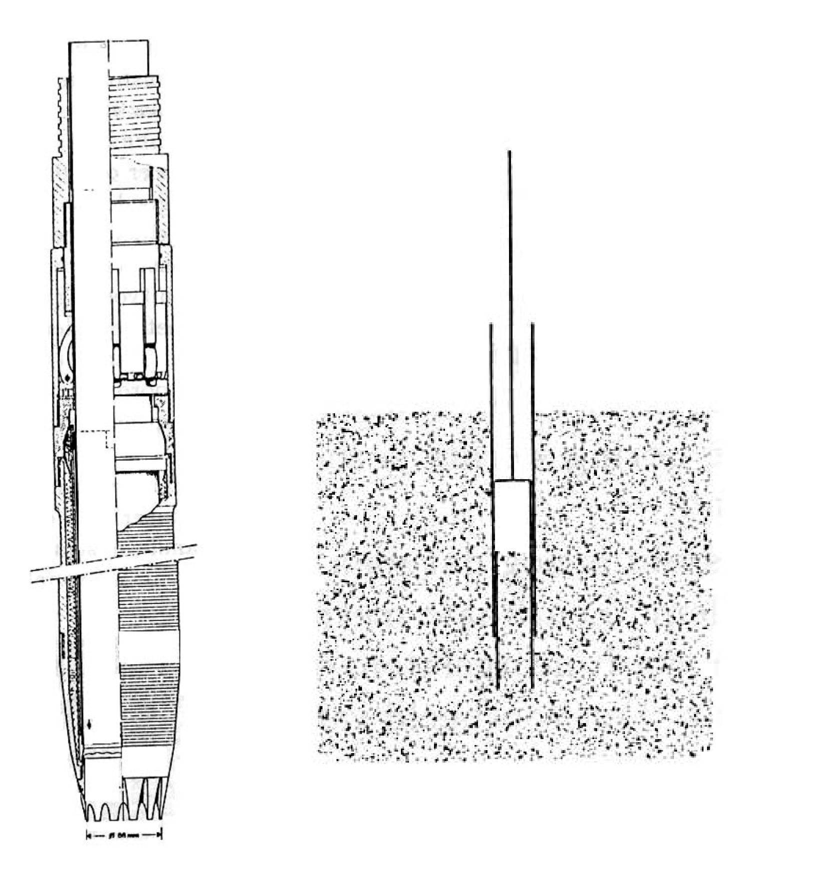
Undisturbed samples





Photograph of sampled soil profile, together with the results of an adjacent Piezo Cone Penetration Test (CPTU)

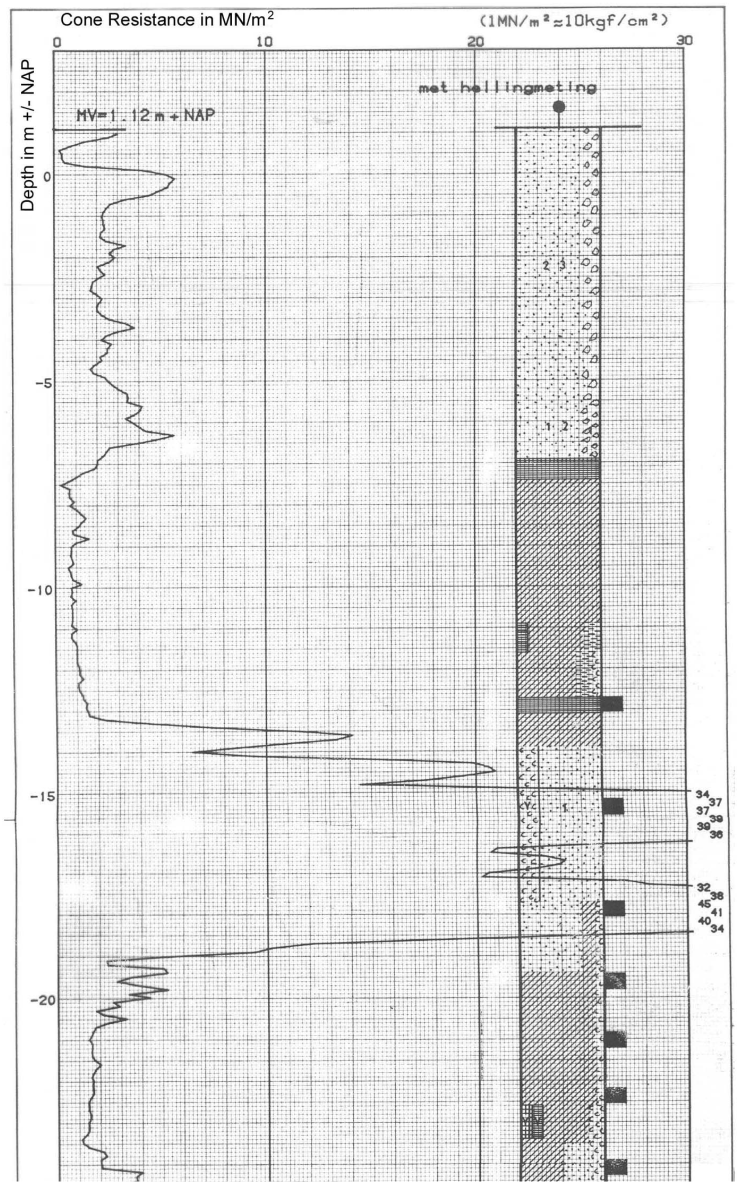


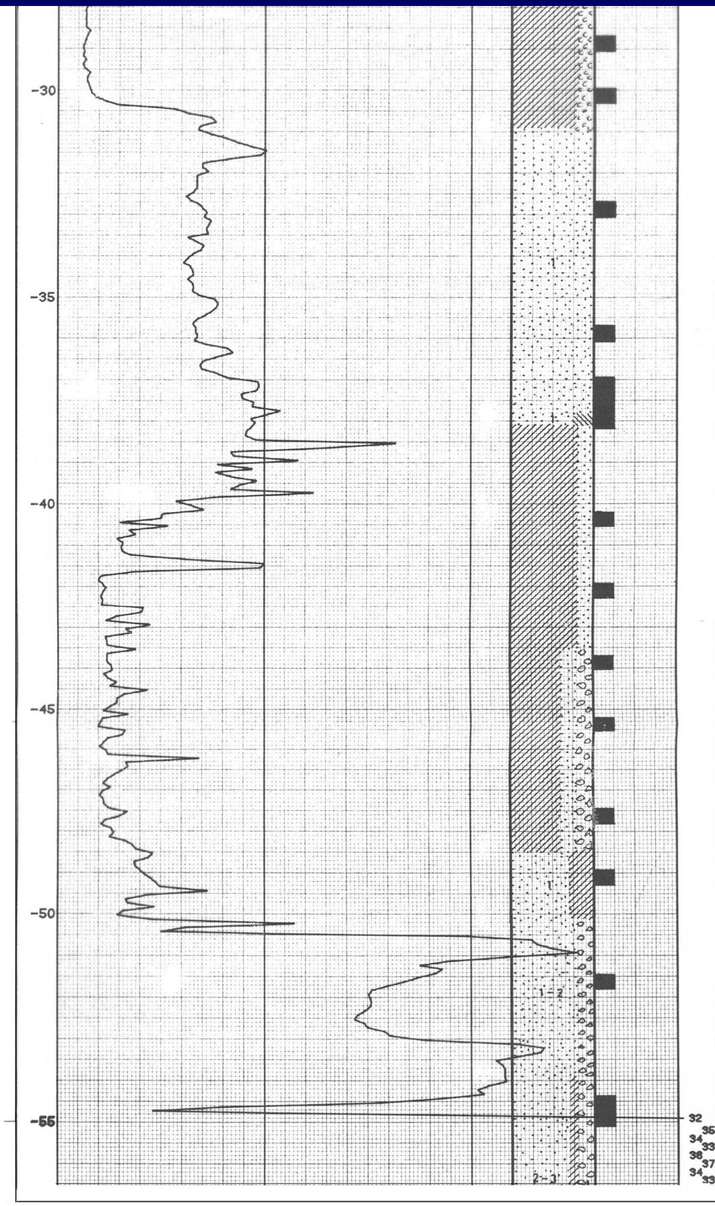


Left side Ackerman "Pulse" boring *(disturbed sample)*

Right side Begeman "Pitch" boring

(Dutch) Cone Penetrometer Test (CPT)

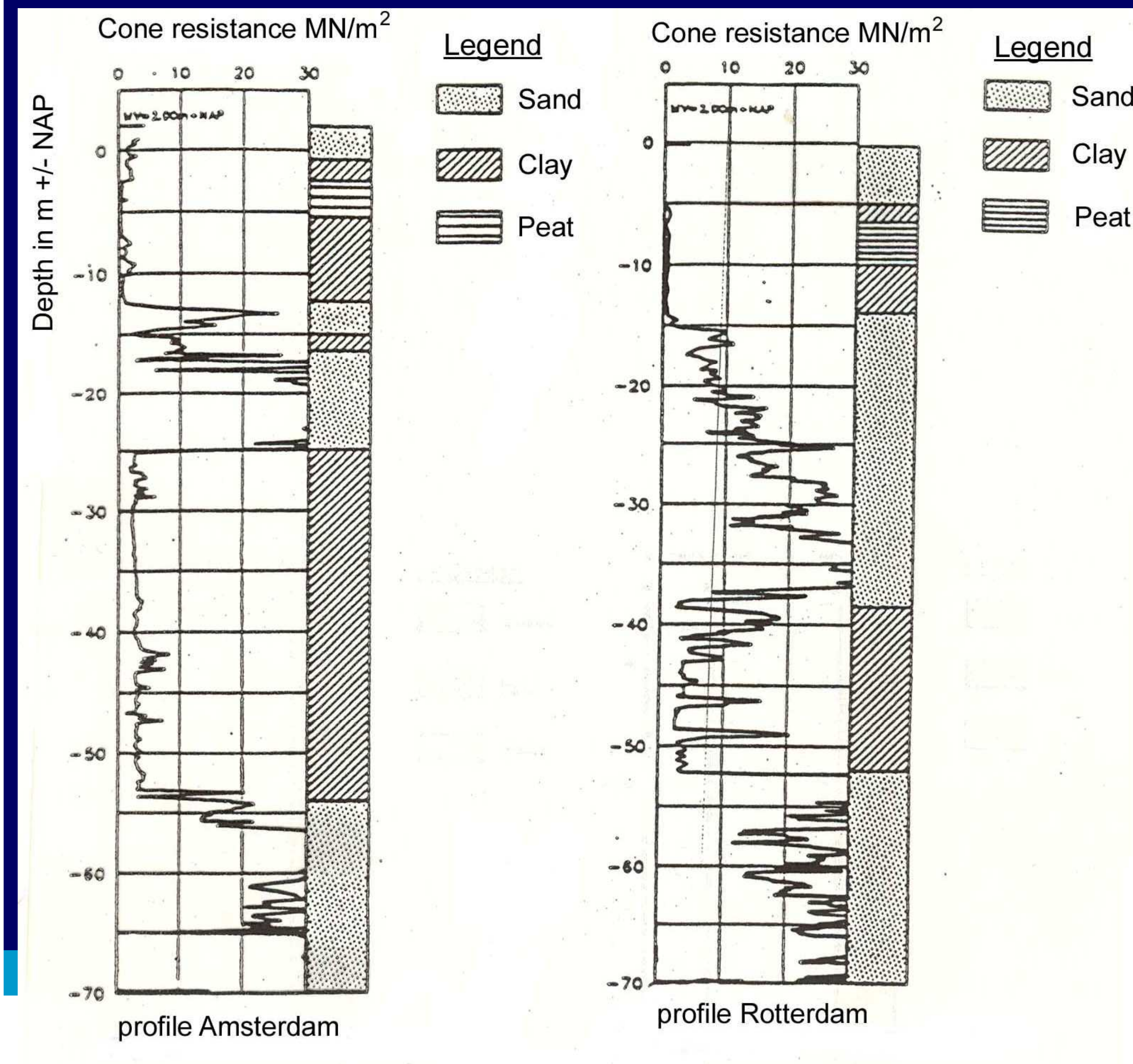




CPT and Borehole

River profile

Profile Amsterdam and Rotterdam



- Toplayers above 12m-NAP are holocene (sand, peat, clay) and (semi-) impermeable

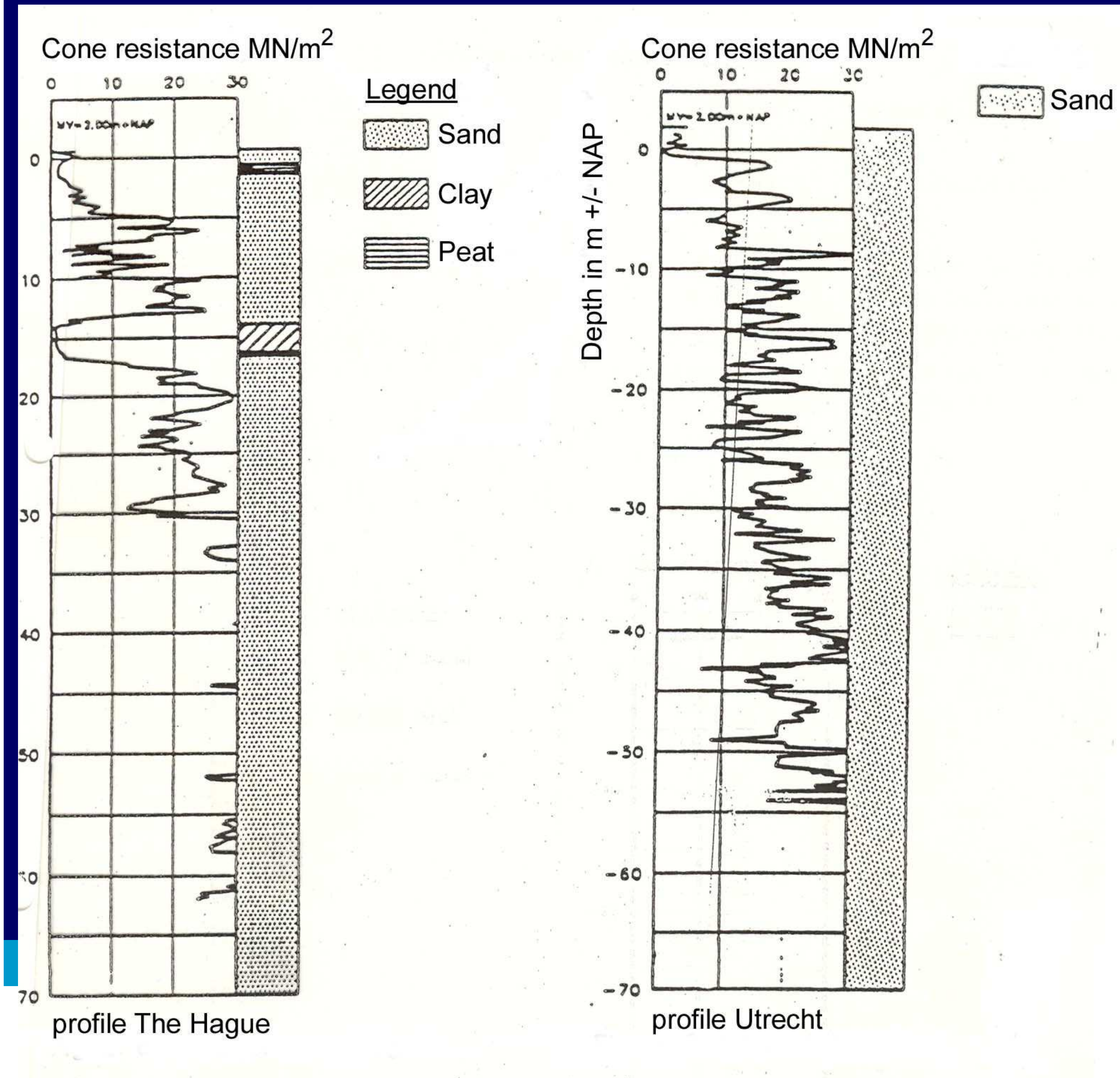
Profile Amsterdam

- The presence of bad bearing and non permeable layers above 12-NAP m are significant for this profile. These layers originate from the Holocene.
- Eem clay not everywhere

Profile Rotterdam

- Clay above 12m-NAP not very good
- Leaks

Profile The Hague and Utrecht



Hardly (the Hague) or
no (Utrecht) sealing layers

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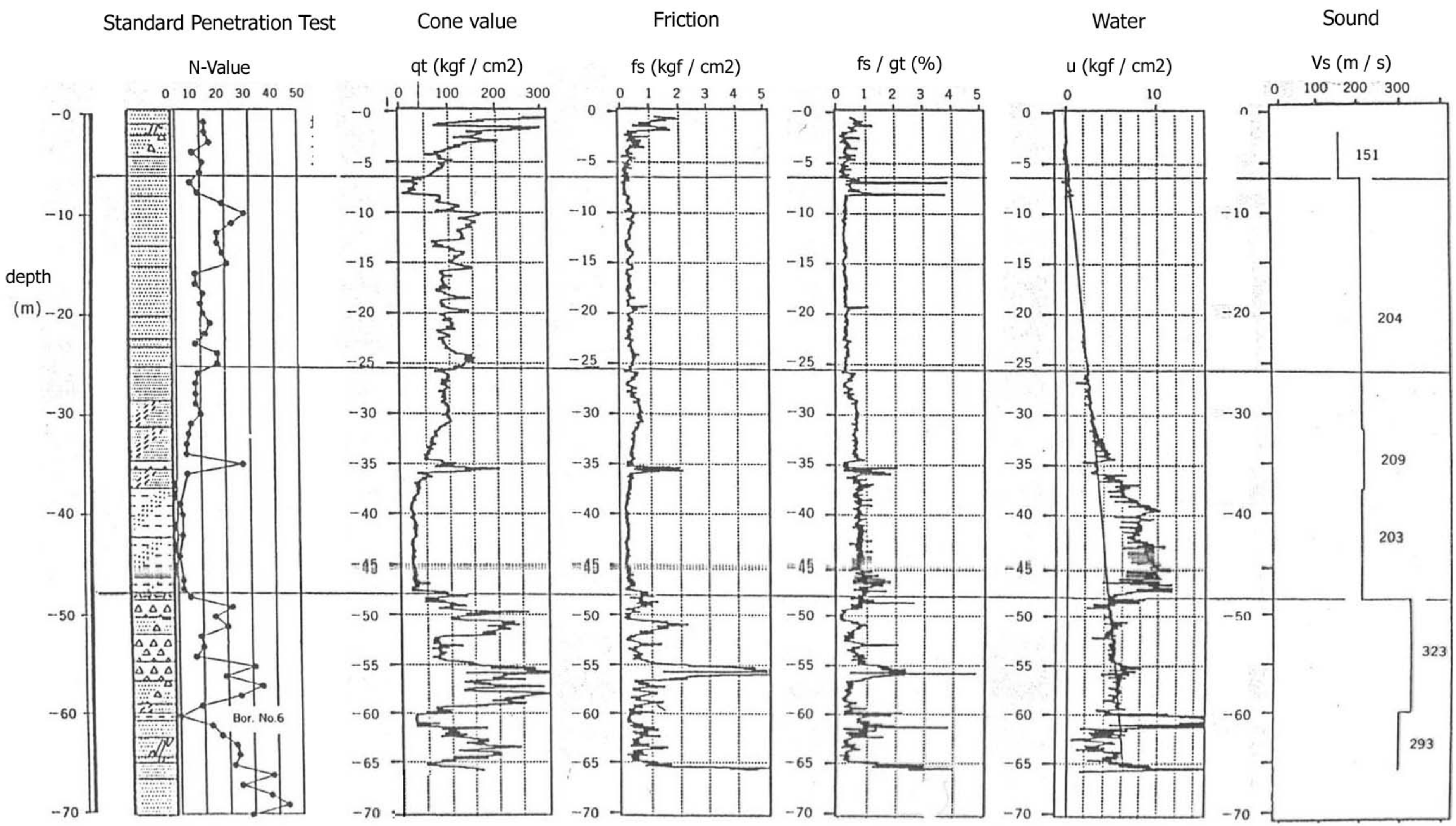
Standard Penetration Test
N-Value
Cone value
qt (kgf / cm2)
Friction
fs (kgf / cm2)
fs / gt (%)
Water
u (kgf / cm2)
Sound
Vs (m / s)
depth
(m)
Bor. No.6
151
204
209
203
323
293

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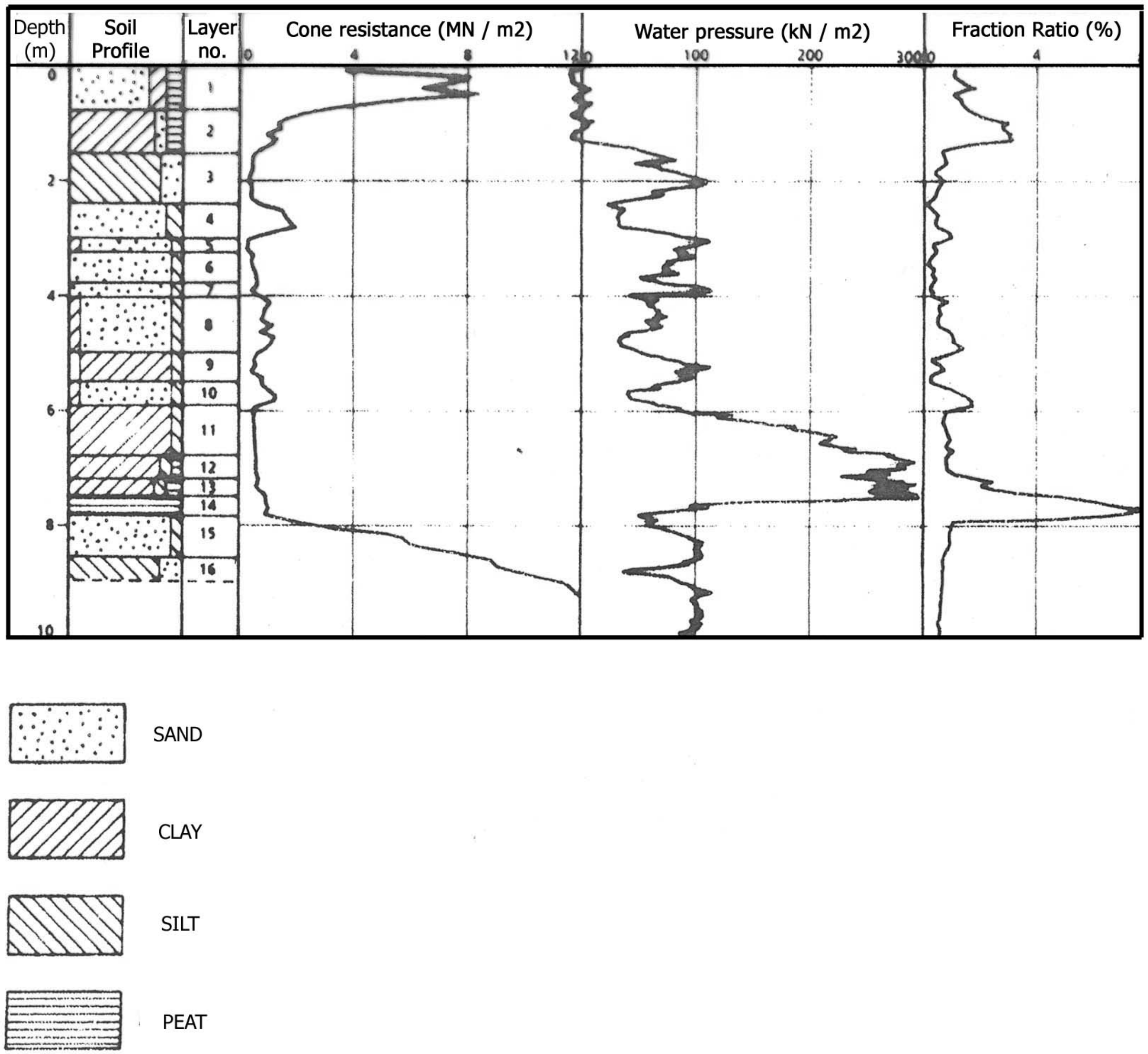
Soil Profile



- Soil profile together with the results of the Piezo Cone Penetration Test (CPTU)
- Note: Excess pore pressure in the clay layers

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Water Table

Water table close to soil surface

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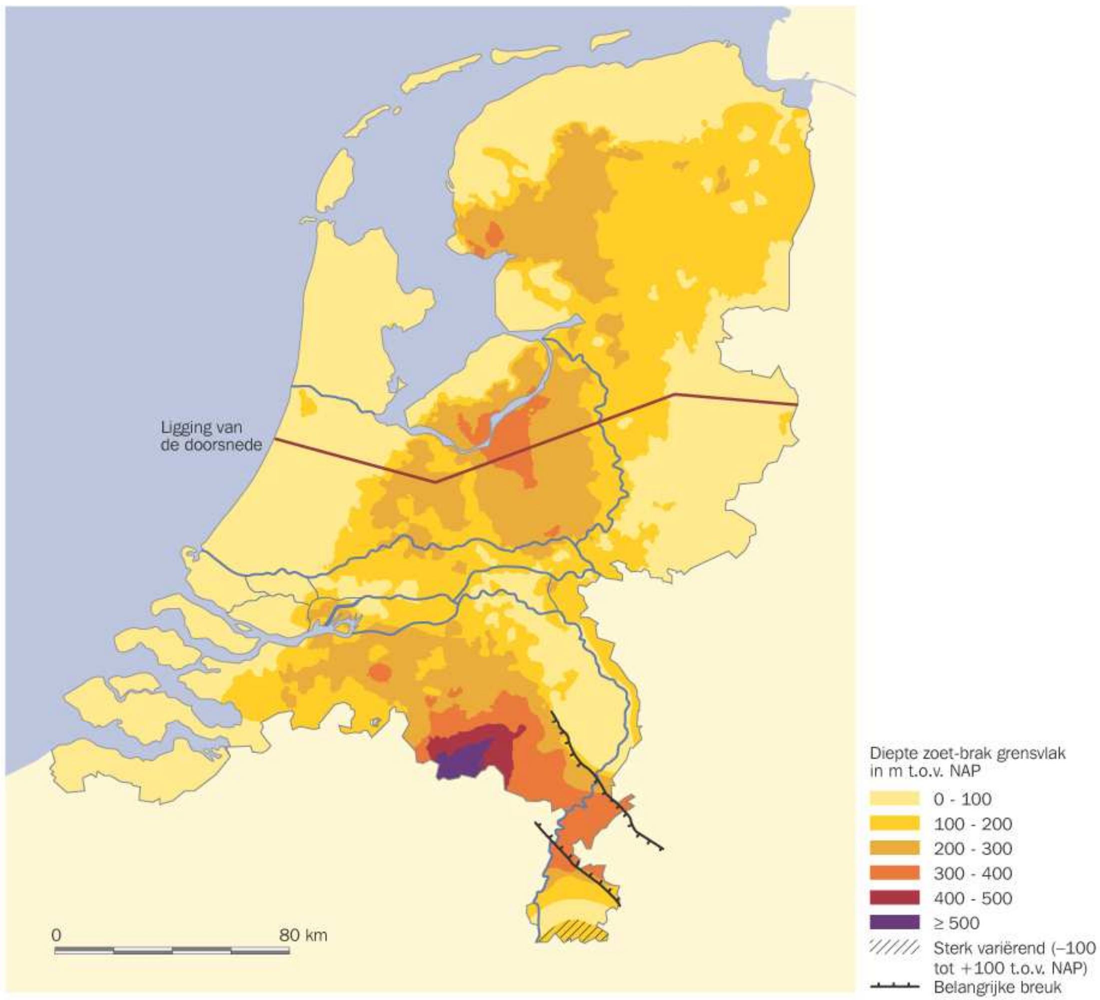
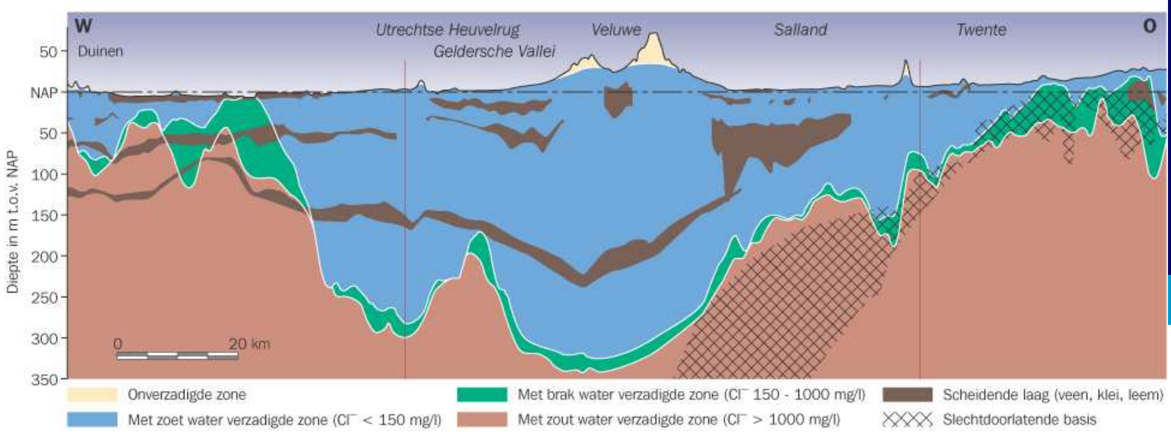
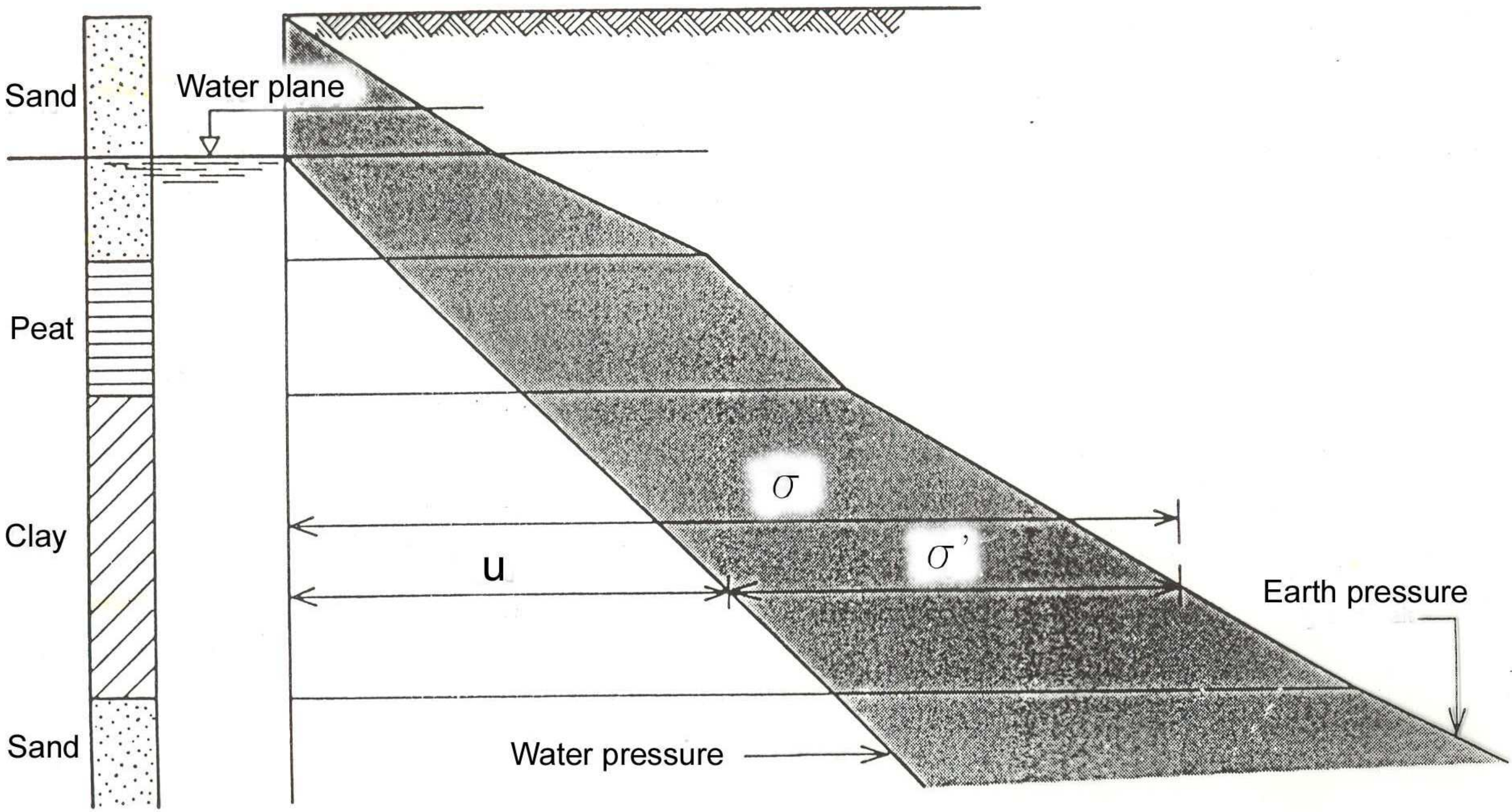




Fresh and salt water under The Netherlands

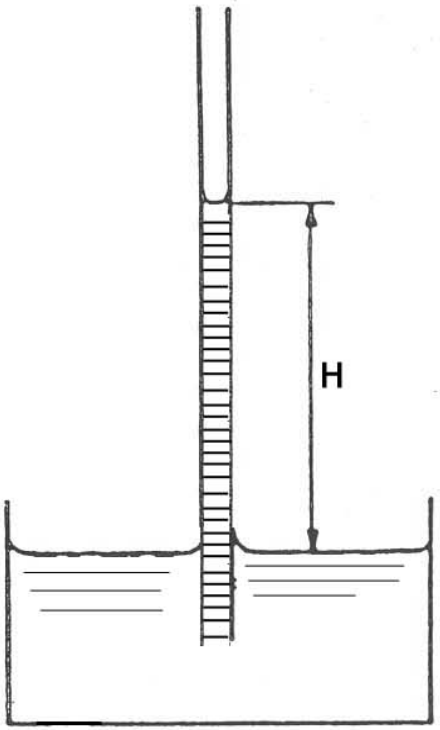
- Effect of dunes and Veluwe
- Deeper layers consist of salty water or rocks
- Salty groundwater in Achterhoek

(De Ondergrond van Nederland TNO/NITG)

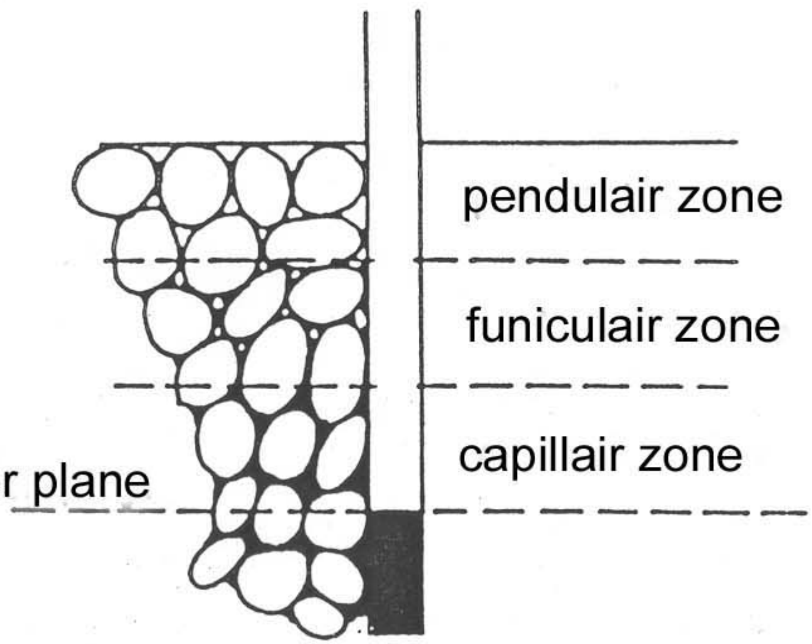


Development of earth pressure, grain pressure and water pressure

Groundwater



capillairy rise of water



capillair, funiculair and pendulair zone in the soil

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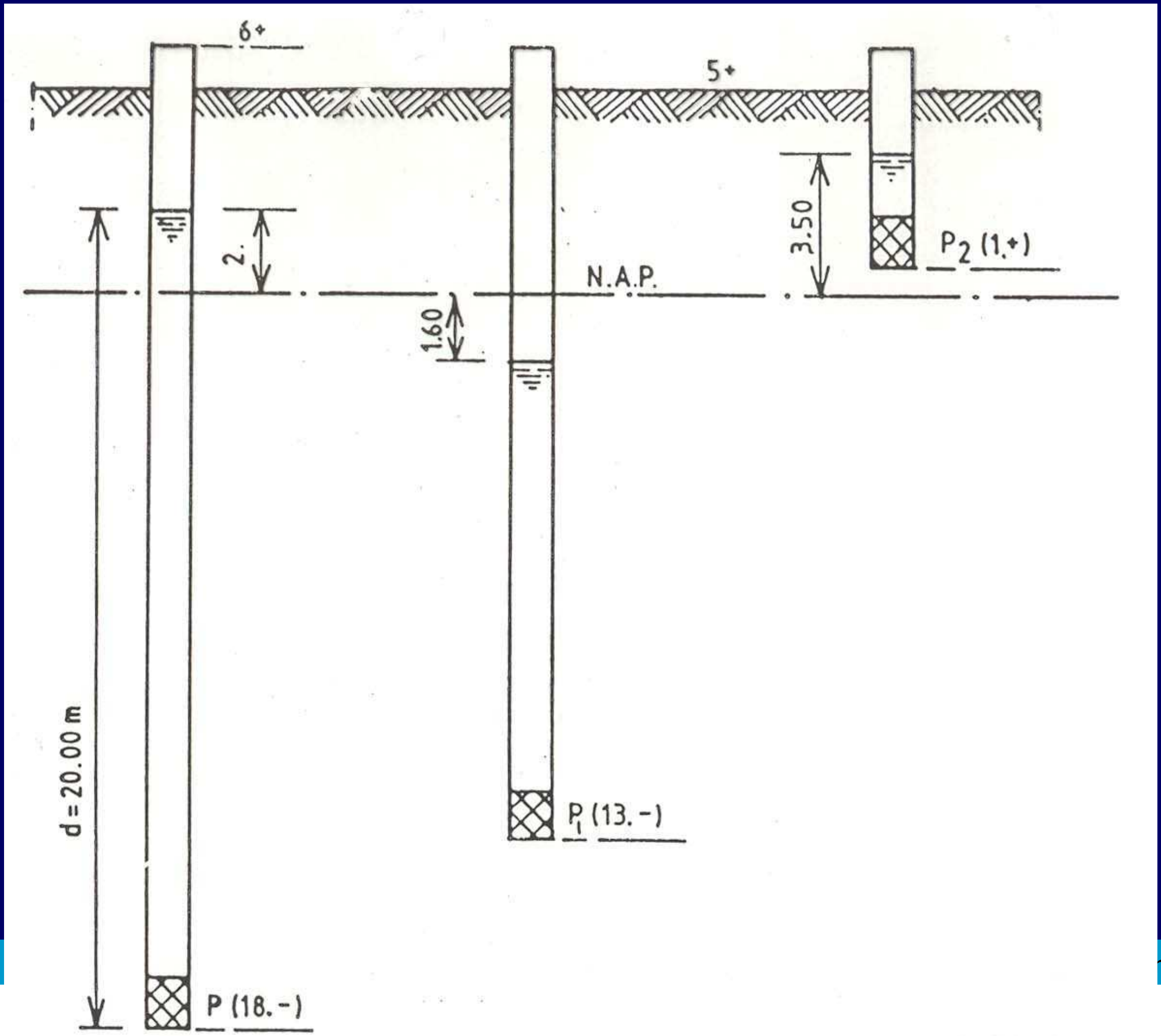
Phreatic Level of Groundwater



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Permeability

$Q = k\, i\, A\, t$ [m³]

k = permeability coefficient [m/s]

Dune sand: $k \approx 10^{-4}$ m/s ←→ Peat: $k \approx 10^{-8}$ m/s

Clay: $k \approx 10^{-10}$ m/s

Type of soil	*k* in m/s
Gravel	10^{-2}
Coarse sand	10^{-2} - 10^{-3}
Moderate coarse – moderate fine sand	10^{-3} - 10^{-4}
Fine sand	10^{-4} - 10^{-5}
Clayey sand	10^{-5} - 10^{-6}
Sandy clay	10^{-6} - 10^{-9}
Clay	10^{-9} - 10^{-11}
Peat	10^{-7} - 10^{-9}

Influence on risk of leakage

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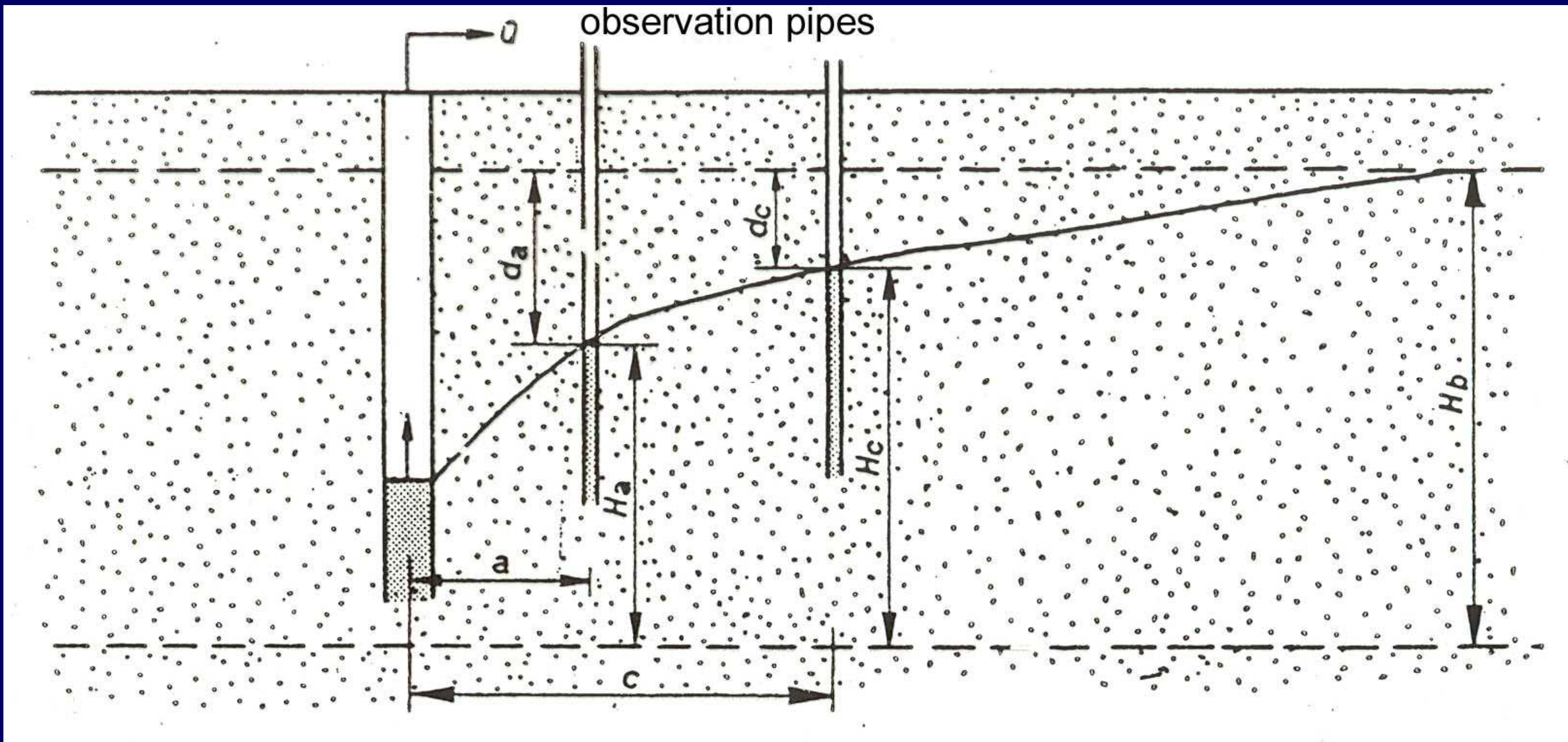
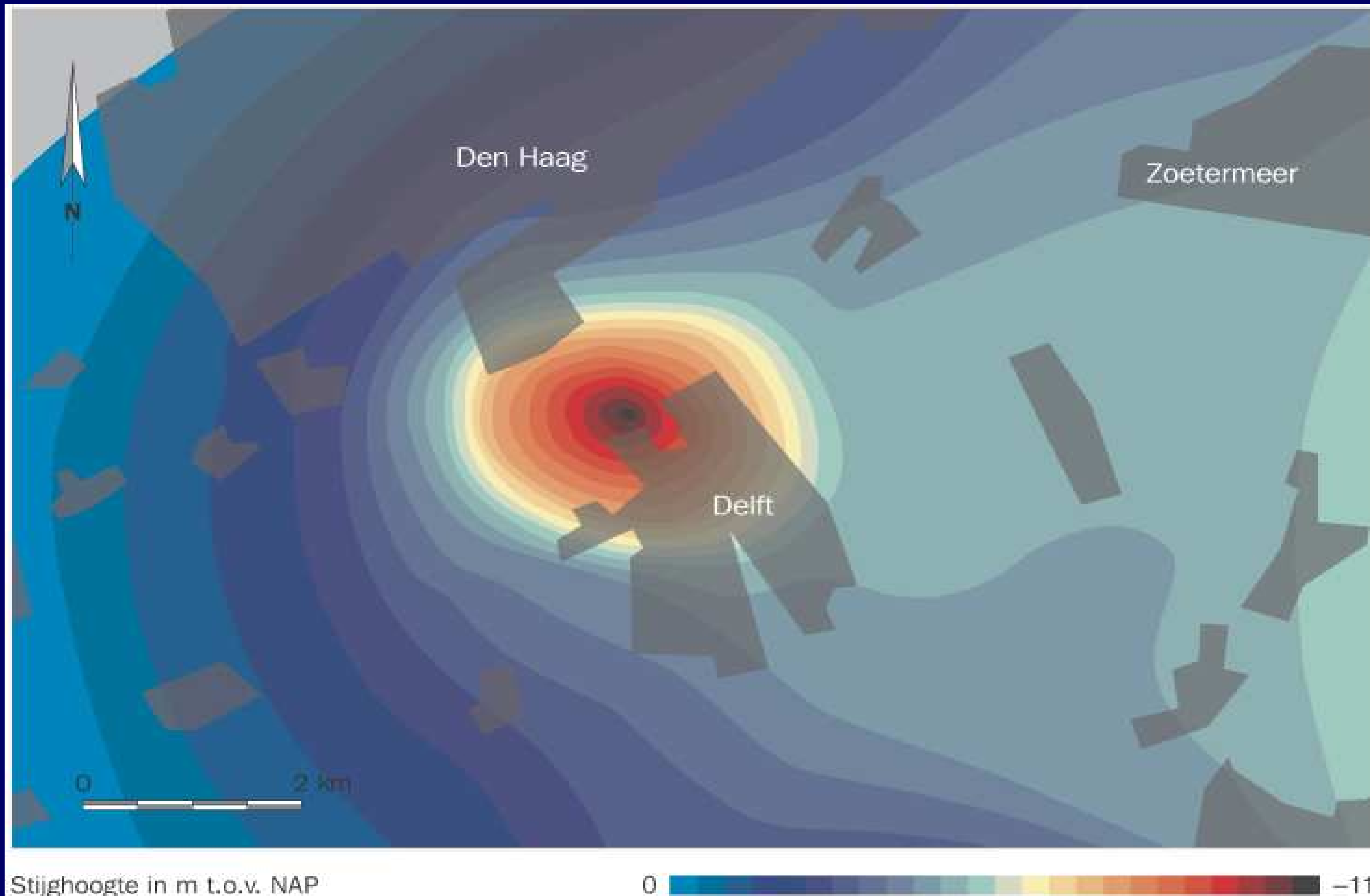
Piezometric Head



Lowering of the ground water level: temporary or permanent

Water Level Drawdown by Gist Brocades



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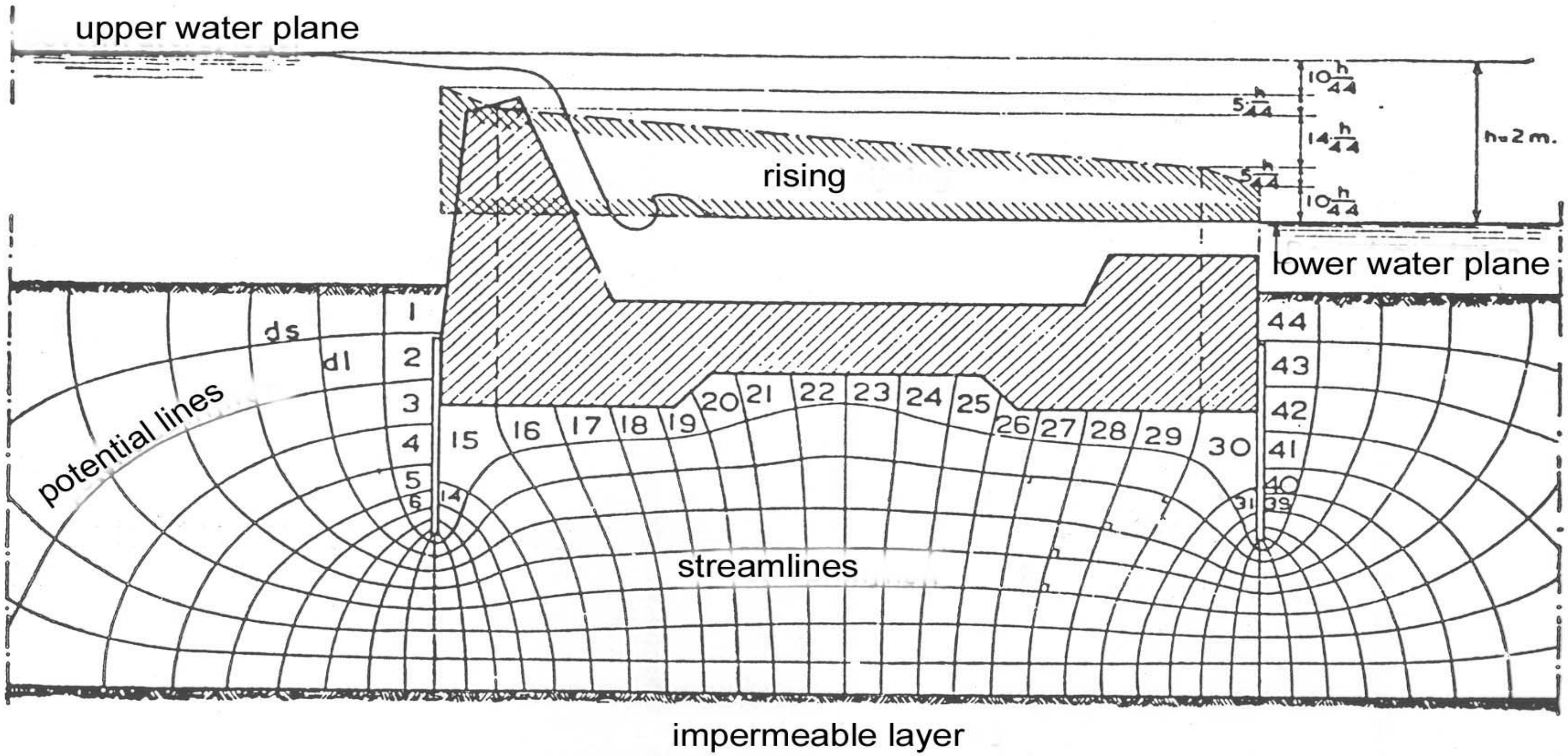
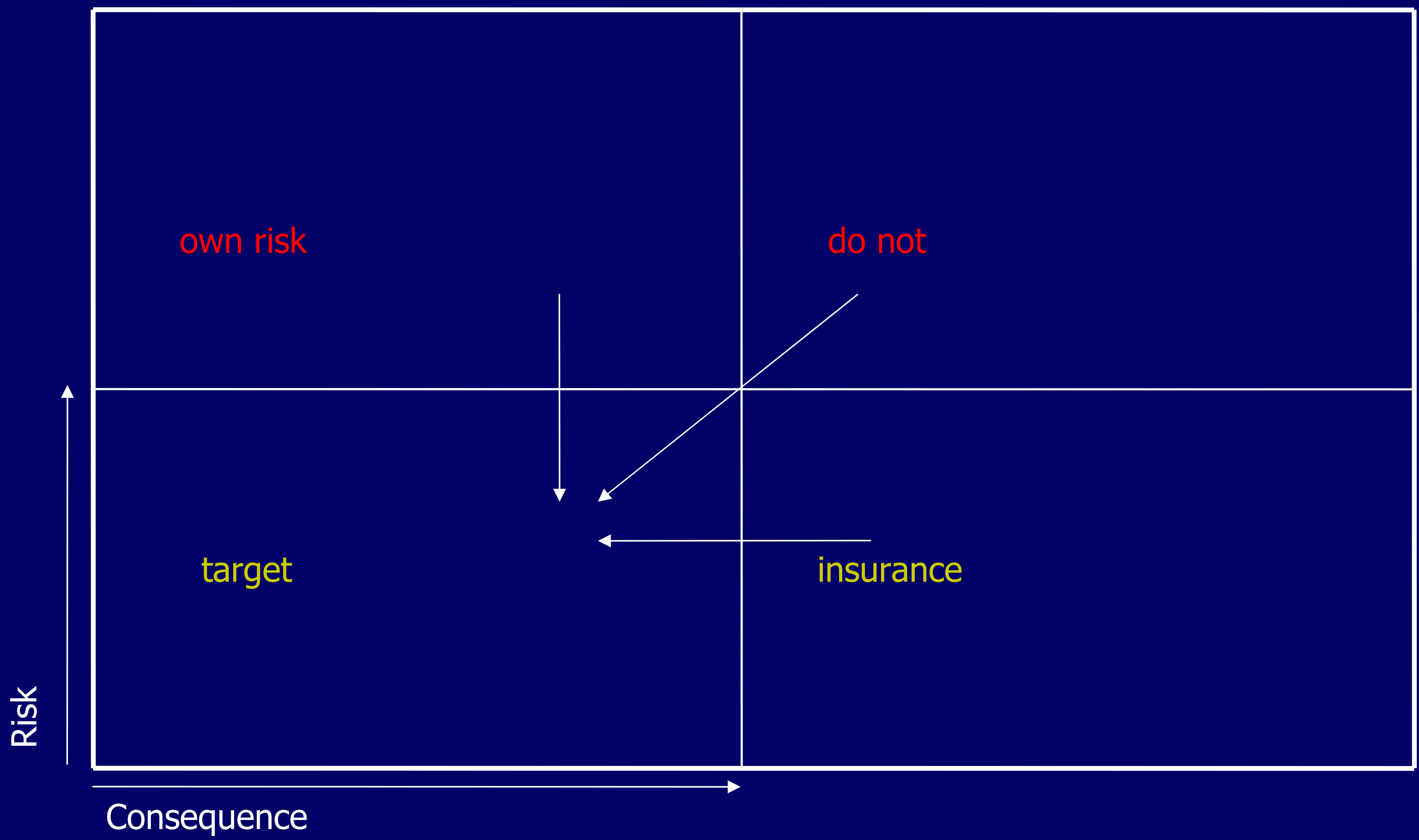


Stream image of groundwater below a dam by a hydraulic flownet

Similar pattern under tunnels

Risk Management



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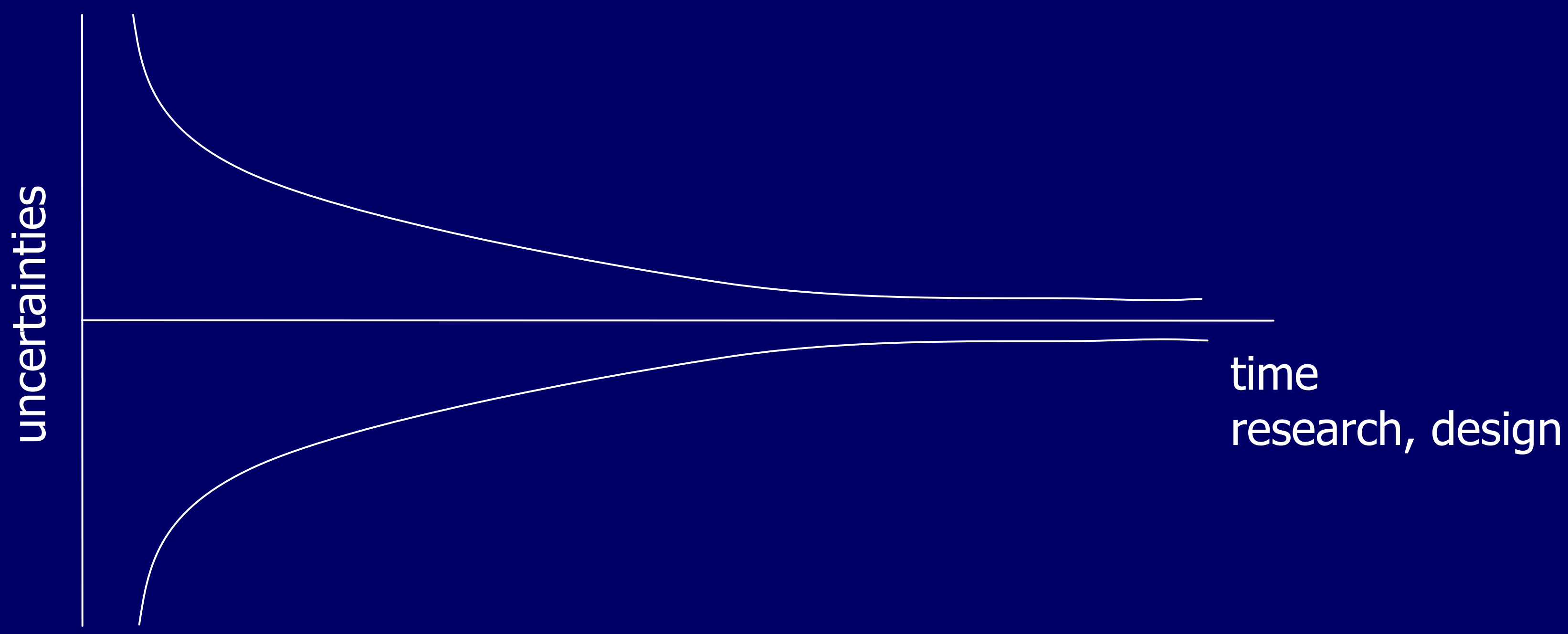
Types of Contract

- Lumpsum
- B of Q
- D and C
- PPC
- etc

Who does what and when

Uncertainties in Time



Risk profile

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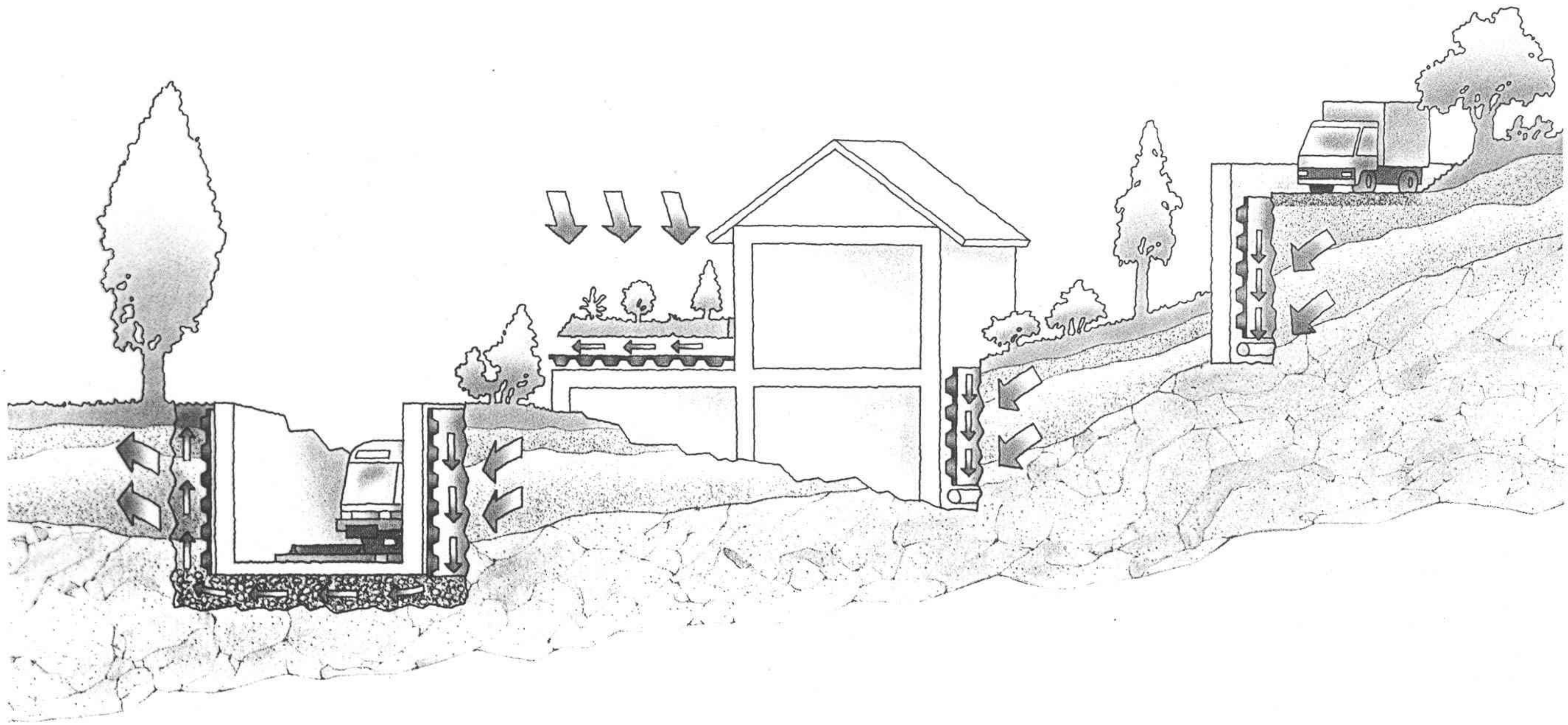

Structures form a barrier: can be cause for earth slides

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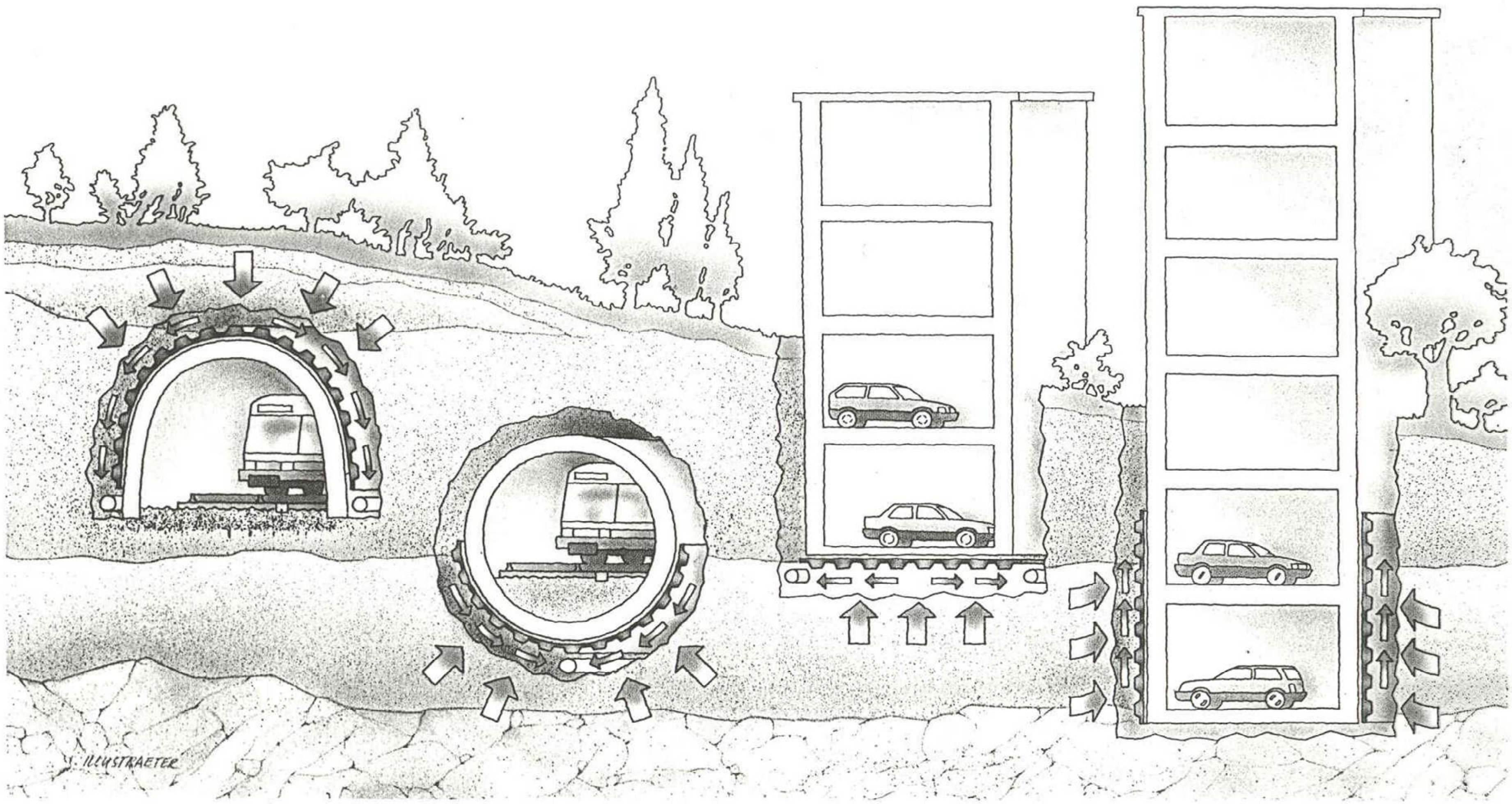

Impeded flow can cause earth slides

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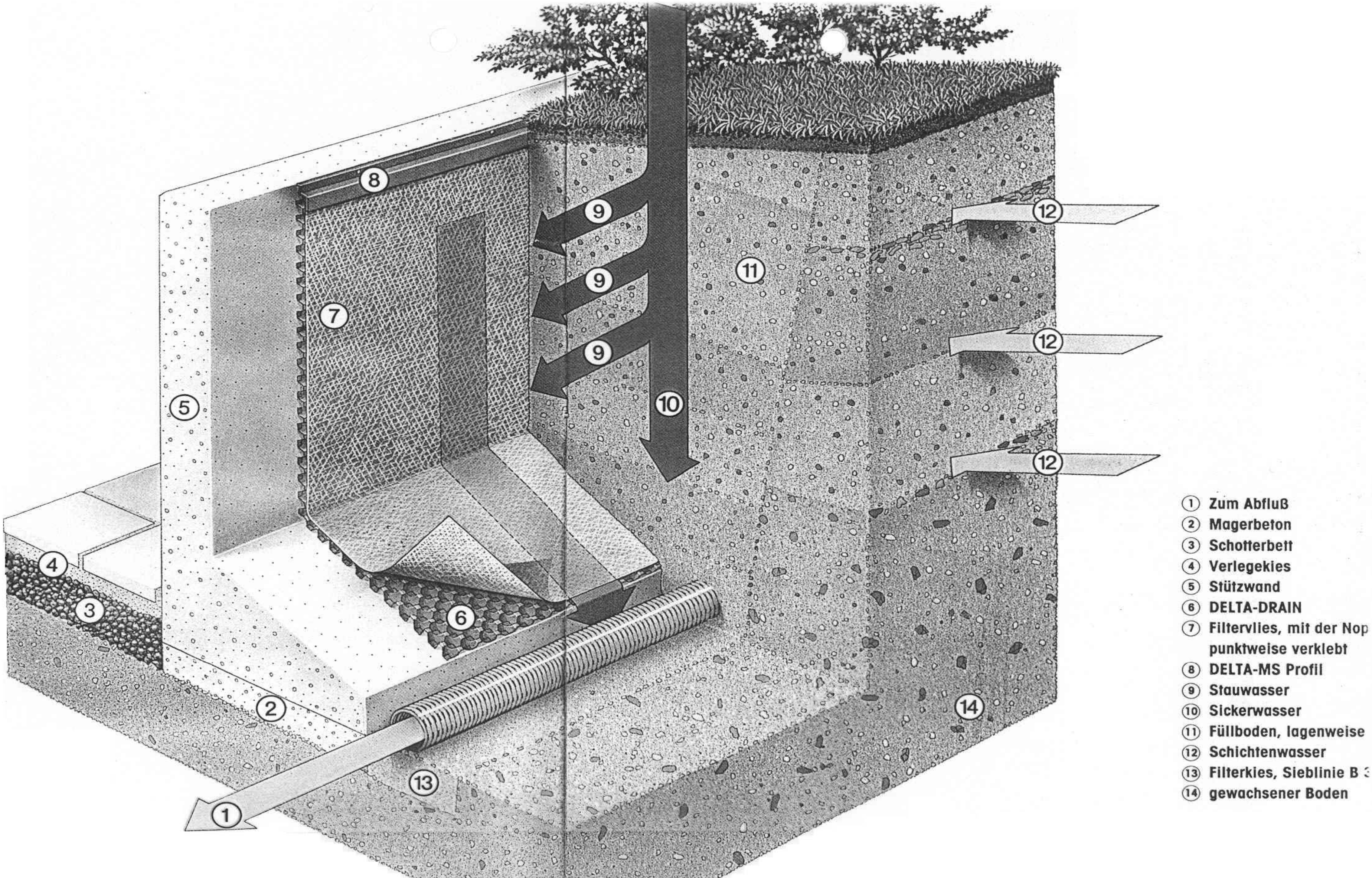

Groundwater discharge by means of drain

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Settlement (Consolidation)

$$\frac{\Delta z}{z} = \frac{1}{C} \ln \frac{p_2'}{p_1'}$$

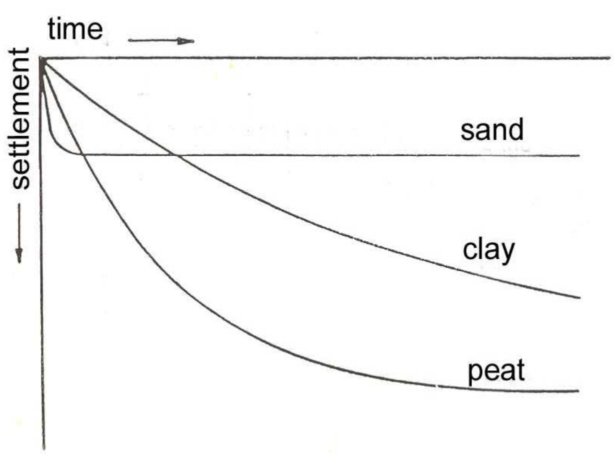
z = thickness of compressed layers [m]

Δz = size of compression of layer by increasing the load p'1 to p'2 [m]

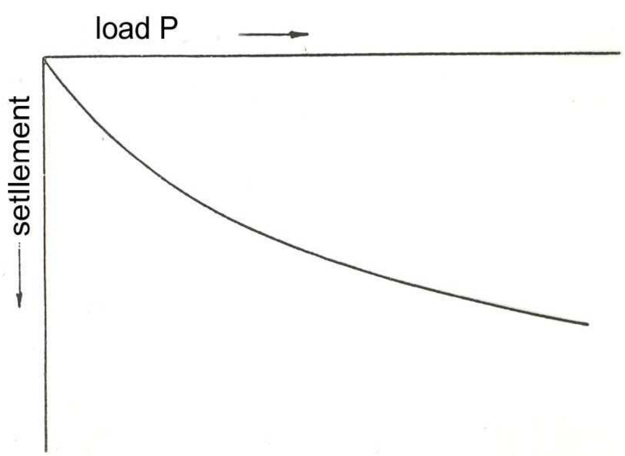
p_1' = initial vertical grain pressure [kN/m2]

p_2' = grain pressure after increasing the load [kN/m2]

C = compression constant



settlement path for different sort of soils



load-settlement curve

Settlement curve depends on type of soil

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Surface Settlements

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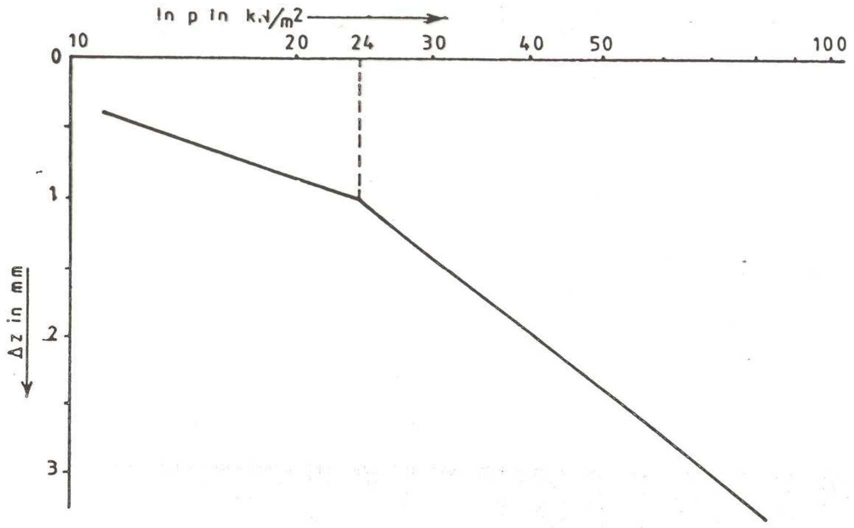
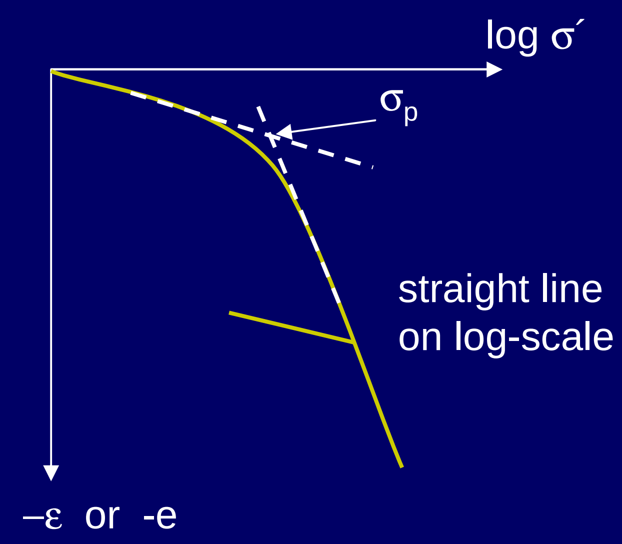
Influence of Preconsolidation



Result of compression test on soil sample

The result of a compression test is a bended line. The initial line (small slope) shows the historical stress situation. One can find the maximum load in history (='pre-tension') at the bending point of the line. This is a way to find out what has been the maximum load in history. In this case this is 24 kN/m2. This load can per example be a glacier.



NB: recuperating of settlement after relieving load (e.g. Elbe Tunnel)

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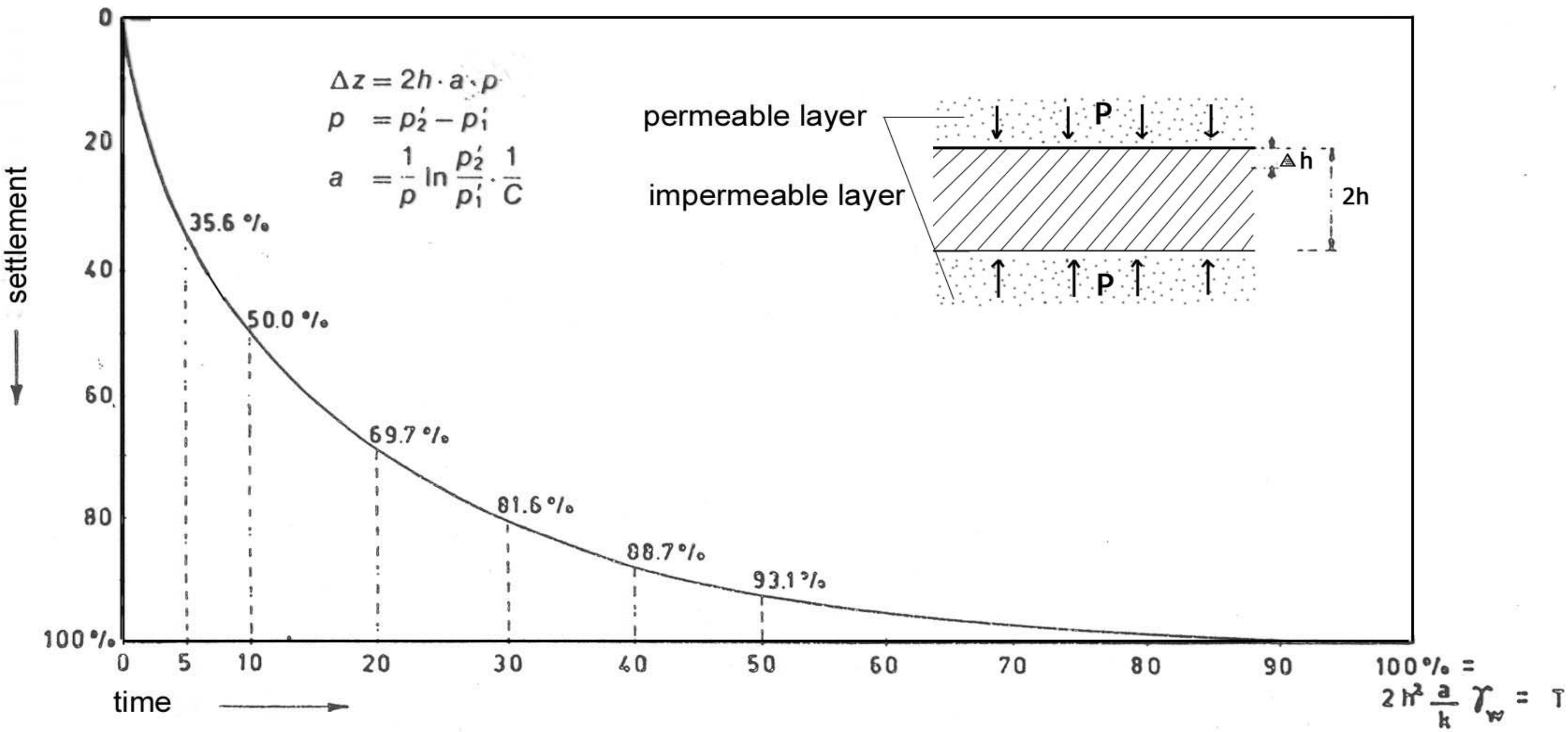
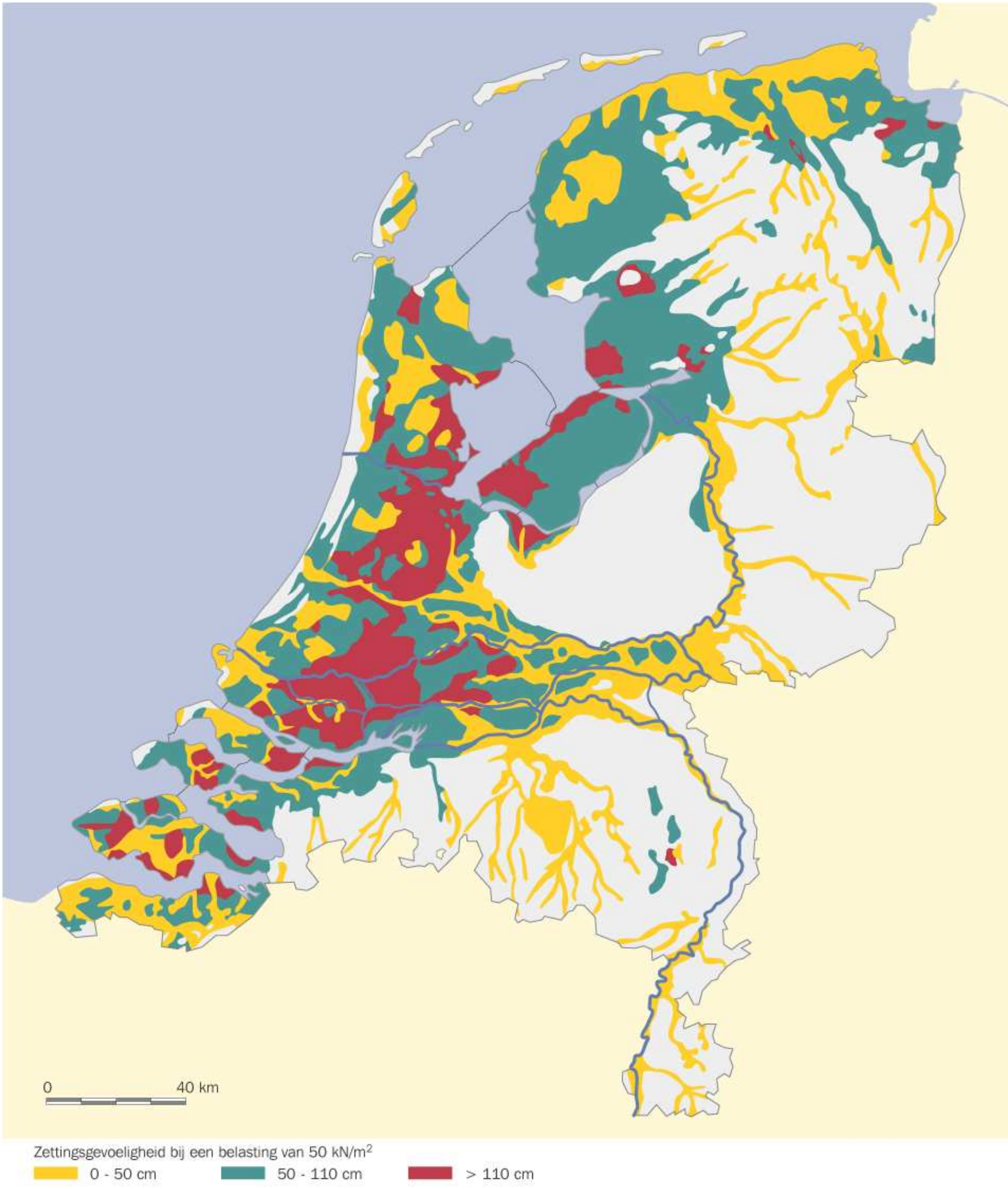


Settlement during hydronamic period by Terzaghi

The hydronamic period:

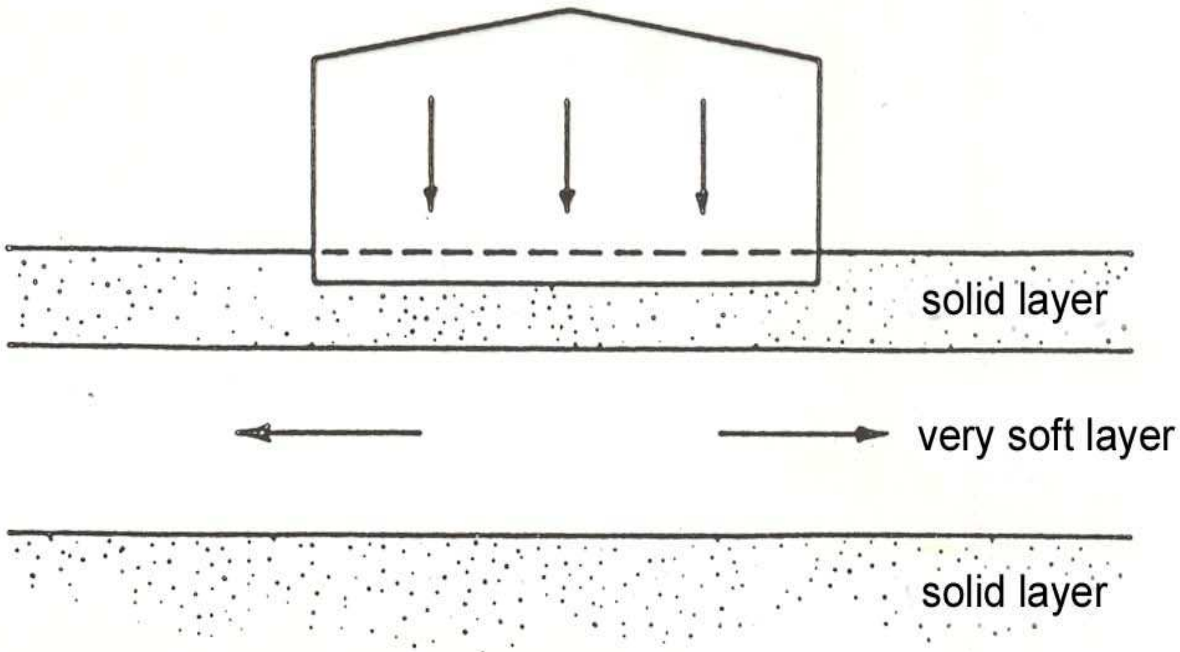
- is directly proportional to the square of the layer thickness.
- increases with a factor 4 by a duplicated layer thickness.
- increases with the compressibility of the soil

Sensitivity for Settlement



De Ondergrond van Nederland TNO/NITG)

Excess Pore Pressures



lateral movement of a soft layer by a load = squeezing

If the loading of the layers occurs too fast, water overstresses will appear in the soft layer. This results in lower shear stresses. This can be very dangerous! So one should be very carefull. Reliable research of the ground and good advise are necessary.

Loading can decrease the grain stresses

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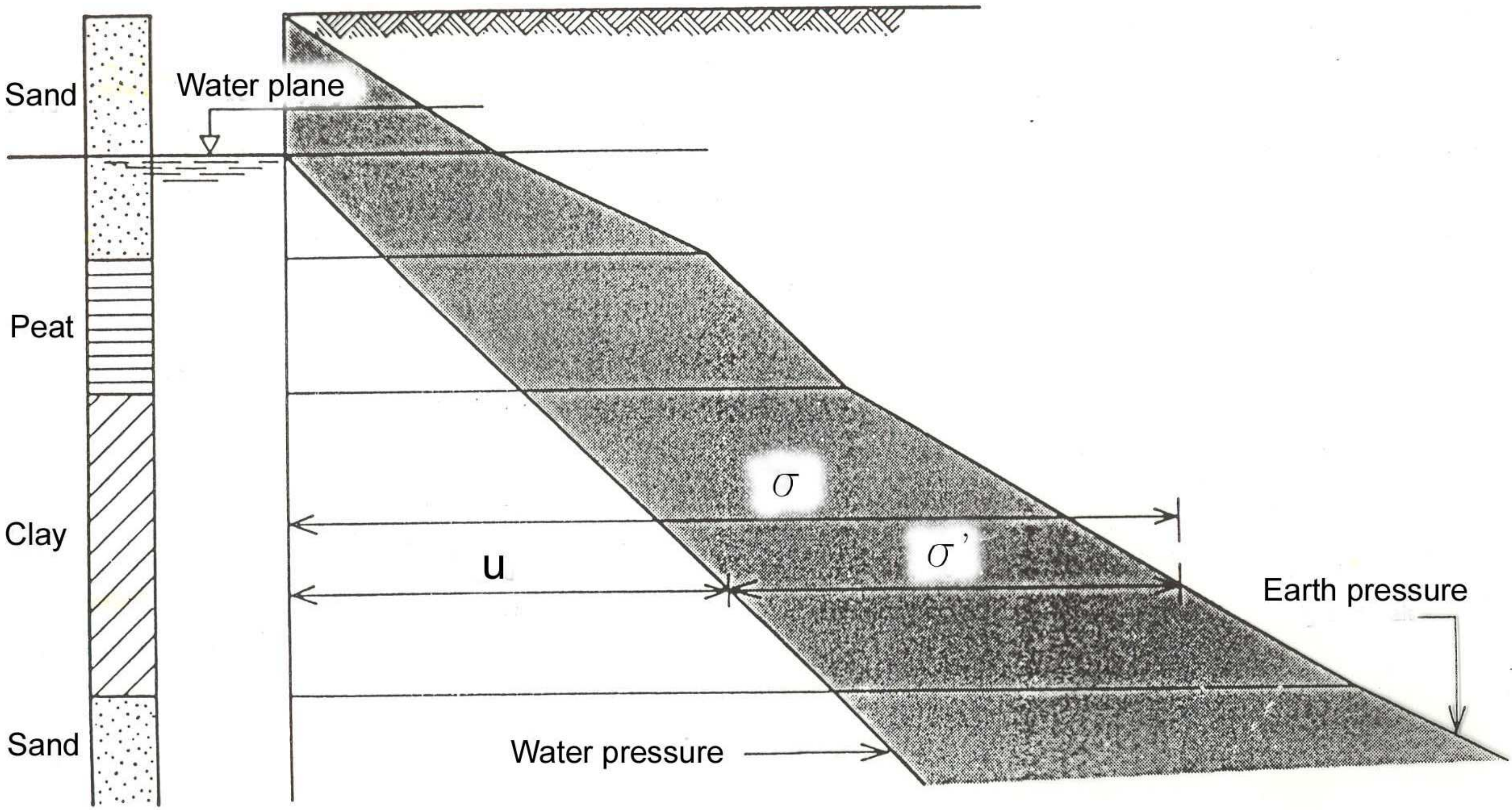
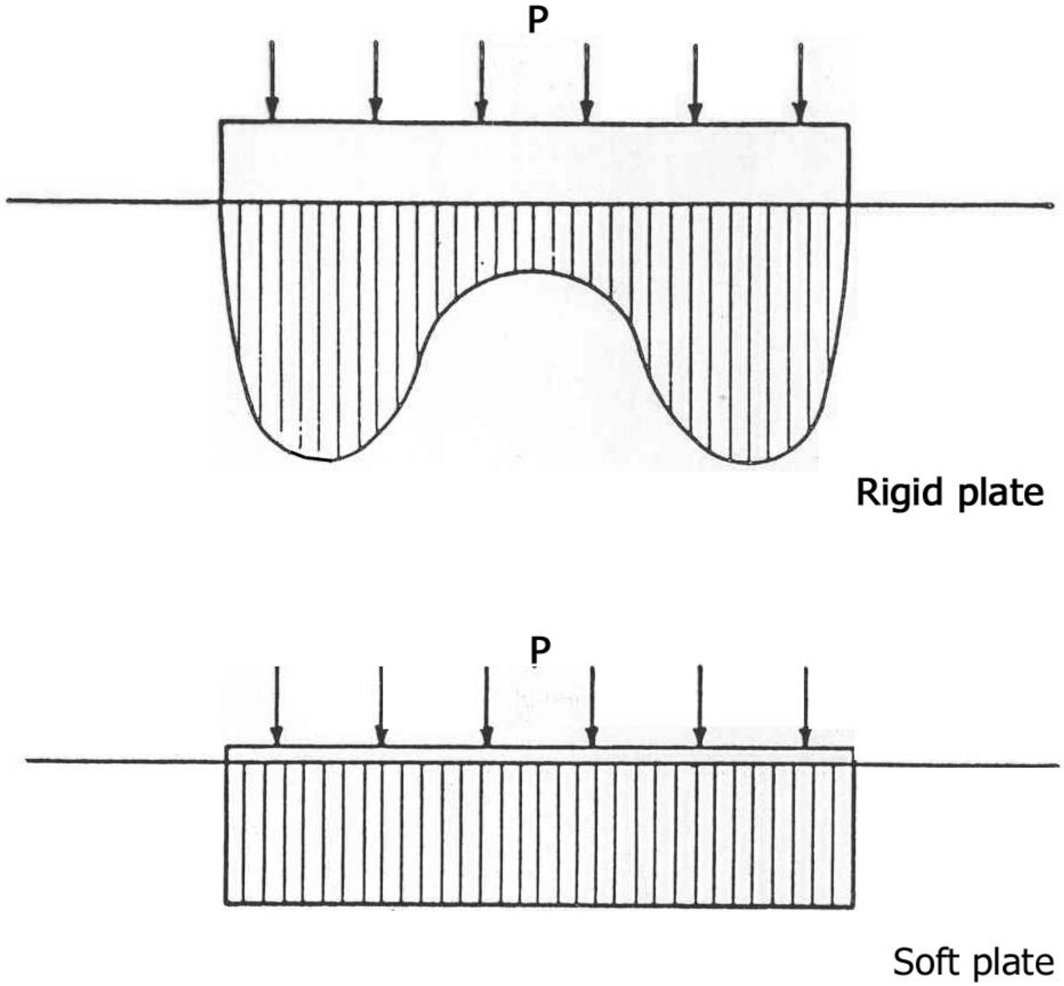


Development of earth pressure, grain pressure and water pressure



Soil reaction forces under a rigid and a soft plate

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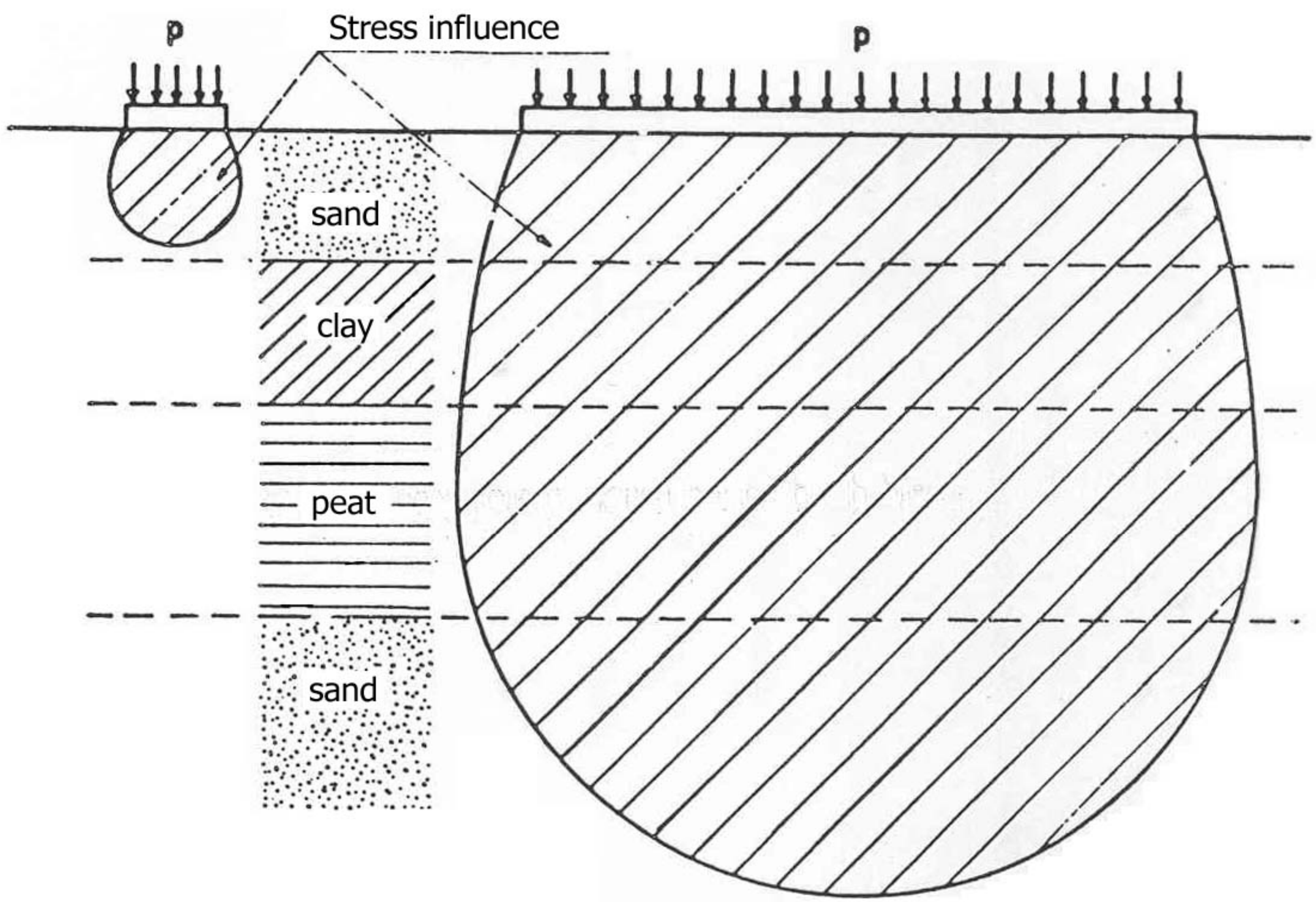
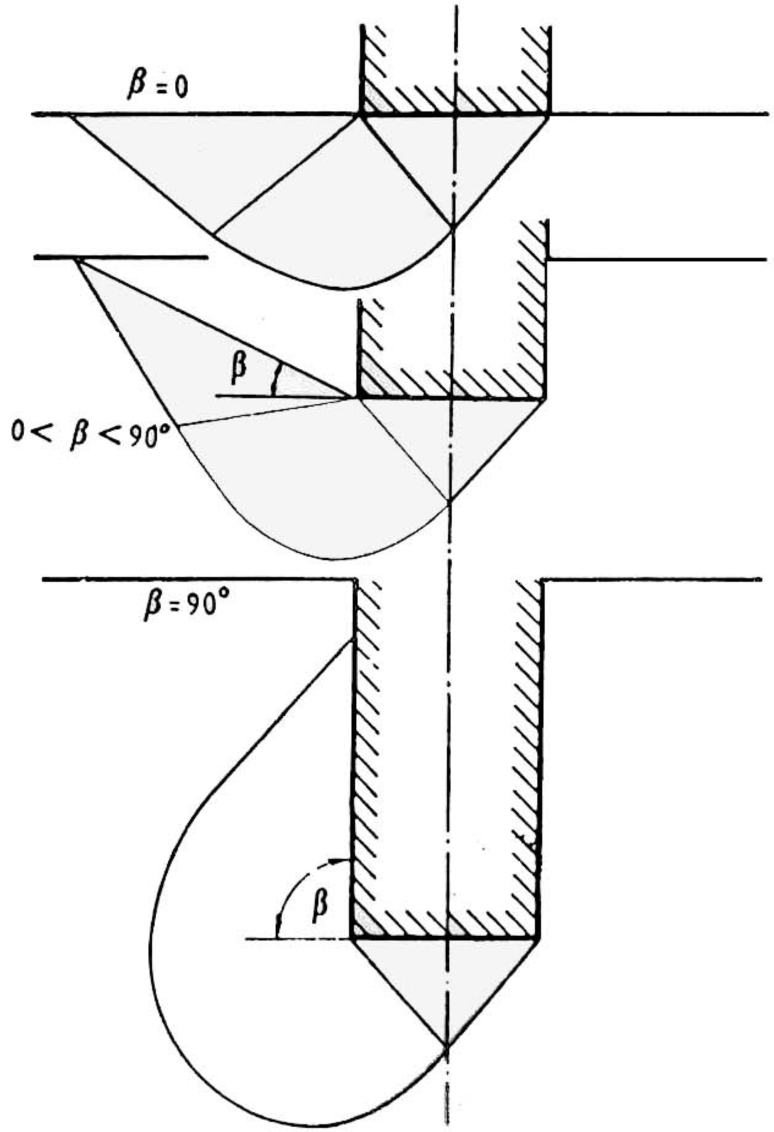


Influence of stress increase by loading as a function of the surface area

Foundation Classes

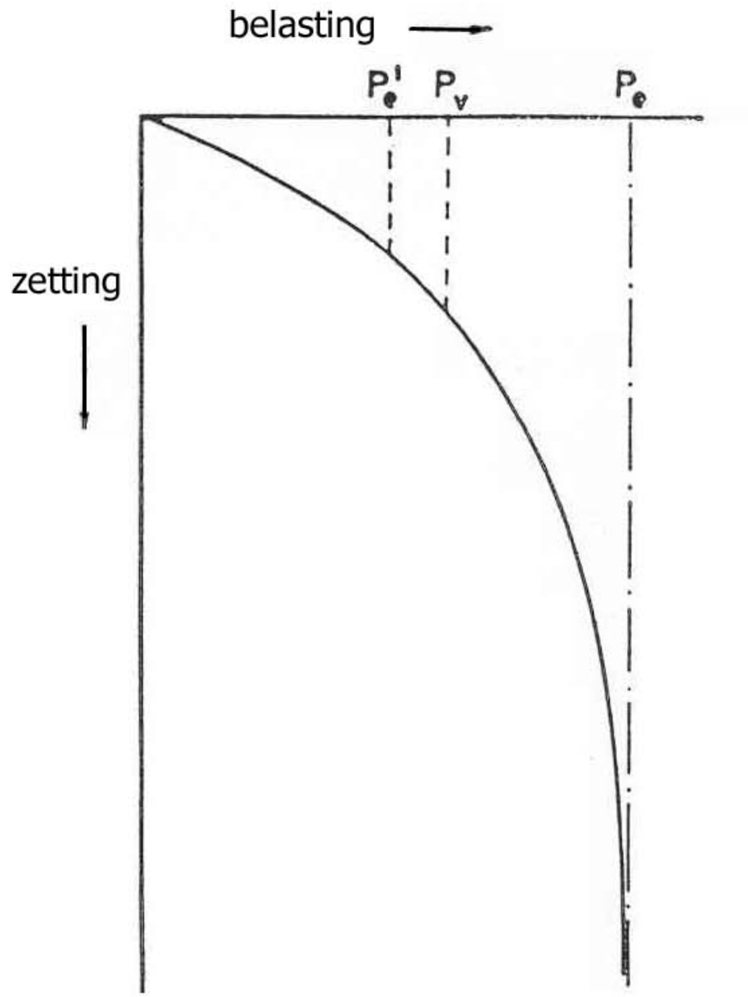


I: Area foundation

II: Transition foundation

III: Deep foundation

Design categories



P_e = Ultimate bearing capacity (loss of balance)

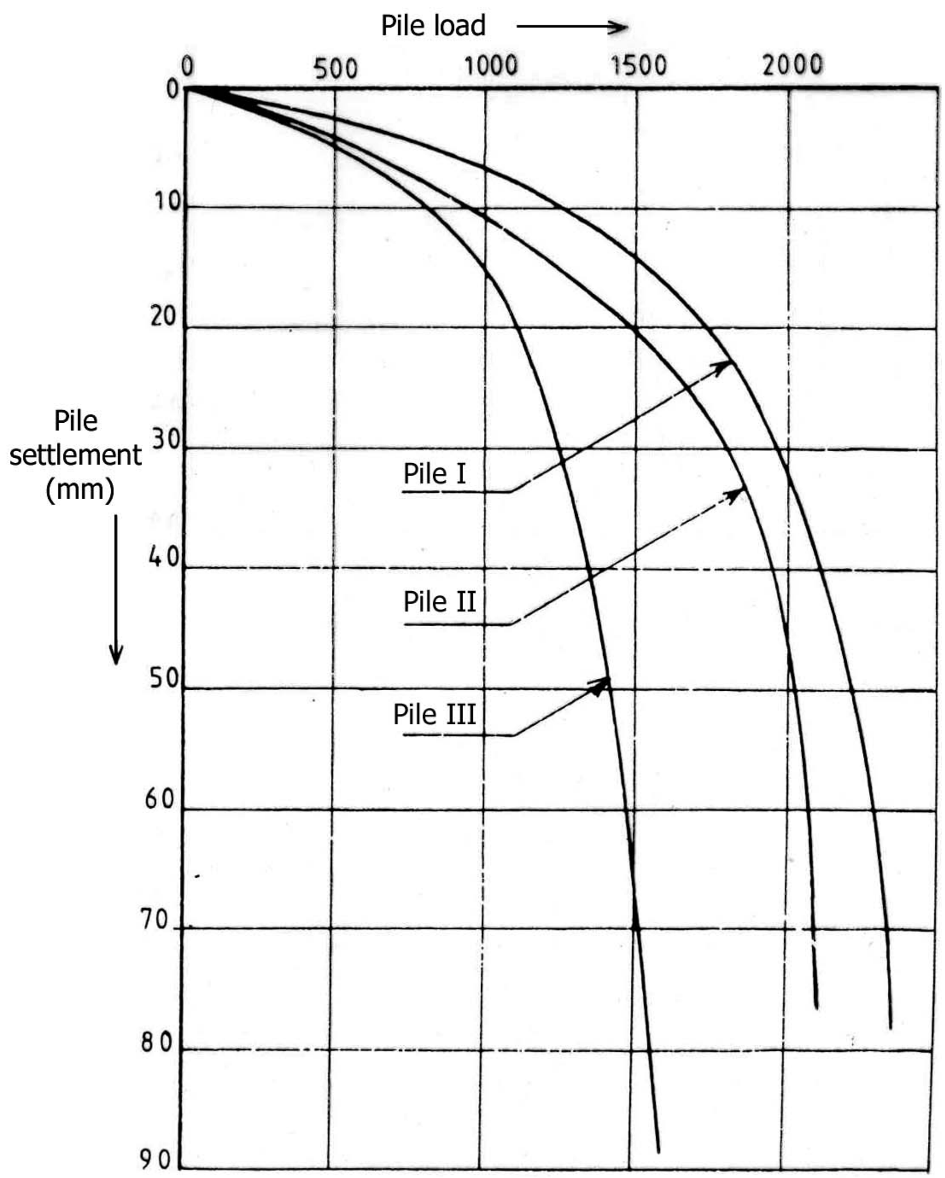
P_v = Deformation bearing capacity

P'_e = Balance bearing capacity

The accepted bearing capacity is the lowest value of P_v or P'_e

Load settlement curve of a loaded plate

Usability limit state design and ultimate limit state design (bearing capacity)
Safety factors



Three identically loaded piles with different reactions due to differences in the subsoil

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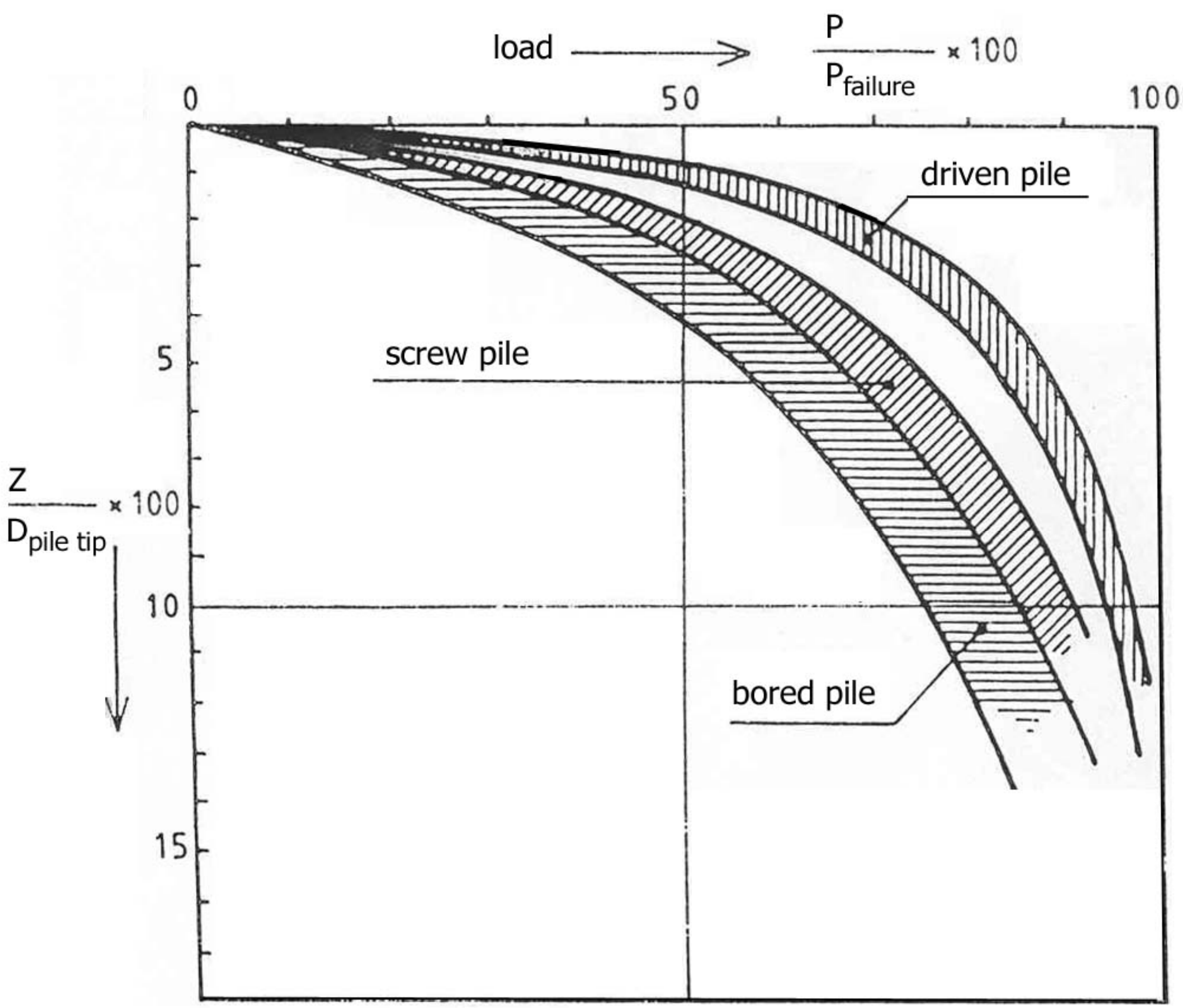

Load settlement pile tip

Load settlement behavior of pile tips of driven, auger and bored piles in sand

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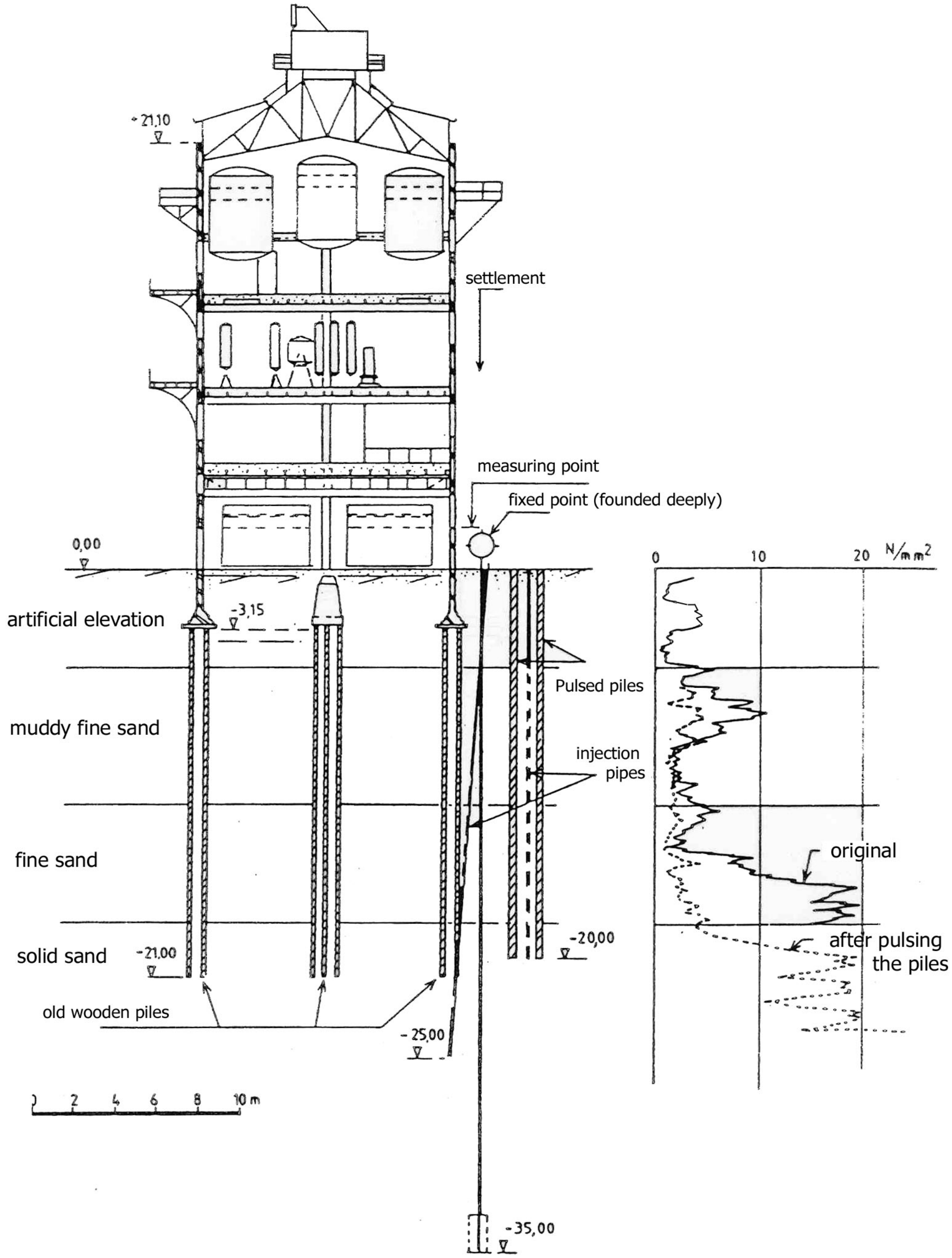

Change in Cone Penetration Test results from of relaxation in the subsoil caused by pulsing piles close to the foundation of a construction.

Danger of vertical and/or horizontal movement

White House - Rotterdam

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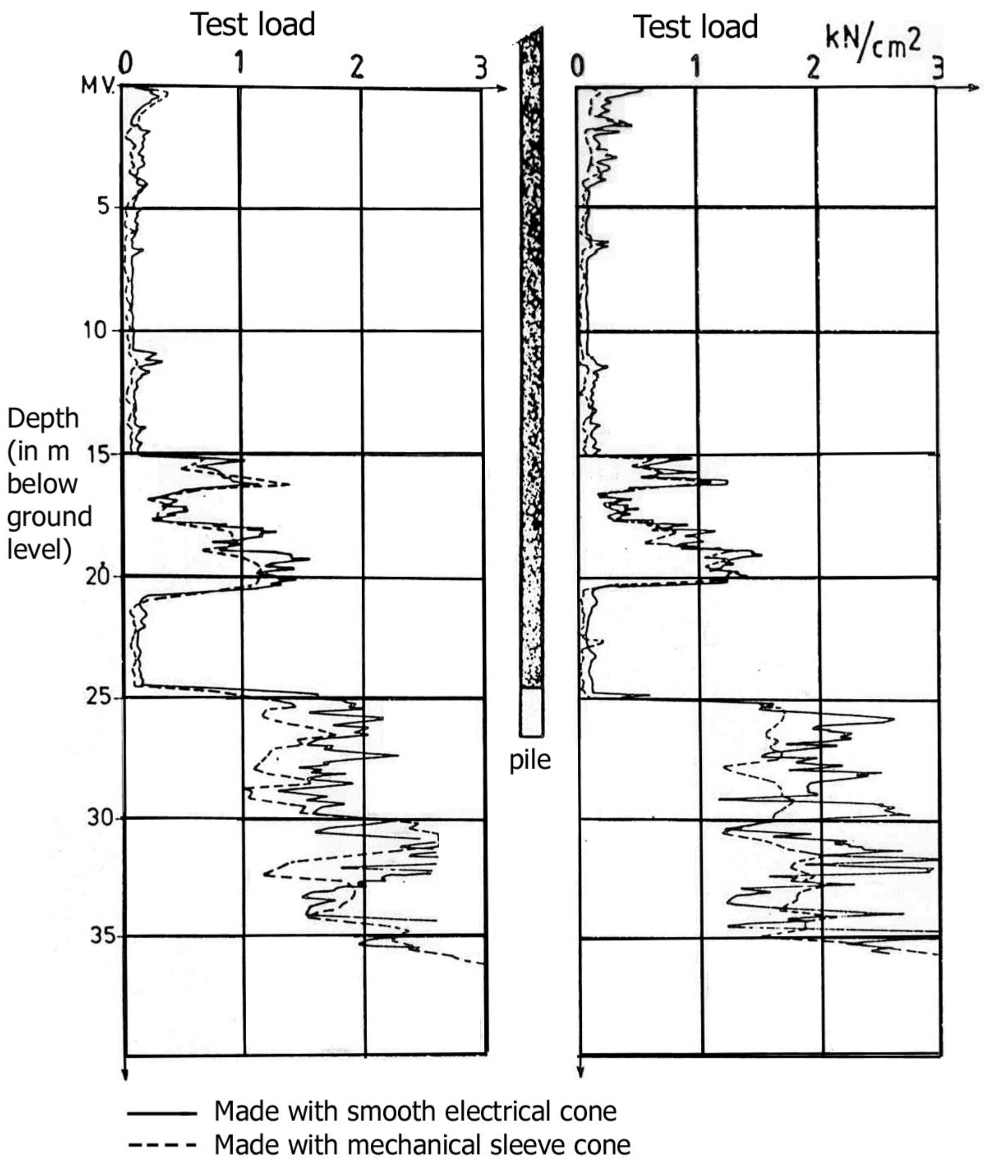

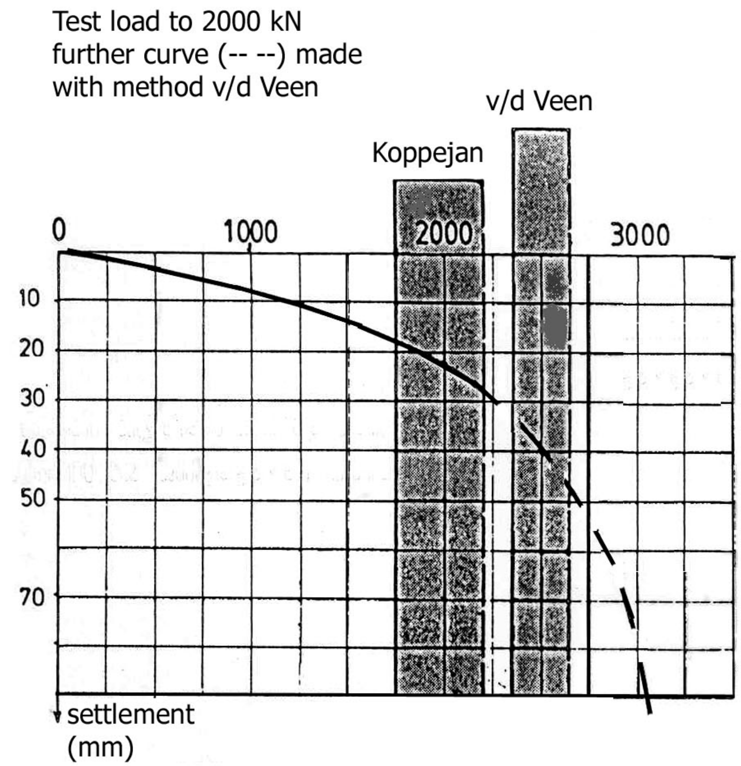

smooth electrical cone			
Method	CPT (-----)	CPT (-----)	average value
1,5 D/3,75 D (v/d Veen)	**2650 kN**	2650 kN	**2650 kN**
4 D/ 8 D (Koppejan)	**2150 kN**	2250 kN	**2200 kN**
mechanical sleeve cone			
Method	CPT (- - -)	CPT (- - -)	average value
1,5 D/3,75 D (v/d Veen)	**2200 kN**	2500 kN	**2350 kN**
4 D/ 8 D (Koppejan)	**1650 kN**	1850 kN	**1750 kN**

Comparison of the results of a test load and the calculated bearing capacity

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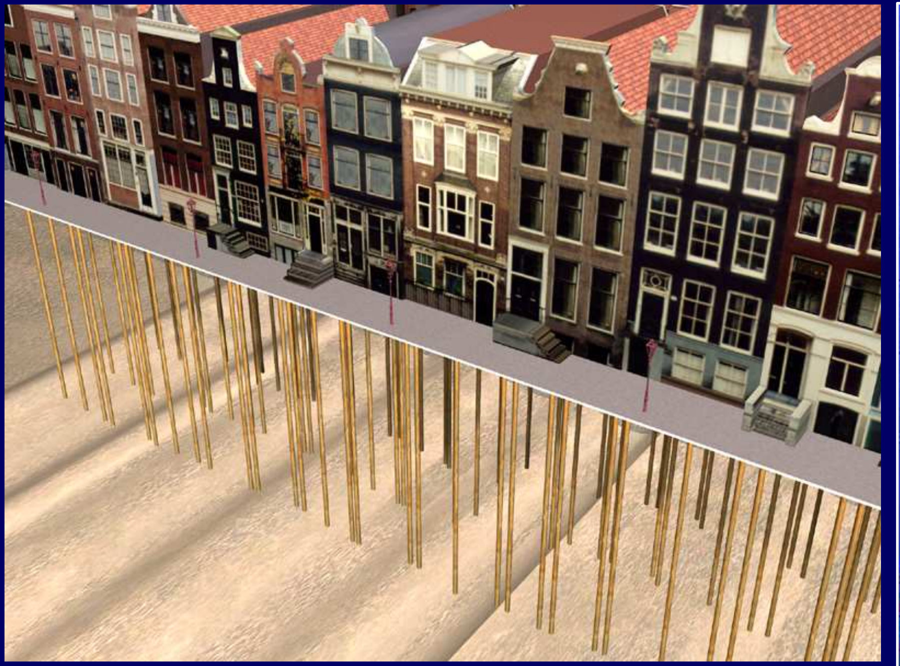
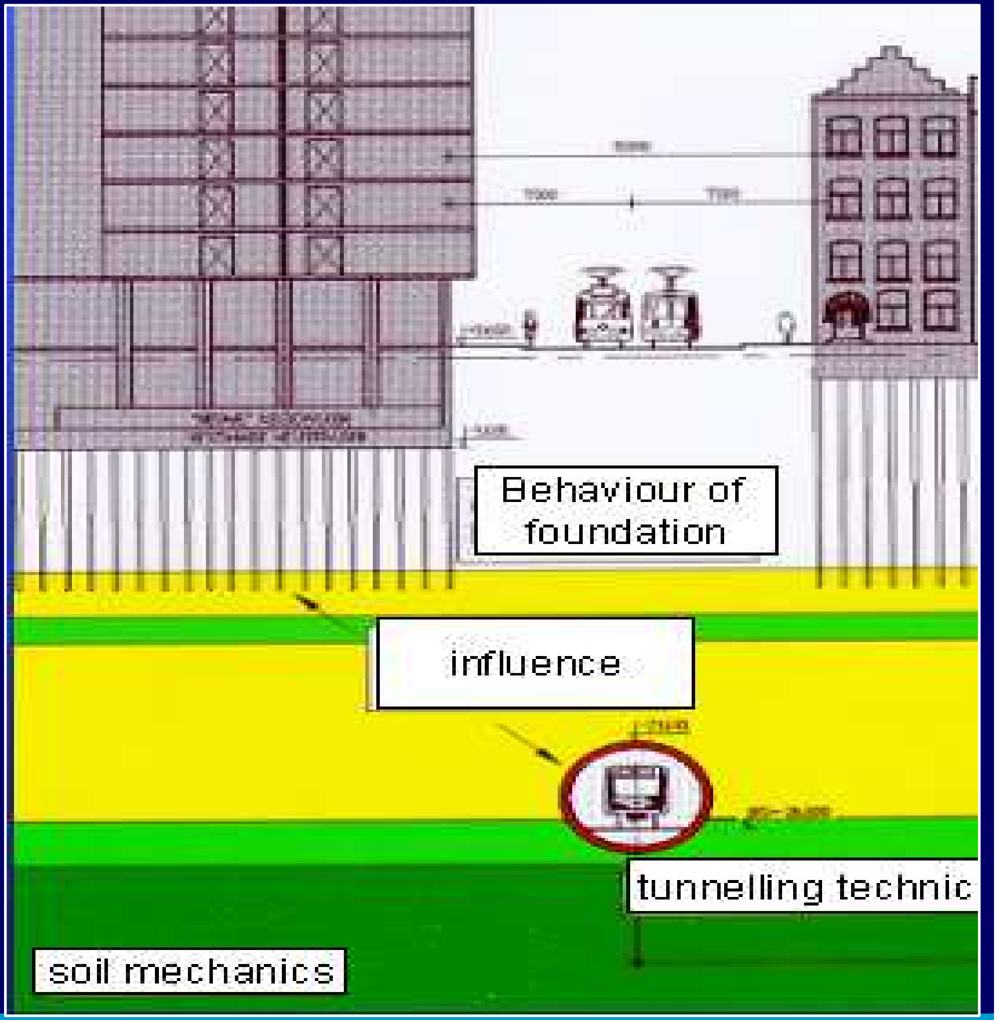
City Surroundings





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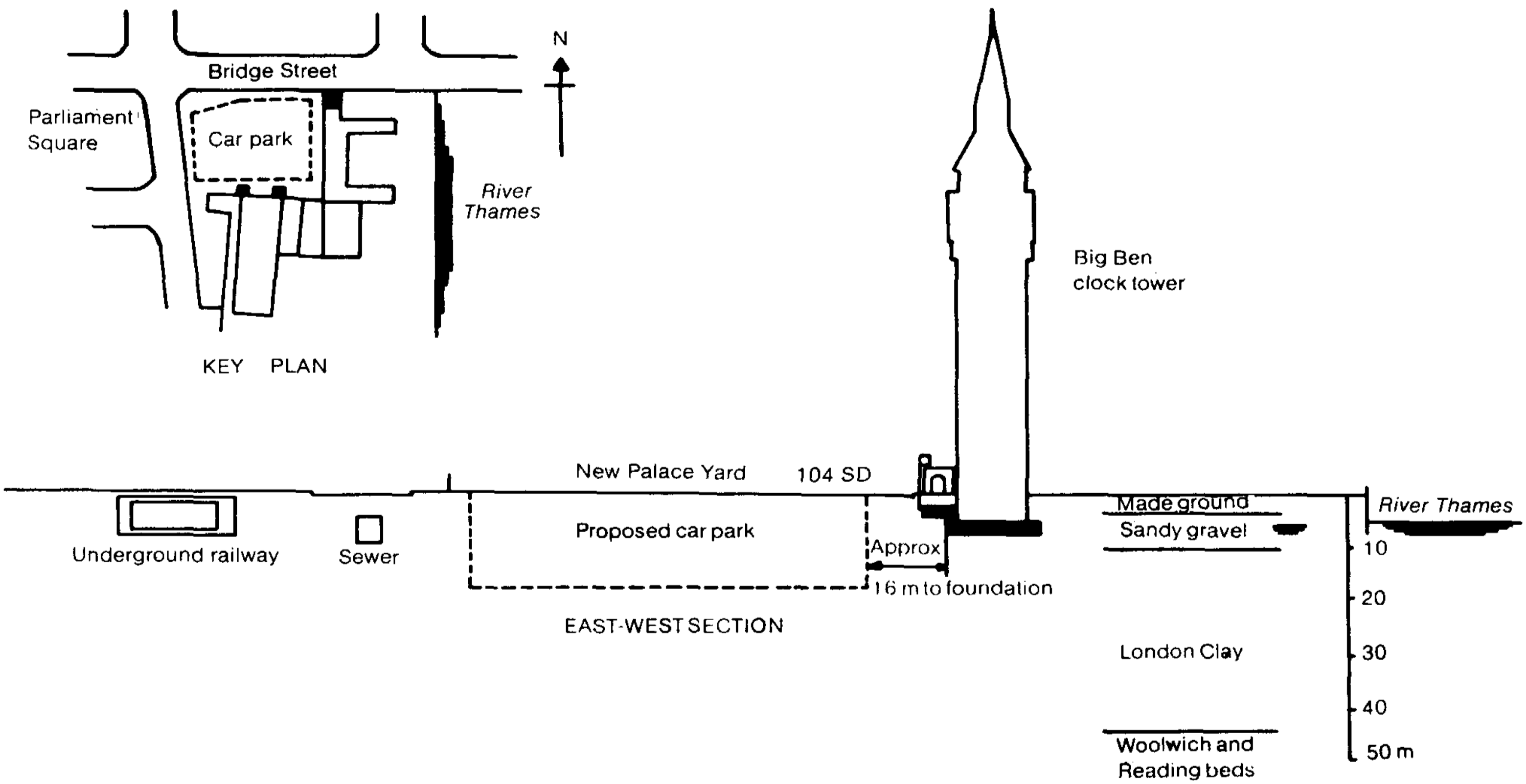
Influence of Calculation Methods



New Palace Yard Unterground Car Park, London (after Burland)

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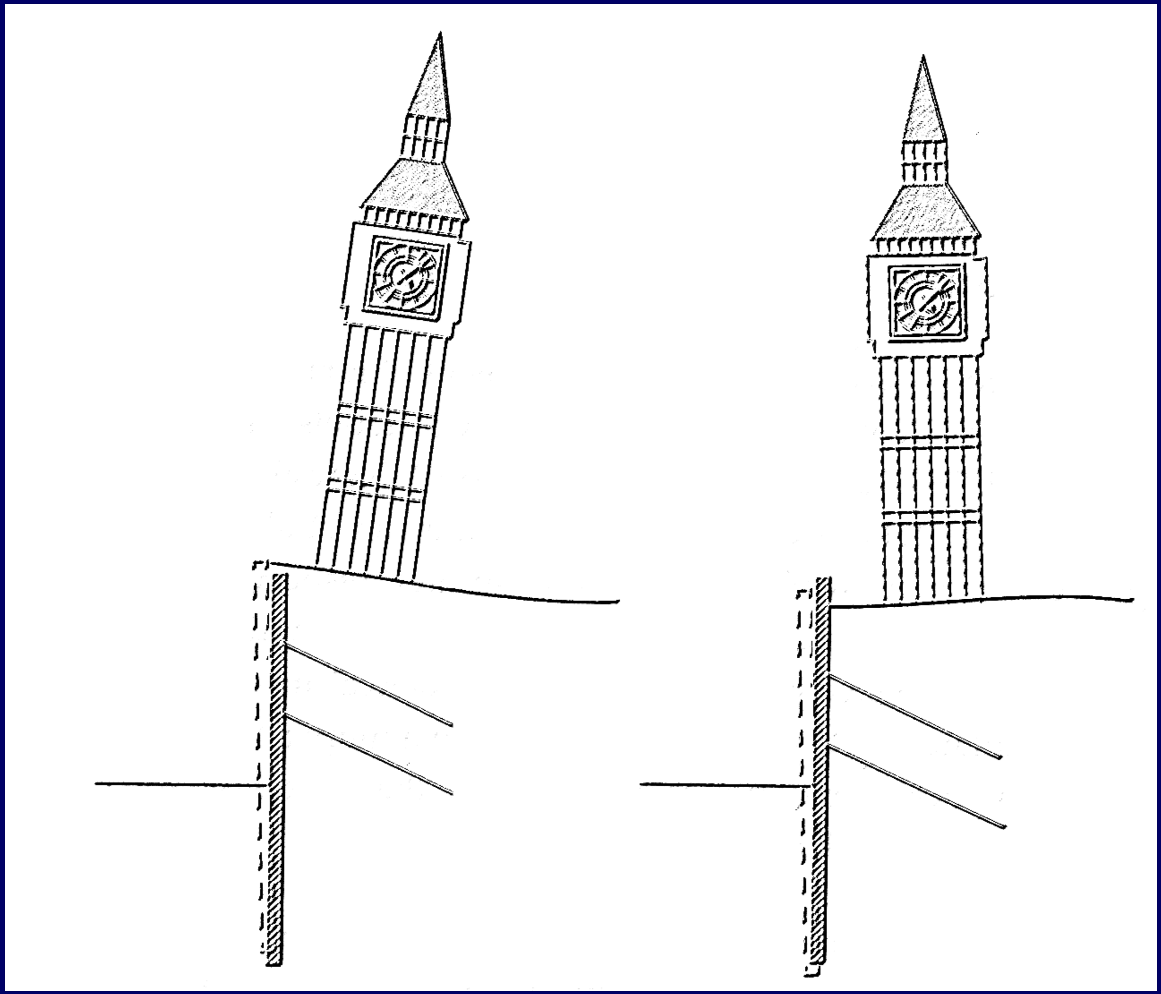
Influence of Calculation Methods



Finite Element Analysis

Mohr-Coulomb
Cam-Clay

Reality

Small-strain Stiffness

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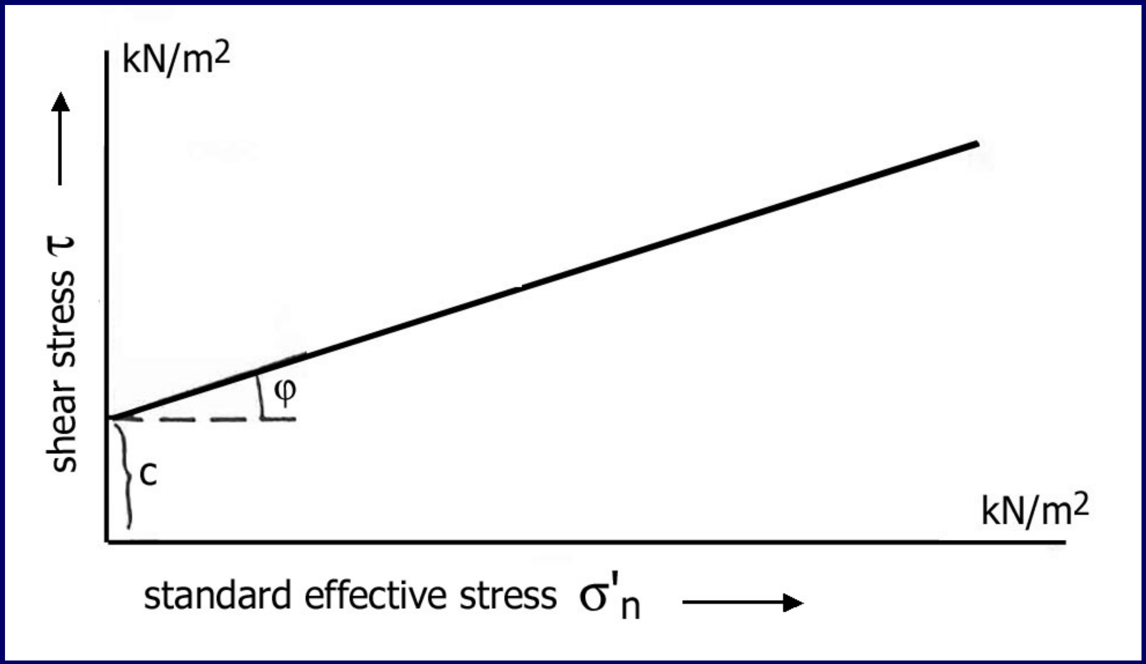
Mohr-Coulomb Model



$$\tau_f = c + \sigma'_n \tan\varphi$$

c = cohesion

φ = angle of (internal) friction

Maximum shear stress as a function of cohesion, normal effective stress and the angle of internal friction (Coulomb's rule)

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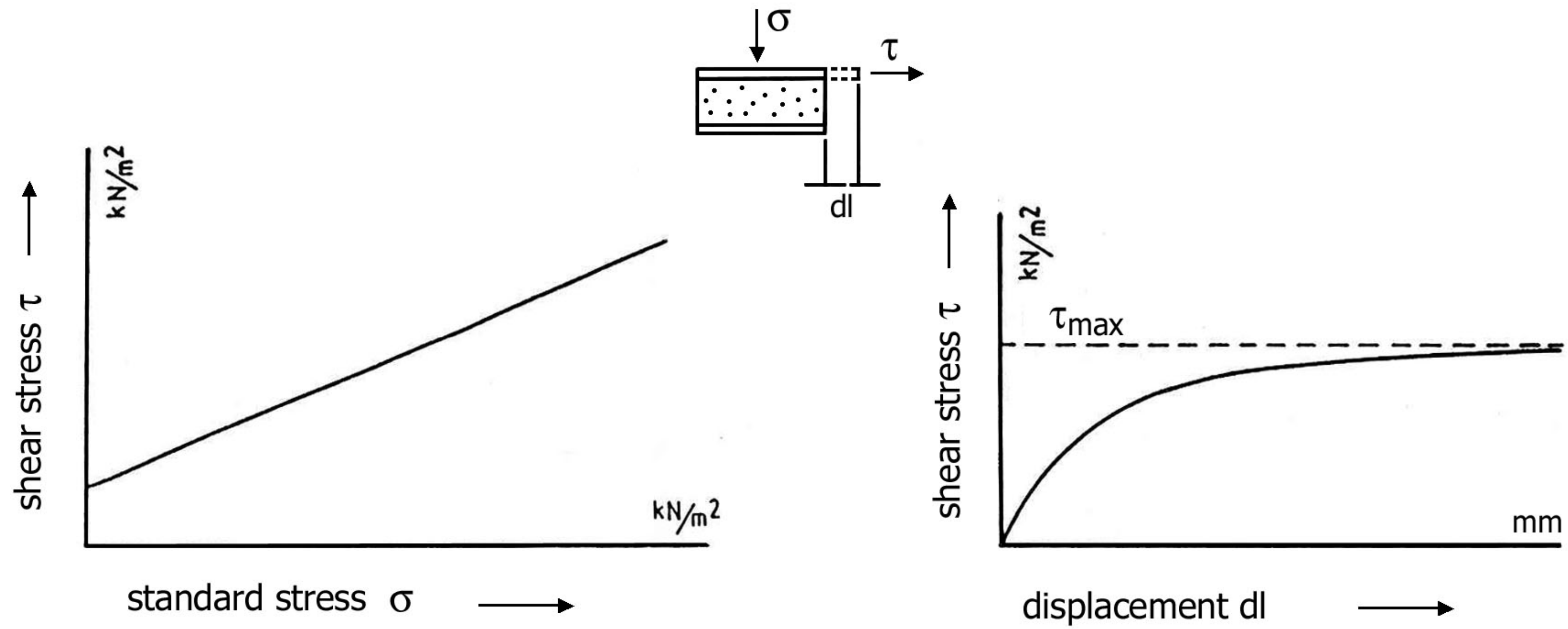
Stress-strain Behaviour



Relation between normal stress and shear stress

Relation between displacement and applied shear stress

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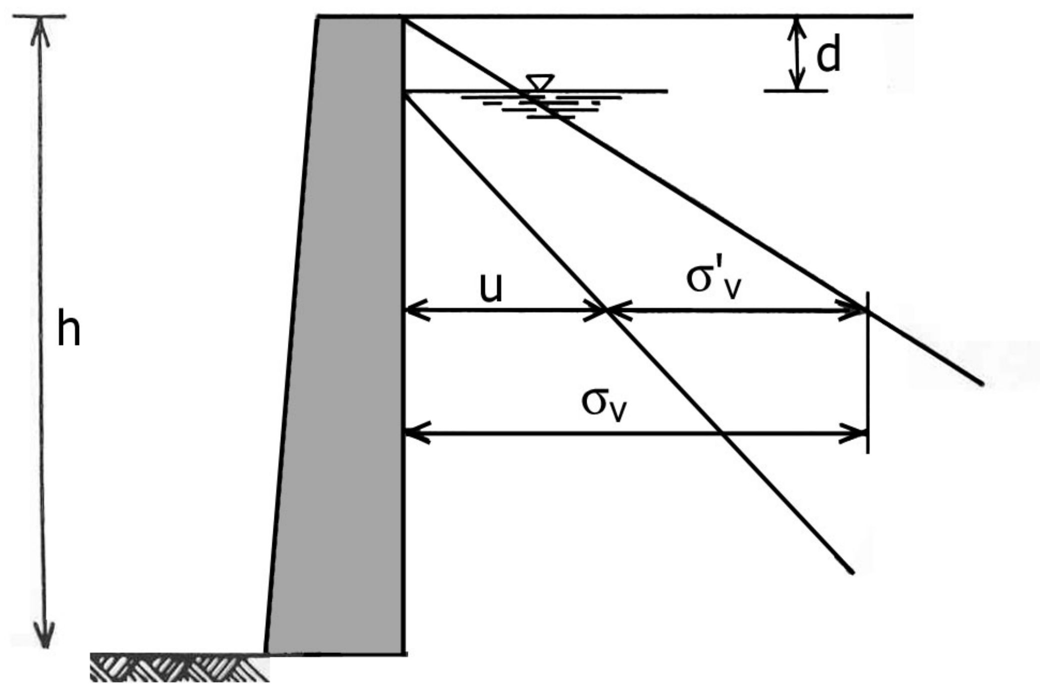
Effective Stress



Total vertical stress, effective vertical stress and water pressure behind a retaining wall

Water pressure:

$$u = \gamma_w (h - d)$$

Vertical effective stress:

$$\sigma'_v = \gamma_s h - \gamma_w (h - d)$$

Horizontal effective stress:

$$\sigma'_h = K \sigma'_v$$

In calculating horizontal effective stresses, we assume that the water pressure (u) is hydrostatic and universal (equal in vertical and horizontal direction).

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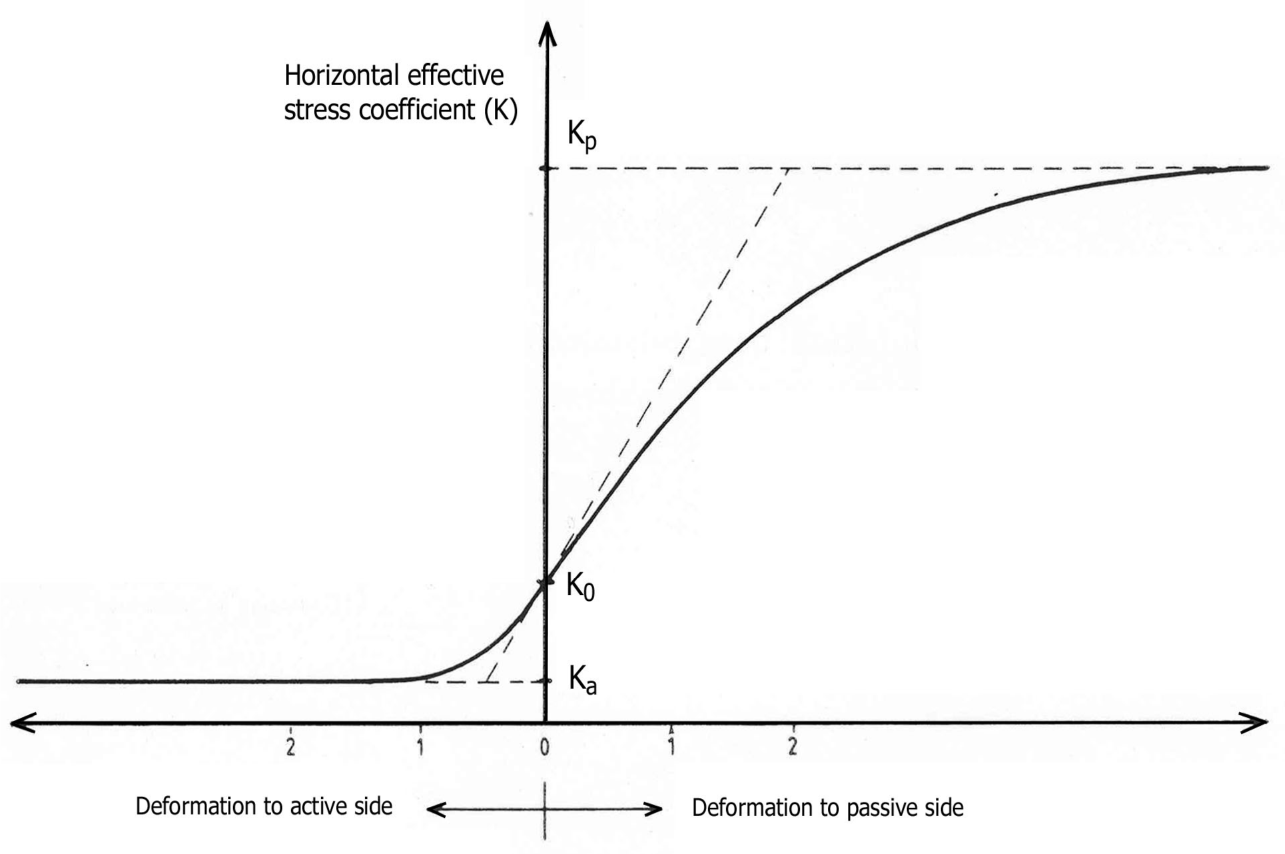
Coefficient of Horizontal Stress



K is the horizontal (effective) stress coefficient.
When no horizontal deformation is prescribed upon a soil mass, it is said to be in the neutral stress state.

The dependency of the K-coefficient to a prescribed deformation of a soil mass

Ka											
φ =	**15**	**17.5**	**20**	**22.5**	**25**	**27.5**	**30**	**32.5**	**35**	**37.5**	**40**
δ=0	0.59	0.54	0.49	0.45	0.41	0.37	0.33	0.30	0.27	0.24	0.22
+5	0.56	0.51	0.45	0.42	0.38	0.35	0.32	0.29	0.26	0.23	0.21
+10	**0.53**	**0.48**	0.44	0.40	0.37	0.33	0.30	0.28	0.25	0.22	0.20
+15	0.50	0.46	**0.42**	**0.38**	0.35	0.32	0.29	0.26	0.24	0.22	0.19
+17.5		0.45	0.41	0.38	**0.34**	0.32	0.29	0.26	0.24	0.21	0.19
+20			0.40	0.37	0.34	**0.31**	**0.28**	0.25	0.23	0.21	0.19
+22.5				0.36	0.33	0.30	0.28	**0.25**	**0.23**	0.20	0.18
+25					0.32	0.30	0.27	0.25	0.22	**0.20**	0.18
+27.5						0.29	0.26	0.24	0.22	0.20	**0.18**
+30							0.26	0.24	0.21	0.19	0.17
+32.5								0.23	0.21	0.19	0.17
+35									0.21	0.19	0.17
+37.5										0.18	0.16
+40											0.16

Kp											
φ =	**15**	**17.5**	**20**	**22.5**	**25**	**27.5**	**30**	**32.5**	**35**	**37.5**	**40**
δ = 0	1.70	1.86	2.04	2.24	2.46	2.72	3.00	3.32	3.69	4.13	4.60
-5	1.88	2.08	2.29	2.54	2.84	3.13	3.52	3.92	4.38	4.95	5.62
-10	**2.10**	**2.33**	2.59	2.89	3.24	3.64	4.12	4.86	5.26	5.99	6.86
-15	2.31	2.61	**2.93**	**3.31**	3.75	4.25	4.85	5.50	6.44	7.42	8.64
-17.5		2.77	3.10	3.56	**4.04**	4.60	5.28	6.58	7.09	8.28	10.28
-20			3.32	3.82	4.33	**4.98**	**5.75**	6.76	7.82	9.29	11.16
-22.5				4.06	4.64	5.46	6.42	**7.41**	**8.88**	10.20	12.85
-25					5.08	5.98	6.99	8.25	9.88	**11.77**	15.05
-27.5						6.48	7.72	9.23	11.26	14.00	**17.73**
-30							8.66	10.48	13.25	16.70	21.72
-32.5								12.65	15.90	20.20	27.00
-35									18.60	24.60	35.10
-37.5										31.50	50.80
-40											70.80

K-values as a function of the angle of internal friction φ and the wall friction δ, for calculating the horizontal effective stress on a vertical wall by horizontal ground level.

δ=0 → K_a= tan^2(45 – φ/2)
K_p= tan^2(45 + φ/2)

K_a and K_p are the coefficients for the horizontal components

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Settlements Caused by Installation of Sheet Piles

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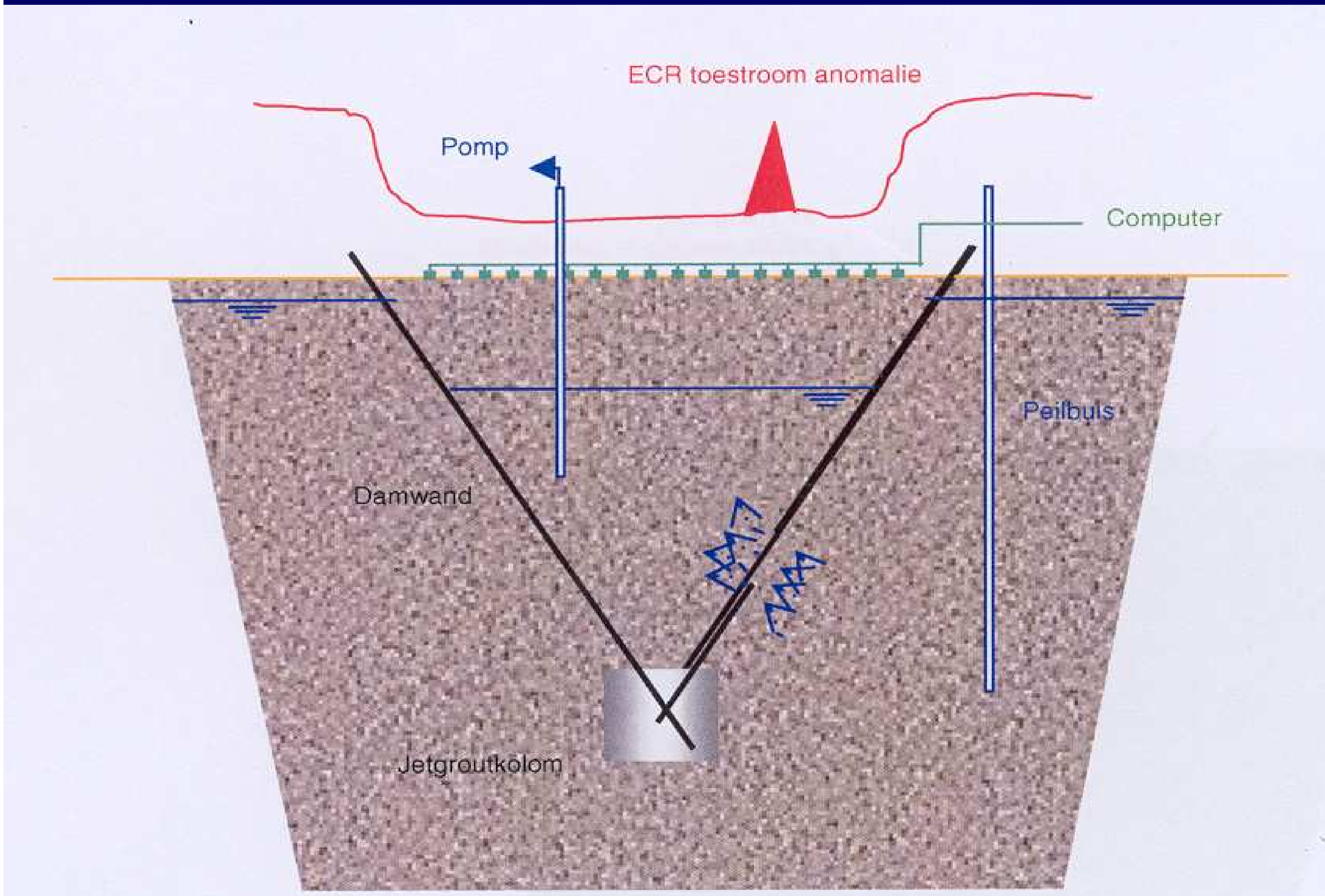
New Developments

- Structures become larger and deeper. More focus on water pressure and leakage.
  - Leakage detection by electrical methods
  - Control and blocking of leakage by classical methods
  - Control and blocking of leakage by micro biological methods

Leakage Detection



Electro-chemical response

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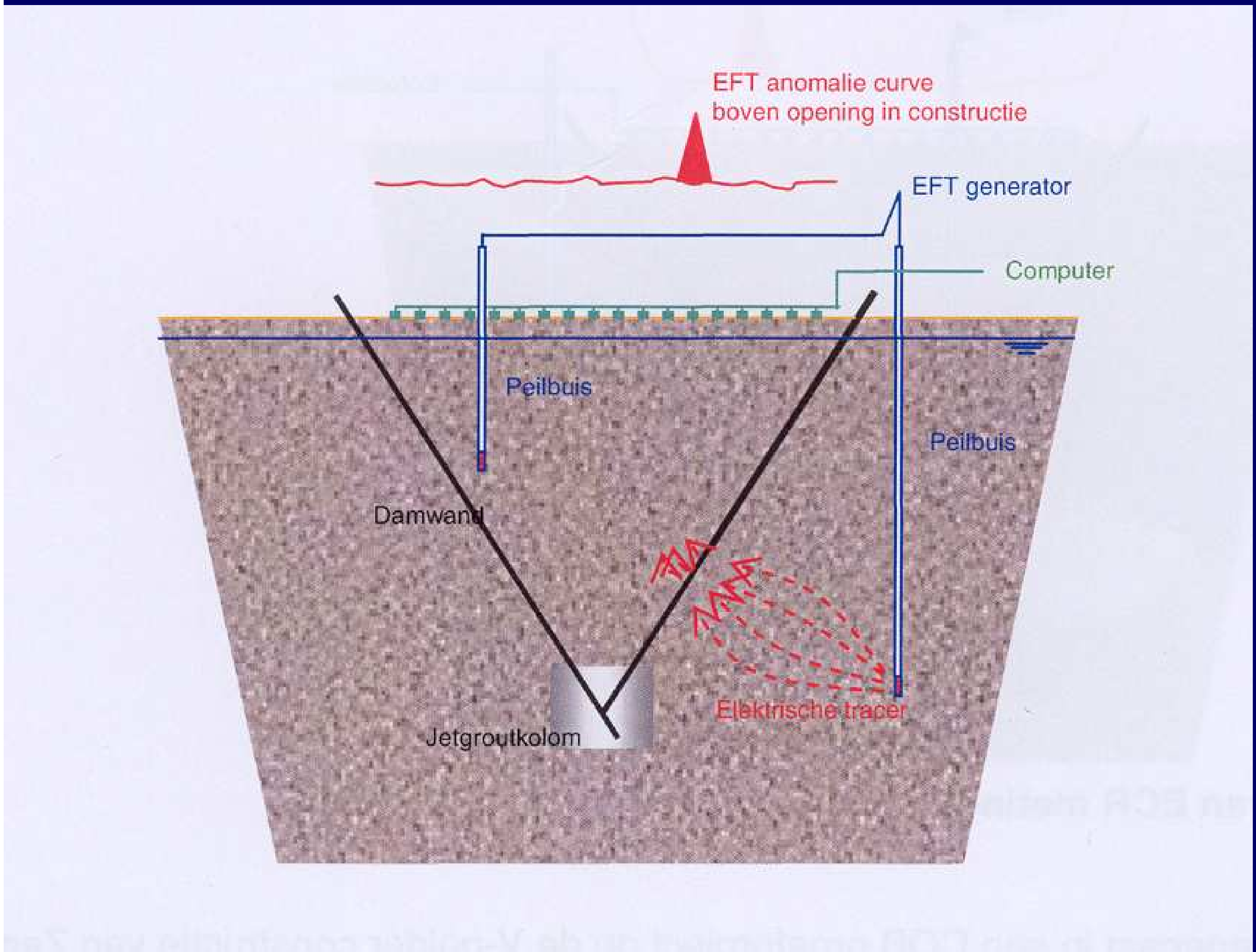
Leakage Detection



Electrical flux tracking

Question

Is Underground Construction different from constructing above ground?

- If yes: Why and in which respects

Underground Construction

- Planning or construction mistakes difficult to repair
- Mostly under water, effects of water pressure
- Effects on the surroundings even when everything goes as planned
- Variety in construction techniques
- Safety
- No 100% clear picture of the underground especially when tunneling or boring

Case CT3300

- The case must be written by 3 or 4 students
- Subject can be chosen freely
- Information: Library UST at room CT 3.29
- Deadline: Preferable in this or next term
- Oral exam: concerning case study and lectures

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Case CT3300

- Underground Shopping Centres
- Hurricane Evacuation Route
- Flood Prevention / Retaining Basins
- A tram or parking below the Mekelweg?
- Underground (Operational) Safety
- Multiple Space Use at Amsterdam CS
- Architecture in Underground Space technology
- Influence of freezing techniques to surroundings
- Pipe line project by using a micro-tunneling method
- Submerged / floating tunnels
- Comparison of application of Underground Construction in different countries
- Safety and risk of and in underground structures
- Heat and cold storage and exchange

Case CT3300

- Underground collection of waste
- The use of HDD and micro tunneling for drainage projects
- Hybrid construction methods
- Comparison of value and cost of Underground Structures
- Archeological aspects of undergound construction
- Zoning of the underground
- Delft Underground Station
- Logistics on major underground civil projects
- HDD and Micro tunneling as prevention for landslides
- Multiple Space Use
- AMFORA